BUILDING A 100 PERCENT CLEAN ECONOMY: PATHWAYS TO NET ZERO INDUSTRIAL EMISSIONS

HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT AND CLIMATE CHANGE

OF THE

COMMITTEE ON ENERGY AND COMMERCE

HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

SEPTEMBER 18, 2019

Serial No. 116–61

Printed for the use of the Committee on Energy and Commerce

govinfo.gov/committee/house-energy
energycommerce.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE
45–262 PDF WASHINGTON : 2022

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WITNESSES

SUBMITTED MATERIAL

BUILDING A 100 PERCENT CLEAN ECONOMY: PATHWAYS TO NET ZERO INDUSTRIAL EMISSIONS

WEDNESDAY, SEPTEMBER 18, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT AND CLIMATE CHANGE,
COMMITTEE ON ENERGY AND COMMERCE,
Washington, DC.

The subcommittee met, pursuant to call, at 10:00 a.m., in the John D. Dingell Room 2123, Rayburn House Office Building, Hon. Paul Tonko (chairman of the subcommittee) presiding.

Members present: Representatives Tonko, Clarke, Peters, Barragán, Blunt Rochester, Soto, DeGette, Schakowsky, Matsui, McNerney, Ruiz, Dingell, Pallone (ex officio), Shimkus (subcommittee ranking member), Rodgers, McKinley, Long, Flores, Mullin, Carter, Duncan, and Walden (ex officio).

Staff present: Adam Fischer, Policy Analyst; Jean Fruci, Energy and Environment Policy Advisor; Caitlin Haberman, Professional Staff Member; Rick Kessler, Senior Advisor and Staff Director, Energy and Environment; Brendan Larkin, Policy Coordinator; Dustin Maghamfar, Air and Climate Counsel; Nikki Roy, Policy Coordinator; Mike Bloomquist, Minority Staff Director; S. K. Bowen, Minority Press Assistant; Ryan Long, Minority Deputy Staff Director; Mary Martin, Minority Chief Counsel, Energy and Environment and Climate Change; Brandon Mooney, Minority Deputy Chief Counsel, Energy; Brannon Rains, Minority Staff Assistant; and Peter Spencer, Minority Senior Professional Staff Member, Environment and Climate Change.

Mr. TONKO. Good morning, everyone. The Subcommittee on Environment and Climate Change will now come to order.

I recognize myself for 5 minutes for the purposes of an opening statement.

OPENING STATEMENT OF HON. PAUL TONKO, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF NEW YORK

Today's hearing will examine greenhouse gas emissions associated with the industrial sector, which includes a wide range of manufactured products and processes, including several energy-intensive and trade-exposed industries.

Many of these industrial products are critical to our economy, including steel and cement, chemicals and fertilizers, glass, paper, and aluminum products, to name a few. Despite their importance to our lives, they are also a large and overlooked source of emissions and projected to grow through mid-century.

We cannot achieve meaningful climate targets, such as our economy-wide net zero by mid-century goal, without significantly reducing industrial emissions but industrial emissions can be difficult to directory. They are often produced from high temperature long-duration heat production and chemical reactions. Unlike much of the power sector and light-duty vehicles, in many cases, cost-effective low-carbon solutions are not commercially available yet and there is no one solution to cut across all the diverse subsectors.

While decarbonizing industry certainly has its challenges, there are near-and long-term solutions. In the near-term, there are well-developed technologies and strategies that, if given the proper incentives and policy certainty, industry can start to make investments. These include improving energy efficiency, deploying CHP systems, CHP systems, fuel switching, and increasing recycled content. The Federal Government could help form markets and provide assistance to incentivize these types of actions right now. For example, the public sector is a major purchaser of steel and cement. Through the power of procurement policy, we can drive market demand for low-carbon industrial products.

Longer-term options will require significant Federal investments in RD&D for technology development, such as: carbon capture, utilization, and storage; breakthroughs in chemistry and materials; and the use of hydrogen. Some of these innovative options may take several years to become widely deployed but will likely be necessary to achieve major reductions in the sector. It is critical that we focus Federal efforts today in order to achieve targets that are still decades away.

Unlike other sectors, many energy-intensive industries face global competition. Poorly designed policies risk the leakage of pollution, production, and jobs overseas. Many of us know the consequences of de-industrialization. I do not have to look any further than my own hometown in New York's 20th Congressional District.

Manufacturing has always been a gateway to the American middle class. It was the lifeblood of my and many other communities across the country and, sadly, we know what happens to communities when production moves overseas. Our policy preferences should seek to both spur decarbonization and promote domestic advanced manufacturing.

Rebuilding, retooling, and reinvigoration American manufacturing must be a fundamental component of our climate response. That is why I believe it is imperative to understand and to seek to mitigate potential competitiveness concerns, rather than dismiss them. At the end of the day, it is good for both us and global climate action if these manufacturers continue to operate here, where they employ Americans and produce more cleanly than their foreign competitors.

In order to succeed, Congress must provide the assistance necessary to enable the United States' industry to achieve ambitious targets on a reasonable and certain time line. This will likely need to be done with a mix of incentives and requirements.

Without a doubt, decarbonization of the industrial sector will be challenging. And I hope today we can better understand those challenges and the potential solutions but, above all, we must recognize that industrial decarbonization is necessary and possible with the right mix of well-designed policies, Federal investments, and market development.

Through smart climate and industrial policy, Congress can help American manufacturers transition to cleaner production while investing in the technologies, the practices, and the people that will make us globally competitive long into the future.

[The prepared statement of Mr. Tonko follows:]

PREPARED STATEMENT OF HON. PAUL TONKO

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Many of these industrial products are critical to our economy, including steel, cement, chemicals, fertilizers, glass, paper, and aluminum products to name a few.

Despite their importance to our lives, they are also a large and overlooked source of emissions and projected to grow through mid-century.

We cannot achieve meaningful climate targets, such as our economy-wide, net-zero by mid-century goal, without significantly reducing industrial emissions.

But industrial emissions can be difficult to decarbonize. They are often produced from high-temperature, long-duration heat production and chemical reactions.

Unlike much of the power sector and light-duty vehicles, in many cases cost-effective, low-carbon solutions are not commercially available yet. And there is no one solution to cut across all the diverse subsectors.

While decarbonizing industry certainly has its challenges, there are near- and long-term solutions.

In the near-term, there are well-developed technologies and strategies that if given the proper incentives and policy certainty, industry can start to make investments.

These include improving energy efficiency, deploying CHP systems, fuel switching, and increasing recycled content.

The federal government could help form markets and provide assistance to incentivize these types of actions right now. For example, the public sector is a major purchaser of steel and cement.

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Some of these innovative options may take several years to become widely deployed but will likely be necessary to achieve major reductions in the sector.

It is critical that we focus federal efforts today in order to achieve targets that are still decades away.

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At the end of the day, it is good for both us and global climate action if these manufacturers continue to operate here, where they employ Americans and produce more cleanly than their foreign competitors.

In order to succeed, Congress must provide the assistance necessary to enable U.S. industry to achieve ambitious targets on a reasonable and certain timeline. This will likely need to be done with a mix of incentives and requirements.

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But above all, we must recognize that industrial decarbonization is necessary and possible with the right mix of well-designed policies, federal investments, and market development.

Through smart climate and industrial policy, Congress can help American manufacturers transition to cleaner production while investing in the technologies, practices, and people that will make us globally competitive long into the future.

Mr. TONKO. With that, I know recognize the ranker of the subcommittee, Representative Shimkus, for 5 minutes of opening statement.

OPENING STATEMENT OF HON. JOHN SHIMKUS, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF ILLINOIS

Mr. SHIMKUS. Thank you, Mr. Chairman.

Whenever I hear an idea for what we can do to keep global warming in check, whether it is over a conference table or a cheeseburger, I always ask this question: What is your plan for steel? I know it sounds like an odd thing to say but it opens the door to an important subject that deserves a lot more attention than any conversation about climate change.

Making steel and other materials, such as cement, plastic, glass, aluminum, and paper, is the third biggest contributor of greenhouses gases behind agriculture and making electricity. It is responsible for a fifth of all emissions and these emissions will be some of the hardest to get rid of. These materials are everywhere in our lives and we don't yet have proven breakthroughs that will give us affordable zero-carbon versions of them. If we are going to get to zero-carbon emissions overall, we have a lot of inventing to do.

Steel, cement, and plastic are so pervasive in modern life that it can be easy to take them for granted. The first two are the main reasons our buildings and bridges are so sturdy and last so long. Steel, cheap, strong, and infinitely recyclable, also goes into shingles, household appliances, canned goods, and computers. Concrete, rust-resistant, rot-proof, and nonflammable, can be made dense enough to absorb radiation or light enough to float on water.

As for plastics, they have a bad reputation these days and it is true that the amount piling up in our oceans is problematic, but they also do a lot of good. For example, you can thank plastics for making that fuel-efficient car you drive so light. They account for as much as half of the car's total volume but only ten percent of its weight.

So how do we cut down on emissions from all steel, cement, and plastic we are making? One way is to use less of all these materials. There are definitely steps we should take to use less by recycling more and increasing efficiency but that won't be enough to offset the fact that the world's population is growing and getting richer.

As the middle class expands, so will our use of some materials. In a sense, that is good news because it means more people will be living in sturdy houses and apartment buildings and driving on paved roads, but it is bad news for climate. Take Africa, for example. Its emissions from making concrete are projected to quadruple by 2005. Emissions from steel could go up even more because the continent uses so little now.

If using less isn't really a viable option, could we make things without emitting carbon in the first place?

That is, in fact, what we will need to do but there are several challenges. First, these industries require a lot of electricity which, today, is often generated using fossil fuels. Second, the processes also require a lot of heat, as in thousands of degrees Fahrenheit, and fossil fuels are often the cheapest way to create that heat.

Finally, and this might be the toughest challenge of all, manufacturing some of these products involves chemical reactions that emit greenhouse gases. For example, to make cement you start with limestone, which contains calcium, carbon, and oxygen. You only want the calcium so; you burn the limestone in a furnace along with other materials.

You end up with the calcium you want plus a byproduct you don't want, carbon dioxide. It is a chemical reaction and there is no way around it.

As brilliant as this opening statement is, it is not from me. It is from a blog post on August 27th by Bill Gates.

I have noted in previous hearings that we should keep appropriate perspective on the scale and source of the problem we are trying to address, and this is especially important when it comes to reducing emissions in the industrial sector. If we impose overly restrictive rules and regulations domestically, we raise the cost of energy and feedstock. We lose control over essential parts of the critical supply chains. We increase reliance on foreign industries and manufacturing and simply displace industrial emissions from the United Sates to other nations, along with our manufacturing jobs.

For emission reductions in this sector to make an impact on global greenhouse gas budgets, the reduction should occur where the industrial output will be growing the most.

That will mostly likely be China, India, and the developing world. The trick for the United States will be to develop the cleaner technologies and practices to explore to developing nations, while avoiding cost and regulatory burdens that will make essential goods more expensive and drive our industries overseas. We do not want to put the United States at a competitive disadvantage to other nations or deprive our nation important opportunities to innovate and develop the new industrial sectors that promise cleaner future energy systems.

Today's testimony will note that reducing emissions across the sector is not easy or even possible, in some cases, based upon brute facts of physics, chemistry, and economics. But we will also note in this hearing that there are practical policies to pursue that can make a difference domestically and can help set the U.S. industry to advance cleaner technologies and processes in the future.

Chairman Tonko, there are bipartisan legislative solutions we can sign into law this Congress that will remove some of the barriers to innovation in the industrial sector. If you want to start making progress on the industrial emissions, let's start with what we know we can do today to make a difference in the innovation landscape, while protecting our national interest and the interest of our workers and consumers.

And with that, I thank you for the time and I yield back my time.

[The prepared statement of Mr. Shimkus follow:]

PREPARED STATEMENT OF HON. JOHN SHIMKUS

Bill Gates noted in a blog post a few weeks ago that, when somebody talks about reducing greenhouse gas emissions, he always asks them: "what's your plan for steel?"

A good question. Gates point is that any serious attempt to reduce greenhouse emissions economy-wide must grapple with the energy and process emissions from the industrial sector. And that means the core ingredients and building blocks of our modern society.

This includes iron and steel, basic chemicals and petrochemicals, cement, fertilizer, plastics, glass, aluminum, paper products, etc. This is what makes up our roads, bridges, buildings, our cars and transportation systems, our computing systems, our factories; it is behind the food we eat and the power we generate, the goods we make and use.

The industrial sector is the largest global user of energy, according to J. P. Morgan's Annual Energy Outlook. Demand for industrial output is expected to grow dramatically in coming decades. The world's building stock alone is anticipated to double by 2060, which Gates has noted, is equivalent to a New York City built every month for the next forty years. That is a lot of steel. And that is a lot of energy and process emissions.

I've noted in previous hearings that we should keep appropriate perspective on the scale and source of the problem we are trying to address. And this is especially important when it comes to reducing emissions in the industrial sector.

If we impose overly restrictive rules and regulations domestically, we raise the costs of energy and feedstock, we lose control over essential parts of critical supply chains, we increase reliance on foreign industries and manufacturing, and simply displace industrial emissions from the United States to other nations, along with our manufacturing jobs.

For emissions reductions in this sector to make an impact on global greenhouse gas budgets, the reductions should occur where industrial output will be growing the most. That will most likely be in China, India and the developing world.

The trick for the United States industry will be to develop the cleaner technologies and practices to export to developing nations, while avoiding costs and regulatory burdens that will make essential goods more expensive and drive our industries overseas.

We do not want to put the United States at a competitive disadvantage to other nations or deprive our nation important opportunities to innovate and develop the new industrial technologies that promise cleaner future energy systems.

Today's testimony will note that reducing emissions across this sector is not easy, or even possible in some cases, based on brute facts of physics, chemistry and economics.

Even in cases where it is feasible to substitute electricity for direct fossil energy use to provide the heat and pressure for industrial processes, the costs can be prohibitive. As the JP Morgan report noted, the cost of electricity is 3 to 5 times higher per unit of output than natural gas in states that are the largest industrial users of energy, so fuel switching and upgrades would require large electricity capacity investments that may not make economic sense.

But there are practical policies to pursue that can make a difference domestically and can help to set up U.S. industry to advance cleaner technologies and processes in the future.

Testimony from the National Association of Manufacturers and on behalf of the Portland Cement Association provide examples of some of the policies that we may pursue in the short term on a bi-partisan basis to foster American innovation and technological advancement.

Some of these measures would reduce the regulatory burdens we have today. These include reforming federal and state permitting regulations to enable more energy efficient upgrades to facilities. They include taking steps to help speed up the permitting process for the infrastructure needed for reducing industrial emissions. And they include appropriate policies that make way for the demonstration and deployment of new technologies to prove they can work commercially, economically.

Chairman Tonko, there are bi-partisan legislative solutions we can sign into law this Congress that will remove some of the barriers to innovation in the industrial sector. If you want to start making progress on industrial emissions, let's start with what we know we can do today to make a difference in the innovation landscape, while protecting our national interests, and the interest of our workers and consumers.

Mr. TONKO. Thank you, Representative Shimkus. The gentleman yields back.

The Chair now recognizes Mr. Pallone, the chairman of the full committee, for 5 minutes for his opening statement.

OPENING STATEMENT OF HON. FRANK PALLONE, JR., A REPRESENTATIVE IN CONGRESS FROM THE STATE OF NEW JERSEY

Mr. PALLONE. Thank you Chairman Tonko.

Combatting climate change is a top priority of this committee. That is why, in July, I joined Chairmen Tonko and Rush, and other committee Democrats in announcing a plan to address the climate crisis by achieving a 100 percent clean economy by 2050.

Recent reports by U.S. scientists and the Intergovernmental Panel on Climate Change paint a grim picture of our future if we do not get carbon pollution under control. We are already experiencing record heat waves, flooding, sea level rise, intense wildfires, extended drought, and severe weather events that experts project would come with increased warming. These events are taking a terrible toll on our communities and the cost of inaction is growing.

We must act and our 100 by 50 plan is supported by scientific consensus. Scientists say we must limit global warming to 1.5 degrees Celsius by the end of the century to prevent the worst effects of climate change.

Now transforming our economy to one that is 100 percent clean will be tough and will take significant resources and ingenuity but it is absolutely necessary. Some sectors of the economy will be more difficult to address than others. So today's hearing will examine the industrial sector, an essential sector of our economy and one with some of the largest challenges, as we look to transition to a 100 percent clean economy.

The industrial sector is a source of good-paying jobs and critical products. These products make up our infrastructure and are essential to a wide array of businesses and services in our modern society. A vibrant manufacturing sector helps our economy flourish. At the same time, this sector is also the third largest source of all greenhouse gas pollution.

Compared to other sectors of the economy, emissions from the industrial sector come from a diverse mix of heat production, power generation, and chemical reactions and that mix also varies widely across individual subsectors and facilities, from manufacturing cement and steel to producing chemicals and paper products. This diversity makes the industrial sector especially challenging to decarbonize.

There is no single policy that will curb carbon pollution from the entire sector. Switching to renewables and electrification will work in some areas but not others. Capturing and storing emissions, rather than eliminating them altogether, will likely be the most effective way to decarbonize certain parts of the industrial sector, since creating certain materials naturally produces carbon.

Transitioning the industrial sector to a clean future is challenging but certainly possible. Pathways to industrial sector decarbonization do exist. We have many technologies available today that, with wider deployment, can improve material and energy efficiency in manufacturing and lower carbon and other harmful pollutants. We also need continued research, design development, and demonstration projects to lower costs and spur technological innovation.

Comprehensive climate action provides an opportunity to transform our economy for the future. The technologies we develop and demonstrate here in the U.S. can be exported to other nations, creating new businesses and millions of good jobs in a climate-resilient economy. Climate action ensures our nation does not fall behind our global economic competitors but, instead, leads the world. The rest of the world is already taking the climate threat seriously, embarking on a major transition into a low-carbon economy. We can either lead that transition or watch as American workers and industries get left behind. Cleaning up the industrial sector is essential to meeting this challenge.

So I just want to mention again that I am committed, and our Democrats are committed, to the 100 by 50 target and to building widely-supported solutions that make the necessary pollution reductions while also strengthening our economy for the future. America has always been a leader in innovation. We can and must use our talent and resources to grow new clean industries here and employ our workers to deliver low-or zero-carbon high-quality products to the world.

So I look forward to hearing from our witnesses today, as we continue to hear ideas about how best to reach our 100 by 50 target.

And thank you, Mr. Chairman. I look forward to the testimony.

[The prepared statement of Mr. Pallone follows:]

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I look forward to hearing from our witnesses today as we continue to hear ideas about how best to reach our 100 by 50 target.

Mr. TONKO. Thank you, Mr. Pallone. The gentleman yields back.

The Chair now recognizes Mr. Walden, ranking member of the full committee, for 5 minutes for his opening statement.

OPENING STATEMENT OF HON. GREG WALDEN, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF OREGON

Mr. WALDEN. Thank you, Mr. Chairman. Good morning. Good morning to our witnesses and those in the audience. We thank you all for being here.

I think it is important to note that America has the most efficient energy usage, when it comes to manufacturing, probably in the world and we have led the world in actual reductions in carbon emissions over the last decade or two. We should not lose sight of that.

It has been seven months since Mr. Shimkus, Mr. Upton, and I wrote an op-ed highlighting the need to find common sense and bipartisan solutions to address current and future climate risk. It has also been seven months since this committee held its first hearing on the climate change, where many members on both sides of the aisle expressed interest in working together to find common sense bipartisan solutions to address climate change.

Following that hearing, Mr. Shimkus and I sent a letter to Chairman Pallone and Mr. Tonko, requesting the committee work together on this important issue but, unfortunately, that has not happened. Our Democratic colleagues have not engaged with Republicans in a meaningful way and the politics of climate change, unfortunately, seems to have overtaken rolling up our sleeves and getting to work on, really, bipartisan solutions.

Regrettably, the loudest most radical voices in Congress and on the presidential trail are dominating the climate debate in the party, the Democratic Party. And that is too bad because I think there is common ground and we could find solutions. The gap between rhetoric and reality, though, among my friends has simply gotten out of hand.

Leading Democrats are calling for the elimination of nuclear power—elimination— fortunately, not our chairman here but nearly every single major candidate on the Democratic side wants to eliminate or phase out nuclear power. I don't believe that is smart.

Nuclear is ideal for dealing with climate change because it is the only emissions-free energy source that is available 24 hours a day. Nuclear represents over half our nation's carbon-free energy and experts, from Bill Gates to former Energy Secretary Ernie Moniz, have said nuclear must be part of our energy mix going forward to reduce emissions. To reduce emissions, we need nuclear power. Democrats who are unable to say those simple words are not doing themselves or the climate crisis any good.

Leading Democrats have called innovation such as carbon capture, quote, unquote, "false solutions." So, if your goal is to reduce emissions, that logic simply doesn't follow. We need to be encouraging these technologies, just as we have with President Trump signing into law critical tax credits for carbon capture technology.

Leading Democrats have also called for a ban on fracking and on natural gas development and yet, the production of natural gas helped the United States become a global leader in energy production and a major energy exporter. It substantially helped us reduce our overall emissions. In fact, in 2017, U.S. carbon emissions were the lowest they had been since 1992 and they are projected to remain steady in upcoming years. The United States achieved these reductions while emissions were climbing in most of Asia and most of Europe. So such a ban would wipe out a major source, not only of American prosperity but also of fuel that has lower emissions, and it would lead to Americans paying higher prices for the same energy, and increase reliance, by the way, on foreign energy sources with no impact on the world's appetite for energy. So, I don't think that is a serious approach.

Now I know that many of my friends on the other side of the dais don't agree with all these positions but, unfortunately, the all-or-nothing talking points for many are preventing us from building on the progress we made last Congress to reduce emissions, boost clean energy, and protect America's economy and workers. Maybe that is why E&E News reported, and I quote: "House Democrats have little to show on climate." Closed quote.

Turning to the topic of today's hearing, as Bill Gates warned in a recent op-ed, we have a lot of inventing to do in order to achieve zero-carbon emissions overall. And I believe Mr. Gates rightly pointed out that we don't yet have any proven breakthroughs that will give us affordable zero-carbon emissions of basic building materials like steel, cement, glass, aluminum, plastic, and paper, which account for a fifth of all emissions. Without more serious consideration of the scale of what would be realistically achievable here and abroad to reduce emissions, the 100 by 50 slogan is less of a solution and, frankly, more of a slogan.

So, if Democrats want to tackle climate change, they should work with us Republicans because that is how we are going to get serious solutions that can become law and it is how we have done it in the past. There are bipartisan bills in Congress we could pass right now to ensure the United States remains a global leader in emissions reductions, economic productivity, and clean energy production. And there are more ideas we could explore together, and I hope we will.

We are waiting at the table. We are ready to continue the work started last Congress with our Democratic colleagues on climate policy focused on innovation, conservation, and preparation. So, let's work together.

With that, Mr. Chairman, I yield back.

[The prepared statement of Mr. Walden follows:]

PREPARED STATEMENT OF HON. GREG WALDEN

Good morning, Mr. Chairman.

It has been seven months since Mr. Shimkus, Mr. Upton, and I wrote an op-ed highlighting the need to find commonsense, bipartisan solutions to address current and future climate risks. It has also been seven months since this committee held its first hearing on climate change where many members on both sides of the aisle expressed interest in working together to find common sense, bipartisan solutions to address climate change. Following that hearing, Mr. Shimkus and I sent a letter to Chairman Pallone and Mr. Tonko requesting the committee work together on this important issue.

Unfortunately, that has not happened. Our Democratic colleagues have not engaged with our side in any meaningful way, and the politics of climate change has taken precedent over rolling up our sleeves and getting to work on bipartisan solutions. Regrettably, my Democratic colleagues are allowing the loudest, most radical voices in Congress and on the presidential campaign trail dominate the climate debate in their party.

The gap between rhetoric and reality among Democrats has gotten out of hand.

Leading Democrats are calling for the elimination of nuclear power—fortunately not our Chairman here—but nearly every single major candidate wants to eliminate or phase out nuclear power. This is not smart. Nuclear is ideal for dealing with climate change, because it is the only emissions-free energy source that's available 24 hours a day. Nuclear represents over half of our nation's carbon-free energy. Experts from Bill Gates to Ernie Moniz have said that nuclear must be a part of our energy mix going forward to reduce emissions. To reduce emissions, we need nuclear power. Democrats who are unable to say those simple words are doing as much harm to solving the climate crisis as any other.

Leading Democrats have called innovations such as carbon capture ″false solutions.″ If your goal is to reduce emissions, that logic simply doesn't follow. We need to be encouraging these technologies, just as we have with President Trump signing into law critical tax credits for carbon capture technology.

Leading Democrats have also called for a ban on fracking and natural gas development. The production of natural gas helped the United States become a global leader in energy production and a major energy exporter. It substantially helped us reduce our overall emissions—in 2017, U.S. carbon emissions were the lowest they have been since 1992, and they are projected to remain steady in upcoming years. The United States achieved these reductions while emissions were climbing in most of Asia and Europe. Such a ban would wipe out a major source of American prosperity, lead to Americans paying higher prices for the same energy, and increased reliance on foreign sources—with no impact on the world's appetite for energy. This is not a serious approach and it should be called out.

Now, I know that many of my friends on the other side of the dais don't agree with all of these positions. But unfortunately, the all-or-nothing talking points from many Democrats are preventing us from building on the progress we made last Congress to reduce emissions, boost clean energy, and protect America's economy and workers. Maybe that's why, as E&E News reported, "House Democrats have little to show on climate."

Turning to the topic of today's hearing: As Bill Gates warned in a recent op-ed, "we have a lot of inventing to do" in order to achieve zero carbon emissions overall. Mr. Gates rightly pointed out that we don't yet have any proven breakthroughs that will give us affordable zero-carbon versions of basic building materials like steel, cement, glass, aluminum, plastic, and paper, which account for a fifth of all emissions. Without more serious consideration of the scale of what would be realistically achievable here and abroad to reduce emissions, "100 by '50" is less of a solution and more of a slogan.

If Democrats want to tackle climate change, they should work with Republicans, because that's how we're going to get to serious solutions that can become law. There are bipartisan bills in Congress that we could pass right now to ensure the United States remains a global leader in emissions reduction, economic productivity, and clean energy production. And there are more ideas that we could explore together.

We are waiting at the table and are ready to continue the work we started last Congress with our Democratic colleagues on climate policy focused on innovation, conservation, and preparation.

Let's work together.

Mr. TONKO. Thank you, Representative Walden. The gentleman yields back.

The Chair would like to remind members that pursuant to committee rules, all Members' written opening statements shall be made part of the record.

So now I introduce our witnesses for today's hearing. We being with Bob Perciasepe, President of the Center for Climate and Energy Solutions, or C2ES; Dr. Jeremy Gregory, Research Scientist of the Department of Civil and Environmental Engineering and Executive Director of Concrete Sustainability Hub Massachusetts Institute of Technology, on behalf of the Portland Cement Association.

Next, we have Dr. Gaurav Sant, Professor and Henry Samueli Fellow: Civil and Environmental Engineering, Material Science and Engineering, and the California NanoSystems Institute, Director, Institute for Carbon Management at University of California, Los Angeles.

Next, we have Ross Eisenberg, the Vice President of Energy and Resources Policy at the National Association of Manufacturers.

Next, Dr. S. Julio Friedmann, Senior Research Scholar for the Center on Global Energy at Columbia University's School of International and Public Affairs.

And finally, Jason Walsh, who serves as Executive Director of the BlueGreen Alliance.

Before we begin, I would like to explain the lighting system. In front of you are a series of lights. The light will initially be green at the start of your opening statement. The light will turn yellow when you have 1-minute remaining. Please begin to wrap up your testimony, at that point, and the light will turn red when your time has expired.

At this time, the Chair will now recognize Mr. Perciasepe for 5 minutes to provide his opening statement. And thank you, Mr. Perciasepe, for joining us today.

PERCIASEPE, PRESIDENT OF THE CENTER FOR CLIMATE AND ENERGY SOLUTIONS; JEREMY GREGORY, PH.D, RESEARCH SCIENTIST, DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING EXECUTIVE DIRECTOR, CONCRETE SUSTAINABILITY HUB MASSACHUSETTS INSTITUTE OF TECHNOLOGY; GAURAV N. SANT, PH.D, PROFESSOR AND HENRY SAMUELI FELLOW: CIVIL AND ENVIRONMENTAL ENGINEERING, MATERIAL SCIENCE AND ENGINEERING, AND THE CALIFORNIA NANOSYSTEMS INSTITUTE, DIRECTOR, INSTITUTE FOR CARBON MANAGEMENT AT UNIVERSITY OF CALIFORNIA, LOS ANGELES; ROSS E. EISENBERG, VICE PRESIDENT, ENERGY AND RESOURCES POLICY, NATIONAL ASSOCIATION OF MANUFACTURERS; DR. S. JULIO FRIEDMANN, SENIOR RESEARCH SCHOLAR, CENTER ON GLOBAL ENERGY POLICY, COLUMBIA UNIVERSITY SCHOOL OF INTERNATIONAL AND PUBLIC AFFAIRS; AND JASON WALSH, EXECUTIVE DIRECTOR, BLUEGREEN ALLIANCE

STATEMENT OF BOB PERCIASEPE

Mr. PERCIASEPE. Thank you, Mr. Chairman and all the members, for being here and also for inviting me to speak to you today.

My name is Bob Perciasepe. I am president of the Center for Climate and Energy Solutions. We are a nonprofit nonpartisan organization that works with businesses to achieve climate goals.

I think there are three themes in my quick opening statement and in my written statement that you all have and I think it is already been mentioned by a number of the opening comments from the members.

The challenge in the industrial sector is complex and difficult. Right now in the United States is close to—including the indirect emissions from electricity used, it is close to 30 percent of the U.S. emissions of greenhouse gases.

Engaging businesses and the diversity of businesses in developing the solution mix is a pretty important part of what we will need to do and what we have been doing at the Center for Climate and Energy Solutions. So engaging the businesses is another important point.

And the third key point I think is that businesses are not going to be able to do this alone. They need policy that will help them achieve the goals that they are setting themselves.

And so given the tremendous diversity, and I think we heard this already from particularly the chair of the full committee, that there are three big components in the industrial sector that are causing the emissions. One is the thermal energy they need—the heat. The second is the different chemical processes like making steel and concrete. And there is also electricity that is used. And so thinking about all of those together gives you a sense of the complexity but it can also set you on a path on how you can start dissecting what the solutions would be.

And I have a lot more of this in my written statement but I want to go through very high-level examples here. So if you look at those processes and then you look across all the different sectors, there are some that are in every sector. They are sort of like across the board. So thermal energy is used in a lot of different, from steel making to chemicals, and mostly, as has been pointed out, fossil fuels are used. So this is where the technology of fuel switching, in some cases, but also carbon capture and how important carbon capture would be for some of those processes. That is across the board.

Combined heat and power to be more efficient, the onsite power generation using different kinds of fuels and greater use of efficiency strategies are all things that cut across the different sectors. But then you have to get down to the different processes in the sectors and I want to say that on carbon capture we often think that this is still an evolving technology. And it is, of course, and we need a lot more work on infrastructure but today, while we are sitting here, there are two industrial applications of carbon capture currently in use, one at air products in Texas, where they are making hydrogen from reforming methane, and they are capturing that carbon. The other one is from Archer Daniels Midland in southern Illinois, who is making ethanol and that refinery produces carbon dioxide. And they are capturing that carbon dioxide and injecting into a saline geologic formation.

Other examples that are out there in the more specific areas, manufacturing practices for steel, for instance, Lanza Tech, a company that is working with the steel industry looking at how to capture the carbon using biological methods.

I am going to do this very quickly because it is getting low here.

Apple has been working with Alcoa and Rio Tinto, a mining company, to look at different ways to produce aluminum from using ceramic anodes, instead of carbon anodes that create carbon dioxide.

DowDuPont and BASF are looking at pathways to make propylene oxide, which is a basic building chemical for many products that we know of from deicers, to food additives, to personal care items and they are looking at new approaches there.

And Lafarge Holcim and Solidia are looking at the very things that several of you have already brought up, the cement manufacturing process and how to use different approaches to both the cement itself and how it could absorb carbon but also how to use carbon in the curing—use different approaches in the curing processes which can reduce emissions by up to 70 percent.

The last thing I want to mention very quickly is I think several people brought up the issue of competitiveness. And I think whenever looking at the policies that could help support this, including a price on carbon, looking at the trade-exposed companies in the United States and their international markets, it is important to include provisions that will deal with that. We believe there are many approaches to dealing with that and would love to work with the committee when that time comes.

I am going to stop there.

[The prepared statement of Mr. Perciasepe follows:]

TESTIMONY OF

BOB PERCIASEPE
PRESIDENT, CENTER FOR CLIMATE AND ENERGY SOLUTIONS (C2ES)

BEFORE THE

HOUSE ENERGY AND COMMERCE COMMITTEE AND SUBCOMMITTEE ON ENVIRONMENT AND CLIMATE CHANGE

SEPTEMBER 18, 2019

Good morning, I am Bob Perciasepe, the president of the Center for Climate and Energy Solutions (C2ES). Before joining C2ES, I was most recently the Deputy Administrator of the U.S. Environmental Protection Agency (EPA) from 2009 through 2014. Before that I was the chief operating officer for the National Audubon Society and the Secretary of Maryland's Department of Environment. A full biography is attached and submitted for the record.

The organization I now lead, C2ES, is the successor to the Pew Center on Global Climate Change, which was founded in 1998 and is widely recognized as an influential and pragmatic voice on climate issues. Our mission is to advance strong policy and action to reduce greenhouse gas emissions, promote clean energy, and strengthen resilience to climate impacts. A key objective is a national market-based program to reduce emissions cost-effectively. We believe a sound climate strategy is essential to ensure a strong, sustainable economy.

C2ES has long believed that **business engagement is critical for developing efficient, effective solutions to the climate problem**. Our Business Environment Leadership Council (BELC), established at our founding with 13 companies, has now grown to three dozen mostly Fortune 500 companies across a wide range of sectors. While individual companies hold their own views on policy specifics, they are united with C2ES in the belief that voluntary action alone will not be enough to address the climate challenge. BELC members subscribe to the following guiding principles:

1. We accept the scientific consensus that climate change is occurring and that the impacts are already being felt. Delaying action will increase both the risks and the costs.
2. Businesses can and should incorporate responses to climate change into their core corporate strategies by taking concrete steps in the U.S. and abroad to establish and meet greenhouse gas (GHG) emission reduction targets, and/or invest in low and zero GHG products, practices and technologies.
3. The United States should significantly reduce its GHG emissions through economy-wide, mandatory approaches, which may vary by economic sector and include a flexible, market-based program. Complementary policies may also be necessary for sectors such as buildings, electricity generation,

forestry, agriculture, and transportation that will help drive innovation and ease the transition to a low-carbon economy.

4. Climate change is a global challenge that ultimately requires a global solution. An international climate framework must establish fair, effective, and binding commitments for all developed and major developing economies.

We are grateful for the valuable contributions that BELC members provide to our work. C2ES, however, is solely responsible for its positions, programs, and publications.

Climate Innovation 2050

For the past 18 months, C2ES has convened more than two dozen BELC members and other leading companies to examine potential pathways toward substantially decarbonizing the U.S. economy.[1] Sectors represented include power, transportation, finance, tech, oil and gas, chemicals, cement, steel, manufacturing, and food/agriculture.

To date, Climate Innovation 2050 has produced:

(1) Background briefs examining key challenges and opportunities in decarbonizing U.S. agriculture/land use, buildings, electric power, industry, oil and gas, and transportation;

(2) A set of near-term federal actions that we believe could garner bipartisan support and strengthen the foundation for comprehensive long-term solutions; and

(3) A report, *Pathways to 2050: Scenarios for Decarbonizing the U.S. Economy*, that presents and draws insights from three alternative scenarios for decarbonizing the U.S. economy.

C2ES is now working with participating companies to develop a comprehensive strategy outlining the key policies and actions needed over the coming decade to put the United States on the path to carbon neutrality by mid-century. We plan to release this decarbonization strategy this fall.

Decarbonizing the Economy and the Industrial Sector

Decarbonizing the U.S. economy is a formidable task. The latest science underscores the imperative of achieving carbon neutrality – a net balance of greenhouse gas emissions to, and withdrawals from, the atmosphere – by 2050. To date, the U.S. reduced its net emissions by 13 percent below 2005 levels.[2] That leaves a significant margin yet to account for.

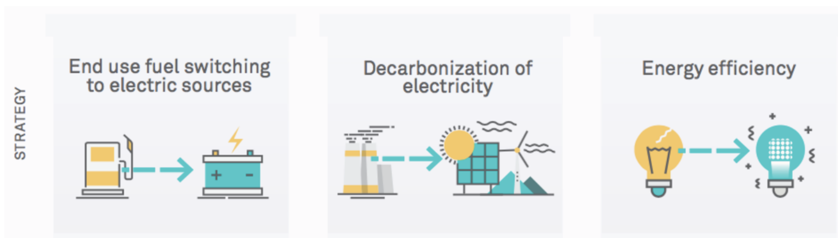
Pathways to deep decarbonization generally focus on three, equally important activities: (1) end-use fuel switching, primarily to electric sources (e.g., switching from gasoline- and diesel-powered to electric vehicles),

[1] Center for Climate and Energy Solutions, "Climate Innovation 2050", https://www.c2es.org/our-work/climate-innovation-2050/

[2] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017", April 2019, https://www.epa.gov/sites/production/files/2019-04/documents/us-ghg-inventory-2019-main-text.pdf.

(2) decarbonization of the electric power sector, and (3) increasing deployment of energy efficiency (Figure 1).[3] All three strategies are relevant to decarbonizing the industrial sector.

Figure 1: Three Pillars of a Clean Energy Economy



Source: Risky Business Project, From Risk to Return: Investing in a Clean Energy Economy, 2016.

According to the Environmental Protection Agency's most recent Inventory of Greenhouse Gases, the industrial sector's greenhouse gas emissions, including both direct emissions and indirect emissions (i.e., from offsite electricity), totaled 915 million metric tons in 2017, or 29.7 percent of total U.S emissions. The bulk of these emissions are from the combustion of fossil fuels to generate energy (i.e., electricity and heat) used in manufacturing processes. Industrial process and product use emissions were nearly 359 million metric tons carbon dioxide equivalent ($MMtCO_2$) in 2017 or 5.6 percent of total U.S. emissions.

U.S. industrial sector emissions have been declining since the mid-1990s. Contributing factors include the adoption of less carbon-intensive manufacturing processes, fuel switching (e.g., coal to natural gas and renewables), increased energy efficiency, a shift in metal production to other countries, and the broader transition to a more service-oriented U.S. economy.

Having fallen through 2010, and remained flat through 2015, the sector's energy-related carbon dioxide (CO_2) emissions are now projected to increase 17.6 percent through mid-century, fueled by low prices for energy, particularly natural gas and natural gas liquids.[4, 5] The six largest sources of manufacturing emissions are expected to continue to be bulk chemicals, refining, iron and steel, food products, paper products, and cement and lime production. In absolute terms, emissions from bulk chemical manufacturing are forecast to increase the most, 126.7 $MMtCO_2$ or 45 percent. Other manufacturing areas expected to see increases are food products (41.4 percent), fabricated metal products (37.1 percent), plastics

[3] "From Risk to Return: Investing in a Clean Energy Economy," Risky Business Project, 2016, https://riskybusiness.org/fromrisktoreturn/.

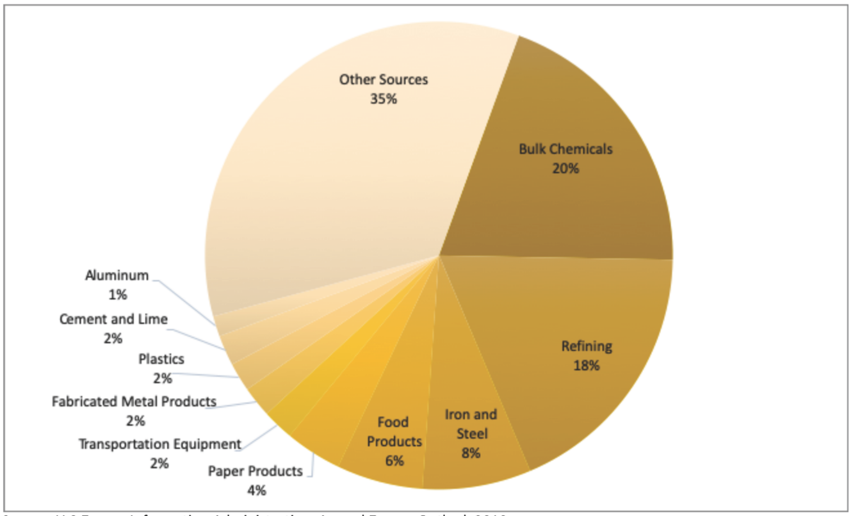
[4] From the Reference Case of the AEO 2019, which assumes current policies only. U.S. Energy Information Administration, "Annual Energy Outlook 2019", January 2019, https://www.eia.gov/outlooks/aeo/.

[5] Industrial sector emissions rose in 2018 by 13 $MMtCO_2$ or 1 percent.

(27.8 percent), aluminum (23.9 percent), and transportation equipment (20.3 percent). These six categories account for 60 percent of projected increases in energy-related CO_2 emissions from U.S. industry.

Given its tremendous diversity, its heavy reliance on large quantities of thermal heat, and the fundamental nature of many core manufacturing process, the industrial sector is especially challenging to decarbonize. Just 10 of the 100-plus industrial sub-sectors account for two-thirds of the sector's energy-related CO_2 emissions (Figure 2). The largest source of this energy demand is heat for industrial processes. Metal, glass, and cement making, for instance, demand temperatures in excess of 2,000 degrees F. Generating this heat with sources other than conventional fossil fuel combustion is challenging, particularly at the higher temperature range.

Figure 2: Energy-Related CO2 Emissions from Industry (2017)



Source: U.S Energy Information Administration, Annual Energy Outlook 2019

Apart from the technical challenges, the industrial sector faces unique economic pressures. For energy-intensive subsectors producing globally traded products, the incremental costs of mitigating emissions may pose a competitive disadvantage if competitors in other countries do not face similar costs. Moreover, global companies with facilities (i.e., large and small) in remote geographies add to this challenge. Often, these facilities are the largest local employer and they contribute substantially to the local tax base. Also, relatively recent long-lived investments in on-site natural gas-fired generation and conversions from coal- to natural gas boilers may lock in emissions for the economic life of those assets.

Given the many challenges to eliminating industrial sector process emissions, two additional strategies will be vital in the long term to achieve carbon neutrality economy-wide. The first is the use of carbon capture technologies to capture industrial CO_2 emissions for storage or for use in commercial products. The second is the generation of "negative emissions" outside the sector – through land-based sequestration and direct air capture technologies – to offset the industrial sectors' remaining emissions.

However, much can and is being done right now to reduce the sector's emissions. As I will highlight, solutions are emerging, and many companies are investing in them.

Innovative Actions by Companies

A large number of actions by companies shows that U.S. industry takes climate change seriously, can continue to be a global leader, as well as maintain competitiveness.

Key Technologies

Some technological emission reduction solutions are applicable across multiple industry sub-sectors while others apply only to specific sub-sectors. Cross-sub-sector solutions include implementation of energy efficiency strategies, greater use of combined heat and power (CHP) systems, adoption of carbon capture utilization and storage (CCUS) for process emissions and on-site power generation, and fossil fuel switching. Emission reductions that derive from developing and deploying new, lower- and non-emitting industrial processes as well as incorporating CCUS into those processes are largely limited to individual sub-sectors.

CCUS is currently in use at-scale (i.e., capturing at least 1 million tons of carbon dioxide per year) at two industrial plants in the United States: Air Products' hydrogen production facility in Texas and Archer Daniels Midland's ethanol production facility in Illinois.[6] Supportive tax credits for CCUS enacted last year under 45Q are expected to significantly increase deployment in the United States. Modeling by the Clean Air Task Force suggests that the 45Q tax credit could provide incentives to capture up to 49 million metric tons in the electricity sector alone. The tax credits, however, can also be claimed by CCUS projects outside the power sector, such as CCUS on ethanol facilities, oil refineries, cement and steel manufacturing plants. To deeply decarbonize the industrial sector, significantly higher deployments will be required over the next three decades.

Multi-Sub-Sector technologies

Improving the efficiency of heating (e.g., better insulation) and equipment (e.g., motors) could yield significant benefits across diverse sub-sectors. Additionally, imbedding digital technologies within industrial machinery creates new opportunities for intelligent efficiency and automation, which can further reduce industrial-scale resource and fuel consumption and emissions. Also, greater use of recycling, particularly in the metals and pulp and paper subsectors can reduce energy consumption thereby reducing emissions.

CHP systems have helped reduce energy use across industrial sectors (e.g., bulk chemicals, pulp and paper, petroleum and coal). Separate centralized electricity generation and on-site heat generation have a combined efficiency of around 45 percent, whereas CHP systems can reach efficiency levels of 80 percent or greater.[7]

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[6] Carbon Capture & Sequestration Technologies @MIT, "Non-Power Plant Carbon Dioxide Capture and Storage Projects," September 30, 2016, http://sequestration.mit.edu/tools/projects/storage_only.html.
[7] U.S. Environmental Protection Agency, "CHP Benefits," Accessed on May 22, 2019, https://www.epa.gov/chp/chp-benefits.

However, adoption of CHP systems has stalled in recent years due to high capital costs, technical complexity, and policy changes. According to DOE statistics, there is more than 80 GW of CHP deployed, and there is the technical potential to install more than 240 GW of CHP across the U.S.[8, 9, 10]

While deploying CHP systems at industrial facilities can deliver significant emission reductions, ultimately all carbon emissions must be avoided. Logically, this will require eventually retrofitting all existing CHP systems with CCUS technology. In the coming years newly deployed CHP systems could make use of novel technology (or a comparable solution) currently being commercialized by Net Power, which is able to eliminate all air emissions after combusting natural gas in a pure oxygen environment.[11]

An additional decarbonization strategy is fuel switching. In some instances, this will involve switching from fossil fuels to electricity (e.g., swapping from fossil fuel to electric boilers for heating requirements) or utilizing alternatives for traditional fossil fuels. For example, using captured natural gas from landfills or synthetic natural gas (SNG) from gasified biomass and anaerobic digestion. Additionally, SNG and hydrogen for industrial purposes can be produced from renewables overgeneration.[12] Also, fuel-switching alternatives for CHP include new small and advanced nuclear power plants (particularly molten salt reactors that operate at very high temperatures), which are capable of supplying many sub-industries with the heat and power they require. These latter options must be inherently safe, cost-effective, and have the public's acceptance.

Single Sub-Sector Technologies

Developing new manufacturing processes that emit fewer greenhouse gases is a key challenge for decarbonizing the industrial sector. Already, improvements are being made in the areas of aluminum, steel, chemicals and cement. And in the bulk chemical space, carbon-free ammonia production may be on the horizon.

As economies continue to grow and develop, aluminum production is expected to expand through mid-century as a lighter weight alternative to steel. In 2015, Apple partnered with Alcoa and Rio Tinto (who formed a joint venture called Elysis) to help expedite deployment of a new carbon-free process to extract pure aluminum from its ore.[13] For 130 years, carbon anodes have been used in the smelting process, which

[8] U.S. Department of Energy, "Combined Heat and Power (CHP) Technical Potential in the United States", March 2016, https://www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf
[9] U.S. Department of Energy, "More than 550 Megawatts of New Combined Heat and Power Capacity Added in United States, Puerto Rico, and Virgin Islands", August 2018, https://www.energy.gov/eere/amo/articles/more-550-megawatts-new-combined-heat-and-power-capacity-added-united-states-puerto
[10] For reference, the total installed capacity of all electric generation resources is around 1,100 GW.
[11] Net Power, "Net Power has Reinvented the Power Plant," Accessed on May 22, 2019, https://www.netpower.com/technology/.
[12] Williams, J.H., B. Haley, F. Kahrl, J. Moore, A.D. Jones, M.S. Torn, H. McJeon (2014). *Pathways to deep decarbonization in the United States*. The U.S. report of the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations. Revision with technical supplement, Nov 16, 2015.
[13] Apple Newsroom, "Apple paves the way for breakthrough carbon-free aluminum smelting method," accessed on May 22, 2019, https://www.apple.com/newsroom/2018/05/apple-paves-the-way-for-breakthrough-carbon-free-aluminum-smelting-method/.

release carbon dioxide and other greenhouse gas emissions. The new process, expected to be commercialized by 2024, relies on patented ceramic anodes, which release no carbon into the atmosphere.[14]

Shifting from basic oxygen blast furnaces to electric arc furnaces in the production of iron-ore steel contributed to a 37 percent reduction in the energy intensity of U.S. crude steel production from 1991–2010.[15] The share of electric arc furnaces is expected to continue to increase through mid-century (though penetration levels are already north of 60 percent) which should help reduce energy consumption from this sub-sector. Additionally, recycling more product (as with other metals) will also reduce energy requirements. And companies like LanzaTech are capturing carbon monoxide from steel (working with ArcelorMittal) and other industrial facilities and converting them into ethanol, jet fuel, and other building blocks for plastics, reducing emissions and demand for fossil fuels.[16]

Dow Dupont and BASF developed a more environmentally friendly pathway to produce propylene oxide that creates less waste and uses less water and energy.[17] Propylene oxide is among the 30 largest volume bulk chemicals, and a raw material for many products including detergents, polyurethanes, de-icers, food additives, and personal care items.[18]

In some cases, switching inputs or raw materials can reduce emissions—for instance, using fly ash from coal-fired power plants instead of carbon-intensive clinker in cement production. Additionally, Lafarge Holcim and Solidia are working to commercialize low-carbon precast concrete that uses lower quantities of limestone and absorbs carbon dioxide in the curing process, which can reduce emissions up to 70 percent.[19, 20]

Additionally, in the bulk chemicals sub-sector, which includes plastics, fertilizers, cosmetics and detergents among other things, carbon-free ammonia (i.e., a fertilizer) may be coming soon. The U.S. Department of Energy is supporting a demonstration project in Indiana that is expected to be operational in 2022, capable of sequestering 1.75 million tons of carbon dioxide a year.[21] Some see greater potential in energy-dense

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[14] Melanie Burton, "Rio Tinto talking to Apple on next step of carbon-free aluminum project," Reuters, March 8, 2019, https://www.reuters.com/article/us-australia-rio-tinto-bauxite/rio-tinto-talking-to-apple-on-next-step-of-carbon-free-aluminum-project-idUSKCN1QP1ED.
[15] Kelly Perl, "Changes in steel production reduce energy intensity," Today in Energy, July 29, 2016, https://www.eia.gov/todayinenergy/detail.php?id=27292.
[16] LanzaTech, "About", Accessed on September 12, 2019, https://www.lanzatech.com/.
[17] U.S. Environmental Protection Agency, "Presidential Green Chemistry Challenge: 2010 Greener Synthetic Pathways Award: The Dow Chemical Company, BASF", Accessed on September 12, 2019, https://www.epa.gov/greenchemistry/presidential-green-chemistry-challenge-2010-greener-synthetic-pathways-award.
[18] Ibid.
[19] Lafarge Holcim Press Release, "Lafarge and Solidia commercialize a new low-carbon solution for the construction sector," April 28, 2015, https://www.lafargeholcim.com/04282015-Lafarge-Solidia-commercialize-new-low-carbon-solution-for-construction-sector.
[20] Akshat Rathi, "The material that built the modern world is also destroying it. Here's a fix," Quartz, December 6, 2017, https://qz.com/1123875/the-material-that-built-the-modern-world-is-also-destroying-it-heres-a-fix/.
[21] Jenny Mandel, "DOE backs 'world's first carbon-free ammonia'," E&E News Energywire, May 21, 2019, https://www.eenews.net/energywire/2019/05/21/stories/1060369553.

ammonia, as a multipurpose fuel source, not unlike hydrogen.[22] Many are looking at more environmentally-friendly ways (i.e., they would not generate carbon dioxide) to synthesize ammonia at commercial scale using clean energy sources.[23]

Policies for Decarbonizing Industry

Federal support is needed to accelerate the efforts of companies and develop new emission reduction pathways. **It is our strong view that economy-wide carbon pricing (e.g., carbon tax, cap-and-trade program or tradable performance standards) can drive private capital to facilitate significant emission reductions across the industrial sector, but a wide range of complementary policies are also needed.** Priorities over the next decade include developing innovative lower-carbon manufacturing processes, using benchmarking to drive energy efficiency and fuel switching, and safeguarding the competitiveness of energy-intensive, trade-exposed sectors.

Advancing Low-Carbon Technologies

Leadership is necessary to rapidly advance a wide range of technologies to reduce or capture emissions from industrial processes and energy use. The federal government should support the research, development and demonstration of critical technologies, stronger public-private partnerships, and fast-track commercialization efforts.

As noted, the largest source of industrial energy demand is heat for industrial processes. Advanced nuclear designs, particularly molten salt reactors, offer a clean alternative for some high-temperature heating needs. Renewable heat sources including renewable natural gas (e.g., from agriculture, wastewater treatment and landfills), solar thermal, and geothermal also hold significant promise. Congress should significantly increase funding to develop and commercialize alternative thermal heat technologies including renewables and advanced nuclear producing combined heat and power. Companies like Cargill, GM, Kimberly-Clark, L'Oreal, Mars, P&G, and Stoneyfield, are working with C2ES and other NGOs to scale up renewable heating and cooling at their facilities as part of the Renewable Thermal Collaborative.[24]

In addition to emissions from energy use, industrial processes themselves produce significant levels of emissions in subsectors such as cement, steel and bulk chemicals. Congress should increase funding to research and develop innovative industrial processes with smaller carbon footprints. Even with such advances, and with reductions in energy-related emissions, significant levels of emissions will likely remain. Capturing those emissions for storage or utilization will be an essential strategy for decarbonizing the industrial sector. It is critical that Congress increase support for the development and deployment of carbon capture technologies.

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[22] Robert F. Service, "Ammonia—a renewable fuel made from sun, air, and water—could power the globe without carbon," Science, July 12, 2018, https://www.sciencemag.org/news/2018/07/ammonia-renewable-fuel-made-sun-air-and-water-could-power-globe-without-carbon.
[23] Ibid.
[24] Renewable Thermal Collaborative, "About", https://www.renewablethermal.org/about/.

Setting Industrial Benchmarks

To orient companies toward decarbonization, the federal government should undertake a benchmarking process to establish greenhouse gas objectives for the major sub-industries. This can be informed by programs already implemented in Canada and Europe. The benchmarking process will highlight best practices and promote industry-wide learning; the intensity-based benchmarks will provide ongoing goals for companies as they pursue their most cost-effective decarbonization options. These benchmarks can also be used to establish companies' or facilities' obligations under an economy-wide carbon pricing program, and to inform measures to address potential competitiveness concerns.

Providing Incentives

To drive the deployment of existing and emerging technologies and help companies reduce emissions, government should provide targeted incentives for efficiency, fuel switching and carbon capture, including:

- Federal, state, and local governments should support the deployment of conventional combined heat and power systems.
- Congress should extend and increase the existing 45Q tax credit for CCUS technologies to support the capture of process and on-site energy-related emissions, and should provide tax credits for energy efficiency improvements.
- To promote electrification and reduce dependence on fossil fuels, federal and state incentives should be offered for the adoption of electric boilers for industrial heat and other electrification measures (e.g., industrial heat pumps).
- CO_2 infrastructure – pipelines, develop regional industrial hubs and infrastructure plans.

DOE has an important role in helping the private sector better understand the opportunities for clean energy and systems efficiency. Congress should expand funding for manufacturing initiatives through DOE's Advanced Manufacturing Office, which should champion a circular economy approach (i.e., recycling) and seek decarbonization opportunities in advanced manufacturing, digitization and automation.

Federal, state, and local agencies procure significant quantities of materials for infrastructure projects, operations and other purposes. As a further incentive to industry to produce lower-emission goods, the federal government should institute "clean procurement" criteria that favor products with the lowest carbon intensity on a full lifecycle basis wherever possible. This requires establishing methodologies and criteria to evaluate a product's embedded carbon.

Industrial Competitiveness

For subsectors that are energy-intensive and trade-exposed – i.e., their products are traded globally – the costs of decarbonizing may pose a potential competitive disadvantage. There may also be a risk that production will move to countries where greenhouse gas policies are not yet as stringent, resulting in "carbon leakage." To date, all existing carbon pricing programs globally include specific provisions aimed at minimizing competitiveness and carbon leakage risks. An economy-wide carbon pricing program should include such provisions (e.g., free allocation of allowances in a cap-and-trade system, offering tax credits, rebates, border adjustments based on best in class benchmarks or other exemptions), all of which should be reexamined periodically.

Past and ongoing C2ES research suggests that potential competitive risks can be managed and should not be an obstacle to strong climate change policy. This conclusion is supported by a new analysis undertaken by C2ES on behalf of the World Bank, which will be released on September 21.

Closing Key Points

Given its tremendous diversity, its heavy reliance on large quantities of thermal heat, and the fundamental nature of many core manufacturing process, the industrial sector is especially challenging to decarbonize. It is our strong view that economy-wide carbon pricing can drive private capital to facilitate significant emission reductions across the industrial sector, but as we outlined above, a wide range of complementary policies are also needed. The large number of actions by companies, some of which were highlighted, shows that U.S. industry takes climate change seriously, desires transparent policy actions, can continue to be a global leader, as well as maintain its competitiveness.[25]

The federal government has a critical role to play. By enacting economy-wide carbon pricing and complementary policies, Congress will send an essential signal to companies, spur investment, and help accelerate the actions necessary to deeply decarbonize the industrial sector and help stave off the worst effects of climate change. So that by mid-century, a modernized U.S. industrial sector will continue to create jobs, growth and exports with a carbon neutral footprint.

[25] A wide range of companies are acting on climate; many have adopted emission reductions goals. An increasing number of large investor-owned utilities have laid out plans to deeply decarbonize their generation portfolios by mid-century. Many large companies have set out goals to procure 100 percent carbon-free electricity for their operations. More than 60 percent of the 2016 Fortune 100 have set targets to reduce greenhouse gas emissions, improve energy efficiency, and/or increase the use of renewables (WWF, Calvert Investments, CDP and Ceres, "Power Forward 3.0: How the largest US companies are capturing business value while addressing climate change", April 2017, https://www.worldwildlife.org/publications/power-forward-3-0-how-the-largest-us-companies-are-capturing-business-value-while-addressing-climate-change). Additionally, companies are employing internal carbon pricing to systematically incorporate climate-related costs into investment and operational decisions and to incentivize least-cost reductions. And, they are working with employees, suppliers and major customers to promote carbon reduction throughout the value chain.

Mr. TONKO. Thank you very much, Mr. Perciasepe.

And now we will go to Dr. Gregory, please, for 5 minutes. You are recognized for your opening statement.

STATEMENT OF JEREMY GREGORY, Ph.D.

Dr. GREGORY. Good morning, Chairman Tonko, Ranking Member Shimkus, and esteemed members of the subcommittee. I am pleased to be here on behalf of the Massachusetts Institute of Technology's Concrete Sustainability Hub and the Portland Cement Association to talk about concrete's role in a sustainable low-carbon economy and how Congress and the cement and concrete industries can work together to achieve this goal.

I am the Executive Director of the MIT CSHub, a dedicated interdisciplinary team of researchers working on science, engineering, and economics for the built environment since 2009. PCA is a premiere organization serving America's cement manufacturers. Since the CSHub is jointly funded by the cement and concrete industries, our research teams regularly interact with companies in this arena and also stakeholders who are involved in decisions related to concrete, such as architects, engineers, and contractors.

In my testimony today, I would like to provide the committee with some key actions related to the cement and concrete industries that will accelerate us on the path to sustainability in the industrial manufacturing sector.

For background, cement is the powdery substance that is mixed with water and aggregates to make concrete. If you didn't realize there was a difference between cement and concrete, you can join my beloved mother in that esteemed club. Although cement and concrete have different manufacturer processes and emission profiles, they are inherently linked as an end use building material whose impacts other emissions, such as building energy consumption or vehicle fuel consumption on pavements. Thus, it is important to consider the embodied emissions for these materials in the context of their full life cycle.

Furthermore, concrete is the most-used building material in the world for a reason. It is a relatively low-cost and low-environmental footprint material that provides critical functionality for buildings and infrastructure. It is necessary to meet societal goals for sustainable development.

There are four primary levers for reducing cement production CO2 emissions. One, improving the energy efficiency of the cement plant; two, switching to alternative fuels that are less carbon-intensive than conventional fuels, such as biomass and waste materials; three, increasing the use of low-carbon materials in the production of blended cements; and four, using emerging carbon capture on utilization and storage technologies, including in the production of new building materials.

A technology roadmap for the global cement industry estimated that meeting targets from maximum two degrees C. global temperature increase would require a 24 percent reduction in cement industry CO2 emissions by 2050, with CCUS accounting for 48 percent of emission reductions followed by use of blended cements at 37 percent. There are fewer CO2 reduction opportunities associated with thermal energy efficiency or switching to alternative fuels and, thus, they only accounted for 15 percent of cumulative CO2 reductions.

Nevertheless, there are several opportunities to improve energy efficiency and increase use of alternative fuels and the cement industry in the U.S. has made significant strides towards these goals. However, regulatory programs are often barriers to making additional improvements. And there are some specific programs and suggested modifications that are detailed in my written testimony.

Cement production is unique from most other industrial processes, in that it has emissions associated with energy generation and the production process. Thus, even if zero- or low-carbon fuels can be used, emissions will still be a fundamental part of the process. As a consequence, CCUS is necessary to meet deep decarbonization goals and pilot programs in the cement industry are underway across the world.

Fortunately, there are several companies that are demonstrating how captured carbon may be used to produce binders and aggregates, thereby enabling circularity for these emissions. However, cost is a significant barrier to the implementation of carbon capture technologies at cement plants, in terms of capital costs, and the adoption of carbon-utilizing materials in terms of higher product costs in the building material marketplace. Thus, there are significant opportunities for Congress to provide targeted CCUS research development and deployment funding that is specific to the cement sector and incentives for adoption of innovative technologies and materials.

Increasing the adoption of blended or alternative binders will require overcoming the risk aversion of engineer's specifying concrete. Engineers typically rely on prescriptive-based specifications that detail the types and limits of materials that can be used in concrete mixture. In addition, there is a significant burden of proof to demonstrate that new low-carbon materials will meet long-term structural and durability requirements. Supporting a shift to performance-based specification for concrete would spur innovation in the design of low-carbon concrete mixtures.

Sponsoring research on the long-term structural and durability performance of concretes using blended or alternative cements will help to mitigate perceived risk by engineers.

As you can see, there are steps Congress, industry, and academia can take together that would ensure the continued role of cement and concrete in sustainable development.

Mr. Chairman and members of the committee, we are ready to work with you to pursue the paths toward the goal of a clean and sustainable economy together.

Thank you.

[The prepared statement of Dr. Gregory follows:]

Testimony for the Congress of the United States House of Representatives Subcommittee on Environment and Climate Change in the Committee on Energy and Commerce hearing on "Building a 100 Percent Clean Economy: Pathways to Net Zero Industrial Emissions"

September 18, 2019

Presented by Jeremy Gregory, PhD
Research Scientist, Department of Civil and Environmental Engineering
Executive Director, Concrete Sustainability Hub
Massachusetts Institute of Technology

On behalf of the Portland Cement Association

Good morning Chairman Tonko, Ranking Member Shimkus, and esteemed Members of the House Subcommittee on Environment and Climate Change in the Committee on Energy and Commerce. I am pleased to be here on behalf of the Massachusetts Institute of Technology's (MIT) Concrete Sustainability Hub (CSHub) and the Portland Cement Association (PCA) to talk about concrete's role in a sustainable low-carbon economy and how Congress and the cement and concrete industries can work together to address emissions from the industrial manufacturing sector and advance our nation's climate reduction goals. I am Executive Director of the MIT Concrete Sustainability Hub, a dedicated interdisciplinary team of researchers from several departments across MIT working on concrete, buildings, and infrastructure science, engineering, and economics since 2009. The MIT CSHub brings together leaders from academia, industry, and government to develop breakthroughs using a holistic approach that will achieve durable and sustainable homes, buildings, and infrastructure in ever more demanding environments.

We conduct our research with the support of the Portland Cement Association (PCA), the premier advocacy, policy, research, education, and market intelligence organization serving America's cement manufacturers. PCA members represent 92 percent of the United States' cement production capacity and have distribution facilities in every state in the continental U.S. Cement and concrete product manufacturing, directly and indirectly, employs approximately 610,000 people in our country, and our collective industries contribute over $125 billion to our economy (see details in Figure 1). Portland cement is the fundamental ingredient in concrete. The Association promotes safety, sustainability, and innovation in all aspects of construction; fosters continuous improvement in cement manufacturing and distribution; and promotes economic growth and sound infrastructure investment. PCA also works hand in hand with our partner associations and companies advancing the interests and sustainability of concrete building materials and products through the North American Concrete Alliance (NACA).

	Unites States	
	Cement	Cement & Related
Employees	13,190	169,375
Payroll ($)	848,203,728	8,838,172,117
Contribution to State Taxes Revenues ($)	181,191,344	2,350,908,147
Economic Contribution ($)	19,293,119,956	124,358,344,936

- Offices - 108 — A red dot indicates the location of a cement sales office or headquarters.
- Plants - 98 — A green dot indicates the location of a plant producing portland cement.
- Terminals - 375 — A blue dot indicates the location of cement distribution terminals and silos.

Figure 1. Statistics on the US cement industry. Source: Portland Cement Association.

In my testimony today, I would like to leave the Committee with five fundamental points about the path to sustainability in the industrial manufacturing sector through the lens of the cement and concrete industries.

First, while cement and concrete are separate and distinct materials, with different manufacturing processes and emissions profile, they are inherently linked as an end-use building material and should be measured in the context of that end-use sustainability profile. Cement and concrete building materials (CCBMs), like steel, wood, glass, and other building materials, should be considered in terms of their embodied carbon across their full life cycle - from materials sourcing and manufacturing, to productive use, reuse, recycling, or disposal. Anything less than a life cycle approach creates a shell game where carbon emissions just shift from one part of the economy to another, or one nation to another, without solving the global challenge of climate change.

Second, CCBMs are and will continue to be critical and irreplaceable building materials for our national economy, providing sustainable, resilient, safe, and energy efficient building solutions for the development and maintenance of our nation's infrastructure and built environment. When considered across their full life cycle, CCBMs provide comparable if not superior performance in terms of embodied carbon, resilience, safety, and climate adaptability when compared against other building materials.

Third, CCBM manufacturers are committed to working with policymakers, environmental scientists and engineers, builders, and customers to improve their sustainability and carbon intensity while maintaining the performance characteristics and value that have made CCBMs so important to our economy. CCBM manufacturers already invested billions of dollars to upgrade manufacturing facilities and processes, increase the fuel and energy efficiency of the manufacturing process, and reduce carbon and other air, waste, and water emissions. Where allowed under federal and state regulations, many of our manufacturers have looked for opportunities to incorporate lower-carbon alternative fuels like used tires, biomass, and other nonhazardous secondary materials into the manufacturing process.

Fourth, the CCBM industry faces unique challenges in building upon these initial sustainability efforts. With respect to fuel-related emissions, most of the opportunities for energy efficiency improvements for cement plants have been leveraged, and those remaining are often prohibitively expensive with limited impact. Federal and state regulations discourage the use of many lower-carbon alternative fuel sources, treating non-hazardous secondary materials like non-recyclable paper, plastic, and fibers as dangerous wastes and cement manufacturers as incinerators. Many cement facilities cannot even transition from coal to lower-carbon natural gas due to the lack of natural gas pipelines and delivery infrastructure.

But fuel emissions are only part of the emissions reduction challenge. Cement manufacturers face a heretofore unsolved basic chemical fact of life - the industrial process for manufacturing cement from limestone results in the chemical release of carbon dioxide. No level of investment in additional energy efficiency technology or alternative fuels will address these process emissions, which constitute the majority of the cement industry's emissions. Only innovation and new technologies for carbon capture, transport, use, and/or storage will address these emissions, and these technologies are still years, if not decades away from plant-scale deployment in the cement industry. Bringing these technologies to market will require billions of dollars of additional investment in research, development, pilot scale testing, and infrastructure.

Fifth, any national carbon reduction strategy will need to recognize the economic realities of today's global market economy. Cement is a fungible global commodity, and domestic cement manufacturers are price takers rather than price makers, with limited ability to pass additional costs on to customers who can easily switch to lower-cost, often higher carbon imported cement. Domestic cement manufacturers cannot compete in a global market against foreign importers and countries who are not doing their fair share to reduce emissions. If the U.S. is to maintain a healthy domestic cement industry and the jobs and contributions to the domestic economy it provides, policymakers will need to address the risk of trade leakage head on. Policymakers in the EU, Canada, and California have recognized the need to protect energy-intensive trade exposed industries from trade leakage, and Congress needs to provide for a level competitive playing field for cement, concrete, and other industrial manufacturers.

With these facts in mind, the concrete and cement industries will need help from Congress to do their part. Congress can start by reducing the barriers manufacturers face to taking early action:

- reform and streamline federal and state permitting regulations under the Clean Air Act's new source review program to update facilities with more energy efficient manufacturing equipment;
- reform federal air and waste laws to treat nonhazardous secondary materials like non-recyclable paper, plastic, and fibers as fuel sources, not just waste products destined for landfills;
- expedite the permitting process for energy infrastructure projects, including pipelines to transport natural gas and other lower-carbon fuels to cement plants; and
- perhaps most important, provide dedicated funding for research, development, and deployment of commercial scale carbon capture, transport, use, and storage technologies needed to manage industrial process emissions and other hard-to-abate emissions from industrial manufacturing.

The remainder of this document provides background on CCBMs and opportunities, barriers, and solutions for enabling low-carbon pathways in the sector.

1 Background on concrete and cement

1.1 Concrete is critical for sustainable development

Concrete plays a critical role in achieving societal goals for sustainable development. It is required for nearly all aspects of our built environment including buildings, pavements, bridges, dams, and other forms of infrastructure. Infrastructure is required to achieve all 17 of the United Nation's sustainable development goals [1]. As growth in urban and suburban areas of the US significantly outpaces growth in rural areas (13%, 16%, and 3%, respectively since 2000) [2], demand for buildings and infrastructure will increase to meet the needs of migration and immigration. Calls for increased housing to address affordable housing shortages and more resilient buildings and infrastructure to mitigate the impacts of natural disasters will also lead to increased construction using concrete. While this development is inevitable, it is possible to make it sustainable.

1.2 Concrete is the most used building material in the world

Concrete's critical role in our built environment is manifest in how much it is used. Figure 2 shows global production (per capita) of common building materials [3]. Production volumes for cement, the binding agent in concrete, are nearly three times as much as steel, and concrete production is approximately seven times as much as cement (as shown in the chart). This significant consumption means it is also important to address when setting industrial emission targets.

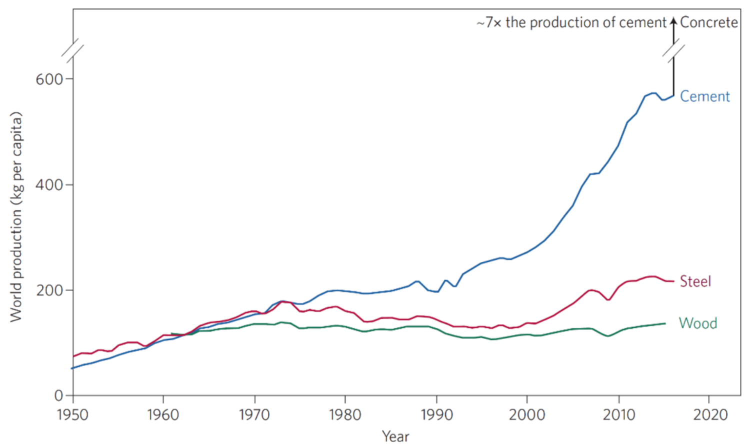


Figure 2. World production (per capita) of cement (the binder in concrete), steel, and wood [3]. Concrete production is about seven times higher than cement, so it is not shown on the chart.

1.3 Concrete is a mixture that usually includes cement as a binder

Concrete is made using five basic ingredients: coarse aggregates (gravel), fine aggregates (sand), binder (including cement), water, and admixtures (chemicals that can change concrete properties). These can be combined in infinite ways to meet performance requirements including strength, stiffness, density, constructability, and durability. When the binder is mixed with water it hardens to create a paste that keeps the aggregates in place.

There are numerous types of binders that can be used in concrete, as shown in Figure 3. Some are based on materials that can be mined and transformed into binders, whereas others are derived from waste materials. The most common binder used is portland cement (the name derives from the type of mineral first mined from the Isle of Portland in the UK when the process was developed in the 1800s). Portland cement is primarily made using limestone, which is abundantly available all over the world, can be produced within tight and reliable specifications, and has been used extensively for over 150 years, thereby making it the preferred binder for producing concrete. Alternative binders to portland cement are referred to as supplementary cementitious materials (SCMs). These include naturally occurring materials, such as natural pozzolans or calcined clays, and waste materials, such as fly ash from coal fired power plants, granulated slag from steel production, and more recently ground post-consumer glass. Availability and composition of SCMs can vary significantly, and they can have a different impact on the performance of concrete than portland cement.

Figure 3. Examples of binders that can be used to make concrete. Binders in the top row are created from materials mined in the earth, whereas those in the bottom row are derived from waste.

1.4 Cement production has energy and process-related emissions

The cement production process is shown in Figure 4 [4]. Limestone and other raw materials are mined and then go through a series of treatment steps before entering the kiln (step 6), which requires significant amounts of energy to maintain at 1,450 °C (these are referred to as energy or thermal emissions). The limestone is transformed into clinker in the kiln in a process called calcination that emits carbon dioxide (these are referred to as process emissions). The clinker may be blended with other cementitious binders and then ground to create the final cement product.

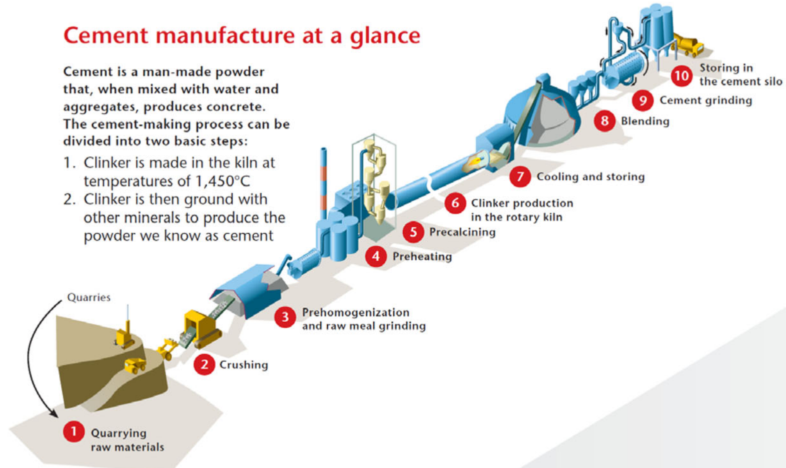


Figure 4. Cement production process [4].

Production of conventional portland cement in the US emits about 1 kg of carbon dioxide for every kg of cement produced [5]. As shown in Figure 5, approximately 50% of these emissions are from the calcination process, and 40% are from thermal or energy generation processes (maintaining the kiln at 1,450 °C).

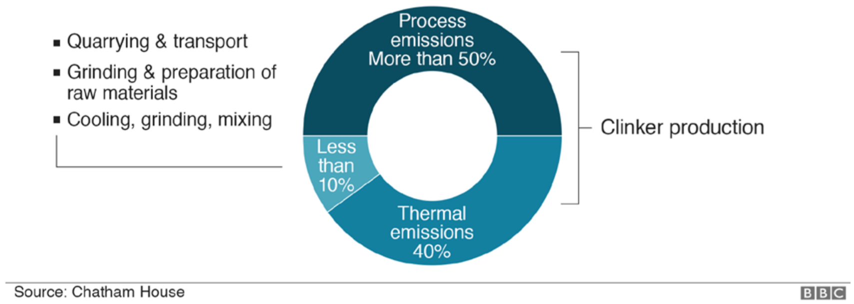


Figure 5. Sources of carbon dioxide emissions in conventional cement production [6].

1.5 Cement drives concrete's environmental impact

Figure 6 shows that by mass, concrete is primarily made up of aggregates. However, the greenhouse gas emissions (which are predominantly carbon dioxide) are from the cement. The aggregates have very low environmental footprint because they are simply mined from quarries without further transformation.

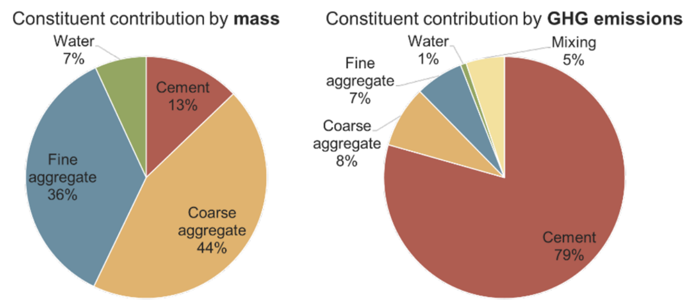


Figure 6. Concrete constituent contributions by mass and greenhouse gas (GHG) emissions for a conventional concrete (3000 psi) without SCMs. Source: CSHub calculations.

1.6 Concrete and cement are low-impact materials

On a per unit weight basis, concrete and cement have low embodied carbon dioxide and energy footprints (i.e., emissions and energy associated with production). Figure 7 compares these measures with those of other industrial materials [7]. Concrete's environmental footprint is so much lower than other materials because it is primarily made from aggregates, which, as noted above, have a low environmental footprint. While cement has significant process and energy emissions, they are smaller than those of other materials such as metals.

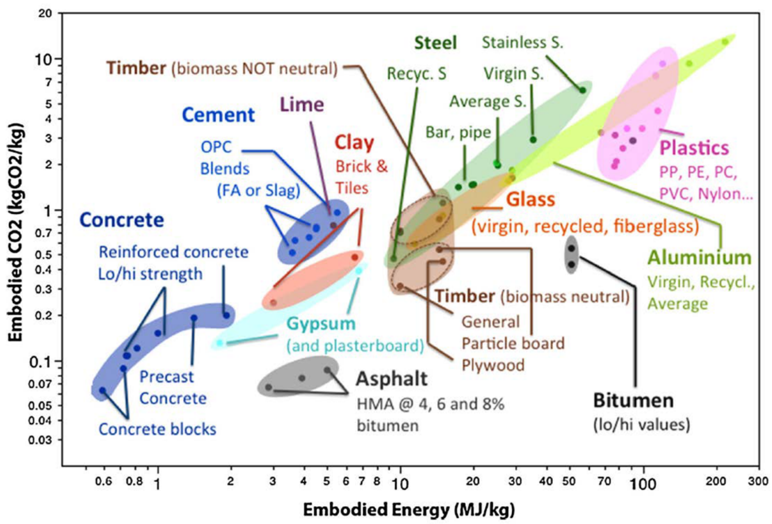


Figure 7. Embodied carbon dioxide emissions and energy from the production of various industrial materials [7]. Note that axes have a log scale.

1.7 Cement emissions constitute approximately 1% of US greenhouse gas emissions

Estimating greenhouse gas (GHG) emissions from cement production is difficult because it requires tracking both process and energy-derived emissions, and energy-derived emissions are rarely tracked for a specific industrial sector. For example, the most reputable quantitative estimate of global cement emissions as a fraction of all emissions has been done by the PBL Netherlands Environmental Agency [8]. They stated that process emissions contributed "to about 4% of the total global emissions in 2015" (pg. 64). To estimate total cement emissions, they state: "Fuel combustion emissions of CO2 related to cement production are of approximately the same level, so, in total, cement production accounts for roughly 8% of global CO2 emissions." (pg. 64-5) Their study details how they estimated cement emissions but does not describe how total GHG emissions are estimated. Thus, the 8% figure is an approximation.

Estimating US cement GHG emissions can be done using the US EPA's GHG inventory [9]. Process-derived emissions from cement production were 40.3 MMT CO2 Eq. (million metric tons carbon dioxide equivalent) in 2017, out of 6,456.7 MMT CO2 Eq., or approximately 0.6%. The inventory does not quantify energy-related emissions from cement production, so we are forced to use a similar approximation to the PBL study that energy and process-derived emissions are the same. This would make total cement industry emissions approximately 1.2% of total US GHG emissions in 2017.

1.8 The US produces a small fraction of the world's cement

China produces more than half of the world's cement, as shown in Figure 8 [6,8]. The US produced approximately 2% of global cement in 2015, compared to China's 58%, India's 7%, and the EU's 4% [8]. Thus, while it is important to strive to lower emissions from US cement production, it is also important to consider that the US has lower production than China, India, and the EU.

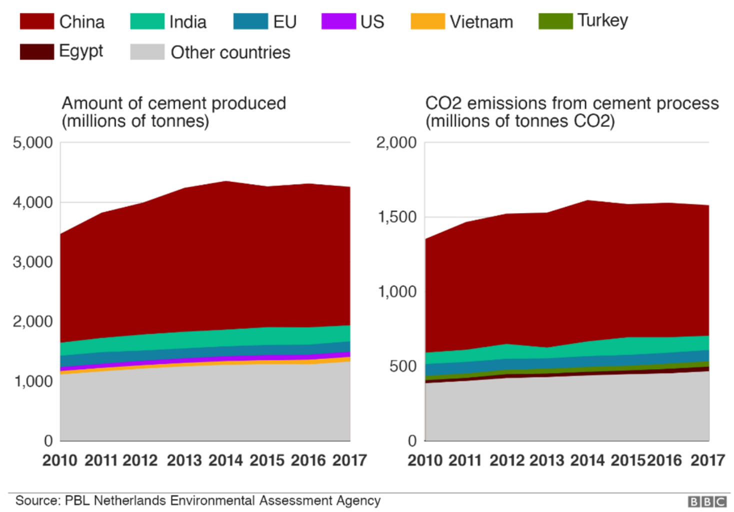


Figure 8. Global cement production volumes and process-related carbon dioxide emissions [6,8].

1.9 Different standards and practices for cement production worldwide present opportunities for leakage

It is basic economics that in a global market for a commodity product like cement, managing the costs of production is critical to ensuring the continued competitiveness of domestically-manufactured products. Facilities that can produce, ship, and deliver cement to customers at a competitive cost will flourish. Those that cannot maintain cost-competitiveness will fail.

These costs are determined in large part by the design and operating practices of the manufacturing facilities where cement is produced. While every cement manufacturing plant is different, the basic steps in the manufacturing process are the same. Costs of production are not, however, particularly with respect to compliance costs imposed by government entities. Government policies that impose additional costs on manufacturers have a direct impact on the global competitiveness of manufacturers and the risk of trade and carbon leakage.

