CONFERENCE TOTAL—WITH COMPARISONS

The total new budget (obligational) authority for the fiscal year 2006 recommended by the Committee of Conference, with comparisons to the fiscal year 2005 amount, the 2006 budget estimates, and the House and Senate bills for 2006 follow:

(In thousands of dollars)

New budget (obligational) authority, fiscal year 2005	$501,344,992
Budget estimates of new (obligational) authority, fiscal year 2006	596,122,425
House bill, fiscal year 2006	601,642,273
Senate bill, fiscal year 2006	612,406,934
Conference agreement, fiscal year 2006	601,673,301
Conference agreement compared with:	
New budget (obligational) authority, fiscal year 2005	+100,328,309
Budget estimates of new (obligational) authority, fiscal year 2006	+5,550,876
House bill, fiscal year 2006	+31,028
Senate bill, fiscal year 2006	−10,733,633

RALPH REGULA,
ERNEST ISTOOK, Jr.,
ROGER F. WICKER,
ANNE M. NORTHUP,
RANDY "DUKE" CUNNINGHAM,
KAY GRANGER,
JOHN E. PETERSON,
DON SHERWOOD,
DAVE WELDON,
JIM WALSH,
JERRY LEWIS,
Managers on the Part of the House.

ARLEN SPECTER,
THAD COCHRAN,
JUDD GREGG,
KAY BAILEY HUTCHISON,
LARRY E. CRAIG,
TED STEVENS,
MIKE DEWINE,
RICHARD SHELBY,
PETE V. DOMENICI,
Managers on the Part of the Senate.

PEAK OIL

The SPEAKER pro tempore (Mr. JINDAL). Under the Speaker's announced policy of January 4, 2005, the gentleman from Maryland (Mr. BARTLETT) is recognized for 60 minutes.

Mr. BARTLETT of Maryland. Mr. Speaker, I have in front of me a document called Peaking of World Oil Production, Impacts, Mitigation and Risk Management. As I look at the second page, it says this report was prepared as an account of work sponsored by an agency of the United States Government. That agency was the Department of Energy, and the organization that was funded to do this work was SAIC, a very prestigious, scientific organization.

Dr. Robert Hirsch was a project leader. He was supported by Roger Bezdek and Robert Wendling in this very important work. It was submitted in February of 2005.

What I would like to do this evening is to go through the salient points of this so-called Hirsch report. Remember, it was funded by the Department of Energy, and it was performed by a very prestigious scientific organization, SAIC.

I have here a quote from page four of this report. This is so important, I have highlighted a couple of phrases, but I would like to read these couple of statements here, because they are so important. The peaking of world oil production presents the United States and the world with an unprecedented risk management problem. What that means is that never in history has there been a risk management problem like this. It is unprecedented, they say.

As peaking is approached, liquid fuel prices and price volatility will increase dramatically and without timely mitigation. The economic, social and political costs will be unprecedented.

Mr. Speaker, what that means is that never in history has there been an occasion when economic, social and political costs will be this big. Viable, mitigation options exist on both the supply and demand sides, but to have substantial impact, they must be initiated more than a decade in advance of peaking.

Dealing with world oil production, peaking will be extremely complex, involve literally trillions of dollars. Now, around here, we talk a lot about billions of dollars, but seldom about trillions of dollars. This will cost trillions of dollars and require many years of intense effort.

Mr. Speaker, what are they talking about? What is this oil peaking that they are talking about that is going to present unprecedented risk-management problems, and have economic, social and political costs, which will be unprecedented? What we need to do to put in this in context to understand it is to go back about 60 years, and our next chart helps us do that?

This begins with the work of a Shell oil scientist by the name of M. King Hubbert. M. King Hubbert worked during the 1940s and 1950s. He was observing the exploitation and the exhaustion of oil fields. He noticed that each oil field followed what we call a bell curve, goes up steeper and steeper, finally reaches a peek, and then down the other side.

He saw this in field after field. He rationalized if he could add up all the fields in the United States and guess as to how many more we were going to find, he could then estimate when the United States would peak in oil production. He made that estimate in 1956, and he said that the United States would peak in oil production about 1970.

As it turned out, he was right on target. You can see here from the graph, this peak in 1970. The smooth curve here is his prediction. The more ragged curve, or the actual data points, and you see that right on target, it peaked in 1970.

The red curve here is the curve for the Soviet Union, now Russia. They kind of fell apart with their dissolution, and they did not reach their potential, so there is going to be a second kind of a much lower short peak here. Russia has already peaked in their oil production.