This is particularly the case for the cement industry for several key reasons:

- The energy intensive nature of the manufacturing process, combined with the significant process emissions resulting from the conversion of limestone to cement makes the cement industry particularly vulnerable to policies that increase the cost to manage carbon emissions
- U.S. cement manufacturers have limited ability to cost-effectively reduce GHG emissions and, therefore, to minimize compliance costs through investments in direct abatement.
- U.S. cement manufacturers have limited ability to pass through compliance costs to customers without a significant loss in market share.

Due to this unique combination of features, carbon pricing is likely to result in significant leakage in the U.S. cement industry unless countervailing measures are applied.

To illustrate this challenge, PCA estimates that given a carbon price of $40 per metric ton, the U.S. cement industry would experience an operating cost increase of more than $2.6 billion per year, representing roughly 50% of the U.S. cement industry's value added ($5.0 billion) and 30% of its total shipments ($8.7 billion) in 2016. Such increases could easily increase the cost of producing cement by more than $30 per ton, making domestic cement uncompetitive in many markets served by imports.

As Congress develops a comprehensive federal climate policy for U.S. manufacturers, this lesson in "economics 101" should be front and center as a consideration. Any comprehensive climate policy that imposes increased operating, compliance, or research and development costs on cement manufacture must include measures to address the risk of leakage from imported products.

2 Opportunities to lower carbon dioxide emissions of cement production

2.1 There are four primary levers for reducing cement production carbon dioxide emissions

The World Business Council on Sustainable Development (WBCSD) and the International Energy Agency's (IEA) Cement Sustainability Initiative (CSI) produced a technology roadmap for the cement sector in 2018 [10]. They identified four *carbon reduction levers*:

- **Improving energy efficiency** in the cement plant.
- **Switching to alternative fuels** that are less carbon intensive than conventional fuels, such as biomass and waste materials.
- **Reducing the clinker to cement ratio** by increasing the use of blended materials (including some of the aforementioned SCMs, among others) in the production of blended cements.
- **Use emerging technologies to capture carbon** and use, store, or sequester it, including in the production of new building materials.

The first three levers are already being used by the cement industry in the US and beyond.

2.2 The US cement industry has made significant efforts to improve energy efficiency and use of alternative fuels

U.S. cement manufacturers continue to invest billions of dollars in technologies to increase the energy efficiency of their plants and reduce carbon emissions associated with the cement manufacturing process. Duke University evaluated the improvement in the cement industry's energy performance over a 10-year period and found that: energy intensity improved 13 percent, the energy performance of the industry's least efficient plants changed most dramatically, total source energy savings were 60.5 trillion Btu annually, and environmental savings were 1.5 million metric tons of energy-related carbon emissions [11]. As a result, today's plants are far more fuel efficient than a generation ago, in many cases approaching the maximum levels of fuel efficiency technically feasible.

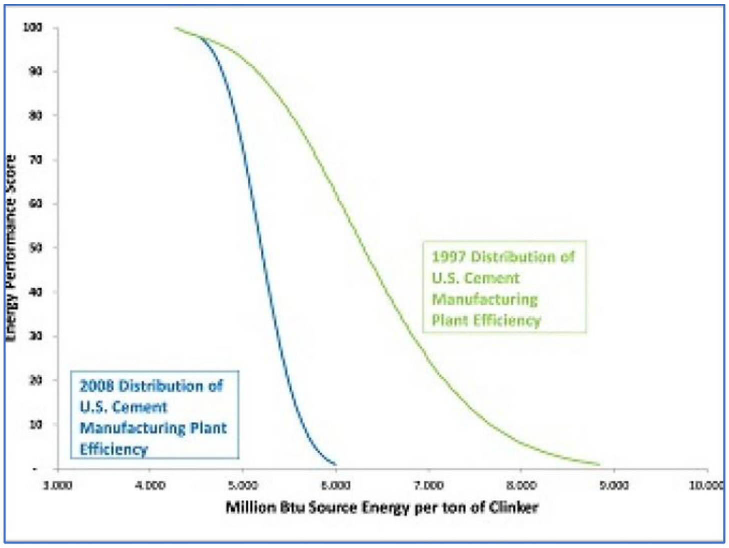


Figure 9. Comparison of 1997 (green) and 2008 (blue) distribution of US cement manufacturing plant efficiency as measured by the ENERGY STAR energy performance indicator [11].

Another key opportunity to reduce fuel emissions is to increase the use of lower carbon alternative fuels. Secondary materials like post-industrial, post-commercial, post-consumer paper, plastic, and other materials have tremendous energy value, providing a cost-effective and sustainable alternative to traditional fossil fuels. The cement industry has a long history of safe and efficient use of alternative fuels, ranging from used tires and biomass to a wide variety of secondary and waste materials. The high operating temperature and long residence times in the kiln make cement kilns extremely efficient at combusting any fuel source with high heating value while maintaining emissions at or below the levels from traditional fossil fuels. For the cement industry, secondary materials that would otherwise have little market value are valuable commodities, offering a cost-effective and environmentally sustainable alternative to traditional fossil fuels. While these efforts are important, there is much more to be done. Today, alternative fuels make up only about 15 percent of the fuel used by domestic cement manufacturers, compared to more than 36 percent in the European Union, including as high as 60 percent in Germany. Legal and regulatory barriers to alternative fuels use prevent the U.S. from having similar alternative fuels utilization rates to Europe.

The CCBM industry faces unique challenges in building upon these initial sustainability efforts. With respect to fuel-related emissions, most of the low-hanging fruit opportunities for energy efficiency improvements for cement plants have been leveraged, and those remaining are often prohibitively expensive with limited impact. Further improvements will also require cooperation by federal and state regulators that determine, through their regulations and permitting programs, whether and when facilities can adopt lower-carbon technologies, facility improvements, operations, and fuels.

2.3 Blended cements are available today

Portland limestone cement (PLC) is an example of a blended cement that is readily available from cement manufacturers. It is made by blending limestone with clinker (Step 8 of Figure 4). The limestone replaces clinker in the cement and therefore, has lower carbon dioxide emissions per unit weight of cement produced.

PLC has been used in Europe for over fifty years [12]. Current European standards allow for up to 35% replacement of cement with limestone, whereas in the US and Canada the limit is 15%. Studies have shown that PLC has nearly the same performance as ordinary portland cement (OPC) [12], but with a 10% reduction in carbon dioxide emissions from production (assuming 15% replacement) [13]. Costs of PLC are similar to OPC, as is its performance. Given, the lower environmental footprint, it would appear to be a strong candidate for increased use. However, PLC is approximately 1% of all cement produced in the US (all types of blended cements make up less than 3% of all cement produced in the US) [14]. This is primarily due to an unwillingness of concrete specifiers (such as engineers) to choose PLC over OPC, which has a longer history of use.

2.4 The technology roadmap for the global cement industry identifies emissions reductions required to meet global targets

CSI's 2018 technology roadmap [10] evaluated the required emissions reductions in the global cement industry required to meet a 2 °C climate scenario (2DS - maximum of 2 °C global temperature increase), as well as a beyond 2 °C scenario (B2DS - lower than 2 °C global temperature increase). They used a reference technology scenario (RTS) that assumed relatively flat direct carbon dioxide emissions until the year 2050 despite increases in cement production. This reference scenario assumes continued progress to reduce emissions associated with cement production at current rates.

As shown in Figure 10, the 2DS represents a 24% reduction in direct carbon dioxide emissions from the RTS by 2050. The B2DS represents an additional 45% reduction in direct carbon dioxide emissions over the 2DS.

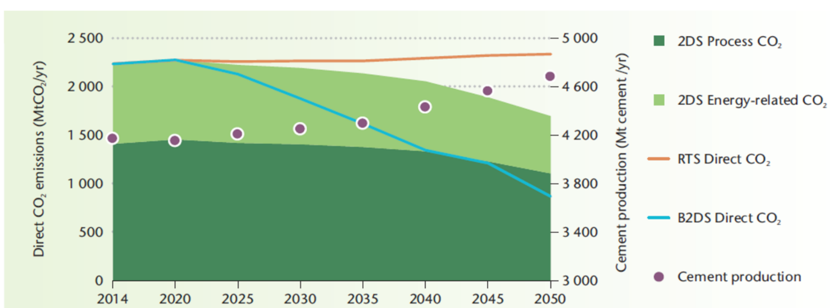
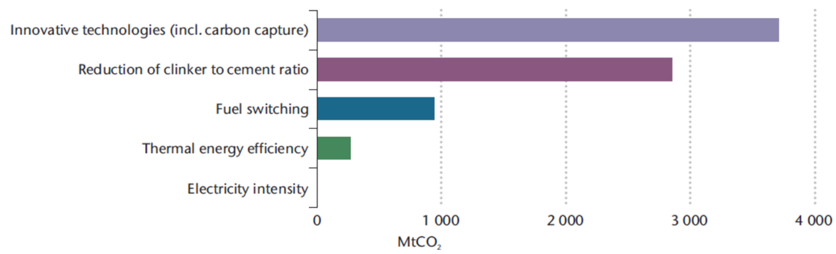


Figure 10. Global direct carbon dioxide emissions from cement production by scenario [10]. RTS = reference technology scenario. 2DS = 2 °C scenario. B2DS = beyond 2 °C scenario.

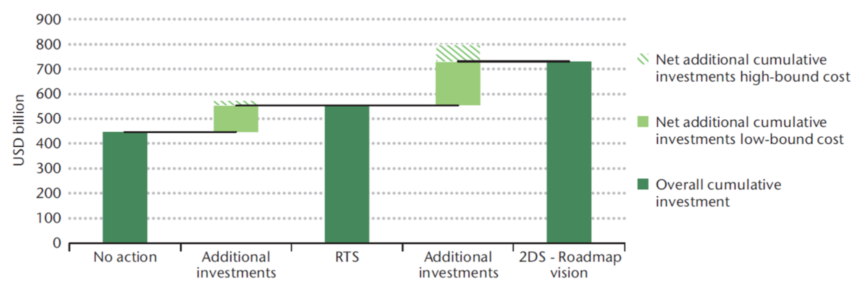
Lowering emissions requires a combination of the four levers mentioned in Section 2.1, as illustrated in Figure 11. Carbon capture technologies contribute 48% of cumulative emissions reductions, followed by use of blended cements (reduction of clinker to cement ratio) at 37%. There are fewer opportunities to improve thermal energy efficiency in cement plants or switch to alternative fuels.



Note: Cumulative CO_2 emissions reductions refer to the period from 2020 to 2050 and are based on the low-variability case of the scenarios.

Figure 11. Global cumulative carbon dioxide emissions reductions by applying the 2 ℃ scenario compared to the reference technology scenario [10].

The CSI roadmap includes estimates of global investments required to meet both the RTS and 2DS (Figure 12). \$107 billion to \$127 billion are estimated cumulative investments to meet the RTS globally by 2050 (24-28% increase over no action), and an additional \$176 billion to \$244 billion required to meet the 2DS (32-43% increase over RTS). No investment estimates are available for the US.



Note: Net cumulative additional investment numbers are assessed considering low- and high-bound sensitivity ranges for specific investment costs. Overall cumulative investments displayed in the above graph refer to the low-bound cost range.

Figure 12. Global cumulative investments required to meet RTS and 2DS by 2050 [10].

3 Opportunities to lower carbon dioxide emissions of concrete

The majority of concrete's environmental footprint derives from the footprint of the materials in the concrete, rather than the production of the concrete, which primarily involves mixing (materials represented 95% of the GHG emissions in the case shown in Figure 6). Thus, use of low-carbon (i.e., low carbon dioxide footprint) constituent materials is the primary mechanism for lowering carbon dioxide emissions of concrete. There are three main categories of low-carbon constituent materials.

3.1 Blended cements

Blended cements, such as portland limestone cement, were described in Section 2.3 and are currently produced by cement manufacturers. They make use of many of the same SCMs used in concrete such as fly ash and blast furnace slags (described in Section 1.3). Production of blended cements varies significantly worldwide depending on demand, which is primarily influenced by historical practices for producing concrete, although availability of SCMs is a factor as well (e.g., China and India have significant availability of fly ash from coal fired power plants). There is currently limited demand for blended cements in the US – they make up less than 3% of all cement produced in the US [14].

3.2 Supplementary cementitious materials

SCMs are used more extensively in the US in concrete than in cement. Conventional SCMs include fly ash and blast furnace slag, although other alternatives exist that are used more commonly in other parts of the world including silica fume, natural pozzolans, calcined clays, vegetable ash. More recently, binders made from ground post-consumer glass have become commercially available at small scales. Availability, chemical composition, performance, and cost often determine whether SCMs are used in concrete.

3.3 Cement, aggregate, and concrete made from captured carbon dioxide

The process of *mineralization* involves exposing minerals to carbon dioxide to create a carbonate mineral. It is a natural process that took place over millions of years to create the limestone used in the production of cement. More recently it has been proposed as a form of carbon capture and utilization (CCU) to create materials that can be used in concrete production. This includes the production of binders, aggregates, and concrete (i.e., carbon dioxide is used in the mixing process) using carbon captured from industrial sources, potentially including cement plants. Several companies have been created over the past decade in an attempt to commercialize mineralization for building products [15]. There is significant variation in the degree to which they make use of carbon dioxide. Most of the companies are in a start-up phase with demonstration plants or small production volumes, but several of them have products currently being used in construction projects. In some cases, the technologies can only be used to make concrete blocks in production facilities (as opposed to cast-in-place concrete on job sites) because of the requirements to control the mixing of carbon dioxide with minerals. As such, this limits their application to cases where concrete blocks can be used (such as buildings).

3.4 Considerations for the use of low-carbon constituent materials

It is important to note that substitution of these low-carbon constituent materials for conventional materials in a concrete mixture will not necessarily result in the same performance (strength, stiffness, constructability, durability) of the concrete mixture. Designing a concrete mixture to meet performance targets can be a complicated process that involves trade-offs of many factors that vary depending on the constituents being used. Furthermore, specifications for concrete often limit the use of blended cements or SCMs [16]. Thus, requirements for substitutions of conventional materials for low-carbon alternatives are not straightforward and may not be feasible for many situations.

4 Importance of a life cycle perspective in evaluating environmental impacts of buildings and infrastructure using concrete

The true environmental impact of concrete can only truly be evaluated using a life cycle perspective that encompasses its application in buildings and infrastructure. For example, a life cycle assessment of several building types conducted by our team at MIT has shown that embodied environmental impacts of buildings (associated with material production and building construction) are at most 10% of the total life cycle greenhouse gas emissions (Figure 13); energy use represents the vast majority of environmental impacts [17].

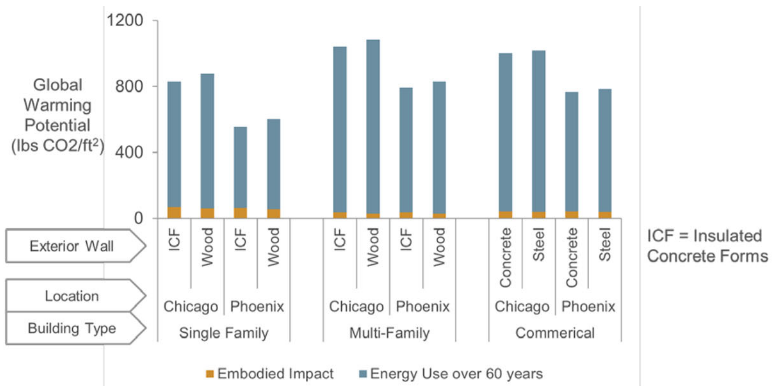


Figure 13. Life cycle global warming potential (greenhouse gas emissions) of three building types in two climates [17]. Embodied impacts include material production and building construction.

Similarly, the life cycle impacts of pavements are dominated by the use phase, which includes excess fuel consumption of vehicles due to roughness or deflection in the pavements (which leads to additional energy dissipation in the vehicle) [18]. In the case of the urban interstate pavements in Figure 14, materials and construction make up only 26% of the life cycle GHG emissions.

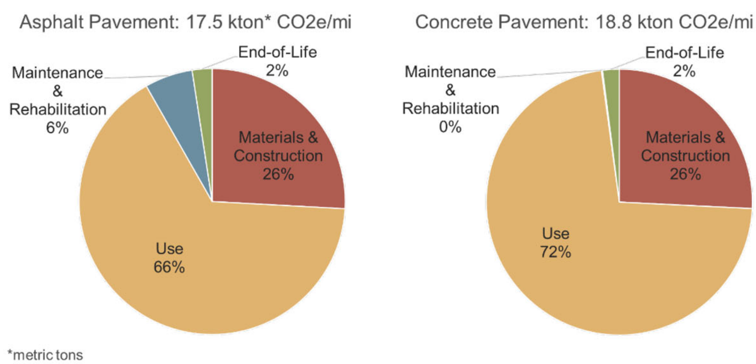


Figure 14. Life cycle greenhouse gas emissions for urban interstate pavements in Missouri.[18] The use phase includes excess fuel consumption from vehicles due to roughness or deflection in the pavements.

Thus, while it is important to seek opportunities to lower embodied emissions in the built environment, it is also important to consider the impact that materials and design choices have on life cycle impacts, particularly if they can enable emissions reductions (e.g., through reduced building energy consumption or lower excess fuel consumption).

5 Barriers to adoption of low-carbon solutions

5.1 Regulations prohibit increased use of alternative fuels in cement plants

Federal policies often discourage rather than embrace the use of secondary materials as fuel in the industrial sector. The industry's use of alternative fuels falls under two environmental laws administered by the U.S. Environmental Protection Agency (EPA), the Clean Air Act (CAA), and the Resource Conservation and Recovery Act (RCRA). The CAA addresses ambient air quality and emissions from manufacturers, power plants, and motor vehicles. RCRA governs the management of solid waste and the generation, transport, and disposal of hazardous materials.

In recent years, narrow judicial and regulatory interpretations of RCRA, the CAA, and EPA regulations have discouraged the use of non-hazardous secondary materials and wastes as fuels, treating these materials as dangerous wastes, and facilities using them as incinerators. These policies are contrary to basic science and public policy, discouraging the productive conservation and recovery of resources and increasing the use of emissions-intensive fossil fuels.

EPA recognized this fact in 2011 and issued a regulation known as the Non-Hazardous Secondary Materials (NHSM) Rule, intended to allow for secondary materials to be used for energy recovery if they met specific legitimacy criteria. In theory, the rule provided a way to distinguish between true waste materials with little to no value as fuel and those material streams that, while may have been traditionally discarded as a waste, could now be put to far more productive use as alternative fuels. In practice, the rule has become yet another roadblock to sound energy and materials recovery policy.

Manufacturers face a costly and time-intensive process to prove, on a case-by-case basis, why commonly landfilled materials such as unrecycled plastics, paper, fabrics/fibers, and other secondary materials should qualify for treatment as fuels, despite their demonstrably lower greenhouse gas and other air emissions and heat value. The result is predictable.

5.2 New Source Review and other permitting processes discourage energy efficiency and carbon capture improvements and critical infrastructure

One of the common-sense strategies for any industry to reduce GHG emissions is to maintain and improve the operational efficiency of its facilities over time. Unfortunately, the current Clean Air Act New Source Review program, as interpreted by the courts and some prior administrations, actually penalizes companies for increasing the efficiency of its facilities. This forces companies to reject upgrades and investments. To address these process emissions and further reduce industry GHG emissions, manufacturers will need to install carbon reduction and carbon capture, use, and storage (CCUS) technologies, other technological advances developed in the future, and implement process improvements. Under the NSR program, such investments would face the same permitting and regulatory barriers that new facilities would face, particularly where the addition of new emissions control technology for one pollutant has a negative impact on the emissions profile for another. Congress should revise the NSR process to encourage, rather than discourage, investments in energy efficiency and carbon capture, use and storage technologies.

Other energy improvements require investment in infrastructure, like pipelines and distribution networks. Cement kilns operate 24 hours per day and almost 365 days per year, and have historically used fossil fuels, such as coal and petroleum coke, due to the need for plentiful fuel supplies that can easily be stored and are in plentiful supply. In recent years, the cement industry has used more natural gas to reduce GHG and other air emissions. According to the PCA's Labor and Energy Survey, from 2011 to 2016 the industry increased natural gas use from 3.9% to 15.5% of its fuel use, displacing higher carbon fuels like coal and petroleum coke and, as a result, lowering GHG emissions. Natural gas use at cement plants could be further increased if pipelines and related infrastructure were in place to supply these plants. Unfortunately, the permitting process under NEPA, the Clean Water Act, and state standards is preventing many industries from taking advantage of natural gas by preventing or delaying the necessary supply infrastructure. Congress should reform the infrastructure permitting process for badly needed energy infrastructure.

5.3 There is limited room for additional energy efficiency improvements in cement plants

The heat energy required to heat raw materials to the temperatures needed to trigger calcination makes cement manufacturing an inherently energy-intensive process. As noted in Section 2.2, the cement industry has invested significantly to increase the energy efficiency of its kilns, grinding equipment, and other operations. Moving forward, the industry will face increasing challenges in squeezing additional efficiency improvements out of its operations.

Further increases in efficiency improvements in cement manufacturing are not on the horizon without a revolutionary advancement in a completely new technology. The industry's efficiency is already close to the theoretical maximum. Martin Schneider, a cement processing expert has noted, "Taking into account all process-integrated measures, thermal process efficiency [in cement manufacturing] reaches values above 80% of the theoretical maximum." [19] That level of thermal process efficiency is unparalleled.

Any marginal increases in efficiency that could be gained, including technologies such as waste heat recovery, require additional energy. The basic laws of thermodynamics dictate that it takes energy to save energy; there is no free lunch. That additional energy increases the carbon footprint of a cement plant, making each additional joule of energy efficiency that much more difficult to gain. This explains why the CSI technology roadmap shows thermal energy efficiency gains as having the smallest opportunity for carbon dioxide emissions reductions (Figure 11 in Section 2.4).

5.4 Increased cost of low-carbon cement and concrete products

Publicly available data on prices of low-carbon cement and concrete products relative to conventional products is not available. However, anecdotal evidence suggests that there are usually cost premiums for the low-carbon products. Although one would expect there to be increased demand for these products in a place like Europe where a carbon cap and trade system exists, that has so far not been the case. Furthermore, there is at least one case of an American start-up company that created a binder using a mineralization process but never achieved commercial success and had to pivot to other applications [15]. The highly cost-conscious nature of the construction industry will likely make this a key barrier for some time.

5.5 Risk aversion of engineers specifying concrete

Given the high stakes involved in structures that use concrete, it is understandable that civil engineers specifying concrete mixtures would be risk averse. Engineers typically rely on prescriptive-based specifications that detail the types and limits of materials that can be used in concrete mixtures. Following such specifications helps to mitigate risk for them and the concrete producers because they can point to the specifications in case there are unforeseen problems. They also prefer to rely on the use of constituent materials that have been used in the past because of their perceived familiarity with performance. The downside of this practice is that it often limits the use of low-carbon materials, either explicitly or implicitly [16]. As such, prescriptive specifications inhibit opportunities for innovative concrete mixtures that make use of low-carbon materials, included blended cements and SCMs that are available for use today. In addition, there is a significant burden of proof to demonstrate that new low-carbon materials will meet long-term structural and durability requirements.

6 Solutions to enable a low-carbon cement and concrete industry

6.1 Promote adoption of energy efficiency technologies for new and retrofit cement plants

As noted in Section 5.3, it is possible to make energy efficiency improvements in cement plants, but they will require more than a simple federal mandate. Industry will have to partner with government to identify promising new energy efficiency technologies and make the investments in research, development, and deployment to bring them to market.

6.2 Encourage and facilitate increased use of alternative fuels in cement plants

There is a step the Committee could take today to reduce greenhouse gas emissions: provide manufacturers with enhanced flexibility to expand their use of alternative fuels. Congress can and should address this issue as a simple and early first step by amending the definitions of "Recovered Materials" and "Recovered Resources" within RCRA to distinguish them from solid waste. A core mandate of the Resource Conservation and Recovery Act is to conserve and recover national resources. To do so, it must start by clearly recognizing that materials with energy value are truly "resources," not waste.

In the interim, the Committee should urge EPA to revise the NHSM Rule, implementing guidance, and interpretations to limit the processing requirements for "discarded" materials to those activities necessary to create useful fuel. EPA should not impose processing requirements that add costs to fuel use without materially improving the fuel value or the emissions associated with its use. Finally, Congress should urge EPA to act on PCA's pending petition to provide a categorical exemption for the use of nonrecycled paper, plastics, fiber, and fabrics as fuel, based on the extensive data already provided to EPA.

6.3 Encourage and facilitate use of blended cements

As noted in Section 2.3, several blended cements are produced in the US today, including portland limestone cement and other blended cements that make use of SCMs, but there is limited demand for them, most likely due to risk aversion of engineers specifying concrete. The adoption of performance-based specifications (described below in Section 6.5) would make it easier to use such cements. In addition, sponsoring research on the long-term structural and durability performance of concretes using blended cements will help to mitigate perceived risk by engineers.

6.4 Support development and deployment of emerging and innovative low-carbon technologies for cement production including carbon capture, storage, and utilization

With at least half of the cement industry's greenhouse gas emissions resulting from the chemical conversion of limestone and other ingredients into clinker, any long-term carbon reduction strategy for the cement manufacturing industry will require significant advances in carbon capture, use, distribution, and storage (CCUS) technologies.

But while many promising technologies are under development domestically and overseas, few have reached the commercial stage of development, and most of the research and all of the federal funding has focused on the energy sector (power, oil, gas), not industrial sector solutions. This is an important point because, if the US is going to develop a long-term strategy to reduce carbon emissions from the industrial sector, policymakers must realize there is no one-size-fits-all solution to capturing, transporting, and using or storing carbon emissions. Industrial sources face different and far more complex technical challenges and operating conditions in adopting carbon capture, use, and sequestration technologies.

In short, successful commercialization and deployment of any broadly-applied CCUS carbon mitigation strategy will require targeted funding and financial incentives to move the technology from the demonstration and pilot stage to commercial-scale use – particularly within the industrial sector.

Potential policy mechanisms that can help accelerate these technologies include:

- Provided targeted CCS research, development, and deployment funding for the cement sector.
- Use long-term and predictable tax policy to incentivize R&D and rapid investment in carbon capture, distribution, use, and storage technologies and infrastructure.
- Reward early investment and adoption in new technologies.

6.5 Support deployment of performance-based specifications for concrete to spur innovation in concrete mixtures

In contrast to prescriptive-based specifications, performance-based specifications define performance targets for concrete (strength, stiffness, constructability, durability) with minimal limitations on the constituent materials that may be used [20]. This enables significant opportunities to spur innovation in concrete mixtures by enabling use of low-carbon materials [21]. Although performance-based specifications have been proposed for over two decades, there has been limited adoption within the architecture, engineering, and construction community, most likely due to a preference for using materials and practices that have been used in the past. A shift in paradigm to performance-based specifications will require encouragement and incentives.

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Mr. TONKO. Thank you very much, Dr. Gregory.

We now move to Dr. Sant, please, for 5 minutes.

STATEMENT OF GAURAV SANT, Ph.D.

Dr. SANT. Thank you, Chairman Tonko, Ranking Member Shimkus, and members of the subcommittee for having us here today.

I am going to try and build a case or try and talk about the idea of how you really achieve net zero emissions with six talking points.

The first one is, I think, and as has been said quite a few times before, heavy industry operations are the foundation of the world that we live in. So you can look at the screen in your iPhone. You can look at the building that we are in. All of this came out of heavy industry operations. So an important part of what heavy industry does is actually provide us with the way of life that we actually have and the way of life that we live.

Of course, this comes at a price. It comes at the price of carbon emissions, which are very substantial, a third, as we heard others say. But we should also keep in mind that this is really what provides us with the standard of living that we have today and it is about a century and a half of deployment of these technologies which really leads us to where we are.

The second part, with regards to decarbonization, is we really need to keep in mind potentially the most critical need to mitigate the accumulation and release of carbon dioxide into the atmosphere is a regulatory certainty. And that being say, regulatory certainty is the minimum pathway that we need to undertake to determine what happens next.

Of course engineering solutions are a big part of this but engineering solutions really need to focus on simplicity. We need pathways which are simple, which can bolt onto existing facilities because, as you can imagine, building a cement plant, or building a refinery, or building a steel plant, these are all really expensive undertakings. What that means is we cannot do this at substantial cost burden. So we need to think about simple ways how you do process integrations and optimizations to make sure that we integrate with existing processes simply enough without disrupting our way of life while we think about carbon management.

When we think about mitigation solutions beyond carbon capture and storage, we need to create other pathways. And I think utilization, carbon dioxide utilization is an important part of this because it can result in the production of salable products. As an example, think about CO2 concrete that we are working on, which involves the absorption of carbon dioxide into concrete.

However, I will caution by saying while these pathways are very attractive and especially so in the short-term, they are fractional solutions. So they are by no means a comprehensive pathway to carbon management but they are an important short- to medium-term pathway to being able to think about beneficial ways by which we can reutilize CO2.

When we think about economic incentives, systematic and substantial Federal support is needed to innovate mature de-risk and bring down the cost of technologies. This is something which has happened and which continues to happen, which we will need to expand substantially so in time to come, across technology readiness levels and across both basic and applied research.

But beyond R&D support, we need to have support of policy, strategic actions and consistency messaging. This includes direct financial support, for example, grants to innovate those incorporations, targeted procurement actions, incentives, for example, tax credits, but also disincentives, penalties which actually incentivize a mechanism of change.

We need to focus on the consumer. As consumers, we are actually all each individually responsible for what heavy industry does because we are the consumers of these products. That being this case, we need to build consumer awareness and conscientiousness to achieve carbon efficiency individually and societally. This is extremely important. And, as an example, you can think about our programs in energy efficiency that we have in place for decades now. They have been an extremely important part of how we have achieved energy efficiency by imposing standards, by having products which are energy efficient, by pointing out to the consumer that there is benefits in this. And so there is a pathway that you can follow that is based on what we will call a carbon efficiency standard.

We want to keep in mind that the U.S. provides effectively the knowledge reservoir to the world. This has come about the last 70 years or so by consistent systematic and deep spending in R&D dollars that go to U.S. universities and national laboratories. A lot of the innovations that we take granted around us going from the iPhone to the internet actually came out of these places. And that being the case, we want to make sure that we continue to provide this nature of support because we want to also establish a basis of carbon leadership industrially.

A couple of other things to keep in mind. When we think about heavy industry, these are what you classically call commodity sectors, which means that they are comparatively low profit and very high volume. And so you have got to think carefully about what are really the nature of pathways that need to be undertaken when sectors of the sort think about change. It is not easy to build a new cement plant. It is not easy to build a new steel plant.

So when we think about strategic actions, we need to think about a way that you both integrate regulatory certainty and a market pull that both demand a change in how we function.

Finally I think the closing comment to be made is really one of competitiveness. The rest of the world is looking very aggressively at standards around carbon efficiency and carbon management. You don't want to have U.S. corporations which are at a competitive disadvantage because they have got to have two standards to functions with one in the U.S., one elsewhere, and I think that particularly demands that we establish a basis of consistency, where U.S. corporations continue to lead the world in carbon efficiency.

With that, I would like to conclude.

[The prepared statement of Dr. Sant follows:]

COMMITTEE ON ENERGY AND COMMERCE: SUB-COMMITTEE ON ENVIRONMENT AND CLIMATE CHANGE (116TH CONGRESS)
U.S. HOUSE OF REPRESENTATIVES

SEPTEMBER 18, 2019

HEARING ON: BUILDING A 100 PERCENT CLEAN ECONOMY: PATHWAYS TO NET ZERO INDUSTRIAL EMISSIONS

WRITTEN TESTIMONY:

GAURAV N. SANT, PH.D.

PROFESSOR AND HENRY SAMUELI FELLOW: CIVIL AND ENVIRONMENTAL ENGINEERING, MATERIALS SCIENCE AND ENGINEERING, AND THE CALIFORNIA NANOSYSTEMS INSTITUTE

DIRECTOR: INSTITUTE FOR CARBON MANAGEMENT
UNIVERSITY OF CALIFORNIA, LOS ANGELES (UCLA)

Introduction

Thank you, Chairman Tonko, Ranking Member Shimkus and Members of the Sub-Committee for inviting me to appear before you as you review and examine pathways to address the emissions of carbon dioxide (CO_2) from heavy industry operations. Herein, I encompass the definition of heavy industry broadly, e.g., to include sectors including oil and gas refining, petrochemical and chemicals production industries, and cement, steel and glass production; amongst others. As requested by the sub-committee, I am focusing my testimony on opportunities, pathways, and solutions to address the emissions of carbon dioxide (CO_2) from heavy industry. This includes, for example, pioneering research initiatives that are underway at UCLA's Institute for Carbon Management [] that seek to specifically enable heavy industry to mitigate its carbon emissions, and thereby adapt, expediently, and cost-effectively, to a low-carbon world. The views expressed herein are my own, and do not necessarily represent those of UCLA.

For reference: I am a Professor and Henry Samueli Fellow in the Samueli School of Engineering at the University of California, Los Angeles (UCLA), where I am the Director of the Institute for Carbon Management [1]. I am a civil engineer, and a materials scientist with broad competencies in materials synthesis, characterization and processing with special expertise in the materials of modern construction including: cement, concrete, steel, glass and ceramics [2].

Summary: My testimony today encompasses the key sections that are outlined below:

Motivation: Heavy industry operations which result in the manufacture and production of materials and products including: cement and concrete, glass, liquid fuels, steel, etc. are foundational to the world that we live in. From the automobiles that we drive, to the buildings that we live, and work in, to the (smart) screens of our personal handheld devices, heavy industry operations affect, and improve the quality of each of our lives, while contributing to ongoing, and continuous developments of our society as a whole.

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1 Institute for Carbon Management. UCLA ICM http://icm.ucla.edu/ (accessed Sep 12, 2019).
2 Gaurav N. Sant. Google Scholar Profile https://scholar.google.com/citations?user=p_kytiYAAAAJ&hl=en&oi=ao (accessed Sep 12, 2019).

While invaluable, heavy industry operations, either on account of their processing energy demands, and/or the nature of chemical separations, modifications, and transformations that they seek to carry out result in substantial emissions of carbon dioxide into the atmosphere. For example, worldwide, chemical and petrochemical processing, the production of cement (ordinary portland cement, OPC), and iron and steel production result in the emission of around 5 % [[3]], 10 % [[3]], and 9 % [[3]] of anthropogenic CO_2 emissions, respectively. Carbon dioxide emissions from heavy industry – cumulatively amounting to nearly 36 % of global emissions [[4]] – are particularly difficult to address because, often, switching energy sources from fossil-based to renewable energy generation (i.e., a potential pathway to reduce the carbon intensity of industrial operations) may be infeasible on account of the: (a) insufficient energy density of typical renewable energy sources [[5]], and/or (b) 24/7 nature of manufacturing operations [[6]]. While energy storage approaches would indeed assist in enabling and improving the integration of renewable energy into powering heavy industry operations, the substantial cost of deploying energy storage (currently), renders this option challenging for the vast majority of heavy-industry sectors. Often, in processes such as oil refining, cement production and others – feedstocks are broken down into simpler components, before being re-composed into more chemically, and commercially desirable products such as gasoline, and OPC. Thus, in such operations, a majority of the carbon burden is associated with the chemical route that is chosen; e.g., in the case of OPC production [[7]] the thermal decomposition of limestone ($CaCO_3$) and the associated release of CO_2 is a far more significant contributor to the carbon emissions of the process than the combustion of fuel to heat the kiln [[8]]. It should be furthermore noted, the emplacement of heavy industry manufacturing facilities requires substantial capital expenditures, and therefore, demands long amortization periods. Since new capital investments may be difficult to justify, it is necessary that carbon management technologies, ideally, "bolt-on" to large intensive CO_2 emitters and furthermore make use of waste heat, if available, to reduce energy burdens. These considerations may be helpful, even partially so, to accelerate new technology commercialization and deployment.

Unquestionably, decarbonizing heavy industry is a critical need to mitigate the accumulation and release of CO_2 into the atmosphere; a key driver of climate change. However, such decarbonization on account of both, being technically challenging and our societal dependency on these industries, needs to be implemented speedily, without dramatically disrupting the material contributions of these sectors to our way of life. Thus, it is important to stage, support, and incentivize the transformations of these sectors from being valuable contributors, and major CO_2 emitters, to exclusively valuable contributors by 2050.

Enabling and empowering the decarbonization of heavy industry: Decarbonization as we understand it, at the scales that it is needed to abate climate altering carbon emissions, is often taken to imply carbon capture and storage (CCS) [[9]]. While unquestionably CCS remains the preeminent route to address CO_2 emissions at a sufficient scale, globally, this approach is not inconsequential to implement. For example, CCS is not always viable due to: (i) its high cost, (ii) uncertainty associated with the permanence of the sequestration solution, and/or, (iii) the lack of suitable geological features, or logistics facilities to convey

[3] International Energy Agency. Tracking Clean Energy Progress: Industry https://www.iea.org/tcep/industry/ (accessed Sep 12, 2019).
[4] International Energy Agency. CO2 Emissions Statistics https://www.iea.org/statistics/co2emissions/ (accessed Sep 12, 2019).
[5] de Pee, A.; Pinner, D.; Roelofsen, O.; Somers, K.; Speelman, E.; Witteveen, M. *Decarbonization of Industrial Sectors: The Next Frontier*, McKinsey & Company, 2018; p 63.
[6] International Energy Agency; Cement Sustainability Initiative. *Technology Roadmap: Low-Carbon Transition in the Cement Industry*, World Business Council for Sustainable Development, 2018; p 66.
[7] The production of ordinary portland cement (OPC) – the primary binding agent used in traditional concrete – accounts for nearly 9% of global CO2 emissions with 0.9 t of CO2 being emitted per ton of OPC produced. Therefore, the development of new cementation agents that take-up CO2 is critical to reduce the CO2 emissions associated with cement/concrete production,
[8] International Energy Agency; Cement Sustainability Initiative. *Technology Roadmap: Low-Carbon Transition in the Cement Industry*, World Business Council for Sustainable Development, 2018; p 66.
[9] In traditional carbon capture and storage (CCS), CO_2 emitted from industrial processes or from the combustion of fossil fuels is first concentrated to >95 % purity, following which it is transported by pipelines to locations that it can be geologically disposed, e.g., in hydrocarbon depleted reservoirs, saline aquifers, etc.

CO_2 to locations where CCS can be achieved [4,10,11]. This is especially relevant for heavy industry sectors – which broadly speaking, on account of their commodity products, and consequent low-profit margins are poorly equipped, financially speaking, to implement dramatic capital expenditure intensive transformations in an accelerated manner. Therefore, it is necessary to curate a multiplicity of short-, medium- and longer-term pathways empowered by: research, development, and technology deployment and piloting support, explicit financial incentives that promote industrial transformations, and strategic procurement actions; i.e., which involves the preferred sourcing of products, not only on the basis of (lowest) cost, but both cost and embodied carbon intensity [12]. Of course, the basis of each of these actions is: credible policy, regulatory certainty, and national motivation to transition the U.S. economy to a low-carbon/net-zero paradigm.

Over the past several years, federal R&D support provisioned to UCLA has been foundational to the curation of pioneering CO_2 removal/utilization technologies that upcycle dilute-state CO_2 (e.g., secured from industrial flue gases, or the atmosphere) – via thermodynamically favorable mineralization reactions – into stable carbonate compounds. This approach of single-step/integrated carbon capture, utilization and storage (CCUS) is significant as the stable carbonates thus produced can form: (a) CO_2Concrete-based construction materials and components that are cost- and functionally-equivalent to traditional concrete albeit with an embodied carbon intensity (eCI) which is up to 75 % lower [13,14,15,16], and/or (b) solid wastes, e.g., in the form of sand and stone, that could be disposed on the earth's surface, or repurposed in construction thereby reducing the need for geological (CO_2) disposal [17]. However, and in spite of the progress made (e.g., a pilot-system of the CO_2Concrete process will be demonstrated at two coal power plants in 2020 [18]); the industrial deployment of solutions of this nature requires further confidence building and greater support. This is necessary, for example, to allow the cement/OPC industry to gain confidence in the scalability, cost-effectiveness, and the technology's potential to offer a reduced CO_2 trajectory for concrete production. Thus, in the short-term, government support is critical to upscale and demonstrate mineralization technologies such as CO_2Concrete, and other pathways which seek to transform CO_2, at gigaton scales into benign wastes, or saleable products; or that seek to otherwise abate the CO_2 emissions from industrial processes. But, beyond enabling technology developers (N.B.: for a successful model of this nature see the Department of Energy's Carbon Capture Program [19]), early-stage incentives also need to motivate corporations to deploy, trial and integrate new CO_2 abatement technologies into existing operations. Such motivation and commercialization support may take one of many forms including: direct incentives (e.g., financial grants in support of process modifications and improvements), tax credits, or other support structures or even seek to impose (carbon) tax obligations.

First, timely action to mitigate the effects of climate change requires the deployment, de-risking and demonstration of new technologies, in the short-term (<5 years), that can help heavy industry mitigate

[10] Kulichenko, N.; Ereira, E. *Carbon Capture and Storage in Developing Countries: A Perspective on Barriers to Deployment*; Energy and Mining Sector Board Discussion Paper, No. 25; World Bank Publications, 2012.
[11] Bachu, S. *Energ. Convers. Manage.* **2000**, *41* (9), 953–970.
[12] Bonta, R.; Eggman, S.; Steinorth, M. Assembly Bill 262 - Buy Clean California Act; 2017.
[13] Vance, K.; Falzone, G.; Pignatelli, I.; Bauchy, M.; Balonis, M.; Sant, G. *Ind. Eng. Chem. Res.* **2015**, *54* (36), 8908–8918.
[14] Wei, Z.; Wang, B.; Falzone, G.; La Plante, E. C.; Okoronkwo, M. U.; She, Z.; Oey, T.; Balonis, M.; Neithalath, N.; Pilon, L.; et al. *J. CO_2 Util.* **2018**, *23*, 117–127.
[15] Mehdipour, I.; Falzone, G.; La Plante, E. C.; Simonetti, D.; Neithalath, N.; Sant, G. *ACS Sustain. Chem. Eng.* **2019**, *7* (15), 13053–13061.
[16] CO_2Concrete: https://www.co2concrete.com/ (accessed Sep 12, 2019)
[17] The production of solid carbonates including calcite and magnesite exploits favorable thermodynamics and produces stable mineral reaction products that are known to persist at ambient temperature and pressure, without risk of CO_2 leakage, or release over billions of years. Furthermore, the handling of solid mineral carbonates, i.e., as compared to fluid-state CO_2 is simpler and presents distinct advantages, including existing and highly cost-effective infrastructure (e.g., as used today for municipal waste disposal), and a comprehensive understanding of the economics of such surficial disposal.
[18] DOE National Energy Technology Laboratory. A Scalable Process for Upcycling Carbon Dioxide (CO_2) and Coal Combustion Residues Into Construction Products https://netl.doe.gov/project-information?p=FE0031718 (accessed Sep 12, 2019).
[19] DOE National Energy Technology Laboratory. Carbon Capture Program https://www.netl.doe.gov/coal/carbon-capture (accessed Sep 12, 2019).

its carbon emissions. However, the deployment of such technologies, requires a combination of strategic actions; e.g., government support of technology demonstration projects, and industry partnerships so that the lessons learned hasten, motivate and inform further deployments, drive cost-reductions and therefore, accelerate technology diffusion and adoption. Why? Because commodity sectors (i.e., an identification that is typical for heavy industry) which will not be offshored – e.g., cement/OPC production, oil refining, etc. – feature little, if any appetite for deploying new technologies that are unproven at scale due to: uncertainty in revenue, profit pressures, prevailing and substantial regulatory and compliance burdens, and the very high costs associated with emplacing greenfield facilities with long operating horizons. Therefore, it is necessary for the government to underwrite the costs associated with maturing, and de-risking technologies which can help heavy industries to reduce the eCI of their products, and processes. However, once industry is assured of the viability and scaling of new technologies; this greatly simplifies and accelerates subsequent market penetration, and diffusion.

Second, in the medium- and longer-term it is critical that the government greatly expand research, development, deployment and innovation (RDDI) funds – encompassing both basic and applied research – that will create transformational carbon (CH_4 and CO_2) removal and utilization technologies (e.g., see recent reports developed by the National Academies [[20],[21]]). Such support forms the basis of developing newer, more efficient and more effectively scalable technologies for carbon emissions mitigation; the need for which becomes increasingly more significant with the passage of time [[22]]. Major programs for the development, de-risking and deployment of the next generation of technologies, including CCUS (carbon capture, utilization, and storage) solutions enabled via support provisioned by the Departments of Defense, Energy, Transportation, Housing and Urban Development, and, National Science Foundation amongst others is critical to maintain the U.S.'s intellectual leadership in the broad theme of carbon management. This is needed to: (a) ensure that U.S. corporations are able to monetize and diffuse their spirit of creativity, innovation and societal welfare, globally, (b) ensure that U.S. corporations are able to diminish the intensity of their operations, thereby enabling them to operate across global jurisdictions in a low-carbon world, and (c) ensure that the U.S.'s deep intellectual reservoir that is housed within its world-class universities, national laboratories and corporate R&D organizations continues to train, sustain, support and grow the talented scientists, engineers and subject matter experts that have ensured the U.S.'s global technological leadership, and spirit of innovation over nearly the last century.

Major, long-term, and comprehensive actions by heavy industry in support of rationalizing and reducing their CO_2 emissions intensity are assured to require substantial capital expenditures. While this will also (likely) affect the operating cost bases of such sectors; clarity and commitments to making such capital expenditures requires certainty regarding upcoming regulations, and policy. Unquestionably, our current state of regulatory uncertainty is perhaps the most significant detriment that prevents, or otherwise hinders our collective capability to limit the emissions of CO_2 into the atmosphere. The reasoning is simple: first, corporations which owe, on the basis of today's prevalent although evolving business model, to create value for shareholders are only going to make decisions and selections which ensure a competitive advantage in the marketplace. Therefore, unless heavy industry processes and products are brought under a CO_2 limiting ambit (e.g., a carbon emissions cap; and a consequent penalty for unbounded excess; see also California's Assembly Bill 32 [[23]]); there is no incentive, or lack thereof to make investments that would reduce the carbon intensity of these industries. It may be argued, that strategic actions, i.e., governmental purchasing decisions that prefer low-carbon products may be equally valuable. Unquestionably this is so and should be pursued aggressively – however, many examples belie

[20] National Academies of Sciences, Engineering, and Medicine. *Gaseous Carbon Waste Streams Utilization: Status and Research Needs*; The National Academies Press: Washington, DC, 2018; p 254.
[21] National Research Council. *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*; The National Academies Press: Washington, DC, 2015; p 154.
[22] Mercator Research Institute on Global Commons and Climate Change (MCC). Remaining carbon budget https://www.mcc-berlin.net/en/research/co2-budget.html (accessed Sep 12, 2019).
[23] Nunez, F.; Pavley, F. *Assembly Bill 32 - California Global Warming Solutions Act of 2006*; 2006.

the proof that the most substantial successes come about by affecting supply chains holistically; i.e., both upstream and downstream: i.e., from the point of raw material procurement, to the point of finished product consumption. This raises an important point that was previously alluded to: we, society in general, are the consumers of the products (and thereby processes) that heavy industry implements. As such, an important aspect of carbon management involves affecting consumer choices, selections, and awareness regarding the products that we seek to consume. This issue whose success is seen in our implementations of energy efficiency programs – requires us to develop a national basis of measuring, affecting and incenting carbon efficiency via robust, progressive, and transparent methods of analysis. The reason: small changes affected by, and demanded by 330 million consumers (citizens) in the U.S., and 7 billion consumers, globally, would result in vast CO_2 emissions reductions that are motivated by both "industry-push and market-pull". Simultaneous actions of this manner undertaken by governments, corporations, consumers, and markets are foundational to create a non-villainized basis of ensuring major industrial transformations from producer to consumer; i.e., a market-driven basis of change.

It is particularly important to highlight that issues related to carbon management are based on the premise of affecting societal good. This is an outcome in which, national governments, more than any other (private) entity have a vested interest. Therefore, it is necessary that governments take action in this regard. The U.S. plays a special role in this international effort. Because, over the last century or so, the U.S. has come to be regarded as the bellwether for the future; such that directions implemented by the U.S. are legitimized and thus easier to implement for other national governments, worldwide. Of interest, the U.S. contributes nearly 15 % of global CO_2 emissions, while hosting only 5 % of the world's population [[24]]. For reasons of leading by example, it is essential that the we place emphasis on robustly maximizing our carbon efficiency, and in turn, diminishing our CO_2 emissions intensity.

The role of incentives and market mechanisms: Reducing, limiting and reversing CO_2 emissions, from heavy industry, and other sectors requires the development and broad-based deployment of incentives, disincentives, and market-forcing mechanisms that reward and empower reductions in CO_2 emissions, and/or CO_2 removal from the atmosphere. Such incentive mechanisms, some of which are already in place include the 45-Q tax credit [[25]] and other incentives made available via California's low-carbon fuel standard (LCFS) [[26]], as two prominent examples. These mechanisms, which offer incentives/credits up to $35 per ton (for CO_2 utilization, by 2027 [[25]]), up to $50 per ton (for CO_2 sequestration, or for EOR operations; by 2027 [[25]]), and up to $180 per ton (LCFS) [[26]] offer a means to substantially offset the cost of emplacing CO_2 abatement technologies. While this is unquestionably a step in the right direction; more is needed. For example, tax credits are valuable only if there is a tax-obligation to address. Thus, established corporations are disproportionately advantaged by tax credits, while new entrants, are less so. Simultaneously, while many CO_2 abatement pathways may result in the production of a (lower) carbon fuel; in other cases, other products may be produced. Thus, it is necessary to develop support structures and systems (i.e., subsidies, rebates, advantaged financing mechanisms, etc.) that incentivize CO_2 emissions mitigation by both early-stage innovators who seek to transform the heavy industry sector, and established (heavy industry) corporations. These types of progressive actions lie at the origin of the tremendous success of community (and grid-scale) solar power generation in the U.S. Thus, more expansive thinking, e.g., in terms of incentive mechanisms and the consequent market forces that they could unleash, is needed to support the creation, adoption and diffusion of new technologies and economic opportunities that may otherwise be unfeasible to exploit, but that are prerequisite to deploy CO_2 mitigation/net-zero technologies; rapidly, scalably and globally.

[24] Our World in Data. CO_2 emissions per capita vs GDP per capita https://ourworldindata.org/grapher/co-emissions-per-capita-vs-gdp-per-capita-international- (accessed Sep 12, 2019).
[25] Office of the Law Revision Council. 26 USC 45Q: Credit for carbon dioxide sequestration https://uscode.house.gov/view.xhtml?req=(title:26%20section:45Q%20edition:prelim) (accessed Sep 12, 2019).
[26] California Air Resources Board. Low Carbon Fuel Standard Program https://www.arb.ca.gov/fuels/lcfs/lcfs.htm (accessed Sep 12, 2019).

Thank you again for the opportunity to testify on this important topic.

Mr. TONKO. We thank you very much, Dr. Sant.

And we now move to Mr. Eisenberg for an opening statement for 5 minutes, please.

STATEMENT OF ROSS E. EISENBERG

Good morning, Chairman Tonko, Ranking Member Shimkus, Ranking Member Walden, for today, members of the subcommittee.

My name is Ross Eisenberg. I am delighted to be here representing the National Association of Manufacturers and talk about our commitment to climate change.

In the eyes of America's manufacturers, it is time to act on climate now. And the real question for policymakers should not be whether to act but, frankly, how to do so effectively. Manufacturers are doing our part. We have been and we will continue to do that.

Over the past decade, manufacturers in the United States have reduced the carbon footprint of our products by 21 percent, while we have increased our value of the economy by 18 percent over that same time frame. Overall, the U.S. manufacturing sector has one the world's lowest carbon intensities per dollar of GPD because we are so efficient, a fraction of the carbon intensities other major manufacturing economies like China and India.

For example, just to put a finer point on this, aluminum produced in the United States is less carbon-intensive than just about any other aluminum produced somewhere else and imported into the United States. It is three times cleaner in that respect than aluminum produced in the Middle East and imported into the United States. It is four times cleaner than aluminum produced in China and imported into the United States. So, our efficiency is a win here for us and we should really be encouraging manufacturing to come back and really operate here because that is where it is going to be done the cleanest.

The type of deep decarbonization called for by this committee would require a dramatic set of technology and lifestyle changes across the economy. It is going to be extremely difficult. That is pretty much without question. It is going to require us all to work together here and around the world and it will, almost certainly, carry a cost. It is not, however, impossible. I want to make that clear. It is no, however, impossible and we are at the table for this discussion for that reason.

Manufacturers do appreciate the careful, considerate, deliberate approach that this committee has taken to listen to us, frankly, and to have the conversation that you are all having. In the course of those deliberations, two prevailing views have really emerged. The first is should we really be focusing on enabling innovation and the other is should we be empowering the Government to take action.

In the eyes of manufacturers, we believe we need to do both and here is why. We need innovation because the manufacturing sector is different from other sectors and the technologies that may work in other sectors just may not work so well in ours. The process used to make a brick is substantially different than the process used to make steel, or paper, rubber, plastic, fertilizer, aluminum, not to mention finished goods like trucks, and cars, and airplanes, and food and beverage, and electronics. Innovation is and always will be the key to reducing the carbon intensity of those sectors and it is encouraging to hear everybody on this panel really say the same thing.

Innovation by itself, however, is just not going to be enough and so, for that reason, the Federal Government does have a clear role in setting climate policy. This begins by reengaging on the international stage to achieve binding fair global climate treaty. And with that backdrop, we hope that the Congress will enact a single unified climate policy that meets specific targets, ensures a level playing field and avoids carbon leakage, in other words, not simply outsourcing our carbon to another country that has lower standards than we do, and it will preserve consumer choice and manufacturing competitiveness.

My written testimony provides more details on both of these proposals but, together, we believe they should be the foundation of the U.S. response to climate change.

Now as we embark down this road, we need to have a serious discussion about cost. For manufacturers the math really does matter. The average manufacturer pays about $20,000 per employee per year to comply with regulations. The small manufacturers pay even more, about $35,000 per employee because they can't scale it up. Any new cost imposed by a climate policy will be added to that already hefty base of costs and regulatory expenditures. So the extent that manufacturers have to bear those extra costs, Congress should consider reducing regulatory tax or other economic burdens to basically make manufacturers whole, and keep us whole, and keep us competitive.

The math also matters for the internal decision-making and I think that is something that I really want to stress today. A great deal of potential reductions are going to come from installation of new equipment, new processes—innovation, essentially. Manufacturers budget for discretionary investments like this. They are always looking to make these investments but, at the end of the day, the decision on whether to spend that money involves consideration of a wide range of factors, including payback time, the risk of stranded investments, operating risks, reliability, environmental permitting, and external factors like the future of the plant itself in a competitive environment. Focusing on this math should be a top priority of anyone seeking to reduce the carbon intensity of the manufacturing sector.

The NAM believes we can be a part of this solution and we look forward to working with this committee to pass and implement some of our preferred policy solutions. There are many near-term actions that we believe Congress and the administration could take to accelerate our progress towards deep emission cuts. My written statement includes a number of these and I hope we can talk about them during the Q and A section. We think these would make a real difference and ensure that emissions continue to decline in the manufacturing sector, while Congress and the administration work out some of these bigger policy issues as well.

I appreciate the time to testify today and thank you.

[The prepared statement of Mr. Ross Eisenberg follows:]

NATIONAL ASSOCIATION OF Manufacturers

Leading Innovation. Creating Opportunity. Pursuing Progress.

Testimony

of Ross Eisenberg
Vice President
Energy and Resources Policy
National Association of Manufacturers

before the House Committee on Energy and Commerce
Subcommittee on Environment and Climate Change

on "Building a 100 Percent Clean Economy:
Pathways to Net Zero Industrial Emissions"

September 18, 2019

Summary of Testimony

In the eyes of America's manufacturers, it's time to act on climate—and the real question for policymakers now should not be *whether* to act on climate but *how* to do so effectively. We are already doing our part to reduce greenhouse gas emissions, and we will continue to do so. Over the past decade, manufacturers have reduced the carbon footprint of our products by 21 percent while increasing our value to the economy by 18 percent. Overall, the U.S. manufacturing sector has one of the world's lowest carbon intensities per dollar of GDP, a fraction of the carbon intensities of other major manufacturing economies like China and India.

The type of deep decarbonization needed to reach the targets sought by the Committee will require a dramatic set of technological and lifestyle changes across the economy. It is not, however, impossible. We need policies that unleash innovation because the manufacturing sector is different from other sectors, and the technologies that may work in other sectors may not work in ours.

The federal government also has a clear role in setting climate policy. This begins by reengaging on the international stage to achieve a binding, fair global climate treaty. The NAM also recommends Congress enact a single, unified climate policy that meets specific targets, ensures a level playing field, avoids carbon leakage and preserves consumer choice and manufacturing competitiveness.

Finally, there are many near-term actions that Congress and the Administration could take to accelerate manufacturers' progress toward deep GHG emissions reductions. The NAM recommends:

- Enact the Clean Industrial Technology Act (H.R. 3978/S. 2300);
- Pass legislation and take regulatory action to improve New Source Review;
- Ratify the Kigali Amendment and/or enact legislation to phase out hydrofluorocarbons;
- Commercialize and deploy carbon capture, utilization and storage technology;
- Permanently authorize the provisions of Title 41 of the FAST Act;
- Scale up investment in public- and private-sector energy and water efficiency;
- Fund and expand climate and clean energy R&D federal programs at the Department of Energy and elsewhere; and
- Pave the way for a smart grid.

TESTIMONY OF ROSS EISENBERG

BEFORE THE HOUSE COMMITTEE ON ENERGY AND COMMERCE
SUBCOMMITTEE ON ENVIRONMENT AND CLIMATE CHANGE

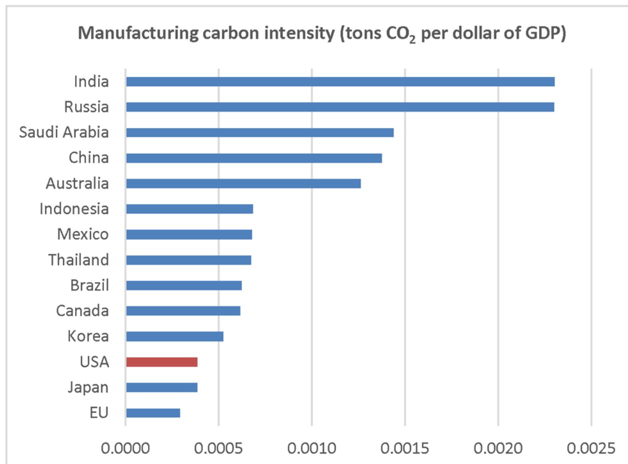
Hearing on:
"Building a 100 Percent Clean Economy: Pathways to Net Zero Industrial Emissions"

SEPTEMBER 18, 2019

Good morning, Chairman Tonko, Ranking Member Shimkus and members of the Subcommittee on Environment and Climate Change. My name is Ross Eisenberg, and I am vice president of energy and resources policy at the National Association of Manufacturers. The NAM is the nation's largest industrial trade association, representing 14,000 small, medium and large manufacturers in every industrial sector and in all 50 states. I am pleased to represent the NAM and its members and provide testimony on manufacturers' commitment to addressing climate change.

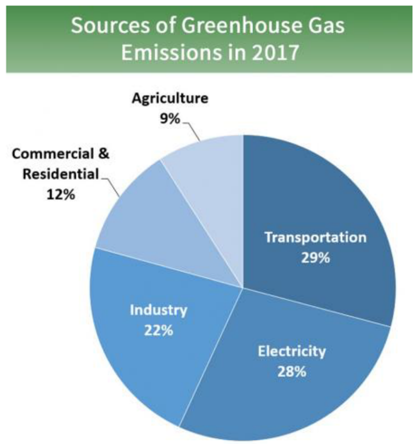
In the eyes of America's manufacturers, it's time to act on climate—and the real question for policymakers now should not be *whether* to act on climate but *how* to do so effectively. Manufacturers are doing our part to reduce GHG emissions, and we will continue to do so. Over the past decade, manufacturers in the U.S. have reduced the carbon footprint of our products by 21 percent while increasing our value to the economy by 18 percent. Overall, the U.S. manufacturing sector has one of the world's lowest carbon intensities per dollar of GDP, a fraction of the carbon intensities of major manufacturing economies like China and India.

As the Committee considers how to reach its ambitious goals, I must stress that the type of deep decarbonization needed will require a dramatic set of technological and lifestyle changes across the economy. It will be extremely difficult. It will require the collective effort of all sectors and stakeholders, all producers and end users. It will require global coordination and enforcement. And it will carry a cost.



It is not, however, impossible. Manufacturers appreciate the careful, deliberate approach this Committee has taken to assessing the scope of the problem and the effect policies would have on the many stakeholders involved. Two defining views have emerged from Committee members: whether we should focus on crafting policies that spur innovation, or whether we should craft policies that enable the federal government to take action. I believe we need both.

We need innovation because the manufacturing sector is different from other sectors, and the technologies that may work in other sectors may not work in ours. Manufacturers primarily emit GHGs in two ways: energy-related emissions and process-related emissions. The types of energy and processes used across manufacturing sectors are typically very different. For instance, the manufacturing process to make a brick is markedly different than the process used to make steel. The same goes for other energy-intensive sectors like paper, plastic, rubber, fertilizer and aluminum, not to mention finished goods like cars, trucks, airplanes, computers, food and beverages, and household products. Innovation is and will always be the key to reducing the carbon intensity of these sectors.



Source: Environmental Protection Agency

Innovation by itself will not be enough, however. The federal government has a clear role in setting climate policy. This begins by reengaging on the international stage to achieve a binding, fair global climate treaty. The goal of such an agreement must be to address the climate threat in a manner that prevents carbon leakage by ensuring that no country gains a competitive advantage by failing to take action to reduce carbon emissions. It must be fair, on target, enforceable, transparent, innovative and pro-trade. It must also protect intellectual property rights and eliminate all possible tariff and non-tariff barriers to the purchase of environmental goods and technologies.

With the backdrop of an effective international treaty, the NAM also recommends Congress enact a single, unified climate policy that meets specific targets, ensures a level playing field, avoids carbon leakage and preserves consumer choice and manufacturing competitiveness. Any solution must be economy-wide and apply to all sources of emissions. It must work in lockstep with the global framework to avoid carbon leakage—in other words, it shouldn't simply offshore carbon emissions from one country to another, which *won't* help address climate change but *can* hurt our economy. It must be a holistic replacement for the current patchwork of federal, state and local laws and regulations that address climate change, and it must displace current and future climate liability suits (which make a lot of noise but do not actually solve the problem). It should be fuel-neutral and should not require any particular manufactured product to be phased out of the economy. It should provide compliance flexibility for regulated entities and give credit for early action. Finally, it should seek to balance any new costs on manufacturers with relief in other areas, with the goal of keeping manufacturers whole.

This last point—the math—bears more explanation. The average manufacturer pays about $20,000 per employee, per year to comply with regulations, nearly double the amount of companies in other sectors.[1] Small manufacturers pay even more, incurring regulatory costs of about $35,000 per

[1] https://www.nam.org/the-cost-of-federal-regulation/.

employee, per year.[2] Any new cost imposed by a climate policy will be added to that already-hefty base of regulatory expenditures. To the extent manufacturers must bear extra costs, Congress should consider reducing regulatory, tax or other economic burdens on manufacturers to make them whole. A particular focus should be placed on regulations of other air pollutants, which may be reduced as a "co-benefit" of reducing GHGs.

The math also matters for internal decision-making purposes on manufacturing shop floors. A great deal of the potential GHG reductions available to the manufacturing sector will come from the purchase and installation of new, more efficient equipment and the design of new manufacturing processes. Manufacturers budget for discretionary investments and are constantly looking for opportunities, but at the end of the day, the decision whether to spend that money on new equipment must be justified. This involves consideration of a wide range of factors, such as payback time, the risk of stranded investments, operating risks, reliability, environmental permitting and external factors like the future of the plant itself in a highly competitive, constantly evolving global marketplace. Impacting *this* math should be one of the top priorities of anyone seeking to reduce the carbon intensity of the manufacturing sector.

There are many near-term actions that Congress and the Administration could take to accelerate manufacturers' progress toward deep GHG emissions cuts. The following bipartisan measures would reduce GHG emissions from the manufacturing sector meaningfully and ensure that emissions continue to decline

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[2] *ibid.*

while the larger, more complicated international and federal climate policies are worked out. The NAM recommends the following:

- Enact the Clean Industrial Technology Act (H.R. 3978/S. 2300). CITA would set up a transformational industrial technology program at the Department of Energy and would drive new technologies aimed at increasing the technological and economic competitiveness of manufacturing in the United States. The program would also find pathways to reduce GHG emissions and create a technical assistance program to help local communities and states evaluate and incentivize the adoption of technologies that reduce industrial GHGs.

- Pass legislation and take regulatory action to improve New Source Review, a federal air permitting program that has, at times, stood in the way of efficiency upgrades and environmentally beneficial projects at manufacturing facilities. Simple reforms to NSR could unlock a massive market for the installation of efficient technologies that would drive manufacturers' already-impressive emissions reductions down even further.

- Ratify the Kigali Amendment and/or enact legislation to phase out hydrofluorocarbons (HFCs). The Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer was agreed to in October 2016 by more than 170 countries and entered into force in January 2019. The Kigali Amendment sets a path for phasing out HFCs, GHGs that are used in many manufactured products. HFCs were primarily used to replace ozone-depleting substances, but their high potency as GHGs has led to the development of replacement products with a smaller environmental impact. These products already exist or are close to market. The Kigali Amendment would reduce the global warming equivalent of 4.1 billion tons of CO_2 per year by 2050. It could also create up to 150,000 more U.S. jobs by 2027 if ratified.

- Commercialize and deploy carbon capture, utilization and storage technology. The expanded Section 45Q carbon capture tax credit established by Congress in 2018 was a positive development for CCUS adoption. However, for the 45Q tax credit to achieve its potential, regulators must clarify the rules to access the credit so that project developers have the certainty they need to make investments in CCUS projects. Lawmakers should also develop a clear standard for the handling of long-term liability for CO_2 transfers; resolve pore space ownership issues; correct barriers to CO_2 storage on federal lands; reform the class

VI underground injection program to foster the build-out of underground CO_2 storage projects; increase funding for federal CCUS research, development and demonstration programs and ensure programs are authorized; and reduce permitting barriers that delay construction of CCUS projects.

- Permanently authorize the provisions of Title 41 of the FAST Act. FAST-41 is a voluntary permitting improvement program for infrastructure projects that are likely to require a total investment of more than $200 million. The bulk of the projects in the program are clean energy or resiliency based, and FAST-41 has improved their permits' cycle time, reduced conflict among agencies and generated more complete environmental permitting than in the past. Significant emissions reductions will require massive deployment of new infrastructure; these projects will need access to FAST-41.

- Scale up investment in public- and private-sector energy and water efficiency. These oft-ignored strategies can generate significant climate savings. The International Energy Agency found that energy efficiency alone could meet up to 40 percent of the Paris Agreement's global GHG reduction goals.[3] A recent study by the Natural Resources Defense Council projected that to reach an 80 percent GHG emissions reduction goal, the U.S. could get almost 42 percent of the way by maximizing energy-efficiency investments and strategies.[4]

- Fund and expand climate and clean energy R&D federal programs at the Department of Energy and elsewhere. Federal agencies house a multitude of valuable tools and resources to help reduce emissions, such as the Advanced Research Projects Agency – Energy, the DOE Advanced Manufacturing Office and the Federal Energy Management Program. These programs should be sufficiently funded and expanded.

- Pave the way for a smart grid. Modernization of the electric grid will allow for better integration of advanced technologies, onsite generation and end-use efficiency. It would also reduce GHG emissions. A 2010 DOE study found that smart grid improvements could eliminate 277 million to 359 million tons of CO_2 per year.[5]

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[3] https://www.iea.org/newsroom/news/2018/october/energy-efficiency-is-the-answer-for-building-a-secure-and-sustainable-energy-syst.html.
[4] https://www.nrdc.org/sites/default/files/americas-clean-energy-frontier-report.pdf.
[5] https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-19112.pdf.

The strength of the manufacturing sector—its diversity—also makes it challenging to approach from a climate policy standpoint. The NAM believes we can be a part of the solution and looks forward to working with this Committee to pass and implement several of our preferred climate policy solutions.

Mr. TONKO. Thank you very much, Mr. Eisenberg.

Next, we will go to Dr. Friedmann for an opening statement. You are recognized for 5 minutes, please.

STATEMENT OF JULIO FRIEDMANN

Dr. FRIEDMANN. There we go. Chairman Tonko, Representative—Chairman Pallone, Ranking Member Walden, all of the members here—I am so delighted to see so many people here for so long—thank you, thank you, thank you for calling this hearing and for inviting me to testify.

My name is Dr. Julio Friedmann. I am the only one you will ever meet. This is the 5-minute version of the 5-hour testimony. I ask that if you have any questions or follow-ups, please invite me back. I am a resource and you know where I live.

This is an intensely difficult and complicated topic. This is not something that is easy or digestible in soundbites. You already have my testimony. I am happy to explain it in great depth but I want to take this time to hit a couple of key points.

First of all, I work at the Center for Global Energy Policy at Columbia University and we exist to provide information of this kind to people like you to help make good decisions. I lead an effort on carbon management. We have two reports coming out in the next month, all of them associated with heavy industry decarbonization specifically for heat. Fun fact: Heat for heavy industry is ten percent of global emissions—just heat. It is more than all the cars and planes in the world together. If you have to melt a rock to do something, you need heat. Most of our industrial processes start by melting a rock. That is properly hard. There aren't easy ways to replace that service and there aren't really reliable or straightforward substitutes for things like concrete, or steel, or plastics, or petrochemicals. We all have plenty to do. That is what the work looks like. So, to cut to the chase, a couple of facts, three findings, five ideas.

A couple of facts: The good news is that most of industrial production in the United States is concentrated in a couple of geographies—New Jersey, Texas, California, Oklahoma, Chicago, along the Great Lakes. These things are all in one place. That actually means that there are ways to think about managing them in a straightforward way.

Another thing that is helpful to understand in this is that, as many people have mentioned, these are internationally traded commodities, for the most part. As such, the margins are small and small increases in cost and price have dramatic increases in market share. And of course, these sit in communities which have a great deal of stake in them, both positive and negative. In some cases, these are real sources of pride. They are essential sources of wealth for these communities. At the same time, many of these facilities are also sources for pollution. This question is about environmental justice associated with that. So these are fraught complex issues and that is exactly why we need deliberation, discussion, and thought.

So a couple of other quick facts, then three findings, five ideas.

Quick facts, like I said to begin, we don't really have substitutes for this stuff. Second, the assets are long-lived. A steel plant or a petrochemical plant that exists today is going to run for a long time. That means that the idea that we will just replace it with some other thing is unlikely in the near-term. We are on the clock on climate change. So we have to make rapid emission reductions. So you have to work within the existing asset base.

And the options we have, as many people have said, are not great. We have chronic underinvestment in this sector, perhaps because we don't have a Department of Industry. I am not recommending we create one but it means that this jurisdiction is spread across the entire government in a strange way.

You may not know this but ammonia is tracked by the United States Geological Survey. That is because it is considered a mineral resource. So they are the ones who gather the data on this.

So there is plenty of stuff to do. In that context, three findings: First, as many have said here already, CCUS is essential. It is not optional in this space. Ten percent of global emissions are from steel and cement. Half of those emissions are the byproduct chemistry emissions and we don't have processes today that are substitutes for that. So if you want to get five percent of global emissions, you have got to do that. That is it.

And you can refer to my last round of testimony. I talk on that subject in great depth. That was back in May 2019.

Second finding: Hydrogen is pretty promising. If you look at the things that can burn at that temperature or that can be good feedstocks, hydrogen is one of the good ones. Today, the way we make hydrogen that we call hydrogen, which is steam methane reforming and we vent the CO2 into the air.

At the Air Products facility that was mentioned earlier, we have what we call blue hydrogen, where we make hydrogen but we capture the CO2 and keep it underground. There is also green hydrogen, where you use green, renewable, or nuclear electrons to make hydrogen through electrolysis and you use that.

Today, green hydrogen costs five to twenty times more than blue hydrogen. So today, blue hydrogen is the best looking option. That costs about 20 to 50 percent more than gray hydrogen but it is pretty cheap, by comparison to a lot of the things we can do. It is also a gaseous fuel, which means you can swap it in with other stuff.

Last, as others have said, innovation is essential. We simply can't get from where we are to where we need to be if we don't have a deep, large, committed program for innovation.

I have to stop there but I thank you all for your testimony and look forward to answering your questions.

[The prepared statement of Dr. Friedmann follows:]

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Center on Global Energy Policy

Sept. 18, 2019

Congressional Testimony of
Dr. S. Julio Friedmann
Senior Research Scholar, Center on Global Energy Policy, Columbia Univ. School of International & Public Affairs

Before the
Committee on Energy and Commerce
United States House of Representatives
2nd Session, 115th Congress

Chairman Pallone, Ranking Member Walden and Members of the Committee, thank you for inviting me here today to discuss Industrial Decarbonization. My name is Dr. Julio Friedmann. I am a Senior Research Scholar at Columbia University's Center on Global Energy Policy at the School of International and Public Affairs, where I lead an initiative on carbon management. It is an honor, and timely, to appear before this Committee to discuss greenhouse gas emissions from heavy industry.

Since my last congressional testimony in May 2019,[1] the topic of industrial emissions has grown in prominence, in part due to growing public concern over the environmental, economic and social impact of climate change, as evidenced by the Green New Deal and the presidential primary debates. This is long overdue. Global industrial GHG emissions represent about 24% of all GHG emission – more than from all of transportation and almost as much as from power. In the U.S., industry emits 15% of total greenhouse gases, more than all cars. National and global emissions in these sectors are growing fast. To make progress on climate change, it is essential to make rapid progress in decarbonizing industry.

Heavy industry, including the manufacturing of steel, cement, refining, petrochemicals, fertilizer, and glass, is essential to the U.S. economy and national security. Industry is a major employer (notably for organized labor and underserved communities across the nation, and could be jeopardized by international border tariffs based on carbon content. In many cases, margins are very tight for these sectors, and (unlike for power or transportation fuels), international competition is fierce.

Industrial emissions are highly localized in large central facilities in a few states, notably Texas, Louisiana, Oklahoma, New Jersey, California, and along the Great Lakes. These facilities are important sources of local pride, high-paying jobs, thriving communities, and state revenues. They undergird other key sectors like automobile manufacturing and construction, and are the focus of

[1] https://energypolicy.columbia.edu/research/testimony/enhancing-future-ccus

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questions regarding environmental justice and equity. To maintain global commercial competitiveness and serve our communities in many ways, we must understand what is possible and discuss what is effective and fair in the context of climate change and energy transition.

The bad news is that progress on industrial emissions is extremely difficult. We have very few options and our current options are expensive due to the very nature of industrial physics, chemistry, engineering, and markets. There are potential new pathways, yet these are underdeveloped due to chronic underinvestment and many uncertainties face the companies and policy makers in considering viable options. The good news is that there are things to do that are likely to prove cheap, effective, impactful, and low-risk. Swift action could provide both commercial and competitive advantages for the U.S., and if done well, could reduce both criteria pollution and greenhouse gas emissions with little impact to customers.

The challenges to managing industrial emissions are both difficult and straightforward:

- **No substitutes**: There are few viable substitutes for many commercial industrial products – cement, steel, glass, paper, and plastics. We use more of these materials every day both in the U.S. and the world and attempts at reducing consumption have not been successful.
- **Long-lived critical assets**: Cement kilns, blast furnaces, ammonia plants, and refineries are multibillion-dollar assets. They operate today making money for their owners, are pretty efficient, and serve key manufacturing chains and stakeholders (including cities, the military, the Army Corps, etc.). Some facilities have just been upgraded and most anticipate long operational lives. This makes it unlikely that they'll be replaced soon.
- **Few options**: Even if we could replace major industrial facilities, it's unclear what would serve to both produce critical products with minimal emissions. Primary steel and cement production have byproduct chemical emissions from coking and clinker production – we lack technology options that don't emit. Similarly, most of these options require very high temperature heat – glass, steel, and cement production basically melt rocks as their first step – for which we lack alternatives to fossil fuels. Electrification of many of these systems is not possible as a retrofit and is very challenging or speculative as a new facility.

Thankfully, a number of groups and scholars, including at Columbia University, are diving into this sector. In part we do so, following President Kennedy's words, because it is hard and because it is required. My own work focuses both on industrial heat and on other pathways to industrial decarbonization, which I chose for that reason.

The good news is that the community of scholars and experts agree to the findings of what actions would be most effective:

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- **CCUS is essential**: Analysis from the Intergovernmental Panel on Climate Change and dozens of other organizations conclude that carbon capture, use, and storage (CCUS) is essential to achieve important climate targets, including 2°C, let alone 1.5°.[2] Without CCUS most models do not converge on a solution at all. Those that do cost more than twice as much to reach the same targets. This is largely due to the role CCUS can play in heavy industry.[3] It is the ***only*** technology known today that can capture process emissions from cement[4]. It is the first, cheapest, largest fraction of what can be deployed in the U.S. and globally.[5] It is the fastest, cheapest pathway to low-carbon hydrogen and can help enable other key approaches like biofuels and renewable hydrogen. It is also the lowest cost for mitigation available today and will drop further in price through deployment. I spoke to this in some detail during my Senate testimony last May, which may be found at this link (https://energypolicy.columbia.edu/research/testimony/enhancing-future-ccus).
- **Hydrogen is promising**: To provide high-quality heat on demand, low-carbon hydrogen is the first, best option for many industries. This is especially true for industries that use natural gas, such as refining and petrochemicals, which can readily exchange one gaseous fuel for a new one with only modest retrofits and costs. Overall, hydrogen appears to provide minimal disruption to existing operating assets and could quickly and substantially reduce GHG emissions. The lowest cost low-carbon hydrogen options today involve steam methane reforming plus CCUS. As the costs for renewable electricity and electroyzers drop, renewable "green" hydrogen can begin to substitute for fossil-based low-carbon hydrogen.
- **Innovation investments are essential**: Most of the other options (e.g., biomass based or electrical based approaches) are not yet mature. The U.S. has underinvested in advanced technology options for heavy industry, including ways to deeply reduce carbon pollution. Today, the U.S. essentially supports no programs and no funding for such work. A new innovation focus on clean heavy industry would help maintain a muscular U.S. heavy industry, help us remain globally competitive, and could prove the cornerstone for future

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[2] IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, 32 pp. https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf
[3] Global CCS Institute, 2018, Global Status of CCS Report: https://www.globalccsinstitute.com/resources/global-status-report/
[4] Energy Transition Commission, 2018, Mission Possible: Reaching near-zero emissions from harder-to-abate sectors by mid-century: **www.energy-transitions.org**
[5] IEA 2018b, The future of petrochemicals: Towards more sustainable plastics and fertilizers (full report), https://www.iea.org/petrochemicals/

infrastructure and jobs investments.[6] Doing so would also reduce conventional pollution, improving the quality of life for those living near such facilities and strengthening our national commitment to environmental justice.[7] There are several bills pending now, including the EFFECT act[8] and the Clean Industrial Technology Act (CITA)[9] which would stimulate RD&D for industrial applications.

Given what's at stake and what's required, it's clear we need to start now on this difficult set of challenges. Thankfully, there are straightforward policies and actions that Congress can undertake today with either near- or long-term impact.

- *Procurement Standards*: Unlike in the power sector, Federal, State and City governments directly or indirectly buy enormous fractions and volumes of industrial products - for example, roughly 90% of cement and concrete, 50% of steel and 5% of fuels[10]. This gives government procurement enormous leverage in these markets. A well-designed national zero-emissions 'buy clean' standard would immediately create demand for low-carbon industrial products and stimulate private investment in decarbonizing industrial sources. Importantly, analysis suggests that even substantial wholesale increased in the costs of primary industrial products (like cement and steel) would have almost no effect on the final price of finished goods (like bridges and cars) – in many cases only a 1% difference in final costs.[11] Governments also need to develop procurement and performance standards to advise companies the specific technical requirements needed to obtain an offtake contract. Recent state legislative proposals and new laws provide a model for how this might be enacted.[12]

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[6] Energy Futures Initiative, 2019, Advancing the Landscape of Clean Energy Innovation, https://energyfuturesinitiative.org/news/2019/2/6/clean-energy-innovation-report
[7] Mckinsey, 2018, Decarbonization of the industrial sector: the next frontier. https://www.mckinsey.com/industries/oil-and-gas/our-insights/decarbonization-of-industrial-sectors-the-next-frontier
[8] US Senate, 2019, S. 1201, https://www.congress.gov/bill/116th-congress/senate-bill/1201/text
[9] US House, 2019, H. 4230, https://www.congress.gov/bill/116th-congress/house-bill/4230?q=%7B%22search%22%3A%5B%22clean+industrial+technologies%22%5D%7D&s=3&r=1
[10] Dell R., in press, Pathways to Deep Decarbonization
[11] Op Cit.
[12] CA Legislature, 2017, public contract code amendment 3500-3505 https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?division=2.&chapter=3.&part=1.&lawCode=PCC&article=5. And https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act

- *Infrastructure*: Whether for CCUS, hydrogen, or electrification, it is likely that more public infrastructure would accelerate adoption. For example, almost all CCUS is accomplished through the 5000 miles of shared CO_2 pipelines. Deployment of conventional CCUS will require thousands of miles more, mostly in the form of small regional networks that serve communities and regions while storing in local, high-quality geological storage sites.[13] Similarly, additional high-voltage DC and/or AC transmission to heavy industry or hydrogen infrastructure would serve to reduce costs and operational obstacles to adoption (Appendix A & B). Laws such as the USE IT Act, currently under consideration, could reduce risk and ambiguity for CO_2 and hydrogen pipelines and make financing and operation easier. Additional incentives, such as block grants to states or regions, a competitive grant program managed by the Office of Fossil Energy, or a bespoke investment tax credit, could help greatly.
- *Innovation agenda:* It appears that power sector decarbonization will be faster and easier that industrial systems, in part because there are options available. This is in part follows over 50 years of R&D and government procurement for renewables, advanced nuclear, and natural gas production. Given the challenges facing industrial decarbonization, we must invest now in developing alternatives that could be fielded in the future. This will help maintain U.S. competitive in the complex global markets and support innovators in small companies and universities across the country. Such work is essential in early deployment, and is a good complement to other policies like tax incentives and carbon pricing that might follow in the future.[14]

These policies have the advantage of being fairly cheap, serving multiple interests, and delivering change quickly. In contrast, many other conventional climate policies may prove less effective in industry than in other sectors (like power). For example, an economy-wider carbon tax may prove helpful but insufficient to drive industrial decarbonization, in part because of the lack of technical options and in part due to the high current cost of direct management of greenhouse gas emissions in these sectors. Moreover, the trade implications for industrials like steel and petrochemicals might prompt protectionist approaches like a border carbon adjustment. While that might prove effective, the potential consequences could be negative and enormous to trade, international partnerships, and domestic industries broadly. That's why I have two final recommendations:

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[13] Great Plains Institute, 2017, 21st Century Energy Infrastructure: Policy recommendations for development of American CO2 pipeline networks, 27p,. https://www.betterenergy.org/wp-content/uploads/2018/02/GPI_Whitepaper_21st_Century_Infrastructure_CO2_Pipelines.pdf
[14] Sivaram V. & Kaufman N, 2019, The next generation of federal electricity tax credits., CGEP report, https://energypolicy.columbia.edu/research/commentary/next-generation-federal-clean-electricity-tax-credits

- Analysis: While other countries have Ministries of Industry, the U.S. does not have a Department of Industry. There is no government agency tasked with aggregating all the relevant data on fuel use, emissions, commercial production, health effects, and trade for industry that would advise either the Executive or Legislative branches. To be clear, I am not proposing the creation of a new agency or department. Rather, agencies, like DOE, EPA, Transportation, and Commerce and entities like NIST, the Export/Import Bank, and others share aspects of the U.S. industrial enterprise. They require better understanding of the current state of affairs and the likely costs and timelines of current and future options. Congress should consider how and where best to create such an analytical authority that can bridge and serve these agencies and provide it with access to the funding and data required to inform them well (for example, vesting the job of analysis and data gathering at the DOE in partnership with other agencies). Some of these provisions are mentioned in the draft CITA language.
- Internationally coordinated sector agreements: Trade concerns inhibit investment and action in reducing industrial emissions, in large part due to concern about disadvantaging domestic industries in a global market. One way to manage these concerns is to coordinate international activity and agreements in specific sectors (e.g., chemicals, steel, aluminum). International discussions and agreements could be modeled after the Montreal Protocol, with specific caps and reduction targets and timelines agreed to by all key parties and with growing ambition over time.

In summary, we have little choice. To remain globally sustainable and globally competitive, it's essential to start the work of industrial decarbonization in a way that respect the limits of physic and chemistry, the needs of communities and industries, and the urgency of the challenge. With that, I look forward to your comments and questions.

Mr. TONKO. Thank you, Dr. Friedmann.

And finally, Mr. Walsh, thank you for joining us, and you are recognized for an opening statement of 5 minutes, please.

STATEMENT OF JASON WALSH

Mr. WALSH. Thank you, Chairman Tonko, Ranking Member Walden, and distinguished members of the subcommittee. Thank you for convening this really important hearing today.

The BlueGreen Alliance unites America's largest and most influential labor unions and environmental organizations. Our partnership is firm in the belief that Americans don't have to choose between a good job and a safe environment. We can and must have both.

Reducing emissions from the U.S. industrial sector is a clear example of this principle. If done right, a robust Federal commitment to rebuild American manufacturing and reduce greenhouse gas emissions from this sector will grow American competitiveness and secure and create a new generation of good middle-class jobs across America.

The industrial sector is the largest source of emissions in the United States when electricity is distributed to its end use. And importantly, emissions are projected to increase significantly between now and mid-century by roughly 17 percent. That compares to other sectors, at least under a business as usual scenario, are projected to see flat or declining emissions. So any gains that we see in other sectors would be more than outweighed by increases in industrial sector emissions, unless we act.

Tackling industrial sector emissions must, therefore, be central to any climate strategy moving forward. This is a significant challenge, as has been pointed out by a number of my fellow witnesses. Reducing emissions to the level required by climate math, which is pretty brutal, will require smart policies, tremendous technological ingenuity, and significant investment but we have barely gotten started.

Policymakers and philanthropy have focused, to date, on emission reductions in other sectors—buildings, power, transportation, all for very good reasons, but the industrial sector has received relatively little attention by comparison and it will be the single hardest sector to net out zero emissions.

Tackling emissions is also an issue of global economic competitiveness. Prioritizing investments in U.S. manufacturing will not only reduce emissions but will create and retain good jobs in the United States for two primary reasons: One, a significant proportion of emission reductions can be realized by reducing energy waste, saving money manufacturers can invest in capital and in their workforces, supporting jobs through the installation of energy efficiency technologies as well; and two, U.S. manufacturers' ability to produce clean technologies and use cleaner processes will make them more competitive in an increasingly carbon-constrained global economy.

Let me take the steel industry as an example, which also speaks to Ranking Member Shimkus' very good question which, in turn, echoed Mr. Gates' very good question. The steel industry currently generates about seven percent of the world's CO2 emissions, contributing over three gigatons of CO_2 annually. Global steel demand is forecast to increase from 1.7 billion tons in 2018 to 2.6 billion tons in 2050.

There are several ways to reduce emissions from iron and steel production, including industrial energy efficiency, material efficiency and reuse, fuel and feedstock switching, and of course, carbon capture utilization and sequestration. Investments are happening today to drive these innovations and to develop cutting edge technologies and practices.

But where are these investments happening? They are not happening here. They are happening in Germany, in Sweden, in the United Arab Emirates. These types of cutting edge projects are not being built in the United States because we don't have the policies and programs in place that incent and support the kind of investments needed to make them a reality. If we don't start playing catch up, the future of innovative, low, and zero emission steelmaking will be commercialized by our global competitors in their own countries. We can't let that happen.

We need to move forward an aggressive American agenda to regain our leadership in clean technology innovation and deployment and we need to do it now. We need a holistic approach to retaining and growing clean energy manufacturing in the U.S., while also investing in these industries to make them the cleanest and most competitive in the world. These investments must result in good paying jobs and go hand in hand with common sense tax procurement and trade enforcement policies to stop the offshoring and leakage of jobs and pollution, as have been noted by a number of witnesses and members of this committee.

My written testimony outlines a number of specific policy recommendations to achieve these goals.

In closing, we look forward to working with this committee as you move forward your agenda for the 116th Congress. Thank you again for the opportunity to testify today.

[The prepared statement of Mr. Walsh follows:]

BLUEGREEN ALLIANCE

CREATING GOOD JOBS, A CLEAN ENVIRONMENT, AND A FAIR AND THRIVING ECONOMY

WRITTEN TESTIMONY

Jason Walsh
Executive Director, BlueGreen Alliance
Before the 116th United States Congress, House Committee on Energy & Commerce
Subcommittee on the Environment and Climate Change
Building a 100 Percent Clean Economy: Pathways to Net Zero Industrial Emissions
Rayburn House Office Building, Room 2123
Wednesday, September 18, 2019

Thank you Chairman Tonko, Ranking Member Shimkus, and distinguished members of the subcommittee. My name is Jason Walsh, and I am the Executive Director of the BlueGreen Alliance, a national coalition of labor unions and environmental organizations. On behalf of my organization, our partners, and the millions of members and supporters they represent, I want to thank you for convening this hearing today to examine opportunities to reduce emissions in the U.S. industrial sector.

The BlueGreen Alliance unites America's largest and most influential labor unions and environmental organizations to solve today's environmental challenges in ways that create and maintain quality jobs and build a stronger, fairer economy. Our partnership is firm in its belief that Americans don't have to choose between a good job and a clean environment—we can and must have both.

Reducing emissions from the U.S. industrial sector—the topic of today's hearing—is a clear example of this principle. If done right, a robust federal commitment to rebuild American manufacturing and tackle emissions from this sector will grow American competitiveness in the global economy and secure and create a new generation of good, middle-class jobs across America—all while tackling the climate crisis.

The world's leading scientific organizations have been unambiguous that climate change is a dire and urgent threat and that the longer we delay, the stronger the action required. Over the last decade, we have witnessed the worsening impacts climate change is having on our communities.

At the same time, our nation is struggling with deep and crippling economic inequality. According to the Economic Policy Institute, "the bottom 90 of the American workforce has seen their pay shrink radically as a share of total income," from 58% in 1979 to 47% in 2015. That is almost $11,000 per household, or $1.35 trillion in additional labor income. There is a direct correlation with the decrease of worker power over this time, as the share of workers in a union fell from 24% in 1979 to under 11% now.[i]

Americans face the dual crises of climate change and increasing economic inequality, and for far too long we've allowed the forces driving both crises to create a wedge between the need for economic security and a living environment. We know this is a false choice—we know that we can and must have both, and we need a bold plan to address both simultaneously.

That's why this summer the BlueGreen Alliance alongside our labor and environmental partners released **Solidarity for Climate Action**, a first of its kind platform to fight climate change, reduce pollution, and create and maintain good-paying, union jobs across the nation.

If we do it right, innovating, manufacturing, and installing the clean economy can protect the environment while creating quality jobs. Prioritizing the industrial sector and U.S. manufacturing must be a key focus—both to reduce climate emissions, but also to create more good jobs in manufacturing and ensure our industries' global competiveness.

Tackling the Industrial Sector Must be Key Policy Focus

The industrial sector represents a significant source of U.S. emissions. In 2016, the largest sources of greenhouse gas emissions by sector were transportation (nearly 28.5%), electricity production (28.4%), and industry (22 %).[ii] However, distributing electricity by end-use reveals that the industrial sector is the largest source of emissions in the United States, responsible for 29% of emissions overall.[iii]

Not only are industrial sector emissions large today, they have been growing and are projected to increase further. Globally, industrial sector emissions increased at an average annual rate of 3.4% between 2000 and 2014, significantly faster than total carbon dioxide (CO2) emissions.[iv] Industrial sector emissions are also growing at a faster rate than other sectors. Between 1990 and 2014, industrial sector emissions increased by 69%, while emissions from buildings, power, and transport increased by only 23%.[v] Industrial sector emissions in the United States are projected to increase 17.6% through mid-century.[vi]

While other economic sectors are projected to see flat or declining emissions,[vii] these climate benefits will be offset by increases in industrial emissions under a business-as-usual scenario. Reductions in the power and transportation sectors, for example, are projected to be offset by an increase in carbon emissions from industrial sources.[viii] Therefore, while progress must be made across sectors, industrial sector emissions are a current and growing threat to climate progress.

While emissions from a range of economic activities are included in the industrial sector, manufacturing accounts for roughly three-quarters of it. And within manufacturing, several key energy-intensive manufacturing sub-sectors are responsible for the majority of emissions.[ix] The six largest sources of industrial sector emissions, now and looking ahead, are chemicals, petroleum refining, iron and steel, food products, paper products, and cement and lime production.[x]

Addressing the emissions associated with these industries is a significant challenge. Reducing emissions to the level required by climate math will require smart policies, tremendous technological ingenuity, and significant investment. In the industrial sector, we've barely gotten started. Philanthropy and policymakers have focused to date on emission reductions in other parts of the economy—in the power, transportation, and buildings sectors. The industrial sector has received little attention by comparison, a dynamic that needs to change, not least because it will be the single hardest sector in which to zero out emissions.

This is a Competitiveness Issue

Tackling emissions from the industrial sector is not only critical from a climate change mitigation perspective. It is an issue of global economic competitiveness. Prioritizing investments in U.S. manufacturing will not only reduce greenhouse gas emissions, but it will create and retain good jobs for two primary reasons: (1) a significant proportion of emission reductions can be realized by reducing energy waste, which saves money that manufacturers can otherwise use for workforce and capital investments, and which also supports jobs through the installation of energy efficiency technologies; and (2) U.S. manufacturers' ability to produce clean technologies and to use cleaner processes will make them more competitive in a global economy in which market demand is shifting inexorably in that direction.

Let's take the steel industry as an example.

The steel industry currently generates approximately 7% of the world's CO2 emissions, contributing over three gigatons of CO2 to global emissions annually.[xi] Global steel demand is forecast to increase from 1.7 billion tons in 2018 to over 2.6 billion tons by 2050.[xii] Emissions are therefore likely to increase absent intervention.

There are several ways to look at reducing emissions from steel production:

Industrial Energy Efficiency and Material Efficiency and Reuse

A key way to improve the energy efficiency of manufacturing is through the use of co-generation systems, often referred to as combined heat and power (CHP), or waste heat to power (WHP).[xiii] In addition to CHP and WHP, a range of commercially available efficiency technologies and measures exist that could reduce greenhouse gas emissions from steel manufacturing. Studies have shown that efficiency improvements could result in a 15 to 20% reduction in energy consumption for steel.[xiv]

A range of other advanced manufacturing practices and technologies can drive continued yield improvement from crude steel production to final steel in products, equipment, buildings, and infrastructure. This can help reduce the amount of steel production needed for the same products.[xv]

We also need more innovation of technologies and business models to scale up the reuse of materials and support circular economies within manufacturing. Recycling is already an integral part of steel production, although we need to do more to reduce contaminants in steel products to further increase the recyclability of scrap steel. But increasing high-quality material recirculation is most important in subsectors like chemicals, where the recycling of plastics lags far behind other commodities.

Fuel and Feedstock Switching

Fuel switching to clean sources can also help reduce greenhouse gas emissions from the industrial sector, particularly with respect to process heat, which is the biggest source of energy use and related emissions in the sector. This could include switching to dispatchable renewable sources, such a solar thermal or sustainable biomass, and the electrification of certain processes. Steelmaking, however, relies on very high temperatures for process heat, which we can't yet achieve with heat from cleaner sources.

New technological innovations are under development to address the emissions associated with high-temperature heat generation. One promising new innovation is a process called "electrolysis," which could replace high-temperature chemical processes. In this method, electricity, rather than heat, would drive reduction and oxidation reactions.[xvi] The combination of renewable energy with electrolysis is currently being developed. [xvii]

A second innovative approach under development entails reducing emissions from the consumption of fossil fuel for heat and emissions from certain feedstocks by switching them with zero-carbon hydrogen or biomass. [xviii, xix] For example, primary steel can be produced through direct reduction of iron ore with renewables-based hydrogen[xx] as a fuel and feedstock instead of coal.[xxi]

Carbon Capture, Utilization, and Sequestration (CCUS)

The Intergovernmental Panel on Climate Change (IPCC) Special Report found that CCUS plays a major role in decarbonizing the industrial sector in pathways limiting warming to both 1.5°C and 2°C, particularly in the key manufacturing industries with higher process emissions that result from the conversion of feedstocks into commodities—for example, iron ore into iron and steel, limestone into cement, and bauxite into aluminum.[xxii] It needs to be emphasized that these emissions are associated with chemical conversions rather than energy use and we do not currently have near-term options other than CCUS to manage them.

Industrial facilities that capture and sell CO2 can reduce their emissions while also gaining an extra revenue stream, creating jobs in their company as well as downstream industries and suppliers. The economic benefit of this would encourage more carbon producers to capture their emissions, and could result in reduction of stationary source CO2 emissions from current levels. Adoption of CCUS also means that we can find more effective ways to safely utilize CO2 emissions in ways that do not damage the environment. CO2 is already used in some industrial processes, such as waste gas recycling used in steelmaking (see below), and has the potential to shift from a burden to a valuable commodity in the future as research into safe carbon utilization advances.

The Future of U.S Competitiveness is at Stake

Investments are happening today to drive these innovations in iron and steelmaking and develop the cutting edge technologies and practices that will significantly reduce emissions in this industry. But where are these investments happening? For the most part, they're happening in other countries, not in the United States.

For example, in Hamburg, Germany, ArcelorMittal launched earlier this year a €65 million pilot project to test hydrogen steelmaking on an industrial scale. And in Ghent, Belgium, with its partner Lanzatech, ArcelorMittal is building the first large-scale plant to capture waste gas and biologically convert it into bio-ethanol. It predicts a CO2 reduction of up to 87% compared with fossil transport fuels. In Sweden, SSAB, a global steel company, joined with LKAB, Europe's largest iron ore producer, and Vattenfall, one of Europe's largest electricity producers, on a project to produce steel using hydrogen.[xxiii] Lastly, in 2016, the Al Reyadah project in Abu Dhabi came online, becoming the world's first commercial steel carbon capture project.[xxiv]

Many of these projects benefit from public support. The SSAB project, for example, will receive SEK 500 million from the Swedish Energy Agency, on top of the SEK 60 million already contributed. And the Al Reyadah CCUS project would not have happened without state support from the United Arab Emirates.

These types of cutting edge projects are not being built in the United States because we don't have the policies and programs in place that incent and support the kind of investments needed to make them a reality. If we don't start playing catch up with the countries that do, the future of innovative, low -and zero-emission steelmaking will be commercialized in countries that are our global competitors. We cannot let that happen. In iron and steel and other manufacturing sub-sectors, we must move forward an aggressive agenda to regain American leadership in clean technology innovation and deployment, which are inextricably linked.

Recommendations

We need a holistic approach in this country to retaining and growing clean energy manufacturing in the United States while also investing in these industries to make them the cleanest and most competitive in the world.

American leadership in inventing—and manufacturing—the most advanced technology of all kinds was once a cornerstone of a strong and growing middle class and a pathway for many out of poverty. Innovating, building, and installing the clean economy can be a critical pathway to revitalize American manufacturing while protecting the environment and creating quality jobs across the country. We can rebuild American competitiveness in the global economy, and secure and create a new generation of good, middle-class jobs across America through a national strategy to lead in clean and emerging technology production. This must include:

- Technical and financial assistance targeting the biggest energy using and emitting manufacturers in the United States, enabling them to deploy fully commercialized industrial energy efficiency technologies and energy performance systems;
- Major new investments to spur domestic manufacturing and supply chain development in rapidly growing clean technologies;

- Increased funding for research, development, demonstration, and deployment of the transformative technologies that will be required to decarbonize the industrial sector, in particular those related to electrification, fuel -switching, and industrial CCUS;
- Expanding and adapting clean technology manufacturing loan and grant programs such as U.S. Department of Energy's (DOE) Advanced Technology Vehicles Manufacturing Loan Program and the Sec. 132 Domestic Manufacturing Conversion Grants program; and
- A focus on environmentally, economically, and socially responsible mining projects, as well as reclamation and recycling initiatives to ensure we're creating the materials necessary for a clean and secure energy future here in the United States.

Nationwide improvements in industrial energy efficiency and pollution reduction enjoy the diverse support of the labor, business, and environmental communities. Measures to help reduce energy costs, decrease pollution, and boost productivity and efficiency within the industrial sector will support U.S. manufacturers and help maintain our competitive edge in the global economy. Congress should:

- Increase appropriations for the key federal programs within the DOE that focus on the industrial sector, including the Advanced Manufacturing Office (AMO);
- Pass the Clean Industrial Technology Act (CITA), sponsored in the House by Congressman Casten and others, which would establish a new advisory council at the Department of Energy to coordinate funding for developing innovative technologies for industrial processes;[xxv]
- Extend, modify, and create tax credits for industrial efficiency improvements like CHP and waste heat to power, as well as the advanced energy manufacturing tax credit (48C) to once again support manufacturers as they expand into the clean economy;
- Create a program modeled after the successful DOE Industrial Technologies Program to provide matching funds for major industrial efficiency projects, which was the direct driver for ArcelorMittal's Indiana Harbor Combined Heat and Power project;
- Establish a grant or revolving loan fund program to provide resources to manufacturers for producing clean energy, transportation, and infrastructure technology and energy efficient products and for reducing greenhouse gas emissions from manufacturing facilities—with criteria for domestic, high-quality job creation, particularly in low-income communities. This could be modeled on the IMPACT Act of 2009; and
- Utilize "Buy Clean" or other federal procurement standards that require the federal government to consider the carbon footprint of goods they're purchasing, and to prioritize manufacturing firms that uphold strong labor standards and create good jobs in low-income communities.

Lastly, any approach to industrial emissions reduction must consider the unique challenge the industrial sector faces related to global competitiveness. Many U.S. manufacturers are in "energy-intensive, trade-exposed" (EITE) industries and are very vulnerable to global competition. Steel, glass, metal casting, pulp and paper, aluminum, and chemicals are all traded globally and purchased predominantly based on price in a global marketplace.[xxvi, xxvii, xxviii]

Additionally, policies intended to reduce emissions could unintentionally—through increased costs to U.S. manufacturers—result in a phenomenon known as "carbon leakage." Rising costs could push production to manufacturers in countries with less stringent standards, which could ultimately result in an increase in global greenhouse gas emissions in the long term.[xxix] Any federal effort to tackle industrial sector emissions and grow U.S. manufacturing therefore must include:

- Using common sense tax, procurement, trade enforcement, and border adjustments policies to stop offshoring and the leakage of jobs—and pollution—overseas; and
- Ensuring that trade agreements are enforceable, fair for all workers, and benefit the environment and the climate.

Ensuring Quality Job Creation

At the same time, we must ensure that these investments result in good-paying jobs. While many clean economy jobs are good, union jobs, too many still are not. Too many companies are offshoring jobs, offering substandard wages, conditions and benefits, or failing to provide safe, healthy workplaces. We cannot rebuild prosperity if working people and the communities they live in fail to see the gains from innovation and a cleaner economy.

Therefore, in addition to investments in innovation, manufacturing, and emission reduction technologies, we need an ironclad commitment to *high-quality* job creation across all sectors of the economy—but especially related to clean energy, adaptation, and resilience. That means a commitment to:

- Increase union density across the country through strong support of the right to organize throughout the economy, including in the clean technology sectors;
- Apply mandatory labor standards that include prevailing wages, safety and health protections, project labor agreements, community benefit agreements, local hire, and other provisions and practices that prioritize improving training, working conditions, and project benefits. This includes respect for collective bargaining agreements and workers' organizing rights such as neutrality, majority sign-up, and first contract arbitration for construction, operations, and maintenance;
- Raise labor standards in the non-construction sectors through improved wages and benefits and the prioritization of full-time work that eliminates the misclassification of employees and misuse of temporary labor;
- Invest in training, equipment, preparedness, plan development, and other tools including through registered apprenticeship programs to ensure a robust, skilled, and well-prepared workforce to address the extreme weather events and other impacts caused by climate change; and

- Utilize community benefit, workforce, and other similar agreements that improve access to jobs and career paths, and identify and implement mechanisms to ameliorate and improve local economic and environmental impacts, particularly in low-income communities and communities of color.

In closing, I want to reiterate that reducing emissions in the U.S. industrial sector—if done right—is a significant opportunity to ensure a more equitable society, increase U.S. global competitiveness, and create good-paying jobs across the country—all while reducing the emissions driving climate change.

We look forward to working with this Committee as you move forward your agenda for the 116th Congress. Thank you again for the opportunity to testify today.

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Mr. TONKO. Thank you, Mr. Walsh.

So that concludes the opening statements provided by our witnesses. We now will move to member questions. Each Member will have 5 minutes to ask questions of our witnesses.

I will start by recognizing myself 5 minutes.

We know that there are challenges but we should not underestimate what can be accomplished over the course of a few decades. If we start right now putting in place the right incentives, the research investments, and standards, how much progress can we make by mid-century to decarbonize industry? And what is your recommendation for the very first thing we should do to get started?

Let's start with you, Mr. Perciasepe. How much progress can we make and what is the first thing we should do?

Mr. PERCIASEPE. Well I think what you heard from a lot of the witnesses is that there is a lot of progress already underway, including some of the very difficult pieces that have been mentioned by members in their opening statements, in steel and in cement. Those industries we have to look at how to improve the actual processes.

But one other thing, there is also companion activities here because all of industry uses electricity. And so to the extent that we are decarbonizing electricity with other approaches, with renewable energy, nuclear, and carbon capture, the electricity that the industry will be getting is going to be cleaner and there is also transportation moving the products around.

So I think that probably the first thing to do is, at a minimum, is to put more incentives in place to stimulate the innovation of the new technologies, ones that cut across industrial sectors like carbon capture, and we have some of that already as has been mentioned under the Tax Code, 45Q, but also the innovation needed in these new processes for making steel, making steel or iron, pure iron from a reduction with hydrogen as opposed to the current methods. It uses a lot less—creates a lot less carbon dioxide just to make the iron. That is, obviously, the main ingredient in steel.

So these processes that companies are working on could really be accelerated with public incentives.

Mr. TONKO. Thank you.

Dr. Gregory, what progress can we make and what is the first thing we can do?

Dr. GREGORY. I think that actually one of the simplest things that can be done that are specific to the cement and concrete sector are related to this use of performance-based specifications that I mentioned because you know we heard a lot of discussion about CCUS, which should definitely be done but, if we develop new materials that have a lower carbon footprint but we can't create a market demand for them, then they won't be used. And we have already seen failures of companies that produced these things in this country, who couldn't do it in a cost-competitive way and also couldn't get adoption of this from engineers who use it. And so encouraging, essentially, engineers rather than to say this is the mixture that we have already used that is something safe and we know, get them to say what are the performance metrics that you are interested in and then tell me what the measurement is of the carbon footprint as well.

And believe it or not, that seems like a simple and obvious thing but it is sort of like instead of using a specific recipe to make cookies, tell me what are the kind of cookies that you are interested in. What are the attributes of them? That is what we need for materials as well, to create demand for these low-carbon materials.

Mr. TONKO. OK. We have about two minutes remaining for my time. If we could just get quick answers from the remaining four witnesses, please.

Dr. SANT. Sure. Very quickly, I think the two things that we should really try and focus on is really, number one, carbon efficiency standards, which we can apply across the nation, across a series of products.

The second part, technologically, we have done a lot of work to develop new technologies. The issue with most of them is we have not demonstrated them suitably at scale. So I think we really need support to be able to demonstrate things at relevant scales so that manufacturers can start to see whether these are cost-effective enough for them to actually integrate into their operations.

Mr. TONKO. Thank you.

Mr. Eisenberg.

Mr. EISENBERG. We all agree that innovation is the key here. Please give us the tools to do it. We need the incentives. We need the access to the labs, the partnerships with the Federal Government and within the private sector, and we need to make sure that the math works at the plant level.

Mr. TONKO. And how much progress can we make?

Mr. EISENBERG. We can make a lot of progress, especially in the near-term, especially since you are going to have a lot of hard decisions to make on the federal policy side. But getting that in now, funding those things up and giving us access to them, will make an appreciable difference and a real difference for manufacturers.

Mr. TONKO. Thank you.

Dr. Friedmann.

Dr. FRIEDMANN. A comprehensive approach could get us 65 to 75 percent. We could get a lot.

The number one thing: Procurement. You said it yourself, Chairman. The number one thing is procurement.

The Government buys 60—sorry—90 percent of cement and concrete, 50 percent of the steel that is made in this country. You guys have an outsized role. And by driving that procurement process, you can create new customer base and new options for the manufacturers themselves, so that they can sell a better product into a better market.

Mr. TONKO. Thank you very much.

And finally, Mr. Walsh.

Mr. WALSH. We need to deploy the technologies that we already have commercialized more fully—industrial energy efficiency, cogeneration. We can carve about 15 to 20 percent emissions out of the industrial sector as a whole.

Industrial sector decarbonization is really hard but one of the ways in which it is easier is that we know where those facilities are. We also know from DOE's Barriers to Industrial Efficiency Report, which was issued in 2015, that one of the primary barriers for manufacturers is lack of information. They don't know the technologies are out there. They don't know the payback times. They don't know different pathways. We have got a whole set of resources that DOE, the Advanced Manufacturing Office, international labs, that could be put—could be brought to bear. It is nothing but benefit for U.S. manufacturers.

Mr. TONKO. Thank you very much to each of our witnesses.

I then will now recognize Representative Walden for, as the ranker for the full committee, for 5 minutes to ask questions.

Mr. WALDEN. Thank you, Mr. Chairman. I want to thank all of you. This has been a really good panel and we really appreciate your input and your counsel on these issues, and they are not easy. It is far beyond just a slogan. We have got a lot of important work to do.

Dr. Gregory, we are glad to have you here. I understand you grew up in Bend, Oregon. So, there are two of us from the Second District here, at least. We appreciate that.

Mr. Eisenberg, our view is the path to cleaner technology comes from the ground up from innovators, from investors. We know you have got to have the right incentives.

Can you speak to the importance of the 45Q tax credit, which we extended as part of the tax bill? It has two different variants to it. Is that having a positive impact and incentive in the market that we want to see results from? Is it working?

Mr. EISENBERG. So it is working to the—and I am hearing it from my members. We actually recently this year brought in a group called the Energy Advance Center into the NAM. It is a project of the NAM. It is manufacturers that came together around the 45Q tax credit and are looking to try to find ways to turn that into innovation on the ground, principally, in the oil and gas sector but definitely other manufacturing sectors as well. We are going to need it all.

There is a lot more we can do beyond that but it was a heck of a start. And it is one of those things where you can use incentives and they work. I mean we saw it on a number of issues in the energy space, and this is no exception, where incentivizing the technology has brought manufacturers out of the woodwork ready to actually test some of this and put it into place.

There is plenty more that we can do in this space, including starting with enacting the USE IT Act and passing the USE IT Act.

Mr. WALDEN. Right.

Mr. EISENBERG. But also, things like port space, ownership, and plenty of other issues to get this off the ground but it is good to hear that we all agree that this is important.

Mr. WALDEN. Yes, I think so. And I guess I approach it from, how do we give the carrot as opposed to the stick. I mean that is where I tend to come down and not over-regulate, or overtax, or whatever on the Government side of this but, rather, how do we put in the incentives in place for our great innovators to respond and act?

And Dr. Gregory, and Mr. Eisenberg, Oregon's only cement manufacturing plant, as it turns out, would be in the district I have the great privilege to represent in Durkee, Oregon. It employs about 100 people, directly effects around 600 jobs in the area, which is enormous in this very rural county, as you know. It is a very trade-exposed plant. And I have been out there. I have toured it. They have invested tens of millions of dollars to reduce all kinds of emissions, mercury, everything else. They really do care about the environment.

It costs roughly the same amount to ship the cement they manufacture to Portland, Oregon, not Portland cement but Portland, Oregon, as it does for China to ship their cement from China to Portland, OK, which is pretty hard to believe but that is what they tell me.

And our concern is if Oregon replicates some of the other climate proposals and policies, we could end up losing that plant and those jobs, and cleaner emission cement. And as a result, they estimate we would import the cement and it would be 400,000 tons more per year of emissions globally. So, as I sort through these policies, we don't want to do that.

And in fact, a lot of the mercury pollution we get on the West Coast I am told originates from Chinese manufacturing.

So, how do we work through these trade-exposed policies, especially on cement? Dr. Gregory, can you comment on that?

Dr. GREGORY. Yes, sure. I mean China makes more cement than the rest of the world combined. Right? And so the U.S. manufacturers two percent of the world's amount of cement.

Mr. WALDEN. And—what are standards? Is there a graph of standards here for cement emissions?

Dr. GREGORY. There very much is a range. And as many of the other panelists here have mentioned, you know trade leakage is a really significant concern if we shift the standards that we are using to produce cement here today.

I think, just like we also heard, the power of—the purchasing power that Government has, whether that is at the Federal, or the State level——

Mr. WALDEN. Right.

Dr. GREGORY [continuing]. Or even municipal levels——

Mr. WALDEN. Right.

Dr. GREGORY [continuing]. Oregon is one of the states that is really looking at the concrete that it produces. What is the quality of it? And I think whether it is efforts going on in the City of Portland or in the State of Oregon to look at that, that is a great place to start to ask producers, local producers, where did you get this. What was the quality of it?

Mr. WALDEN. Right.

Dr. GREGORY. What was the environmental footprint of it? And ask for that. And have that start out. Producers will——

Mr. WALDEN. But do we have data on the amount of emissions from Chinese manufacturing or some other country—I am not just picking on China here—versus U.S. manufacturing for the same products? Is there a place where consumers can go and see that?

Dr. GREGORY. Yes, we do have some high-level numbers on overall Chinese emissions. What is a little bit different is getting data from individual plants, where there can be significant variation.

The types of cement that they make are a little bit different than what we make in the U.S.

Mr. WALDEN. Right.

Dr. GREGORY. So it is not quite an apples to apples comparison.

Mr. WALDEN. Right. Right.

Dr. GREGORY. And so that ends up being a little bit——

Mr. WALDEN. Because any consumer power is really powerful.

Dr. GREGORY. Absolutely.

Mr. WALDEN. And disclosure, and information, and we were just talking about your comment, Dr. Friedmann, maybe Mr. Walsh, this information is not even available for some.

I know my time has expired, Mr. Chairman. Thank you.

And again, thank you all for your participation in this.

Mr. TONKO. The gentleman yields back.

The Chair now recognizes Mr. Pallone, full committee chair, for 5 minutes to ask questions, please.

The CHAIRMAN. Thank you Chairman Tonko. And let me thank all the witnesses for your testimony and assistance in developing policy solutions to achieve 100 percent clean economy, while keeping and increasing good jobs here at home.

But I want to—I don't have a question for Mr. Eisenberg but I did want to particularly thank him and the National Association of Manufacturers for your very constructive testimony. Thanks so much.

Mr. EISENBERG. Thank you. It is my pleasure.

The CHAIRMAN. It wanted to start on the topic of jobs. And Mr. Walsh, you testified, and I quote, that if done right, federal climate policy can help not just maintain but grow American competitiveness in the global economy.

So let me ask you what would be the number one thing you think we should do now to position American manufacturing to lead and produce low-carbon products, if you will?

Mr. WALSH. Well, I think we need to start by recognizing where we have already done that, right, where we have increased U.S. manufacturing competitiveness, while also reducing emissions. One of those sectors, of course, is the automotive sector, right, through a combination of very careful fuel economy standards, coupled with manufacturing policy. We have a whole generation of autoworkers that are making a high-efficiency, in some cases, zero-emission vehicles not only for markets in the United States but for markets abroad.

The challenge is more—I think the bigger challenge in front of us is the energy-intensive commodities manufacturers that I talked about in my testimony and that several other witnesses have spoken to. We are going to need to do a whole lot of things at the same time.

I have already talked about industrial energy efficiency. I want to emphasize high-temperature heat and the importance of finding low- and zero- emission alternatives. I mentioned some of the exciting innovations going on in Europe and a few other parts of the world. We need the same thing here. In order to get it, we are going to need a whole set of policies that range from making sure that manufacturers have access to affordable capital, to technical assistance, to consistent and smart regulatory and tax policy.

The CHAIRMAN. Thank you, Mr. Walsh.

I wanted to move to carbon capture. When we talk about the U in CCUS, people often think of enhanced oil recovery as the default way to utilize captured CO2 but, as we know, there are many other potential uses for captured CO2, including in the type of product that Dr. Sant is developing at UCLA.

So I just wanted to pose this question to three of you, to Dr. Sant, Dr. Friedmann, and Mr. Perciasepe: What are some of the more novel uses for captured CO2 and how can those uses be developed, both economically and at scale?

And let's begin with Dr. Sant and then we will go to the other two, if you would.

Dr. SANT. Thank you. That is a very important question. So you know when we started to work on this, and I think I will speak to the context more generally, is we really wanted to look at markets where you can use a substantial quantity of CO2, which is why we started to look at concrete as an example because it is a large market globally. It is also a carbon-intensive commodity. So being able to rationalize its carbon footprint is important.

There are other things that you can produce, some of them which are competitively large, some of which are smaller. So you could produce liquid fuels as an example. You could also produce things like formic acid.

I think the question around utilization is extremely significant because first, to point out, it is highly unlikely we will ever use anything more than 10 to 15 percent of global emissions to be able to produce product. So it is not a pathway for carbon management, relatively speaking. However, it is an important revenue generation pathway to undertake in the short- to medium-term to be able to create utilization solutions. However, I think we need to be very pragmatic and analytical about utilization solutions to make sure that the life cycle analysis does actually demonstrate that you are using more CO2 in the utilization step than you make. And I think this is something that we often lose sight of but I think this is something we need to be critically focused on.

So as an example, speaking for ourselves, it is something that we have taken into great account as we have looked at developing cementation solutions based around CO2. But I think this is a sentiment that really requires standards and bases of analysis to be able to actually effect utilization properly.

The CHAIRMAN. I think I am going to run out of time but I said Dr. Friedmann next. So, we will go to him.

Dr. FRIEDMANN. I will be brief.

Along the lines of what Dr. Sant just said, you can't balance the climate books on utilization. There is just not enough tons to put places but you can get a couple of gigatons. And the markets where you can get a couple of gigatons start with cement and aggregates. The next big market is fuels and chemicals. I have written three reports on this. I am happy to send them to you all.

The CHAIRMAN. Doctor—I mean Mr. Perciasepe.

Mr. PERCIASEPE. Some people do call me doctor every once in a while.

The CHAIRMAN. That is all right. Maybe you are. I don't know.

Mr. PERCIASEPE. I would concur with Julio that building materials and fuels are the most likely to be at scale but you asked for some of the interesting things.

Well you know there is complex materials like carbon fibers and nanotubes. There are agricultural products, including fertilizers. There is a number of things that people are working on all across the board but those two are the most likely for at-scale that we need in the near-term.

The CHAIRMAN. Thank you.

Thank you, Mr. Chairman.

Mr. TONKO. The gentleman yields back.

The Chair now recognizes the Representative from Washington State, Representative Rodgers, for 5 minutes, please.

Mrs. RODGERS. Thank you, Mr. Chairman. And I, too, want to thank all of the panel for being here today. I appreciate your leadership, your commitment to making our economy more efficient, more sustainable. It is essential.

As others have highlighted, the U.S. already leads the world in reducing emissions, in developing new and innovative technologies to increase efficiencies and reduce waste. As plan for the best way forward for a clean energy future, we must ensure that we do not harm our competitiveness in an increasingly global economy. It is really free market innovations that have made the U.S. a leader in both emissions reduction and technological solutions, such as carbon capture.

Unnecessary burdensome regulations will only succeed in hamstringing our manufacturing economy. And we are celebrating right now 500,000 new jobs, new manufacturing jobs in America. We do not want to be forcing these jobs overseas to countries like China and India, who account for a disproportionate share of global emissions. From my perspective, we should be encouraging new innovations and technologies that can increase efficiencies and decrease emissions.

You know in my home State of Washington, emissions have increased six percent since 2012 and this is despite Governor Inslee's increased mandates and regulations on our energy and industrials. By developing and exporting new processes and new technologies to the developing world, we can continue to lead the world in emissions reductions and remain competitive in the global economy.

Innovation is the key to combatting climate change, growing the economy, and raising the standard of living in our communities.

Mr. Eisenberg, I would like to discuss the central role of global competitiveness when we develop these industrial emissions policies, from past experience as a parent, that there is a tremendous risk to our ability to make and do things in America, if policymakers impose unnecessary cost on industrial processes and the energy used in those processes.

Would you just share with us from your perspective what we can be doing as policymakers to make it less expensive and more efficient for manufacturers and industry to innovate, rapidly deploy, and eventually export new products?

Mr. EISENBERG. Thank you for the question. And I really appreciate, frankly, everybody's commitment to manufacturing here. I mean it is so encouraging to hear everybody talk about how important manufacturing is in your districts into the future. We obviously feel that very, very strongly. That is why I took this job.

There is a number of things in the climate space and in the emissions space that I think would really work here, especially in the near-term. It starts with—and a lot of them are in my testimony. I will quickly run through a bunch of them.

First things first. There is a bill called the Clean Industrial Technology Act that came out of the Science Committee and I believe has dual jurisdiction here. It would create, basically, a program at DOE that would have sort of long-term advanced focus on decarbonization of the industrial manufacturing sector. That is one way to really get us out there doing this kind of work with the Government and with the labs in making it happen. Ratify the Kigali Amendment or enact legislation that will get you there, that will reduce serious tonnage and keep us competitive on the greenhouse gas side.

Scale up energy efficiency. Scale up energy efficiency. This is something that I think we are all saying. My counterpart Jason said it best. This is where we really need to focus on the math and give us the tools to install that stuff with the right payback period. Full and complete expensing in the Tax Reform Bill made a big difference to a couple of my manufacturing companies. It gave them the opportunity to change the math and allowed them to put in things like CHP and some of those newer technologies to let them be more efficient, the permitting process, the work you are doing on NSR, reauthorizing Title 41 of the Fast Act. There is plenty more I can get into but these are all kinds of things that we think would be bipartisan strong measures that we can do right now that would help keep manufacturing competitive while reducing our emissions.

Mrs. RODGERS. Great. In the time I have left, Dr. Gregory, I wanted to ask if you would just elaborate more on the promise of carbon capture and just what is your understanding as far as what other countries are doing related to carbon capture.

Dr. GREGORY. Sure. Yes, carbon capture for cement plants is a little bit different than it is for other types of industrial sectors because we have these two sources of emissions; one set associated with generating energy for the kilns that operate at over 2500 degrees Fahrenheit and another set that comes from the process of making the cement itself.

So there are pilot plants that exist, that I know of at least, in Canada, and in Germany, and I believe one in China, as well, where they are testing these out but they only occur when there is a significant decision to be able to invest in those things. And basically, a lot of them are very small scale in order to pilot them but in order—it is a fixed cost on top of the production of cement. So in order to really accelerate that there needs to be additional incentives or investment in order for that happen.

Mrs. RODGERS. OK. Thank you for that. I have run out of time. But I think we also should be promoting those policies that are going to encourage carbon capture. I yield back.

Mr. TONKO. Thank you. The gentle lady yields back.

The Chair now recognizes the chair—vice chair of the full committee, Representative from New York, Representative Clarke, for 5 minutes.

Ms. CLARKE. I thank our Chairman, Mr. Tonko, and our Ranking Member Shimkus for convening this important hearing on how we can protect our environment from industrial emissions and increase American competitiveness in the global economy.

We have heard already today greenhouse gas emissions from the industrial sector holds a major challenge to tackling the climate crisis. When you include the energy that industrial facilities purchase from the electricity grid, the industrial sector as a whole is actually the single largest source of greenhouse gas emissions in the United States, larger than each of the buildings and transportation sectors and these emissions are growing. While the emissions from the other sectors of our economy are projected to decrease or stay relatively flat, industrial sector emissions are actually projected to continue increasing over the next 30 years.

But there is good news, too. Many solutions already exist to reduce emissions from certain industrial sources today. And where the solutions don't yet exist, there is still significant room for innovation. Therefore, as we strive towards a 100 percent clean economy by the year 2050, it is important that we continue to think openly and critically about the challenges, so that we in Congress can create the right policies and programs to foster innovation, reduce pollution, and help the U.S. industrial sector lead the world towards a low-carbon future.

My first question is to Mr. Walsh. There are some who would continue to put forward a false narrative that we must choose between the environment and our economy. However, those of us who have studied this know that the opposite is true. By cleaning our economy, we can also increase the competitiveness of our manufacturers on the global stage.

Could you please talk a little bit more about the global marketplace for industrial goods and about the demand for products that are made under cleaner industrial—excuse me—environmental standards. Just how far behind is the U.S. in this regard and what will happen if we do not catch up?

Mr. WALSH. Thank you for that important questions, Congresswoman. Yes, let's talk a little bit about global competitiveness.

I think what we need to recognize is that the rest of the world is already moving in terms of their industrial processes and the policies and investments that support it in a low- and zero-carbon direction.

We are actually lagging behind. There are various ways in which we are doing that. Certainly, the fact that we have withdrawn from the Paris Agreement, or in the process of doing that, the only nation in the world that is, is a significant signal. But as you pointed out, this is not just an issue of equity. It is also an issue of competitiveness.

So we want workers in the United States to be building the products that we know are going to be demanded around the rest of the world, whether that is low-carbon steel or high-efficiency light weight vehicles, or even appliances that have gasses in them with low global warming potential. We have talked mostly about industrial sector emissions. We have talked less about the way in which the industrial sector, if we decarbonize it, can lower embedded emissions in the products that we sell to the rest of the world as well and that includes a range of things from automobiles to appliances, to you name it.

So you know when we talk about global competitiveness, I think your question is really on point because we need to be talking about where this world is going, where markets are going, and where we are falling behind.

Ms. CLARKE. Dr. Friedmann, I saw you somewhat nodding and pointing. Did you want to add to that?

Dr. FRIEDMANN. Yes, absolutely. This is a key question that always comes up is well, how do we think about China and what makes sense because they are a huge source of industrial emissions.

We have to have a better product to sell. We have to have a better technology to sell. We have to have better manufacturing to deliver those. So we actually have to invest in the innovation. We have to build plants and we have to do things like protect the workers in those sites for things like a procurement standard, or a border tariff, or some international partnership. And that is actually how we can drive down emissions in the rest of the world, as well as in the United States.

Ms. CLARKE. As we clean our economy and make our companies more competitive on this global stage, it is extremely important that we create good-paying jobs, especially in low-income, black, and Latinx communities, who continue to suffer most greatly from environmental pollution and economic inequality.

Mr. Walsh, can you ensure, as we work towards a clean economy, that investments are also made into good-paying domestic jobs and that new pathways are created to bring more young people of color into our future of industrial and manufacturing workforce?

Mr. WALSH. Yes, let's start by acknowledging that generations of economic and racial injustice have disproportionately exposed communities of color and low-income communities to pollution, and as well to climate threat.

So they need to be at the front of the line for new opportunities as we build new products and reconfigure our manufacturing sector. I think there are some very intentional ways in which we can do that. In the construction industry, we have seen models that involve community workforce agreements, community benefit agreements, which include local hiring pathways for folks in those communities into the jobs that are being created. We are beginning to see some of that in the industrial sector in automobiles, in particular. I think we need to see more of it.

We also need to be constantly paying attention to the issue of environmental justice. Right? So let's also talk about the importance of regulation. Right? Let's talk about the importance of making sure industrial plants don't blow up which, of course, not only kills or injures workers, it also kills and injures people who live on fenceline communities.

So we need to be weighing both of those.

Ms. CLARKE. Thank you very much.

Mr. Chairman, I yield back.

Mr. TONKO. The gentle lady yields back.

The Chair now recognizes the Representative from West Virginia, Representative McKinley for 5 minutes, please.

Mr. MCKINLEY. Thank you, Mr. Chairman.

Dr. Gregory, I am probably the only one on this panel who has ever written a specification for concrete. I have been writing concrete specs or been involved in it since 1965. And one of the things that pointed out was the fight we had, the contradiction where people wanted to use fly ash as a hazardous material, would not allow it to be used in concrete. Without a doubt, I think you would say we want to continue to use fly ash in concrete.

Dr. GREGORY. Yes. Yes, absolutely.

Mr. MCKINLEY. So we were able to prevail on that. There was quite a fight on that.

But I want to learn from the rest of the panel here on this. I think this concept of being able to get down to zero emissions, it can be achieved. It is going to be very expensive to do that but we can achieve that. But the concern I have is we are addressing America. We are not addressing our competitors.

And we know that Gina McCarthy would come before this panel in years past and she would say, yes, we can do these things. We can lower emissions in America but it won't really make any difference. She said she recognized that what it was going to do to the whole greenhouse gas problem of the globe but she said we are trying to get people to—we are going to lead and the other nations are going to follow.

But it was John Maxwell that said a leader has no followers is merely a man taking a walk. And I am afraid what has happened here in America is we are just taking a walk. We are not getting other nations to follow.

Look at greenhouse emissions over the last 16 years. In America, those emissions, and several of you testified, that America is already voluntarily reducing its emissions by 16 and I think, Eisenberg, you might have even said 21 percent.

We are already making those reductions. But in the meantime, India has increased its emissions by 235 percent and China by 290 percent. They are not following what we are doing. We are putting ourselves at disadvantage.

So what I would like to hear from you is why should we expect any other nation to follow our lead? Why are they going to put themselves at a competitive disadvantage by us making that reduction? Why are they going to adopt that?

Can any of you—Eisenberg, do you want to share on that?

Mr. EISENBERG. So we agree with that sentiment wholeheartedly and that is specifically why we have called for us to reengage on the international scale and get a real good agreement in place that is fair and equitable. And we will make sure that we are not putting ourselves at a disadvantage. It has got to be the backbone of our climate policy.

Mr. MCKINLEY. But how? Don't go 30,000 feet with me. How do we get it? Is it in a trade policy or what are we going to do to get other nations to adopt so we are on a level playing field? Because I am afraid what is going to happen is more and more of our companies, the industrial companies are going to locate or essentially go offshore and outsource their CO2 emissions because it is going to be cheaper to operate someplace else.

Mr. EISENBERG. I mean I think there is a very real concern here and that is why—I mean it is 30,000-foot because we haven't really gone there but we made a lot of progress last time when we engaged internationally. There is more to be made.

We really need to get this right and there is a lot of different ways to go about it.

Mr. MCKINLEY. Give us a policy. How do we adopt—what is a policy that would allow us to be competitive—excuse me—that would force other nations to adopt a standard that we all are producing it under those little missions?

I see your hand up. I just wanted Eisenberg to finish his thought because I wanted something more specific, not 30,000 feet.

Mr. EISENBERG. No, I appreciate that. I won't take too long.

So all countries have to, including all of the major emitters have to agree to reductions. Right? And there can't be this inequity of some countries basically getting a free pass until 2030, 2040, 2050, while we impose stuff on ourselves. It has got to be enforceable. It has got to be transparent. It has to be pro-trade. It has to be innovative. It has to be enforceable by the WTO. I mean these are all things that we are going to need to make sure that that leakage doesn't happen and that we stay competitive.

Aluminum is a good example, right? So——

Mr. MCKINLEY. Go ahead. You seem to have drifted up to 30,000 feet again. I want to hear specifics.

Dr. FRIEDMANN. I have got three discrete policies that can do the job.

Mr. MCKINLEY. OK.

Dr. FRIEDMANN. So those are in my testimony. One of them is a border tariff. This is a topic which is extremely difficult, extremely dangerous, and extremely fraught. I don't say that lightly. But it is an option.

If we had a border carbon adjustment, that would protect U.S. workers in U.S. industries, as long as we decarbonized, and it would advantage us compared to some of those other countries. If they wanted to sell to us, they would have to hit that standard.

Second option, something basic like the Montreal Protocol, where you have a sectoral group working together. We have multiple countries coming together and they all set a standard for emissions for steel. You do that with the EU. You do that with Canada. You do that with Mexico, the United States, you get a bunch of countries together. At that point, they create a market that those other countries can't sell into. Japan, Korea, China, India, they can't enter those markets if they don't hit that standard. So you can either go alone or you can go together.

The third thing is you can just be better. You can just have a better product and that is a combination of procurement and innovation.

Mr. MCKINLEY. OK, thank you. And Dr. Friedmann, I do hope you come back. You seem to be colorful in your presentation. I like your passion.

Mr. FRIEDMANN. I told Chairman Tonko that when I was in government, I hated testifying. Now that I am out of government, I love testifying.

Mr. MCKINLEY. It is a sickness.

I yield back.

Mr. TONKO. We are just so happy you are having fun.

The gentleman yields back.

The Chair now recognizes the gentleman from California, Representative Peters for 5 minutes, please.

Mr. PETERS. Thank you, Mr. Chairman. It has been a fascinating hearing. Emissions from industrial sectors account for over a third of global carbon emissions and just steel, cement, and basic chemicals account for a little more than over half that total.

To me, it sounds like we have got sort of three general challenges. One is an infrastructure challenge. What is the infrastructure that needs to be built out to accommodate these changes? Second, what would a standard look like, a carbon standard that we would measure against? And third, what are the incentives we could get for industry to adopt these things, given that we have very low margin businesses and we have international competition?

Dr. Friedmann, I am going to go you first, at the risk—the one thing we have noticed is, as happy as you are, you are bad at the clock. So I want you to briefly explain to me kind of—you talked a little bit about how there is an advantage that some of these things were located together. There is an implication about infrastructure in that. I would like you to follow-up on what pipeline and transport infrastructure might look like and why that is important to carbon capture and utilization.

Dr. FRIEDMANN. Thank you. I am guilty as charged.

As my testimony says, a massive important option to exercise is building CCUS infrastructure.

Mr. PETERS. What does that mean?

Dr. FRIEDMANN. That is mostly pipelines. Just as one example, though, 28 percent of the U.S. emissions come from Texas and Louisiana in the Gulf Coast, all around those petrochemical facilities. You could get about a third of those emissions, maybe half of them, if you had a pipeline that connected them together and good dedicated storage sites.

Mr. PETERS. So carbon dioxide pipelines—CO2 pipelines.

Dr. FRIEDMANN. CO2 pipelines.

There are other things you can do. Hydrogen pipelines are inevitable. We are going to build those someday. We should think about it. If we want to electrify these things, we are going to have to add high-voltage transmission lines into these facilities, which don't exist today, necessarily, or may not have the capacity. But the big lever is CCUS and that means the big lever is CO2 pipelines.

Mr. PETERS. OK, good.

Let me ask about incentives, what a carbon standard would look like. Dr. Sant, you talked a little bit about that. What would be the metric you are talking about? How would we measure success in this area?

Dr. SANT. So I think there are a couple of ways to do it but I think we really want to look at what is the amount of carbon that is emitted over the course of production of any given material or product that we want to consider. You could consider it for something like cement. You could do it for something like steel.

Mr. PETERS. Would it be per unit? Would it be carbon per unit of cement?

Dr. SANT. Per unit mass, as an example, per pound, per ton, per kilograms, choose as you may.

And the reason that a ranking system of this sort becomes useful is then you can start to take lots of different which are produced, for example, in different places, in different locations, not only in the U.S. but internationally. And then set criteria on what your minimum for, as an example, purchasing might be.

So if you are a private buyer versus the Government that decides to implement a procurement standard, you can actually start to say we will only buy a product if it is at or below a particular carbon efficiency standard. And that turns into a really powerful way of forcing both the public and the private sector to act.

Mr. PETERS. OK, good. Thanks.

And then finally I did—you know, I would like 15 minutes to talk about all these things but I just wanted to touch on what incentives would look like. We talked about incentives for business to adopt this.

Why is Germany doing this, Mr. Eisenberg? Is there a profit in this at some level? What would it be that we would have to do to get businesses to want to invest in this?

Mr. EISENBERG. So it is tough to compare the U.S. and Germany for a couple reasons. One is, obviously, the fuel sources available to us. I mean we have tremendous energy from all kinds of different sources. And so it needs to be a technology discussion first and foremost, rather than you know I mean they don't have all of the natural gas that we have and things of that nature.

But certainly, they have a very top-down approach. They passed a ——

Mr. PETERS. Well, forget about them because we don't want them, but what is it about? What should we be doing, as Congress, to incentivize American businesses to make these investments?

Mr. EISENBERG. So we absolutely believe incentives to work. You know they are not the only way to get there but——

Mr. PETERS. What do you mean by incentives?

Mr. EISENBERG. So——

Mr. PETERS. Because they can be carrots or sticks.

Mr. EISENBERG. So carrots, obviously, would be preferential. Right? There is—you look over time at the different carrots that have kind of worked in the energy space, in terms of electric vehicles, in terms of carbon capture, in terms of different types of energy sources. They do make a difference and they help bridge that gap towards commercialization. They are not the only way to do it. They are a big deal.

Certainly in the energy efficiency space, I think that is really one that, especially in the industrial sector, that we need to focus on. Because at the end of the day, so much of that, as much as and everybody is saying like 50 percent could come from industrial energy efficiency deployment.

Mr. PETERS. I get that.

Mr. EISENBERG. And so changing that math so that——

Mr. PETERS. I have got to write language that says this is an incentive to get your business to invest.

Dr. Friedmann, do you have any ideas on what we might do, as Congress, to incentivize these investments?

Dr. FRIEDMANN. First, create a procurement standard. Second, exercise it. Period.

If the Army Corps of Engineers could buy low-carbon concrete and were directed by Congress to do it, and the standard was written by NIST and other experts like Dr. Gregory and Dr. Sant, then it could just be done. Ninety percent of cement and concrete is bought by governments.

In addition to that, just super quick, the cost for the finished product goes up one percent. Even if you doubled the cost of concrete in the United States, the cost of a bridge goes up one percent.

Mr. PETERS. OK.

Dr. FRIEDMANN. So the actual cost to the taxpayer is relatively light in terms of this but it gets U.S. companies doing stuff. It incents them to have a better product. That is, I think, where we want to go.

Mr. PETERS. OK, thank you.

My time has expired. Thank you, Mr. Chairman.

Mr. TONKO. The gentleman yields back.

The Chair now recognizes the ranking member of the subcommittee, Representative Shimkus, for 5 minutes.

Mr. SHIMKUS. Thank you, Mr. Chairman. I apologize for being absent. I was in another meeting that I had to attend.

But let me go to Mr. Walsh first. As he knows, U.S. Steel Granite City Works was idled in December 2015 due, in part, to pressure from Chinese steel dumping. In January 2017, part of the facility reopened, bringing back about 730 United Steel Workers to the plant. My grandfather worked in this steel mill years ago.

In March 2018, President Trump announced he would impose tariffs after the U.S. Department of Commerce Section 232 investigation and U.S. Steel announced it would reopen the blast furnaces at Granite City and ramp up production soon after.

Over Labor Day this year, workers at the facility were even talking about mandatory overtime. That is good. Regardless of whether one approves of the President's approach to trade or not, nobody can deny that cheap Chinese steel produced under lower environmental standards is a threat to our workers and the climate.

If we impose additional cost on domestic steel production, what do you think would happen to the workers at Granite City?

Mr. WALSH. If it is done well and smartly, which we have been talking about, so in a context where we might be looking at different policies doing something around border adjustments, it could be a win-win.

If it is done badly, of course, we offshore jobs.

Mr. SHIMKUS. Thank you.

Mr. WALSH. There is I think on this full panel absolutely no support for the idea of offshoring U.S. manufacturing jobs.

Mr. SHIMKUS. Right. No and I think that is a major point. We have got to be careful in this debate that we don't offshore these jobs or lower environmental conditions and for workers. So, I appreciate that.

And we would—I mean based upon your answer, you also kind of alluded to this. If we offshore these steel worker jobs and the plants, what would be the net environmental impact?

Mr. WALSH. Bad. Bad because it would be offshored to countries that have lower labor standards and environmental standards.

Mr. SHIMKUS. Thank you. Exactly.

Mr. Eisenberg, thanks for being here. For 20 years I have been talking about new source review. You had mentioned it in your testimony. That is low-hanging fruit, I would say. Why don't we go there?

Mr. EISENBERG. I have been asking the same question. In fact, I testified on it a couple of years ago and asked the same question. This seems like an easy one, right?

You know this has been a barrier, both real and perceived, to the installation of equipment that would be more efficient and would reduce pollution at the manufacturing shop floor. Fixing this program, to cure both the real and the perceived impacts of this would do a lot. And it is just one of the many things that will help us get those things into the line. We think it is so important.

Mr. SHIMKUS. Yes, and for my colleagues, the basic premise is, correct me if I am wrong, you have clean air standards. You maintain those clean air standards, so the boilers and emissions are already under the Clean Air Act. You replace a generator with a more efficient generator. No effect. The emissions are still the same but because of the rules and regs, we have to totally re-permit that facility. So, there is an example of something I believe I wish we would have done years ago.

Mr. EISENBERG. And it opens the door to a much broader look at the facilities, and the processes, and everything else. And so it is just—it is operated as a barrier. When you are kind of working it out and you have to meet deadlines and things like that, more often than not, you are just not going to do it. And that is unfortunate. We need to make sure that they will do those things.

Mr. SHIMKUS. And would you agree, I think the 45Q, what we passed last Congress, that its helpful? I mean the last Congress did. So that is a tax incentive. So that is a positive thing that we have done.

Mr. EISENBERG. Yes.

Mr. SHIMKUS. And then we have not totally finalized it yet, but we are working through the process, it is in the NDA Conference Report—Dr. Friedmann, you are shaking your head—the USE IT Act. Would that be good, and helpful, and low-hanging fruit?

Dr. FRIEDMANN. 45Q immensely important. Passing the USE IT Act would definitely be helpful. Will it actually capture the CO2 from the steel plant? No. The incentives are not large enough. You actually need more on top of that if you really want to go after the emissions. Those are necessary and useful but not sufficient.

Mr. SHIMKUS. Right. Anyone else?

Mr. PERCIASEPE. I just want to add on the 45Q that any encouragement the committee could provide to the Internal Revenue Service to get the rules done so that we can actually implement it, that would be great.

Mr. SHIMKUS. Good. Great.

Dr. SANT. So maybe the one comment to add, you know one of the things that we want to think about is incentives and approaches that really help with ground-up innovation with entrepreneurship. So there is lots that we are doing. We were talking about large manufacturing facilities that are owned by large corporations but, fundamentally, U.S. success started with entrepreneurship that went ground-up.

And I think what is not really incentivized sufficiently at this point is this ground-up innovation and I think there would be tremendous, tremendous value to trying to do that. And it is something that we don't hear spoken about a lot. And in many ways, we count on the venture capital community to do it but, as you can imagine, these are not sectors in which the venture capital community, as an example, substantially invest because long time horizons, lower return on investment, hard problems, regulations. You know you want to think about the problem a little bit more holistically than sort of thinking about really what can only large corporations do but what can small innovators do.

Mr. SHIMKUS. Thank you. My time has expired. I need to plagiarize Bill Gates a little bit more every now and then. I sound smarter that way.

I yield back.

Mr. TONKO. The gentleman yields back.

The Chair now recognizes the gentle lady from Delaware, Representative Lisa Blunt Rochester, for 5 minutes.

Ms. BLUNT ROCHESTER. Thank you, Mr. Chairman and thank you to Ranking Member Tomkus [sic]—Shimkus for holding today's hearing.

This is actually a phenomenal—sorry I called you Tomkus. I see. I see. It is a combination. You are one and I think it is representative of today's hearing.

I have heard some real consistency, which is phenomenal. I also have heard some very consequential things that we can do for our country. So this is a very important hearing and I want to thank our witnesses.

As you all acknowledged, decarbonizing the industrial sector is a challenge but that is exactly why we are here today, to confront those challenges to climate action head-on and to find innovative solutions to overcome them. And in my home State of Delaware, companies are looking for ways to do just that, as was mentioned earlier.

Several of the country's largest chemical companies are based in my State and these companies recognize the need to do the hard work of reducing our carbon footprint. I want to make sure that these companies have the tools they need to reverse that trend and to lead the world in reducing emissions from chemical production.

I am going to start my first question with Dr. Sant. I know that you also recognized how climate action can create economic opportunities, especially the early stage innovators. And I was really glad that you focused on that ground-up innovation. In your testimony, you described the importance of supporting entrepreneurs and researchers who are developing creative solutions for industrial decarbonization.

As Congress considers legislative options to reduce emissions from industry, how can we ensure that policy helps early stage innovators like you and are there certain tools that we at the federal level can provide that would help overcome some of the primary barriers to research development and deployment?

Dr. SANT. So a couple of comments. I think the first high-level comment is really regulative certainty. I think having guidance regarding where the Government is going to go is super helpful.

The second part, procurement standards. Again, super helpful because they give you targets of what you really want to fulfill.

The third thing to point out is, in some ways, this is a space in which there is a little bit of a gap between very early stage research and sort of commercial full maturity application. And so I think we need quite a bit more funding to sort of flesh out the gaps.

As I say, in one role as a university professor, you know there are programs that you can go to. Of course, they need to be quickly expanded, potentially by an order of magnitudes and by substantial amounts of money. But that kind of support exists and we have a mechanism for putting it into place.

I think where we don't have as much support is being able to translate technologies from that very early stage. There is something that industry can actually start to look at, take on, and do something useful with. And I think that is something that we really need to work on fleshing out.

Ms. BLUNT ROCHESTER. One of the solutions that I am looking at that would include a revolving loan fund that would provide capital for energy efficiency upgrades. Would that be helpful to early stage innovators?

Dr. SANT. My first guess is probably not because early stage innovators don't have a need for funds of that sort. It is also the same reason why you can't really explore a tax credit.

Ms. BLUNT ROCHESTER. Right.

Dr. SANT. I think what you need for this very early stage innovation is actually direct grants, direct support that actually helps to get things off the ground.

Ms. BLUNT ROCHESTER. Great. Thank you.

And Mr. Perciasepe, in your testimony you discuss some of the ways that chemical manufacturers are developing more environmentally friendly chemical production—chemicals production. Can you please elaborate on the opportunities for low-carbon chemicals production in the United States?

Mr. PERCIASEPE. There are a lot of chemicals that are made and, in many cases, there are no greenhouse gas emissions from those chemical reactions but sometimes there are.

And so almost every chemical company, DowDuPont, for instance, are looking at those. What kind of catalysts they use in the reaction where you have this chemical and this chemical and you put it through some catalytic reaction or some heated reaction to create the third chemical. I am being very simplistic here. My organic chemistry is failing me.

And I mentioned one in particular, polypropylene, that was being looked at for reducing the emissions that are coming from it by using different kinds of reactors. And this is all kind of green chemistry and innovation. And it is the area of, I think, the greatest challenge but also the greatest opportunity in the industrial sector.

I mean we look at the carbon capture. We know we get these emissions. Let's capture it. We need to do that. We need to innovate on that. And we know that the electricity and the heat, we have to find ways to do that in a different way or capture that. But the chemical processes, whether it is making—taking——

Ms. BLUNT ROCHESTER. I only have 5 seconds left.

Mr. PERCIASEPE. I am sorry.

Ms. BLUNT ROCHESTER. Friedmann, you have got three seconds.

Dr. FRIEDMANN. University of Delaware has a world-leading program on turning CO2 into chemicals and plastics. For them to get funding the way that Dr. Sant needs it, there is two bills in front of Congress now, the CITA Act and the EFFECT Act. Both of those would create authorities within the Department of Energy, hundreds of millions of dollars to fund that kind of work.

Ms. BLUNT ROCHESTER. Fantastic. Thank you so much.

And I yield back.

Mr. TONKO. The gentle lady yields back.

The Chair now recognizes the very patient Representative Long for 5 minutes.

Mr. LONG. Thank you, Mr. Chairman.

And my friend, Ranking Member Shimkus, has been quoting Bill Gates all morning and I am sitting here thinking about Jed Clampett and his cement pond. That is the difference between Missouri and Illinois.

Dr. Gregory, in your testimony, you referenced the use of alternative fuels as an easy way to reduce emissions in the cement production process. In the United States, only 15 percent of fuel comes from these alternative sources, compared to the more than double that in the European Union.

Can you explain why these alternative fuel sources would reduce emissions?

Dr. GREGORY. Yes. Basically, the use of alternative fuels goes back to that heating the kiln that I mentioned, over 2500 degrees Fahrenheit. Usually, we use fossil fuels, coal, and in some cases, natural gas because we need it to get that hot. The alternative fuels are often biomass or waste materials, like scrapped tires, and essentially those are the types of alternative fuels. The limitations usually are about concerns about clean air but, as you mentioned, in other countries they use significantly more because the type of incineration that is done in those can still generate that energy from the waste materials, while maintaining clean air.

Mr. LONG. Thank you, kindly.

Then to my next question: How does federal policy discourage the use of these fuels and how could environmental laws be reformed to promote their use?

Dr. GREGORY. It is exactly that, trying to amend acts like the Clean Air Act and also RCRA to basically better allow for increased use of these alternative fuels in cement plants.

Mr. LONG. And in your opinion, is this the easiest way to reduce carbon emissions in the cement industry? And how much of a reduction of carbon emissions would we see if the amount of alternative fuels we use rises to the level of the EU?

Dr. GREGORY. This is one of the low-hanging fruits. We can definitely get increased emissions reductions associated with these alternative fuels. Like I said, at a global level, there has been some estimates that we can increase reductions by about ten percent, and so which is definitely significant and something that we should go after.

Mr. LONG. There would be a ten percent reduction in carbon emissions?

Dr. GREGORY. Yes. Yes. Yes, carbon emissions.

Mr. LONG. Mr. Eisenberg, your testimony references the need to modernize the electric grid and make use of smart grid technologies. More broadly speaking, how do the new digital technologies drive innovation and lower greenhouse gas emissions and can this be achieved without new government regulation?

Mr. EISENBERG. So there is a lot of new technologies out there. The grid, which was traditionally a one-way thing, a one-way highway, right, from the power plant to the end user, it is now becoming much more of a two-way street, where we have things like demand response and a lot of these new technologies that allow the user and—the user to become a producer, and you can have things like microgrids, and things like that that really change it.

You know there is a lot of ideas, some that involve government involvement, some that involve the private sector. I don't know whether there is one perfect approach here but it has unquestionable greenhouse gas emissions reductions benefits.

DOE found that you could eliminate 277 million at 359 million tons of CO2 per year by upgrading this grid and allowing those new technologies the access that they need.

Mr. LONG. OK. Unless anyone else needs my time, I will yield back.

Mr. TONKO. The gentleman yields back.

The Chair now recognizes the gentleman from Florida, Representative Soto for 5 minutes, please.

Mr. SOTO. Thank you, Mr. Chairman.

You know I want to talk about sorting out fact from fiction here. You know we have heard a lot of comments today. First, the facts that climate change is, in part at least, human-caused and it is an existential threat to humanity. Another fact is that our chairman has set out a goal of getting to net zero-carbon dioxide emissions by 2050.

In addition, another fact is that we are going to have hearings from the fall through early winter to develop a plan by the end of 2019. I thank all of you here, as our panelists, to help us with that.

And another fact, we are open to all of the above strategy on this ambitious net zero-carbon dioxide goal by 2050.

Some fictions: That this committee is not prepared to work to develop bipartisan solutions. Another fiction is that we have already ruled out nuclear or carbon capture. These are things that we are prepared to work together on.

Many of you have said that innovation is key. So I would like to know, by a show of hands: How many of you believe the Trump administration's elimination of California's fuel emission standards hurts innovation by a show of hands?

So there is many ways we could do that. I know that is not exactly manufacturing, although obviously auto manufacturing is a big part of our manufacturing base.

I would like to start with Mr. Eisenberg. You know we have had some staff information point out that in 2015 the Department of Energy estimated that adopting high-efficiency technologies could reduce energy consumption in the industrial sector by as much as 32 percent by 2025. They gave some ideas: One, installing advanced motor systems, high-efficiency boilers, and smart manufacturing; and two, using combined heat and power systems.

Could these technologies, and others, assist in getting us to a 32 percent reduction?

Mr. EISENBERG. They absolutely could. They can be effective. We have just got to get the math right, and make sure that manufacturers have the incentives and really the opportunities to put them in place, and have the payback be good.

Mr. SOTO. Thank you.

And for Dr. Sant and Dr. Gregory, it would be great to hear. Our staff has mentioned that by switching to low-carbon fuel stocks and feedstocks, such as the electrifying industrial process could reduce both direct and indirect emissions by switching to hydrogen or biomasses of fuel or feedstock, for the industries that you all are studying—oh, and as well—yes, excuse me. For the industries you all are studying, is that feasible going forward as part of a plan for 2050?

Dr. SANT. So a couple of comments to point out. In general, switching to alternative fuels is beneficial but it is not trivial because, in many ways, it requires changes around how we actually handle solid waste and how we actually categorize solid waste prior to combustion. That is comment number one.

The second comment that goes with it is a lot of the process that we look at, which withstand, as Julio put it some time ago, trying to burn and melt rock, it is not terribly trivial to switch processes from a fossil fuel source to a renewable source. It is not out of the question but we are not close to doing it.

That being the case, running a cement kiln electrically is not trivial because you are trying to produce 10,000 tons of cement a day.

Mr. SOTO. Dr. Friedmann——

Dr. SANT. Oh.

Mr. SOTO. Last sentence, then, I have got to switch.

Dr. SANT. I think when we think about these things, we want to take an economy-wide perspective to how we actually manage carbon. It is not sufficient to just look at heat, or power, or a single process.

I will close with that, sir.

Mr. SOTO. Thank you.

Dr. Gregory.

Dr. GREGORY. Yes. Yes, I wholeheartedly concur. To get to that 2500 degrees Fahrenheit, you really right now have to do it with fossil fuels. There is our people looking at how you can do that through electrification but it is not employed anywhere in the world because it is so difficult.

So alternative fuels are sort of a short-term step that can be used until that type of technology or the hydrogen technology can be employed.

Mr. SOTO. And Dr. Friedmann, I know there was a discussion here among our staff about that carbon capture utilization storage may be a more cost-effective way in some subsectors for, they reference, ammonium production to get the biggest reduction as quickly as possible for CO2 emissions. Would you agree with that?

Dr. FRIEDMANN. A hundred percent.

Mr. SOTO. And lastly, for Mr. Walsh, you know we saw a decline in jobs in steel in the '70s and '80s because we didn't embrace new technologies. Is this a juncture where embracing new technologies will actually make us more competitive over the next 10 to 20 years?

Mr. WALSH. Yes, in addition to avoiding bad trade policy.

Mr. SOTO. Thanks so much.

I yield my time back.

Ms. BARRAGÁN. [presiding]. The gentleman yields back.

The Chair recognizes Mr. Mullin for 5 minutes to ask questions.

Mr. MULLIN. Thank you, Madam Chair, and thank you to our witnesses for being here.

I want to circle real quick to the follow-up with trying to generate 2500 degrees with electricity. Have we even ran the numbers of how much that would take, what kind of power we are talking about here, Mr. Gregory—or Dr. Gregory, if you want to answer that?

Dr. GREGORY. Yes. There are people who have done sort of theoretical studies on how this could be done.

Mr. MULLIN. So they have measured like how many kilowatts this is going to take?

Dr. GREGORY. Yes and I don't know it off the top of my head and I can definitely get you those numbers on those studies but it is——

Mr. MULLIN. Well, I kind of figured we would have to start with that because we would have to figure out is it feasible when we start talking about how many furnaces we are going to be heating.

Dr. GREGORY. It is a question of economics.

Mr. MULLIN. Is it even—I mean when you start talking about wind power and solar power, how are you going to generate that? How much is that going to take off the electrical grid to be able to do that? I don't—I am just a country boy from Oklahoma but I have sure worked with a lot of boilers. I have my boilers license and I have installed a ton of them. I just don't think it is feasible. I just don't know how you get there.

Dr. GREGORY. In the short-term, it isn't and that is why it is not being adopted.

Mr. MULLIN. Well, already to take all the fossil fuels off our grid, according to the studies that we have already seen, it would take a wind farm the size Texas to replace it. Is that correct?

Dr. GREGORY. I haven't seen that specific one but it is—it is a lot of electricity.

Mr. MULLIN. It is a lot. And now you are going to be adding everything else on to it. I just—and we are not even factoring in heating our boilers up to 2500 degrees with electricity.

I mean we all want clean air and clean water but we have got to do it in an economic-responsible way, too.

With that being said, we are talking about a lot, Dr. Gregory, talking about cement plants. And we know that we have moved to roughly 15 percent of our plants now are using natural gas instead of coal because coal has been the main source for a long time. I am not against coal. I am truly all of the above energy, as long as we do it in a clean way.

What is prohibiting the rest of them to move to natural gas? Is it the accessibility? Is it the price? I mean natural gas is pretty cheap right now. What is it that is prohibiting the other plants from moving?

Dr. GREGORY. Both of those; having access to natural gas and then also just the investments associated with it.

Mr. MULLIN. Access, meaning just to the pipelines?

Dr. GREGORY. Like getting natural gas to the plant.

Mr. MULLIN. And so it is the pipelines.

Dr. GREGORY. Yes, absolutely.

Mr. MULLIN. The permitting process.

Dr. GREGORY. Yes.

Mr. MULLIN. Because there is a lot of areas around the country right now they would love to be able to sell their gas.

Dr. GREGORY. Yes.

Mr. MULLIN. But without the infrastructure to do so, this would be very difficult.

And I think you mentioned a while ago that we, just by switching from coal to natural gas, you are going to affect roughly ten percent of our—I mean a reduction of ten percent of the CO2 emissions. Is that what I remember you saying or am I——

Dr. GREGORY. I was talking about different alternative fuels that can be used——

Mr. MULLIN. OK.

Dr. GREGORY [continuing]. Like the scrapped tires and things like that. I would expect that it would be a similar order of magnitude in terms of——

Mr. MULLIN. So how does that work? I heard you mention scrapped tires. So how does that work? I mean I have seen a few tires burn, and maybe on brush piles, or something like that once or twice in my life, and they are pretty black when they are burning. So how do you make that clean if you can't make coal clean?

Dr. GREGORY. It helps that you burn at 2500 degrees. Basically, that takes care of a lot of bad stuff when you are burning it that high.

Mr. MULLIN. But you have got to get it to 2500 degrees first, right?

Dr. GREGORY. You do and that is why you don't see any cement plant that is doing 100 percent scrapped tires. Right?

Mr. MULLIN. It is kind of tough.

Dr. GREGORY. And in the U.S. there is a maximum of about 15 percent. In Europe, it is about 35 percent maximum.

Mr. MULLIN. So you have got to get it to 2500 degrees before you throw the first tire on it, right?

Dr. GREGORY. Absolutely, yes.

Mr. MULLIN. So that would take a fossil fuel of some sort.

Dr. GREGORY. Yes. Yes.

Mr. MULLIN. And once again, I am not opposed to clean energy at all. I am just saying it is feasible. It is fun that we put out these goals of 2050 and we want to knock the President for saying guys, we are not listening to California; they don't set the standard for the rest of the world. And we can say yes, it is going to cut innovation. That is an easy question because it does, when you have California go out there and make these emissions, it does force people to start getting there. But if it is not feasible, if the technology is not there, the regulation can't outrun the technology. It is not there yet.

And I know we want to incentivize them to do it but we do. We incentivize by creating an environment for them to do that. We don't do that by regulating businesses out of business along the way.

Dr. GREGORY. Absolutely.

Mr. MULLIN. With that, I will yield back.

Thank you guys so much.

Ms. BARRAGÁN. The gentleman yields back.

The Chair now recognizes Ms. Schakowsky for 5 minutes to ask questions.

Ms. SCHAKOWSKY. So I have to tell you my heart is pounding over this very high-level conversation because I am not hearing the sense of urgency about this.

You know the United States of America has known about climate change since the Johnson administration. And I am hearing about incentives and I am hearing about making progress but we are really and truly running out of time.

There is a 16-year-old that is over at the Supreme Court right now, Greta Thunberg, who some know from Sweden, who made an important address to the United Nations and is now leading young people. She is 16 years old. A lawsuit, the Juliana suit, that says that young—this is 21 young people who are suing the Government of the United States of America for knowing about climate change and doing nothing about it.

Now I just heard from my colleague saying well, if we don't provide these incentives—look, carbon emissions went up worldwide. They went up in the United States of America. We are not making progress. We are actually going backwards. And it is shameful that we are not sensing what young people are feeling, which is the sense of urgency.

So I do have some questions. So we have been hearing for decades this issue, Mr. Walsh, this false claim that somehow tackling climate change will be a job-killer. We are hearing it today.

As someone who has worked closely with unions all your life, how would you respond to that argument?

Mr. WALSH. Well, I think it is a strawman. I think we can both create quality jobs and preserve a livable planet at the same time.

And what we have been talking about today—and by the way, we share your sense of urgency, which is why it is so important to be focused on the industrial sector now because the lifespan of a lot of this capital equipment is so long.

But we can do both. This is not a false choice but we need smart policy. We need to support strong innovation. And we need to deploy. We have talked a lot about innovation but, at the end of the day, we are going to have commercialize these technologies.

Ms. SCHAKOWSKY. OK but you know what? My sense of innovation is when there is regulation, industry responds and finds a way to do it.

And I would like to ask you, Mr. Friedmann—Dr. Friedmann, is it? Have you not talked about a carbon tax?

Dr. FRIEDMANN. I have not talked about a carbon tax. Part of the reason why is because there aren't actually carbon tax. Our analysis shows that it is helpful. It is in my testimony it is helpful but, actually, this sector is insensitive to a lot of carbon tax regulation.

If you actually had a $50 a ton carbon tax, it wouldn't be enough to actually decrease the emissions from these facilities.

Ms. SCHAKOWSKY. So it would be helpful?

Dr. FRIEDMANN. Probably with some stuff, like the efficiency bits, you probably get. But even a substantial, a high carbon tax is only one part of the solution set that you need.

Ms. SCHAKOWSKY. So what are some of the other parts?

Dr. FRIEDMANN. Well, if you want urgency, I have spent the last 20 years of my career trying to keep CO2 emissions out of the air and oceans. We have this technology said today that works. It is called carbon capture storage. The best place in the country to do it is Texas. The second best place in the country to do it is Illinois. In fact, you can capture the CO2 for those facilities and put them underground.

We already have a beginning with the tax incentives but we actually need things like pipelines to take the CO2 from the Great Lakes District and move them down to Central Illinois, where you can store the CO2.

We actually know everything we need to know about this, except for how to get financed.

Ms. SCHAKOWSKY. So——

Dr. FRIEDMANN. And that is actually where we think policy will be most important.

Ms. SCHAKOWSKY. I mean it just seems to me that this idea of we somehow have to woo industry, at long last, to do what they need to do to come up with innovation is a too late strategy. The time has come for us to take incredibly strong action.

Does anyone else want to comment on that?

Mr. PERCIASEPE. Well first of all, you are correct. But one thing I do want to point out to the committee is many of us on this panel have been to many hearings about what do with electricity, what to do with automobiles and transportation. This is the first time I have ever come before the United States Congress to talk about this very complicated issue of this remaining amount of emissions in the industrial sector that are very complicated.

Now we get those other two going with different kinds of electric vehicles. We know how to decarbonize electricity with nuclear, and carbon capture, and renewable energy but this sector is something that hasn't been talked about enough and I appreciate the fact that we are doing it.

It is not urgent enough to just talk about it but it, to me, it is a move in the right direction for the United States Congress to even have a hearing on this particular issue.

Ms. SCHAKOWSKY. Well it is a pathetically small effort and I am for it. And I appreciate all of you being here today but the talk is not going to solve the problem. And any of the ideas that you have that we have heard today could be very useful.

Thank you and I yield back.

Ms. BARRAGÁN. The gentlewoman yields back.

AThe Chair recognizes Mr. Flores for 5 minutes of questions.

Mr. FLORES. Thank you, Madam Chair. And I want to thank the leaders of this subcommittee for hosting this hearing today.

As I mentioned during our last hearing in July, we haven't always celebrated how the U.S. is leading in terms of emission reductions. And to correct the record from the last person who was asking questions, the EI has recently put out their forecast that carbon emissions in the U.S. are going to decline again in 2019. So we are making progress in this regard but it has been through innovation and market forces that have gotten this done, not government mandates or taxes. Innovation is the greatest contributor to our emissions reductions, which have been significant.

As we continue to dramatically reduce our emissions, the U.S. has been able to retain the world's largest, and fastest growing economy, and a significant creator of jobs and economic opportunity. So instead of new taxes or mandates to decarbonize in some sort of a chaotic fashion, our climate policy should adapt on things that work, like innovation, conservation, adaptation, and resiliency. Unleashing these innovations at home will continue to ensure that not only do we maintain economic growth balanced with a healthy environment, but more importantly, we can export these technologies, and as we are leading the can-do spirit to contribute to growing energy demand in developing countries abroad.

And today, I am glad we are talking about the industrial sector. This is a sector which is responsible for numerous modern conveniences, from the roads we drive on, to the buildings we live and work in, down to fertilizers that farmers use to feed families around the world. This sector, however, faces unique challenges, as almost all of you laid out in your testimony and I want to thank you for sharing those with us today.

Now for our questions. Dr. Gregory, are there any technologies currently under development, which would greatly reduce or eliminate emissions from Portland Cement—the Portland cement manufacturing process?

Dr. GREGORY. Yes, there is basically four different ways that you can lower emissions from cement production. One is through CCUS that we have discussed. Another is through the use of blended cements, which are kind of a lower carbon alternative of cement. A third is the use of alternative fuels. And the last is increasing the energy efficiency within the cement plants.

Mr. FLORES. What would the—this is a little bit of an abstract question but what would the Green New Deal do to U.S. cement manufacturing and jobs?

Dr. GREGORY. You know, at least for me, that is a little bit of a hard question to ask because I think there is a lot of large or high-level ideas but it is hard to know exactly how that is implemented. There is kind of different ways in which it could go.