Mr. Speaker, more than half of all of the oil-producing countries in the world, some 25, I believe, have already peaked. Their peak oil production is already behind them. The next chart shows a schematic that helps us understand this, perhaps a little better.

This represents a 2 percent exponential growth in oil. Now, all the oil that was produced was used. For the first part of the curve the production of oil and the use of oil are the same thing. Obviously, you are not going to produce oil that you do not use.

If you need more oil, and it can be produced, your price indicators will mean that more oil is going to be produced. So for this part of the curve, we have used the oil as fast as we produced it.

At some point in time, it will peak. It peaked for the United States in 1970. M. King Hubbert said it would peak for the world about now. Actually, he said a few years earlier, but he could not have known of the Arab oil embargo and the world oil price hike spikes which sent the world into a recession, which reduced the demand for oil. That moved the peak a little forward. We believe, many observers believe, that we are peaking about now, or will shortly be peaking.

Mr. Speaker, I hope that the message that is in this document, peaking of world oil production, and the things that I am going to say, I hope they are wrong. Because if they are not wrong, we in United States and the world is in for a very rough ride. By the way, we can make this a very sharp peak or a very gradual one, by simply changing the scale on the abscissa and the ordinate. This represents a 2 percent increase in oil use.

It is 2 percent of what it was last year, so it keeps growing, it grows what we call exponentially. With a 2 percent growth, it doubles in 35 years. Since this point is half of that point on the ordinate scale, this represents 35 years.

□ 2100

So you see that some years before we actually reach peak, and we believe that we may be here at this point, but a few years before you reach peak, you actually are not producing as much as you would like to use. Just a very few years ago in 1998, I think, oil was under $10 a barrel, and now it was about $60 a barrel. So, clearly, there is not as much there as the world would like to use; and because there is not as much there, there is a higher demand for it, and so the price goes up.

We will be talking this evening about filling the gap. This is the gap we are talking about filling here. What are we going to do now that we have reached this point? There are two things we can do. One of them is simply reduce our consumption of oil so that there is enough to go around, and the other is to try to find some other source of energy so we can fill this growing gap; and the further out we go, you will see the bigger the gap gets. We will be talking about that a little later.

The next chart is an interesting one that shows the relationship between the oil we found and the oil we used. This is the difference between the oil we found and the oil we used. You see this is about the year 1980. Up until about 1980, every year we found more oil than we used. So we were accumulating an excess. This much excess was accumulated. From about 1980 on, we did not find as much oil as we used; and so to have enough oil available, we had to now start pumping our reserves. And so since 1980 our reserves have been going down and down because we have never, I think, in any year since about 1980 found as much oil as we pumped.

The next chart shows these relationships in a somewhat different way that may be a little easier to understand. Here we have these bars and they represent, you see that was very similar to the previous chart, and this shows the actual discovery of oil. This does not subtract what we use from what we found because we have a second curve here, which is the use curve, and you will see this black curve here. That is the amount of oil that we have used.

Now, it is very obvious that you cannot pump oil that you have not found. So if you kind of round this curve out and you get a curve here that has an area under it, that is the amount of oil that we can use. The amount that we have used is under this curve here. And since about 1980 we have had to make up for what we did not find by borrowing from that which we had found. So you are going to have to borrow some of this and fill in this space here to get us to where we are now in 2005.

Where do we go from here? Well, where we go from here is going to be determined by how much of this oil that we found is still available and how much more oil we are going to find.

Now, the people who put this graph together guessed that the oil could keep going down because it has been going down for 20 years. See the slope down for about 20 years? They guessed it would keep on going down at that slope. So the amount of oil we can use in the future is going to be the difference between what we find, which they think is going to be less and less each year which I am sure it will be because it has been for the last two decades, and the amount of oil that we use, and that will be made up by the oil that is here.

So you can draw very many curves that do not have you falling off a cliff. And clearly the wells do not perform the way that you pump full bore and you get the last drop out and you do not get any the next day. It tapers off little by little as you come down what is called Hubbert's peak.

The next chart is from the Hirsch Report, and in this chart he has simplified Hubbert's peak. And for purposes of their presentation here, they have depicted Hubbert's peak as not being the bell curve that we looked at before, but as simply being a slope up and they slope down. And they will tell you in the report that they have simplified that because of the points that they want to make later.

The bottom of the chart here shows something very interesting. It shows our production of oil in our country peaking in 1970. After 1970, we have developed some really good techniques for improving the discovery of oil and the recovery of oil.

Mr. Speaker, really big increases in our technologies for both finding oil and for pumping it, enhanced recovery of oil, did not make any appreciable difference in the amount of oil that we were able to pump. This points to the fact that the geology really determines how much oil we are going to get in the enhanced recovery techniques, and the field exploration techniques do not make much difference.