It is certainly, like Mr. Walsh mentioned, that it certainly is possible, I think, to create more jobs associated with green materials but it has to be done in a way such that we ensure that the standards associated with those materials really can be done in this country, right, and it doesn't lead to leakage that happens in other countries where they don't have those same standards.

Mr. FLORES. Well, I think it is safe to assume that a dramatic increase in energy prices or a curtailment of energy availability would dramatically cause the export of our cement manufacturing to overseas locations.

Dr. GREGORY. It is certainly one potential option but it, as we have heard, you know a lot of concrete is actually purchased by governments. And so that is certainly one way to start out is to make sure those governments make decisions that are consistent with our values.

Mr. FLORES. And continuing with you, Dr. Gregory, you mentioned the fact that concrete and other industrial processes have the need for high-temperature heats sustained over long periods of time. There have been—we have talked conceptually here about electrifying that process, which I think is a good direction to go. The challenge is where does the electricity come from. What produces the electrons?

And so Mr. McNerney from California and I introduced a bill that passed the House last week to create new fuels for next-generation reactors because, at the end of the day, nuclear energy is the only zero-carbon, zero emissions source of baseload power that we have. You can't get it from wind. You can't get it from solar.

So would this be promising technology to pursue to accelerate the decarbonization of the industrial sector?

Dr. GREGORY. Yes, I actually happen to work very closely with colleagues at MIT in the Nuclear Science and Engineering Department, who just published a Future of Nuclear Report that speaks exactly to this potential.

One of the things we have talked about is basically how today's nuclear energy is not your parents'——

Mr. FLORES. Exactly.

Dr. GREGORY. —or grandparents' nuclear energy. There are a lot of opportunities to do it in a much more innovative fashion using small modular reactors where, basically, the price is a primary focus, making sure that price of nuclear is competitive with other energy sources.

Mr. FLORES. Right.

Dr. GREGORY. So it is a significant opportunity.

Mr. FLORES. I would like to supplementarily ask you or to ask you to supplementarily respond with a question about what are the challenges to get wind and solar to do the same thing that we could do with next-generation nuclear.

And so that gives me a second to ask one final question. Are there other ways to sequester carbon, to sink carbon, other than CCUS. And that is open for the panel.

So Mister—I can't pronounce your name.

Mr. PERCIASEPE. That is all right. If they could just put Bob up there, you would be OK.

Mr. FLORES. Bob. OK.

Mr. PERCIASEPE. Well I think there are a lot of different ways to capture the carbon. Sometimes you can change the process—the carbon dioxide. Sometimes you can change the actual process of like running a turbine so that the exhaust that comes out is actually relatively pure carbon dioxide, so you don't need to have some chemical process to capture it. And then what you do with it can be sequestration in the geology. We have been using it for enhanced oil recovery to reuse old oil wells.

Mr. FLORES. Right.

Mr. PERCIASEPE. And there are many—you know we talked earlier about building materials and actually using it to make fuels.

Mr. FLORES. Dr. Gregory, and try to keep your answer short, if you can.

Dr. GREGORY. Sure.

Mr. FLORES. I am at the forbearance of the chair here.

Dr. GREGORY. Absolutely. We have heard several options for taking carbon and putting it back into building materials. Binders are actually only like ten percent of concrete. Aggregates are much heavier and present, actually, a larger source of opportunity to store carbon that can be used in asphalt, and concrete, and all kinds of things.

Mr. FLORES. OK.

Ms. BARRAGÁN. The gentleman's time has expired. The gentleman yields back.

Mr. FLORES. Thank you.

Ms. BARRAGÁN.

The Chair now recognizes the gentleman from California, Mr. McNerney for 5 minutes of questions.

Mr. MCNERNEY. I thank the Chair. I am going to thank the panel. Your testimony has been very informative and I appreciate that. There is an effort that goes into this.

And we hear a lot about innovation but, Dr. Friedmann, would you say that innovation and regulation go hand-in-hand?

Dr. FRIEDMANN. Before I answer that question, as a proud citizen of Livermore, California, I have been a long-time fan of yours, Congressman.

Mr. MCNERNEY. Well, thank you.

[Laughter.]

Mr. MCNERNEY. I want my time back. Go ahead.

Dr. FRIEDMANN. That is between me and my spin doctor.

It is often helpful to have a combination of carrots and sticks. Part of the reason that I am enthusiastic about procurement is that it provides a market signal that drives the innovation. Part of the reason that I am enthusiastic about things like the EFFECT Act, and CITA, and increased appropriations for national labs, and for universities is because that stimulates that kind of innovation.

I think if you try to make it just regulatory, it is harder to get that innovation out but, sometimes when well-crafted and well-exercised regulation can provide the appropriate focus to drive new innovators to new ideas.

Mr. MCNERNEY. Thank you. Well, in a highly competitive global marketplace, it is essential that we view any policies from a global perspective. The last thing we want to do is see American jobs ship overseas and increase in carbon emissions. Some of the countries seem to be able to manage that balance.

Mr. Walsh and Dr. Sant, can you have recommendations on stuff to craft American policy to make that balance between emissions and jobs?

Dr. SANT. Sure. So I think two comments. The first one, I think, really going after the carbon efficiency standards is an important thing to go after. In effect, it lets you do more with less. It is exactly what we do with energy efficiency, as an example, and I think that is something that we have to follow.

I think that the second comment is something which Julio touched on not very long ago is really border data adjustments. I think the moment you signal globally that it doesn't matter where you produce but if you bring a product into the U.S. and sell it in the U.S. market, there is a natural adjustment that happens that is based upon a U.S. standard. This is the easiest way to get rid of any sort of complexity that comes from where a product is purchased.

Because I think it is clear that in the world of today, material flaws are interlinked and that means that where you sell should determine the rules you play with.

Mr. MCNERNEY. Thank you.

Mr. WALSH. I want to echo what Dr. Sant said about border adjustments. We talked about procurement and the purchasing power of the Federal Government. I just want to be specific that we have an example from your State of California, Julio's State of California, it is called Buy Clean. It is using the purchasing power of the State government on infrastructure projects to identify the global warming potential of structural steel and some other basic building blocks of infrastructure projects in the State. That is a model that we can build on and use in other States but, most importantly for the purposes of this conversation, at the federal level as well.

Mr. MCNERNEY. Thank you. Doctor, you said something that intrigued me, that we need more performance-based specifications than prescriptive specifications. Could you talk about that a little bit?

Dr. GREGORY. Sure, yes. Usually, when concrete is specified by engineers, including perhaps Mr. McKinley who is no longer here, but basically they are very specific about like the amount of cement that needs to be used. We are actually usually putting limits on what we call supplementary cementitious materials, like fly ash from coal-fired power plants or slag from seal. And they limit those because of concerns that exist, maybe at one point, about durability or the performance of the concrete.

It turns out a lot of those prescriptive specifications that are very specific, a lot of people don't remember why they were put in place, so they don't have justification for them. So instead of saying here is exactly how you make the concrete, say this is what we are looking for in terms of strength, durability, stiffness, et cetera, and then require a test to basically demonstrate that you can meet those.

And that is exactly the type of thing that I think if you implement like a Buy Clean Act, you need those types of things to go hand-in-hand with it because not all concrete is the same. Different mixtures are different.

Mr. MCNERNEY. Very good. Thank you.

Mr. Perciasepe, I appreciate your comments about trade exposure. I think that has sort of been fleshed out a little bit here, the trade adjustments but we need to have standards in the United States before we can start imposing trade adjustments, border adjustments. Wouldn't that be the case?

Mr. PERCIASEPE. Yes. Obviously, you would be trying to protect you know some exposed part of the industrial sector and this is where most of it comes. When you do climate policy, it is going to be in the industrial sector. It has to actually have a requirement that may, and I want to point out that it is always possible some of these process we are talking about could reduce the cost of making some of these things.

But if it is a trade exposed, then it does have unique increased costs and there is an importation of products that are not meeting those standards. That is where you put the border adjustment on so that you—I am being very simplistic here. It can get very complicated very quickly.

Mr. MCNERNEY. In a 5-minute thing, you don't have time to be more than simplistic. Thank you.

I yield back.

Ms. BARRAGÁN. The gentleman yields back.

I see nobody on this side.

The Chair recognizes the gentlewoman from California, Ms. Matsui for 5 minutes to ask questions.

Ms. MATSUI. Thank you very much, Madam Chair, and I thank the witnesses for being here with us today so we can discuss options in what is considered to be one of the most difficult sectors of our country to decarbonize.

While decarbonizing the industrial sector may seem daunting, I look at policies and initiatives championed in my State of California and take hope in that the State has paved the way and we all know that proposing and testing out solutions that are already making a difference in emissions and how industries are designing their operations.

As you may know, the State of California has, for the past nine years, under the Low Carbon Fuel Standard, which sets an average carbon content for fuels to decline annually. One of the leading contributors of emissions in the industrial sector, petroleum refineries, is a regulated party under the LCFS. The LCFS has been successful in incentivizing refiners to switch operations to produce biofuels and other alternative fuels and has introduced and expanded the use of cleaner alternatives for fuel consumption.

Mr. Perciasepe or Dr. Sant, can you describe the benefits in terms of emissions reduction we see in expanded use of low-carbon or zero-carbon fuels in the industrial sector?

Mr. PERCIASEPE. Well, in the industrial sector, unlike some of the transportation fuels——

Ms. MATSUI. Right.

Mr. PERCIASEPE [continuing]. In California, there is a lot of opportunity. I mean we were talking about the extremes earlier of 2500 degrees——

Ms. MATSUI. Right.

Mr. PERCIASEPE [continuing]. Which is very hot, warm even. But there are lots of thermal needs in industry that are a lot less temperatures that can be converted to electricity, as an alternative to using a fossil fuel.

Ms. MATSUI. Sure.

Mr. PERCIASEPE. And if the electricity is coming from a decarbonized electric system, then you have got the impact.

So it is like many things we deal with in these complicated issues. It is never binary. It is neither this or that.

Ms. MATSUI. Right.

Mr. PERCIASEPE. But the extremely high temperatures, we have to find alternative ways to do it——

Ms. MATSUI. Sure.

Mr. PERCIASEPE [continuing]. That we are not quite sure yet. But the lower temperature—the lower heat temperature——

Ms. MATSUI. We have already got options.

Mr. PERCIASEPE [continuing]. We got ideas.

Ms. MATSUI. OK, great.

How important do you think nationwide price on carbon, such as cap and trade, is to reduce the emissions from the industrial sector, Dr. Sant or——

Dr. SANT. I think it is fundamentally important. I think it is something that we have to be able to do, to have a nationally-agreed upon price.

The reason I say this is you know a couple of comments. Of course, California has been tremendously progressive. We have done some remarkable things and we continue to do so.

I think looking nationwide, you want to have consistency. And so you don't want to again have, like I say, two sets of standards——

Ms. MATSUI. Right.

Dr. SANT [continuing]. One for California and ones for elsewhere. And so having consistency in pricing helps industry plan for what they are going to do across the nation.

Ms. MATSUI. So you think it is economically feasible for the industrial sector across the country to do this more broadly, is what you would like to see.

Dr. SANT. In principle, it is, absolutely. No question. It is also where the world is headed. So I think it behooves us to do it.

That being the case, I think we need to be thoughtful about how we approach it.

Ms. MATSUI. OK. Cleaning up our industrial sector means adopting, as we said, all of the above approach, including considerations to how our Federal Government sources materials for buildings, infrastructure, and government equipment. This is all the more timely, as conversations around a robust infrastructure package continue.

California has passed and begun implementing the Buy Clean California Act, which requires the State to take into account the supplier's emissions performance when contracting byproducts, such as steel, flat glass, and mineral wool for infrastructure products.

Dr. Friedmann, you mentioned in your testimony the importance of procurement standards in decarbonizing our industrial sector. What percent of cement, concrete, and steel is bought by our Federal Government?

Dr. FRIEDMANN. If you look at all governments, federal, state, and local governments, they buy 90 percent of cement and concrete.

Ms. MATSUI. Wow. OK.

You allude to a well-designed zero-emissions by clean standard. Can you expand on what well-designed means? What considerations should be taken when developing such a standard?

Dr. FRIEDMANN. First, as others have testified, we actually need to create a performance-based standard for the stuff. If, in California, Caltrans can't buy clean concrete and cement because they are required by law to buy Portland Cement.

Ms. MATSUI. Right.

Dr. FRIEDMANN. So until they exercise their performance-based standard, they can't do it. Caltrans has been working it for a while but that is like step one. It can't enter the market until that is done.

Step 2, life cycle analysis. This is something both Dr. Gregory and Dr. Sant have also mentioned. You have to really make sure that you are doing the job and that you are tall enough to go on that ride.

Ms. MATSUI. OK.

Dr. FRIEDMANN. And then third, you actually have to buy it. And I have advocated for a while sort of a ratchet which grows. So you start with a fairly small volume—one percent, two percent.

Ms. MATSUI. Yes.

Dr. FRIEDMANN. You have groups like the National Academy or NIST work to try to figure out what that is but then you increase ambition over time. By 2025, it may be two percent but by 2030, it may be twenty percent. And you do that based on how the manufacturers can deliver the stuff. You don't ask for more than they can make but you set a market signal and you drive it up.

Ms. MATSUI. OK, fine. Thank you very much.

And I have already run out of time. So thank you very much. I yield back.

Ms. BARRAGÁN. The gentlewoman yields back.

The Chair recognizes Mr. Ruiz from California for 5 minutes to ask questions.

Mr. RUIZ. Thank you for holding this hearing on this important topic and thank you to our panel for being here today.

Our world is sick, showing symptoms of climate change that can lead to disastrous consequences for human food, security, water consumption, and safety from extreme natural disasters. I care deeply about climate change because I have seen the human toll, the suffering that will only get worse as people who lose their homes and their loved ones from wildfires. And the people who are most vulnerable are those who are not rich enough to move or build another more secure home elsewhere.

This week, climate activists around the world will be making their mark to raise the alarm and demand climate justice for everyone. And I agree with that sentiment and their efforts.

Sixteen-year-old Greta Thunberg has picked the consciousness of an entire planet and pushed a call to action. And this committee must answer that call to action with real policies that lead to real changes to reduce our dependency on fossil fuels through a clean economy for a clean environment. We must do it for my twin daughters, for our children, our grandchildren, and their children, for our public's health, and our nation's security.

And we are already witnessing and living the negative effects of climate change in increasingly more dramatic ways. For example, in my district, in California's 36th District, drought has crippled our water supply for years. Increased heat and dryer environments have led to more intense and frequent wild fires in our mountain forests. Extreme rains have led to expensive infrastructure damage requiring federal disaster aid, even Joshua Trees. At our beloved Joshua Tree National Park, the iconic symbol of desert life may go extinct due to rising temperatures.

America, California especially has been a leader in replacing harmful fossil fuels by pioneering new technologies that harness natural resources, including wind, solar, and hydrogen for everything from homes to transportation. For example, some SunLine Transit in my district uses buses that run on clean hydrogen. Homes and schools are powered by wind farms and solar panels that use nature's awesome power without threatening our ozone.

Clean energy is the future, the antidote to climate change that we must work towards as a country. A clean energy future is attainable and essential and the time for talking is over. The time for action is now.

One sector that plays a key role in reducing carbon emissions is heavy industry. Steel, concrete, and other materials are literally the foundation of buildings and roads, and they essential to our economic success. So how can we reduce the carbon output of the manufacturing sector, while protecting good-paying jobs? Well, we must develop and deploy new technologies that help the manufacturing sector further reduce their carbon footprint.

This is where the value of international agreements comes in. We must hold other countries accountable through international climate agreements. This is why withdrawing from the Paris Agreement hurts our efforts to reduce climate change. This is why the U.N. Summit on Climate is such an important opportunity. Without a global agreement, other countries will continue to burn fossil fuels without any obligation to invest in new technologies. In fact, we have heard from several of you today on how other countries, like those in the Southeast Asia, are increasing their coal and fossil fuel emissions. We have also discussed how we can ensure that American companies don't lose out while making an effort to reduce emissions.

With that in mind, I would like to dig further into how we establish that advantage for U.S. companies.

Dr. Friedmann, given that our goal is to help the industrial sector achieve a competitive advantage, what is the best way for Government, academic research institutions, and industry to work together?

Dr. FRIEDMANN. As I said in my testimony, procurements, innovation, infrastructure investments. We need to actually have a government analytical function so that we can make sense out all this stuff. But if you want to even just find facts on these topics, it is hard to do.

And then last, we actually do need to have international agreements and partnerships on this exact topic because this is all bound into international trade.

Mr. RUIZ. Dr. Gregory, as an expert, you have watched these technologies evolved. What is the best way to make sure that newly developed technologies are deployed in a timely and efficient manner?

Dr. GREGORY. It has to—there has to be market demand for them. And one of the best ways to do that is through procurement policies because there is so much government purchasing of concrete.

Having said that, we need to make sure that the engineers are also interested in specifying these low-carbon materials. So we need to ask for their performance and also for their carbon footprint as well.

Mr. RUIZ. Thank you.

Ms. BARRAGÁN. The gentleman yields back.

The Chair now recognizes myself for 5 minutes to ask questions.

First of all, I thank the witnesses for being here today. I want to thank you, Mr. Walsh, for your testimony about bringing up the issue of frontline communities, and communities of color who are disproportionately impacted by the pollution that is happening and by what we are seeing happening on climate.

I happen to represent one of those districts. It is a district that includes the Port of Los Angeles in South L.A. It is about almost 90 percent Latino-African American. It is a district where it is low income. It is minority. There is industry there. There is manufacturing and, of course, the port. And on top of all that, we are surrounded by three freeways.

And so when you talk about air pollution and you talk about negative health impacts, my communities are often seen with inhalers around their necks, and doctors' offices pack these inhalers for the children. It is heartbreaking to see.

And so we are seeing across the country a call, a demand for action climate. In my own community, I see it day in and day out because of the health impacts and because of what is happening with the planet.

And so one of the things that we have talked about today has been very helpful talking about procurement and the different ideas here. You touched a little bit about a just transition. And I would like for you maybe to expand a little bit on that.

When drafting policy and legislation, what can we put in that to make sure that we are not leaving communities behind, like my district? And I think the second part of that is, and I think you mentioned this as well, is that they should be first in line, and they should get priorities, and if they don't, they won't be able to participate in a clean economy.

Mr. Walsh?

Mr. WALSH. Thank you for that very important question and for putting a really fine point on the fact that we are not just talking about climate here. We are talking about health and health as it affects particular communities.

I think with respect to just transition, we also need to acknowledge that neither the impacts, in terms of environmental pollution and climate change, are felt disproportionately by particular communities and particular people.

There are also, as we transition away from certain fossil fuels, like coal impacts, in that transition away in coal communities, for example, that are not spread evenly across the country. They are hitting eastern Kentucky or southern West Virginia.

So I think a first order of business is just being very clear about where impacts are being felt and who is being impacted, and targeting Federal investment, particularly in this respect, economic and workforce investment, both to make sure that we are taking care of workers and providing opportunities to workers to get into new jobs created.

It is also about community revitalization and economic diversification. You have to be very targeted about that as well. We don't always have the ability to target with broad scale federal programs. There are regionally-focused programs we used quite a bit, like the Appalachian Regional Commission, to target investments. I think we need to do a better job to get those investments to districts like yours.

Ms. BARRAGÁN. So one of the things I hear back, I get pushback on, is well, that is great, we are going to train people for cleaner jobs but then the jobs won't be there.

Is that accurate? Is that the choice?

Mr. WALSH. I think we have to be careful about not over-promising anything. I certainly have been guilty in the past of probably doing a little bit too much green jobs evangelism, even though I think these are an important opportunity.

But we are more interested now in making sure we develop very concrete pathways into those jobs. There are specific ways we know work. We know registered apprenticeship programs work. We know pre-apprenticeship programs that get folks from low-income communities, and communities and workers who have been underrepresented, in the construction trades, as an example, into those registered apprenticeship programs, so that we are not just creating jobs; we are creating career pathways and careers for those folks.

Ms. BARRAGÁN. Thank you.

You know one of my colleagues earlier said that he was unclear why we set goals and that you know when California sets goals and standards that are different than the rest of the country, it is not feasible for business.

I happen to disagree with that. I happen to think that when you set goals, when you set bold and aggressive action and milestones, it does force people to come up with innovation quicker. It forces Congress to come up with incentives quicker.

In California, in particular, and especially today with what is going on with the administration and the rollback on the fuel standards in California, I think that we actually have the industry, the car industry saying don't do this. And so to hear that it is not feasible for industry, you actually have industry saying no, wait a second; don't roll these back.

And so I just wanted to take a moment to disagree on the record and say that there are benefits. When you set goals, when you set milestones, sometimes it gets Congress to act quicker. Sometimes it gets companies and industry to act quicker.

In this instance, I think that seeing the positive benefit of what is happening to the clean air and the cleanup of pollution in California is happening.

Mr. Walsh, I can give you three seconds.

Mr. WALSH. I just wanted—you make an important point. I also want to add a jobs point.

By the Federal agencies' own analysis, not only when the current administration proposes to roll back fuel economy standards, not only are we having a pollution impact, we are actually losing jobs. They estimate that 60,000 fewer jobs will result from their rollback of fuel efficiency standards because we are investing in a whole set of new technologies that create those jobs.

Ms. BARRAGÁN. Thank you, Mr. Walsh.

And with that, I yield back.

The Chair recognizes the gentle lady from Michigan, Mrs. Dingell, for 5 minutes of questions.

Mrs. DINGELL. Thank you, Madam Chair.

A hundred percent clean economy by 2050 may be ambitious but we have to get there. And since you both closed on the subject of California, I think I will start there.

I am probably as angry as anybody at the announcement that was made today by the President when every single car company asked him not to do it. And he has rolled back. He has created uncertainty. He is putting this in the courts for years to come. It is taking capital away from investment needs to be done to get the newer technologies.

I want to ask Mr. Perciasepe and Mr. Walsh: What is the ultimate impact of the President's decision today to revoke California's fuel emissions waiver as it relates to our efforts to reduce emissions? I will start with Mr. Perciasepe and let Mr. Walsh go next. Yes.

Mr. PERCIASEPE. So I think what you pointed out, Congresswoman, that the automobile industry, by and large, wants to continue making the fuel-efficient cars that it has been making, my expectation, at least in the near-term, is that they will continue to do that, regardless of what the Federal Government does in the current situation. And then while they continue to do that, on top of that, there will be a lot of litigation.

But I think in the near-term, the long-term may be different but, in the near-term, the automobile industry, as you well know, is four years ahead of what we are doing. Right? What it is doing now, it was working on four years ago. And what it is going to be doing four years from now, it is working on now and it is not going to stop.

Mrs. DINGELL. The industry is not going to stop but it could——

Mr. PERCIASEPE. The industry is not.

Mrs. DINGELL. I don't want to answer my own question. I want the experts to give us the answer.

Mr. PERCIASEPE. That is what I would guess.

Mrs. DINGELL. Mr. Walsh?

Mr. WALSH. BGA issues a report which found that clean car standards and the consistency of those standards helped drive investment of over $63 billion in facilities across the country in 100 factories.

So to my earlier point, this is a jobs issue. When you see that level in investment, you are also creating and sustaining automotive jobs. When we take away that standard, when we create regulatory uncertainty, we freeze investment and we lose jobs.

Mrs. DINGELL. So let me ask you this again, both of you: How will instituting strong fuel economy standards, or what President Obama was trying to do, help with year-to-year increases, help us achieve that net zero that we are trying to get to by 2050? And is permanent damage being done to that goal in the transportation sector?

Mr. PERCIASEPE. Well, the concept behind the performance standards over a period of time, and these standards only went to 2025——

Mrs. DINGELL. That is correct.

Mr. PERCIASEPE [continuing]. So we need to be—we are into 2050. But to 2025, they kept reducing the average of emissions. It is actually a performance standard, grams per mile of greenhouse gases, even though we say CAFE. And so that declines over time to a point where the translation was to somewhere near 50 miles per gallon on average.

Now that has a significant reduction in those vehicles that are sold in 2025 in the amount of greenhouse gases they produce on an annual basis. But of course, this is all related to how many miles somebody drives, and all this other stuff, but you are looking at the average.

I think, as I just mentioned, and I believe, in the near-term, in the next couple of years, the automobile industry will continue to sell the kinds of cars that they were programmed to make.

Mrs. DINGELL. At least some of them are.

Mr. PERCIASEPE. Yes.

Mrs. DINGELL. Let me ask you—I am not going to have you answer that question because I am down to a minute. What does this do to the electric vehicle? Which I frequently get asked by some young people why are you so focused on the electric vehicle.

Mr. Walsh, anybody who wants to answer this: Are we correct the electric vehicle is key to getting to a carbonless, or a non-gasoline, or engines, other forms, there are other forms that are being done? And are we doing enough in the transportation sector to get to where we need to go, instead of—or do you think we are going backwards instead of forward?

Mr. WALSH. Well, today we are going backwards.

Mrs. DINGELL. Yes, I agree.

Mr. WALSH. But electric vehicles are absolutely essential to decarbonizing the transportation sector, as long as we also continue progress in decarbonizing the power sector as well.

Mrs. DINGELL. And are we doing—well, we all have to work together to do that, which you have all talked about.

Now, I am down to four seconds, so I can't——

I guess I yield back my zero seconds.

Ms. BARRAGÁN. The gentlewoman yields back.

The Chair now recognizes Ms. DeGette from Colorado for 5 minutes for questions.

Ms. DEGETTE. Thank you so much, Madam Chair.

As we have heard, some industrial processes release carbon dioxide, not only as a result of the energy they use but also because it is a byproduct of the chemical processes involved and, as we heard today, cement manufacturers are a good example of this.

So even if we completely decarbonize our energy production and use, we would still need to have carbon capture utilization and storage to keep the emissions from these industries from getting into the atmosphere. And we also know that we are going to have remove existing carbon dioxide from the atmosphere if we are going to keep global warming at the goal of below 1.5 degrees Celsius.

So I think that the U.S. is in the best position to develop these technologies. And I want to ask you guys some questions about these issues. I guess we can just go down the line.

The first question is: Do you agree that the United States needs to make a major investment in the development and deployment of technologies that capture, utilize, and store carbon dioxide from a wide variety of energy and industrial sources, as well as from the atmosphere?

We will start down here.

Mr. PERCIASEPE. Yes, it is an essential tool that needs to be in the climate change battle toolkit.

Ms. DEGETTE. You bet.

Dr. GREGORY. Yes. And, as you mentioned, cement and concrete has this unique opportunity where the carbon can be captured and then used again to make new cement and concrete.

Ms. DEGETTE. Right. Right.

Dr. Sant?

Dr. SANT. Unquestionably, yes, but I think we need to really focus on cost reductions in these technologies——

Ms. DEGETTE. Right, as part of the development because it has to be marketable worldwide.

What about you?

Mr. EISENBERG. Yes and we may not be able to do without them, as well.

Ms. DEGETTE. OK.

Dr. FRIEDMANN. My Twitter handle is CarbonWrangler.

Ms. DEGETTE. So your answer is yes?

Dr. FRIEDMANN. The answer is hell, yes.

Ms. DEGETTE. OK, thanks.

Mr. Walsh?

Mr. WALSH. Yes.

Ms. DEGETTE. So are we on track, do you think—and we already have a sense of the answer to this but are we on track to deploy and develop these technologies at scale right now? I think we probably can get agreement on this, too.

Mr. PERCIASEPE. We are not on track. We need more to go.

We talked about 45Q, which, obviously, many members have been involved with. We need to get the IRS to get the regulations and the rules done so we can actually implement it. And we need some thoughtfulness from the Congress on infrastructure to help move carbon after it has been wrangled.

Ms. DeGETTE. Thank you.

Dr. GREGORY. 45Q actually, it doesn't specifically apply to cement plants. So actually having programs specifically for cement plants would be more beneficial.

Ms. DeGETTE. Great.

Dr. SANT. Yes, what we are doing would be but we need to do a lot more. And I will go so far as to say we need to step up our investments in these areas by an order of magnitude, at least.

Ms. DeGETTE. OK.

Mr. EISENBERG. Agreed, we need to do more.

Ms. DeGETTE. Yes, Dr. Eisenberg—Mr. Eisenberg.

Mr. EISENBERG. Agreed. We need to do more.

Dr. FRIEDMANN. We need more investment. We need more incentives. We need more innovation on all of it, especially on CO2 removal.

Ms. DeGETTE. And Mr. Walsh?

Mr. WALSH. We need to do more, particularly in industries where the CO2 is more low-purity. We have a lot of opportunity for high-purity. CO2 ammonia has been mentioned but in steel and cement, these are low-purity sources. We have got to reduce the cost of carbon capture.

Ms. DeGETTE. Right.

Mr. WALSH. We do that through R&D, and innovation, et cetera.

Ms. DeGETTE. Aside from some of the things that this panel has said we need to do, the infrastructure, the R&D, and so on, are there other things that Congress and the Federal Government could be doing to develop and deploy these technologies at scale? Anyone.

Mr. PERCIASEPE. I will start very quickly.

Ms. DeGETTE. OK.

Mr. PERCIASEPE. Think of a layer cake and you have layer after layer of incentives for different technologies and then you have got to put an icing on the cake. The icing on the cake would be a price on carbon.

Ms. DeGETTE. OK.

Dr. GREGORY. Just practice what you preach, in terms of the Government's construction that it does. You know make the choices to low-carbon materials for those practices.

Ms. DeGETTE. That is a good point.

Dr. SANT. I think public-private partnerships, which start form the innovation stage and work towards commercialization would be really attractive.

Mr. EISENBERG. We need a single unified response here. I mean we have a really good opportunity here today to actually kick that off and move towards some federal unified response that captures all of these things. It really is important.

Dr. FRIEDMANN. I will gladly send you my last four congressional testimonies on exactly these subjects with the policy recommendations.

The most important number one thing to get going today, the infrastructure.

Ms. DEGETTE. Yes.

Dr. FRIEDMANN. If we had the pipelines in place, we would have more projects today because 45Q would help. It already helps but it is not enough without the pipelines.

Ms. DEGETTE. Right.

Mr. WALSH. As we make investments on infrastructure on other deployment pathways, it is absolutely essential that we have prevailing wage standards, other kinds of labor standards, and buy American provisions, and make sure that the jobs we are creating are U.S. jobs and high quality jobs.

Ms. DEGETTE. And that they are good jobs. Great.

Well, wonderful job, everybody.

I am now happy to yield back and I appreciate your unity on these answers.

Ms. BARRAGÁN. And the gentlewoman yields back.

As the Chair, I request unanimous consent to enter the following documents into the record: letter from Rebecca Dell, Industry, Strategist at the ClimateWorks Foundation; Climate Action Report from ArcelorMittal, the largest steel producer in the world; report entitled Mission Possible: Reaching Net-Zero Carbon Emissions from Harder-to-Abate Sectors by Mid-Century; two reports from C2ES entitled Decarbonizing U.S. Industry and Carbon Utilization: A Vital and Effective Pathway for Decarbonization; statement from the American Iron and Steel Institute; fact sheet from the Fertilizer Institute.

Without objection, so ordered.

[The information appears at the conclusion of the hearing.]

Ms. BARRAGÁN. And I would like to thank all of our witnesses for joining us at today's hearing. Very informative. I am a firm believer this should be a bipartisan issue, where we come together. And this committee has been able to do that on issues. I am hoping we can do that here.

I remind Members that pursuant to committee rules, they have ten business days to submit additional questions for the record to be answered by our witnesses. I ask each witness to respond promptly to any such questions that you may receive.

At this time, the subcommittee is adjourned.

[Whereupon, at 12:48 p.m., the subcommittee was adjourned.]

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17 September 2019

Chairman Paul Tonko
Subcommittee on Environment and Climate Change
House Committee on Energy & Commerce
2125 Rayburn House Office Building
Washington, DC 20515

Ranking Member John Shimkus
Subcommittee on Environment and Climate Change
House Committee on Energy & Commerce
2322 Rayburn House Office Building
Washington, DC 20515

Dear Chairman Tonko and Ranking Member Shimkus:

Thank you for the opportunity to provide this statement for the record on your upcoming hearing on "Building a 100% Clean Economy: Pathways to Net Zero Industrial Emissions," to be held tomorrow, 18 September 2019. I work for the ClimateWorks Foundation, a nonprofit 501(c)(3) organization working to solve the climate crisis and ensure a prosperous future.

While I welcome the opportunity to discuss any part of path toward industrial decarbonization, in this letter, I will focus on the following points:

(1) We cannot reach our climate goals without making significant progress on reducing industrial emissions.
(2) There are a number of affordable options already available to reduce industrial emissions starting immediately. The most important thing that government policy can do is to create markets where businesses can be successful by reducing industrial emissions.
(3) Simultaneously, we should invest in research, development, demonstration, and deployment of the technologies that can be commercialized over the coming decade.
(4) The success of all of our efforts rests on a foundation of national technical capacity and clear and transparent emissions accounting, so we must invest in making these available to everyone.

Addressing industrial emissions is not just sensible environmental protection. It is also an opportunity for American businesses and workers to develop technologies, skills, and practices that will be in wide demand around the world in the coming decades, and to renew the American manufacturing and construction sectors.

(1) We cannot reach our climate goals without making significant progress on reducing industrial emissions.

Direct emissions from industrial facilities in the United States are about a fifth of total emissions. If we include the indirect emissions from generating electricity consumed by industrial facilities, that number rises to about a quarter. If we also include the imported industrial emissions generated in other countries while manufacturing products that were consumed in the United States, that portion rises to a third of national emissions. The trends in these emissions are shown in the figure below. Unfortunately, the flat or declining industrial emissions within the United States are more a result of offshoring of manufacturing activity than of success in reducing the emissions intensity of our economy.

Given these high emissions, it will not be possible to prevent the worst impacts of climate change unless we make significant and rapid progress on reducing our industrial emissions. Fortunately, this can be very cost effective.

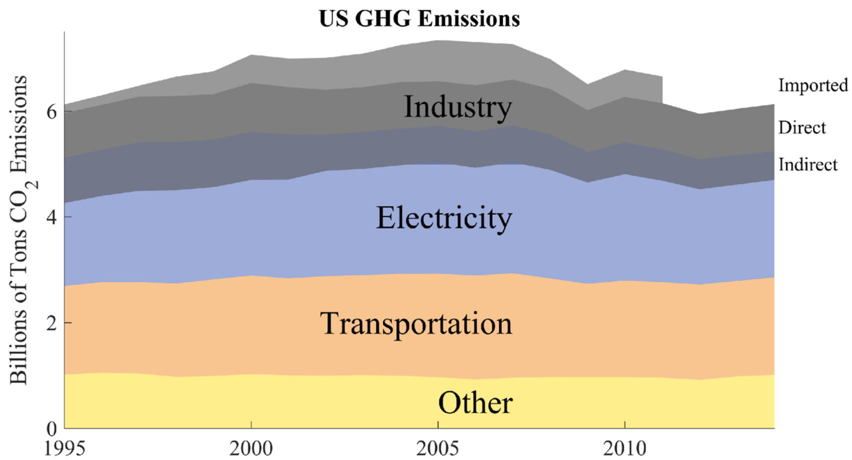


Figure. U.S. national GHG emissions. Note the imported emissions have not yet been calculated for recent years and are omitted. Sources: EPA (2019), International Energy Agency (2017), Organization for Economic Cooperation and Development (OECD) (2016).

(2) There are a number of options already available to reduce industrial emissions starting immediately. The most important thing that policy can do is to create markets where businesses can be successful by reducing industrial emissions.

Industrial emissions are heavily concentrated in a small number of commodity processing industries, especially petrochemicals (largely fertilizer and plastics), refining, steel manufacturing, cement making, pulp and paper, and aluminum. Efforts to reduce industrial emissions should likewise be concentrated in these sectors. In order to reduce these emissions, we can make changes at the industrial facilities. We can also make other changes throughout the economy to increase the amount of valuable services that these materials provide and so decrease the need for new materials. By reducing the amount of material needed to make a given product, improving recycling and high-value material recovery, and increasing the utilization rate of our products, we will reduce industrial emissions. These types of options are often called 'material efficiency,' in analogy to energy efficiency.

There are usually few technological barriers to improving material efficiency. In addition, there are a number of emissions-reducing technologies that are ready to be deployed, but have not been because of a lack of market signals. Examples of things we could do immediately with existing technology to substantially reduce industrial emissions include:

- Typical commercial buildings use 50% more structural material than is required to comply with the already safety protective building codes. By optimizing the design and construction, we could substantially reduce demand for structural steel and cement.
- Today only about 10% of plastic is actually recycled, and often the recycled products are very low value. Plastic packaging could be simplified to allow for easier and higher-value recycling.
- The U.S. uses the most GHG-intensive cement in the world. We could modify the way we mix cement and concrete, using formulations widely used around the world and by many state Departments of Transportation, and both reduce GHG emissions and improve the durability and performance of the concrete.
- Carbon capture and storage could be used as a retrofit at existing industrial facilities or integrated into the design of new industrial facilities, using widely deployed technologies like amine scrubbing. Retrofits will likely be able to capture 30-50% of GHG emissions from facilities, but new builds could capture much higher rates.

None of these interventions would require new technologies, and each of them would reduce our industrial emissions by potentially tens of millions of tons of CO_2 per year. None will significantly increase the cost of the products involved. The reason that we have not done any of them is that there do not exist markets where businesses can make a profit by doing them.

The most important thing that federal policy can do to reduce emissions in the industrial sector is to create those markets. This could be through:

- *Administrative actions*, like creating low-carbon procurement requirements for federally-funded construction projects;
- *Regulatory actions*, like setting a GHG intensity standard on carbon-intensive types of products or limiting the range of plastic types in disposable packaging; and
- *Fiscal actions*, like creating a production tax credit for industrial commodities like hydrogen gas (H_2) in analogy to the wind power production tax credit, or a contract for differences for the cost difference between high- and low-emissions production.

It is so important for federal policy to focus on creating markets for low-carbon commodities for three reasons:

(1) Businesses cannot make investments in lower-carbon production—including building or upgrading facilities, hiring and training workers, and developing new products—unless they are *confident that markets will exist for those products*. Many lower-carbon materials are more expensive, especially as we are learning how to best produce, use, and dispose of them. No one will take the risk and expense of retrofitting a cement kiln with CCS unless they know they can get a premium price for the cement it produces. Commitments through public procurement systems are one of the most powerful ways to provide that confidence, and the public sector purchases half of the cement and a sixth of the steel in America.

(2) By focusing on market creation, we *eliminate the competitiveness concerns* that many previously discussed policies raise. We are not putting any requirements on American businesses that offshore businesses could avoid, as might happen with a carbon price or direct regulation of the emissions of domestic facilities. All producers regardless of location access the markets for low-carbon products and processes that we can create, so there's no risk of undercutting by non-compliant competitors. Additionally, domestic producers would have the advantages of lower transportation cost, greater understanding of the markets, and easier compliance with domestic requirements. In many industries, like steel, U.S. producers are already considerably cleaner than the global average.

(3) Most importantly, from the perspective of the final consumer, the cost of reducing emissions from the industrial sector is negligible. For example, if it costs $100 per ton to capture and store CO_2 from a hypothetical cement plant, that would almost double the costs at the plant—very hard to afford. However, it would only add $500 to the cost of a single-family home or $10 million to the cost of a $1 billion bridge. The final consumer can afford the costs of decarbonizing much more easily than the original commodity producer. By focusing on market creation, we ensure that the costs of decarbonization go to the people best able to afford it.

By creating markets that reward low-emissions ways to make and use carbon-intensive products, we will improve our environment, get useful new technologies deployed, drive costs down, and ensure that American workers and businesses are not put at a disadvantage. We do not have to choose between solving climate change and a prosperous economy.

(3) Simultaneously, we should invest in research, development, demonstration, and deployment of the technologies that can be commercialized over the coming decade.

At the same time as we create markets to deploy the options we already have, we should be working to develop new technologies that can come online over the next decade. These include both zero-carbon production pathways for key materials—steel, cement, plastics, ammonia, aluminum, paper—and much better recycling pathways for these materials. Each subsector will require its own innovation and commercialization options. These might include:

Steel	**Cement**	**Chemicals**
Hydrogen reduction	Electric kilns	Carbon-free H_2 gas
Direct electrolysis	High capture rate CCS	Chemical recycling
Copper separation in recycling	Prefabrication and precision molding	Electric process heat
		Plastic sorting and control
New CCS production pathways	Low-clinker mixes	CO_2 separation
	Alternative chemistries	

An appropriate innovation program for the industrial sector should include activities from the lab to actual deployment of first-few-of-a-kind facilities. It should be in partnership with the industries in question and include strong components for developing technology roadmaps and providing technical assistance to both firms and subnational governments to ensure that the new technologies are actually taken up. Sufficient investment would be at the scale of at least several billion dollars per year for innovation activities, with more needed for deployment. To appreciate the urgency of these activities, consider a typical investment timeline for a large piece of industrial capital. If a company decides today that it is serious about building a new steel mill using hydrogen reduction, it would be followed by a front-end engineering study that would typically take two years, followed by more detailed design and engineering, a final investment decision, contracting, and construction. That means a priority project with no major technological hurdles might come online in seven years. To reach our climate goals, we need to be ready for widespread deployment of near-zero emissions technologies starting in 2030, so the early projects need to be approved in the next couple years.

When we look out over the coming decades, we can see that the options available to reduce industrial emissions change over time. We can improve operational efficiency at existing facilities, shift production to higher-performing facilities, and start substituting lower embodied emissions materials immediately. Over the next couple years, we can create niche markets for low-carbon materials and products. Over the next five to ten years, we can deploy the first few of a kind of new process technologies, retrofit existing facilities, and significantly improve our waste recovery and recycling systems. It will take ten to twenty years for the lessons of material efficiency to really penetrate into architecture, engineering, and product design and to start widespread deployment of new process technologies. We need to begin all of these processes immediately.

(4) The success of all of our efforts rests on a foundation of national technical capacity and clear and transparent emissions accounting, so we must invest in making these available to everyone.

Expertise and high-quality information are the foundation of any successful endeavor and public goods with enormous spill-overs. Currently, as a nation, we have a severe shortage of these for low-carbon industrial systems and engineering. There is a clear federal role to invest in these public goods with activities like:

- Training and technical assistance funding in all clean industry innovation activities. These should include workforce development, training for the relevant skilled trades, and training for engineers, designers, and scientists.
- Improved public data sets on industrial facilities and their key assets, relative performance of U.S. and international facilities, and the cost and performance of various technologies.
- Improved modeling of the industrial sector within existing energy models like DOE's National Energy Modeling System (NEMS), to include all relevant technologies, material flows between sectors, and material efficiency interventions.
- Improved calculations of consumption-based U.S. GHG emissions.
- Public and validated methodologies for accounting for the embodied emissions in significant products like buildings and vehicles. These must include facility-specific emissions information for all relevant materials, as there is enormous variation in the environmental performance of different facilities making the same product. These also must include appropriate verification, so the methodologies can be used for government activities by federal, state, local, and tribal agencies.

Without high-quality people and information, all of our other efforts cannot succeed.

In conclusion, the industrial sector is essential to meeting our climate goals, we have good options for reducing industrial emissions today an in the future, and there is a clear role for the federal government in supporting the knowledge, information, technologies, and markets to make that happen. If we design our policies correctly, this effort can increase the competitiveness of American firms and the strength of our manufacturing sector.

Sincerely,

Rebecca Walsh Dell, PhD
Industry Strategist
ClimateWorks Foundation


ArcelorMittal
Climate Action
Report 1
May 2019
"Our ambition
is to significantly
reduce our
carbon footprint."

"Central to a successful transition will be supportive policy to ensure a global level playing field, access to renewable energy at affordable prices and access to finance."

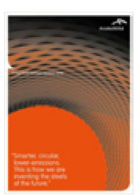
Contents

About this report

This report outlines the analysis behind ArcelorMittal's strategy on climate action, summarised in its Integrated Annual Review 2018. As such it is the company's first comprehensive response to the recommendations of the TCFD for climate disclosures. It reflects the views of the ArcelorMittal group in May 2019. Data on ArcelorMittal's carbon emissions are for financial years up to and including 2018. All financial values given in dollars are US dollars, and those given in Euros are where funding has been received in that currency.

Our reporting

Our portfolio of corporate reports aims to engage stakeholders on material aspects of our financial and non-financial performance. In addition to our statutory requirements, we publish an Integrated Annual Review and a Fact Book containing in-depth data on our business. Our Basis of Reporting explains the methodology behind our metrics, and our Reporting Index references a range of different frameworks we use in preparing our reports. These reports can be downloaded from annualreview2018.arcelormittal.com



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Fact Book

Reporting Index

Basis of Reporting

Annual Report

20F

Introduction from our Chairman and CEO

Our work on low-emissions technologies underpins our ambition to significantly reduce our carbon footprint by 2050 in line with our commitment to the Paris Agreement.

Dear stakeholders,

Welcome to ArcelorMittal's first Climate Action report. We are publishing this because we understand the enormity of the climate challenge for society and the responsibility of ArcelorMittal as an emitter of CO_2 to reduce our carbon footprint. We also acknowledge the interest of our stakeholders in understanding how we plan to do so and the requirement for additional disclosure in line with TCFD.

In December 2015, world leaders adopted the Paris Agreement, which aims to keep the global average temperature increase to well below 2ºC and pursue efforts to hold the increase to 1.5ºC. Clearly, success will require unprecedented levels of coordination on a global level. There are no borders in the sky, so every region and country will need to make a meaningful contribution.

The industrialisation of the world has been powered by fossil fuels. In the steel industry this has involved using coal-based products, such as coke, to reduce iron ore in the blast furnace. While steel may have a lower carbon intensity than many other materials, the large volumes of steel produced globally mean that the industry emits over three gigatons of CO_2 annually.

Now that the unintended consequences of using fossil fuels have become clear, the world needs to find a new way of doing things that enables further economic and social development while minimising environmental damage. Steel is prevalent in our society because it has a combination of properties that make it ideal for building much of the infrastructure we need. As the world continues to develop, with an increasing population aspiring to achieve improved living standards, demand for steel and materials generally is only expected to further increase. Indeed, our forecast indicates demand rising from 1.7 billion tonnes in 2018 to 2.6 billion tonnes in 2050.

This means we need to significantly reduce the carbon footprint of steel, which requires finding new ways to make steel in a less emissions-intensive process. Scrap, unfortunately, is not a sufficient answer as there is not enough scrap available in the the world to simply make all steel through the electric arc furnace process.

So, we need to develop breakthrough low-emissions steelmaking technologies. We are working on the technologies for several potential pathways including circular carbon and clean power, and these underpin our ambition to significantly reduce our carbon footprint by 2050. We are in the process of running pilots of these different technologies at various plants in Europe, where regulation today is most advanced, and where we have an ambition to reach carbon neutrality by 2050. This work will enable us next year to publish a more specific 2030 reduction target.

The suite of technologies we are developing gives us confidence that we are well positioned to align with the science-based trajectory for our sector. But we cannot solve the problem by ourselves. Central to a successful transition will be supportive policy to ensure a global level playing field, access to renewable energy at affordable prices and access to finance. The dynamics of the global steel industry need to be fully understood, and support provided at levels similar to those which have enabled the growth of renewables in the energy sector.

This report does not have all the answers because we do not yet have all the answers. But as the world's leading steel company, we are committed to the objectives of the Paris Agreement and I want to reassure our stakeholders that we will do our best to contribute effectively to a low-carbon world and, in doing so, help them manage their own risks and ambitions.

Lakshmi N. Mittal,
Chairman and Chief Executive

May 2019

1 Our climate action at a glance

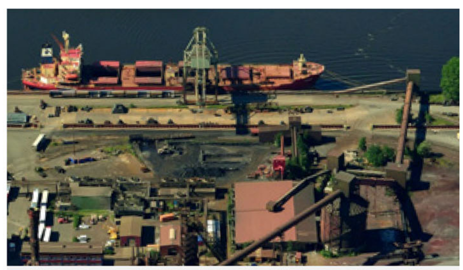
ArcelorMittal's readiness to advance the low-carbon economy can be seen throughout its operations, from the breakthrough technologies it is demonstrating to the solutions it offers its customers.

Circular carbon technologies

In 2018, we launched a €40 million Torero demonstration project at Ghent, Belgium, to convert 120,000 tonnes of waste wood into biocoal for use in iron ore reduction in place of fossil fuels. The technology has the potential to work with a variety of society's waste streams. We've also been running an industrial pilot of IGAR technology in Dunkirk, France since 2017 to reform waste carbon gases so they too can be reused for iron ore reduction. Both technologies will reduce the amount of coal and coke needed in the blast furnace and lower associated CO_2 emissions.

At our steelworks in Ghent, Belgium, we are building a €120 million industrial-scale demonstration plant for technologies developed with LanzaTech[1] to both capture carbon offgases and convert them into the Carbalyst® range of products. Capable of producing 80 million litres of ethanol per year, this project alone has the potential to annually reduce CO_2 equivalent to 600 transatlantic flights.[2]

See chapter 5



Clean power technologies

ArcelorMittal is exploring iron ore reduction technologies using hydrogen and electrolysis, both of which could deliver significant carbon reductions if powered with clean electricity. In March 2019, we launched a €65 million pilot project in Hamburg, Germany to test hydrogen steelmaking on an industrial scale, with an annual production of 100,000 tonnes of steel. At the same time, we have been exploring direct iron ore reduction using electrolysis for a number of years. We lead the EU-funded Siderwin project, which is now constructing an industrial cell to pilot the technology.

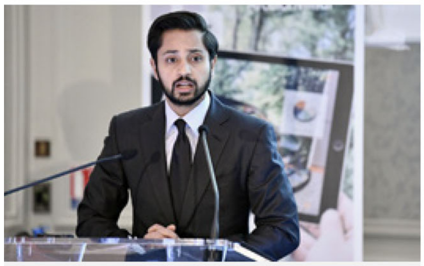
See chapter 5

2050

Carbon ambition

Our ambition is to significantly reduce our CO_2 emissions by 2050 and, in Europe, to achieve carbon neutrality by this date, in line with the objectives of the Paris Agreement and the science-based trajectory for our sector. Supportive policies will be central to achieving this ambition. We are building a strategic roadmap based on potential improvements and our suite of breakthrough technologies, and in 2020 we will set a 2030 reduction target.

1 This project is also known as Steelanol.
2 https://corporate.arcelormittal.com/news-and-media/our-stories/capturing-and-utilising-waste-carbon-from-steelmaking



Green border adjustment

ArcelorMittal has been publicly calling for a green border adjustment since early 2017. We believe it is an essential policy that needs to be applied wherever carbon policy exists to ensure that steelmakers bearing the structurally higher costs of low-emissions technologies can compete on a level playing field with imports from higher-emissions steelmakers. This forms a central part of our policy scenario analysis.

See chapter 6

$728m

Energy efficiency

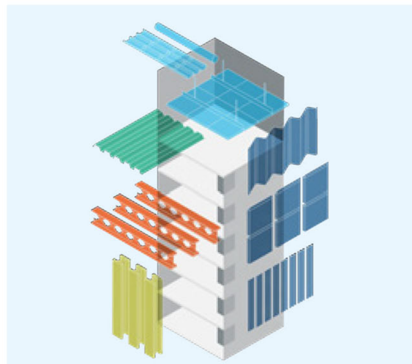
Each year we spend large amounts of capex to modernise our plants with the latest technology. $728 million has been allocated in the past three years alone.

Comprehensive climate-related disclosure

We have been making annual climate change disclosures to CDP since 2010, and in 2018 our disclosure was rated B. We report comprehensively on the methodology and scope of our CO_2 emissions, and ensure that we measure the carbon intensity of our steel in a way that includes all the processes involved in steelmaking rather than simply those we own and operate. In 2018, we became a supporter of the Task Force on Climate-related Financial Disclosures' (TCFD) recommendations. This Climate Action Report represents our first comprehensive response to these recommendations.

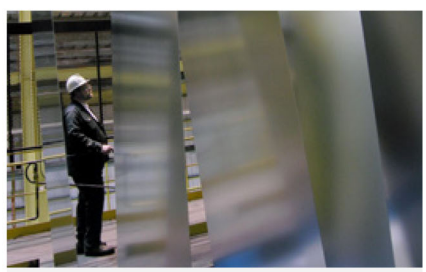
See chapter 7

CDP TCFD



Steligence®

In 2018, ArcelorMittal launched the Steligence® concept to facilitate the next generation of high-performance buildings and construction techniques for our customers. Built into the holistic Steligence® approach is a broad range of thinner, lighter, high-performance steel solutions. Demonstrating the potential to reduce the embedded carbon footprint of a building by 38%, the Steligence® approach can also enhance its flexibility and economics. Considering the share of global emissions from the built environment, the impact of Steligence® could be particularly significant.



S-in motion®

S-in motion® is a set of advanced high-strength steels launched by ArcelorMittal in 2010. Since then, S-in motion® steels have been providing the lightness and strength carmakers need to make mobility solutions ever more sustainable. It enables a reduction in vehicle lifecycle emissions of 14.5%,[3] while at the same time ensuring the safety of vehicle users at an affordable cost.

3 https://corporate.arcelormittal.com/news-and-media/our-stories/cutting-carbon-ensuring-safety-serving-customers-s-in-motion

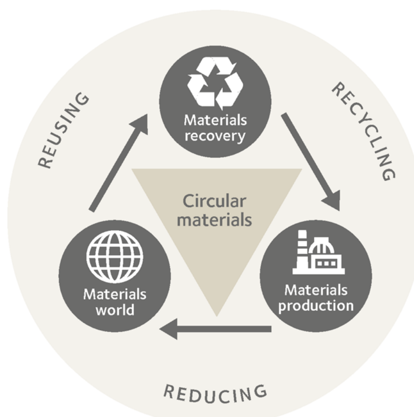
2 The future of materials: growing, circular, sustainable

Our world, and our lifestyles, have been built around the use of a variety of materials. All industries making these materials face the same issue: meeting the global demands of a growing population while significantly reducing their climate impact.

The world's materials challenge

Materials are an integral part of modern society, human development and well-being. Global consumption of materials has grown significantly over the past 30 years (**see box 1**), and has been instrumental in the economic development which has lifted over one billion people out of poverty. Today, the production of the main material groups globally account for over 19% of global CO_2 emissions.[4] The majority of these emissions come from using mostly fossil fuel-based energy to transform primary raw material sources into the materials we use (iron ore for steel, bauxite for aluminium, oil for plastics, etc.). Producing materials from secondary sources (i.e. recycling materials at their end of life) represents a small proportion of material production today, mainly because the strong growth of demand for materials outstrips the stock available for recycling, but also due to the fact that most materials – steel being an exception – cannot be fully recycled (**see box 1**).

Materials demand is forecast to continue growing for several decades as emerging economies pursue the infrastructure needed to achieve the United Nations' Sustainable Development Goals, and as the world transitions to low-emissions sources of energy. In this context, primary sources will continue to be essential to meet the world's material needs. Therefore, the challenge for materials producers is to lower the carbon footprint of materials production whilst meeting continuing demand growth. Contributions will come from improvements in energy efficiencies and production yields, and the move from today's prevalent linear use-and-dispose model towards a circular reduce-reuse-recycle model. What will be critical, however, is to develop and deliver low-emissions technologies for materials production.



In the long term, the world will transition towards a stable demand for materials in a fully circular economy, where efficiently designed products are reused repeatedly, and ultimately recycled into new products. This means for each application, manufacturers and designers will increasingly choose materials based not only on their physical characteristics such as weight, strength and flexibility, but also for their ease of reuse, recovery and recyclability. This will be enabled by policies aimed at restricting landfill and incineration. Effective recovery and recycling of materials from different waste streams at their end of life will be vital to the transition to a circular economy. In addition, segregation of materials to avoid degradation and loss of recycling capability will be important.

4 ArcelorMittal estimates of main material groups' CO_2 emissions as percentage of World Bank reported global CO_2 emissions; material groups included: cement, steel, aluminium, other metals, plastics and fibres, glass, bricks, and cardboard and paper.

Box 1: materials production and recyclability

Global materials production has grown significantly over the past three decades; steel is the only manufactured material that can be fully recycled.

Figure 1: global production (1990=100)

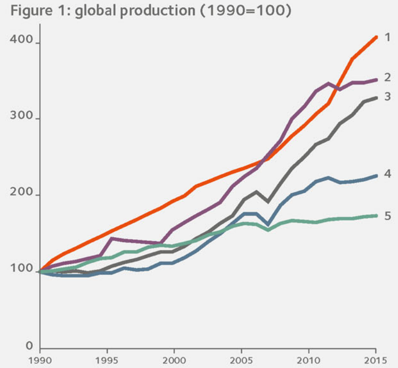


Table 1

Material group	Recyclability*	Made from end-of-life material
1 Plastics and synthetic fabrics	◒	5-10%
2 Cement[5]	○	0%
3 Aluminium	◕	21%
4 Steel	●	22%
5 Paper and cardboard	◕	50-60%

*Ability to make same material again at end of life

● Fully recyclable, low risk of downcycling

◕ Highly recyclable, risk of downcycling

◒ Partially recyclable, risk of downcycling

○ Little or no recyclability

Source: ArcelorMittal corporate strategy

5 Concrete, made from cement, is recyclable to a limited extent in the form of aggregate.

The future of materials: growing, circular, sustainable

With its high rate of recyclability, steel is the ideal material for a sustainable, circular economy. It is also a key enabler for CO_2 emission reductions.

Bright future for steel

We believe that steel is the only major material group today that can meet tomorrow's challenge of a fully circular economy. Steel's recyclability is unmatched by any other major material group. Today, up to 85-90% of steel products are recovered at their end of life and recycled to produce new steel. The magnetic properties of steel make it easy to segregate from other materials, so whereas other materials are often downcycled, steel retains all of its original properties, making it stand out as one of the most easily recycled materials.

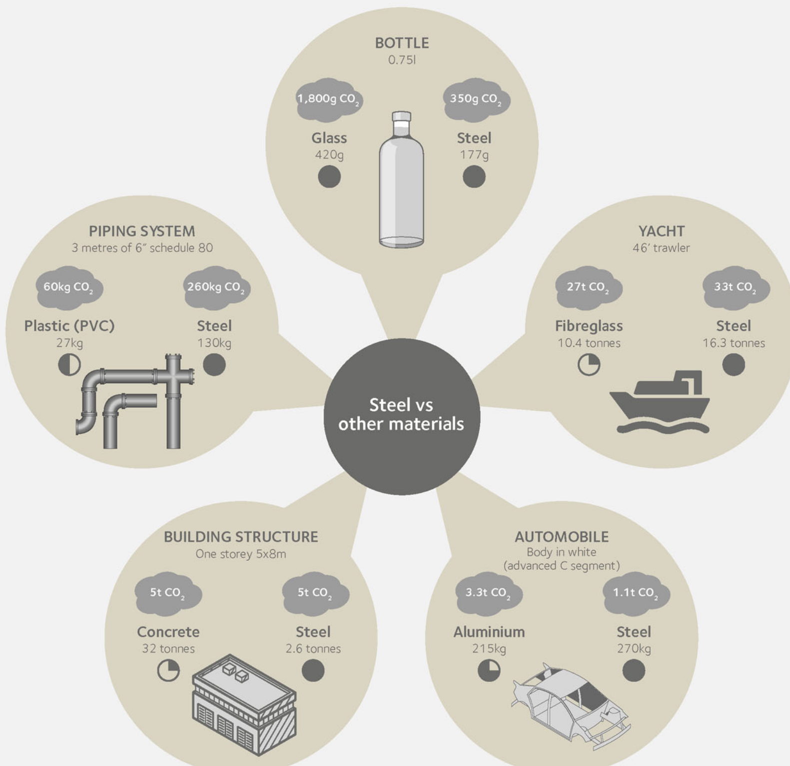
In the very long term beyond 2070, once there is a sufficient stock of steel to meet the needs of a fully developed world, the majority of steel products will be made from recycled end-of-life steel. We believe that as societies transition towards a sustainable circular economy, steel will be increasingly favoured over other less circular materials in overlapping applications.

Even today, there are fewer CO_2 emissions embedded in the production of steel in many applications in comparison with other materials. For example in the automotive sector, for the structural 'body-in-white' of a vehicle, the CO_2 emissions associated with an automotive part made of advanced high-strength steel are less than half of those associated with an equivalent aluminium automotive part, and less than a third of those associated with a part made of carbon fibre reinforced plastic.

Steel is also a key enabler as a core material in many leading technologies for global CO_2 emissions reductions. These technologies include offshore wind turbines, efficient transformers and motors, and lighter-weight vehicles. A study by BCG and VDEh found that on average, the CO_2 emissions reductions enabled by steel outweigh emissions from steel production by 6 to 1.[6] It is hard to imagine a future where steel is not a critical material in a sustainable circular economy.

6 BCG and VDEh (2013), *Steel's Contribution to a Low-Carbon Europe 2050.*

Figure 1: comparative CO_2 emissions from production of steel vs other materials for selected applications*



Icons represent the level of recyclability as in Table 1 on page 7.

*Figures relate only to emissions from production of material from primary (virgin) sources, not lifecycle CO_2 emissions of different materials.

Source: ArcelorMittal corporate strategy

3 The carbon challenge for steel

The steel industry currently generates approximately 7% of the world's CO_2 emissions. With demand for steel forecast to continue growing for several decades to come, the carbon challenge is significant.

Continuing need for primary steel production

Global steel demand has more than doubled since 1990 as societies across the world (China and the developing world especially) have increased their steel stocks in products, equipment, buildings and infrastructure. Steel can essentially be made using either primary sources or secondary sources. Today the majority of steel is made via the primary (iron ore based) route, the first step of which is to smelt or reduce iron ore. Nature has dictated that separating oxygen from iron requires a substantial amount of energy, because there are strong chemical bonds between oxygen and iron in iron ore. That energy today comes primarily in the form of carbon. Carbon dioxide, or CO_2 emissions are the result.

Steel produced via the secondary (scrap based) route, which uses electricity as the main energy input to melt end-of-life scrap, and has lower CO_2 emissions, has increased in recent decades. However, although steel stock in maturing economies has plateaued, the strong demand growth for steel in the developing world means that end-of-life scrap is only sufficient for a modest share (approximately 22%) of metallic input for global steel production. The availability of end-of-life scrap is forecast to grow, and this will support the increased use of scrap-based steelmaking. When powered with clean electricity, this will further reduce the carbon intensity of steelmaking. However, the availability of end-of-life scrap lags demand for steel by several decades, typically 10-50 years or more after production depending upon application. This means the world will still be reliant on primary steelmaking from iron ore until nearer the end of this century.

Although steel is less carbon-emitting per application than many other materials from primary sources, the sheer scale of global steel production means the industry contributes over three gigatons of CO_2 to global emissions annually. Global steel demand is forecast to increase from 1.7 billion tonnes in 2018 to over 2.6 billion tonnes by 2050 under current consumption patterns. This will be driven primarily by continued growth in the developing world, as well as increased steel demand to support the global energy transition, since more steel will be needed per unit of renewable electricity than conventional technologies.[7]

Time for transition

The global steel industry therefore faces the challenge of reducing CO_2 emissions in line with the ambition of the Paris Agreement whilst at the same time responding to the growing demand for steel. According to the Intergovernmental Panel on Climate Change (IPCC), in order to limit global warming to 2°C or less, the world needs to reach net zero CO_2 emissions around 2070. Achieving a limit of 1.5°C brings this date forward to around 2050.[8] While help will come from continued energy efficiency gains and yield improvements in steel production, as well as society's shift to a circular economy, achieving this ambitious goal will require a fundamental transition to low-emissions technologies. This essentially means either capturing and storing the emissions, or utilising a different, lower-emission energy source to extract the iron from the iron ore.

7 Source: ArcelorMittal global R&D
8 IPCC (2018), *Summary for Policymakers*. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emissions pathways, in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty.

Box 2: growing demand for steel

Global demand is forecast to increase from 1.7 billion tonnes in 2018 to over 2.6 billion tonnes by 2050 under current consumption patterns. Yield improvements and circular economy dynamics are likely to moderate this growth.

Construction

A significant share of growth in steel demand will come from the construction sector, particularly in developing countries for new buildings and infrastructure.

Energy

As the transition to a low-emissions economy unfolds, reduced steel demand from the oil and gas sector will be more than offset by growth from the renewable energy sector.

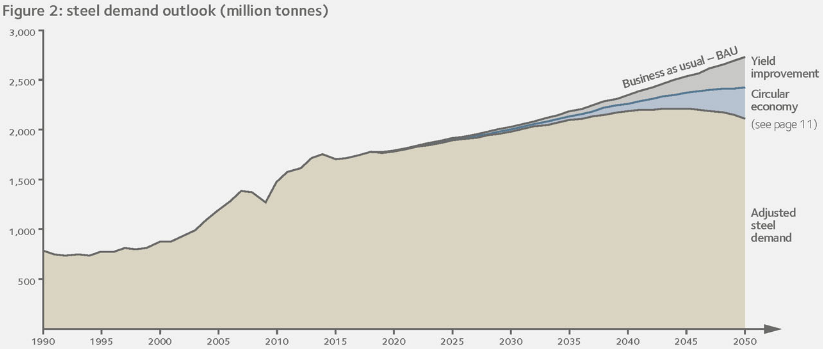
Packaging

Pressure to reduce plastic waste and use more recyclable materials is leading to growth in demand for steel in the packaging sector.

Transport

Steel use for transport will significantly increase due to economic growth in developing countries. The use of high-strength steels for lightweighting helps automakers improve vehicle emissions while maintaining safety standards. We take a neutral view on the impact of electric vehicles (EVs) on steel demand. We see significant opportunities for steel in EVs due to additional uses and recovery in traditional ones, given the cost and lifecycle CO_2 advantages of steel. Growth in the automotive sector may be moderated by the emergence of automated vehicles in the long term.

Figure 2: steel demand outlook (million tonnes)



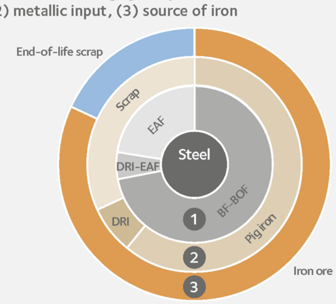
The carbon challenge for steel

Box 3: the role of end-of-life scrap in low-emissions steel transition

Global steel production will continue to rely on primary sources (iron ore) until around 2100.

Today, most primary sources of iron (iron ore) used to make steel are processed through a blast furnace (BF) for ironmaking and subsequently through a basic oxygen furnace (BOF) for steelmaking, using coal-based products such as pulverised coal and coke as energy inputs to reduce the iron ore. To a lesser extent, steel from iron ore is also produced via the direct reduced iron (DRI) process using natural gas or gasified coal. Although both these routes partially add scrap to make steel, most scrap used globally is processed into steel directly through an electric arc furnace (EAF), using electricity as the main energy input (see annex 1).

Global steelmaking by (1) production route, (2) metallic input, (3) source of iron

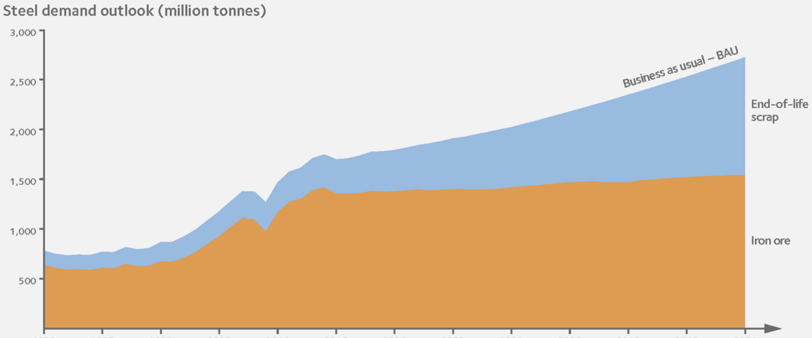


Scrap used in steelmaking comes from two different sources:

- Pre-consumer scrap, arising from yield losses in iron and steelmaking and manufacturing of steel-based products.
- End-of-life scrap, arising from the recovery of steel-based products at the end of their operational life, typically 10-50 years or more after production, depending upon application. As a result, the availability of end-of-life scrap lags steel demand by several decades.

Although the availability of end-of-life scrap is forecast to grow (see graph below), global steel demand growth means end-of-life scrap will meet less than 50% of steel needs by 2050. As living standards improve and infrastructure across the globe matures, demand for steel will eventually plateau. After that, enough end-of-life scrap will be available to meet the bulk of steel demand, leading to a fully circular steel value chain. Since this transition is unlikely to become reality much before the end of the century, iron and steelmaking from iron ore will continue to play an important role in meeting global steel demand well beyond 2050.

Steel demand outlook (million tonnes)



Source: ArcelorMittal Corporate Strategy

Meeting the carbon challenge for steel will require continued energy and yield improvements, a shift to a circular economy, and the adoption of low-emissions technologies.

Business as usual (BAU)

This projection of CO_2 emissions shown in figure 2 below is based on the BAU steel demand outlook, which includes the increasing volumes of end-of-life scrap forecast shown in **box 3 on page 12**.

Steelmaking yield improvement

Continued improvements in the steel supply chain, particularly through the digital revolution and evolving manufacturing technologies, will drive continued yield improvement from crude steel production to final steel in products, equipment, buildings and infrastructure. This will reduce the amount of steel production needed for the same products, equipment, building and infrastructure under a BAU scenario.

Circular economy

Products, equipment, buildings and infrastructure designed to use less steel will all moderate the growth rate of steel demand compared to a BAU scenario. The transition to a circular economy – with new business models focused on greater sharing of our material world (homes, cars, etc.), extended product longevity and reuse at end of life – will also reduce demand for steel compared to a BAU scenario.

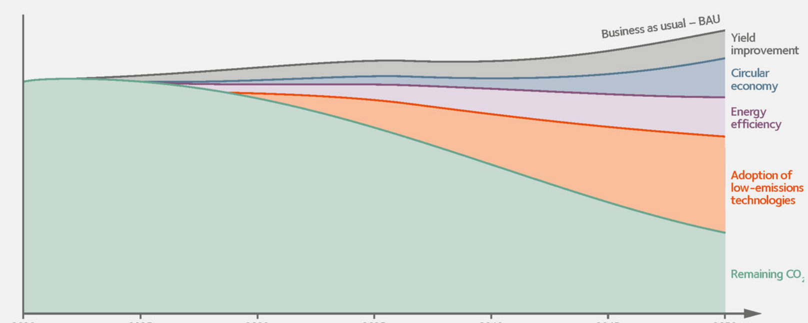
Energy efficiency

Over the last 50 years, the steel industry has reduced its energy consumption per tonne of steel by 61%.[9] A recent World Steel Association study shows potential for a further 15-20% reduction in energy intensity.

Adoption of low-emissions technologies

Steel production will continue to depend on primary sources (iron ore) to meet future demand, as shown in figure 4. To achieve the Paris Agreement objectives, this primary steel production will have to transition to low-emissions technologies for iron ore reduction. This will entail a transition to low-emissions energy sources through a combination of use of clean power, circular carbon (**see box 4 on page 15**), and continued use of fossil fuels with carbon capture and storage. Detailed descriptions of low-emissions technology pathways for the steel industry are given in **chapter 4**, and ArcelorMittal's innovation programme to demonstrate such technologies is described in **chapter 5**.

Figure 2: Indicative CO_2 emissions outlook for steel



9 World Steel Association (2019), *Steel's Contribution to a Low Carbon Future and Climate Resilient Societies.*

4 Low-emissions technology pathways and policy scenarios

Low-emissions steelmaking will be achieved through the use of a combination of clean power, circular carbon, and fossil fuels with capture and storage (CCS).

Future energy inputs for primary steelmaking

The steel industry has made significant improvements in energy and yield efficiency, reducing the emissions intensity of steel production during recent decades. Further technological innovation should lead to continued reductions in emissions intensity over the next decade.

However, to accelerate emissions reduction and align with the demanding objectives of the Paris Agreement, the steel industry will have to transition to one or more low-emissions technology pathways. These are illustrated on pages 14-15. They include transitioning to new energy inputs in the form of a) clean power, b) circular carbon and c) fossil fuels with carbon capture and storage.

a) Clean power used as the energy source for hydrogen-based ironmaking, and longer term for direct electrolysis ironmaking, and also contributing to other low-emissions technologies.

b) Circular carbon energy sources including bio-based and plastic wastes from municipal and industrial sources and agricultural and forestry residues (**see box 4**).

c) Fossil fuels with carbon capture and storage (CCS) enabling the continued use of the existing iron and steelmaking processes while transforming them to a low-emissions pathway. This shift would require national and regional policies to create the necessary large-scale infrastructure network for the transport and storage of CO_2.

Box 4: the importance of circular carbon

While climate change needs to tackle the increased concentration of carbon-based gases in our atmosphere, carbon is and will remain an essential building block of nature and our material world. Circular carbon treats carbon as a renewable resource that can be reused indefinitely.

Today over half of the renewable energy used in Europe already comes from circular carbon in the form of renewable biomass and bio-waste. Increased use of renewable biomass globally is also a critical enabler to three of the four IPCC pathways to 1.5°C in their latest report.[10]

More of society's waste – including construction wood, agricultural and forestry residues, and plastic waste – can potentially be used sustainably as a valuable source of circular carbon. The steel sector has the potential to be one of the most efficient users of the limited quantity of circular carbon available in society.

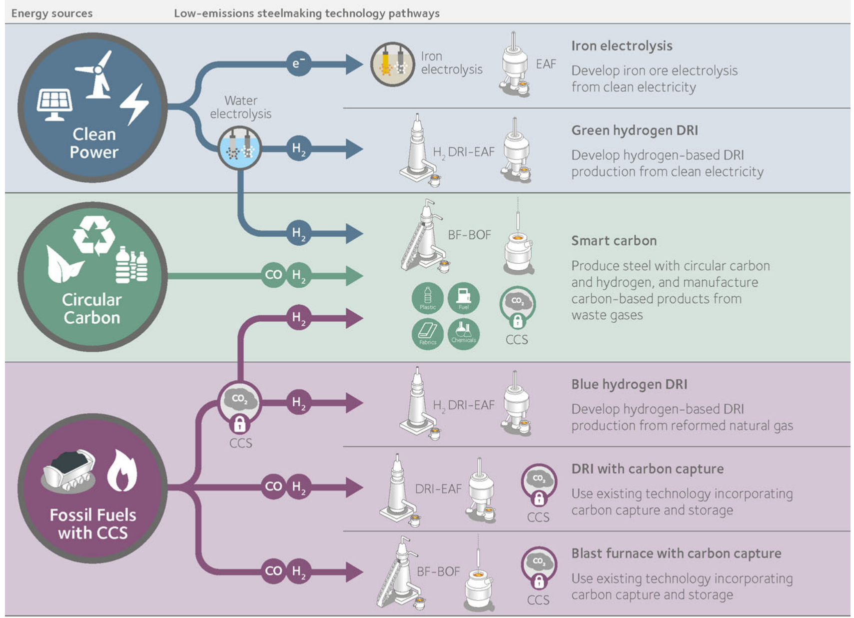
Furthermore, the carbon gases that result from iron and steelmaking with circular carbon can be captured and converted into recyclable products. At the end of their use, these products will themselves become sources of circular carbon, closing the loop and creating an endless cycle of carbon.

10 IPCC (2018), *Summary for Policy Makers*

Low-emissions technology pathways and policy scenarios

Box 5: possible low-emissions technology pathways using different energy sources

All technology pathways to low-emissions steelmaking entail higher costs and require time, investment and clean energy infrastructure.



A successful transition to low-emissions steelmaking will require policies that offset higher costs, provide access to sufficient clean energy and financial support to accelerate technology innovation.

Policy needs

The viability of different low-emissions steel technology pathways at each steelmaking site is likely to differ by region, depending on three aspects of policy:

- Policies to ensure steelmakers compete on a level playing field. Where carbon policy drives steelmakers to adopt low-emissions technologies, involving **structurally higher operating costs**, mechanisms such as a green border adjustment enable steel from these producers to compete fairly with imports from higher emitting steelmakers.
- National and regional policies regarding **energy infrastructure and allocation by sector.** These may affect the availability of green and blue hydrogen, circular carbon (bio-waste, waste plastic, and agricultural and forestry residues), and large-scale carbon transport and storage infrastructure.

Incremental costs to produce steel* (OPEX and CAPEX)	Commercial horizon	Energy infrastructure challenge	Energy technology challenge	Steel technology challenge
To be determined	20-30 years	Power infrastructure exists – to be expanded to accommodate steelmaking needs		Electrolysis ironmaking
+60-90%	10-20 years	Green hydrogen economy needs to be created – can be done incrementally	Lowering green hydrogen production costs	Hydrogen ironmaking
+20-35%	5-10 years	Circular carbon and hydrogen economy expansion – can be done incrementally	Develop commercial bio-coals, bio-cokes and bio-gases for steelmaking	Commercial combined carbon and hydrogen steelmaking; upside of carbon capture and use
+35-55%	10-20 years	Develop large commercial natural gas-based hydrogen and carbon storage projects		Hydrogen ironmaking
+35-55%	5-10 years	Develop economy-wide commercial carbon transport and storage infrastructure		Commercial CO_2 capture technologies
+30-50%	5-10 years	Develop economy-wide commercial carbon transport and storage infrastructure		Commercial CO_2 capture technologies

Source: ArcelorMittal internal estimates for transition to low-emissions steelmaking in Europe based on current factor prices.
*Compared with average annual net income of steel industry, which between 2010-2017 was 2% of revenues.

- The level of **private and public investment support.** This will dictate the speed of development of low-emissions innovation projects in order to assess their commercial viability; and, where such projects are successful, for the roll out of low-emissions technologies across different steel plants.

In view of these needs, we believe steel companies need to maintain a flexible technology innovation roadmap to adapt to the various technology development timelines, clean energy and policy landscapes of the future. Conversely, policy certainty from national and regional governments and institutions will be instrumental in supporting the steel industry to decarbonise at a pace commensurate with supporting the objectives of the Paris Agreement.

We have developed four policy scenarios to assess the implications of different levels of policy commitment for the steel industry's ability to meet the carbon challenge. We have used this analysis to inform our policy recommendations presented in chapter 6.

Policy scenarios: driving the transition to low-emissions steel

A concerted public and private investment effort is essential to accelerate the pace of development and roll out of commercial low-emissions technologies and advance the timeline to make the steel industry 'technology ready' to meet the objectives of the Paris Agreement.

Steel is a global material traded directly across countries and continents in the form of sheets and bars for steel products, equipment, buildings and infrastructure. It is also embedded in the imported goods consumers buy, such as cars, appliances, etc.

Countries and regions that introduce a cost of CO_2 emissions, but with neither supportive energy policies nor effective mechanisms to maintain the competitiveness of low-emissions versus higher-emissions steel, will fail to decarbonise their steel. What is more, it may in fact disadvantage their steel industry as production will migrate to other countries and regions that do not support decarbonisation, thereby exacerbating the carbon challenge globally **(Stagnate scenario).**

Even in jurisdictions actively providing financial support to develop and roll out low-emissions technologies, the steel industry will need further support. Without effective mechanisms to offset the structurally higher operating costs of deploying these technologies, and affordable access to the clean energy they need, the steel industry will be unable to make the necessary shift needed to meet the goals of the Paris Agreement **(Wait scenario).**

Countries and regions developing supportive energy policies, and establishing a fair mechanism to offset the structurally higher costs of low-emissions steel producers, will succeed in transitioning to low-emissions steelmaking **(Accelerate scenarios).** They will reap the benefits of a positive steel industry that contributes to their economies and to the carbon challenge. But only if such mechanisms are applied globally can this acceleration take place on a global scale and the steel industry become a successful partner in meeting the objectives of the Paris Agreement.

STAGNATE

- Lack of access to sufficient and affordable clean energy
- No mechanism to address high risk that steel production is made structurally uncompetitive across countries/regions
- Slow development of low-emissions steelmaking technologies
- No meaningful reduction in global steel CO_2 emissions as production shifts to less carbon-regulated jurisdictions
- Insignificant global progress to goals of Paris Agreement

WAIT

- Technology makes encouraging progress and is potentially ready for significant deployment within 10-20 years
- But only fragmented access to affordable clean energy
- No mechanism to address high risk of steel production being structurally uncompetitive in affected countries/regions
- Marginal steel CO_2 reductions globally as production shifts to less carbon-regulated jurisdictions
- Limited progress towards goals of Paris Agreement

ACCELERATE regionally

- Technology makes encouraging progress and is potentially ready for significant deployment within 10-20 years
- Access to sufficient and affordable clean energy in supportive countries/regions
- Regions with more active climate legislation ensure mechanisms are in place to enable steel production to remain competitive, e.g. green border adjustment
- Significant reductions in steel CO_2 in supportive countries/regions
- Partial global progress to goals of Paris Agreement

ACCELERATE globally

- Technology makes encouraging progress and is potentially ready for significant deployment within 10-20 years
- Access to sufficient and affordable clean energy globally
- Low-carbon legislation in place in the majority of countries, ideally with a common global framework or mechanism to ensure steel production remains competitive globally
- Significant global reductions in steel CO_2
- Global industry alignment with goals of Paris Agreement

Box 6: policy scenarios and their effectiveness in driving de-carbonisation of the steel industry

Figure 3

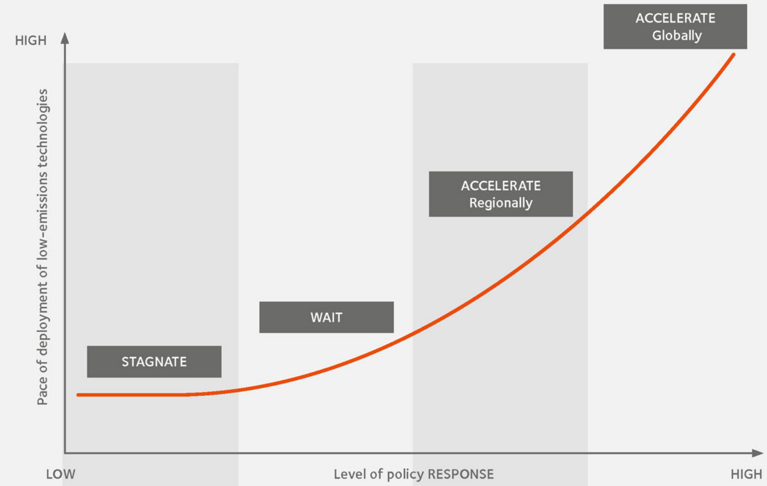


Table 2

Policy challenge				
Structurally higher operating costs of low-emissions steelmaking	Ineffective mechanism in place to offset structurally higher operating costs of low-emissions steelmakers versus higher-emissions steelmakers	Ineffective mechanism in place to offset structurally higher operating costs of low-emissions steelmakers versus higher-emissions steelmakers	Mechanisms to maintain competitive market by offsetting structurally higher operating costs of low-emissions steelmakers versus higher-emissions steelmakers and imports set in some countries and regions, e.g. green border adjustment	Common global framework is implemented to maintain competitive market to offset structurally higher operating costs of low-emissions steelmakers versus higher-emissions steelmakers
Clean energy infrastructure and allocation by sector	No concerted policy in any market to incentivise and allocate clean energy to steel sector	No concerted policy in any market to incentivise and allocate clean energy to steel sector	Support for clean energy to steelmaking industry from clean power, circular carbon and carbon capture and storage infrastructure provided in only some countries and regions	Support for clean energy to steelmaking industry from clean power, circular carbon and carbon capture and storage infrastructure provided globally
Investment in low-emissions steelmaking technologies (development and roll out)	Limited public support for R&D to bring technologies to commercialisation maturity	Accelerated public support for R&D to bring technologies to commercialisation maturity; some investment support for roll out of technologies	Accelerated public support for R&D to bring technologies to commercialisation maturity; high levels of investment support for roll out of technologies	Accelerated public support for R&D to bring technologies to commercialisation maturity; high levels of investment support for roll out of technologies

5 ArcelorMittal strategy towards low-emissions steelmaking

Energy efficiency, increased use of scrap, technology innovation and policy engagement are the four components of our climate action strategy.

Over the last 150 years, the steel industry has seen significant energy efficiency and yield improvements.[11] While incremental improvements will continue, far more is needed to meet the objectives of the Paris Agreement.

Significant emissions reduction requires creative and innovative thinking, which is at the heart of our €250 million low-emissions steelmaking innovation programme.[12]

ArcelorMittal's low-emissions strategy has four components:

1. **Energy efficiency** in our steelmaking operations across the globe to help meet our medium-term emissions reduction targets.
2. Consideration of opportunities for further steel production using end-of-life scrap based on its availability in the regions where we operate.
3. A flexible, integrated **innovation programme** to develop the technologies for steelmaking in a low-emissions circular future.
4. **Policy analysis and engagement** to understand and advocate for the policies that will support the transition to a low-emissions future in the different geographies where we operate.

$728m
Capex allocated to energy efficiency improvements in the last three years

1. Energy efficiency programme

Over the last decades, the steel industry has significantly reduced the carbon intensity of steel, by focusing on **energy efficiency gains** and **yield improvements**.

For example, ArcelorMittal is today a leader in industrial gas-injection technology. This has enabled us to increasingly replace metallurgical coke with alternative sources of carbon such as pulverised coal or natural gas. Some of our most advanced blast furnaces are now injecting 50% of the total carbon required for the process using this technology – with the effect of reducing the total amount of fossil fuels required. This capability to use the blast furnace as a large-scale 'gasifier' in industry puts us in a good position for the adoption of low-emissions technologies for steelmaking.

Our business segments are now required to prepare CO_2 reduction plans as part of the annual planning cycle, making use of a range of existing and innovative approaches.

To support them, our global R&D team is continually innovating to deliver energy efficiency and yield improvements. In 2018, we deployed 19 new processes to this end. However, many plants are approaching the physical limits of energy efficiency, and a transition to low-emissions technologies is needed to deliver further substantial emissions reductions.

Each year our Investment Allocation Committee (IAC) allocates capital to investment projects that improve energy performance. Proposals to the IAC are required to assess the CO_2 benefit of the project, enabling an assessment with a suitable carbon price to reflect the local context.

In 2018, ArcelorMittal made capital allocations totalling $247 million for 26 projects aimed at improving energy efficiency, bringing the three-year total to $728 million.

11 By 50% in about 75 years, based on DEH data of consumption of reducing agents used in blast furnaces in Germany (including Eastern Germany from 1991).
12 This is the multi-year budget covering our low-carbon development and demonstration programme with partners, aimed at building industrial pilots and demonstrations and is additional to our annual R&D expenditure.

2. Further opportunities for secondary steelmaking

The availability of end-of-life scrap is projected to increase globally over the coming decades as increasing amounts of building structures and equipments approach their end of life. By 2050, there will be sufficient supplies to feed some 50% of global steel production. As this availability increases in regions where we operate, we will consider creating additional opportunities for secondary steelmaking in electric arc furnaces.

ArcelorMittal currently operates 32 electric arc furnaces across the world, of which 13 are located in Europe. In 2018 we produced 19% of our steel from these furnaces.

Blast furnace facilities and electric arc furnaces

*The 2018 BF footprint presented above is not including the Ilva remedies (Ostrava and Galati). Including these assets the total number of BFs is 58.

3. Flexible, integrated, circular approach to innovation

The global challenge posed by the transition to low-emissions steelmaking is large and complex, and will require multiple solutions. Our innovation approach is focused on providing flexibility to adapt to different possible clean energy futures in different regions and countries, whether it is clean power, circular carbon, or fossil fuels with CCS, or a combination of all three.

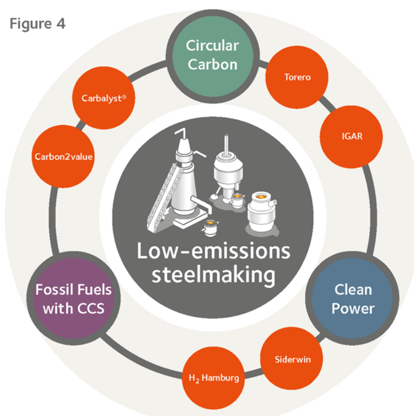
The strength of our €250 million research and demonstration programme is its breadth and flexibility. While each of our technologies can be stand alone and scaled up individually, we can also integrate them to deliver significant advantages for the various low-emissions steelmaking pathways.

The key technologies in this programme are represented in Figure 4.

In addition, our innovation approach supports three key underlying principles of a low-emissions circular economy:

- Supporting the advancement of renewable energy by developing technologies that can make use of intermittent renewable power from wind and solar (either directly or indirectly through hydrogen), thus helping to reduce grid instabilities.
- Accelerating the circular economy by developing technologies that enable waste streams to be reused commercially, turning them into materials and feedstock for other industries and sectors.
- Creating industrial symbiosis between the steel, chemicals and cement industries through a logistics network to share and reuse CO_2 as a feedstock for the production of chemicals. The logistics network can be expanded further to transport and store CO_2, for example in depleted oil fields.

Figure 4



4. Policy analysis and engagement

We have analysed the energy resources, costs and infrastructure needed for each low-emissions technology pathway and assessed the implications of different policy scenarios on the pace of deployment of these technologies (**see chapter 4**).

This analysis forms the basis for our policy recommendations to accelerate the transition to low-emissions steelmaking, which are presented in **chapter 6.**

To build an understanding of the need for policy support, ArcelorMittal engages with customers and investors as well as policymakers and global organisations regarding our outlook for low-emissions steelmaking. This includes organisations such as the We Mean Business coalition, the World Business Council for Sustainable Development, CDP, the Science-Based Targets Initiative and the International Energy Association.

There is no 'one size fits all' solution to move away from emissions-intensive steelmaking. Our technology portfolio enables us to pursue the full range of possible technology pathways, depending on which becomes the most viable in the countries and regions where we operate.

ArcelorMittal's low-emissions innovation programme

Today, the reduction of iron ore to iron is predominantly achieved using high temperature carbon monoxide (CO), sourced from fossil fuels – coke and pulverised coal – which is also used as an affordable source of energy.

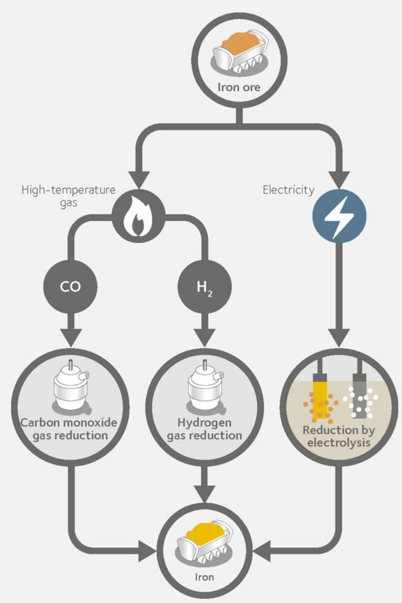
Science has given us three alternatives to this: deriving CO from circular forms of carbon, applying the process of electrolysis, or using high-temperature hydrogen gas.

The latter two pathways require vast amounts of electrical energy, which would all need to come from clean sources. Such quantities of clean power will not become available to the steel industry overnight at affordable prices.

To reduce emissions within the timeframe needed, therefore, ArcelorMittal is exploring opportunities to combine technologies that use more clean power with those that involve circular sources of carbon, alongside carbon capture, carbon utilisation and carbon storage.

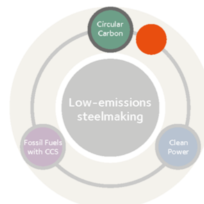
Our portfolio of technologies offers us the ability to respond to whichever energy sources are made affordable by the policy frameworks in place. Our key projects are outlined in detail over the pages that follow.

Figure 5: From iron ore to iron for primary steelmaking



ArcelorMittal strategy towards low-emissions steelmaking

With its high-tech gasification technology, the modern steel industry is the ideal sector to advance the circular economy by reusing bio-waste, plastic waste, and agricultural and forestry residues.



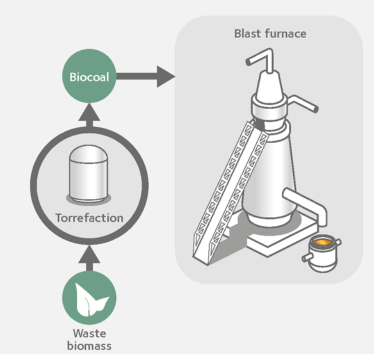
Torero: reducing iron ore with waste carbon

Today, most blast furnaces reduce iron ore using a high-temperature, synthetic gas derived from coal and coke. This makes the modern blast furnace with its high-tech gasification technology ideal for replacing fossil fuels with 'circular carbon' inputs, such as bio-waste, including agricultural and forestry residues, and even waste plastics.

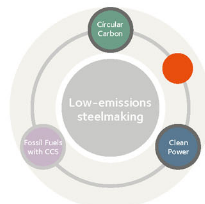
Our Torero project targets the production of bio-coal from waste wood to displace the fossil fuel coal that is currently injected into the blast furnace. We are developing our first large-scale Torero demonstration plant in Ghent, Belgium. In this €40 million project (with €12 million funding from EU Horizon2020) we aim to convert 120,000 tonnes of waste wood annually into bio-coal. This source of waste wood is considered hazardous material if burnt in an incinerator as harmful gases would be emitted, but in the blast furnace no such pollutants can be formed.

Future projects would see expansion of sources of circular carbon to other forms of bio-based and plastic waste.

Figure 6: the Torero process



Waste CO_2 can be reformed into a synthetic gas suitable for reducing iron ore, giving it a second life. Our ultimate goal is to use clean power and waste plastics for low-emissions circular carbon steelmaking.



IGAR: reforming carbon to reduce iron ore

The IGAR[13] project aims to capture waste CO_2 from the blast furnace and convert it into a synthetic gas (syngas) that can be reinjected into the blast furnace in place of fossil fuels to reduce iron ore. Since the amount of coal and coke needed in steelmaking is reduced, this process helps to reduce CO_2 emissions.

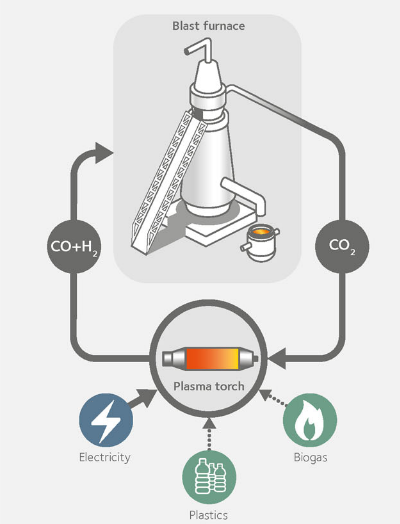
The syngas we need is made up of carbon monoxide (CO) and hydrogen (H_2). To form this, waste CO_2 is heated with natural gas (CH_4) to very high temperatures using a plasma torch – a process called dry reforming.

In future, we hope to use bio-gas or waste plastics in place of natural gas, furthering the use of circular carbon. And with the plasma torch running on clean power, the entire process enables substantial emissions reductions.

The IGAR project has seen a number of phases. Last year, to overcome the corrosive effects of the high-temperature syngas involved, our R&D labs in Maizières, France, developed both the specialist metals and refractories needed.

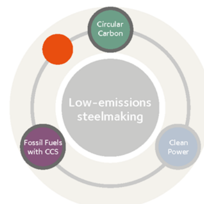
Today in Dunkirk, France, ArcelorMittal is running a €20 million project, supported by the French ADEME, to construct a plasma torch. To test-use the hot syngas created by the plasma torch, a pilot project is also running at the same plant.

Figure 7: IGAR process



13 Injection de Gaz Réformé

The carbon-intensive gas produced in ironmaking is an ideal feedstock for biotechnology. With our partner Lanzatech we are working on a family of novel recycled chemicals: Carbalyst®



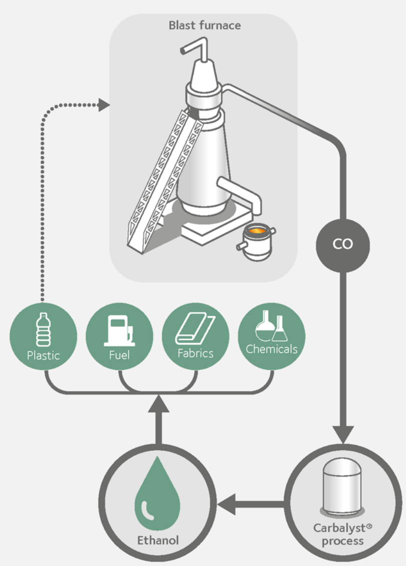
Carbalyst®: capturing carbon gas and recycling into chemicals

The waste gases that result from iron and steelmaking are composed of the same molecular building blocks – carbon and hydrogen – used to produce the vast range of chemical products our society needs. Today most waste gas is incinerated, resulting in CO_2 emissions.

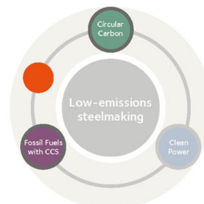
With our partner Lanzatech, supported by the EU Horizon2020 Steelanol project, we are building the first large-scale plant to capture the waste gas and biologically convert it into bio-ethanol, the first commercial product of our Carbalyst® family of recycled carbon chemicals. Thanks to a lifecycle analysis study, we can predict a CO_2 reduction of up to 87% compared with fossil transport fuels, so this bio-ethanol can be used to support the decarbonisation of the transport sector as an intermediate solution during the transition to full electrification. In the future, we will expand the family of Carbalyst® products to other biochemicals and biomaterials.

Construction started recently on a €120 million demonstration facility in Ghent, Belgium. Once completed in 2020, the facility will capture around 15% of the available waste gases at the plant and convert them into 80 million litres of ethanol per year. This result will be a CO_2 reduction equivalent to 100,000 electric vehicles or 600 transatlantic flights per year.

Figure 8: Carbalyst® technology



We are integrating breakthrough technologies to bring down the costs of capturing, purifying and liquefying CO_2 from our waste gases. Liquid CO_2 can be made available to other industries for reuse, or transported for storage underground.



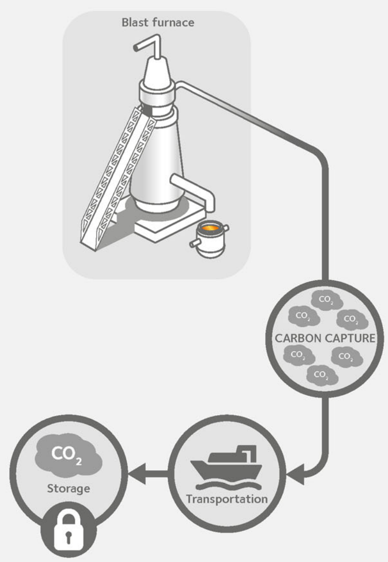
Carbon2Value: capturing fossil fuel carbon for storage or reuse

Developing cost-effective technologies to capture and separate CO_2 from our waste gases, and liquefy it for subsequent transport and storage or reuse, could be key to the transition to low-emissions steelmaking. Combining this with a circular carbon energy input would further reduce CO_2 emissions.

A pilot plant to capture CO_2 has been built in Ghent, Belgium, together with Dow Chemicals as part of the Carbon2Value project supported by INTERREG2Seas.[14]

Additionally, at Dunkirk, France, a €20 million industrial pilot to capture CO_2 using only low-temperature waste heat is under construction with our partner IFPen, supported by the French administration ADEME. This pilot project is aimed at achieving the cost reductions required to make such processes commercially viable.

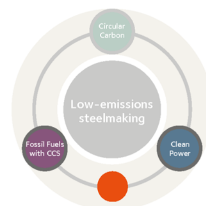
Figure 9: fossil fuel carbon capture and storage



14 Interreg2Seas: North of France, Flanders, South of Netherlands and UK

ArcelorMittal strategy towards low-emissions steelmaking

Abundant and affordable clean power would also enable low-emissions steelmaking with 'green hydrogen'. We are preparing a demonstration project in Hamburg to test this on a large scale.



H_2 Hamburg: reducing iron ore with hydrogen

Today, in a Direct Reduced Iron (DRI) furnace fed with natural gas (CH_4), approximately 50% of the reaction comes from hydrogen (H_2), and the remainder from carbon monoxide. Technologies can be developed to increase the proportion of hydrogen used up to 100%.

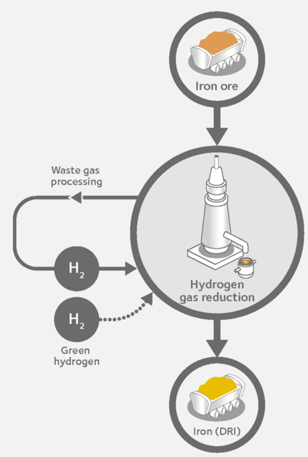
We are planning a new project at our Hamburg site to use hydrogen on an industrial scale for the direct reduction of iron ore in the steel production process. Project costs amount to around €65 million.

The project will allow us to develop an understanding of how our existing DRI plants could take advantage of green hydrogen (generated from renewable sources), should this become available and affordable at some point in the future. While theoretically the reduction of iron ore with pure hot hydrogen is understood, a large number of practical roadblocks still exist. These can only be studied when the process is running on a large scale, which has until now not been done due to the lack of hydrogen infrastructure.

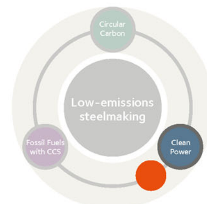
The process of reducing iron ore with hydrogen will first be tested using hydrogen generated from gas separation. We aim to achieve the separation of H_2 with a purity of more than 95% from the waste gas of the existing plant, using a process known as 'pressure swing absorption'. In the future, the plant should also be able to run on green hydrogen when it is available in sufficient quantities at affordable prices.

The experimental installation at the Hamburg DRI plant will demonstrate the technology with an annual production of 100,000 tonnes.

Figure 10: reducing iron ore with hydrogen



Once affordable clean power is abundantly available, direct electrolytic iron ore reduction becomes a very attractive route. With the Siderwin project, we are building an industrial pilot.



Siderwin: reducing iron ore via electrolysis

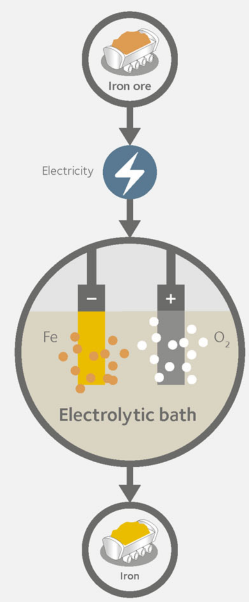
In principle, iron can be reduced from iron ore (Fe_2O_3 or Fe_3O_4) through direct electrolysis. When iron ore is introduced into an electrolytic bath (a bath with an electrical current running through two electrodes), the iron (Fe) will be attracted to one electrode and the oxygen (O) to the other.

Our R&D laboratories in Maizières, France, have developed the first electrolytic cell prototype, proving the viability of iron electrolysis. It also showed that the process can operate in a highly flexible start/stop mode, ideal for power grids dependent on large amounts of intermittent renewable power. Moreover, our tests have shown that less power is required than is needed to make hydrogen from water using electrolysis.

ArcelorMittal is the lead company of the Siderwin project, which is further developing this technology. Together with 11 partners and with €7 million funding from EU Horizon2020, a three-metre industrial cell is under construction and various types of iron ore sources (including waste sources) will be tested.

With sufficient access to affordable clean power, the development of this process will pave the way to zero-emissions iron ore reduction.

Figure 11: the Siderwin process



6 Policy recommendations

ArcelorMittal advocates the development and implementation of carbon regulations and market mechanisms to enable the rapid deployment of low-emissions steelmaking that will deliver the global objectives of the Paris Agreement.

Global recommendations

1. Global level playing field. A global framework to create a level playing field is needed to avoid the risk of carbon leakage, for example, through green border adjustments. This is to ensure that steelmakers bearing the structurally higher operating capital costs of low-emissions technology can compete with imports from higher-emissions steelmakers.

2. Access to abundant and affordable clean energy. Policies giving the steel industry access to abundant and affordable renewable electricity will be key to scaling up the Clean Power pathway. For acceleration of the circular carbon pathway, the steel industry requires priority access to biomass and waste.

3. Facilitating necessary energy infrastructure. In addition to abundant renewable electricity, policies to support investments in hydrogen infrastructure will be needed to advance large-scale hydrogen-based processes. Similarly, for the Fossil Fuels with CCS pathway, enabling policies are also important to accelerate the development of carbon transport and storage infrastructure and services.

4. Access to sustainable finance for low-emissions steelmaking. The scale of the challenge requires an acceleration of technology development and roll out. Breakthrough steelmaking technologies need to be identified as a key priority area for public funding.

5. Accelerate transition to a circular economy. Materials policy should divert waste streams from landfill and incineration. It should focus on driving recycling and reuse of all waste streams and incentivise the use of waste streams as inputs in manufacturing processes. It should reward products for their reusability and recyclability.

Given that our most substantial climate-related risks are located in the EU, we present specific policy recommendations for this region in box 8.

Box 7: ResponsibleSteel™

ArcelorMittal has taken a leading role in forming ResponsibleSteel™, the steel industry's first multistakeholder global certification initiative. ResponsibleSteel™ aims to give businesses and consumers confidence that steel certified under this standard has been sourced and produced responsibly at all levels of the supply chain: from mining to production processes, to final stage sales and distribution. The certification standard includes requirements on carbon alongside other air emissions, water responsibility, biodiversity, human rights, labour laws, local communities, business integrity and supply chain management.

The carbon standards within ResponsibleSteel™ are undergoing consultation in 2019 and are expected to be in line with the Paris Agreement. So whilst this initiative will not compensate steelmakers for the structurally higher costs of low-emissions steelmaking, it could play an important role in driving the commitment of steel companies to achieving the Paris objectives.

Box 8: long-term EU climate policy recommendations for steel

To reduce the risk of carbon leakage, the EU Emissions Trading Scheme (ETS) includes a system of free allocation of emissions allowances. The amount of allowances allocated to each facility is based on a benchmark, which should mean that the top 10% best performing plants are not faced with additional carbon costs. However, the benchmark currently determined for integrated steel plants means that even the best performing plant in the world must purchase emissions allowances.

In Phase 4 of the EU ETS, we could face an increase in marginal production costs by around €50 per tonne of steel[15] with €5 billion in potential cumulative costs as a result (**see chapter 8**).

At the same time, steel is also imported into Europe, often from countries without a comparable carbon cost. This means that EU producers absorbing the structurally higher structural costs of breakthrough technologies are competing against more carbon-intensive manufacturers with lower operating costs. A recent study estimated that about a quarter of global CO_2 emissions are embedded in products that are traded across national boundaries, a substantial share of which contain steel.[16]

Without a green border adjustment, the lowest-cost approach to reduce GHG emissions within the EU ETS is to import steel from outside the EU (carbon leakage).

In addition to the global policy recommendations, therefore, the following are needed in the European context:

1. Green border adjustment to ensure level playing field. To incentivise long-term investments in carbon efficiency and low-emissions technologies, a level playing field is an essential first step. The best way to do this in the framework of the EU ETS is to implement a green border adjustment, where steel importers pay for the embedded CO_2 emissions of imported steel at the same rate as European manufacturers. This would safeguard the competitiveness of the European steel industry. We are engaging with European governments on the implementation of a green border adjustment, a position also supported by the European Steel Association (Eurofer).

2. Access to abundant and affordable clean energy. This is currently not available nor economically viable in Europe. Improvements are therefore needed in the EU state aid rules for energy and environment to enable the roll out of low-emissions steelmaking.

3. Access to sustainable finance for low-emissions steelmaking. Some of our current R&D projects are funded by EU Horizon 2020. Accelerating and rolling out low-emissions steelmaking will need further public funding through, for example, the EU ETS Innovation Fund. Definitions of projects eligible under the draft EU Sustainable Finance legislation should consider their contributions to the low-carbon circular economy. In particular, the development of smart circular carbon loops should be incentivised.

4. Update the benchmark methodology for free allocation in Phase 4 of the EU ETS to make it technically feasible.

5. Accelerate transition to a circular economy. EU climate and materials policy should be integrated, taking a lifecycle perspective to ensure that materials are used in as circular way as possible.

15 Assuming an EU Emissions Allowance price of €25/t CO_2 and a carbon intensity of about 2 tonnes of CO_2/t primary steel.
16 KGM, GEI and ClimateWorks Foundation (2018), *The Carbon Loophole in Climate Policy*.

7 Carbon performance and targets

ArcelorMittal is making more primary steel, but emissions intensity remains constant.

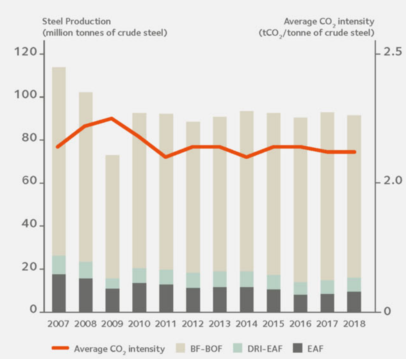
Carbon intensity improvements

The overall average carbon footprint intensity of all our steelmaking routes was 2.12 tCO_2 per tonne of crude steel in 2018.[17] As shown in figure 14, this has remained relatively stable since 2007 (although when looking at the sites we own today that we operated in 2007, there is a 6% improvement over the same period). During this period, the share of primary steelmaking in our production increased from 73% to 78% as we responded to changes in structural market demand.[18]

Primary steelmaking using coke and coal to reduce iron ore is more carbon-intensive than secondary steelmaking using scrap powered with electricity. The increase in the primary:secondary production ratio would, other things being equal, lead to an increase in the average carbon intensity of our steel. However, as shown in figure 14, this is not the case, and our carbon intensity has remained relatively constant. During this period, we have seen improvements in energy and yield efficiencies in our primary steelmaking plants, and a reduction in the carbon intensity of the electricity grid used in our EAF plants. These two factors are effectively negated by the increased proportion of primary steelmaking, leaving the overall average carbon intensity of our steel in 2018 at a similar level to 2007.

By comparison, the global average carbon footprint intensity is 1.83 tCO_2 per tonne of crude steel.[19] ArcelorMittal's higher average intensity is due to our higher use of the emissions-intensive primary steelmaking route: in 2018, we used this route for 78% of our steelmaking, compared to a global average of about 72%.[20]

Figure 13: carbon emissions and our changing portfolio



17 This carbon intensity covers all plants which were in our operational control in the reporting year. Using worldsteel methodology, data covers scope 1 and scope 2 CO_2 emissions, as well as those scope 3 emissions covering purchased pre-processed materials or intermediate products. Comparison is thus of CO_2 emitted for each tonne of steel made within a uniform boundary, and may relate to a broader perimeter than is represented in other steel company data.

18 The financial crisis in 2007/8 led to a protracted decline in demand for steel, particularly from the construction industry in developed countries. In response, we gradually reduced our steel production from EAFs in Europe and North America, which serve these markets. We have also seen a relative rise in the demand for flat products over this time, which are mainly made from the primary BF-BOF route.

19 World Steel Association, *Sustainable Steel: Indicators 2018 and industry initiatives.*

20 World Steel Association, World Steel in Figures 2018.

Our total CO_2 footprint across our steelmaking sites was 194 million tonnes of CO_2 in 2018. ArcelorMittal also has mining activities which had a carbon footprint of nearly 9 million tonnes of CO_2 equivalent in 2018.

Figure 14: CO_2 emissions from steelmaking 2018 (million tonnes)

Scope 1: 167.35
Scope 2: 12.12
Scope 3: 14.65

Our carbon target

ArcelorMittal's current target is to reduce our average carbon footprint intensity by 8% by 2020 against a 2007 baseline. This target relates to those sites we operate today that we owned back in 2007, and therefore excludes acquisitions and divestments.

Our pursuit of this target since 2007 has focused on efficiency and process improvements, many of which have been capital-intensive (**see chapter 5**). By the end of 2018, we had achieved a 6% reduction since 2007.

Towards a new carbon target

We are now focusing on building a roadmap which will underpin a new 2030 carbon reduction target for our steelmaking operations. This will incorporate both the potential for further technical efficiencies across our portfolio and a limited deployment of breakthrough technologies from our innovation programme.

ArcelorMittal's underlying carbon efficiency is improving.

Carbon efficiency

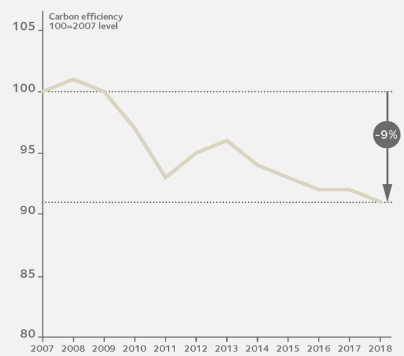
Steelmaking is dependent on a number of external factors influencing the carbon footprint intensity of steel. In order to understand the underlying carbon performance of our sites, ArcelorMittal created an internal metric in 2007.[21] This normalises the carbon inputs and outputs of each process to understand the performance gaps between our different sites. The sheer number of sites in our portfolio enables us to use this metric to benchmark the carbon efficiency of each one.

This process standardises the major external factors that influence carbon emissions such as raw material quality, scrap and slag reuse, and the emissions intensity of national electricity grids. These factors are mainly related to market forces and government policies, which we have limited ability to change while remaining competitive in the global steel market.

In the absence of these factors, our carbon efficiency metric allows us to monitor the performance of our sites in relation to those factors which we do directly control, such as the way our staff manage and reuse energy and carbon onsite, and the technologies we deploy.

The metric shows a 9% improvement in the carbon efficiency of our sites since 2007, as shown in figure 16. This is mainly due to our continued investment in process and efficiency improvements. It is notably greater than the progress we have made in our overall average carbon footprint intensity, which is influenced by the external factors described above.

Figure 15: carbon efficiency improvement per tonne hot rolled coil (2007=100)



21 NB This is a different metric to that used for our carbon intensity target.

Summary of key metrics

Metric		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Steel production (Mt crude steel)		113.9	102.3	73.1	92.5	92.2	88.6	90.9	93.4	92.7	90.4	92.9	**91.5**
BF-BOF / DRI-EAF / scrap-EAF ratio		77:8:15	77:8:15	79:7:15	78:7:15	79:8:14	79:8:13	79:8:13	80:8:12	81:7:11	85:6:9	84:7:9	**83:7:10**
Total CO_2 emissions ($MtCO_2$) – steel only[22,23]		244	227	164	201	194	189	195	196	198	193	196	**194**
	Scope 1	203	189	135	167	163	159	162	167	168	167	170	**167**
	Scope 2	24	23	18	19	18	17	18	14	14	12	13	**12**
	Scope 3	17	15	11	15	13	13	16	14	15	14	13	**15**
Avoided CO_2 emissions from slag used in cement ($MtCO_2$)		11	10	7	8	9	9	10	10	10	10	11	**11**
Avoided CO_2 emissions from use of scrap steel ($MtCO_2$)		53	44	33	41	40	38	40	40	38	35	38	**37**
Average CO_2 intensity (tCO_2 / t crude steel)[24]		2.14	2.22	2.25	2.18	2.10	2.14	2.14	2.10	2.14	2.14	2.12	**2.12**
Average BF-BOF CO_2 intensity (tCO_2 / t crude steel)		2.44	2.54	2.57	2.48	2.38	2.40	2.41	2.35	2.37	2.33	2.31	**2.33**
Average scrap-EAF CO_2 intensity (tCO_2 / t crude steel)		0.74	0.67	0.65	0.66	0.67	0.66	0.70	0.63	0.61	0.53	0.60	**0.66**
Change in crude steel carbon intensity since 2007 (target – 8% by 2020)		0.0%	3.3%	2.6%	0.3%	-4.3%	-4.1%	-3.3%	-5.8%	-4.1%	-5.2%	-6.2%	**-5.6%**
% sites below ArcelorMittal carbon efficiency benchmark		13%	19%	22%	28%	31%	33%	30%	38%	38%	42%	50%	**44%**
Approvals for energy efficiency capital investment projects (million USD)[25]		–	–	–	–	–	–	–	180	11	108	373	**247**

22 Using worldsteel methodology, which ensures that CO_2 emissions for each tonne of steel are measured for the same set of steelmaking processes, whether or not they are owned by the reporting company.
23 Our mining footprint was under 9 million tonnes CO_2 equivalent in 2018.
24 The boundary for this metric covers all of our sites; it is different to the boundary for our carbon reduction target, which only includes sites we have owned since 2007.
25 Before 2014, reporting on capex approvals was not broken down by type.

8 Governance and risk

Board of Directors

Chaired by CEO and Chairman **Lakshmi Mittal**.

The Board and Chairman have overall responsibility for the governance and strategic direction of ArcelorMittal, which includes taking into account the effects of climate change. The Board has two **committees** with further oversight and responsibilities on climate-related issues. Risks are also considered by boards of subsidiaries worldwide.

Appointments, Remuneration, Corporate Governance and Sustainability (ARCGS) Committee

Chaired by lead independent director **Bruno Lafont**.

The ARCGS oversees the implications of sustainability issues under five sustainability pillars, of which one is climate change. The chair of the ARCGS also liaises closely with the chair of the Audit & Risk Committee.

The Committee considers the implications of climate change for the business and oversees the company's strategic planning in response to the risks and opportunities that arise. It receives regular reports from senior management, led by executive officer Brian Aranha, on stakeholder expectations, the company's low-emissions technology strategy, climate-related policy engagement and carbon performance.

Audit & Risk Committee

Chaired by non-executive independent director **Karyn Ovelmen**.

The Audit & Risk Committee ensures that the interests of the company's shareholders are properly protected in relation to risk management, internal control and financial reporting. It oversees both the identification of risks to which the ArcelorMittal group is exposed, via regular senior management reports, and the management response to these risks.

Risk identification and reporting

ArcelorMittal identifies, assesses and manages risks – including climate-related risks – on an ongoing basis. The group level strategy, R&D and sustainable development functions, and segment level experts where appropriate, assess social, environmental, regulatory, stakeholder and technological trends on an ongoing basis. In the medium to long term, climate change poses a number of risks to the business, as identified on pages 34-35. Key risks are analysed by building models and developing scenarios to understand potential financial impacts, such as our exposure to the EU ETS in Phase 4.

Short-term risks within a 12-month timeframe are identified through a bottom-up process by site management teams. Business segments consolidate the identified risks and report the top risks to the CEO office quarterly.

The company uses a risk management framework based on a blend of a COSO, ISO 31000 and an in-house model. Sites assess risks by assigning them a probability of occurrence and a potential financial impact and/or non-financial consequence such as environmental harm. The corporate risk officer works with the environment team to track and strengthen site-level understanding of environmental risks. The corporate risk officer uses Monte Carlo simulations to conduct a stress-testing exercise for the consolidated top ten short-term risks above a $50 million materiality threshold. This exercise quantifies the financial impacts for each top risk to an appropriate confidence level, and the outcome is shared with the Audit & Risk Committee.

Group executive management

The CEO office (chief executive officer, Mr. Lakshmi N. Mittal, and president and chief financial officer, Mr. Aditya Mittal) works closely with relevant **executive officers** and members of the senior management on key strategic issues.

Executive officer Brian Aranha oversees the Group's strategy on climate change and emissions reporting, as well as relevant corporate functions covering strategy, technology, R&D, communications and corporate responsibility.

Climate-related risks and group-level strategy are discussed regularly at the group-wide management committee. Responses are determined by each business segment, on the basis of the markets they serve and national or regional regulatory trends.

Business segment CEOs report quarterly to the CEO office on climate change. Europe Flat Products currently faces the most significant climate-related regulatory risk due to its exposure to the EU ETS. Executive vice-president and CEO ArcelorMittal Europe Flat Products, Geert Van Poelvoorde reports on the strategy and performance of this business segment.

Investment Allocations Committee

Chaired by **executive officer Brian Aranha**.

This committee also includes VP technology strategy and VP head of strategy. This committee makes capex decisions, which includes investment to improve environmental performance, energy and carbon efficiencies.

Climate & Environment Working Group

Chaired by **executive officer Brian Aranha**.

The group is responsible for informing and shaping the company's climate change strategy. Members of the group include VP government affairs, VP corporate communications & CR; VP head of strategy; VP technology strategy; GM, head of SD.

This group links to the GBTC via VP technology strategy.

Global Breakthrough Technology Council (GBTC)

Chaired by **Carl de Mare,** VP, technology strategy.

The GBTC consists of regional/project based R&D officers. GBTC coordinates progress on the low-emissions technology programme.

Government Affairs Council

Chaired by **Frank Schulz**, VP government affairs.

This group is responsible for aligning local climate change policy strategies with the overall Group strategy. This ensures consistent engagement activities on climate-related issues across the Group.

Risk management and strategic planning

Climate-related trends and risks identified by management are used to inform the company's strategic outlook, led by executive officer Brian Aranha. This is discussed on a regular basis by the Group management committee.

To develop our response to our longer-term climate-related risks and opportunities, we assess long-term market trends such as scrap metal availability, develop alternative low-emissions technologies, undertake cost analysis of these technologies, engage continuously with key stakeholders, and analyse the implications of different levels of policy support through the scenario analysis outlined in this report.

Central to our approach to mitigating our key climate-related risk – policy risk – is our adoption of a low-emissions technology strategy. Integral to this is our work to engage policymakers on supportive frameworks to enable significant emissions reductions to be viable, as outlined in this report. At the same time, all our business segments are required to prepare CO_2 reduction plans as part of the annual planning cycle.

This report, and the assessment of the resilience of our business to the transition and physical risks described in this report, has been discussed and approved by executive officer Brian Aranha; president, group CFO and CEO ArcelorMittal Europe Mr. Aditya Mittal; lead independent director and ARCGS committee chair Bruno Lafont; and chairman and CEO Mr. Lakshmi N. Mittal.

Managing climate-related risks

At ArcelorMittal, we review our risk universe regularly, including specific climate-related risks. In summary, we have identified and are managing the following top climate-related risks:

TRANSITION RISKS	Type & status	Response
Policy & Regulation	Our most substantial climate-related policy risk is the EU ETS, which applies to all our European plants, making up 44% of our total capacity. The risk concerns our primary steelmaking plants which are exposed to this regulation and yet unprotected against competition from imported steel. We have evaluated this risk against a carbon price of €15 per tonne of CO_2, and the cumulative risk exposure[26] for our European business over 2021 to 2030 stands at more than €3 billion, rising to €5 billion under a carbon price of €25 per tonne of CO_2. We are also tracking carbon market policy developments in South Africa, Mexico, Brazil, Kazakhstan and Canada, where a further 30% of our production capacity resides. We consider that the financial risks arising from these are less immediate. Furthermore, we are also closely monitoring policy developments in the United States, which has shifted from federal climate policy to more decentralised policies at the state and local levels.	We are developing a range of low-emission technologies, and many of these to demonstration stage. However, significant long-term mitigation requires supportive policies to ensure the roll out of our low-emissions technologies is viable. We have analysed the implications of different policy and technology scenarios (**see chapter 4**) and this has informed our policy positions outlined in **chapter 6.** In the medium term, we are developing an emissions reduction roadmap to support a new 2030 carbon target.
Reputation	Our stakeholders' views on our response to the climate challenge affect the ratings we receive from investors. In the context of the transition to a low-emissions economy, our social licence to operate is defined by several key factors including: our transparency on carbon emissions, our ability to communicate on a complex subject, and our ability to make a credible commitment to meeting the objectives of the Paris Agreement.	We respond to CDP annually. We also engage with stakeholders on climate risk issues and we hope that this Climate Action Report helps to build further understanding of our climate-related commitments and current constraints.
Technology	As the world acts to mitigate GHG emissions, investments in technological innovations such as Carbalyst® and Torero are vital to our long-term resilience and competitiveness. The risk of these technologies not becoming viable for us in the medium to long term is dependent on the development of the technologies, the availability of investment to implement them, access to sufficient renewable energy to support them, and policies that promote these conditions. Novel technologies require a long timeline to be scaled up. The risk is increased by the slow and uncertain development of policies needed to create sufficient incentives to exploit these opportunities. A key problem is that current policies are based on a linear economic model; by contrast, the novel technologies we are already advancing adopt a circular approach to reusing resources and so both energy and materials policies need to be integrated.	**See chapter 4** on low-emissions technology pathways and policy scenarios. **See chapter 5** on ArcelorMittal's low-emissions innovation programme.

26 Non discounted with current technologies

TRANSITION RISKS Type & status		Response
Market	We have faced the risk of substitution from competing materials displacing steel in particular applications. We have seen this from aluminium and cement due to an excessive focus on emissions from products in their use phase only (where the lightest weight wins) rather than on a whole lifecycle basis (cradle to grave). However, as customers deepen their understanding of embedded and lifecycle emissions of the materials, steel compares favourably, and so we see this risk diminishing. With the switch to electric vehicles, we see opportunities for high-strength steels for battery protection and electrical steels. We also project that the move to wind and solar power generation will require more steel per unit of electricity generated compared to conventional technologies.	We continue to grow opportunities in all these markets, for example via our S-in motion® and Steligence programmes (**see page 5**).

PHYSICAL RISKS Type & status		Response
Acute physical risks	Adverse weather events, such as extreme low temperatures in North America, very high winds in Europe and flooding in Spain have on occasion hampered our supply and distribution routes. Our Calvert JV plant is in an area prone to hurricanes and tornadoes, and wildfires are a risk to our sites in Kazakhstan and South Africa. With 3 to 4°C of warming, hurricanes are projected to increase in intensity – along with associated increases in heavy precipitation – but not in frequency.	Our risk management process enables us to build resilience at our plants and in supply chains where extreme events already occur; this may need further development where extreme events are currently rare, but may be more frequent or intense in the future.
Chronic physical risks	Water is crucial to our steelmaking processes and where plants are in areas of water stress, this is even more important. Some facilities are at risk of being affected by long periods of drought conditions.	Where these risks exist, such as in South Africa and Brazil, we have developed local resource management plans to ensure that operational water requirements can be met. We are fully engaged with local stakeholders on this issue.

9 Alignment with TCFD recommendations

TCFD Recommended Disclosures	Chapter	Further information (where applicable)
Governance		
A) Describe the board's oversight of climate-related risks and opportunities.	8	
B) Describe management's role in assessing and managing risks and opportunities.	8	2018 CDP Climate Change response C1.2
Strategy		
A) Describe the climate-related risks and opportunities the organisation has identified over the short, medium, and long term.	2, 3, 8	2018 CDP Climate Change response C2.1, C2.2c, C2.3a, C2.4a
B) Describe the impact of climate-related risks and opportunities on the organisation's businesses, strategy, and financial planning.	5, 8	P13 – 15 Form 20f Item 3 Section D. Risk Factors[27] 2018 CDP response C2.3, C2.5, C2.6
C) Describe the resilience of the organisation's strategy, taking into consideration different climate-related scenarios, including a 2°C or lower scenario.	4	2018 CDP response C3.1
Risk Management		
A) Describe the organisation's processes for identifying and assessing climate-related risks.	8	2018 CDP response C2.2b
B) Describe the organisation's processes for managing climate-related risks.	8	2018 CDP response C2.2d
C) Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organisation's overall risk management.	8	
Metrics and Targets		
A) Disclose the metrics used by the organisation to assess climate-related risks and opportunities in line with its strategy and risk management process.	7	2018 CDP response C4.1b
B) Disclose Scope 1, Scope 2, and, if appropriate, Scope 3 greenhouse gas (GHG) emissions, and the related risks.	7	2018 CDP response C5.1, C6.1, C6.3, C6.5
C) Describe the targets used by the organisation to manage climate-related risks and opportunities and performance against targets.	7	2018 CDP response C4.1b

27 https://corporate.arcelormittal.com/~/media/Files/A/ArcelorMittal/investors/20-f/2018/form-20f-2018.pdf

10 Annex 1: The steelmaking process

Steel is a material that consists almost completely of iron, with small shares of carbon and even smaller shares of other elements such as manganese and nickel. Today, steel is primarily made using two different technologies: the integrated steel plant and the electric arc furnace (EAF).

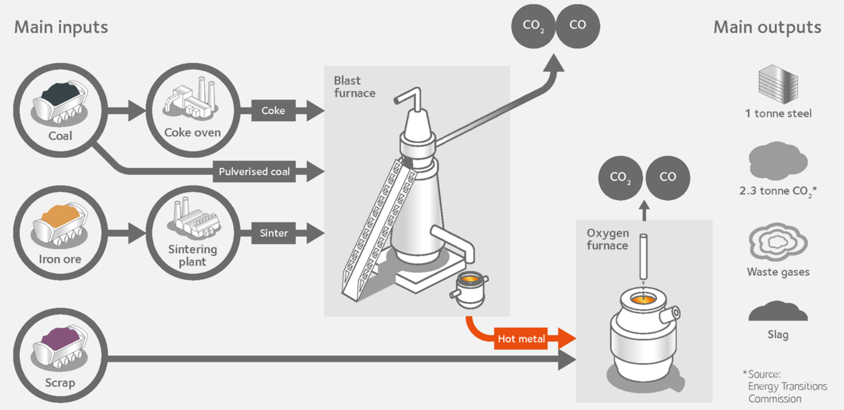
We use an integrated steel plant to make primary steel (i.e. virgin steel) mostly from iron ore, which is extracted from mines, and a small share of scrap steel. As iron ore – a compound made up of iron and oxygen – is found in nature, it is chemically a very stable compound. Iron is not alone in this respect – most metals from aluminium to uranium are found in nature bound to oxygen. In primary steelmaking, we use energy and carbon to separate iron from oxygen in a blast furnace, and in subsequent steps, we adjust the product chemically and physically into the final desired form with characteristics such as strength, flexibility and corrosion tailored to the needs of the end user.

In contrast, in an electric arc furnace (EAF), we use scrap steel and/or scrap substitutes such as direct reduced iron (DRI). We melt these materials using electrical energy, thus entirely replacing all of the steps up to and including the energy-intensive blast furnace. Similar to the integrated steel plant route, we cast, and then shape or roll the liquid steel produced from the EAF into its final form.

These two steelmaking routes are outlined in more detail on the following two pages.

The steelmaking process

Figure 16: steelmaking at an integrated steel plant (using iron ore)



Integrated steel plant

Preparation of materials for the blast furnace

The first steps in the primary steelmaking route are to prepare the materials used in the blast furnace – coke and sinter. Coke is a material high in carbon made by heating metallurgical coal at high temperatures in a coke oven in the absence of oxygen. The process of making coke also results in the production of a hydrogen-rich synthetic gas (coke oven gas) which we can use as an energy source to heat coke ovens. Alternatively, we can use blast furnace gas to heat the coke oven. Combustion of these gases in the coke oven creates CO_2.

Sinter is an agglomeration which is produced from a mixture of all kinds of iron ores, coal and coke particles. We ignite the coal/coke particles in the mixture using coke oven gas, blast furnace gas or natural gas. This results in sinter cake, which we later crush and cool. CO_2 is a by-product of the sinter plant. Sinter accounts for about 70 to 90% of the metals loaded into the blast furnace; the remaining part of the burden consists of pellets and lump ore.

Ironmaking in the blast furnace

In the blast furnace, we load sinter, coke and lime into the top, and we inject hot air from the bottom. We also inject pulverized coal into the blast furnace to reduce the amount of coke used, which reduces costs as well as CO_2 emissions. The hot air reacts with the coke and coal to form carbon monoxide (CO), which is the reducing agent that separates the elements of iron ore: iron and oxygen. When CO extracts oxygen from iron ore, CO_2 is formed. Carbon is therefore essential in the integrated steel plant and CO_2 is an inevitable by-product of the chemical reactions. The waste gases from the process contain equal amounts of CO and CO_2, as well as hydrogen and nitrogen.

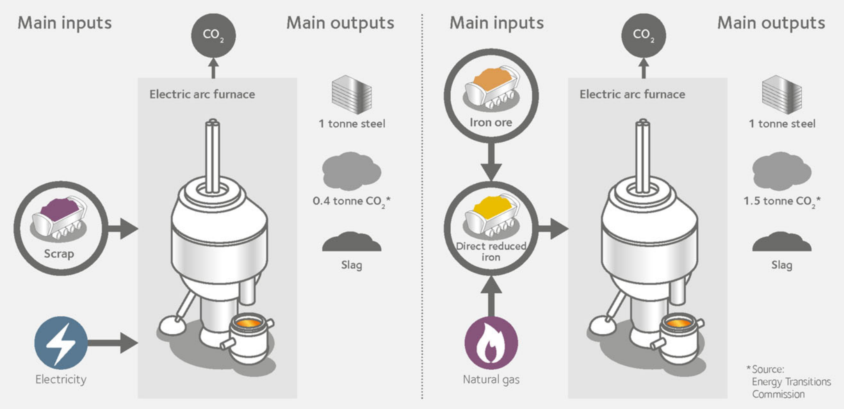
Heat is also generated in the blast furnace, which is essential to melting the reduced iron ore to form liquid hot metal (molten iron). The impurities react with lime to produce slag, which floats on top of the liquid hot metal and contains impurities in the iron ore, coke and coal ash. Slag has a chemical composition similar to clinker, which is used to make cement. This means that slag can be used as a substitute for clinker.

Steelmaking in a basic oxygen furnace

To make steel, we need to adjust the chemical composition of the liquid hot metal in a basic oxygen furnace (BOF). We charge the furnace with 15-25% scrap steel and 75-85% liquid hot metal. We also inject oxygen into the furnace, which reacts with carbon and other impurities in the liquid hot metal. In the BOF, the process converts the impurities into slag, which floats on top of the liquid steel, and into waste gases (or BOF gas), which mostly consists of CO.

We tap the liquid purified steel into a steel ladle, where we can further adjust the steel chemistry. We then transport it to a continuous caster for casting and we further shape or roll the steel into its final form. Various finishing or coating processes may follow this casting and rolling. The steel slag is tapped into another vessel to be cooled down and prepared for external use.

Figure 17: EAF steelmaking (using scrap or DRI)



Electric arc furnace

Most electric arc furnaces (EAFs) are charged with scrap steel to make secondary or recycled steel. As the process is mainly one of melting scrap steel using electricity and not separating iron from oxygen, carbon's role is not as dominant as it is in the integrated steel plant. In an EAF, direct CO_2 emissions are mainly associated with the consumption of the carbon electrodes, and indirect CO_2 emissions are produced from the carbon intensity of the electricity grid. As with the integrated route, slag is also a by-product of EAF steelmaking.

The quality of secondary steel produced by the EAF route is primarily limited by the quality of the metallic raw materials used in steelmaking, which in turn is affected by the availability of high-quality scrap. As described in chapter 3, we currently do not have enough scrap to meet demand for steel. This means that today, it is most efficient to make lower grades of steel in an EAF, which have fewer constraints on impurities.

We can also charge EAFs with DRI. DRI is made by reducing iron ore (i.e. separating iron and oxygen) using natural gas; by-products of the process include CO_2. Steel made using this route can reach the qualities obtained by an integrated steel plant, since DRI has fewer impurities than scrap steel. In 2017, DRI accounted for about 7% of primary iron production, with the remainder of iron produced via the blast furnace route.[28]

28 World Steel Association (2018), *Steel Statistical Yearbook 2018*.

11 Annex 2: Glossary

Basic oxygen steelmaking	The process whereby hot metal and steel scrap are charged into a Basic oxygen furnace (BOF). High purity oxygen is then blown into the metal bath, combining with carbon and other elements to reduce the impurities in the molten charge and convert it into steel.
Blast furnace (BF)	A large cylindrical structure into which iron ore is combined with coke and limestone to produce molten iron.
Circular carbon	Circular carbon energy sources include bio-based and plastic wastes from municipal and industrial sources and agricultural and forestry residues. The term may also refer to the reuse of carbon in circular flows throughout the economy, for example, in the production of plastics made from waste carbon.
Coal	The primary fuel used by integrated iron and steel producers.
Coke	A form of carbonised coal burned in blast furnaces to reduce sinter, iron ore pellets or other iron-bearing materials to molten iron.
Coke ovens	Ovens where coke is produced. Coal is usually dropped into the ovens through openings in the roof, and heated by gas burning in flues in the walls between ovens within the coke oven battery. After heating for about 18 hours, the end doors are removed and a ram pushes the coke into a quenching car for cooling before delivery to the blast furnace.
Crude steel	Steel in the first solid state after melting, suitable for further processing or for sale. Synonymous with raw steel.
Direct reduction	A family of processes for making iron from ore without exceeding the melting temperature. No blast furnace is needed.
Electric arc furnace (EAF)	A furnace used to melt steel scrap or direct reduced iron.
Iron ore	The primary raw material in the manufacture of steel made up of iron and oxygen.
Limestone	Used by the steel industry to remove impurities from the iron made in blast furnaces. Magnesium-containing limestone, called dolomite, is also sometimes used in the purifying process.
Pellets	An enriched form of iron ore shaped into small balls.
Pig iron	High carbon iron made by the reduction of iron ore in the blast furnace.
Sintering	A process which combines ores too fine for efficient blast furnace use with flux stone. The mixture is heated to form lumps, which allow better draught in the blast furnace.

Designed and produced by Falcon Windsor www.falconwindsor.com

ArcelorMittal

Published in May 2019

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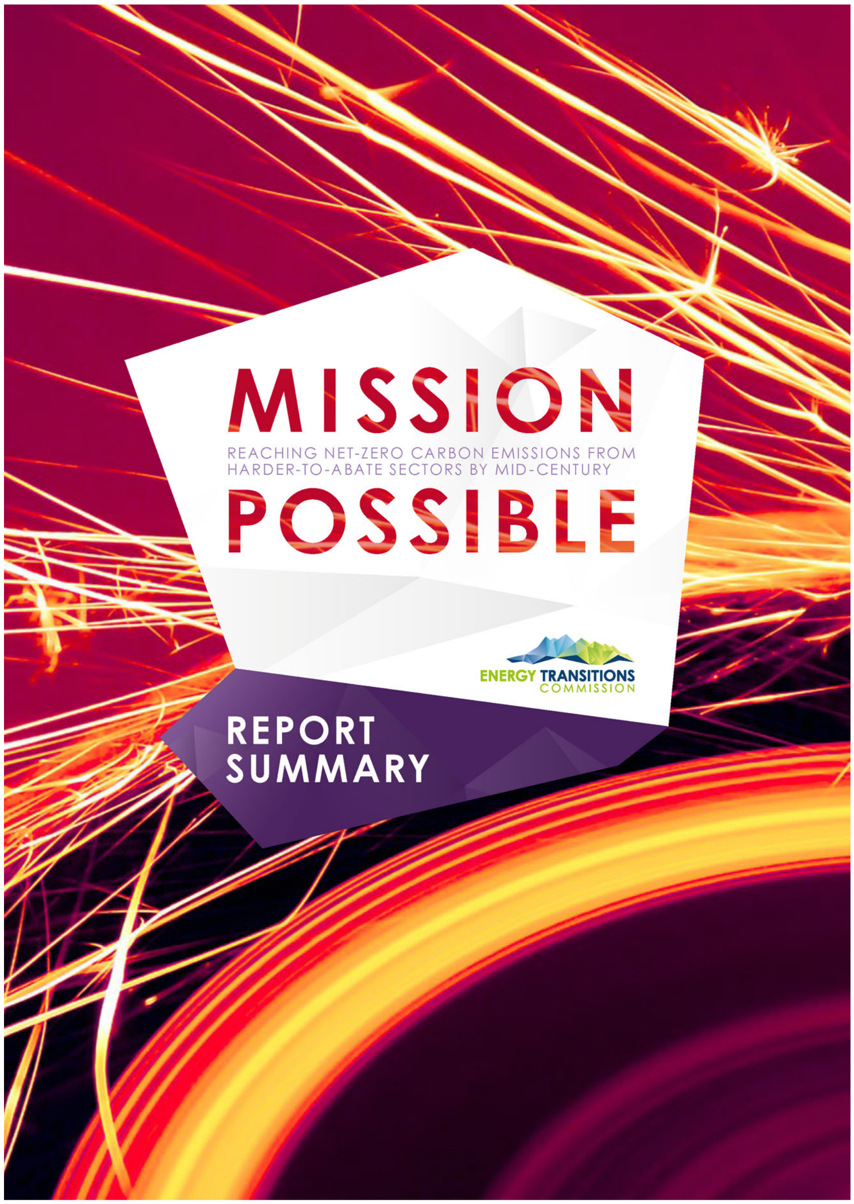
MISSION
REACHING NET-ZERO CARBON EMISSIONS FROM
HARDER-TO-ABATE SECTORS BY MID-CENTURY
POSSIBLE
ENERGY TRANSITIONS
COMMISSION
REPORT
SUMMARY


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REPORT
SUMMARY
NOVEMBER 2018

The Energy Transitions Commission

The Energy Transitions Commission (ETC) brings together a diverse group of leaders from across the energy landscape: energy producers, energy users, equipment suppliers, investors, non-profit organizations and academics from the developed and developing world. Our aim is to accelerate change towards low-carbon energy systems that enable robust economic development and limit the rise in global temperature to well below 2˚C and as close as possible to 1.5˚C.

The ETC is co-chaired by Lord Adair Turner and Dr. Ajay Mathur. Our Commissioners are listed on the next page.

The *Mission Possible* report was developed by the Commissioners with the support of the ETC Secretariat, provided by SYSTEMIQ. It draws upon a set of analyses carried out by Material Economics, McKinsey & Company, University Maritime Advisory Services and SYSTEMIQ for and in partnership with the ETC, as well as a broader literature review.

Emerging findings were subject to a six-month consultation process through which we received inputs from nearly 200 experts from companies, industry initiatives, international organizations, non-governmental organizations and academia. We warmly thank them for their contributions.

This report constitutes a collective view of the Energy Transitions Commission. Members of the ETC endorse the general thrust of the arguments made in this report, but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse the report.

The ETC Commissioners not only agree on the importance of reaching net-zero carbon emissions from the energy and industrial systems by mid-century, but also share a broad vision of how the transition can be achieved. The fact that this agreement is possible between leaders from companies and organizations with different perspectives on and interests in the energy system should give decision-makers across the world confidence that it is possible simultaneously to grow the global economy and to limit global warming to well below 2˚C, and that many of the key actions to achieve these goals are clear and can be pursued without delay.

Learn more at:
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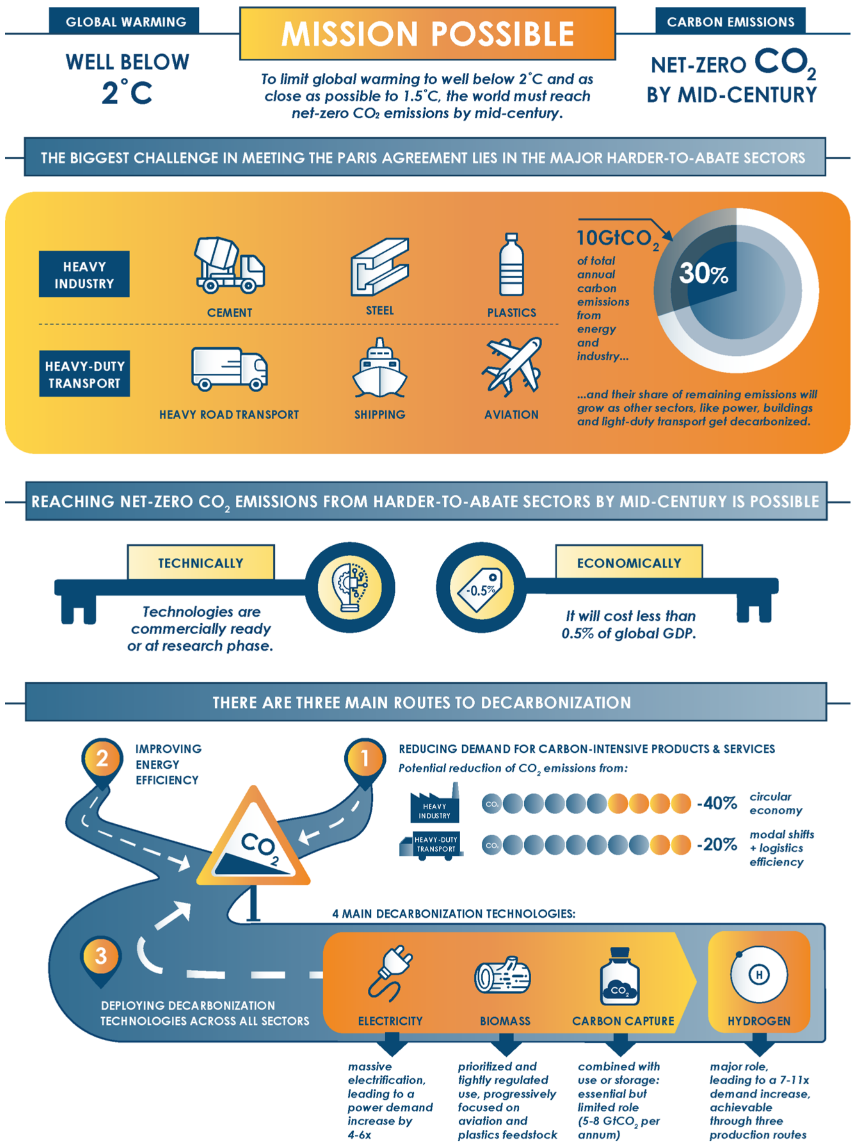

GLOBAL WARMING
WELL BELOW 2°C
MISSION POSSIBLE
To limit global warming to well below 2°C and as close as possible to 1.5°C, the world must reach net-zero CO₂ emissions by mid-century.
CARBON EMISSIONS
NET-ZERO CO2 BY MID-CENTURY
THE BIGGEST CHALLENGE IN MEETING THE PARIS AGREEMENT LIES IN THE MAJOR HARDER-TO-ABATE SECTORS
HEAVY INDUSTRY
CEMENT
STEEL
PLASTICS
HEAVY-DUTY TRANSPORT
HEAVY ROAD TRANSPORT
SHIPPING
AVIATION
10GtCO2 of total annual carbon emissions from energy and industry...
30%
...and their share of remaining emissions will grow as other sectors, like power, buildings and light-duty transport get decarbonized.
REACHING NET-ZERO CO2 EMISSIONS FROM HARDER-TO-ABATE SECTORS BY MID-CENTURY IS POSSIBLE
TECHNICALLY
Technologies are commercially ready or at research phase.
-0.5%
ECONOMICALLY
It will cost less than 0.5% of global GDP.
THERE ARE THREE MAIN ROUTES TO DECARBONIZATION
2 IMPROVING ENERGY EFFICIENCY
1 REDUCING DEMAND FOR CARBON-INTENSIVE PRODUCTS & SERVICES
Potential reduction of CO2 emissions from:
HEAVY INDUSTRY -40% circular economy
HEAVY-DUTY TRANSPORT -20% modal shifts + logistics efficiency
CO2
3 DEPLOYING DECARBONIZATION TECHNOLOGIES ACROSS ALL SECTORS
4 MAIN DECARBONIZATION TECHNOLOGIES:
ELECTRICITY
BIOMASS
CARBON CAPTURE
HYDROGEN
massive electrification, leading to a power demand increase by 4-6x
prioritized and tightly regulated use, progressively focused on aviation and plastics feedstock
combined with use or storage: essential but limited role (5-8 GtCO2 per annum)
major role, leading to a 7-11x demand increase, achievable through three production routes

The Paris climate agreement committed the world to **limit global warming to well below 2°C and keep it as close as possible to 1.5°C above preindustrial levels.** The latest IPCC report[1] has warned the world of the major negative impacts on humanity and the planet of a rise in global temperatures of 1.5°C, and the even more dramatic consequences of 2°C global warming. It therefore urges the world to aim for 1.5°C and recommends achieving net-zero CO_2 emissions globally by 2050.

The Energy Transitions Commission (ETC) – a coalition of business, finance and civil society leaders from across the spectrum of energy producing and using industries – supports the objective of limiting global warming ideally to 1.5°C and, at the very least, well below 2°C.

To achieve even the 2°C goal, and to have any chance of reaching the aspired 1.5°C limit, **it is essential for energy and industrial systems to achieve net-zero CO_2 emissions within themselves** – i.e. without permanently relying on offsets from the land use sector. The ETC strongly believes that **this is achievable by 2050 in developed economies and 2060 in developing economies[2].**

This is an imperative, but also a major opportunity. As the New Climate Economy has demonstrated, the **new economic model** required to avoid harmful climate change will also drive rapid technological innovation, increase resource productivity, create jobs in new industries and deliver local environmental benefits which increase quality of life.

Action over the next decade will be vital, both to deliver the early emissions reductions needed to limit the growing stock of CO_2 in the atmosphere, and to make it possible to reach net-zero emissions from the energy and industrial systems by mid-century.

Achieving net-zero CO_2 emissions from the energy and industrial systems will require **rapid improvements in energy efficiency** combined with **the rapid decarbonization of power and the gradual electrification of as much of the economy as possible[3]**, mainly light-duty road transport, manufacturing, and a significant part of residential cooking, heating and cooling. In the Energy Transitions Commission's first report – *Better Energy, Greater Prosperity* – published in April 2017, we focused on these challenges. In particular, we demonstrated that dramatic reductions in the cost of renewable electricity generation and of energy storage options now make it possible to plan for cost-competitive power systems which are nearly entirely dependent on wind and solar (e.g. at 85-90%)[4].

However, to reach a fully decarbonized economy, we must also **reduce and eventually eliminate emissions from what we have labelled the "harder-to-abate" sectors in heavy industry (in particular cement, steel and chemicals) and heavy-duty transport (heavy-duty road transport, shipping and aviation)**. These sectors currently account for 10Gt (30%) of total global CO_2 emissions, but, on current trends, their emissions could account for 16Gt by 2050 and a growing share of remaining emissions as the rest of the economy decarbonizes[5]. To date, many national strategies – as set out in Nationally Determined Contributions (NDCs) to the Paris agreement – focus little attention on these sectors.

Over the last year, the ETC has therefore focused on defining a path to net-zero CO_2 emissions in the harder-to-abate sectors[6]. The good news is that **this is technically possible by mid-century at a cost to the economy of less than 0.5% of global GDP** with a minor impact on consumer living standards. The technologies required to achieve this decarbonization already exist: several still need to reach commercial viability; but we do not need to assume fundamental and currently unknown research breakthroughs to be confident that net-zero carbon emissions can be reached. Moreover, **the cost of decarbonization can be very significantly reduced** by making better use of carbon-intensive materials (through greater materials efficiency and recycling) and by constraining demand growth for carbon-intensive transport (through greater logistics efficiency and modal shift).

However, **this vital and technically possible transition will not be achieved unless policymakers, investors and businesses jointly take immediate and forceful action** to transform economic systems.

This report therefore describes in turn:

A. Why reaching net-zero CO_2 emissions from harder-to-abate sectors is technically and economically feasible (p.8);
B. How to manage the transition to net-zero CO_2 emissions in heavy industry and heavy-duty transport (p.20);
C. What policymakers, investors, businesses and consumers must do to accelerate change (p.24).

1 IPCC (2018), *Global warming of 1.5˚C*
2 If the world is to be net-zero CO_2 emissions by mid-century, negative emissions from the land use sector will therefore be needed during the transition period to compensate for remaining emissions from the energy and industrial systems in the 2050s.
3 The pace of electrification will need to be adapted to the pace of power decarbonization, as explained on page 15.
4 Energy Transitions Commission (2017), *Better Energy, Greater Prosperity*
5 IEA (2017), *Energy Technology Perspectives*
6 Throughout this report, the ETC presents quantifications whose aim is to identify likely orders of magnitude that can inform policy and investment, rather than develop a scenario and suggest that precise prediction is possible. In particular, the ETC's illustrative pathway assesses the implications for the energy system of an illustrative mix of supply-side and demand-side decarbonization solutions by mid-century.

8

A. MISSION POSSIBLE: REACHING NET-ZERO CO_2 EMISSIONS FROM HARDER-TO-ABATE SECTORS IS TECHNICALLY AND ECONOMICALLY FEASIBLE

It is technically possible to decarbonize all the harder-to-abate sectors by mid-century at a total cost of well less than 0.5% of global GDP. Three complementary sets of actions are required:

- **Limiting demand growth** – which can greatly reduce the cost of industrial decarbonization and, to a lower extent, of heavy-duty transport decarbonization;
- **Improving energy efficiency** – which can enable early progress in emissions reduction and reduce eventual decarbonization costs;
- **Applying decarbonization technologies**[7] – which will be essential to eventually achieving net-zero CO_2 emissions from the energy and industrial systems.

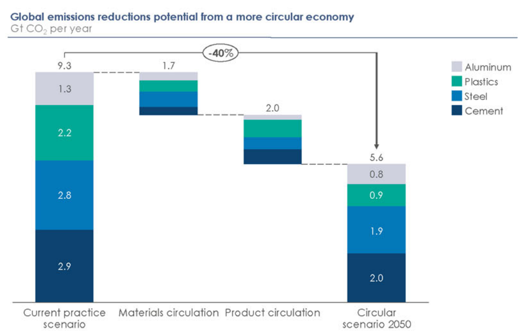
REACHING NET-ZERO CO_2 EMISSIONS FROM HEAVY INDUSTRY

Demand management through materials efficiency and circularity

A more circular economy can reduce CO_2 emissions from four major industry sectors (plastics, steel, aluminum and cement) by 40% globally, and by 56% in developed economies like Europe by 2050[8] [Exhibit 1]. This entails two major developments: (i) making better use of existing stocks of materials through greater and better recycling and reuse and (ii) reducing the materials requirements in key value chains (e.g. transport, buildings, consumer goods, etc.) through improved product design, longer product lifetime, and new service-based and sharing business models (e.g. car sharing).

- **Primary plastics production could be reduced by 56%** versus business as usual, through more extensive mechanical and chemical recycling, and reduced use of plastics in key value chains.
- **Primary steel production could be cut by 37%** versus business as usual levels, through reduced losses across the value chain, reduced downgrading in the recycling process, greater reuse of steel-based products, and a shift to new car-sharing systems.

A more circular economy can cut emissions from the harder-to-abate sectors in industry by 40% by 2050



Source: Material Economics analysis for the Energy Transitions Commission (2018)

Exhibit 1

7 We use the term "decarbonization technologies" to describe technologies that reduce anthropogenic carbon emissions by unit of product or service delivered through fuel/feedstock switch, process change or carbon capture. This does not entail a complete elimination of CO_2 use. First, the use of biomass or synthetic fuels can result in the release of CO_2 previously sequestered from the atmosphere through biomass growth or direct air capture. Second, CO_2 might still be embedded in the materials (e.g. in plastics). We exclude energy efficiency technologies from the scope of "decarbonization technologies", as they are considered separately.

8 Material Economics analysis for the Energy Transitions Commission (2018)

- **Primary aluminum production could be cut by 40%** through the same mix of approaches applied in steel.
- In cement, recycling opportunities are more limited, but **improved building design could reduce total demand by 34%.**

Capturing these opportunities will require major changes to product design and to relationships between companies operating at different points in value chains. Strong policies are required to create incentives for these changes.

Energy efficiency

In the industrial sectors, opportunities for energy efficiency improvement within existing processes (through advanced production techniques or the application of digital technologies) can enable short-term emissions reductions. They are unlikely to exceed **15-20% of energy consumption,** but will be essential to reduce emissions from existing, long-lived industrial assets, in particular in developing countries.

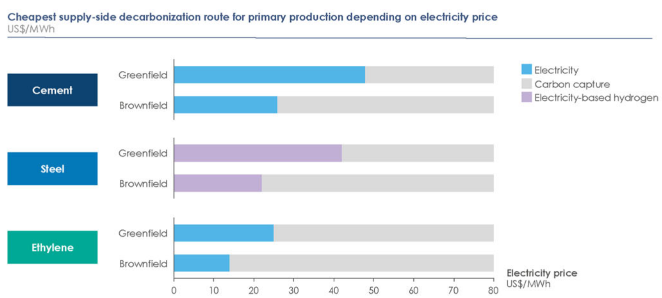
Decarbonization technologies

In each industrial sector, there are four main pathways to the decarbonization of production:

- Using **hydrogen as a heat source or as a reduction agent,** in the case of steel and chemicals production, with zero-carbon hydrogen derived from electrolysis (which will likely be the predominant route in the long term) or near-zero-carbon hydrogen derived from steam methane reforming (SMR) with carbon capture[9];
- **Direct electrification of industrial processes**, in particular the generation of high temperature heat;
- **The use of biomass as an energy source for heat production**, as a reduction agent in steel production or as a feedstock in particular for plastics production;
- **Carbon capture**, combined with either use or underground storage.

In each of the industrial sectors, the most cost-effective route to decarbonization will likely **vary by specific locations depending on local resources.** In particular, the choice between the electricity-based routes and either biomass or carbon capture options will be strongly influenced by the price at which zero-carbon electricity is available locally[10] [Exhibit 2].

Whether electricity-based decarbonization is cheaper than a carbon capture route will be strongly driven by the electricity price



Note: Biomass may be lower cost in some geographies but is not considered as a priority option due to limited availability
Source: McKinsey & Company (2018), *Decarbonization of the industrial sectors: the next frontier*

Exhibit 2

9 Zero-carbon hydrogen could also theoretically come from biomethane reforming, although this route is unlikely to play a major role given constraints on sustainable biomass supply.
10 Exhibit 2 only presents the trade-off between the electricity-based route and carbon capture at different electricity prices. The cost of carbon capture, when combined with underground storage, may vary depending on location. Biomass may be lower cost in some geographies, but is not considered as a priority option due to limited availability.

10 Regardless of the route, our analysis makes us confident that it will be possible to decarbonize the harder-to-abate industrial sectors at costs per tonne of CO_2 saved of US$60 or less for steel, US$130 or less in cement, and US$300 or less in the case of plastics (ethylene production).

REACHING NET-ZERO CO_2 EMISSIONS FROM HEAVY-DUTY TRANSPORT

Demand management through logistics efficiency and modal shifts

Opportunities to reduce demand growth are more limited in the transport sectors than in the industrial sectors, as freight transport is driven by global economic growth and passenger transport by higher mobility demand in emerging economies. Nonetheless, **a combination of greater logistics efficiency and modal shifts** – from trucking to rail and shipping, and from short-haul aviation to high-speed rail – **might still deliver up to 20% reduction in CO_2 emissions** [Exhibit 3].

Energy efficiency

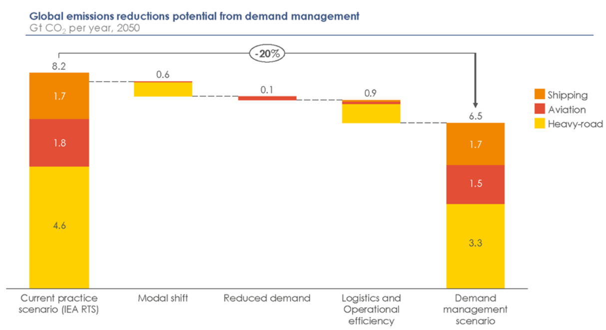
There are significant opportunities to **improve energy efficiency by 35-40% in the transport sectors** without radical changes in technology, and potentially more with technology breakthroughs. This potential will be particularly important in shipping and aviation, given the long lifetime of planes and ships: potential energy efficiency improvements in engine and vessel/airframe design could very significantly reduce the cost of switching to a new fuel.

Decarbonization technologies

The predominant route to full decarbonization and the costs incurred will likely be significantly different for heavy road transport than for shipping and aviation [Exhibit 4].

- **In heavy road transport, electric drivetrains will almost certainly eventually dominate** given their efficiency advantage over internal combustion engines, with energy storage either in battery or hydrogen form. Electric trucks are likely to become cost-competitive with diesel or gasoline vehicles during the 2020s. As a result, any role for biofuels and natural gas will and should be only transitional.

Demand management can cut emissions from the harder-to-abate sectors in transport by 20% by 2050



Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

Exhibit 3

- **In both shipping and aviation, electric engines using battery or hydrogen energy storage will likely play a role in short-distance transport.** But, unless and until there is a major breakthrough in battery density, **long-distance aviation will probably rely either on bio jet fuel or synthetic jet fuel, while long-distance shipping will likely use ammonia or (to a lower extent) biodiesels**[11] in existing engines. Since these fuels will likely be more expensive than existing fossil fuels, decarbonization costs could be US$115-230 per tonne for aviation and US$150-350 for shipping, although technological progress and economies of scale could reduce these costs over time.

MINIMAL COSTS TO THE ECONOMY AND TO CONSUMERS

Cost to the global economy

Estimated marginal costs of abatement, based on already proven decarbonization technologies, vary greatly by sector; but, in most of the harder-to abate sectors, they are significant [Exhibit 5].

Even with these costs, and even if demand grows in line with business-as-usual forecasts, the maximum additional cost of decarbonized heavy industry and heavy-duty transport would only be **0.5% of global GDP by mid-century** [Exhibit 6]. The cost of running a net-zero-CO_2-emissions economy would be well less than 1% of GDP.

These costs are dominated by four sectors. Within industry, **cement** will be relatively costly to decarbonize because of process emissions, but so too will **plastics**, given the need to eliminate both production and end-of-life emissions. Within transport, **aviation and shipping** will be relatively costly to decarbonize, whereas shifting to battery electric or hydrogen fuel-cell trucks is likely to entail minimum costs given the inherent energy efficiency advantage of electric engines[12].

These decarbonization costs could be significantly reduced by three factors:

- **Lower renewable energy costs:** If zero-carbon electricity was available at US$20/MWh across the world (instead of US$40/MWh), decarbonizing heavy industry would cost 25% less. Similarly, the cost of decarbonizing shipping and aviation would fall by 55% if the additional cost of biofuels or synfuels could be brought down to US$0.30 per litre (instead of US$0.60

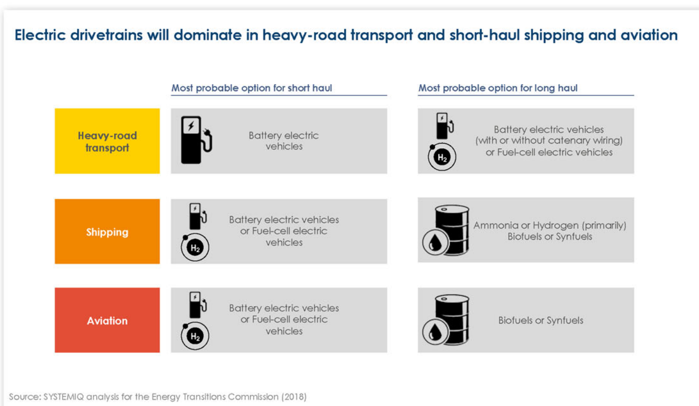


Exhibit 4

11 Given constraints on the sustainable supply of biomass, bioenergy use should indeed be limited in sectors where alternative low-carbon fuels exist.
12 BEVs and FCEVs will, however, demand infrastructure investment addressed later in this report.

12

per litre). Overall, lower renewable energy prices could reduce the total cost to the global economy from 0.45% to 0.24% of global GDP.

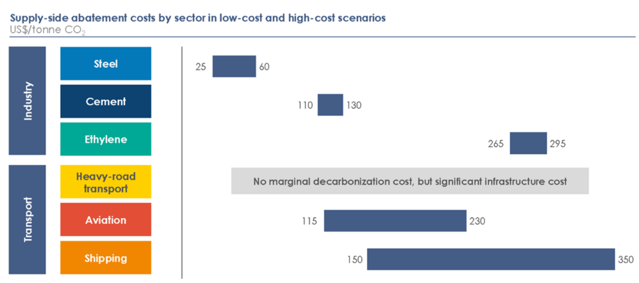
- **Demand management:** Greater recycling and reuse of materials within a more circular economy, combined with logistics efficiency and modal shifts in transport sectors, could reduce the decarbonization costs for harder-to-abate sectors by 40-45%, bringing them down to 0.15-0.25% of global GDP.
- **Future technological development:** History tells us that learning curve and economies of scale effects often reduce technology costs by more than anticipated, and that new technologies emerge which could not be anticipated in advance. If this occurred in the future, the cost of decarbonization could be dramatically reduced. For instance, the cost of decarbonizing cement could be far lower if learning curve and scale bring down the cost of carbon capture, and the cost of decarbonizing aviation and shipping would be far lower if dramatic battery density improvements allowed a greater role for electrification.

Analysis of total capital investment needs further confirms that **decarbonization is achievable at an affordable cost.**

- In the **industrial sectors**, total incremental capital investment from 2015 to 2050 could amount to US$5.5 to US$8.4 trillion[13], representing about 0.1% of aggregate GDP over that period and **less than 0.5% of probable global savings and investments.**
- In **heavy-road transport**, European Commission estimates suggest that the investments required for recharging or hydrogen refueling infrastructure would be **less than 5% of business-as-usual investment in transport infrastructure**[14].
- In the **aviation and shipping sectors**, if decarbonization is achieved primarily via the use of zero-carbon fuels in existing engines, **no major incremental capital investment would be needed**.

Investments in infrastructure and industrial assets required to transition heavy industry and heavy-duty transport to net-zero CO_2 emissions are therefore not large compared to global savings and investment, and **there is no reason to believe that shortage of finance will constrain the path to net-zero CO_2 emissions if adapted financing mechanisms are developed**.

Costs of supply-side decarbonization vary greatly by sectors



Source: Industry: McKinsey & Company (2018), *Decarbonization of industrial sectors: the next frontier* / Shipping: UMAS analysis for the Energy Transitions Commission (2018) / Other transport sectors: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

Exhibit 5

13 McKinsey and Company (2018), *Decarbonization of the industrial sectors: the next frontier*
14 European Environment Agency (2018)

Cost to end consumers

The impact of decarbonization on prices faced by end consumers will vary by sector, but will overall be small [Exhibit 7]. Decarbonizing steel is unlikely to add more than US$180 to the price of a car, while using zero-emissions plastics would increase the price of a litre of soft drinks by less than US$0.01. **The most significant cost to end consumer would be in aviation:** if biofuels or synthetic fuels remain significantly more expensive than conventional jet fuel, zero-carbon international flights may require a 10-20% increase in ticket prices. Since expenditure on international aviation accounts for less than 3% of global household consumption, however, the total impact of this on living standards would still be very slight.

Intermediate product costs

Even if the impact on end-product prices is small, **price implications at the intermediate product level could be significant.** For instance, producing zero-carbon steel may cost 20% more per tonne than conventional steel. Some companies may find it difficult to finance upfront investments in low-carbon technologies, in particular if this entails writing off existing assets before the end of their useful life. In addition, where intermediate products are internationally traded, unilateral imposition of domestic carbon prices or regulation could produce harmful competitiveness effects, and international carbon prices or regulations are therefore ideal [Exhibit 8].

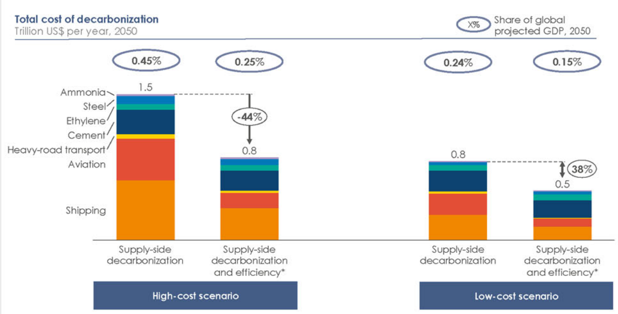
Key implications for policymakers:

- Carbon prices will be required and can be withstood by consumers, but should be carefully designed to avoid international competitiveness effects.
- Harder-to-abate sectors should benefit from public support to innovation and investment.
- Driving energy efficiency, materials efficiency and circularity, and demand management in transport – alongside decarbonization technologies – is essential to reduce the overall cost to the economy.

A PORTFOLIO OF SUPPLY-SIDE DECARBONIZATION TECHNOLOGIES

It is neither possible nor necessary to determine in advance the precise balance between the four main routes to supply-side decarbonization – electricity, bioenergy, carbon capture, and hydrogen – that will be needed to achieve net-zero CO_2 emissions from harder-to-abate sectors.

Decarbonizing harder-to-abate sectors would cost significantly less if pursuing energy efficiency improvement and demand management opportunities



Note: The term "efficiency" covers energy efficiency, materials efficiency, materials circularity, and demand management in transport.
Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018) based on McKinsey & Company (2018), *Decarbonization of industrial sectors: the next frontier* and Material Economics analysis for the Energy Transitions Commission (2018)

Exhibit 6

14 **The optimal balance will vary by region in light of different natural resource endowments** (solar, wind and hydro resources; sustainable biomass resources; availability of underground carbon storage) and will evolve over time following uncertain technological and cost trends.

Public policy should therefore focus primarily on creating strong incentives for decarbonization, while leaving it to markets to determine the most cost-effective route forward per sector. But it is possible to **define some almost certain features of the path to net-zero CO_2 emissions,** which carry implications for public policy and private investment priorities.

A major role for hydrogen

Hydrogen is highly likely to play a major, cost-effective role in the decarbonization of several of the harder-to-abate sectors, and may also be important in residential heat and flexibility provision in the power system. Achieving a net-zero-CO_2-emissions economy will therefore require **an increase in global hydrogen production from 60 Mt per annum today to something like 425-650 Mt by mid-century**, even if hydrogen fuel-cell vehicles play only a small role in the light-duty transport sector.

It is therefore essential to foster the large-scale and cost-effective production of zero-carbon hydrogen via one of three routes:

- **Electrolysis using zero-carbon electricity:** This will be increasingly cost-effective as renewable electricity prices fall and as electrolysis equipment costs decline. If 50% of future hydrogen demand were met by electrolysis, the total volume of electrolysis production would increase 100 times from today's level creating enormous potential for cost reduction through economies of scale and learning curve effects.
- **The application of carbon capture to steam methane reforming, and the subsequent storage or use of the captured CO_2:** This may be one of the most cost-effective forms of carbon capture given the high purity of the CO_2 stream produced from the chemical reaction, if energy inputs to the process are electrified. For hydrogen from SMR plus CCS to really be near-zero-carbon, however, carbon leakage in the capture process, as well as methane emissions throughout the gas value chain, would have to be brought down to a minimum. If 50% of future hydrogen demand were met using SMR with carbon capture on chemical reaction, the related carbon sequestration needs would amount to 2-3Gt.

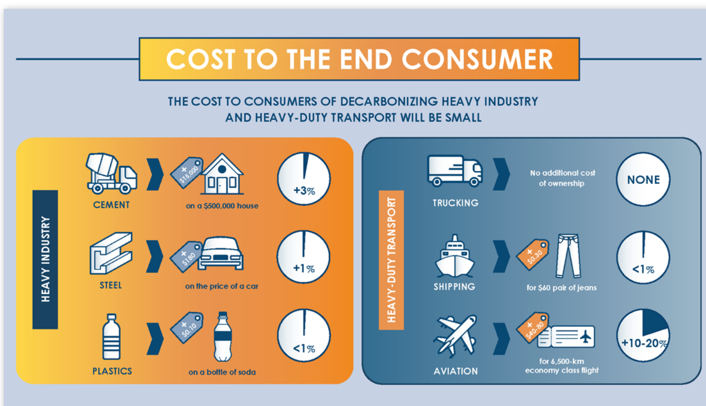


Exhibit 7

- **Biomethane reforming:** SMR could also be made zero-carbon if biogas were used rather than natural gas, but is unlikely to play a major role, given other higher priority demands on limited sustainable biomass resources.

Key implications for policymakers:

- Electrolysis cost reduction is a key innovation priority, targeting capital costs of US$250/kW.
- CCS infrastructure needs to be developed to enable production of near-zero-carbon hydrogen from SMR plus CCS.
- Further reduction in fuel-cell costs and hydrogen tanks are also key priorities.
- International trade in hydrogen or ammonia is likely to play a key role, potentially requiring significant infrastructure investment.

Vital and massive electrification

In any feasible path to a net-zero-carbon economy, electricity's share of total final energy demand will rise from today's 20% to over 60% by 2060. As a result, total global electricity generation must grow from about 20,000 TWh today to 85-115,000 TWh by mid-century while switching for high-carbon to zero-carbon power sources.

Strong policies to improve energy efficiency, increase materials efficiency and circularity, and manage demand for heavy-duty transport could reduce this requirement by a useful 25% – or more in developed economies. Given the scale of the investment challenge, it is vital to maximize these opportunities.

But **a very rapid expansion of zero-carbon electricity will still be required.** Our analysis suggests that this expansion, while challenging, is technically and economically feasible:

- **Renewable electricity is increasingly cost-competitive with fossil-fuel-based power.** It will be possible, within 15 years, to run electricity systems in which 85-90% of power demand is met by a mix of wind and solar, combined with batteries for short-term back-up and with the remaining 10-15% met by dispatchable peak generation capacity (e.g. dispatchable hydro, biomass or fossil fuels with carbon capture). Dramatic reductions in the cost of renewable electricity and of batteries will make it possible to operate such a power system at an all-in cost of US$55/MWh in most geographies, and below US$35/MWh in the most favorable locations by 2035, especially if appropriate market design is in place[15] [Exhibit 9]. This is lower than today's conventional electricity costs.

Decarbonization of the harder-to-abate sectors would have a significant impact on the price of intermediate products

		Impact on intermediate product cost US$ / % price increase	
Industry	Cement	+$100 per tonne of cement (+$30 per tonne of concrete)	+100% (+30%)
	Steel	+$120 per tonne of steel	+20%
	Plastics	+$500 per tonne of ethylene	+50%*
Transport	Heavy road transport	No price impact	None
	Shipping	+$4 million on typical bulk carrier voyage cost per annum	+110%
	Aviation	+$0.3-0.6 per liter of jet fuel equivalent	+50-100%

*Assuming an initial price of US$1000/tonne for ethylene, although the price of ethylene is very volatile.
Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

Exhibit 8

15 SYSTEMIQ analysis for the Energy Transitions Commission (2018), based on Climate Policy Initiative for the Energy Transitions Commission (2017), *Low-cost, low-carbon power systems*

16

- **At the aggregate global level, there is easily sufficient land to support renewable electricity generation on the scale required, but with large regional variations.** In favorable geographies like north-west China, mid-west US and the Middle East, renewable electricity could be produced at low cost in quantities exceeding local demand. But less favorable locations, with high population density or less favorable renewable resources, may need to draw on zero-carbon power sources that are less land-intensive and have higher capacity factors (e.g. nuclear or fossil fuels with carbon capture) or on imports of power (via long-distance transmission lines or in the form of hydrogen or ammonia).
- **A rapid increase in the pace of renewables deployment is needed.** To meet power demand of 100,000 TWh by 2050 with 90% renewable power, the deployment rate of solar and wind would need to increase by more than 10% per year (i.e. double every 7 years). This will also require a strengthening of power grids.

If electrification occurs before adequate power decarbonization, with electricity still produced mainly from fossil fuels, CO_2 emissions could increase in the short term. Our analysis suggests that, in developed economies where the carbon intensity of electricity is below 750gCO_2 per kWh, this danger is limited both in surface transport and in many industrial applications, but much lower carbon intensities are required before a switch to hydrogen, ammonia and synfuels, or to electric heating, will reduce emissions. By contrast, immediate electrification in some coal-dependent developing economies – for instance in India where the carbon intensity of electricity is above 1000gCO_2 per kWh – could result in significant carbon emissions. **Rapid progress towards power decarbonization is therefore essential, combined with careful coordination of the pace of power decarbonization and electrification.**

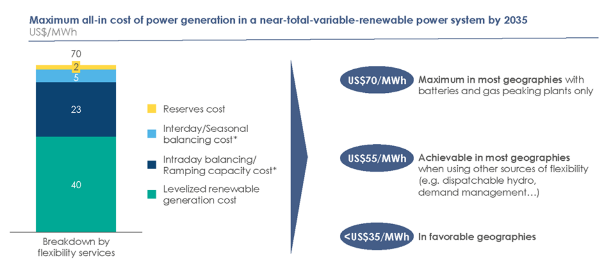
Key implications for policymakers:

- Power decarbonization policies should plan for very significant increases in power demand, accelerating renewable power deployment.
- National decarbonization plans, as described for instance in the NDCs, should set out an integrated vision for power decarbonization and electrification, ensuring that increased power demand will be met by zero-carbon power[16].

A prioritized and tightly regulated use of biomass

Biomass – whether used as a source of energy for heat production, as a reduction agent in steel production, or as a feedstock in chemicals production – could in principle play a role in the

Low-cost, low-carbon electricity is likely to be available in most geographies, with electricity below $35/MWh produced in most favorable locations



Note: Based on German resource and load profile / *Considers only two flexibility technologies: CCGT & Lithium-ion batteries / Levelized renewable energy generation cost includes all energy potentially produced, including amount curtailed or stored/shifted.
Source: Adapted from Climate Policy Initiative for the Energy Transitions Commission (2017), *Low-cost, low-carbon power systems*

Exhibit 9

16 Or in the NECPs of EU member states.

decarbonization of each of the harder-to-abate sectors. When used in power, heat or industry, it could be combined with carbon capture, and potentially generate negative emissions. Timber could also offer an alternative low-carbon building material.

However, **the use of biomass must be constrained by limits on the available supply of truly sustainable biomass,** given competition for land use. This requires that biomass comes from sources or land that would not otherwise provide food or carbon storage, and that its use is compatible with biodiversity and ecosystem conservation imperatives, in particular, the need to avoid deforestation. Moreover, bioenergy typically produces less than 1% of the energy that solar power can produce per hectare, making electricity-based solutions more effective where available and technically feasible.

Estimates of sustainable biomass supply vary widely, but analysis suggests that **70EJ per annum of sustainable biomass for energy and feedstock would certainly be available by mid-century,** when accounting for 10-15EJ from municipal waste, 46-95EJ from agricultural wastes and processing residues, and 15-30EJ of wood harvesting residues[17]. This estimate excludes any biomass production from dedicated energy crops whether in the form of oil plants (e.g. soya) or forest crops (e.g. fast-growing willow or poplar).

The key uncertainties relate to the supply of lignocellulosic material which could be sustainably harvested from forest crops (through a large-scale reforestation program, focused on degraded land in tropical countries), as well as to the availability of winter cover crops and algae-based products. Several factors could decrease the amount of sustainable biomass available for energy, in particular reduced crop yields due to climate change.

A sustainable supply of 70EJ (or even 100EJ) would be insufficient to meet all the potential sectoral claims on biomass from the energy, industry and transport sectors. **Its use must therefore be focused on sectors where alternative decarbonization routes are least available:**

- **The highest priority sector appears to be aviation,** where a zero-carbon equivalent of jet fuel is essential to decarbonize long-haul flights. A maximum of 42EJ of biomass would be required for complete decarbonization. This could be lowered if synfuels are used, as well as through energy efficiency and demand management.
- **The second highest priority sector is likely to be plastics,** where bio-feedstock is essential to compensate for end-of-life emissions, unless end-of-life plastics are recycled or securely landfilled. Bio-feedstock could not entirely substitute for fossil fuels: 28EJ of biomass supply would be required to cover only 30% of feedstock needs. The strategy for plastics decarbonization must therefore combine an as complete as possible shift towards a circular model, with carbon sequestration – in the form of solid plastics placed in permanent, secure and leak-proof storage – and an as limited as possible use of bio-feedstock to compensate for inevitable losses in the value chain.
- If not constrained by tight sustainability criteria, however, **the biggest demands for biomass** could emerge not in the harder-to-abate sectors considered in this report, but **in residential heating and in electricity generation** (where it could create negative emissions if combined with carbon capture and sequestration)[18]. It is therefore essential to minimize this need, especially in the power sector, by driving maximum progress of renewables, energy storage technologies and smart demand management.
- By contrast, **biofuels/biomass are not essential to drive the decarbonization of heavy road transport, shipping, and other industrial sectors,** where other routes to decarbonization are available.

When used, **biomass, biogas and biofuels are highly likely to be more expensive than fossil fuels**. Carbon prices and regulations will therefore be essential and appropriate to make them economic. Biomass-based solutions may also be more expensive than alternative decarbonization routes like electrification or hydrogen in some applications, where they would then naturally be driven out of the market.

17 IEA (2017), Technology roadmap: *Delivering Sustainable Bioenergy*
18 The ETC's illustrative pathway suggests up to 28EJ of biomass input if biogas plays a significant role in residential heating, and as much as 34EJ if biomass-based power generation provides only 4% of global electricity supply to help meet peak generation needs.

18

Key implications for policymakers:

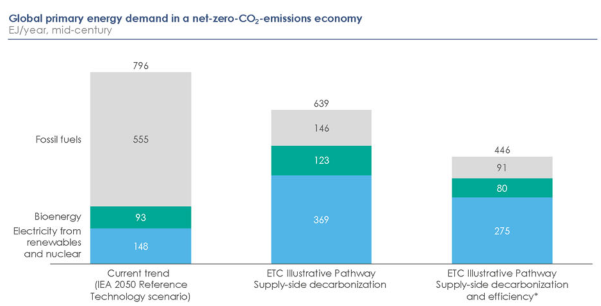
- Tight regulations on biomass sustainability are vital. This will likely exclude energy crops, which often compete with agriculture and ecosystem services, with some local exceptions like winter cover crops in temperate climates.
- The development and cost reduction of truly sustainable bio jet fuels for aviation and bio-feedstock for plastics is a high priority for innovation support.
- Public support to biomass development should transition away from non-priority sectors to high-priority sectors, except when local conditions provide a clearly sustainable supply for a larger portfolio of applications.
- It is essential to develop non-biomass-based peak generation capacity and energy storage options for power and residential heating.
- Improved efficiency in the biorefinery process is key to enable greater bioenergy and bio-feedstock use from a given level of primary supply.

An essential, but limited, role for carbon capture

Dramatic reductions in the cost of renewables over the last 10 years mean that carbon capture is **likely to play a relatively small role in the power sector,** potentially providing dispatchable low-carbon electricity to complement variable renewables. But achieving net-zero CO_2 emissions in the harder-to-abate industrial sectors will probably be impossible, and certainly more expensive, without a role for carbon capture and sequestration: it is likely to be the **only route to achieve total decarbonization of cement production** (unless a breakthrough in cement chemistries eliminates process emissions) and, in some locations, is likely to be the most cost-effective route to decarbonization of steel, chemicals, and hydrogen production.

But there is **no current consensus about the necessary scale of carbon capture.** Several scenarios for achieving the Paris climate objectives assume that, by 2100, carbon capture and sequestration could account for 18Gt per annum of emission reductions (or more), with its application to biomass-based processes producing significant negative emissions. There are concerns that these huge volume assumptions are used to justify continued large-scale fossil fuel production use. In addition, fears are sometimes expressed that underground carbon storage is unsafe or not permanently effective.

Electricity from renewables and nuclear could account for ~60% of primary energy demand



Note: The term "efficiency" covers energy efficiency, materials efficiency, materials circularity, and demand management in transport
Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018); IEA (2017), *Energy Technology Perspectives*

Exhibit 10

It is therefore vital to achieve some consensus around the required role for carbon capture, as well as the respective roles of carbon storage and carbon use in CO_2-based products. The ETC's judgement is that:

- A net-zero-carbon economy can be achieved without the very large quantities of carbon capture (e.g. 18Gt per year) assumed in some models, but **a more modest scale of carbon capture (e.g. around 5-8Gt per year)** is highly likely to be a necessary and cost-effective part of an overall decarbonization strategy.
- **Around 1-2Gt of the CO_2 captured annually could then probably be used in CO_2-based products that enable long-term storage,** with the greatest opportunities lying in concrete, aggregates and carbon fiber. This implies a potential synergy between carbon capture in cement plants and use within concrete production.
- **Some storage is however likely to be required** – 3-7Gt of CO_2 storage per annum – and best expert opinion – including from the IPCC – suggests that carbon storage can be safe and adequately secure provided it is effectively regulated[19].
- **Achieving these volumes of carbon capture by mid-century would require a step change in the pace of deployment,** which will not occur unless governments play an active role in (i) building social acceptance of carbon transport and storage on the back of independent scientific evidence of their safety, (ii) making carbon capture and storage economically viable through carbon pricing, and (iii) planning and regulating the deployment of carbon transport and storage infrastructure. These conditions are not yet met today. Immediate and forceful collective action from policymakers and industries is needed to meet them in the next 10 years.

Key implications for policymakers:

- Commercial-scale carbon capture and carbon use technologies, in particular in the cement-concrete value chain, should be a key innovation priority.
- A carbon price will be vital to support any form of carbon capture and sequestration.
- For underground carbon storage to be part of the portfolio of solutions, governments need to:
  - Regulate carbon transport and storage sufficiently tightly to achieve social acceptance;
  - Plan and support the deployment of carbon transport and storage infrastructure.
- If underground carbon storage is not developed, governments would need to:
  - Plan for an even faster deployment of renewables and electricity-based solutions for industry;
  - Bring to market low-carbon materials to substitute for cement;
  - Bring to market carbon dioxide destruction technologies to treat remaining carbon emissions.

Optimal supply-side path to a net-zero-carbon economy

The optimal path to a net-zero-carbon economy will require use of all the decarbonization levers. Within the overall balance, **electrification will play the greatest role, accounting for roughly 65% of final energy demand by mid-century and with electricity also used to produce a significant share of hydrogen.** Around 85-90% of electricity will in turn be derived from renewables or other zero-carbon sources, with no more than 10-15% from biomass or fossil fuels with carbon capture. Primary energy demand would be significantly lower if pursuing opportunities for energy efficiency, materials efficiency/circularity and demand management in transport. [Exhibit 10]

The optimal balance will however vary significantly by location, given wide variations in relevant natural resource endowments:

- **Large differences in solar and wind resources** mean that, while some countries could meet well over 65% of final energy demand from locally produced cheap renewable electricity, others will need to rely on other zero-carbon power sources or on power imports. The cost of renewable generation will also vary widely.
- **Biomass resources per capita and costs also vary greatly by region,** which will likely trigger international trade of biorefined products for aviation and plastics, and very different levels of biomass use by geography in other (localized) sectors of the economy, such as heat and power.
- **In the case of underground carbon storage, huge regional variations in the known scale of available storage capacity in part reflect limitations to current knowledge in various geographies** (in particular Africa). But, once a comprehensive survey is complete, available storage capacity is likely to vary greatly between regions.

19 IPCC (2005), *Carbon Dioxide Capture and Storage*; IPCC (2014), *Mitigation of climate change*

B. THE PATH TO NET-ZERO: MANAGING THE TRANSITION TO NET-ZERO-CO_2-EMISSIONS INDUSTRY AND TRANSPORT

Our analysis shows that all harder-to-abate sectors could achieve net-zero CO_2 emissions by mid-century at low cost to the global economy and to the end consumer. But the path to net-zero matters as well as the end point. It is therefore essential to:

- **Recognize the complexities which determine the feasible pace of transition;**
- **Reduce the scale of the decarbonization challenge through energy efficiency improvement and demand management;**
- **Determine an appropriate role for transitional solutions,** in particular unabated gas as a transition fuel and offset purchase as a transitional abatement strategy.

TECHNICAL, ECONOMIC AND INSTITUTIONAL CHALLENGES BY SECTOR

Three categories of transition challenges are important: technical, economic and institutional challenges.

Technical challenges:

- **Many of the relevant technologies are not yet commercially ready.** While electric trucks could be cost-competitive by 2030, cement kiln electrification may not be commercially ready till a decade later. Hydrogen-based industrial processes also require significant development. **Accelerating development and scaling deployment of key technologies is therefore vital.**
- **Reaching zero lifecycle emissions from plastics constitutes a significant challenge,** as it requires eliminating end-of-life as well as production emissions. Limits to sustainable biomass supply will likely make it impossible to entirely substitute fossil fuels by bio-feedstock. It will therefore be essential to manage the existing and future fossil-fuels-based plastics stock through **mechanical and chemical recycling, as well as secured end-of-life storage for solid plastic.**
- In most cases, **carbon capture technologies will capture about 80-90% of the CO_2 stream,** with the remaining 10-20% still released into the atmosphere. The development of capture technologies with higher capture rates should be a priority, but some level of negative emissions from land use or BECCS will probably be required to compensate for these residual emissions.

Economic challenges:

- Since most decarbonization routes will entail a net cost, **market forces alone will not drive progress;** and strong policies – combining regulations and support – must create incentives for rapid decarbonization.
- A particular difficulty is to **create strong enough financial incentives today** to trigger the search for optimal decarbonization pathways **without imposing a disproportionate burden** on sectors for which full decarbonization technologies are not yet available.
- **In heavy industry, very long asset lives will delay the deployment of new technologies,** unless there are strong policy incentives for early asset write-offs. In steel, for instance, a switch from blast furnace reduction to hydrogen-based direct reduction may require scrapping of existing plant before end of useful life.
- **High upfront investment costs may act as a barrier to progress** even where carbon prices make a shift to zero-carbon technologies in theory economic, in particular in sectors or companies facing low margins. Direct public investment support (for instance through loan guarantees or repayable advances) may therefore be required.
- Although beneficial on an aggregate scale, the transition to a zero-carbon economy will inevitably create winners and losers, impacting local economic development and employment in some regions. Moreover, the impact on end consumer prices, although limited, might have a greater impact on lower-income households, especially in developing countries. **Policy should anticipate and compensate for these distributional effects through just transition strategies.**

Institutional challenges:

- **Current innovation systems are poorly connected,** with little coordination between public and private R&D, and a lack of international forums to carry an innovation agenda focused on harder-to-abate sectors.

- In sectors exposed to international competition, **domestic carbon prices or regulations could produce harmful effects on competitiveness and movement of production location.** This implies the need for international policy coordination, or alternatively the use of downstream rather than upstream taxes, border tax adjustments, or free allocation within emissions trading schemes or compensation schemes (combined with increasingly ambitious benchmark technology standards).
- **Some industries, like shipping or construction, are so fragmented that incentives are split.** Even cost-effective efficiency technologies and circular practices are not easily deployed. Innovative policy should strengthen incentives, for instance regulations imposed at port level or obligations for materials recycling.

Implications for industry and heavy-duty transport

Given these technical, economic and institutional barriers, transition paths will vary significantly by sector:

- **In the industrial sectors, progress to full decarbonization will inevitably take several decades.** Public policy must therefore provide strong incentives for long-term change, established well in advance, whether via carbon pricing, regulations, or financial support. Proactive action from industries over the next decade would reduce costs of subsequent decarbonization efforts.
- In the **transport sectors**, transition paths are less complicated:
  - In heavy road transport, considerably shorter asset lives could allow **rapid decarbonization of truck fleets** (e.g. over 15 years rather than 30) once alternative vehicles (whether battery electric or hydrogen fuel-cell) become cost-competitive at point of new purchase.
  - **In long-distance shipping and aviation,** the fact that the likely route to full decarbonization entails the **use of zero-carbon fuels within existing engines** means that the longevity of shipping and aviation engines is not a constraint on the pace of transition, which will instead be determined by the relative costs of zero-carbon versus conventional fuels[20].

REDUCING THE DECARBONIZATION CHALLENGE THROUGH EFFICIENCY IMPROVEMENT AND DEMAND MANAGEMENT

Given the time required to achieve supply-side decarbonization, especially in industry, **efficiency improvement and demand side reductions are essential not only to deliver short-term emissions reductions, but to decrease the cost of long-term decarbonization** by reducing the volume of primary industrial production or mobility services to which supply-side decarbonization technologies need to be applied [Exhibit 11].

Energy efficiency improvements will be particularly important in shipping and aviation, where lower fuel consumption per kilometer could reduce the penalty cost of using zero-carbon fuels and reduce claims on a limited sustainable supply of biofuels.

The potential for demand management differs between the transport and industrial sectors:

- **In the transport sectors, the biggest potential lies in modal shift** from road to rail for freight and from plane to high-speed rail for short-haul passenger trips, as well as logistics efficiency, but total available potential is unlikely to exceed 20%.
- **In industry, however, greater materials efficiency and circularity could reduce CO_2 emissions by 40% globally** – and by more than 55% in developed economies – by 2050, with greatest opportunities lying in the plastics and metals supply chains.

Most of the technologies required to achieve this demand-side reduction potential are already available. Their deployment at scale will likely drive cost reductions, for instance in recycling industries. But **major changes in product design, industry practice and regulation will be essential** to seize the opportunity.

- **Improved materials circularity cannot occur without more coordination between different companies along the manufacturing, automotive and buildings value chains.** High-quality recycling indeed requires new approaches to product design as well as to end-of-life dismantling and materials separation, which will not occur unless required

20 Although some retrofitting will be needed in shipping to adapt fuel handling and storage equipment to the use of ammonia or hydrogen.

by regulation, in particular through extended producer responsibility.

- **Improved logistics efficiency will also rely on greater coordination between companies,** facilitated by big data computing, while **driving modal shifts will require improving public transport infrastructure,** in particular railways, and creating financial incentives to change for both passenger and freight.

LEVERAGING TRANSITIONAL SOLUTIONS: GAS AND OFFSETS

The appropriate use of these solutions will vary by sector depending on when the end-state solution will be commercially available. Transitional solutions are therefore **particularly appropriate in heavy industry, where many zero-carbon solutions are not yet market ready;** whereas they are likely to play **a smaller role in transport**, given the relative ease of transition to either electric vehicles (in trucking) or biofuels and synfuels (in shipping and aviation).

Gas as a transition fuel

Since **gas combustion can produce about 50% less emissions than coal** – if and only if methane emissions are tightly controlled –, switching from coal to gas within otherwise largely unchanged production processes/equipment could in principle achieve significant short-term emissions reductions. **Switching from oil to gas would deliver more limited reductions (5-20%).** However, the climate benefits can be reduced significantly or even disappear if methane leakages in the gas value chain are above 1-3% (depending on applications).

- **In industry, there could be significant potential to switch from coal to gas,** in industries where coal is still used as a heat source (e.g. cement) and in countries where coal is still used as a feedstock in chemicals production (e.g. China). However, this potential could be constrained by limited domestic gas supplies, particularly in China and India.
- **In transport, the optimal role of gas is more limited.** There may be a limited transition role for CNG in trucking and LNG in shipping, if these technologies can be retrofitted on existing vehicles now and replaced, respectively, by electric vehicles and by zero-carbon fuels in the next 10-15 years and the related infrastructure repurposed or written off[21].

The optimal path to net-zero CO_2 emissions might entail a roughly flat or even slightly rising gas production by 2040, provided that:

- **Strong policies ensure that methane emissions (from flaring, venting and leaking) across the whole production and use chain reaches sufficiently low levels** (0.2% for upstream leakage and below 1% when jointly considering upstream, midstream and downstream emissions) prior to any expansion of gas use;
- Pre-announced strategies ensure that gas-using sectors will eventually:
  - **Switch to biogas** – while taking into account constraints on sustainable biomass availability which, in turn, will put pressure on prices;
  - **Apply carbon capture and sequestration** to existing gas-fired production processes;
  - **Move beyond natural gas to electricity, hydrogen, or bioenergy,** which implies the need to plan in advance for either writing off gas infrastructure and equipment prior to end of useful life or repurposing them for hydrogen.

Indeed, it is clear that **unabated gas consumption would need to rapidly fall beyond 2040** to be compatible with the Paris objectives.

The appropriate role of offsets

Since the marginal cost of decarbonization varies greatly among the harder-to-abate sectors and across the whole economy, **the early stages of sectoral paths to net-zero could allow for the purchase of offsets from other sectors of the economy or from the land use sector**[22]. These schemes (sometimes labelled "market-based measures") will also create incentives to search for longer-term decarbonization solutions by facing sectors with a marginal price of carbon.

In addition, the purchase of offsets from the land use sector could provide a valuable source of financing to support investment in more sustainable land use, for instance preventing deforestation and facilitating reforestation.

But any reliance on offset purchases must be strictly controlled and clearly time-limited:

- **Offsets purchased from other energy-using sectors must only occur within the framework of emissions trading schemes whose total volumes are tightly capped and declining at a pace**

21 In addition, natural gas may play a transitional role in residential heating, alongside greater electrification, and could subsequently be substituted by biogas or hydrogen. However, the ETC has not analyzed this issue in detail.
22 Legal disputes related to how to account for carbon emissions reductions from offsets which are traded internationally outside of regulated emissions trading schemes are not covered in this report.

compatible with the Paris climate objective. This implies that by mid-century there will be almost no remaining potential for such purchases.

- Land use offsets should also ideally play only a transitional role, given **limits to the total possible scale of natural carbon sequestration.** Land use offsets must also be subject to extremely tight regulation to ensure that the purchase of offsets truly does result in incremental carbon emissions reductions, and to avoid adverse effects of biodiversity.

However, our analysis suggests that, while the energy and industrial systems can get very close to net-zero by 2060, there may be small residual emissions (around 2Gt per annum) which would be very expensive to eliminate. A small long-term role for negative emissions from land use or BECCS may therefore be required.

But, given constraints on long-term negative emissions, sectoral strategies can only claim to be compatible with the Paris climate agreement if they aim for as close as possible to net-zero CO_2 emissions within the sector by mid-century.

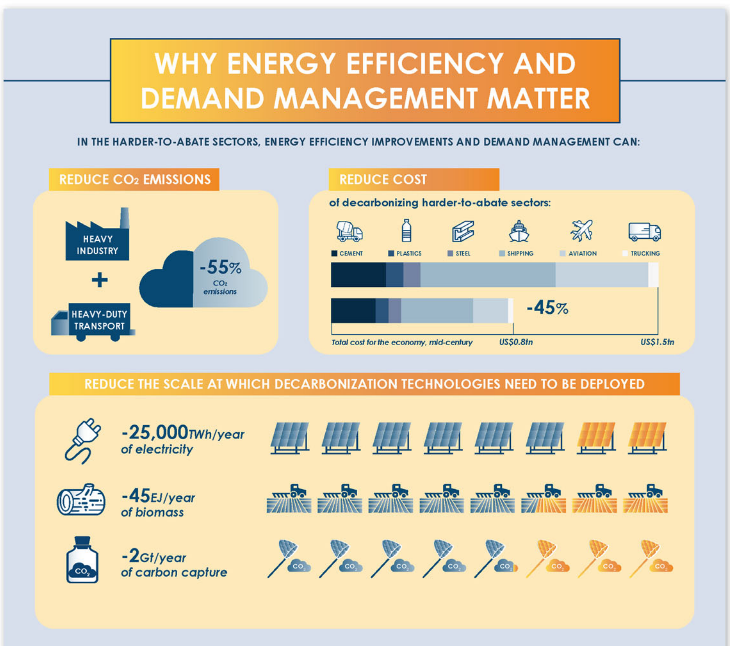


Exhibit 11

C. ACTION: WHAT POLICYMAKERS, INVESTORS, BUSINESSES AND CONSUMERS CAN (AND SHOULD) DO

DRIVING PROGRESS THROUGH INNOVATION

Complete decarbonization of all the harder-to-abate sectors **could be achieved using technologies already under development**. But many of them are still not market-ready, nor have been deployed at commercial scale. In addition, **future unpredictable technological breakthroughs** will almost certainly, some time over the next decades, allow different and cheaper routes to decarbonization. Both private investment and public policy support are required to drive incremental innovation and maximize the likelihood of more fundamental breakthroughs.

Enabling greater efficiency and circularity

Achieving the potential for energy efficiency as well as materials efficiency and circularity will require innovation in three major areas:

- **Product design** to enable:
  - Increased energy efficiency – e.g. improved design of air frames and ships;
  - Use of new low-carbon fuels – e.g. radical redesign of air frames to enable the use of hydrogen;
  - Improve materials efficiency and circularity – e.g. conceiving buildings, vehicles or packaging in a way that reduces over-specification of materials and facilitates end-of-life dismantling, sorting and recycling of materials;
- **Improving materials processing systems,** in particular:
  - New manufacturing or construction techniques that reduce waste from production;
  - New high-strength materials that reduce the materials input required;
  - Materials traceability systems, enabled by digital technologies;
  - Automated sorting systems, enabling advanced separation of materials;
  - Methods to separate the constituents of composite materials (such as textiles);
  - Improved metallurgy, to remove impurities from scrap metals and produce high-quality metals from mixed scrap;
- **New business models relying on longer product lifetimes** (through design, maintenance, higher-quality materials, re-manufacturing and re-use) and more intensive use (through sharing or increased occupancy levels).

Enabling electrification of transport and industry

In the transport sectors the crucial challenge is further to reduce the cost and improve the performance of batteries:

- Massive private investments now flowing into the currently dominant lithium-ion technology make it highly likely that **battery prices will fall to meet be BNEF's projection of US$100 per kWh** (for cells plus pack) by 2025 – and probably before.
- **Improvements in energy density, charging speed and battery life will then become more important than further cost reductions.** Battery density improvement of 2 to 3 times would make battery electric vehicles dominant even for long-distance surface transport and improvement of 5 to 10 times would be required to make electrification feasible for long-distance shipping and aviation. These will require more fundamental changes in battery chemistry.

In the industrial sectors, the key challenge is to **develop electric cement kilns and electric furnaces.** Alongside these, fundamental research should explore the potential for more **radical breakthroughs in electrochemistry,** in both the steel and chemicals industry.

Driving down the cost of hydrogen production and use

Given the major role that hydrogen will almost certainly play, it is crucial to reduce the cost of hydrogen production and use, aiming in particular:

- To radically **reduce the cost of electrolysis equipment**, achieving US$250 per kW by the mid-2020s versus US$1000 per kW today;
- To **reduce the cost of steam methane reforming plus carbon capture;**
- To **reduce the cost of fuel-cells** from around US$100 per kW today to less than US$80 per kW by 2025 for medium duty vehicles and of hydrogen tanks from $15 per kW today to less than $9 per kW by 2025.

Revolutionizing the chemicals industry through biochemistry and synthetic chemistry

While emissions from industrial processes can be eliminated via electrification, biomass combustion, or carbon capture and sequestration, **the more difficult technical challenge is to address end-**

of-life emissions produced in multiple dispersed locations and in particular those resulting from the remaining use of liquid hydrocarbon fuels (in aviation and shipping), plastics and fertilizers (which produce both CO_2 and N_2O emissions).

This makes four areas of innovation vital:

- **Biochemistry**, where the key challenge is to enable the development of liquid fuels or feedstocks for plastics production, while minimizing the use of biomass sources which compete with food production and threaten biodiversity, through:
  - Biochemical technologies which can enable the exploitation of lignocellulosic sources,
  - Genetic engineering of crops which can grow on arid land or sea water, including algae,
  - Increased efficiency of biorefinery processes;
- **Synthetic chemistry**, where the two key innovation challenges are:
  - To reduce the cost of direct air capture of CO_2 (DAC),
  - To find effective routes to produce aromatics used in plastics;
- **Hybrid chemical routes** – i.e. combining bio and synthetic chemistries;
- **Chemical recycling of plastics** to limit the need for new bio and synthetic feedstock.

Developing new materials

There is significant potential to substitute less carbon-intensive materials for carbon-intensive ones, for instance:

- In the buildings sector, **using timber or pozzolan-based concrete to substitute for Portland cement;**
- In packaging, textiles and manufacturing, **using cellulose-based fibers to substitute for plastics** (and for bio-based plastics, which would require a much greater biomass input than direct fiber use).

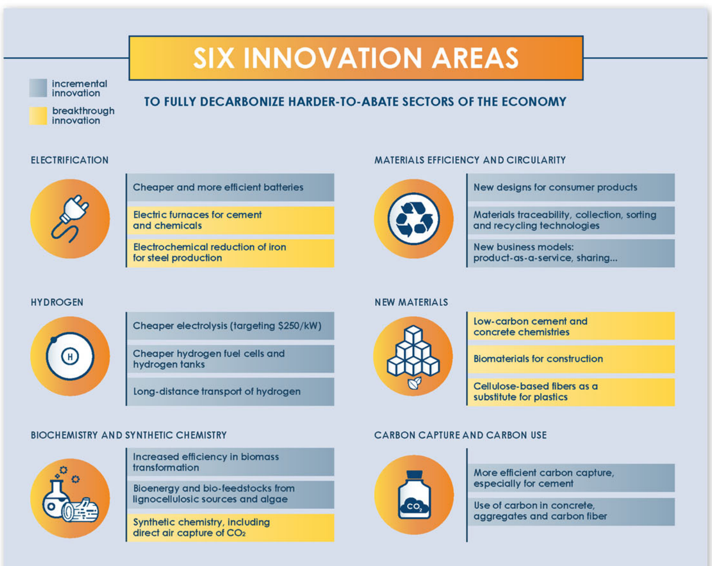


Exhibit 12

26

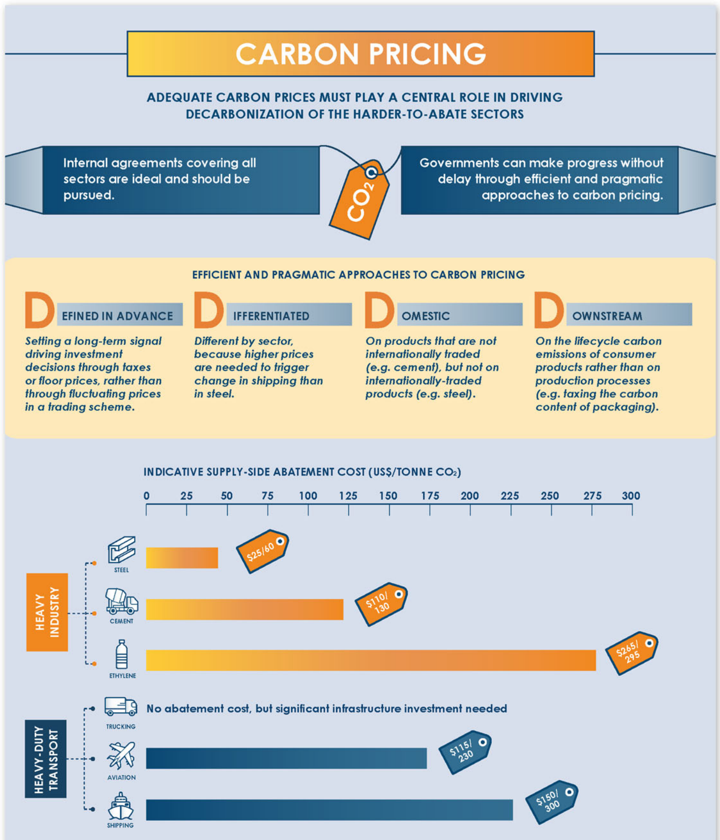


Exhibit 13

Driving down the cost of carbon capture and carbon use technologies

The key challenge with carbon capture and use is not a fundamental technological one, but rather a question of how to achieve sufficiently large-scale deployment to drive economies of scale and learning curve effects.

DRIVING PROGRESS THROUGH POLICY

Since there are multiple routes to the decarbonization of harder-to-abate sectors, **policy should aim to unleash a market-driven search for the optimal solution, while also ensuring focused support for those aspects of the transition which are certain to be needed.** Four complementary sets of policies are required to drive progress.

Efficient and pragmatic approaches to carbon pricing

Adequate carbon prices must play a central role, simultaneously incentivizing improved energy efficiency, supply-side decarbonization, and demand reduction.

Existing carbon pricing schemes, like the EU-ETS, have begun to play a role in driving down carbon emissions, but three challenges have limited their effectiveness to date:

- The danger that if international agreement cannot be achieved, imposing carbon taxes in one country could result in **shifts in the production location of internationally traded goods and services** (e.g. steel and aluminum), which has often led to exceptions within carbon pricing schemes, including the EU-ETS;
- **Very different marginal abatement costs by sector,** which, together with high emissions caps, mean that the resulting prices may be far too low to provoke change in the higher-cost sectors (e.g. aviation);
- The uncertainty on long-term prices in emissions trading systems, which do not provide a sufficiently strong long-term price signal to spur technology development.

It is essential to overcome these challenges. International agreements covering all sectors remain ideal and it is vital to pursue them. However, policymakers should also recognize that, if the ideal is not possible, there is still an opportunity to make progress by strengthening existing emissions trading schemes and by developing complementary, imperfect but still useful, approaches that might be [Exhibit 13]:

- **Defined in advance,** with specific taxes or floor prices in some cases providing greater certainty and thus more powerful incentives than can be achieved through fluctuating prices;
- **Differentiated by sector to reflect different marginal abatement costs and technology readiness,** with for instance far higher carbon price applied in shipping and aviation than to the materials-producing industrial sectors;
- **Domestic/regional,** with for instance a significant carbon price applied to cement (where competition is primarily domestic) even while not applied at the same level to steel, (using free allocation within emissions trading schemes or compensation schemes to avoid carbon leakage dangers (with allocations/ compensations combined with increasingly ambitious benchmark technology standards so as to provide incentives for innovation and investment);
- **Downstream,** i.e. applied to the lifecycle carbon emissions of consumer products rather than production processes, as is the case with excise duties on gasoline and diesel, which are effectively subject to a carbon tax whatever the location of crude oil production and refining.

Such approaches to carbon pricing would need to be designed to limit risks of carbon leakage between sectors and between regions, and might require new systems to ensure the traceability of lifecycle carbon emissions. They should ideally build up towards a globally consistent carbon pricing framework.

Mandates and regulations

In addition to carbon pricing, specific regulatory mandates could and should include:

- **Energy efficiency regulation,** which has been a key driver of improvements in automobile and appliance efficiency, and which is already being applied by the IMO to drive improvements in the energy efficiency of new ships;
- **Tightly defined sustainability standards** for low-carbon fuels (including bioenergy and hydrogen), based on robust lifecycle carbon accounting and assessment of other environmental impacts;
- **Green fuel mandates** which could require airlines and ship operators to use a rising percentage of zero-carbon fuels;

- **Regulations which ban the sale of diesel or gasoline ICE trucks**, beyond given future dates, and/or ban their use in major cities;
- **Labelling – and regulations on – embedded carbon in products,** ensuring traceability of the source, carbon intensity and recycled content of materials used in consumer products (e.g. cars or appliances);
- **Standards on materials efficiency,** especially in infrastructure, buildings and key consumer products;
- **Regulations to drive the circular economy,** in particular by enforcing end-of-life product recycling responsibility and requiring product designs which make recycling possible.

Public support for infrastructure development

Most of the investments required to build a net-zero-carbon economy will be made by the private sector. But active public policy coordination or direct investment support may be required in:

- **Long-distance power transmission** to support high penetration of variable renewables;
- **Vehicle charging and refueling infrastructure** along road networks as well as in ports and potentially airports (if hydrogen and ammonia use develops);
- **Railway infrastructure,** especially high-speed rail connections on a regional level, to enable greater modal shift;
- **Port and pipeline infrastructure** to drive the development of domestic and international trade in new fuels such as hydrogen and ammonia;
- **Carbon transport and storage networks**, where governments have a key role to play in imposing tight regulatory standards, and in planning and approving the routing of pipelines.

Public support for research, development and deployment of new technologies

The optimal public policy role in driving technological progress will differ depending on the market readiness of different technologies:

- **Deploying proven technologies at commercial scale:** Here most of the investment must come from the private sector, but governments could accelerate progress by facilitating financing (for instance via loan guarantees or reimbursable advances) and by using public procurement to create demand for low-carbon products and services.
- **Bringing technologies under development to commercial readiness:** A combination of public and private innovation funding will be required to accelerate the process to bring technologies to market, in particular to fund pilot projects.
- **Fostering radical technology game changers:** Public funding should provide direct support for specific areas of research, in particular via target-driven programs which define specific quantitative objectives 10-15 years ahead and stand willing to support multiple R&D efforts that could deliver the objectives.

DRIVING PROGRESS THROUGH PRIVATE SECTOR ACTION

Private sector action will also be vital to achieve full decarbonization of harder-to-abate sectors.

Industry associations in harder-to-abate sectors

Many industry associations in key industrial sectors and in heavy-duty transport (especially shipping and aviation) are already aiming to achieve significant carbon reductions by mid-century. These efforts could be further strengthened by:

- **Developing roadmaps to net-zero carbon emissions by mid-century,** including clear specification of how transitional solutions such as offsets or use of unabated natural gas will be phased out over time;
- **Developing cross-sectoral initiatives to develop demand for low/zero-carbon products** (e.g. partnership between airlines, airports and travel agencies to develop a zero-carbon flight offer) and to support materials circularity (e.g. partnership between steel producers and manufacturers to improve collection rates and quality of steel scrap);
- **Using their lobbying capacity to advocate ambitious international agreements on carbon pricing.**

Companies in harder-to-abate sectors

In parallel, **leading industry companies have already started to prepare for a low-carbon transition,** with some companies committing to science-based targets and a few making bolder commitments to net-zero carbon emissions. We hope that an increasing number of companies will continue to:

- **Invest in R&D projects, especially pilot plants,** focused on key innovation priorities outlined above;
- **Develop partnerships which can deliver greater materials efficiency and circularity;**

- **Develop regional partnerships in industrial clusters**, to support infrastructure development and industrial symbiosis;
- **Base their long-term business strategy and shareholder reporting on tightened science-based targets,** which aim to net-zero carbon emissions by mid-century.

Major buyers of materials and mobility services

Major buyers – in particular businesses and public procurement services – can accelerate change in the harder-to-abate sectors by creating demand for "green" materials and mobility services, initially at a premium price. Initiatives could include:

- **The expansion of the EV100 commitment** (commitment to 100% electric vehicles) taken by businesses and cities to electric trucks and buses (BEVs or FCEVs);
- **A commitment to low-lifecycle-carbon-emissions materials for commercial and industrial buildings,** completing existing operational energy efficiency targets;
- **A commitment to green flights purchase** as an alternative to buying offsets to compensate for business air travel.

Consumers

With the exception of aviation and some subsectors of shipping and heavy-road transport (i.e. buses), **harder-to-abate sectors are not directly exposed to consumer pressure**. However, materials and freight transport are essential to the delivery of key end consumer products. **Adequate labelling of lifecycle and embedded carbon intensity of products** (e.g. cars, appliances) and services (e.g. flights) could create traceability and be a powerful tool for consumer awareness. It could also facilitate the creation of a "green offer" at a premium price, given that the cost impact of decarbonization on end consumers is relatively small.

Public and private investors

New investment opportunities will arise both in low-carbon infrastructure, and in companies that take advantage of low-carbon innovation in materials, products and business models. Investors could help accelerate decarbonization by:

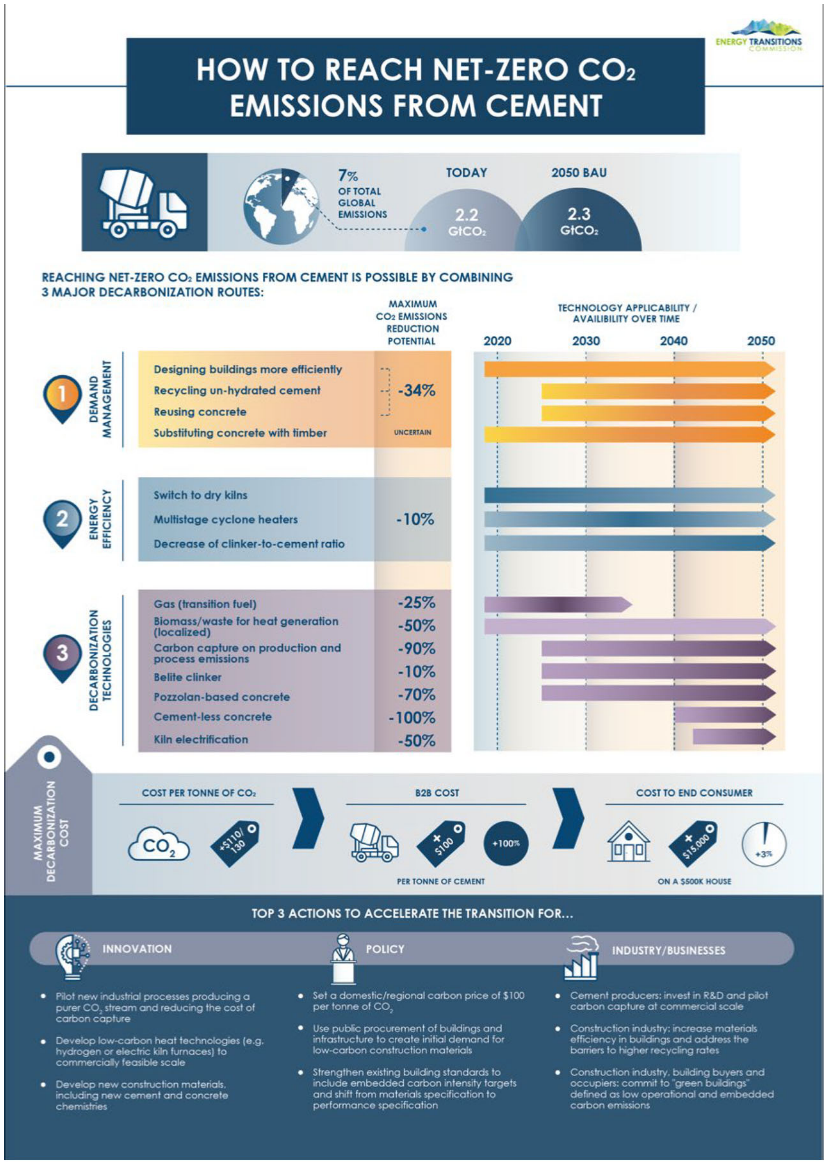
- **Better evaluating climate-related risks and opportunities** focusing not only on energy, but also on the industry and transport sectors;
- **Developing clear plans to shift their investment portfolios through time,** increasing investment in low-carbon infrastructure, technologies and companies, and cutting investments in potentially stranded assets;
- **Developing a range of "green investment" products with different risk-return profiles,** with the support of development banks to facilitate sustainable infrastructure investment in developing countries (through policy development, public investment and private capital mobilization via blended finance).

WINNING THE CLIMATE WAR

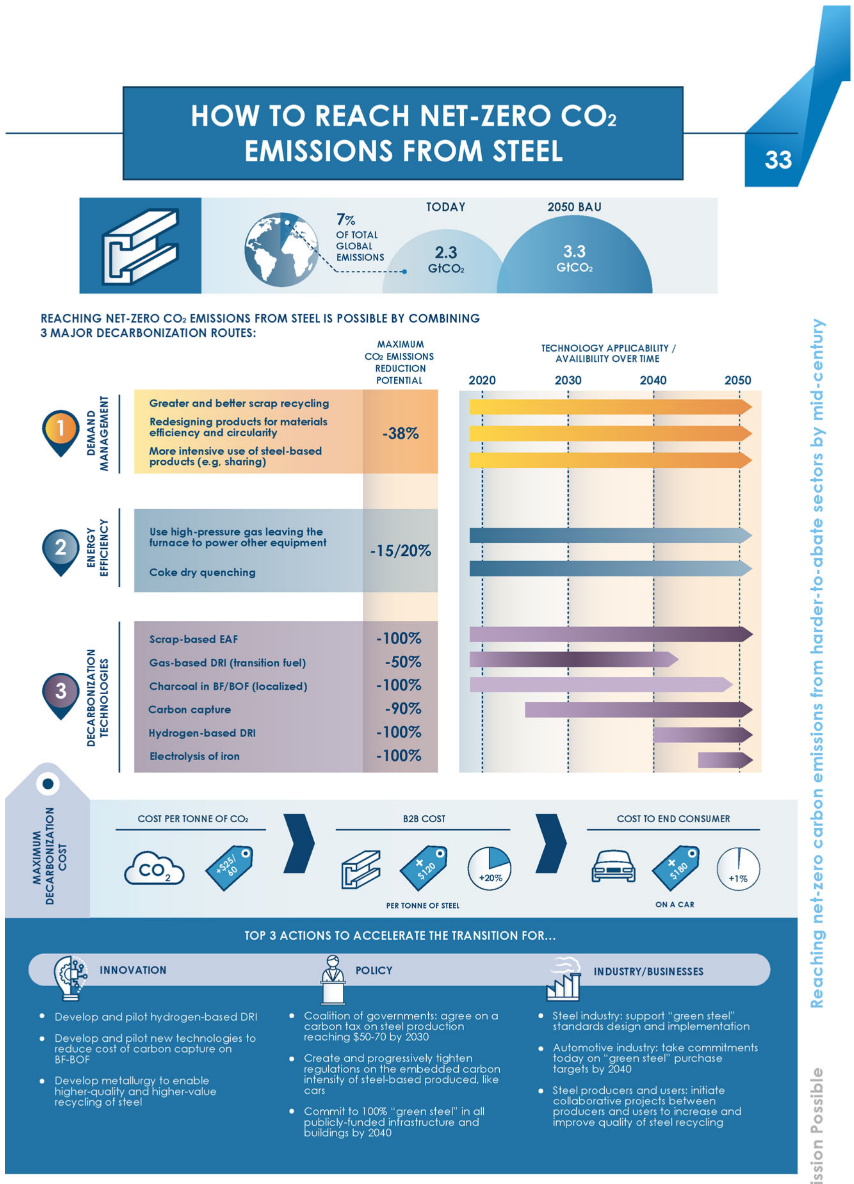
The Energy Transitions Commission believes it is possible to achieve the near-total decarbonization of the harder-to-abate sectors of the economy by mid-century, significantly increasing the chance of limiting global warming to 1.5˚C. Succeeding in that historic endeavor would not only limit the harmful impact of climate change; it would also drive prosperity, through rapid technological innovation and job creation in new industries, and deliver important local environmental benefits. National and local governments, businesses, investors and consumers should therefore take the actions needed to achieve this objective.

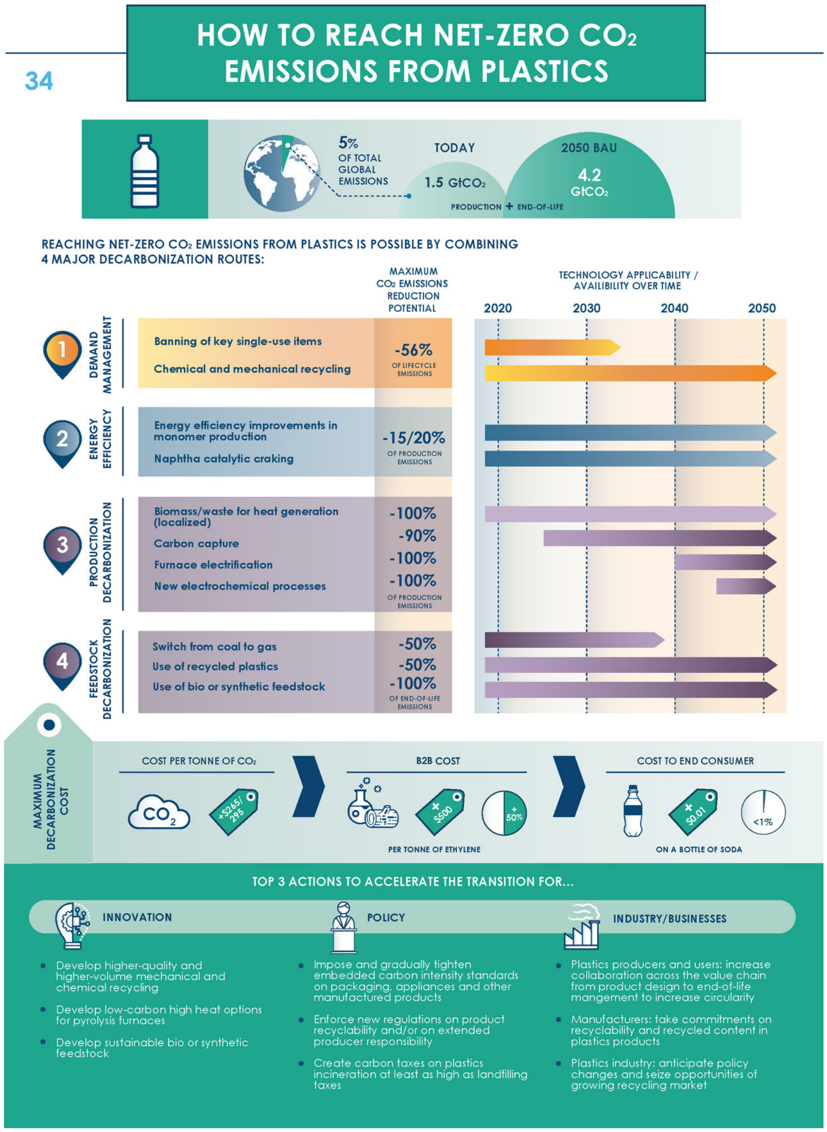
WINNING THE CLIMATE WAR

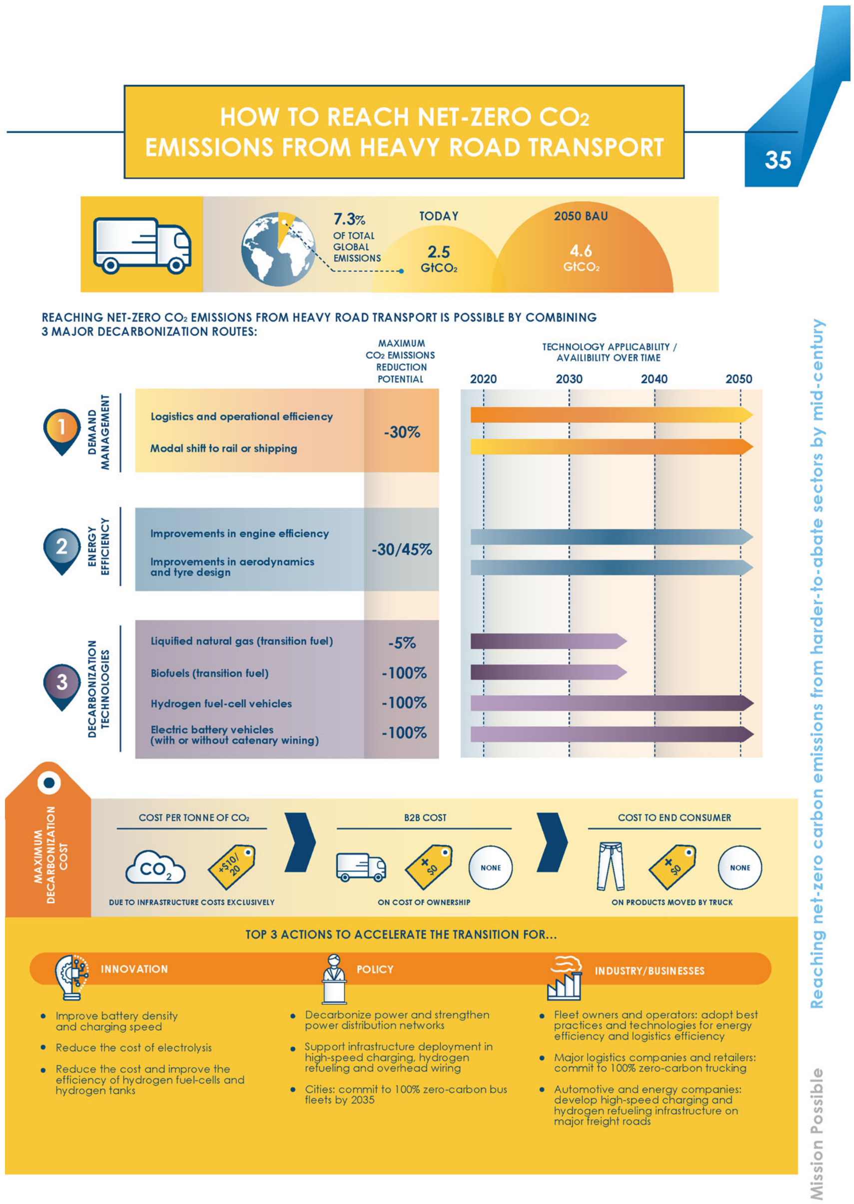
With immediate collective action, reaching net-zero CO_2 emissions from harder-to-abate sectors of the economy – in heavy industry and heavy-duty transport – is technically and economically feasible.

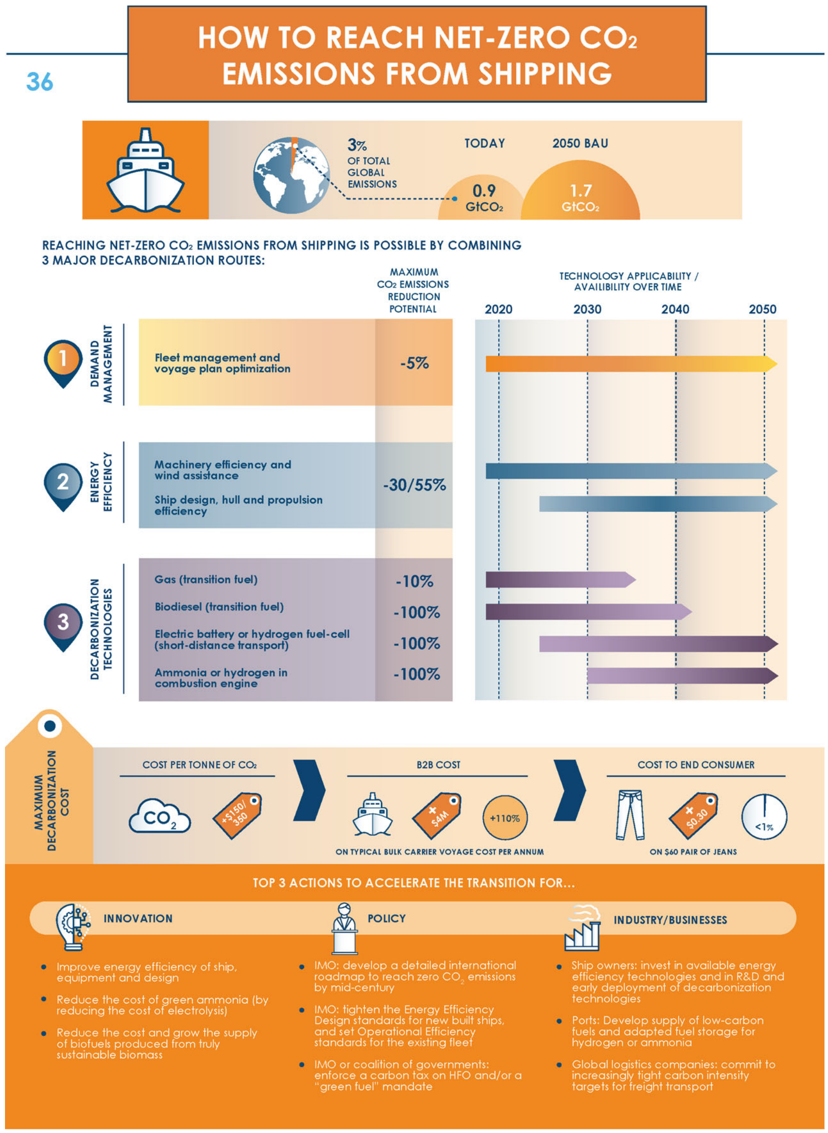


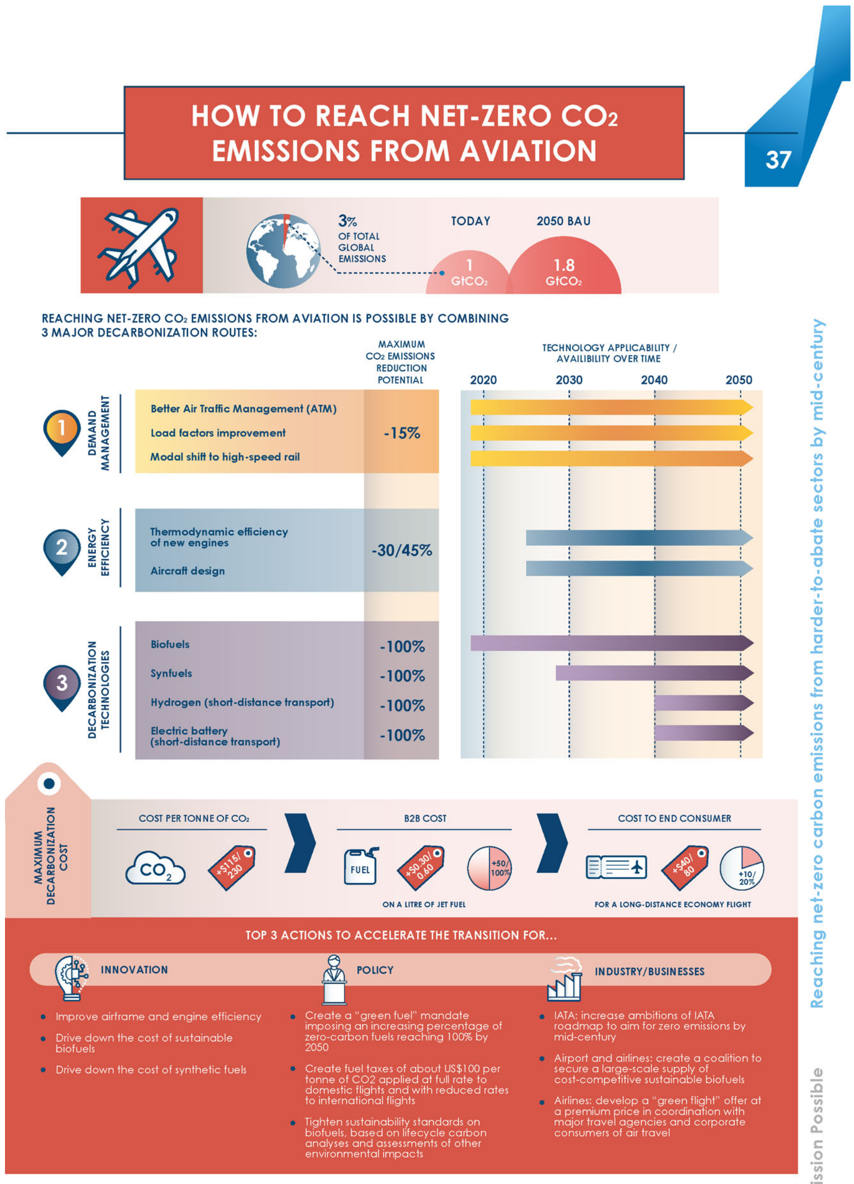
ENERGY TRANSITIONS COMMISSION
HOW TO REACH NET-ZERO CO2 EMISSIONS FROM CEMENT
7% OF TOTAL GLOBAL EMISSIONS
TODAY
2.2 GtCO2
2050 BAU
2.3 GtCO2
REACHING NET-ZERO CO2 EMISSIONS FROM CEMENT IS POSSIBLE BY COMBINING 3 MAJOR DECARBONIZATION ROUTES:
MAXIMUM CO2 EMISSIONS REDUCTION POTENTIAL
TECHNOLOGY APPLICABILITY / AVAILIBILITY OVER TIME
2020
2030
2040
2050
1 DEMAND MANAGEMENT
Designing buildings more efficiently
Recycling un-hydrated cement
Reusing concrete
-34%
Substituting concrete with timber
UNCERTAIN
2 ENERGY EFFICIENCY
Switch to dry kilns
Multistage cyclone heaters
Decrease of clinker-to-cement ratio
-10%
3 DECARBONIZATION TECHNOLOGIES
Gas (transition fuel) -25%
Biomass/waste for heat generation (localized) -50%
Carbon capture on production and process emissions -90%
Belite clinker -10%
Pozzolan-based concrete -70%
Cement-less concrete -100%
Kiln electrification -50%
MAXIMUM DECARBONIZATION COST
COST PER TONNE OF CO2
CO2
+$110/130
B2B COST
+$100
+100%
PER TONNE OF CEMENT
COST TO END CONSUMER
+$15,000
+3%
ON A $500K HOUSE
TOP 3 ACTIONS TO ACCELERATE THE TRANSITION FOR...
INNOVATION
Pilot new industrial processes producing a purer CO2 stream and reducing the cost of carbon capture
Develop low-carbon heat technologies (e.g. hydrogen or electric kiln furnaces) to commercially feasible scale
Develop new construction materials, including new cement and concrete chemistries
POLICY
Set a domestic/regional carbon price of $100 per tonne of CO2
Use public procurement of buildings and infrastructure to create initial demand for low-carbon construction materials
Strengthen existing building standards to include embedded carbon intensity targets and shift from materials specification to performance specification
INDUSTRY/BUSINESSES
Cement producers: invest in R&D and pilot carbon capture at commercial scale
Construction industry: increase materials efficiency in buildings and address the barriers to higher recycling rates
Construction industry, building buyers and occupiers: commit to "green buildings" defined as low operational and embedded carbon emissions


HOW TO REACH NET-ZERO CO_2 EMISSIONS FROM STEEL
33
7% OF TOTAL GLOBAL EMISSIONS
TODAY
2.3 $GtCO_2$
2050 BAU
3.3 $GtCO_2$
REACHING NET-ZERO CO_2 EMISSIONS FROM STEEL IS POSSIBLE BY COMBINING 3 MAJOR DECARBONIZATION ROUTES:
MAXIMUM CO_2 EMISSIONS REDUCTION POTENTIAL
TECHNOLOGY APPLICABILITY / AVAILIBILITY OVER TIME
2020
2030
2040
2050
1
DEMAND MANAGEMENT
Greater and better scrap recycling
Redesigning products for materials efficiency and circularity
More intensive use of steel-based products (e.g. sharing)
-38%
2
ENERGY EFFICIENCY
Use high-pressure gas leaving the furnace to power other equipment
Coke dry quenching
-15/20%
3
DECARBONIZATION TECHNOLOGIES
Scrap-based EAF -100%
Gas-based DRI (transition fuel) -50%
Charcoal in BF/BOF (localized) -100%
Carbon capture -90%
Hydrogen-based DRI -100%
Electrolysis of iron -100%
MAXIMUM DECARBONIZATION COST
COST PER TONNE OF CO_2
CO_2
+$25/ 60
B2B COST
+ $120
+20%
PER TONNE OF STEEL
COST TO END CONSUMER
+ $180
+1%
ON A CAR
TOP 3 ACTIONS TO ACCELERATE THE TRANSITION FOR...
INNOVATION
• Develop and pilot hydrogen-based DRI
• Develop and pilot new technologies to reduce cost of carbon capture on BF-BOF
• Develop metallurgy to enable higher-quality and higher-value recycling of steel
POLICY
• Coalition of governments: agree on a carbon tax on steel production reaching $50-70 by 2030
• Create and progressively tighten regulations on the embedded carbon intensity of steel-based produced, like cars
• Commit to 100% "green steel" in all publicly-funded infrastructure and buildings by 2040
INDUSTRY/BUSINESSES
• Steel industry: support "green steel" standards design and implementation
• Automotive industry: take commitments today on "green steel" purchase targets by 2040
• Steel producers and users: initiate collaborative projects between producers and users to increase and improve quality of steel recycling

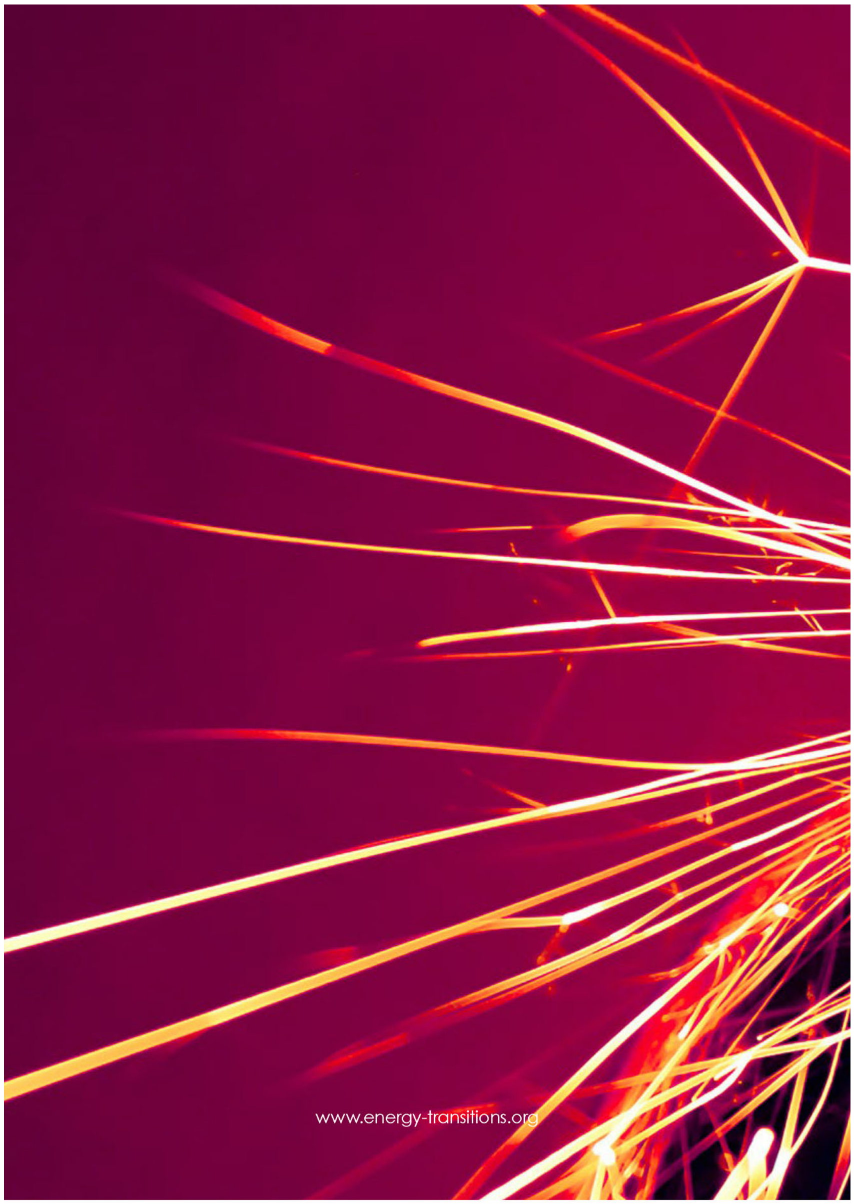

34
HOW TO REACH NET-ZERO CO2 EMISSIONS FROM PLASTICS
5% OF TOTAL GLOBAL EMISSIONS
TODAY
1.5 GtCO2
2050 BAU
4.2 GtCO2
PRODUCTION + END-OF-LIFE
REACHING NET-ZERO CO2 EMISSIONS FROM PLASTICS IS POSSIBLE BY COMBINING 4 MAJOR DECARBONIZATION ROUTES:
MAXIMUM CO2 EMISSIONS REDUCTION POTENTIAL
TECHNOLOGY APPLICABILITY / AVAILIBILITY OVER TIME
2020
2030
2040
2050
1
DEMAND MANAGEMENT
Banning of key single-use items
Chemical and mechanical recycling
-56%
OF LIFECYCLE EMISSIONS
2
ENERGY EFFICIENCY
Energy efficiency improvements in monomer production
Naphtha catalytic craking
-15/20%
OF PRODUCTION EMISSIONS
3
PRODUCTION DECARBONIZATION
Biomass/waste for heat generation (localized)
Carbon capture
Furnace electrification
New electrochemical processes
-100%
-90%
-100%
-100%
OF PRODUCTION EMISSIONS
4
FEEDSTOCK DECARBONIZATION
Switch from coal to gas
Use of recycled plastics
Use of bio or synthetic feedstock
-50%
-50%
-100%
OF END-OF-LIFE EMISSIONS
MAXIMUM DECARBONIZATION COST
COST PER TONNE OF CO2
CO2
+$265/295
B2B COST
+ $500
+ 50%
PER TONNE OF ETHYLENE
COST TO END CONSUMER
+ $0.01
<1%
ON A BOTTLE OF SODA
TOP 3 ACTIONS TO ACCELERATE THE TRANSITION FOR...
INNOVATION
Develop higher-quality and higher-volume mechanical and chemical recycling
Develop low-carbon high heat options for pyrolysis furnaces
Develop sustainable bio or synthetic feedstock
POLICY
Impose and gradually tighten embedded carbon intensity standards on packaging, appliances and other manufactured products
Enforce new regulations on product recyclability and/or on extended producer responsibility
Create carbon taxes on plastics incineration at least as high as landfilling taxes
INDUSTRY/BUSINESSES
Plastics producers and users: increase collaboration across the value chain from product design to end-of-life mangement to increase circularity
Manufacturers: take commitments on recyclability and recycled content in plastics products
Plastics industry: anticipate policy changes and seize opportunities of growing recycling market


HOW TO REACH NET-ZERO CO2 EMISSIONS FROM HEAVY ROAD TRANSPORT
35
7.3% OF TOTAL GLOBAL EMISSIONS
TODAY
2.5 GtCO2
2050 BAU
4.6 GtCO2
REACHING NET-ZERO CO2 EMISSIONS FROM HEAVY ROAD TRANSPORT IS POSSIBLE BY COMBINING 3 MAJOR DECARBONIZATION ROUTES:
MAXIMUM CO2 EMISSIONS REDUCTION POTENTIAL
TECHNOLOGY APPLICABILITY / AVAILIBILITY OVER TIME
2020
2030
2040
2050
1
DEMAND MANAGEMENT
Logistics and operational efficiency
Modal shift to rail or shipping
-30%
2
ENERGY EFFICIENCY
Improvements in engine efficiency
Improvements in aerodynamics and tyre design
-30/45%
3
DECARBONIZATION TECHNOLOGIES
Liquified natural gas (transition fuel)
-5%
Biofuels (transition fuel)
-100%
Hydrogen fuel-cell vehicles
-100%
Electric battery vehicles (with or without catenary wining)
-100%
MAXIMUM DECARBONIZATION COST
COST PER TONNE OF CO2
CO2
+$10/20
DUE TO INFRASTRUCTURE COSTS EXCLUSIVELY
B2B COST
+$0
NONE
ON COST OF OWNERSHIP
COST TO END CONSUMER
+$0
NONE
ON PRODUCTS MOVED BY TRUCK
TOP 3 ACTIONS TO ACCELERATE THE TRANSITION FOR...
INNOVATION
• Improve battery density and charging speed
• Reduce the cost of electrolysis
• Reduce the cost and improve the efficiency of hydrogen fuel-cells and hydrogen tanks
POLICY
• Decarbonize power and strengthen power distribution networks
• Support infrastructure deployment in high-speed charging, hydrogen refueling and overhead wiring
• Cities: commit to 100% zero-carbon bus fleets by 2035
INDUSTRY/BUSINESSES
• Fleet owners and operators: adopt best practices and technologies for energy efficiency and logistics efficiency
• Major logistics companies and retailers: commit to 100% zero-carbon trucking
• Automotive and energy companies: develop high-speed charging and hydrogen refueling infrastructure on major freight roads
Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century
Mission Possible


36
HOW TO REACH NET-ZERO CO2 EMISSIONS FROM SHIPPING
3% OF TOTAL GLOBAL EMISSIONS
TODAY
0.9 GtCO2
2050 BAU
1.7 GtCO2
REACHING NET-ZERO CO2 EMISSIONS FROM SHIPPING IS POSSIBLE BY COMBINING 3 MAJOR DECARBONIZATION ROUTES:
MAXIMUM CO2 EMISSIONS REDUCTION POTENTIAL
TECHNOLOGY APPLICABILITY / AVAILIBILITY OVER TIME
2020
2030
2040
2050
1
DEMAND MANAGEMENT
Fleet management and voyage plan optimization
-5%
2
ENERGY EFFICIENCY
Machinery efficiency and wind assistance
Ship design, hull and propulsion efficiency
-30/55%
3
DECARBONIZATION TECHNOLOGIES
Gas (transition fuel)
-10%
Biodiesel (transition fuel)
-100%
Electric battery or hydrogen fuel-cell (short-distance transport)
-100%
Ammonia or hydrogen in combustion engine
-100%
MAXIMUM DECARBONIZATION COST
COST PER TONNE OF CO2
CO2
+$150/350
B2B COST
+$4M
+110%
ON TYPICAL BULK CARRIER VOYAGE COST PER ANNUM
COST TO END CONSUMER
+$0.30
<1%
ON $60 PAIR OF JEANS
TOP 3 ACTIONS TO ACCELERATE THE TRANSITION FOR...
INNOVATION
Improve energy efficiency of ship, equipment and design
Reduce the cost of green ammonia (by reducing the cost of electrolysis)
Reduce the cost and grow the supply of biofuels produced from truly sustainable biomass
POLICY
IMO: develop a detailed international roadmap to reach zero CO2 emissions by mid-century
IMO: tighten the Energy Efficiency Design standards for new built ships, and set Operational Efficiency standards for the existing fleet
IMO or coalition of governments: enforce a carbon tax on HFO and/or a "green fuel" mandate
INDUSTRY/BUSINESSES
Ship owners: invest in available energy efficiency technologies and in R&D and early deployment of decarbonization technologies
Ports: Develop supply of low-carbon fuels and adapted fuel storage for hydrogen or ammonia
Global logistics companies: commit to increasingly tight carbon intensity targets for freight transport



HOW TO REACH NET-ZERO CO2 EMISSIONS FROM AVIATION
37
3% OF TOTAL GLOBAL EMISSIONS
TODAY
2050 BAU
1 GtCO2
1.8 GtCO2
REACHING NET-ZERO CO2 EMISSIONS FROM AVIATION IS POSSIBLE BY COMBINING 3 MAJOR DECARBONIZATION ROUTES:
MAXIMUM CO2 EMISSIONS REDUCTION POTENTIAL
TECHNOLOGY APPLICABILITY / AVAILIBILITY OVER TIME
2020
2030
2040
2050
1 DEMAND MANAGEMENT
Better Air Traffic Management (ATM)
Load factors improvement
Modal shift to high-speed rail
-15%
2 ENERGY EFFICIENCY
Thermodynamic efficiency of new engines
Aircraft design
-30/45%
3 DECARBONIZATION TECHNOLOGIES
Biofuels
-100%
Synfuels
-100%
Hydrogen (short-distance transport)
-100%
Electric battery (short-distance transport)
-100%
MAXIMUM DECARBONIZATION COST
COST PER TONNE OF CO2
CO2
+$115/230
B2B COST
FUEL
+$0.30/0.60
+50/100%
ON A LITRE OF JET FUEL
COST TO END CONSUMER
+$40/80
+10/20%
FOR A LONG-DISTANCE ECONOMY FLIGHT
TOP 3 ACTIONS TO ACCELERATE THE TRANSITION FOR...
INNOVATION
• Improve airframe and engine efficiency
• Drive down the cost of sustainable biofuels
• Drive down the cost of synthetic fuels
POLICY
• Create a "green fuel" mandate imposing an increasing percentage of zero-carbon fuels reaching 100% by 2050
• Create fuel taxes of about US$100 per tonne of CO2 applied at full rate to domestic flights and with reduced rates to international flights
• Tighten sustainability standards on biofuels, based on lifecycle carbon analyses and assessments of other environmental impacts
INDUSTRY/BUSINESSES
• IATA: increase ambitions of IATA roadmap to aim for zero emissions by mid-century
• Airport and airlines: create a coalition to secure a large-scale supply of cost-competitive sustainable biofuels
• Airlines: develop a "green flight" offer at a premium price in coordination with major travel agencies and corporate consumers of air travel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TECHNOLOGY

CARBON UTILIZATION— A VITAL AND EFFECTIVE PATHWAY FOR DECARBONIZATION

Summary Report

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

by

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ACKNOWLEDGEMENTS

This report was made possible by a grant from the William and Flora Hewlett Foundation. In addition, the Center for Climate and Energy Solutions (C2ES) gratefully acknowledges the involvement of individual members of the Carbon Capture Coalition, Coalition co-convenor the Great Plains Institute, the Carbon XPRIZE Foundation, Algae Biomass Organization, Renewable Fuels Association, and individual technology developers, all of whom who contributed their time and expertise. Finally, C2ES wishes to thank the U.S. Department of Energy Office of Fossil Energy and the National Academy of Sciences for sharing their knowledge with the work group.

EXECUTIVE SUMMARY

The capture and utilization of CO_2 and other carbon oxides emitted from power generation and industrial facilities has been technologically feasible for generations and has gained greater attention in recent years as a tool for reducing greenhouse gas emissions. Captured carbon can be stored in geologic formations, or used either to produce oil from depleted wells through the enhanced oil recovery (EOR) process (which sequesters the CO_2 underground), or in the creation of a variety of products. These measures generate revenue that can partially offset the costs associated with capture.

Because EOR is already widely practiced, it is not considered by this report. Instead, the focus is on non-EOR utilization of captured carbon, which offers the potential to significantly contribute to greenhouse gas emissions reduction. Pathways include the production of construction materials, fuels, plastics, chemicals, and algae-based products (e.g., fuels, animal feed, and fertilizers). Each of these sectors, along with their potential for market growth is explored herein.

Carbon capture and utilization (CCU) includes the use of all carbon oxides, including CO_2 and carbon monoxide (CO), that would displace the release of greenhouse gases into the atmosphere. The alternative term "CO_2U" applies to technologies that use only CO_2 specifically. Other broad terms for utilization include "carbon recycling" and "carbontech."

While non-EOR carbon utilization does not, at present, greatly contribute to greenhouse gas reduction it offers significant potential to do so in the coming decades, given advances in technology, wider commercialization, and supportive government policies. CCU may be an especially useful tool for decarbonizing certain industrial sectors and providing an option in locations where either social issues or land constraints do not allow for other types of carbon disposition. Also, the continued development of CCU technologies may help drive carbon capture innovation generally, making broader greenhouse gas reductions possible.

Numerous government agencies, non-governmental entities, and academic institutions have recently considered the potential development of carbon utilization and how government polices might encourage it. Rather than duplicate that body of research, this report seeks to provide an overview of options, growth and greenhouse gas reduction potential summarized by use category.

CARBON UTILIZATION PRODUCTS AND PROCESSES

As to particular sectors, construction materials that rely on CO_2 utilization today represent the most widespread of all non-EOR CCU sectors and are projected to continue growing as market preferences for low-carbon materials expand. However, prescriptive standards for products like concrete are a significant challenge to the wider acceptance of CO_2-based materials. Low-carbon aggregates (the gravel, sand, or crushed stone used with cement to form concrete) do not face the same hurdle to market entry, but they are not currently competitive purely on price, and so would require some form of policy support. Taken together, low-carbon construction materials (including aggregates) offer the greatest prospects for growth in both market value and greenhouse gas reduction potential.

Low-carbon fuels, chemicals, and plastics are diverse categories of products that are considered together here because their production processes have similarities. Conversion of CO_2 to fuels and chemicals often entails adding hydrogen to the carbon in CO_2. Developing catalytic, electrochemical, photolytic and other processes that can facilitate this type of reaction and generate products inexpensively is an important research priority. Advancing these processes to operate at commercial scale represents a significant technical challenge.

Another key challenge to carbon utilization for the production of fuels is the availability of low-cost, low-carbon hydrogen. Steam methane reforming (SMR), the process by which methane reacts with steam at a high temperature to produce hydrogen, is in use with carbon capture at a number of projects worldwide. Water electrolysis, where hydrogen is separated from water in an electrochemical cell, is far more expensive and requires low-carbon electricity but is an area of active research. An increase in market demand for hydrogen would likely be met in the short term by SMR in conjunction with carbon capture.

Algae-based carbon utilization offers significant near-term opportunities in some product categories (e.g., biofertilizers, aquaculture, livestock feed, and feed additives), while other product categories (e.g., fuels, bioplastics) require research and development (R&D) efforts to drive down costs, especially downstream processing costs. One significant advantage of algae-based carbon utilization is that high-purity CO_2 is not required to support algae growth, and some combustion waste products such as nitrogen oxides (NOx) and sulphur oxides (SOx) can actually serve as algal nutrients.

POLICY CONSIDERATIONS

All CCU sectors face challenges to commercialization in terms of either technology, cost, or market acceptance. These can be overcome with supportive government policies in four areas: financial enablers, R&D support, development of CO_2 transportation infrastructure, and market preferences such as procurement policies and "green labeling." Some broad policy approaches, such as those that encourage all applications of carbon capture (not only beneficial carbon utilization), may be necessary to generally help foster decarbonization. However, sector-specific challenges may also be addressed.

One broad-based policy currently in place is the "45Q" tax credit, enacted in 2018, which offers a tax preference for either qualified utilization of carbon oxides, or geologic storage (including in saline formations or through EOR). However, the U.S. Internal Revenue Service is not expected to publish the guidance necessary to implement the law until later in 2019, which has caused uncertainty for CCU developers who might expect to benefit from the tax credit. Given the delay in implementation, Congress may need to extend the law's deadline for commencing project construction and lower the eligibility threshold requirement if it expects small CCU developers to benefit.

Several policies currently before Congress would encourage the deployment of CCU. Legislation known as the USE IT Act, introduced in both houses of Congress, would facilitate coordinated development of CO_2 pipelines and provide CCU research prize funding. Similarly, CCU will advance sooner if relevant federal R&D is expanded both in terms of its funding level and its support for pilot-level work. Finally, facilitating the construction of adequate infrastructure for the movement of CO_2 is also important to sparking widespread CCU deployment.

As for sectoral issues, government procurement rules can act as market drivers, while federal R&D spending should be targeted to ensure successful pathways to commercialization, not only basic research. Low-carbon construction materials will benefit from incentives at all levels of government that encourage the use of components containing captured carbon. For fuels, renewable fuel standards, low-carbon fuel standards, and other incentives will grow the low-carbon fuel market, if they include fuels from carbon utilization.

This report focuses on policy actions that can foster growth in carbon utilization by 2030, in part because markets beyond that timeframe are difficult to predict, but mostly because deliberate near-term action is needed if CCU is to expand significantly. However, more general climate policies, such as carbon pricing or the inclusion of fossil-based carbon capture in clean energy standards, are also necessary to lay the foundation for a low-carbon economy that includes new demand for CCU-based products and processes.

I. INTRODUCTION AND CONTEXT

The scientific evidence for climate change is undeniable, and the consequences of climate change are already being felt through sea level rise and extreme weather events. The most recent estimates by the Intergovernmental Panel on Climate Change (IPCC, 2018) stated that impacts on health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5 degrees C and increase further with 2 C above pre-industrial levels. To avoid these impacts and give adaptation efforts a better chance of success, economies must transition to lower-carbon technologies.

One component of the suite of technologies necessary for deep decarbonization is carbon capture, utilization, and storage (CCUS). The IPCC has noted that without CCUS, the costs of addressing climate change will be significantly higher.[1] The most economical and immediate path forward for the development of carbon capture is closely tied to creating corridors of CO_2 transportation infrastructure that link sources of CO_2 to enhanced oil recovery (EOR) markets, and eventually other types of geologic storage.

Additionally, accelerating deployment of carbon utilization would provide a number of important pathways for decarbonization. For instance, while many sources of carbon emissions can be addressed through traditional carbon capture, certain industrial sectors are harder to decarbonize. One example would be aviation fuel emissions, which cannot be "captured" in real time by traditional means; using captured carbon to produce aviation fuel that has lower carbon content *before* it is combusted offers an effective pathway to reduce emissions in this sector.

Geography may represent another circumstance where carbon utilization may be useful. In certain jurisdictions, such as those where any type of carbon storage may be constrained by social license to operate issues or by land use restrictions, carbon utilization may be an important decarbonization option. In other locations, the small size and proximity of existing CO_2 sources may not justify building the infrastructure necessary to transport and store the CO_2. In those regions, creating an on-site market for carbon capture and use (CCU) may be a pathway for decarbonization.

This paper summarizes the current state of knowledge on CCU in an effort to highlight the potential for using carbon as part of the transition to a lower-carbon economy. To understand the technologies and the importance of policies to accelerate their availability, this report is built on a review of existing literature, a series of interviews and finally a workgroup of technical experts who provided significant insights and direction for this work. C2ES interviewed more than 20 developers and other leaders to better understand how policy could spark growth in beneficial carbon utilization. The questions used to guide those interviews can be found in **Appendix B.**

WHAT IS CARBON UTILIZATION?

The capture, utilization, and storage of carbon oxides has been technologically feasible for generations and has been in operation since the early 1970s. Currently, 19 "full-scale" projects are in operation worldwide. Of these, 14 use captured CO_2 for enhanced oil recovery (EOR) while five store CO_2 in saline aquifers.[2]

Carbon utilization (a term used in this report interchangeably with CCU) is a broad term used to describe the many different pathways where captured CO_2 —or in some cases carbon monoxide (CO)—can be used or "recycled" to produce economically valuable products or services.

EOR using CO_2 is the most widely practiced form of carbon utilization today. Approximately 17 million metric tons per year of anthropogenic CO_2 are currently used in the United States for EOR, along with much higher quantities of CO_2 from naturally-occurring, but depleting, sources. Future domestic CO_2 use applying current state-of-the-art CO_2-EOR techniques for economically recoverable oil is projected to be 10.7 gigatons (Gt). Projections based on the development of "next-generation" EOR techniques applicable to U.S. resources, such as those designated as the residual oil zone (ROZ), are more uncertain than for state-of-the-art techniques, but indicate the use of an additional 23.6 Gt of CO_2.[3]

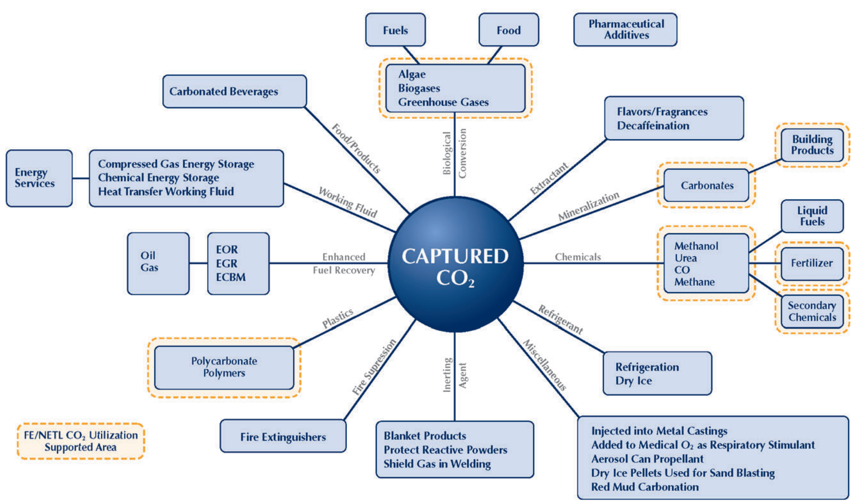
Because it is already widely practiced, CO_2-EOR is not further addressed in this report. Instead, non-EOR utilization approaches are the focus of material presented below.

The wide array of carbon utilization options is illustrated in **Figure 1**. Each carbon utilization pathway has specific characteristics in terms of technical maturity, market potential, economics, and CO_2 reduction impact. Given this diversity, implementing both broad-based policies and sector-specific ones together will have the greatest impact on CCU development.

Entities from across the spectrum of greenhouse gas emissions stakeholders are increasingly focused on new uses for recycled carbon and how policies can encourage them. Five prominent examples include:

- The U.S. Department of Energy commissioned the development of a report by the National Coal Council (NCC) entitled *CO_2 Building Blocks: Assessing CO_2 Utilization Options*[3]. The 2016 report's primary focus, "is to assess opportunities to advance commercial markets for CO_2 from coal-based power generation and the extent to which CO_2 markets for EOR and non-EOR utilization could incentivize deployment of carbon capture, utilization and storage (CCUS) technologies."
- China's Ministry of Science and Technology (MOST) published the results of its comprehensive scientific assessment of geologic and non-geologic CO_2 utilization technologies in the country, highlighting the following technologies as holding particular promise: (1) CO_2-EOR, with and without enhanced water recovery; (2) use of CO_2 from coal conversion technologies for use in enhanced coal-bed methane recovery; and (3) use of CO_2 from steel and cement production for mineralization of bulk solids and cultivation of microalgae that could

FIGURE 1: CO2 utilization pathways



Source: National Energy Technology Laboratory www.netl.doe.gov be used for fertilizer or as feedstock for fuels and other chemicals.[4]

- The European Commission published a report[5] in 2018 that concluded, among other things, that, 1) carbon utilization may play a role to reduce the role of fossil fuels in the economy and provide help reaching climate change mitigation targets, and 2) uptake of carbon utilization will depend on a favorable legislative and investment environment.
- The XPRIZE Foundation is holding a competition with $20 million in total prize money, funded by utility company NRG and Canada's Oil Sands Innovation Alliance (COSIA), in which teams from multiple countries are testing and demonstrating breakthrough technologies that will convert CO_2 emissions into valuable products like building materials, fuels and other items. Teams will be scored based on how much CO_2 they convert and the net value of their products.[6]
- In 2016, the Global CO_2 Initiative released *A Roadmap for the Global Implementation of Carbon Utilization Technologies*,[7] which estimated the potential market size and emissions reduction associated with the "Carbon Based Products Industry" (CBPI)—essentially non-geologic carbon utilization.

II. CARBON UTILIZATION'S MARKET AND EMISSIONS POTENTIAL

The Global CO_2 Initiative *Roadmap* (2016) provided a useful projection of how carbon utilization could grow in coming years if certain scenarios and assumptions are realized. To provide insight into what full potential might look like, the *Roadmap* lays the ground work for what might be considered high-end markers for the potential of carbon utilization moving forward. A significant conclusion summarized from the report was that, "Funding, incentives and prompt strategic action are necessary to move the CBPI [Carbon Based Products Industry] to its full potential... [at which] CBPI could reach or exceed US $800 billion by 2030."

As for emissions reduction, the *Roadmap* concluded that, "Critically, the CBPI has the potential to utilize seven billion metric tons of CO_2 per year by 2030—the equivalent of approximately 15 percent of current annual global CO_2 emissions."

The *Roadmap* divided utilization approaches into seven general categories, as illustrated in **Figure 2.**

The status of these technologies, and their associated opportunities for market growth and greenhouse gas reduction potential are presented together graphically in **Figure 3** and summarized in tabular form in **Appendix A**. The sizes of the "balloon" markers in **Figure 3** correspond to the relative emission reduction potential for each sector at different points in time. While current product volumes across all CCU sectors are small, they offer significant potential in the longer term.

FIGURE 2: General categories of utilization technologies

Construction Materials
- Cement and Concrete
- Asphalt
- Aggregate
- Timber/super hardwood

Fuel
- Synthetic (methanol, butanol, natural gas, syngas, etc)
- Micro-algae fuel
- Macro-algae fuel

New Materials
- Carbon Fiber
- Carbon nanotubes and fullerenes
- Graphene

Industrigas & Fluids
- Enhanced oil recovery
- Enhanced coal bed methane recovery
- Enhanced water recovery
- Semiconductor fabrication
- Power cycles

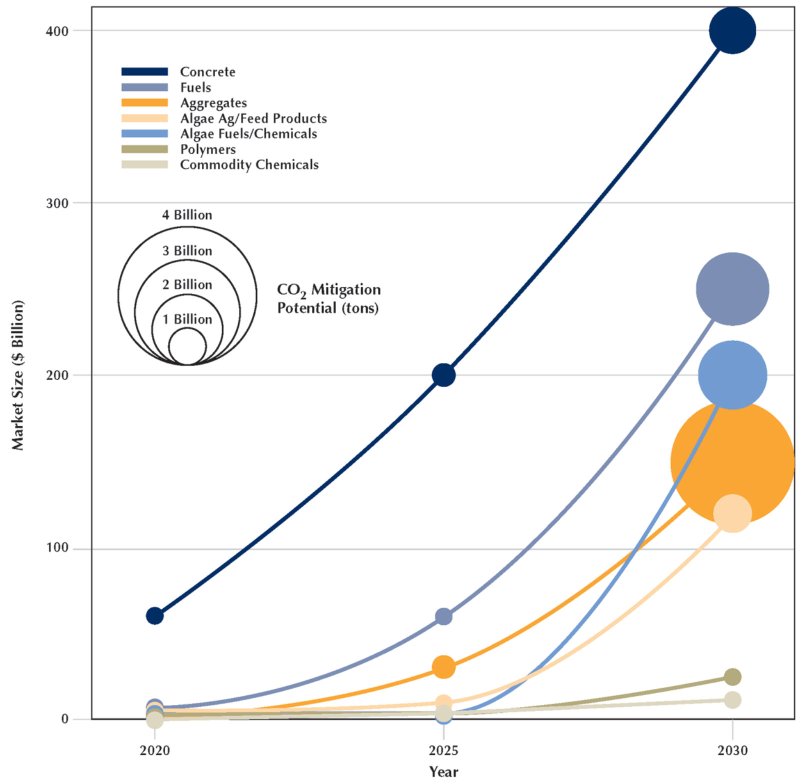
Plastics
- Polyurethane foams
- Polycarbonate (glass replacement)
- Acrylonitrile butadiene styrene
- Many more

Agriculture & Food
- Algae-based food or animal feed
- Microbial fertilizer
- Biochar, bio-pesticides, bio-cosmetics

Chemicals
- Preservatives (formic acid)
- Medicinal
- Antifreeze (ethylene glycol)
- Carbon black
- Many more

Source: A Roadmap for the Global Implementation of Carbon Utilization Technologies https://assets.ctfassets.net/xg0gv1arhdr3/5VPLtRFY3YAIasum6oYkaU/48b0f48e32d6f468d71cd80dbd451a3a/CBPI_Roadmap_Executive_Summary_Nov_2016_web.pdf

FIGURE 3: Market size and GHG mitigation potential of selected CCU sectors



Source: C2ES/Cogentiv Solutions analysis of market trends and potential greenhouse gas reduction capacity based on market projections from the Global CO_2 Initiative's Roadmap.

Figure 3 helps to visualize the notion that the respective market potential for each sector is different, and doesn't always correlate with its greenhouse gas reduction potential. For instance, the current market value of low-carbon concrete is greater than all other sectors, as is its level of greenhouse gas reduction. And while concrete promises to remain the largest CCU sector in terms of market value, the potential greenhouse gas reduction contributed by other sectors, including low-carbon fuels, algae-based fuels and products, and aggregates, may surpass that of concrete by 2030. This suggests that, given favorable policies, all CCU sectors have significant potential for market growth and emission reduction.

Table 1 shows the numeric values associated with the different sectors shown in **Figure 3**, which were compiled from a variety of sources, including reports focused specifically on carbon utilization opportunities,[8,9] energy related publications,[10] trade publications,[11] financial market analyses,[12] technical publications,[13] and United Nations organization reports.[14] To achieve these projections, policies and measures will be needed to support the growth of carbon utilization technologies and products across the various value chains. Without this support, it is uncertain whether this potential can be realized. Additional detail regarding various CCU technologies and policies is presented in the sections below.

TABLE 1: Market size and GHG mitigation potential of selected CCU sectors

MARKET SIZE: $ BILLION	2020	2025	2030
Concrete	60	200	400
Fuels	5	60	250
Aggregates	4	30	150
Algae Ag/Feed Products	3	10	120
Algae Fuels/Chemicals	2	4	200
Polymers	1	3	25
Commodity Chemicals	0	5	12

GHG MITIGATION: BILLIONS OF METRIC TONS OF CO_2	2020	2025	2030
Concrete	*	0.7	1.4
Fuels	*	*	2.1
Aggregates	*	0.7	3.6
Algae Ag/Feed Products	*	*	1.2
Algae Fuels/Chemicals	*	*	2
Polymers	*	*	*
Commodity Chemicals	*	*	*

* less than 0.5 billion tons CO_2

Source: C2ES/Cogentiv Solutions analysis of market trends and potential greenhouse gas reduction capacity based on market projections from the Global CO_2 Initiative's Roadmap.

III. CARBON UTILIZATION'S SECTORS AND TECHNOLOGIES

CONSTRUCTION MATERIALS

Construction materials represent a large, near-term opportunity for carbon utilization, principally through cement and aggregate (the gravel, sand, or crushed stone used with cement to form concrete). The current global market for concrete is around 30 billion tons and is estimated to grow to about 40 billion tons by 2030. Similarly, the global aggregates market is 25 billion to 35 billion tons, and is estimated to grow to about 50 billion tons by 2030. If carbon is used as an input and replacement for calcium carbonate, the Global CO_2 Initiative estimates the associated emissions reduction potential in the construction materials sector could be in the range of 1 billion to 10 billion tons by 2030 (see **Appendix A**).[15] Technologies to develop new structural materials from captured carbon, such as carbon fibers, are also in development.

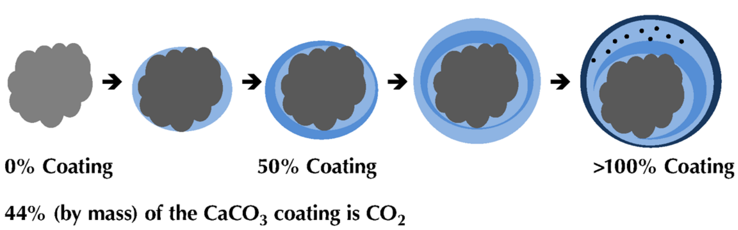
One of the most significant challenges of utilizing CO_2 is that it is a very low-energy molecule. For most applications, a form of energy (either thermal, chemical, or electrical) has to be added to convert CO_2 into a different molecule to form fuels and chemicals. In contrast, carbonates are even lower-energy than CO_2, which minimizes the energy needed to form them. When CO_2 is incorporated into the production of cement and aggregate (and thus concrete), forming carbonates, it is not necessary to add energy to overcome thermodynamic constraints. This is important because the energy required to make large volumes of material could be extremely expensive, rendering the materials non-cost-competitive and potentially less beneficial to greenhouse gas reduction efforts.[16]

One way that CO_2 can be incorporated into building materials involves formation of a carbonate coating on small solid materials, as illustrated in **Figure 4**. In order to form carbonate-based solids, the negatively charged carbonate ions must be balanced by positively charged ions. For cement and aggregate, those ions are most commonly either calcium or magnesium.

Unfortunately, ionic calcium and magnesium are not widely available in easily accessible forms. Possible sources include seawater, volcanic rocks, slags and other alkaline industrial wastes, though each of these is challenged by the need for proximity to a CO_2 source in order to be economic. Development of methods to produce reliable, sustainable, low-cost calcium and magnesium is an area of active research.

Another way that CO_2 can be used in construction materials is referred to as direct utilization or adding CO_2 to concrete during curing. This reduces the amount of cement required to produce equivalent-strength concrete, reducing emissions from cement production

FIGURE 4. Formation of aggregates using carbonate coatings and waste CO_2



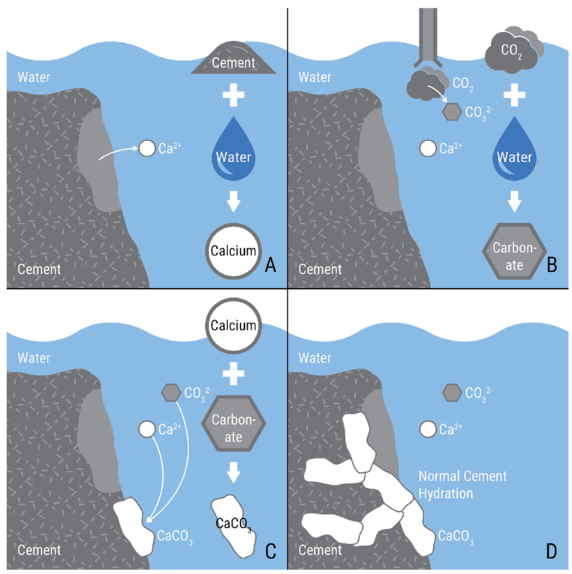
Source: Blue Planet http://www.blueplanet-ltd.com/

in addition to the CO_2 incorporated into the concrete. The company Carbon Cure has applied this approach to over 100 conventional, Portland Cement-based ready-mix concrete plants in the United State and Canada. CO_2 is injected into the concrete mix, and as the concrete cures, the CO_2 is permanently mineralized, as illustrated in **Figure 5**.[17]

Solidia Technologies uses a cement that contains more silica-rich materials than conventional Portland Cement. This unconventional cement binds with more CO_2 during curing and can be used to make low-carbon, high-strength, pre-cast materials. The technology has been demonstrated at pilot scale and is anticipated to be ready for commercialization soon. Current research and pilot projects associated with direct utilization focuses on increasing the amount of CO_2 absorbed while still maintaining concrete product standards.

The existence of prescriptive standards, such as those of ASTM International (formerly known as the American Society for Testing and Materials), represents a significant challenge for advancing the use of CO_2-based construction materials. ASTM standards, for example, narrowly define a variety of parameters/characteristics including setting times and compressive strength for Portland Cement-sand mixtures, and the specific amounts of ground limestone and inert extender that can be blended with cement, among many others. If CO_2-based construction materials do not match those

FIGURE 5: CO_2 utilization in the Carbon Cure process



NOTE: Process consists of a) water added to cement leading to dissolution; b) CO_2 introduced and enters solution; c) solid phase calcium carbonate ($CaCO_3$) formed; d) normal cement hydration with $CaCO_3$ acting as a nucleating agent

Source: Adapted from Monkman http://nas-sites.org/dels/files/2018/02/MonkmanNASEM-Webinar-CarbonCure_180118-export.pdf specific requirements, they may not be accepted for use, even when they exceed performance levels of traditional materials. Successful entrants to the market, such as Carbon Cure, have focused on making incremental changes to traditional concrete formulations to minimize the acceptance challenges.

The use of carbonate as aggregate does not face the same hurdles to market entry, but its cost is a significant barrier. Current gravel aggregate costs are typically near \$50/ton depending on location, while technology developers say low-carbon aggregate might sell for \$70 to \$100/ton[18]. Thus, it is unlikely that CO_2-based aggregate could be widely competitive purely on price, and instead would require some form of policy support.

FUELS/CHEMICALS/PLASTICS

Fuels, chemicals and plastics represent a significant opportunity for utilization technologies. Their potential markets are diverse and varied, but they are considered together here because their carbon utilization production processes tend to have some commonalities.

The Global CO_2 Initiative *Roadmap* estimates the total market size potential for the three product categories to range from \$1 billion to more than \$250 billion per year. That corresponds to an emissions reduction potential of 100,000 to 2.1 billion metric tons per year (**Table 2** and **Appendix A**). Again, while these estimates may represent high-end market potentials, a key takeaway is that fuels may have a much larger market and a much larger emission reduction potential than chemicals and polymers. Industrial emissions containing CO and CO_2 already are being biologically converted to low-carbon fuels at commercial scale today, creating fuels with over 70-percent greenhouse gas reductions compared to their fossil counterparts.

As noted in the section describing construction materials, CO_2 is a very low-energy molecule. And while formation of carbonates for construction materials does not require input of large amounts of energy, the use of CO_2 for fuels, chemicals, or polymers does require significant energy inputs to convert CO_2 into products. An exception to this occurs in cases where CO is present in industrial waste gases.

At a basic level, conversion of CO_2 to fuels and chemicals entails adding hydrogen (either in molecular form or from other reaction partners) to the carbon in CO_2. The two primary pathways for doing this are direct hydrogenation of CO_2, and indirect production (**Figure 6**), which involves conversion of CO_2 to carbon monoxide (CO) followed by synthesis of specific products.

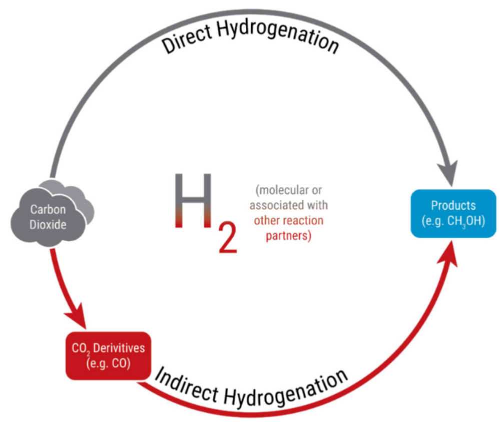
TABLE 2: Market Size Potential

Product	Current Potential Revenue (\$ billion)	2030 Potential Revenue (\$ billion)	Current Emissions Reduction Potential (million tons)	2030 Emissions Reduction Potential (million tons)
Fuels	1 – 5	10 – 250	10 – 30	700 – 2,100
Methanol	0.1 – 0.2	1 – 12	0.1 – 1	5 – 50
Polymers	0.1 – 0.6	2 – 25	0.02 – 0.05	0.1 – 2

Note: Methanol is used as a representative for commodity chemicals.

Source: Global CO_2 Initiative, A Roadmap for the Global Implementation of Carbon Utilization Technologies *https://assets.ctfassets.net/xg0gv1arhdr3/5VPLtRFY3YAIasum6oYkaU/48b0f48e32d6f468d71cd80dbd451a3a/CBPI_Roadmap_Executive_Summary_Nov_2016_web.pdf*

FIGURE 6. Primary pathways for production of fuels from CO_2



Source: Carbon Dioxide Utilization (CO_2U) ICEF Roadmap 2.0 https://www.icef-forum.org/platform/upload/CO2U_Roadmap_ICEF2017.pdf.

Note that some industrial sources contain CO and do not require an initial conversion step.

Mechanisms for accomplishing this fall into the following categories:

- **Thermocatalytic:** Energy is provided in the form of heat (and pressure) and the reaction is driven by a catalyst that activates CO_2 so that it can react with hydrogen.
- **Electrochemical:** Energy is provided in the form of electricity and reactions take place in an electrochemical cell.
- **Biochemical:** Living organisms or the unique products they generate (e.g. enzymes) convert CO_2 or CO to products.
- **Photochemical:** Solar energy provides the heat or electricity needed to drive catalytic conversion reactions.
- **Hybrid approaches:** The approaches noted above are combined (e.g. electrolysis coupled with thermocatalytic approaches, electrochemical reactions driven by microbes, etc.).[19]

In general, the two leading methods of hydrogen production are steam methane reforming (SMR) and electrolysis of water. Hydrogen production using SMR is currently much less expensive than water electrolysis. However, electrolytic production of hydrogen is an area of active research, and there is significant potential for reduced costs in the future. If demand for hydrogen to support CCU increases in the short term, it is likely that SMR coupled with carbon capture would be the lowest-cost option for meeting that short-term demand. Current examples of carbon capture technology paired with steam methane reforming include the Shell Quest project near Edmonton, Canada, an Air Products facility in Port Arthur, Texas, and the Tomakomai project in Hokkaido, Japan.

Direct Hydrogenation Pathway

Technology for direct hydrogenation—the process of adding hydrogen to CO_2 without first converting it to a different compound—exists and has been commercialized for production of methane, methanol and other chemicals. Methanol (CH_3OH) is an attractive product for CO_2 utilization because commercial processes exist to convert methanol to gasoline and other chemicals that are used in multiple industrial processes. Production of methanol from CO_2 has been tested at pilot scale, and a five million-liter-per-year CO_2-to-methanol plant is currently operating in Iceland (which enjoys the benefit of inexpensive hydroelectric power generation and geothermal heat that can be used for hydrogen production and process heating—see below).

However, costs associated with direct hydrogenation of CO_2 to methanol and other products are too high without some form of policy support to be competitive with the production of chemicals starting with fossil fuel-based feedstocks. The two components of the process needed for conversion—catalytically activated CO_2 and hydrogen—both have extremely high costs associated with them. Research to create better catalysts and more efficient separation processes is essential to drive down costs for the CO_2 activation step.

Availability of inexpensive, low-carbon hydrogen is another challenging piece of the puzzle. Many advocates for the utilization of CO_2 for fuels assume that availability of excess renewable energy will drive down the costs of electrochemical hydrogen production. Currently, electricity costs make electrochemical splitting of water to generate hydrogen uneconomic. The argument has been made that with excess renewable energy available at certain times on the grid, the cost of electricity for hydrogen production can be driven to nearly zero, making the process more economic.

However, that argument does not account for the intermittent nature of excess renewable electricity availability. If an electrochemical hydrogen production facility is only available for operation for a limited amount of time each day, the economics of the argument tend to fall apart due to the lower capacity factor and corresponding increase in capital costs per unit of production. The capital investment made for the facility would be based on continuous operation, which could not be delivered. One of the significant needs to help advance CO_2 utilization for fuels is a mechanism to deliver low-cost, low-carbon hydrogen that does not depend on the assumption of nearly-free electricity.

Direct electrochemical processes that convert CO_2 to fuels and chemicals have been demonstrated at laboratory-scale to generate a variety of products, including formic acid, methanol, methane, and ethylene. Challenges associated with direct electrochemical conversion processes include low selectivity in transferring charge (faradic efficiency); low current density that limits production rates; and poor stability of the electrodes. R&D is needed to develop improved electrode materials and structures and improved process designs for practical applications. One other promising area of active research is "hybrid" microbial electrolysis cells, in which microbial communities living in the electrochemical cell convert CO_2 to chemicals.

Indirect Production Pathway

The indirect fuels and chemicals production pathway involving conversion of CO_2 to CO prior to processing is similar to direct conversion but with a defined CO intermediate product. It is attractive because CO is much more chemically active than CO_2. The process of converting CO and hydrogen (i.e., syngas) into methanol and into hydrocarbons via Fischer-Tropsch (F-T) synthesis is very well-known, although it does require hydrogen.

The principal challenge for this approach is the CO_2-to-CO conversion step. Options include catalytically-driven processes such as reverse water gas shift (RWGS) to generate CO from CO_2, various forms of reforming, which use methane (or other light hydrocarbons) to convert CO_2 to CO, and electrochemical approaches such as polymer electrolyte membranes or solid oxide eclectrochemical cells. Fundamental advances such as catalysts that operate at lower temperatures and advanced gas separations techniques are required to commercialize these processes.

A near-term opportunity to advance CO_2 conversion technology that can potentially overcome the hydrogen cost/availability issue noted above is dry reforming of methane and CO_2 to produce methanol in natural gas producing regions. Natural gas producers in the Permian Basin, Bakken Formation, and the Marcellus/Utica Formation are under regulatory pressure to reduce flaring.

One mechanism to reduce flaring would be to produce methanol using the methane and CO_2 present in the natural gas. Traditional, low-pressure dry reforming is technically viable but is currently uneconomic for a variety of reasons, including issues surrounding coking. There are, however, technologies under development/commercialization that appear promising. An R&D initiative to support development of lower-cost technologies could provide an opportunity for a public/private partnership that advances CO_2 conversion technologies broadly, lowers CO_2 emissions associated with flaring, generates a saleable product, and addresses the methane regulatory issue for gas producers.

A good example of the importance of advancing this indirect conversion pathway is provided by technology developed by LanzaTech. The company has created a process through which engineered microbes convert CO into ethanol. This technology has been demonstrated at commercial scale using waste gas from steel production, which is high in CO content. The availability of CO was a critical component that allowed for the development of this successful utilization technology. Inexpensive, widespread availability of more chemically active CO generated from CO_2 could result in the advancement of multiple technologies to generate fuels and chemicals from CO_2.

Plastics are included in this section on fuels and chemicals because the building blocks of most polymers include the commodity chemicals discussed above. Processes that generate commodity chemicals from CO_2 will inherently produce polymers with lower life-cycle carbon emissions than those generated from petrochemicals.

Polymers can also play a significant role in carbon utilization through direct inclusion of CO_2 into the polymer matrix of various materials. For example, Covestro has developed a process that imbeds CO_2 within the polymer chain of polyols used in the manufacture of foams for products such as mattresses. Production using this approach started in 2016 near Cologne, Germany. The facility now produces approximately 5,000 tons/year of foams that incorporate CO_2. Research is being conducted to develop approaches that incorporate more CO_2 into their polymer blends.

ALGAE-BASED PRODUCTS

Algae-based carbon utilization holds near-term promise in some product categories (e.g., biofertilizers, aquaculture, livestock feed, and feed additives), while other product categories (e.g., fuels, bioplastics) will require additional R&D to drive down costs to be commercially viable.

Algae are extremely efficient photosynthetic organisms—sometimes referred to as CO_2 eating machines. In 2015, the IEA Clean Coal Centre noted several advantages to algae-based carbon utilization:[20]

- High-purity CO_2 is not required to support algal growth.
- Flue gas containing varying amounts of CO_2 can be fed directly to the microalgae, reducing or eliminating the need for CO_2 capture systems.
- Some combustion waste products such as nitrogen oxides (NOx) or sulphur oxides (SOx) can be used as nutrients for microalgae (microscopic algae).
- Microalgae could yield high-value commercial products. The sale of these high-value products could offset the capital and operating costs of the process.
- Algae can be grown in open raceway pond systems and closed photobioreactor systems, including flexible plastic film systems, tubular reactors, and flat panel systems.

The U.S. Department of Energy (DOE) has also noted that algae-based CO_2 conversion offers a number of economic and environmental benefits, including:[21]

- High potential yield per acre
- The ability to grow on land not suited for agriculture, as well as in brackish or waste water
- High absorption of CO_2 and relative ease of conversion into fuels and products.

One of the most attractive features of algae-based utilization is the wide range of potential products that can be generated, as noted in **Table 3**.

TABLE 3: Potential microalgae products and prices

PRODUCT	SUBSTITUTE	PRICE	UNIT
Biodiesel	Diesel	$2.27	USD/gal
Bio-ethanol	Gasoline	$3.96	USD/gal
Bio-methane (fuel)	Liquefied petroleum gas	$1.92	USD/gal
Bio-jet fuel	Jet fuel	$2.49	USD/gal
Electricity	Fossil energy	$0.13-$0.21	USD/kWh
Bio-methane (electricity)	Natural gas	$0.05-$0.06	USD/kWh
Biofertilizers	Synthetic fertilizers	$0.25-$0.63	USD/kg
Biostimulants	Growth promoters	$37.50-$312.50	USD/kg
Biopesticides	Synthetic pesticides	$5.00	USD/acre
Bioplastics	Fossil based plastics	$1.75	USD/kg
Food	Proteins, carbohydrates, oils	$50.00	USD/kg
Beta-carotene	Synthetic/natural	$275.00-$2750.00	USD/kg
Omega-3 polyunsaturated fatty acids	Fish	$50.00	USD/g
Aquaculture	Fishmeal/fish oil	$68.75-$625.00	USD/kg
Livestock Feed	Soybean meal	$300.00	USD/tonne
Feed additives	Botanicals, antibiotics	$20.00	USD/kg

Source: Adapted from http://bioenergykdf.net/billionton2016/overview

A potentially significant long-term product pathway associated with algal uptake of CO_2 is the production of fuels—which is similar in some respects to the fuels production pathways previously described. Fuels can be produced from algae through whole biomass conversion techniques such as hydrothermal liquefaction, through lipid extraction or through fermentation of carbohydrates. Some strains of algae, such as certain cyanobacteria, are capable of excreting fuel or fuel precursors, eliminating the need for extraction or conversion.

EPA analyses of algae-based fuel pathways under the federal Renewable Fuel Standard (RFS) program found greenhouse gas reductions of 69-85 percent on a full lifecycle basis versus petroleum-based alternatives. Algae-based renewable diesel is also approved by EPA under the RFS as a qualified advanced biofuel with lifecycle greenhouse gas emissions reductions of greater than 50 percent versus petroleum-based diesel.[22]

In addition, several very high-value algae-derived nutraceuticals (dietary supplements) such as astaxanthin and betacarotene, already have small but well-established and growing markets with values that can exceed $1 million per ton of product.[23]

Animal feed and feed ingredients are also significant markets for algae-based products—particularly aquafeeds for fish and shellfish. CO_2-based algae are effective substitutes for traditional wild fish sources of nutrients because they can serve as the base of the marine food chain that many fish meal species rely on. Bloomberg estimates the potential market size for fish feed is $9 billion and for livestock feed is $370 billion and expected to grow up to 40 percent in the next 20 years.[24]

IV. THE ROLE OF POLICY IN ACCELERATING CO_2 UTILIZATION

As described above, carbon utilization applications have enormous commercial and decarbonization potential. However, if carbon utilization is to approach the levels of market value and CO_2 removal outlined by the 2016 Roadmap study, specific policies are needed to help overcome the challenges noted above. These policy options fall into four general categories:

- **Financial enablers** include incentives like tax credits and subsidized project finance.
- **Research** includes more and better coordinated federal spending on all phases of research, development, demonstration, and deployment (RDD&D).
- **Infrastructure** includes development of CO_2 transportation infrastructure.
- **Market enablers** include industry standards, and procurement policies that provide preferential demand for products with recycled carbon.

Congress provided an important financial enabler with the 2018 passage of the FUTURE Act, which improved and extended the federal "45Q" tax credit for carbon storage and utilization. This was a landmark for both carbon management and climate policy since it made the tax credit available for non-EOR utilization for the first time. When implemented, the tax credit has the potential to encourage all of the carbon uses identified above. But because individual CCU sectors are dissimilar both in terms of their levels of development and their future capacity, policymakers must also consider policies designed to overcome sector-specific challenges.

In the pages that follow, a variety of policies and measures are outlined. The first section discusses cross-cutting mechanisms while the second focuses on specific sectoral challenges. **Appendix A** offers a summary comparison of specific policies along with an overview of the status, barriers and market potential of the individual carbon-use sectors.

BROAD POLICY APPROACHES TO ACCELERATING CARBON UTILIZATION

Financial Enablers

The enactment of 45Q in 2018 was a significant achievement for all carbon uses, but two of its requirements may prevent non-EOR CCU from qualifying for the tax credit.

First, because of the time involved in planning and developing a new project, developers may have difficulty reaching the law's "begin construction" cutoff date of Dec. 31, 2023. Even then, they may not be able to ramp up to the 25,000-ton threshold level of CO_2 usage necessary to qualify for the credit. If the tax credit is not claimed by a significant number of CCU developers, Congress should push back or eliminate the begin-construction deadline and lower the tax credit's eligibility threshold to as little as 1,000 tons.

In addition to the 45Q tax credit, making carbon capture projects (including CCU projects) eligible for existing forms of preferable treatment would improve their financial profile. For example, **private activity bonds** (PABs) are tax-exempt bonds that allow project developers to qualify for lower-cost financing for privately-run projects that provide a public benefit. Also, **master limited partnerships** (MLPs) allow entities organized as partnerships to be publicly traded (therefore combining the lower-tax treatment of a partnership with access to securities markets). Making carbon utilization projects eligible for these financing options like PABs and MLPs would make them more attractive to investors, with little direct cost to the U.S. Treasury.

Finally, **FEED (front end engineering design) studies** represent a critical early step in project development, and one whose cost is not insubstantial for a startup. DOE presently has a selection process to fund FEED studies for capture projects; it could do the same for utilization projects. Meanwhile, incumbent industries such as oil and gas companies and chemical manufacturers have substantial expertise incorporating new technologies into existing production. DOE could work with those industries to fund FEED studies to help determine how components of carbon utilization technologies could be incorporated into existing facilities, especially refineries and ammonia production facilities.

Research, Development, Demonstration, & Deployment (RDD&D)

Experts consulted for this report mentioned the importance reforming and enhancing federal R&D spending. The budget for U.S. Department of Energy's Fossil Energy (DOE-FE) CO_2 utilization program has been in the $10-12 million range in recent fiscal years, out of a total R&D budget of approximately $500 million per year. Suggestions included:

- **Increasing spending:** Doubling or even tripling the relatively small current budget for utilization R&D (without robbing other FE R&D programs) would have an outsize impact on the rate of development. In October 2018, the National Academy of Sciences (NAS) released an evaluation of research agendas for each CCU sector. While NAS did not endorse a specific level of federal R&D spending, current spending levels simply won't permit the realization of the research agendas evaluated. Expanded R&D investment also would be consistent with the goals of the multilateral Mission Innovation (MI) and would enable greater focus on the "priority research directions" identified by the MI Carbon Capture Challenge.
- **Applying federal R&D support to all phases of development and deployment:** Current DOE-FE research dollars are directed mainly toward the Lab/Bench and Small Pilot phases (Technology Readiness Levels (TRL) 3-6, on the 1-9 TRL scale. Providing funding for later stage pilots was seen as important. Additional funding would also allow for follow-through on current projects to the commercialization stage. Getting beyond the "valley of death" (between pilot and full commercialization) is a challenge for any new product, but especially for CO_2 utilization, where so many additional challenges are present.
- **Allowing the conversion of CO_2 capture pilot projects to CO_2 *utilization* pilots:** CO_2 capture pilot projects currently use a "catch and release" approach that simply vents the captured CO_2 into the atmosphere. Moreover, capture project developers do not have any incentive to continue capturing or providing disposition for the related CO_2 after their pilot projects are completed. Incentivizing the continued operation of pilots could provide the CO_2 needed for new utilization projects at an appropriate scale.

Federal R&D Legislation

The DOE-FE R&D program still operates under its 2005 authorization, thus many of its current research objectives were barely envisioned by Congress when it was last considered. Certainly, the concept of beneficial use of captured carbon oxides in commercial products was in its infancy at that time.

Separate bipartisan bills to rewrite the DOE-FE R&D authorization have been introduced in both houses of Congress in 2019. The House bill, known as the Fossil Energy Research and Development Act, would provide additional money and direction specifically to develop CCU technologies. It was introduced as H.R. 3607 by Reps. Marc Veasey (D-Texas) and David Schweikert (R-Ariz.) and includes House Science, Space and Technology Committee chair Eddie Bernice Johnson (D-Texas) as a cosponsor.

In the Senate, the EFFECT Act (Enhancing Fossil Fuel Energy Carbon Technology, S. 1201) was introduced in May 2019 by Energy and Natural Resources Committee Ranking Member Joe Manchin (D-W.Va.), with committee chair Lisa Murkowski (R-Alaska) as primary cosponsor. The bill would support development of fossil emissions technology through all levels of development, including traditional R&D, large-scale pilot projects, demonstration projects, and FEED studies. Both the House and Senate R&D reauthorization bills have been approved by their respective committees and, at this writing, await floor action.

Also, a key provision of the USE IT Act (Utilizing Significant Emissions with Innovative Technologies) would direct the U.S. EPA to initiate an R&D program for utilization of CO_2 generated by industrial processes. Identical bills have been introduced in both the Senate and House in the 116th Congress (S. 383 and H.R. 1186).

Federal R&D Coordination

Finally, while total federal spending on all CCU activities is relatively small, it is also spread between many federal agencies, including multiple DOE offices and the Pentagon. These offices separately manage CCU research, with little high-level coordination of various research priorities and outcomes. Creation of an Interagency CCU Task Force could elevate carbon utilization in the government's science agenda and help inform decisions about future Funding Opportunity Announcements (FOAs).

Along with DOE-FE, DOE's Bioenergy Technology Office (BETO) also receives carbon utilization research funding. Increasing funding for BETO's algae carbon utilization research alongside that for the DOE-FE R&D program would advance algae project development. Other federal agencies that receive funding for synthetic biology include DOE's Advanced Research Projects Agency-Energy (ARPA-E) and the Pentagon's Defense Advanced Research Projects Agency (DARPA). Better coordinating the goals of all of these programs would ensure alignment of research priorities.

CO_2 Transportation Infrastructure

Pipelines

A threshold issue for most carbon use applications is the siting and building of transportation infrastructure to move captured CO_2 to users. For example, capturing CO_2 from ethanol production plants is relatively inexpensive given that the process emits a high-purity stream. However, ethanol plants are often located far from where developers could use the CO_2 and the compression and transportation costs can be substantial. The USE IT bill includes language to spur federal, state, and non-governmental collaboration in the development of facilities and CO_2 pipelines needed to capture and transport CO_2 from source to market.

Another potential legislative vehicle for creating a national CO_2 pipeline network would be national infrastructure legislation, which has been discussed for years and may finally advance in the 116th Congress. If Congress moves forward on this front, inclusion of language authorizing CO_2 pipelines adequate to linking sources of CO_2 with both geologic storage and potential CO_2 utilization opportunities would be helpful. Also, the Carbon Capture Coalition has suggested authorizing the "supersizing" of new CO_2 pipelines to account for future demand for CO_2 transportation needs.[25] (Since most pipeline construction costs are fixed, increasing pipeline diameter to substantially expand capacity adds little to total project costs.) This would be helpful for handling the growth in CO_2 transportation demand that future utilization projects would create.

CO_2 Opportunity Zones

A continuing challenge is simply access to low-cost, high-purity CO_2 itself. Currently, most CO_2 for utilization applications is purchased in relatively small quantities and transported by truck. One approach to solving the access problem would be to locate utilization development near high-purity CO_2 sources. Co-location of CO_2 utilization facilities with major industrial sources of CO_2 could be mutually beneficial and would reduce or eliminate the cost of transportation infrastructure. (Power generation is not a good source of low-cost, high-purity CO_2, given the impurities in flue gas, compared with a "pure stream" that can be captured from ethanol production, for instance.)

To help with this, incentives such as tax preferences that encouraged locating multiple utilization CO_2 applications near large sources of high-purity CO_2 would be helpful. This may be best accomplished by state-level policies that take economic development into account; for instance, tax forgiveness for a particular period. Such designated "opportunity zones," where investment is focused on CCU applications (among other clean energy technologies), could generate a variety of economic benefits, including new investment and jobs.

Market Enablers

In the absence of an economy-wide price on carbon, federal and state governments can help create a market for beneficial utilization products in a number of ways. These include improved disclosure requirements (including green labeling), so products can be compared on an "apples to apples" basis, as well as updated industry standards that allow and encourage procurement of low-carbon technologies including the use of captured carbon.

To encourage low-carbon markets, consistent standards are needed for determining the carbon footprint of materials, especially the lifecycle emissions of those products. Many companies are interested in the carbon footprint of their operations, including their building and materials. Companies increasingly disclose these metrics to various sustainability platforms and standards. Climate reporting and disclosure has grown significantly in recent years, particularly in response to recommendations made by the Task Force on Climate-related Financial Disclosures (TCFD) in 2017.[26] Consistent metrics allowing an apples-to-apples comparison between regular and low-carbon materials would help increase demand for these materials.

Related to this, consumers have also demonstrated their interest in supporting companies and products with environmentally beneficial attributes and are accustomed to federal "green labeling" standards that can guide them on issues like energy efficiency. At the same time, the extent to which consumers are willing to pay a premium varies by product. Products like low-carbon cement, for example, may attract a premium price, while other low-carbon products like chemicals and polymers may only reach the consumer market indirectly through business-to-business transactions. Accurately measuring the carbon footprint for these products, however, can be useful as more large retailers are asking for this information from their supply chains.

Industry Standards

Updated and enhanced industry standards have the potential to promote the development and deployment of CCU technologies. For example, enhanced information about embodied carbon in infrastructure could play a role in encouraging the use of captured carbon. The University of Washington Carbon Leadership Forum is developing the open-source Embodied Carbon Construction Calculator (EC3) tool to help real-estate developers, architects, engineers, and the public better understand the carbon footprint of the built environment. Some Fortune 500 companies already have agreed to take a closer look at embodied carbon. For instance, Microsoft will be piloting the use of EC3 to develop its new campus in Redmond, Washington. Beyond pilot projects, there is an opportunity for tools like EC3 to be integrated into existing green building standards, such as the U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) standard and various International Standards Organization standards.

Procurement Policies

Federal and state governments are large purchasers of building materials for infrastructure and of fuel for government fleets of vehicles. Some state programs already prioritize the use of building materials and fuels with environmental attributes. For example, the "Buy Clean California" program requires state agencies to consider the emissions performance of suppliers of materials for infrastructure projects. The program applies to steel, mineral wool (insulation), and flat glass. Concrete is exempt, however, which may reduce the impact of the program. For fuels, policies that would require the use of a certain percentage of fuel derived from captured carbon could expand upon existing procurement policies that are focused on ethanol and biodiesel.

Expanding these programs could create large markets for the re-use of captured carbon. Government agencies have the capacity to be "market makers" based on their own buying patterns. Thus, the establishment of federal, state, and local procurement standards requiring incrementally increasing use of low-carbon fuels, concrete and aggregate would both ensure a growing demand for these products and spur investment in their development.

SECTORAL POLICY ISSUES

While taking action on the above issues could provide a boost to all recycled carbon based products, it is important to consider sector-specific challenges as well.

Construction Materials

While the buildings sector has made significant progress reducing its carbon footprint through energy efficiency, the carbon footprint of the steel, concrete, and other materials used to construct the built environment should be a focus for policy. Utilization of CO_2 in the production of construction materials like cement and aggregate has relatively low technological barriers. However, these products must be commercially competitive in markets that are characterized as being both low-margin, and highly standardized by widely adopted technical specifications and building codes.

Despite the proven qualities of low-CO_2 building materials, those specifications and codes may or may not currently allow their use in many construction applications. This has led developers of low-carbon construction materials to focus initially on markets for pavers and other products that are covered by fewer performance standards than structural materials. The low-carbon construction materials market could grow rapidly in response to building codes that are performance-based and are updated to expressly encourage greater use of these materials while ensuring that they meet both quality and safety requirements.

While updating building codes often takes time, state governments could incentivize this activity by providing performance-based incentives for jurisdictions that have updated their building codes to encourage the use of captured carbon in building materials.

Fuels

The markets for low-carbon fuels of all types face similar challenges as they tend to be low-margin, highly standardized, and compete with conventional fuels whose retail prices do not reflect externalities related to climate change. Policies are needed to level the playing field for such fuels in order to realize their potential benefits in terms of energy security and economic growth.

Policies that allow either carbon sequestration or recycled carbon as compliance-eligible can help create more demand for these products. For example, the International Civil Aviation Organization decision to allow recycled carbon-based fuels to count as low-carbon fuels has spurred airline interest in these technologies.

Similarly, California's low-carbon fuel standard (LCFS) has gained attention for its focus on reducing the carbon intensity of transportation fuels. The state's LCFS was amended in 2018 to allow CCS to count toward this standard and again can only help increase demand for the technology. California could broaden its LCFS to include storage through mineralization in construction materials, which would pose no threat of subsurface leakage and therefore require no monitoring of groundwater. In addition, other states might consider changing what qualifies under existing rules to allow materials made using carbon sequestration or with recycled carbon.

Chemicals and Plastics

Unlike the markets for building materials and fuels, CCU-derived chemicals represent a higher-margin and lower-volume market. It's useful to think of the "ecosystem" of products that can be made from captured carbon in the same way that most people are aware that petroleum can be used to make chemicals and plastics, as well as fuels.

While some carbon utilization chemicals and plastics comply with existing ASTM standards, incentives or use requirements would help grow this market. In Europe, the organization CO_2 Value Europe has been engaging governments, businesses, and consumers around this goal.

Algae

Responsibility for federal algae policy is shared by three Cabinet-level departments and the EPA. Those four agencies (along with the National Science Foundation) coordinate through an interagency work group. DOE's recent annual research spending through BETO has been in the range of \$30-32 million (although only a small portion is spent on carbon utilization research).

The public is likely more aware of the role that forests and land management play in mitigating climate change as carbon sinks, so consumer education is needed regarding algae-based products.

Also, a regulatory regime that ensures both quality and safety is necessary. As with other sectors, government procurement rules would be a market driver. Federal and state authorities, for instance, could require incrementally increasing use of algae-based products (e.g., soil supplements) for public lands management.

V. CONCLUSIONS AND RECOMMENDATIONS

The increased attention recently devoted to carbon utilization by both the private and public sectors suggests the potential these nascent processes may have to help drive decarbonization. However, because the levels of technology and commercial readiness differ so widely from sector to sector, no proposed single policy reform offers a "silver bullet," rather, a portfolio of policies is needed to address technology development, financing, and market preferences. Moreover, federal action alone is not sufficient. States and local governments may be in the best position to tailor policies that address their specific circumstances.

The principal recommendation of contributors to this report is straightforward: *The focus of policy toward carbon utilization should aim for growth by 2030,* ensuring that a significant amount of CO_2 is being sequestered by utilization processes in that timeframe. The year 2030 is a useful target because many state and local climate plan goals are tied to it, and because the report issued in October 2018 by the UN Intergovernmental Panel on Climate Change, pegged 2030 as the timeframe by which the planet may reach the threshold of 1.5 C above pre-industrial levels.

If carbon utilization sectors have not developed by then to the point where commercial forces are driving continued growth, the expected contribution of CCU to decarbonization may not be reached. If CCU development falls short of its potential, an important capacity for greenhouse gas reduction will remain unfulfilled.

Wide agreement exists among stakeholders and experts consulted in the preparation of this report regarding the policy pathways that will grow carbon utilization. At the federal level, it starts with immediate action on three initiatives—the USE IT Act, reauthorizing the Department of Energy's Fossil Energy (DOE-FE) research program, and infrastructure legislation—which would significantly strengthen the foundation upon which carbon utilization's future can be built.

However, these proposals are only first steps; an aggressive strategy to stimulate low-carbon market demand is needed if CCU is to meet its economic and environmental potential, especially if the goal is 2030. Actions including carbon intensity disclosure requirements, better lifecycle analysis, incentives for using carbon-based products, expanded low-carbon fuel standard and renewable fuel standard policies, and targeted procurement policies are all critical tools to scale up carbon utilization.

Policymakers should consider goals for carbon utilization development set out by reports including the National Academy of Sciences Report, 2018; University of Michigan CCUS Report, 2017; the National Coal Council *CO_2 Building Blocks* Report, 2016; and the CCU *Roadmap,* 2018. The understanding of these new processes and their development needs has increased in recent years, and together these reports form a basis for action.

In sum, the following actions are recommended as a path forward for CO_2 utilization policy.

IMMEDIATE ACTIONS (2019)

45Q Tax Credit

While Congress enacted the 45Q tax credit in February 2018, it cannot take effect until the IRS publishes the guidance for taxpayers to claim the credit. The actual value of the credit to advancing a particular project is unknown until that guidance is published. The IRS should act swiftly to put forth its guidance on the many issues needing clarification and definition. Of particular importance to the CCU developers will be the guidance on a required greenhouse gas lifecyle analysis (LCA).

Meanwhile, Congress should note that provisions of the new law already threaten to limit the policy's impact on encouraging CCU. As such, Congress should proactively address those issues, by lowering the threshold for credit eligibility and extending or eliminating statutorily imposed deadlines, including the begin construction date.

Other Federal Legislation. Congress has the opportunity to pass three pieces of legislation before the next election that would advance carbon utilization.

- First, the USE IT Act was expressly proposed by Congressional carbon capture supporters as a logical set of next steps after 45Q. For carbon utilization, USE IT promises to improve coordination of CO_2 transportation and to provide additional research support.
- Second, both the House and Senate committees of jurisdiction for the DOE-FE research and development (R&D) program have begun crafting reauthorization legislation that committee leaders hope to advance with bipartisan support. This is a critical opportunity for Congress to prioritize the development of CCU technologies, and to authorize the funding levels that would support an amibitious research agenda.
- Third, national infrastructure legislation, if and when it begins to move, should prioritize the construction of CO_2 transportation that will facilitate linking CO_2 sources with potential CCU development.

NEAR-TERM ACTIONS (2019–2022)

Research and Development

CCU R&D is at a critical stage, and continued progress in specific areas such as electrolytic hydrogen, as discussed above, may have significant impact by the end of the "near-term" period. Regardless of whether Congress is able to agree on a new FE R&D authorization, it has the authority to continue increasing spending levels through this period. (It should also continue increasing the Bioenergy Technology Office's research budget.)

As for research priorities, the needs described by the 2018 National Academy of Sciences Report are a good starting point for considering government R&D agenda for both the near- and longer-term. Establishing interagency coordination of federal CO_2 utilization policy at senior level would help to align priorities.

In addition, consideration should be given to:

- Authorizing the funding of more and larger pilots ($5 million–$10 million range)
- Ensuring follow-through funding through the commercialization stage to address the "valley of death" problem;
- Allowing for the conversion of carbon capture pilot projects to carbon *utilization* pilots (Some pilot projects that receive funding for CO_2 capture could be incentivized to continue operating to provide CO_2 for project developers).

Project Financing

Making carbon utilization projects eligible for private activity bonds and treatment as master limited partnerships would make financing projects more attractive. Congress could extend these options to carbon capture projects, including CCU, with little cost to the U.S. Treasury. Another small but significant action would be to allow for the subsidization of private industry front-end engineering design (FEED) studies.

Market Enablers

Pipelines, technology, and financing are "supply side" policies, but providing incentives on the demand side will help as well. They could include the following supportive actions:

- Establish incentives for businesses that adopt CCU technologies, such as construction materials, fuels, chemicals, and plastics, into their supply chains.
- Expand incentives for low-carbon fuels, such as by expanding Low Carbon Fuel Standards, Renewable Fuel Standards, and other mandates to include fuels made from captured carbon.
- Increase state and local procurement policies that encourage the use of captured carbon in materials for infrastructure development and fuels for government fleets.

While not a government policy issue, industry standard setters could encourage the use of captured carbon by reforming guidelines like the Leadership in Energy and Environmental Design (LEED) standard for buildings, and those set by the International Standards Organization (ISO) and ASTM (formerly known as the American Society for Testing and Materials) for commercial and industrial activities.

MID-TERM ACTIONS (2023–2030)

If government can accomplish the above policy reforms by 2023, the rest of the decade can be focused on implementation. A significant expansion of CO_2 transportation pipelines will take time but will be dependent upon the above-described actions at both the federal and state level.

As markets for CO_2 develop, economic approaches to linking sources with utilization may become clearer. State and local governments may consider establishing Carbon Opportunity Zones to create incentives for co-location of utilization with higher-purity CO_2 sources. Meanwhile, both technology advancements and experience—development of "n^{th} of a kind" practices—should lead to the deployment of larger pilots and commercial projects.

Another broad incentive would be for more states to adopt a Clean Energy Standard (CES) which would recognize abated fossil power generation as a form of clean energy alongside renewable energy. A CES provides a market incentive for electric utilities to capture CO_2, which in turn provides a supply for the CO_2 market.

Finally, the greatest potential variable for all carbon management projects is whether governments (state and/or federal) may impose a price on carbon, and how such rules would be implemented. Carbon pricing is beyond the scope of this paper, but it should be noted that forms of carbon pricing already play a role in some CO_2U markets (e.g., California's LCFS). Implementing carbon pricing would ensure that building materials, products, and fuels reflect the true environmental and climate costs of competing alternatives.

LONGER-TERM ACTIONS

This report deliberately avoids suggesting policy actions in a timeframe beyond 2030 because, as described above, the consensus of contributors that significant progress on all fronts must be evident by 2030, and policies and action should aim for growing CCU sectors during that timeframe. Policymakers at all levels of government must be prepared to implement a portfolio of interconnected policies if CCU is to contribute both to economic development and to greenhouse gas reduction.

APPENDIX A: SUMMARY OF STATUS, OPPORTUNITIES, CHALLENGES, AND POLICY CONSIDERATIONS FOR CARBON UTILIZATION APPROACHES

PRODUCT	CURRENT STATUS	OPPORTUNITIES	CHALLENGES	POLICY CONSIDERATIONS
Construction Materials	Cormmercial/Near Commercial	• Current market size = 55–65 billion metric tons • CO_2 use potential (by 2030) = 1–10 billion metric tons/year • Time frame = now (small scale); 5+ years broad commercial scale	• R&D needs: Decreased cost and increased availability of alkaline materials to provide needed Calcium and/or Magnesium • Low-margin, highly standardized markets that are difficult to penetrate with new products • Cost pressures	• Foster a regulatory environment that promotes a measured and fair process to ensure that products meet both quality and safety requirements • Establish government (fed/state/local) procurement requirements that require incrementally increasing use of low-carbon concrete and aggregate
Fuels	Wide range - near commercial to early stage R&D	• Current market size = 55 million barrels/day[27] • CO_2 use potential (by 2030) = 0.07–2.1 billion tonnes/year • Time frame = now (small scale); 5–20 years broad commercial scale	• R&D needs: catalyst development, low carbon, low cost hydrogen; electrochemical process development; photocatalytic processes; LCA development • Low-margin, highly standardized markets that are difficult to penetrate with new products • Cost pressures	• Expansion of policies such as the California low carbon fuel standard to additional states or perhaps nationally • Establish government (fed/state/local) procurement requirements that require incrementally increasing use of low-carbon fuels

PRODUCT	CURRENT STATUS	OPPORTUNITIES	CHALLENGES	POLICY CONSIDERATIONS
Chemicals/ Plastics	Wide range—near commercial to early stage R&D	• Current market size = 350 million metric tons[i] • CO_2 use potential (by 2030) = 50–100+ million metric tons/ year[i,ii] • Time frame = now (small scale); 5–20 years broad commercial scale	• R&D needs: catalyst development, low carbon, low cost hydrogen; electrochemical process development; photocatalytic processes; LCA development • For commodity chemicals—Low-margin, highly standardized markets that are difficult to penetrate with new products • Cost pressures	• Establish government (fed/ state/local) procurement requirements that require incrementally increasing use of low-carbon products (e.g., those made from low-carbon commodity chemicals) • Economy-wide incentives for use of low-C products
Algae (agriculture, aquaculture, nutraceutical, and consumer products)	Cormmercial/Near Commercial	• Current market size = $2.5 billion[28] • CO_2 use potential (by 2030) = 0.07–1 billion metric tons/ year[29,30,31] • Time frame = now (small scale); 5+ years broad commercial scale	• R&D needs: testing at scale • Established markets that are difficult to penetrate with new products • Cost pressures	• Foster a regulatory environment that promotes a measured and fair process to ensure that products meet both quality and safety requirements • Establish government (fed/ state/local) procurement requirements that require incrementally increasing use of algae-based products (e.g., soil supplements) for public lands management
Algae (refined products such as fuels/ chemicals)	Cormmercial/Near Commercial	• Current market size = $1.5 billion • CO_2 use potential (by 2030) = up to 2 billion metric tons/year • Time frame = now (small scale); 5+ years broad commercial scale	• R&D needs: testing at scale • Highly standardized markets that are difficult to penetrate with new products • Cost pressures	• Expansion of policies such as the California low carbon fuel standard to additional states or perhaps nationally • Establish government (fed/ state/local) procurement requirements that require incrementally increasing use of algae-based fuels for government vehicles

APPENDIX B: SURVEY QUESTIONS ON CARBON UTILIZATION POLICY

1. To what extent have you benefited from federal R&D funding, either directly or indirectly?
2. The lack of a **coherent government strategy on CO_2U research and development** *has been cited* as a barrier to the development of this industry. *Some advocates* recommend that the R&D budget for CO_2U technologies focus on geologic applications with potentially large volumes, such as enhanced oil recovery or enhanced coal bed methane. *Other experts* have suggested that a portion of the R&D budget for CO_2U technologies be reserved for long-shot technologies with high CO_2 abatement potential. How do you think the R&D budget for CO2U technologies should be prioritized?
3. **Increasing access to hydrogen and sources of carbon-free electricity** would facilitate development of CO_2U technologies. How could Federal and state governments incentivize: a) the production of hydrogen using excess renewable energy and b) the availability of carbon-free electricity for use in CO_2U applications?
4. **International ASTM standards** determine the specifications of building materials and other products. How could Federal or state policymakers help accelerate the updating of these standards to include products made from captured carbon?
5. **Procurement policies** can be used by national and state governments to create markets for advanced technologies. If Congress or state governments created procurement policies focused on increasing the use of materials made from captured carbon, what considerations should policymakers be aware of in designing the policies?
6. State and local governments are responsible for creating and updating **building codes**. In their financial support for state and local infrastructure, should the Federal government offer performance-based incentives for jurisdictions that have updated their building codes to prioritize using materials made from captured carbon?
7. In recent years, companies have responded to consumer demand by **"green labeling"** products with a smaller environmental footprint. How could the Federal government facilitate "green labeling" of fuels made from captured carbon?
8. While there are a variety of options to re-use captured carbon, some of them are geographically specific, such as algae which is more viable in coastal areas. How could the Federal government best **incentivize transportation of captured carbon** through pipelines or trucks to areas where it can be re-used?
9. Large sources of manmade CO_2, such as from power plants, are often subject to environmental regulations and **permits that do not allow for the diversion of CO_2 to CO_2U developers**. How could Congress help provide certainty for power plant operators who would be open to partnering with CO_2U developers to invest in CO_2U solutions and test them on-site?
10. Similarly, the useful life of large sources of manmade CO_2, such as from power plants, are often as long as 30-40 years while technology startups may not remain in business a similar duration and CO_2U investors may require a positive ROI within 10 years. How could the Federal government develop **public-private partnerships** to help bridge the gap?

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CLIMATE INNOVATION

DECARBONIZING U.S. INDUSTRY

C2ES CLIMATE INNOVATION 2050

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July 2018

This brief provides an overview of emissions trends and projections, and of decarbonization challenges and opportunities, in the industrial sector. Key points include:

- While greenhouse gas emissions from the industrial sector have declined over the last 20 years, they are projected to increase through mid-century, fueled by low prices for energy, particularly natural gas and natural gas liquids.
- Direct emissions from a wide range of sources account for more than 73 percent of the sector's total emissions. Indirect emissions from the use of electricity generated off-site account for the rest. On-site fossil fuel combustion is the largest source of industrial emissions.
- Energy-related carbon dioxide (CO_2) emissions (from both on-site fossil fuel combustion and off-site electricity) account for around three-quarters of the sector's total greenhouse gas emissions. In 2016, bulk chemicals, refining, and iron and steel production were responsible for nearly half of the sector's total energy-related CO_2 emissions.
- Options for reducing emissions in the industrial sector include: improved energy efficiency, developing and deploying new manufacturing techniques, switching to lower-emitting fuels, combined heat and power, carbon capture and storage, and more efficient use of resources.

OVERVIEW

The industrial sector encompasses a wide range of subsectors including manufacturing (e.g., steel, cement, chemicals), mining, and construction.[1] Manufacturing, construction and non-oil and gas mining contributed more than $3 trillion in GDP in 2016[2] and employed nearly 20 million people.[3]

The United States' five largest energy-consuming industries—bulk chemicals,[4] oil and gas, steel, paper, and food products—account for 56.5 percent of industrial energy use, but only 20.8 percent of product value. Other energy-intensive industries include glass, cement, and aluminum.

Industrial sector emissions have been declining since the mid-1990s, driven by the adoption of new, less carbon-intensive processes, fuel switching (e.g., coal to natural gas and renewables), increased efficiency, a shift in metal production to other countries, and the United States' continued transition from a manufacturing to a more service-oriented economy and from more energy-intensive to less energy-intensive industries.

In general, energy-intensive industries are growing more slowly in the United States than industries with lower energy intensities.[5] However, sustained investments in the U.S. chemicals industry are expected to continue the strong growth in domestic bulk chemical production.[6]

EMISSION TRENDS AND PROJECTIONS

In 2015, *direct* emissions from the industrial sector represented 21.4 percent of total U.S. greenhouse gas emissions. Direct emissions come from diverse sources and accounted for roughly three-quarters of the sector's total emissions. On-site combustion of fossil fuels for heat and power made up 53.7 percent of the sector's direct emissions for 2015, while various industrial processes were responsible for 16.6 percent. Direct emissions from industry make the sector the third-largest source of greenhouse gases (after transportation and electric power) in the United States.

Indirect emission from the use of electricity generated off-site account for the rest of the sector's emissions. Including its direct and indirect emissions, industry is the largest greenhouse gas-emitting sector in the United States, accounting for nearly 30 percent of total U.S. emissions.

Sub-sector emissions profiles vary widely. According to the Energy Information Administration's (EIA) 2018 *Annual Energy Outlook* (AEO), bulk chemicals, refining and iron and steel production were the three largest sources of energy-related carbon dioxide emissions, which account for around three-quarters of the sector's total (direct and indirect) emissions (**Figure 1**).[7]

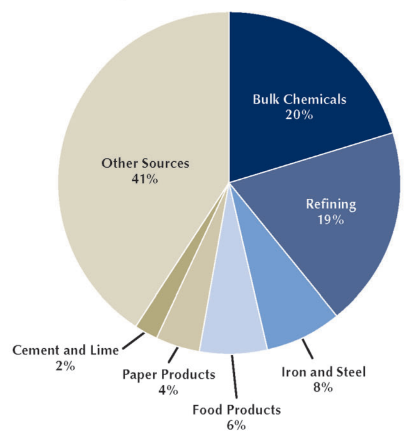
In addition to CO_2, industry accounts for 25 percent of total U.S. non-CO_2 greenhouse gas emissions, including 41 percent of methane, 7 percent of nitrous oxide, and 20 percent of other greenhouse gas (e.g., hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride) emissions.[8]

From 1996 to 2015, industry emissions declined about 18.7 percent, including a 15.1 percent decline in direct emissions and a 27 percent decline in indirect emissions from off-site electricity) as shown in **Figure 2**. While total emissions have been fairly flat since 2010, the share of direct emissions has been increasing.

From 1990 to 2015, direct emissions from industrial processes and product use increased by about 10.5 percent, driven primarily by a 270 percent increase in emissions of HFCs, which are substitutes for ozone-depleting substances.[9] Emissions from cement production increased 19.1 percent during this period due to increased production, primarily driven by increased construction activity. Emissions have also increased in semiconductor manufacturing, titanium dioxide production, and petrochemical production.

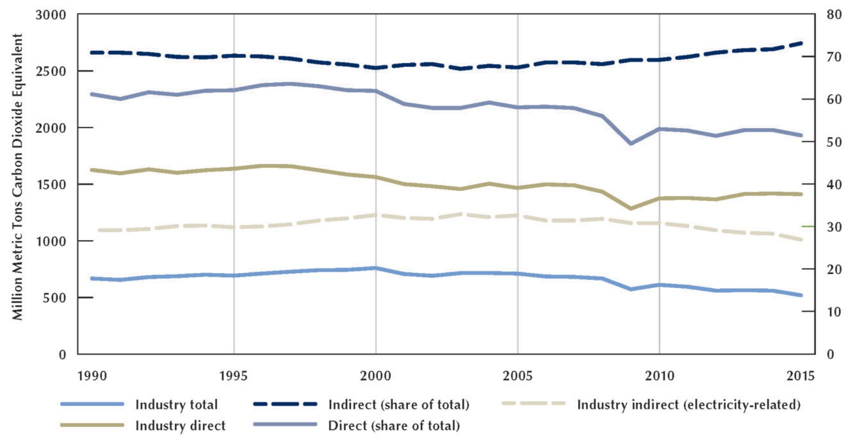
Projections of future emissions focus primarily on energy-related CO_2, which currently represents roughly three-quarters of total industry emissions. The EIA projects total delivered energy consumption in the

FIGURE 1: Energy-Related CO_2 Emissions from Industry (2016)



Source: U.S. Energy Information Administration, Annual Energy Outlook 2018 (Washington, DC: U.S. Department of Energy, 2018), Table 19 Energy-Related Carbon Dioxide Emissions by End Use, https://www.eia.gov/outlooks/aeo.

FIGURE 2: Direct and Indirect Industrial Sector Emissions



Source: U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015 (Washington, DC: U.S. Environmental Protection Agency, 2017), U.S. Greenhouse Gas Emissions Allocated to Economic Sectors, Table 2-12, https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2015.

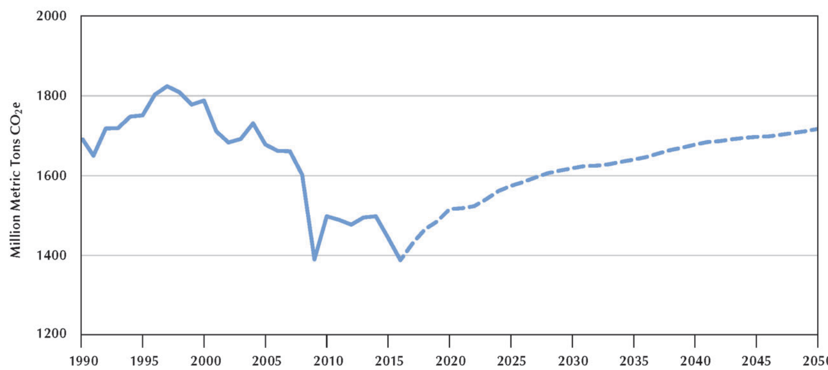
industrial sector will grow about 33.7 percent from 2017 to 2050, driven primarily by economic growth and relatively low energy prices.

Having fallen through 2010, and remained flat through 2015, the sector's energy-related CO_2 emissions are now projected to increase 17.6 percent through mid-century, fueled by low prices for energy, particularly natural gas and natural gas liquids (**Figure 3**).[10] The six largest sources of manufacturing emissions are expected to continue to be bulk chemicals, refining, iron and steel, food products, paper products, and cement and lime production. In absolute terms, emissions from bulk chemical manufacturing are forecast to increase the most, 126.7 $MMtCO_2$ or 45 percent.[11] Other manufacturing areas expected to see increases are food products (41.4 percent), fabricated metal products (37.1 percent), plastics (27.8 percent), aluminum (23.9 percent), and transportation equipment (20.3 percent). These six categories account for 60 percent of projected increases in energy-related CO_2 emissions from industry.

DECARBONIZATION OPPORTUNITIES AND CHALLENGES

Decarbonizing the industrial sector is generally considered more technically challenging than in the building and transportation sectors, as it concerns emissions not only from heat and power but also from products and processes. Potential pathways toward substantially reducing the sector's GHG emissions include: improved energy efficiency; fuel switching; carbon capture, utilization, and storage (CCUS); and process changes.

FIGURE 3: Industry energy-related carbon dioxide emissions, 1990–2050



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ENERGY EFFICIENCY

Improving the efficiency of heating and motors will be particularly important because they account for about 30 percent of total industry energy use and could yield benefits across diverse sub-sectors.

The emergence of the “internet of things” (e.g., embedding digital technologies within industrial machinery) has created new opportunities for intelligent efficiency and automation, which can further reduce industrial-scale resource and fuel consumption and emissions. One recent study found that intelligent efficiency could reduce global CO_2 emissions 20 percent by 2030, with about 22 percent of that reduction potential in the manufacturing sector.[12]

Combined heat and power (CHP) systems have helped reduce energy use across industrial sectors (e.g., bulk chemicals, pulp paper, petroleum and coal). Separate centralized electricity generation and on-site heat generation have a combined efficiency of around 45 percent, whereas CHP systems can reach efficiency levels of 80 percent. However, adoption of CHP systems has stalled in recent years due to high capital costs, technical complexity, and policy changes.[13]

FUEL SWITCHING

Increased electrification of the industrial sector will reduce emissions. Since on-site fossil fuel combustion is the largest direct source of emissions, steps to reduce these emissions, including electrification and the use of (decarbonized) pipeline gas, offer perhaps the biggest reduction potential. While industrial electric technologies (e.g., electric boilers and electric technologies for process heat) already exist, they are only used in a subset of industrial sectors. Challenges in decarbonizing via electrification include large capital investments for equipment, the high relative cost of electricity vs. fossil fuels, and technical hurdles associated with electrifying energy-intensive and high-temperature processes.

CARBON CAPTURE, UTILIZATION, AND STORAGE

Industrial carbon capture, utilization, and storage (CCUS) can play an important role in reducing emissions in subsectors. CCUS technologies can be applied to steel, cement, chemicals, fertilizer production plants, hydrogen and refining.[14] Experience with early CCUS projects like the Archer Daniels Midland Illinois

Industrial Carbon Capture and Storage project—the world's first commercial-scale ethanol plant retrofitted with carbon capture—could help lower the cost of future CCUS projects. Recently adopted federal tax credits for CCUS will help deploy some projects. However, more targeted, industry-specific support is likely needed for research, development, demonstration, and deployment, as well as support for private sector commercialization.

PROCESS IMPROVEMENTS

For specific industries, process improvements can reduce energy needs and, therefore, greenhouse gas emissions. For example, shifting from basic oxygen blast furnaces to electric arc furnaces in the production of iron-ore steel contributed to a 37 percent reduction in the energy intensity of U.S. crude steel production from 1991–2010.[15] In some cases, switching inputs or raw materials can reduce emissions—for instance, using fly ash from coal-fired power plants instead of carbon-intensive clinker in cement production. Other process changes and substitutions can reduce emissions of non-CO_2 gases with high global warming potential.

ENDNOTES

1 Industry sources include: carbon dioxide from fossil fuel combustion, natural gas systems, non-energy use of fuels, coal mining, iron and steel production, petroleum systems, cement production, petrochemical production, substitution of ozone depleting substances, lime production, nitric acid production, ammonia production, abandoned underground coal mines, other process uses of carbonates, HCFC-22 production, semiconductor manufacture, aluminum production, carbon dioxide consumption, adipic acid production, N_2O from product uses, stationary combustion, soda ash production and consumption, ferroalloy production, titanium dioxide production, mobile combustion, glass production, urea consumption for non-agricultural purposes, magnesium production and processing, phosphoric acid production, zinc production, lead production, and silicon carbide production and consumption.

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5 Figures based on Table 24 Industrial Sector Macroeconomic Indicators and Table 19 Energy-Related Carbon Dioxide Emissions by End-Use in U.S. Energy Information Administration, *Annual Energy Outlook 2018* (Washington, DC: U.S. Department of Energy, 2018), https://www.eia.gov/outlooks/aeo.

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C2ES CLIMATE INNOVATION 2050

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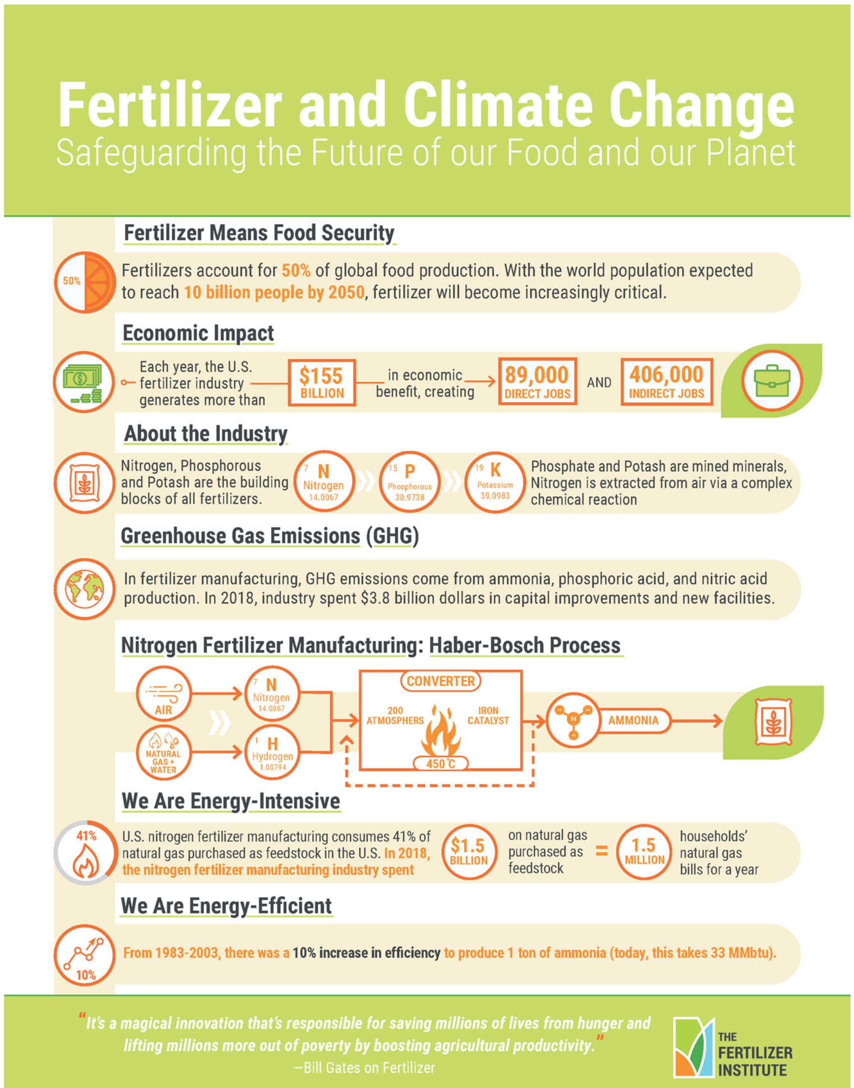
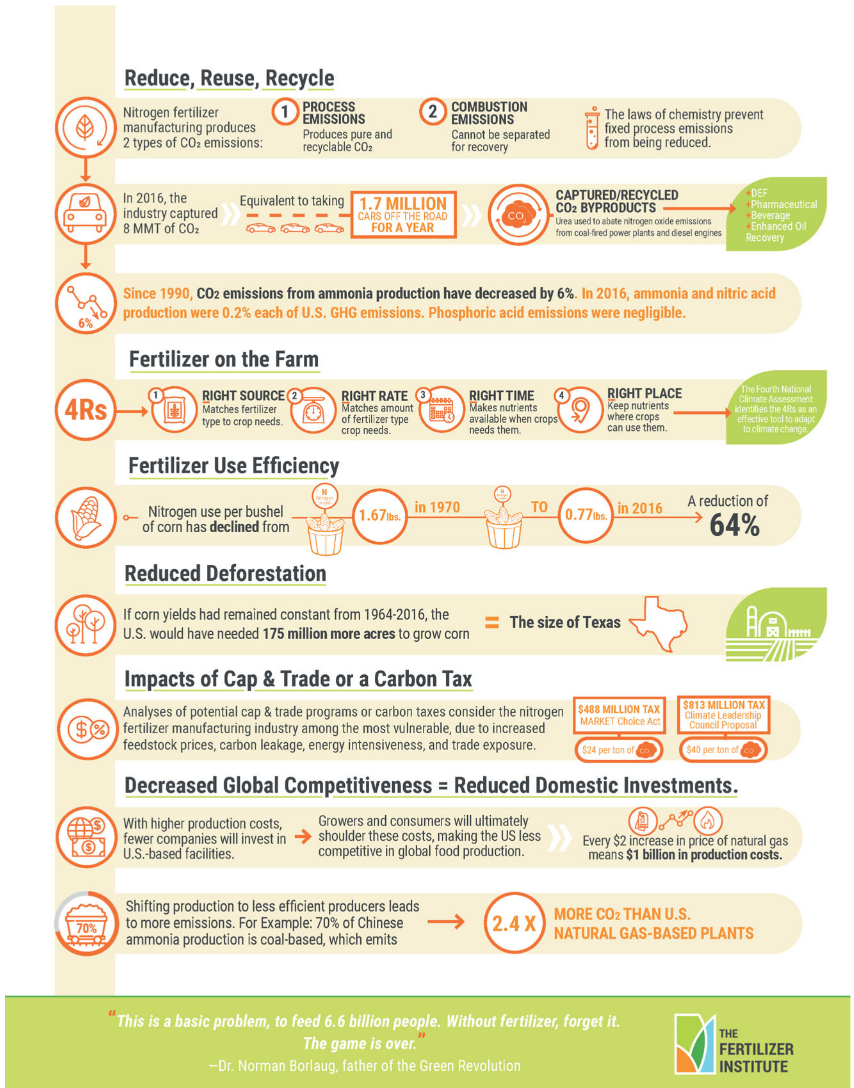


Fertilizer and Climate Change
Safeguarding the Future of our Food and our Planet
Fertilizer Means Food Security
50%
Fertilizers account for 50% of global food production. With the world population expected to reach 10 billion people by 2050, fertilizer will become increasingly critical.
Economic Impact
Each year, the U.S. fertilizer industry generates more than
$155 BILLION
in economic benefit, creating
89,000 DIRECT JOBS
AND
406,000 INDIRECT JOBS
About the Industry
Nitrogen, Phosphorous and Potash are the building blocks of all fertilizers.
7 N Nitrogen 14.0067
15 P Phosphorous 30.9738
19 K Potassium 39.0983
Phosphate and Potash are mined minerals, Nitrogen is extracted from air via a complex chemical reaction
Greenhouse Gas Emissions (GHG)
In fertilizer manufacturing, GHG emissions come from ammonia, phosphoric acid, and nitric acid production. In 2018, industry spent $3.8 billion dollars in capital improvements and new facilities.
Nitrogen Fertilizer Manufacturing: Haber-Bosch Process
AIR
NATURAL GAS + WATER
7 N Nitrogen 14.0067
1 H Hydrogen 1.00794
CONVERTER
200 ATMOSPHERS
IRON CATALYST
450°C
AMMONIA
We Are Energy-Intensive
41%
U.S. nitrogen fertilizer manufacturing consumes 41% of natural gas purchased as feedstock in the U.S. In 2018, the nitrogen fertilizer manufacturing industry spent
$1.5 BILLION
on natural gas purchased as feedstock
=
1.5 MILLION
households' natural gas bills for a year
We Are Energy-Efficient
10%
From 1983-2003, there was a 10% increase in efficiency to produce 1 ton of ammonia (today, this takes 33 MMbtu).
"It's a magical innovation that's responsible for saving millions of lives from hunger and lifting millions more out of poverty by boosting agricultural productivity."
—Bill Gates on Fertilizer
THE FERTILIZER INSTITUTE



Reduce, Reuse, Recycle
Nitrogen fertilizer manufacturing produces 2 types of CO2 emissions:
1 PROCESS EMISSIONS
Produces pure and recyclable CO2
2 COMBUSTION EMISSIONS
Cannot be separated for recovery
The laws of chemistry prevent fixed process emissions from being reduced.
In 2016, the industry captured 8 MMT of CO2
Equivalent to taking
1.7 MILLION CARS OFF THE ROAD FOR A YEAR
CAPTURED/RECYCLED CO2 BYPRODUCTS
Urea used to abate nitrogen oxide emissions from coal-fired power plants and diesel engines
+DEF
+Pharmaceutical
+Beverage
+Enhanced Oil Recovery
6%
Since 1990, CO2 emissions from ammonia production have decreased by 6%. In 2016, ammonia and nitric acid production were 0.2% each of U.S. GHG emissions. Phosphoric acid emissions were negligible.
Fertilizer on the Farm
4Rs
1 RIGHT SOURCE
Matches fertilizer type to crop needs.
2 RIGHT RATE
Matches amount of fertilizer type crop needs.
3 RIGHT TIME
Makes nutrients available when crops needs them.
4 RIGHT PLACE
Keep nutrients where crops can use them.
The Fourth National Climate Assessment identifies the 4Rs as an effective tool to adapt to climate change.
Fertilizer Use Efficiency
Nitrogen use per bushel of corn has declined from
1.67lbs.
in 1970
TO
0.77lbs.
in 2016
A reduction of
64%
Reduced Deforestation
If corn yields had remained constant from 1964-2016, the U.S. would have needed 175 million more acres to grow corn
= The size of Texas
Impacts of Cap & Trade or a Carbon Tax
Analyses of potential cap & trade programs or carbon taxes consider the nitrogen fertilizer manufacturing industry among the most vulnerable, due to increased feedstock prices, carbon leakage, energy intensiveness, and trade exposure.
$488 MILLION TAX
MARKET Choice Act
$24 per ton of CO2
$813 MILLION TAX
Climate Leadership Council Proposal
$40 per ton of CO2
Decreased Global Competitiveness = Reduced Domestic Investments.
With higher production costs, fewer companies will invest in U.S.-based facilities.
Growers and consumers will ultimately shoulder these costs, making the US less competitive in global food production.
$2
Every $2 increase in price of natural gas means $1 billion in production costs.
70%
Shifting production to less efficient producers leads to more emissions. For Example: 70% of Chinese ammonia production is coal-based, which emits
2.4 X
MORE CO2 THAN U.S. NATURAL GAS-BASED PLANTS
"This is a basic problem, to feed 6.6 billion people. Without fertilizer, forget it. The game is over."
—Dr. Norman Borlaug, father of the Green Revolution
THE FERTILIZER INSTITUTE

American Iron and Steel Institute

NORTH AMERICAN STEEL INDUSTRY
LEADING INNOVATION AND ENVIRONMENTAL SUSTAINABILITY

Steel is an essential, irreplaceable material for modern society and the transition to a more sustainable future. The steel industry continues to lead in revolutionary developments of new steel grades for our customers in the automotive, construction, machinery, packaging, and energy sectors. Our industry is facilitating advances in sustainable building construction and energy transmission and development, among other successes. With more than 3,500 steel grades available, approximately 75% of modern steels have been developed in the past 20 years. These products can help reduce energy consumption and greenhouse gas (GHG) emissions throughout the economy.

In North America, the steel industry leads the world in reducing energy use and GHG emissions in our steelmaking processes. AISI member companies have reduced their energy intensity per ton of production by 35 percent since 1990 and our GHG emissions intensity by 37 percent over the same time period. In addition to this world leading environmental performance, the steel products we create demonstrate superior sustainability performance that minimizes environmental impact.

Steel's superior sustainability performance minimizes environmental impact when measured throughout its life cycle of material production, useful life, and end-of-life. A key example is in the automotive market, where innovation is essential to meet higher government fuel efficiency and GHG requirements. To help our automaker customers meet these standards, the steel industry has developed advanced materials and manufacturing technologies that have led to the introduction of new advanced high-strength steel (AHSS) grades – the fastest growing material in automotive manufacturing. Today's steel grades are as much as six times stronger than those a decade ago, and three to four times stronger than the latest aluminum alloys on the market.

The added strength of AHSS allows automakers to continue to deliver vital performance and safety benefits with lightweight products, while lessening their overall environmental and climate impact. An AISI peer-reviewed study demonstrates that the use of advanced high-strength steel (AHSS) for automotive lightweighting results in an immediate and sustained decrease in greenhouse gas (GHG) emissions, whereas the use of aluminum instead of AHSS for lightweighting the same vehicle fleet results in a comparative dramatic increase in GHG emissions lasting for several decades.

Steel products are 100 percent recyclable and each year, more steel is recycled than paper, plastic, aluminum and glass combined. The American steel industry recycles three-quarters of the steel coming from the packaging market, nearly 100 percent of the

American Iron and Steel Institute

automobiles at end of life, and more than 90 percent of steel from infrastructure, appliances and construction products. In doing so, the industry conserves energy, reduces emissions, and more efficiently uses raw materials and natural resources.

The U.S. is recognized as the most energy efficient of any major steel producing country, according to the U.S. Department of Energy. At the same time, AISI members are committed to a suite of research projects designed to develop new technologies to decarbonize steelmaking while conserving energy. We are also partnering with national labs and universities to achieve continued innovations that enable the steel industry to realize the next-generation steel plant of the future.

Subcommittee on Environment and Climate Change

Hearing on, "Building a 100 Percent Clean Economy: Pathways to Net Zero Industrial Emissions"

Mr. Bob Perciasepe

October 25, 2019

The Honorable Paul Tonko (D-NY)

1. Several Members asked about the role for a pollution pricing program to reduce emissions cost effectively. There seems to be agreement that coverage of energy-intensive, trade exposed (EITE) industries must be well-designed and thoughtful about reducing potential competitiveness and leakage risks.

a. How might a pricing program manage those risks?

Every major carbon pricing program on the globe has provisions for protecting EITE industries (and according to the World Bank, as of April 2019 there were 57 carbon pricing initiatives implemented or scheduled for implementation). These programs use a variety of policy tools including: free allocation, output-based allocation, exempting sectors, phasing in sectors, reducing other taxes, grants/tax credits for the use of clean technology and rebates. Border adjustments have recently received much attention as an option with climate policy but have not been widely used to date.

California, which has a carbon price and an energy system connected to several states that do not have a similar program, addressed the competitiveness issue by creating something similar to a border adjustment when they required buyers of imported electricity to also obtain and surrender allowances. California's low-carbon fuel standard (where fuels are produced and imported into the state), also has provisions that are similar to a border adjustment, to protect in-state fuel producers. With these two provisions, California has taken a sector-specific approach to addressing competitiveness and potential carbon leakage that might arise from their carbon regulations on electricity and fuel rather than a single border measure to address all potential leakage that might arise from their economy-wide approach. To address competitiveness implications in other sectors, California uses a hybrid approach of fixed-sector benchmarking and output-based allocation. This approach rewards firms with in-region production with free allowances, while at the same time sending a financial signal through its carbon price that GHG emissions should be reduced.

In the European Union Emissions Trading Program (EU ETS) – a pan-continental cap-and-trade program, energy-intensive and trade exposed (EITE) firms were phased-in to the program and today receive a higher proportion of free allowances than other industrial sectors, based on an evaluation of need and performance benchmarking. In addition, because their program is pan-continental, linkage between programs such that companies have access to a common carbon market also provides a degree of protection from carbon leakage.

In addition, carbon pricing is rarely a sole climate strategy. Often other policies aimed at reducing the cost of low-carbon technologies, increasing renewable energy generation, funding low-carbon technology development, and/or improving energy efficiency, are combined with carbon pricing to form a suite of climate policies. This is what we recommend in our soon to be released report on what it will take to decarbonize the U.S. economy called Getting to Zero: A US Climate Agenda. While these other policies may not be directly aimed at protecting against competitiveness impacts, they can help firms transition to lower-emitting technologies, reduce emissions, and indirectly reduce impacts by lowering the cost of compliance.

b. Do you have recommendations on the policy design decisions that should be considered under an output-based allowance allocation program for EITE industries?

For output-based allocation (OBA), energy-intensive and trade exposed (EITE) firms are allocated emissions credits based on their level of output. The number of credits or "allowances" they get typically depends on a sector-specific performance evaluation, which sets a benchmark for tons of greenhouse gas (GHG) emissions per unit of output. Effectively, firms get an amount of credits that corresponds to what their total emissions would have been if their emissions intensity of production had matched the benchmark. They then must buy credits or allowances and pay the carbon price on the emissions that they don't have enough credits to cover. The worst performers end up paying more to cover their actual emissions and the better performers end up paying less. The firms that can beat the benchmark end up with more credits than they need, which they can then sell to other producers at a profit. Firms have an incentive to reduce emissions by improving their emissions performance, but not by reducing production.

A key decision is the sector-specific performance benchmark. Another key decision is which companies are eligible for the EITE provisions. Finally, such a provision is best implemented in a targeted, temporary and transparent manner. Not every company should be eligible to receives EITE protection. Also an end date or at least a date specific for reevaluation should be determined. Finally, the formula for who is eligible under the provision for EITE and how the benchmark is established, should be clearly and transparently spelled out.

The Honorable John Shimkus (R-IL)

1. Raising energy and production costs in energy intensive or trade exposed industries can be harmful for communities in terms of lost jobs and economic output, especially if the developing world is unable to make the same changes to their energy and manufacturing systems.

a. What are the risks of leakage of U.S. industrial jobs to other nations if cost of energy or processing is increased compared to international competitors?

For subsectors that are energy-intensive and trade-exposed—i.e., their products are traded globally—the costs of decarbonizing may pose a potential competitive disadvantage which might lead to increased imports and/or production moving to countries where greenhouse gas standards are not yet as stringent, resulting in carbon leakage. Researchers who have examined the degree to which carbon pricing has an impact on corporate decisions about where to location or invest have consistently found, however, that a carbon price is only one factor among many that influence these decisions and is not the most important. These same studies have concluded that other variables—corporate tax rates, wage rates, labor availability, infrastructure, geographic location, cost of capital, exchange rates, among others—exert a stronger influence than carbon pricing on most industry decisions to locate or invest. The same is true of other forms of environmental taxation.

The concern, however, is real and one that policy makers must deal with prior to program enactment and implementation. Fortunately, there are a range of policy tools to mitigate the economic impacts that may be foreseen. The increased cost of energy or processing can largely be offset through well-considered policy design. Empirical evaluations of existing carbon pricing programs have repeatedly demonstrated that impacts on industry have overall been small—although a few sectors have seen impacts and additional measures have been required. Because of this, an economy-wide carbon pricing program should include provisions to protect against these impacts (e.g., free allocation of allowances in a cap-and-trade system, tax credits for clean technology transition, rebates for carbon tax system and/or border adjustments based on best in class benchmarks). All of these policy elements should be reexamined periodically for their effectiveness and necessity.

Moreover, an international climate agreement, like the Paris Climate Agreement, that requires action by developed and developing countries alike to reduce greenhouse gas emissions is, in the long run, arguably the most effective way to address leakage and ease competitiveness concerns. Such an agreement can actually strengthens U.S. competitiveness by expanding markets for innovative clean technologies where U.S. companies are well positioned to lead.

b. What are the impacts on technical skills, supply chains, R&D and innovative capacity in U.S. manufacturing and industries exposed to relatively high energy or production costs?

Electricity and other energy purchases represent a large proportion of total production costs for EITE firms. Often more efficient firms and facilities, those that are able to produce a ton of goods using a lower quantity of electricity and/or energy have a competitive advantage.

Also, it is important to note that high energy costs can also stimulate innovation. Without high and volatile natural gas prices 20 years ago, investments in horizontal drilling to increase supply might never have happened. Furthermore, in order to manage energy costs, firms can, and will invest to become more energy efficient and research to develop new, less-energy intensive, lower-emission processes will proceed because there is value in that research. Industrial tax rebates, training and R&D support can help support these efforts, while preserving and enhancing technical skills in industrial subsectors, and maintaining existing supply chains. Additionally, lower production costs from implementing R&D breakthroughs can spur the construction of new industrial facilities and all the accompanying economic benefits.

c. What policy options have been proposed to prevent leakage, to what extent have they been examined for impacts on specific industries, and to what extent will this require international cooperation? Please elaborate.

Most of the carbon pricing proposals introduced in the 116th Congress include some form of a border adjustment to address carbon leakage. A carbon fee could be placed on imported covered fuels, imported carbon-intensive goods, or certain industrial sectors (e.g., manufacturing sectors, metal ores, soda ash, and phosphate processors). A refund could also be issued on the export of carbon-intensive goods. The fee could be reduced (or not applied) to countries that have comparable policies to reduce greenhouse gas emission reduction programs.

These provisions could be tailored to apply to countries with less stringent greenhouse gas emission reduction targets or countries that produce the same good, but less efficiently (i.e., higher emissions per unit). These provisions should also be phased out over time as more countries develop comparably stringent programs

While border measures have not been widely used, studies suggest that they can be very effective. Other policy tools including output-based allocation, free allocation, and benchmarking have been more widely used and they have been studied extensively, particularly for the European emission trading program. Impacts on cement, steel, glass, refining and many others have been studied including whether geographic location matters. Notably, if impacts were detected they were relatively small but again—the E.U. has protections built into their program. Once recent instance, however, between electricity generators in and out of the E.U. where carbon leakage has been identified is now the subject of consideration and further protections are likely to be forthcoming.

Multinational cooperation on carbon pricing and trade issues would likely provide a more durable framework, allowing a sustained ratcheting down of global emissions.

2. What work has been published to your knowledge of the economic costs, the impacts on prices and supply, or employment impacts from reducing emissions in the industrial sectors? What work has been done to evaluate the legal, economic, and socio-economic impacts of deep decarbonization of the industrial sector?

A large body of research has examined the economic costs, the degree of cost-pass through and employment impacts from carbon pricing on the industrial sector. The World Bank's 2019 *Report on the High-Level Commission on Carbon Pricing and Competitiveness* provides an overview of these studies.

- World Bank Group. 2019. *Report of the High Level Commission on Carbon Pricing and Competitiveness*. World Bank Group, Washington, D.C. Sept. 2019. https://openknowledge.worldbank.org/bitstream/handle/10986/32419/141917.pdf.

While a variety of studies have examined the potential economic impacts of economy wide decarbonization, we are not aware of studies that have looked at the legal or socio-economic impacts.

a. Would you please list pertinent studies?

- Arlinghaus, J. 2015. "Impacts of Carbon Prices on Indicators of Competitiveness: A Review of Empirical Findings." Environment Working Paper 87, OECD (Organisation for Economic Cooperation and Development), Paris, March 27, 2015. Accessed October 15, 2018.https://doi.org/10.1787/5js37p21grzq-en.

- Dechezleprêtre, A., D. Nachtigall, and F. Venmans. 2018. "The Joint Impact of the European Union Emissions Trading System on Carbon Emissions and Economic Performance." Economics Department Working Paper 1515, OECD (Organisation for Economic Co-operation and Development), Paris. December 14. Accessed June 20, 2019.https://www.oecdilibrary.org/docserver/4819b016en.pdf?expires=1563212682&id=id&accname=guest&checksum=BEE8052A54050DE45D1742FEB47BC9B4.

- Jaffe, A., S. Peterson, P. Portney, P. and R. Stavins. 1995. "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature* 33, no.1 (March): 132-163. Accessed November 10, 2018. https://scholar.harvard.edu/stavins/publications/environmental-regulation-and-competitiveness-us-manufacturing-what-does.

- Oberndorfer, U., Alexeva-Talebi, V. and Loschel A. 2010. "Understanding the Competitiveness Implications on Future Phases of the EU ETS on Industrial Sectors." Discussion Paper 10-044, ZEW (Leibniz Center for European Economic Research), Mannheim, July 2010. Accessed September 30, 2015. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1649445&download=yes.

- Reinaud, J. 2008. "Issues behind Competitiveness and Carbon Leakage: Focus on Heavy Industry." Information Paper, IEA (International Energy Agency), October 24, 2008. Accessed October 15, 2018. https://www.iea.org/publications/freepublications/publication/Competitiveness_and_Carbon_Leakage.pdf.

3. According to a recent report by the Energy Futures Initiative, many "subnational decarbonization strategy and road-map reports contain insufficient detail for establishing effective and efficient implementation policies and programs."

a. What should be done to develop a more in depth understanding of the cost and economic impacts of state and regional (subnational) decarbonization policies, particularly in the industrial sector?

Given its tremendous diversity, its heavy reliance on large quantities of thermal heat, and the fundamental nature of many core manufacturing process, the industrial sector is especially challenging to decarbonize. Economy-wide carbon pricing, as recommended above, can drive some emission reductions across the sector, but a wide range of complementary policies are also needed. As we outline in our upcoming report *Getting to Zero*, priorities over the next decade include developing innovative lower-carbon manufacturing processes, setting standards to drive energy efficiency, electrification and other forms of fuel switching, and safeguarding the competitiveness of energy-intensive, trade-exposed sectors.

Some states and regions are leading the way on industrial decarbonization efforts, notably California, and the province of Alberta. A landscape analysis of subnational decarbonization efforts can help identify and assess existing policies. Largely, these decarbonization policies reflect regional priorities and differences (e.g., regional differences in carbon-intensity of power generation mix). An analysis of programs would likely find that states have varying definitions of clean energy, decarbonization targets, and programs to achieving these goals. To orient companies toward decarbonization, the federal government should undertake a benchmarking process to establish intensity-based greenhouse gas objectives for the major sub-industries. The benchmarking process, informed by programs already implemented in Canada and Europe, would highlight best practices and promote industry-wide learning. Benchmarking best practices in each subsector will provide ongoing incentive and flexibility for companies to pursue their most affordable decarbonization options. These intensity-based objectives could also be used to determine how a company or facility is treated within the economy-wide carbon pricing system and for purposes of competitiveness protections; in the absence of economy-wide pricing, the benchmarks could serve as the basis of mandatory performance standards that can be traded within and across sub-industries.

In addition, harmonizing definitions, best in class benchmarks and a review of successful programs within and outside of the U.S. would provide a better understanding of decarbonization efforts and successful policies.

Finally, the capture and use of carbon dioxide (CCUS) will be needed in the industrial sector because of the process emissions. The options and incentives needed for deployment in the industrial sector is not well studied and a roadmap for its deployment should be created.

Subcommittee on Environment and Climate Change
Hearing on
"Building a 100 Percent Clean Economy: Pathways to Net Zero Industrial Emissions"
September 18, 2019

Dr. Jeremy Gregory
Executive Director
MIT Concrete Sustainability Hub

The Honorable John Shimkus (R-IL)

1. One issue that your testimony notes about concrete and that also applies to other industrial processes is the need for high-temperature heat, sustained over long periods of time.

    a. Congress has been pursuing policies for advanced nuclear reactor technology that may enable industrial uses at small, localized high temperature reactors. Just a week ago we moved legislation to help develop markets for the fuel infrastructure for advanced reactors, and we hope to enact that into law.

    b. Would this be promising technology to pursue?

    RESPONSE: The cement industry will always need high-temperature heat as part of its production process. While the industry has not explicitly investigated the potential of using heat generated by nuclear reactors, we welcome the opportunity to explore this as a low-carbon source of fuel.

2. Raising energy and production costs in energy intensive or trade exposed industries can be harmful for communities in terms of lost jobs and economic output, especially if the developing world is unable to make the same changes to their energy and manufacturing systems.

    a. What are the risks of leakage of U.S. industrial jobs to other nations if cost of energy or processing is increased compared to international competitors?

    RESPONSE: The cement industry faces considerable risks from international competitors if the federal government controls greenhouse gas emissions through a price on carbon or other measures. Cement is traded globally as a commodity in a heavily competitive marketplace. American cement manufacturers face competition chiefly from China, India, Russia, Vietnam, and Brazil. These countries offer a marketplace advantage in such a system as they could export unregulated, higher carbon cement into the U.S. market without incurring carbon-related costs imposed on domestic manufacturers. Such "leakage" undermines U.S. competitiveness and rewards countries with less rigorous environmental, health & safety regulatory requirements.

As Congress considers comprehensive climate legislation, it will need to consider how interlinked *and* competitive markets are today. It will also need to consider the ability of the manufacturing sector to absorb the uncertainty and costs associated with reducing CO2 and other greenhouse gas (GHG) emissions. The cement industry suffered from the most recent recession from 2007-2010. Seventeen plants have closed since then, and no new cement manufacturing facilities have been constructed in the U.S. since 2009. Further, as of 2017, cement consumption in the U.S. is down 23 percent from its peak in 2005.

Other industrialized economies have pursued varying types and degrees of greenhouse gas regimes, such as the European Union, Canada, Australia, and California. These systems have served as real-world examples for the economic and trade impacts of limiting GHG emissions. Multiple studies from the Environmental Protection Agency, California Air Resources Board, Cement Association of Canada have found that the risks to industry are profound and could lead to plant closings, and job losses.

b. What are the impacts on technical skills, supply chains, R&D and innovative capacity in U.S. manufacturing and industries exposed to relatively high energy or production costs?

   RESPONSE: A strong cement industry will be better able to invest in R&D and innovation. Increasing leakage would weaken the cement industry, thereby limiting its opportunities to invest in R&D and innovation.

c. What policy options have been proposed to prevent leakage, to what extent have they been examined for impacts on specific industries, and to what extent will this require international cooperation? The European Union, Canada, and California all account for the unique situation of the cement industry and other EITEs by adjusting the formula for credit allocation to account for the market disadvantage. A tariff or border adjustment on imported goods could also be utilized in cap and trade, carbon tax, or other system. Foreign competition will be essential for any GHG system to ensure mutual compliance and reporting of GHG emissions, tariffs,

   RESPONSE: Consistent with the findings of these studies, government regulators in each of these jurisdictions have deemed cement manufacturing to be an EITE industry and provide certain protections through adjustments to credits and tariffs on imported goods.

3. What work has been published to your knowledge of the economic costs, the impacts on prices and supply, or employment impacts from reducing emissions in the industrial sectors? What work has been done to evaluate the legal, economic, and socio-economic impacts of deep decarbonization of the industrial sector?

RESPONSE: Multiple studies have found that the cement industry faces additional hurdles that other manufacturers or businesses will not face.

- **A 2008 report on the impact of the European Trading Scheme concluded that:** "Based on the expected cost of production in the EU assuming the carbon cost of CO2 versus the cost of producing in non-ETS countries, clinker and cement production in the EU is not competitive without free allowances allocation. As a result, the "wise businessman" will prefer to relocate production to more competitive countries, this leading to production offshoring."[1]

- A 2016 review by the Cement Association of Canada concluded that "[s]ince the introduction of the carbon tax in B.C. in 2008, imports of foreign-made cement to the province have gradually climbed from less than 5% in 2008 to a peak of over 40% as the tax progressively increased to $30 per tonne."[2]

- In 2017 comments to the California Air Resource Board, the Coalition for Sustainable Cement Manufacturing & Environment (CSCME) warned that "even after accounting for allowance allocations under CARB's proposed framework, an allowance price of just $20 would cause California cement production to decline by 46 percent."[3]

- In 2009, the Environmental Protection Agency found in an analysis of the American Clean Energy and Security Act (Waxman-Markey, H.R. 2454), "If the adoption of a domestic cap-and-trade program leads some manufacturing activity and its associated emissions to shift to countries that do not yet have comparable greenhouse gas regulations, along with the economic concerns that this poses, this presents environmental concerns because the resulting "emission leakage" can undermine the environmental effectiveness of a domestic emissions cap."

a. Would you please list pertinent studies?

RESPONSE: See above.

4. According to a recent report by the Energy Futures Initiative, many "subnational decarbonization strategy and road-map reports contain insufficient detail for establishing effective and efficient implementation policies and programs."

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[1] Boston Consulting Group, *Assessment of the Impact of the 2013-2020 ETS Proposal on the European Cement Industry; Final Project Report* (November 2008)
[2] Cement Association of Canada, *Input From the Cement Association of Canada, March 2016 B.C. 2016 Climate Leadership Plan* (March 23, 2016).
[3] CSCME, *Comments on Proposed Amendments to the California Cap on Greenhouse Gas Emissions and Market-Based Compliance Mechanisms* (Jan. 20, 2017) CSCME; *see also Comments on CARB's May 17 Public Meeting on Allowance Allocation* (June 7, 2010)
4 Environmental Protection Agency, *The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade-Exposed Industries* (December 2, 2009)

a. What should be done to develop a more in depth understanding of the cost and economic impacts of state and regional (subnational) decarbonization policies, particularly in the industrial sector?

RESPONSE: The Cement Sustainability Initiative published a technology roadmap for the global industry in 2018 that identifies pathways for supporting a transition to a low-carbon economy.[4] While this roadmap provides useful insights into actions that the industry can take to decarbonize, additional work is needed to translate this guidance to the US because of the significant variation in cement production practices across the world. In particular, more detailed work is needed to understand the costs of decarbonization of the US cement industry at a regional level and the expected economic impacts.

The Honorable Markwayne Mullin (R-OK)

1. Cement manufacturing is a heat intensive process. What is the primary fuel source?

RESPONSE: For 2016, the most widely used fuel in cement kilns was coal and petroleum coke, which is 57% of the total share of fuels used.

a. Are there other fuel sources cement manufacturing can use?

RESPONSE: The cement industry uses a wide variety of fuels including natural gas, coal, and secondary materials like tires to achieve the high temperatures necessary to create cement. Secondary material is a term for post-industrial, post-commercial, post-consumer paper, plastic, and other materials that have tremendous energy value. Their use as fuels helps to reduce industrial emissions of greenhouse gases (GHG) and other emissions. They also limit landfill disposal of materials that can become public health vectors and safety risks, conserve natural resources, and provide low-cost sustainable fuels.

Increased use of alternative fuels is a strategic priority for the cement industry, which sees them as an important component of the industry's long-term sustainability strategy. Indeed, the percentage of alternative fuels used within the US cement industry is well below that of European manufacturers, a result of the significant regulatory obstacles domestic manufacturers face in using these fuels. We see this as a promising area for further discussion on opportunities to increase the use of alternative fuel sources.

b. How much of the cement industry uses natural gas as fuel?

RESPONSE: As of 2016, natural gas makes up 15.5% of total fuel consumption.

[4] Cement Sustainability Initiative, *Technology Roadmap: Low-Carbon Transition in the Cement Industry* (2018).

c. What is preventing the industry from using more natural gas to offset carbon emissions?

RESPONSE: Price and access constitute barriers to using natural gas to reduce emissions.

2. I understand that around 60% of the CO2 emitted by the cement industry comes from the chemical reaction during the calcination process- and we can't change that. However, you mentioned that carbon dioxide could be embedded within cement, aggregate, and concrete products: how does this technology work, and how soon is it from being commercially available?

RESPONSE: Cement, aggregate, and concrete can be produced from captured carbon dioxide using a process called *mineralization*, which involves exposing minerals to carbon dioxide to create a carbonate mineral. It is a natural process that took place over millions of years to create the limestone used in the production of cement. More recently it has been proposed as a form of carbon capture and utilization to create materials that can be used in concrete production. This includes the production of binders, aggregates, and concrete (i.e., carbon dioxide is used in the mixing process) using carbon captured from industrial sources, potentially including cement plants. Several companies have been created over the past decade in an attempt to commercialize mineralization for building products. There is significant variation in the degree to which they make use of carbon dioxide. Most of the companies are in a start-up phase with demonstration plants or small production volumes, but several of them have products currently being used in construction projects. In some cases, the technologies can only be used to make concrete blocks in production facilities (as opposed to cast-in-place concrete on job sites) because of the requirements to control the mixing of carbon dioxide with minerals. As such, this limits their application to cases where concrete blocks can be used (such as buildings). A good summary of the specific companies working in this space and their current status can be found in an article published this year.[5]

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[5] C. Collins, *Recasting Cement: The Race to Decarbonize Concrete*, Medium (2019).

COMMITTEE ON ENERGY AND COMMERCE: SUB-COMMITTEE ON ENVIRONMENT AND CLIMATE CHANGE (116TH CONGRESS)
U.S. HOUSE OF REPRESENTATIVES

SEPTEMBER 18, 2019

HEARING ON: BUILDING A 100 PERCENT CLEAN ECONOMY: PATHWAYS TO NET ZERO INDUSTRIAL EMISSIONS

RESPONSES TO FOLLOW-UP QUESTIONS: SUBMITTED ON OCTOBER 30, 2019

GAURAV N. SANT, PH.D.

PROFESSOR AND HENRY SAMUELI FELLOW: CIVIL AND ENVIRONMENTAL ENGINEERING, MATERIALS SCIENCE AND ENGINEERING, AND THE CALIFORNIA NANOSYSTEMS INSTITUTE

DIRECTOR: INSTITUTE FOR CARBON MANAGEMENT
UNIVERSITY OF CALIFORNIA, LOS ANGELES (UCLA)

The Honorable Paul Tonko (D-NY)

1. What recommendations do you have for NIST, in consultation with DOE, EPA, or other federal agencies, to develop industrial product performance standards to encourage greater use of low-emissions products?

RESPONSE: In general, it is critically important that low-carbon products are not perceived as a compromise compared to traditional / equivalent / similar products that are available today. Thus, low-carbon products must meet or exceed the (engineering, functional) performance requirements of current products – which are assessed/evaluated using industry accepted protocols – while offering a greatly reduced embodied carbon intensity (eCI); i.e., the carbon emissions that result from raw materials extraction and manufacturing operations. This promotes a basis of functional replacement, i.e., to create "drop in" low-carbon alternatives for existing products. It is herein critically necessary that federal agencies, e.g., NIST and others, develop robust methods for measuring, analyzing and quantifying the eCI of manufactured materials and products; across their entire lifecycle. While this includes the curation and creation of a more robust, and flexible basis for lifecycle analysis (LCA); it also demands innovation and technical improvements to develop a unified and authentic basis by which LCA assessments can be carried out, realistically, without ambiguity, and transparently for processes and materials which are both produced at scale today; and which will be in time to come. This nature of assessment would augment current industrial performance standards that are in place today; that traditionally only consider assessments of the engineering properties or functional attributes of products and materials.

Furthermore, special focus should be paid to understand the contributions and distributions of carbon intensity (CI), and how it accumulates across the different steps ranging from raw materials extraction and manufacturing ("embodied carbon intensity"), to the time a material or product is placed in use ("operational carbon intensity: oCI"). Such information is needed not simply to rank and order materials and products in terms of their CI; but also to chart specific and influential innovations that are needed to reduce the CI of a material or a product as compared to the status quo. Importantly, tabulated metrics of eCI and oCI offer a basis for strategic procurement actions codified by government agencies across all levels (federal, state, city, and so on) wherein the selection and use of materials and products in publicly funded projects is established not simply on the basis of lowest cost, but also the lowest carbon intensity (e.g., California's Buy Clean Act) – thereby promoting, and creating market-pull in support of low-carbon materials, products and processes.

Moreover, it is important that agencies such as NIST develop publicly accessible repositories, tools and simple to use platforms ("apps") which allow corporations, members of the public (i.e., individual consumers), and public agencies to secure and source information related to specific materials and products; and to thereby establish how material and product selections, and changes therein can, result in better awareness, and decision making in support of low-carbon selections, that are foundational to the creation of a low-carbon economy.

2. While the hearing focused on cement, what other industrial goods would benefit from development of a low-emissions performance standard?

RESPONSE: A wide range of materials and products that are produced by heavy industry sectors would be amenable for inclusion in, and the development of low-carbon performance standards. This includes both primary materials, and down-stream products produced using: glass, iron and steel, hydrocarbon-derived petrochemicals (which form a base feedstock in the production of plastics, and other polymers), cement and concrete, etc. That said, it is important to develop an economy-wide basis to develop low-carbon performance standards so that manufacturers, specifiers and consumers/users are all equally incented to make decisions to produce and consume low-carbon impact materials, and products.

The Honorable John Shimkus (R-IL)

1. Raising energy and production costs in energy intensive or trade exposed industries can be harmful for communities in terms of lost jobs and economic output, especially if the developing world is unable to make the same changes to their energy and manufacturing systems.

a. What are the risks of leakage of U.S. industrial jobs to other nations if cost of energy or processing is increased compared to international competitors?

RESPONSE: It is often surmised that the implementation of higher standards (e.g., to reduce energy use, and carbon emissions) in the U.S., by trade exposed industries would compromise their competitiveness, and result in job losses. This is true only if the U.S. did not take other simultaneous steps to prevent such an outcome. Broadly speaking, the U.S. can protect its workers, its markets, and its competitiveness in a variety of ways. This includes: (a) by implementing border tax adjustments (BTAs) whereby materials and products that enter the U.S. are assessed a tax/tariff upon their entry into the U.S. whose magnitude is proportional to the extent of dissimilarity (e.g., in terms of embodied carbon intensity) with similar materials and products that are manufactured in the U.S., (b) by implementing low-carbon performance standards on an economy wide basis that promote strategic procurement decisions, e.g., made at the city-, state- and federal-government levels that ensure the consideration of embodied carbon intensity as a basis of selection and specification of materials and products, on an equal footing, as cost, and (c) by offering leadership on the world-stage to ensure the adoption of uniform standards, and a basis to reduce carbon dioxide emissions, globally – by developed, and developing nations.

While leakage is indeed a concern, often, the costs (and in time, the associated carbon intensity of fossil-fueled transportation modalities) of transportation (may) hinder leakage since, for example, it is most desirable to utilize commodity materials as close as possible to the point of consumption. Nevertheless, even if leakage is to occur, the steps outlined above can combat the negative attributes of leakage thereby ensuring that U.S. based manufacturers compete with internationally based manufacturers, on an equivalent basis, and in time as the world transitions to a low-carbon state, on an even more competitive basis.

b. What are the impacts on technical skills, supply chains, R&D and innovative capacity in U.S. manufacturing and industries exposed to relatively high energy or production costs?

RESPONSE: Base manufacturing sectors, e.g., cement, steel, glass and petrochemicals production, that feature high energy and production costs, and that feature large carbon-exposure would indeed be challenged, initially, to transform, adapt and empower their industries for a low-carbon world. However, a challenge of this nature has been long foreseen by the base manufacturing sector, which has been preparing, albeit incrementally, for this transition. As such, provision of clear guidance, i.e., in terms of legislative policy, regulatory and enforcement certainty, and the development of economy-wide low-carbon standards would accelerate and catalyze these sectors including their supply chains, R&D and innovation capacity, and the skillsets of their technical and non-technical workforce. In fact, the current mismatch of U.S. (federal) policy vis-à-vis state, and city level, and international actions with regards to carbon management is the single biggest detriment to the transformation of manufacturing practices in the U.S. This is major disconnect that needs to be overcome.

In addition to clear guidance, the U.S. should greatly expand federal R&D programs in the general theme of carbon management with special focus on programs that have the ability to catapult already developed, although not-yet-commercial scale technologies, to the point of commercial adoption. Some examples of this nature include the creation of technology demonstration and deployment programs that could be implemented by the Department of Energy in Carbon Capture, Utilization and Storage (CCUS) systems which are foundational to ensure and expand the U.S.'s global leadership and capacity for innovation of low-carbon technologies. These actions are especially important to ensure that the U.S. is not left behind in the development, deployment and commercialization of low-carbon technologies vis-à-vis the rest of the world; an outcome which, in time, would far more dramatically compromise the competitiveness of U.S. industry than U.S. industry's adoption today of decarbonization technologies.

c. What policy options have been proposed to prevent leakage, to what extent have they been examined for impacts on specific industries, and to what extent will this require international cooperation? Please elaborate.

RESPONSE: Absent global consensus and agreement; i.e., regulatory, evaluation (standards), and enforcement based, the most straightforward means of preventing or dis-incentivizing leakage involves the imposition of a border tax adjustment (BTA[*]). In the absence of international cooperation, the U.S. can protect its workers, its markets, and its competitiveness in a variety of ways. This includes: (a) by implementing border tax adjustments (BTAs) whereby materials and products that enter the U.S. are assessed a tax/tariff upon their entry into the U.S. whose magnitude is proportional to the extent of dissimilarity (e.g., in terms of embodied carbon intensity, or other ESG "environmental, social, governance" metrics) with similar materials and products that are manufactured in the U.S., and (b) by implementing low-carbon performance standards on an economy wide basis that promote strategic procurement decisions, e.g., made at the city-, state- and federal-government levels that ensure the consideration of embodied carbon intensity as a basis of selection and specification of materials and products, on an equal footing, as cost.

[*] A border tax adjustment (BTA) is a tariff which is imposed, for example, based on the carbon footprint of a material or product. Thus, materials like cement or steel that are produced inefficiently overseas (e.g., where they result in a high embodied carbon intensity of production) would incur a tax whose magnitude is proportionate to the extent of dissimilarity, e.g., in embodied carbon footprint, to similar materials that are produced in the U.S.; albeit more efficiently. The objective is to apply a tax on imported goods as related to their carbon footprint to provide protection to domestic industry that pursues decarbonization. In combination with strategic low-carbon procurement domestically, a BTA would incent foreign producers that seek to supply the U.S. market to become more efficient (from an energy- and carbon-basis) thereby harmonizing and transitioning production processes globally, to a low-carbon paradigm.

In addition to a BTA and low-carbon procurement standards, to encourage the purchase and integration of low-emissions products, incentives like revenue recycling could vastly increase the sale of low-carbon products by individuals, private- and public-entities. Revenue recycling is a significant mechanism since it offers a means to redistribute – very granularly, i.e., citizen by citizen if so desired – the income generated from carbon pricing mechanisms (e.g., taxes, penalties, etc.) to be returned back to society; an important need to create public support for carbon pricing mechanisms.

Generally speaking, international cooperation is very important to achieve harmonization in carbon management policies globally. This is needed to ensure equity in standards, regulations, penalties, and their enforcement across international jurisdictions. Such equity and harmonization is needed, for example, to offer corporations which operate globally a similar basis of improvement (i.e., rather than a dissimilar basis which may encourage leakage, and promote bad-actors), and evaluation – across national boundaries – as they seek to decarbonize their manufacturing operations. For this reason, it is critical that the U.S. engage with other nations to enact a globally-based and mutually agreed upon strategy and pathway for carbon emissions reductions.

2. What work has been published to your knowledge of the economic costs, the impacts on prices and supply, or employment impacts from reducing emissions in the industrial sectors? What work has been done to evaluate the legal, economic, and socio-economic impacts of deep decarbonization of the industrial sector?

RESPONSE: A substantial body of work published in both the peer-reviewed and non-peer reviewed literature has sought to articulate the economic, supply chain and employment impacts that are associated with decarbonizing the industrial sector. A sample of relevant (recent) studies is noted below for further consideration. And, if additional specific questions may arise we would be pleased to assist the committee in securing, evaluating and examining the conclusions of such work.

*(1) Deep Decarbonization Pathways Project. Pathways to Deep Decarbonization-2015 Report. SDSN - IDDRI **2015**.*

(2) de Pee, A.; Pinner, D.; Roelofsen, O.; Somers, K.; Speelman, E.; Witteveen, M. Decarbonization of Industrial Sectors: The Next Frontier; McKinsey & Company, 2018; p 63.

(3) Gerrard, M.; Dernbach, J. C. Legal Pathways to Deep Decarbonization in the United States; Environmental Law Institute, 2019.

(4) Sustainable Development Solutions Network (SDSN); Fondazione Eni Enrico Mattei (FEEM). Roadmap to 2050: A Manual for Nations to Decarbonize by Mid-Century; 2019; p 139.

*(5) Bataille, C.; Guivarch, C.; Hallegatte, S.; Rogelj, J.; Waisman, H. Carbon Prices across Countries. Nature Clim Change **2018**, 8 (8), 648–650.*

(6) Bataille, C.; Åhman, M.; Neuhoff, K.; Nilsson, L. J.; Fischedick, M.; Lechtenböhmer, S.; Solano-Rodriquez, B.; Denis-Ryan, A.; Stiebert, S.; Waisman, H.; et al. A Review of Technology and Policy Deep Decarbonization Pathway Options for Making Energy-Intensive Industry Production Consistent with the Paris Agreement. Journal of Cleaner Production 2018, 187, 960–973.

(7) Rosemberg, A. Embedding Just Transition in Long-Term Decarbonization Strategies: Why, What, and How; World Resources Institute, 2018.

*(8) Mayer, J.; Bachner, G.; Steininger, K. W. Macroeconomic Implications of Switching to Process-Emission-Free Iron and Steel Production in Europe. Journal of Cleaner Production **2019**, 210, 1517–1533.*

(9) Friedmann, S. J.; Fan, Z.; Tang, K. Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today; Columbia SIPA | Center on Global Energy Policy: New York, NY, 2019; p 100.

(10) Bernstein, P.; Montgomery, W. D.; Ramkrishnan, B.; Tuladhar, S. Impacts of Greenhouse Gas Regulations on the Industrial Sector; NERA Economic Consulting: Washington, DC, 2017.

3. According to a recent report by the Energy Futures Initiative, many "subnational decarbonization strategy and road-map reports contain insufficient detail for establishing effective and efficient implementation policies and programs."

a. What should be done to develop a more in depth understanding of the cost and economic impacts of state and regional (subnational) decarbonization policies, particularly in the industrial sector?

RESPONSE: More expansive thinking in terms of incentive mechanisms and (economy wide) market implications is needed for establishing and implementing effective and efficient policies and programs that granularly reward, incent and motivate decarbonation across public-, private, and jurisdictional domains. For example, rather than simply try to decarbonize specific industries, or sectors, public- and private entities need to: (a) democratize the implications of carbon-emissions by informed, thoughtful and purposeful citizen-by-citizen education and awareness building actions, at city, state and national scales, and (b) create support structures and systems that benefit both early-stage technology innovators and established corporations; both to work independently, and in collaboration with direct and quantifiable benefits. Furthermore, more work is needed to quantify and assess the economic impacts that may result, e.g., for heavy industry, based on its adoption and leveraging of incentives such as the 45-Q tax credit or California's low-carbon fuel standard. Such activities are needed not only to address potential deficiencies in existing policies and incentives but also to identify the lowest overhead pathways by which (business-to-business) industries that do not have consumer-level exposure can transition their business model to profit/grow in a low-carbon world.

Subcommittee on Environment and Climate Change
Hearing on
"Building a 100 Percent Clean Economy: Pathways to Net Zero Industrial Emissions"
September 18, 2019

Mr. Ross E. Eisenberg
Vice President, Energy and Resources Policy
National Association of Manufacturers

The Honorable Paul Tonko (D-NY)

1. What regulatory or technical barriers currently exist that limit utilization of proven industrial efficiency measures, such as deployment of CHP systems and adoption of ISO 50001, or other energy management systems?

   RESPONSE:

   The industrial sector has, over the past 40 years, improved its energy efficiency by close to 40 percent—about one percent per year.[1] EIA projects this rate of improvement to continue in the industrial sector through 2050.[2] However, as you recognize, there is considerably more opportunity available with the right policies.

   I recently talked with a member company (pulp and paper manufacturer) about its recent decision to install a new CHP unit rather than efficiency upgrades to an aging stationary gas engine. A CHP unit would be the most energy efficient solution; upgrades would improve the plant's efficiency but less so than replacement. The company's decision involved several factors. Cost was one factor, but reliability, operating risks, environmental permitting, the future of the facility and the cost of related inputs were factors as well. The single biggest risk is stranded investment; if conditions change, the company cannot get its true payback. For this company, the project was not feasible unless it provided a five-year payback or less; other projects have been required to have a three-year payback. Ultimately, the policy device that allowed the company to move forward with the CHP unit was the tax reform legislation from 2017—specifically the company's ability to utilize full and complete expensing. This tax change reduced the payback for the CHP unit from seven to five years and allowed the company to move forward.

2. What incentives would you recommend to encourage greater utilization of proven industrial efficiency measures, such as deployment of CHP systems and adoption of ISO

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[1] "Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050," Steven Nadel and Lowell Ungar, American Council for an Energy-Efficient Economy, at 14 (September 2019). *Available at* https://aceee.org/research-report/u1907.
[2] *Id.*

50001, or other energy management systems?

RESPONSE:

As illustrated by the paper company example above, a range of barriers exist that could prevent deployment and utilization of proven industrial efficiency measures, and there will not likely be one single solution that solves the problem. We encourage the committee to focus on the following measures, among other things:

- Increase and preserve federal government investment in early-stage energy efficiency research and develop and deploy standards and technologies, including supporting programs like the Advanced Research Projects Agency—Energy (ARPA-E). Public-private partnerships where DOE plays a convener role, such as Better Buildings, Better Plants, are also valuable.
- Scale up the successful Industrial Assessment Center program at DOE, a tool that allows small and medium-sized manufacturers to obtain energy efficiency assessments. There is significant opportunity to increase the number of centers in operation nationwide.
- Direct DOE to provide financial and technical support to encourage building efficiency retrofits. Moreover, any retrofit programs or incentives should be available for all to participate and not exclusive to specific organizations.
- Enact legislation that increases adoption of Smart Manufacturing techniques.
- Enact legislation and encourage regulatory measures to improve New Source Review (NSR) permitting and actively seek improvements in permitting times for energy efficient upgrades.
- Capital investment is key to economic growth, job creation and competitiveness. An effective way to spur investment in innovative technologies is to ensure that our tax code maintains a robust capital cost recovery system, provides strong incentives for research and development and does not increase the cost of financing new equipment purchases.

<u>The Honorable John Shimkus (R-IL)</u>

1. Raising energy and production costs in energy intensive or trade exposed industries can be harmful for communities in terms of lost jobs and economic output, especially if the developing world is unable to make the same changes to their energy and manufacturing systems.

    a. What are the risks of leakage of U.S. industrial jobs to other nations if cost of energy or processing is increased compared to international competitors?

RESPONSE:

There is a real risk of leakage of U.S. industrial jobs, and GHG emissions, to other nations if increased energy or processing costs make manufacturers less competitive. The more energy or process-intense a sector becomes, the higher the risk that increased costs will contribute to leakage.

This is specifically why the NAM recommends a strong, equitable international agreement as the foundation of the U.S. policy response to climate change. Many U.S. industries are already significantly less carbon-intense than their international competitors; an effective international agreement would ensure that all manufacturers would be subject to the same expectations.

b. What are the impacts on technical skills, supply chains, R&D and innovative capacity in U.S. manufacturing and industries exposed to relatively high energy or production costs?

RESPONSE:

Generally speaking, all of the areas listed can be negatively impacted by policies or externalities that make manufacturers less competitive, such as high energy production costs.

c. What policy options have been proposed to prevent leakage, to what extent have they been examined for impacts on specific industries, and to what extent will this require international cooperation? Please elaborate.

RESPONSE:

The most effective tool to prevent carbon leakage is an international agreement that places the same emissions expectations on manufacturers across all countries. That is the preference of the NAM.

In the absence of such an agreement, advocates generally point to a border adjustment as a possible tool to prevent leakage. Think tanks and economic researchers such as Brookings, Resources for the Future and the National Bureau of Economic Research have examined the impacts of a border adjustment. The NAM has not done any independent research on this issue. We would recommend further study of the topic by this Committee.

The American Clean Energy and Security Act of 2009, more commonly known as the Waxman-Markey bill, addressed leakage through the issuance of free emissions allowances to energy-intensive trade-exposed sectors. While the overall economic impact of that bill was measured by NAM at the time to be negative, our modeling did show that the free credits given to EITE sectors would have eased their respective cost burdens. At the time there was also significant unresolved debate over the WTO legality of the bill's structure.

2. What work has been published to your knowledge of the economic costs, the impacts on prices and supply, or employment impacts from reducing emissions in the industrial sectors? What work has been done to evaluate the legal, economic, and socio-economic impacts of deep decarbonization of the industrial sector?

   RESPONSE:

   There have been many studies done, including several by the NAM, over the years that examine the impact of specific emissions reduction policies on industrial competitiveness. Some have examined proposed legislation and others have examined the effect of proposed or final regulations. There have also been studies, including by the NAM, of the cumulative impact of regulations on the industrial sector. These examine the confluence of policies and the effect they are having on particular industries.

   To my knowledge, there are few studies available that examine the legal, economic and socio-economic impacts of deep decarbonization of the industrial sector. I recommend the Committee further examine this highly important issue.

   a. Would you please list pertinent studies?

      RESPONSE:

      (Please note that, notwithstanding the NAM-branded studies, listing below does not imply endorsement.)

      <u>Effects of emission reduction policies on industrial competitiveness</u>

      - "The Cost of Federal Regulation to the U.S. Economy, Manufacturing and Small Business," W. Mark Crain and Nicole Crain (2015), *available at* https://www.nam.org/wp-content/uploads/2019/05/Federal-Regulation-Full-Study.pdf.
      - "Potential Impacts of a Stricter Ozone Standard," NERA Economic Consulting (2014), *available at* https://www.nam.org/potential-economic-impacts-of-a-stricter-ozone-standard/.
      - "Economic Implications of Recent and Anticipated EPA Regulations Affecting the Electricity Sector," NERA Economic Consulting, *available at* https://www.nera.com/publications/archive/2012/economic-implications-of-recent-and-anticipated-epa-regulations-.html.

Impacts of deep decarbonization

- "Decarbonizing Heavy Industry: The Low-Carbon Transition of Canada's Emission-Intensive and Trade-Exposed Industries," Report of the Canadian Standing Senate Committee on Energy, the Environment and Natural Resources, *available at* https://sencanada.ca/content/sen/committee/421/ENEV/reports/2018-03-23_EITE_FINAL_WEB_e.pdf.
- "Industry Matters: Smarter Energy Use is Key for U.S. Competitiveness, Jobs and Climate Efforts," by Jason Walsh, Ryan Fitzpatrick, and Mykael Goodsell-SooTho, *available at* https://www.thirdway.org/report/industry-matters-smarter-energy-use-is-key-for-us-competitiveness-jobs-and-climate-effort.
- "Infrastructure Lost: Why America Cannot Afford to "Keep it in the Ground," U.S. Chamber of Commerce, *available at* https://www.globalenergyinstitute.org/infrastructure-lost-why-america-cannot-afford-keep-it-ground.

3. According to a recent report by the Energy Futures Initiative, many "subnational decarbonization strategy and road-map reports contain insufficient detail for establishing effective and efficient implementation policies and programs."

   a. What should be done to develop a more in depth understanding of the cost and economic impacts of state and regional (subnational) decarbonization policies, particularly in the industrial sector?

   RESPONSE:

   We encourage further research in this area. Manufacturers face a patchwork of federal, state and local laws and regulations to address climate change—policies such as California's Global Warming Solutions Act, the Regional Greenhouse Gas Initiative (RGGI) in the Northeastern United States, Oregon's Clean Fuels Program, the EPA's power plant GHG standards, joint EPA/NHTSA/California automobile regulations and the Climate Mayors pledge by individual cities to meet the U.S. GHG reduction targets from the Paris Climate Agreement. There are also a host of related laws and actions that further complicate the climate policy landscape. For instance, 29 states plus the District of Columbia have a renewable electricity standard. 15 states plus the District of Columbia have energy efficient appliance standards that differ from federal guidelines. Activists have waged a variety of successful campaigns to shut down fossil-fired power plants and stop new pipelines and transmission lines. Climate litigation has increased in recent years, with states, cities and private citizens suing the government, manufacturers and even each other to force federal action, apportion blame and secure damages.

To my knowledge there has been very little examination of the costs or impacts of these and related policies on manufacturing. Understanding their true costs would be helpful as Congress discusses a federal legislative framework to address climate.

4. Last year Republicans developed legislation to reform the Clean Air Act's new source review program, which would have enabled industrial facilities to upgrade with efficiency and pollution control equipment, without costly new regulations.

    a. What would be the impact if we enacted a law like this for increasing cleaner, more efficient operations?

    RESPONSE:

    NSR can be an impediment to the installation of more efficient technologies that would ultimately combat climate change. An inability to define what is "routine maintenance" has resulted in NSR Notices of Violation being issued for environmentally beneficial projects like economizer replacement, steam turbine upgrades, feed water heater replacements, and similar activities. In comments to the EPA's draft Clean Power Plan, the Utility Air Regulatory Group (UARG) cited *more than 400 instances* in which a regulated entity took on a project to improve the energy efficiency of a power generation unit, only to be targeted by the EPA or citizen suits alleging that it had violated NSR.[3]

    The NAM has testified in support of legislation before this Committee that would provide flexibility in the definition of "modification" so that these heat rate improvements and efficiency upgrades will not be deterred by the threat of NSR. It would eliminate the situation where a piece of modern control technology triggers NSR because it generates collateral emissions of another pollutant (e.g., technologies that reduce NOx but increase CO). Most importantly, it could unlock a massive market for the installation of efficient technologies that would drive manufacturers' already-impressive emissions reductions down even farther.

The Honorable Markwayne Mullin (R-OK)

1. Can you speak to the benefits our fracking revolution has had on the availability for the feedstock for the chemicals, plastic and other industrial products and activity in the

[3] Comments of the Utility Air Regulatory Group on Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, Docket ID EPA-HQ-OAR-2013-0602-22768, Attachment A (Dec. 1, 2014).

United States?

RESPONSE:

The NAM released a study[4] in 2016 that concluded that the shale gas revolution contributed $190 billion to real gross domestic product (GDP), 1.4 million additional jobs and $156 billion to real disposable income. Three years earlier, we supported a study that forecasted the full impact of the unconventional oil and gas revolution,[5] which made the following findings:

- The entire unconventional oil and gas value chain and energy-related chemicals will contribute $284 billion in value-added contributions to GDP in 2012, a figure that will increase to nearly $533 billion annually in 2025.
- Between 2012 and 2025, IHS projects a cumulative investment of nearly $346 billion across the midstream and downstream energy and energy-related chemicals value chains. Close to $216 million of this will come in the midstream and downstream segments of the unconventional value chain, including 47,000 miles of new or modified pipeline infrastructure.
- More than $31 billion in new capital investments will drive the addition of more than 16 million tons of chemical capacity by 2016. Cumulative investment will grow to more than $129 billion to support nearly 89 million tons of capacity by 2025.
- Energy-related chemicals (currently supporting more than 53,000 jobs) will support a growing number of jobs in the long term. By the end of the decade, energy-related chemicals will support more than 277,000 jobs—a fivefold increase—and rise to nearly 319,000 by 2025.

a. Given the important role of natural gas in industrial processes, does it make any sense to hear Members of Congress calling to keep it in the ground?

RESPONSE:

Manufacturers do not support efforts to limit or ban specific sources of energy or energy technologies. We support an “all of the above” energy strategy.

[4] “The Economic Benefits of Natural Gas Pipeline Development on the Manufacturing Sector,” IHS Economics (May 2016), *available at* https://www.nam.org/wp-content/uploads/2019/05/NAM_NG_Report_042816.pdf.
[5] “America’s New Energy Future: The Unconventional Oil and Gas Revolution and the Economy—Volume 3: A Manufacturing Renaissance,” IHS Markit (September 2013), *available at* https://news.ihsmarkit.com/press-release/economics/us-unconventional-oil-and-gas-revolution-increase-disposable-income-more-270.

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Center on Global Energy Policy

October. 21, 2019

Congressional Testimony of
Dr. S. Julio Friedmann
Senior Research Scholar, Center on Global Energy Policy, Columbia Univ. School of International & Public Affairs

Before the
Committee on Energy and Commerce
United States House of Representatives
2nd Session, 115th Congress

Additional Questions for the Record

The Honorable Paul Tonko (D-NY)

1. What recommendations do you have for NIST, in consultation with DOE, EPA, or other Federal agencies, to develop industrial product performance standards to encourage greater use of low-emissions products?

NIST should work to augment existing standards or develop new standards for performance of industrial products. Performance based standards sometimes already exist but are not used or are not current given rapid technology evolution. I recommend these specific actions:

- *Assess landscape: NIST, in partnership with DOE, should identify which technology pathways are most mature, have received substantial work already, and have highest promise. Based on that, NIST should (a) generate a plan and timeline to develop and deliver performance-based standards and (b) fast-track those identified as near-term opportunities.*
- *Develop testing protocols: NIST should develop a transparent and open process to test the performance industrial products. They should do so in partnership with DOE and Dept. of Transportation.*
- *Develop LCA process: In parallel with the performance-based testing protocols, NIST should formalize a peer-reviewed methodology to assess life-cycle of all industrial decarbonization pathways and technologies. This MUST include a new effort to gather relevant data and share through an open-access system. NOTE: Industry is developing automated approaches to this task, which should be explored.*
- *Explore international partnerships: NIST should work with the ISO, the World Business Council on Sustainable Development and similar institutions to build partnerships with similar institutions in other countries and to expedite pathways to international adoption of standards.*

2. While the hearing focused on cement, what other industrial goods would benefit from the development of low-emissions standards?

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Many economic sectors could benefit from low-emissions standards on a few important industrial products. These products include glass (flat, container, architectural), metals (iron, steel, aluminum, new alloys), chemical feedstocks (ammonia, methanol, ethylene, carbon black) and finished chemical products (polyethylene, PVC, lubricants). In particular, steel would benefit from separate new standards forboth recycled and for new production, and provide other manufacturing customers 9e.g., auto0 and government purchasers (fed, state, and municipal) with important information they could use to purchase greener products.

The Honorable John Shimkus (R-IL)

1. Raising energy and production costs in energy intensive or trade exposed industries can be harmful for communities in terms of job loss or economic output, especially if the developing world is unable to make the same changes to their energy and manufacturing systems

    a. What are the risks of leakage of U.S. industrial jobs to other nations if cost of energy or processing is increased compared to international competitors?

Leakage is always a risk as a function of many factors, including costs of labor, environmental stringency, and energy costs. If decarbonization approaches were to yield substantially higher product costs for U.S. industrial manufacturers, policy steps would be needed to help prevent leakage. Government procurement policies, tax policies, border tariffs, and other financial incentives (e.g., contract for difference) would be possible ways to avoid leakage.

    b. What are the impacts of technical skills, supply chains, R&D and innovative capacity in. U.S. manufacturing and industries exposed to relatively high production costs?

High quality skilled labor, strong supply chains, and other factors play important roles in maintaining muscular U.S. industrial production and the jobs associated with them. Strong and dynamic government support for RD&D and innovation in novel and low-C manufacturing approaches will help maintain U.S. leadership and competitiveness. As other countries increase their investments in labor skills and innovation, it is essential that the U.S. make investments that serve to keep American industry strong.

    c. What policy options have been proposed to prevent leakage, to what extent have they been examined for impacts on specific industries, and to what extent will this require international collaboration? Please explain.

In my response to question 1a above, I noted that government procurement policies, tax policies, border tariffs, and other financial incentives (e.g., contract for difference) would be possible ways to avoid leakage. In my original testimony, I wrote that one swift and robust policy was for the U.S. government (as well as state and municipal

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government) to develop low-C procurement standards. This would provide secure customers to key industries, stimulate private sector investment in innovative approaches, and pass muster regarding WTO and IMF restrictions. At the Center on Global Energy Policy at Columbia, we are beginning analysis on how to design procurement policies and other policies (e.g, tax and trade policy) to minimize cost to consumers and maximize benefit to companies, workers, and delivering cleaner products to market.

2. What work has been published to your knowledge of the economic costs, the impacts on prices and supply, or employment impacts from reducing emissions in the industrial sectors? What work has been done to evaluate the legal, economic, and socio-economic impacts of deep decarbonization of the industrial sector?

    a. Would you please list pertinent studies?

This is not an area of my expertise, so I can only provide limited assistance. Most of these studies do not provide deep and quantitative responses to your question but do discuss the issues raised by question 2.

1. *Energy Transition Commission, 2018, "Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century, Report," http://www.energy-transitions.org/mission-possible*
2. *The European Chemical Industry Council (CEFIC), "European chemistry for growth: Unlocking a competitive, low carbon and energy efficient future," CEFIC (2013), https://cefic.org/app/uploads/2019/01/Energy-Roadmap-The-Report-European-chemistry-for-growth_BROCHURE-Energy.pdf*
3. *Materials Economics, 2019, Industrial Transformation 2050: Pathways to net-zero emissions from EU heavy industry, 208p. https://materialeconomics.com/publications/industrial-transformation-2050*
4. *Mckinsey, 2018, Decarbonization of the industrial sector: the next frontier. https://www.mckinsey.com/industries/oil-and-gas/our-insights/decarbonization-of-industrial-sectors-the-next-frontier*
5. *The role of steel manufacturing in the global economy, Oxford Economics (2019).*
6. *World Steel Assoc., Steel's contribution to a low-carbon future (2018)*
7. *Third way, Industry Matters: Smart Energy Use is the Key for U.S. Competitiveness (2018)*
8. *Fleschen, D. A possible future of steelmaking: HIsarna. Market Steel (2018).*
9. *Department for Business, Energy & Industrial Strategy, "Contracts for Difference: Policy Paper," Gov.UK (2019), https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference*
10. *US Department of Commerce, International Trade Administration, Steel Import Monitoring and Analysis, "Global Steel Report," Global Steel Trade Monitor (2018), https://www.trade.gov/steel/pdfs/global-monitor-report-2017.pdf at pp. 3 and 11*
11. *Jennifer Hillman, "Changing Climate for Carbon Taxes: Who's Afraid of the WTO?," German Marshall Fund of the United States: Climate & Energy Paper Series 2013 (2013), https://www.scribd.com/document/155956625/Changing-Climate-for-Carbon-Taxes-Who-s-Afraid-of-the-WTO*

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12. Joost Pauwelyn, "Carbon Leakage Measures and Border Tax Adjustments Under WTO Law," Social Science Research Network (SSRN) (2012), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2026879
13. Adele C. Morris, "Policy Brief: Making Border Carbon Adjustments Work in Law and Practice," Tax Policy Center: Urban Institute & Brookings Institution (2018), https://www.taxpolicycenter.org/sites/default/files/publication/155511/policy_brief_making_border_carbon_adjustments_work_in_law_and_practice.pdf

3. According to a recent report by the Energy Futures Initiative, many "subnational decarbonization strategy and road-map reports contain insufficient detail for establishing effective and efficient implementation policies and programs."

   a. What should be done to develop a more in depth understanding of the costs and economic impacts of state and regional (subnational) decarbonization policies, particularly in the industrial sector?

There are several steps the U.S. government should consider to help develop a richer understanding of options, trade-offs, and costs associated with industrial decarbonization

- *Assembling and sharing data: As I wrote in my testimony, simple data associated with industrial production of many products is not aggregated, available, or shared. It is essential for data on industrial energy use, heat use, production, emissions, and labor to be gathered in one place. U.S. DOE (e.g., EIA) could undertake this function, ideally in partnership with agencies like EPA, Commerce, and Labor*
- *New analytical tools: The conventional energy analytical models used by most scholars and economists do not represent industrial energy well. They do not represent technology options well. The U.S. Government should support the development on a new generation of analytical tools that can assess trade-offs and options as well as the potential benefits to trade, labor, and the environment.*
- *Policy analysis: Even with data and new analytical tools, scholars and government experts should develop and assess policy models. Decision makers in Washington fundamentally lack the information needed to craft robust, comprehensive policy for industry or to advise what actions would serve best in international trade discussions and negotiations.*
- *Pursue sectoral international agreements: As mentioned in my written testimony, the U.S. Government should consider how to convene and drive sector specific agreements for GHG reductions. This could be led by Commerce and State with support from other agencies. Such agreements are needed to create consensus within industry, to place all countries on a level playing field, and to determine mechanisms for verification and compliance. The Montreal Protocol could serve as a model for such an approach.*

Subcommittee on Environment and Climate Change
Hearing on
"Building a 100 Percent Clean Economy: Pathways to Net Zero Industrial Emissions"
September 18, 2019

Mr. Jason Walsh
Executive Director
Blue Green Alliance

The Honorable Paul Tonko (D-NY)

1. What lessons should be learned from the development and implementation of California's Buy Clean law?

   RESPONSE: In crafting a policy of this kind, it is essential to work together with agencies, business, labor, and other key stakeholders to develop a strong solution and policy framework. We should also be aware that there are significant differences between California and other states with regards to industry, energy mix, manufacturing investment, and existing climate frameworks when developing this policy.

   In California, it was helpful for the Department of General Services that the policy implementation schedule was phased in over several years. A longer timeline for mandated compliance allowed the State to educate contractors and manufacturers about the requirements. The timeline for Buy Clean California implementation is copied below:

   January 1, 2019 – EPDs will be requested by the state.
   January 1, 2020 – EPDs will be required by the state.
   January 1, 2021 – DGS publishes the maximum acceptable GWP for eligible materials.
   July 1, 2021 – EPDs will be required and used to gauge GWP compliance of eligible materials.

   a. What product types should be covered under a federal Buy Clean program?

      RESPONSE: Under Buy Clean California, structural steel, carbon steel rebar, flat glass, and mineral wool board insulation were covered. There are a few criteria the federal government could consider to determine which products to include.

      It would be helpful to first know what products the federal government procures by agency, above a certain de minimus threshold in order to craft a policy that is impactful. Then, the policy could be structured to include one of the following scopes:

      - Procurement of all construction materials for public building and infrastructure projects;

- Procurement of products within a material type, rather than between material types;
- Create a selected list of "eligible materials" determined by domestic manufacturing, current emissions levels, and potentially considering trade exposed products.

b. What other policy design decisions should be considered by Congress?

RESPONSE: One key design consideration should be the impact of this policy on the U.S. industrial sector and the competitiveness of our manufacturers. This policy must result in a strengthening of U.S. manufacturing and ensure quality manufacturing jobs here in the U.S. Without careful attention to the trade exposed nature of these industries, unintended consequences could occur. This consideration should inform policy design, including structure and application of the standard.

Congress could also consider incorporating high labor standards and land, air, and water pollution into procurement determinations. We believe this could work in tandem with Buy Clean, where the federal government would set emissions, pollution and labor standards for an "eligible entity" to be able to be considered for federal public projects.

The federal government would have to set a list of criteria that a relevant agency could use to certify a manufacturer or contractor as a "responsible/eligible entity." This concept is not entirely new at the federal level. In 2015, President Obama signed EO 13693, Planning for Federal Sustainability in the Next Decade. Although the EO was revoked by the Trump Administration, it directed federal agencies to promote sustainable acquisition and procurement, with a preference for recycled content, energy/water efficient products and bio based products. EO 13693 established a "strategy to reduce GHG emissions across federal operations and the supply chain, including specific actions to better understand and manage the implications of supply chain emissions," and required the seven largest procuring agencies to implement procurements that take contractor GHG emissions into consideration.

In 2016, the DoD, GSA, and NASA issued a proposed rule to further these objectives, revising the Federal Acquisition Regulations (FAR) to add annual representation within the System for Award Management (SAM) for offerors to indicate if and where they publicly disclose GHG emissions and reduction goals. The proposed rule is intended to make "data available in a standardized format to enhance the Federal Government's ability to track GHG management trends with the Federal supply chain and help to inform agency procurement strategies to reduce supply chain emissions" and would be mandatory for vendors receiving $7.5 million or more in federal contract awards and voluntary for all other vendors. It would be informative to look into how far these efforts went, what work was done by individual agencies to comply with this EO, and what insights, if any, were gleaned from the efforts.

Finally, any Buy Clean policy must go hand in hand with complementary policies that invest in U.S. manufacturing. Ultimately, Buy Clean policy should make U.S. industry stronger and more competitive. These investments should include funding and financing for investments to reduce emissions in the industrial sector, technical assistance, and increased funding for research, development, demonstration, and deployment of the transformative technologies that will be required to decarbonize the industrial sector.

The Honorable John Shimkus (R-IL)

1. Raising energy and production costs in energy intensive or trade exposed industries can be harmful for communities in terms of lost jobs and economic output, especially if the developing world is unable to make the same changes to their energy and manufacturing systems.

    a. What are the risks of leakage of U.S. industrial jobs to other nations if cost of energy or processing is increased compared to international competitors?

RESPONSE: Many U.S. manufacturers are in "energy-intensive, trade-exposed" (EITE) industries and are very vulnerable to global competition. Steel, glass, metal casting, pulp and paper, aluminum, and chemicals are all traded globally and purchased predominantly based on price in a global marketplace.[i, ii, iii] Policies intended to reduce emissions could unintentionally—through increased costs to U.S. manufacturers—result in a phenomenon known as "carbon leakage." Rising costs could push production to manufacturers in countries with less stringent standards, which could ultimately result in an increase in global greenhouse gas emissions in the long term.[iv]

Any approach to industrial emissions reduction must therefore consider the unique challenge the industrial sector faces related to global competitiveness. Any federal effort to tackle industrial sector emissions and grow U.S. manufacturing therefore must include:

- Common sense tax, procurement, trade enforcement, and border adjustments policies to stop offshoring and the leakage of jobs—and pollution—overseas; and
- Ensuring that trade agreements are enforceable, fair for all workers, and benefit the environment and the climate.

    b. What are the impacts on technical skills, supply chains, R&D and innovative capacity in U.S. manufacturing and industries exposed to relatively high energy or production costs?

    RESPONSE: We do not have data to answer this question.

c. What policy options have been proposed to prevent leakage, to what extent have they been examined for impacts on specific industries, and to what extent will this require international cooperation? Please elaborate.

RESPONSE: One policy option proposed to specifically address leakage is the Carbon Border Adjustment Tax (CBAT); also called Border Carbon Adjustments (BCA). Several initiatives have been launched in the EU, including the 2005 EUTS, which initiated debate on options at the border. Most recently, Emmanuel Macron, President of France, proposed a carbon border tax for the EU in spring 2019 and the EU recently began seriously investigating the feasibility of implementing a tax. This tax would be EU-wide and would be a fee assessed on imports from non-EU countries that do not have a carbon tax or another form of carbon pricing.[v] In the U.S., several legislative proposals have included a BCA, including the 2009 American Clean Energy and Security Act, and several recent bills have been introduced with BCA as a part of a larger carbon tax program, most recently American Opportunity Carbon Fee Act of 2018 (S.2368/H.R.4926) in 2018.[vi]

2. What work has been published to your knowledge of the economic costs, the impacts on prices and supply, or employment impacts from reducing emissions in the industrial sectors? What work has been done to evaluate the legal, economic, and socio-economic impacts of deep decarbonization of the industrial sector?

RESPONSE: Several studies have been executed to evaluate the economic costs, the impacts on prices and supply, or employment impacts from reducing emissions in the industrial sectors as well as the legal, economic, and socio-economic impacts of deep decarbonization of the industrial sector. Please see the following question for a list of pertinent studies.

a. Would you please list pertinent studies?

RESPONSE:

- Carbon Disclosure Project, "Melting Point", July 2019. https://www.cdp.net/en/investor/sector-research/melting-point
- McKinsey & Company, "Decarbonization of industrial sectors: the next frontier", June 2018. https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20industry%20can%20move%20toward%20a%20low%20carbon%20future/decarbonization-of-industrial-sectors-the-next-frontier.ashx
- Olle Olsson , "Low-emission steel production: decarbonizing heavy industry", SEI, 4/11/2018. https://www.sei.org/perspectives/low-emission-steel-production-hybrit/

- Rebecca Duff and Michael J. Lenox, "PATH TO 2060: Decarbonizing the Industrial Sector", Batten Institute for Entrepreneurship and Innovation, UVA Darden School of Business, December 2018, https://www.darden.virginia.edu/sites/default/files/inline-files/industrialsector-report-8_FINAL.pdf
- "The transition of energy intensive processing industries towards deep decarbonization: Characteristics and implications for future research", Renewable and Sustainable Energy Reviews, Volume 79, November 2017, Pages 1303-1313 https://www.sciencedirect.com/science/article/pii/S1364032117307906

3. According to a recent report by the Energy Futures Initiative, many "subnational decarbonization strategy and road-map reports contain insufficient detail for establishing effective and efficient implementation policies and programs."

    a. What should be done to develop a more in depth understanding of the cost and economic impacts of state and regional (subnational) decarbonization policies, particularly in the industrial sector?

    RESPONSE: We have extensive information about the growing threat of industrial emissions, both in the U.S. and globally. We also have a growing list of reports and models at the national and sub-national level to inform our efforts to tackle industrial sector emissions. And yet, more information and data would certainly be useful in our efforts to craft appropriate policy, including modeling the impact of particular policy pathways on the competitiveness of U.S. industrial sectors. Several states, including Washington, have moved forward with studies along these lines and others, like Minnesota, are in the process of developing them.

4. Given its potential regional flexibility, do you support looking at the deployment of advanced non-light-water SMRs?

    RESPONSE: We do not have a position on this as a coalition. Given the challenges in this sector, we do support looking at the deployment of a wide range of technologies. Several studies have pointed to light water small modular reactors (SMRs) as showing particularly strong promise as a supplier of industrial process heat, given that those in development can produce thermal heat at temperatures high enough to conduct some industrial activities. However, these would likely not be adequate solutions for sub-sectors that require direct heat at the highest temperatures, like the 1,700°C needed for iron and steel manufacturing or 1,500°C for cement.[vii]

    a. How much work has been done to identify the industrial processes that could benefit from switching to electricity as a heat source?

    RESPONSE: Fuel switching to clean sources can also help reduce greenhouse

Mr. Jason Walsh, Executive Director
Blue Green Alliance
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gas emissions from the industrial sector, particularly with respect to process heat, which is the biggest source of energy use and related emissions in the sector. This could include switching to dispatchable renewable sources, such a solar thermal or sustainable biomass, and the electrification of certain processes.

Only 1% of conventional boilers and 10% of process heat applications in the industrial sector are electrified, and it's technically feasible to scale up the deployment of electric boilers and electric heating technologies, including resistive, induction and infrared heating. However, there are barriers to electrification, including the high cost of using electricity compared to direct fossil fuel use to generate process heat.

Therefore, a critical R&D challenge will be to focus on industrial applications where electrification, relative to fossil fuels, can make more efficient use of thermal energy. More fundamentally, however, we need new technological and economic analysis to develop a better understanding of which industrial sector technologies would be the most promising and cost-effective to electrify.[viii]

b. I assume it is feasible to convert fuel to electricity, but is it economically feasible?

RESPONSE: As was noted in the previous answer, the cost of using electricity compared to direct fossil fuel use to generate process heat is currently higher. Reducing this comparative cost and identifying the industrial applications where electrification can make more efficient use of thermal energy must be a focus of federal R&D efforts.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) is spearheading the Electrification Futures Study, a research collaboration to explore the impacts of widespread electrification in all U.S. economic sectors.[ix]

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[i] American Council for an Energy-Efficient Economy, "Energy-Intensive, Trade-Exposed Industries." Available online: http://aceee.org/topics/energy-intensive-trade-exposed-industries.
[ii] *Ibid.*
[iii] *Ibid.*
[iv] *Ibid.*
[v] https://www.climatechangenews.com/2019/07/22/von-der-leyen-make-carbon-border-tax-work/
[vi] https://www.taxpolicycenter.org/sites/default/files/publication/155511/policy_brief_making_border_carbon_adjustments_work_in_law_and_practice.pdf
[vii] https://aflcio.org/sites/default/files/2018-10/Industry-MattersSmarter-Energy-Use-Key-for-US-Competitiveness-Jobs-and-Climate-Efforts.pdf
[viii] https://aflcio.org/sites/default/files/2018-10/Industry-MattersSmarter-Energy-Use-Key-for-US-Competitiveness-Jobs-and-Climate-Efforts.pdf
[ix] https://www.nrel.gov/news/press/2018/nrel-launches-electrification-futures-study-series.html