Another thing that does not make much difference at all is price. We are falling down the slope here. Notice what happened to price. It went way up. That ought to have resulted, if you think the marketplace works, that ought to have resulted in a lot more oil production in our country. It did not.

You see, nothing really happened to the oil production when the price really spiked here. But what this graph does is to make the point that increased technologies and increased price will have little effect on the production of oil from a field that has already peaked and you are going down slope.

The next chart is an interesting one, and what this shows is kind of what was shown in the past one, perhaps in a more dramatic way. By 1980 we were already 10 years down the other side of what was called Hubbert's peak, and the Reagan administration noted that and they knew they needed to have more oil. Their solution to that was to incent our oil companies to go out and drill more, so they provided some tax incentives for that, and it really worked because this is the drill here you see. And it really spiked after 1980; they drilled a lot more wells.

But notice this relationship between the oil that you have found and the oil you are pumping; and in spite of all that drilling, we went negative. What that shows is if it is not there, you cannot drill it. No matter how many holes you drill, you will not get more oil if there is not more oil there to get.

The next chart is kind of a blow-up of the situation in our country since 1935 to roughly the present. This shows where we have gotten our oil from. It shows us peaking in 1970. Oil from Texas, the rest of the United States, the natural gas liquids, and then the big discovery of oil in Prudhoe Bay. We were already slipping down Hubbert's peak. There was a little blip there as we slipped down Hubbert's peak. But notice this source where we are getting 25 percent of our oil really did not stop us from slipping down Hubbert's peak.

Notice the yellow there, Mr. Speaker. That is the fabled Gulf of Mexico oil discovery. You may remember that. A number of years ago that was supposed to solve our problem. It was oil for the foreseeable future. That is all the contribution it made.

Now, we clearly have been using more oil since we peaked, and we have been getting it from overseas; and we now get nearly two-thirds of our oil from overseas because, Mr. Speaker, we have only about 2 percent of the known reserves of oil in the world. We use about 25 percent of the world's oil, and we import about two-thirds of what we use.

The next chart shows the estimate of a number of authorities on when peaking is going to occur. Here we have the dates, and this first block of dates are those between now and 2010. That is pretty soon. You see the individuals there. Several of those I know personally. Colin Campbell, I have talked with him on the phone from over in the British Isles. Matt Simmons is the personal energy adviser of the President, president and CEO of perhaps the largest energy investment bank in the world. Dr. Deffeyes is a professor at Princeton University who has written a book on this subject, ''The End of Oil,'' I think, ''The View From Hubbert's Peak'' is what he calls it. Then we have a few who think the peak is going to be between 2010 and 2015. And then there are three that say that it is going to be there at notice.

Mr. Speaker, there is no argument that there will be a peak except for the last one here, Lynch, who believes it will be a long plateau. He is not arguing that it will not peak, but he thinks it will not reach the top and fall off. It will be a long plateau.

I would like to note, Mr. Speaker, that the economists here tend to be those that think that peak will be sometime in the future. What economists do is simply predict the future from the past. They are very good at studying the past. And if, in fact, there are inexhaustible resources, it is very logical that you ought to be able to predict the future from the past. But if, in fact, there is a limited supply of oil, then you may not be able to predict the future from the past. But notice the big group of experts, and this is who they work for and what they are, and notice several of them are retired.

We find when a military person takes off their uniform, we sometimes get kind of different testimony from them than when they wear the uniform. These people do not have any company they are accountable to. They are retired. For people who are just retired, Mr. Speaker, you tend to get very honest testimony from them. So you know who they are and who they work for and they are very credible people and they are pretty much all saying that peaking is pretty soon.

The next chart shows how we use the oil that we get. The big blue on top here is transportation. That is where we use about 70 percent of it. The yellow is industrial. The purple down here is electric power, and then what we use in our homes, residential, and then commercial at the very bottom.

The important part of this is the transportation, important for two reasons. One is that it is the biggest chunk of it and, secondly, it is that use of oil that cannot be readily replaced by something else. In industry they can use energy from many other sources for much that they do; but for transportation, we are pretty much stuck with oil.

The next chart shows us some of the characteristics of the fuels that we use and this is talking about energy density, how many gigajoules you get per ton. Gigajoules is a technical term. It simply means BTUs or calories or heat or energy that you get from a given volume of this. We tend to think of it in gallons or barrels, 42 gallons in a barrel by the way.

Here you see that crude oil is here at 449, and then diesel automotive as you start to refine it you get higher and higher densities.

Now, as we run down Hubbert's peak and start running low on oil and still want to drive our cars and our planes and so forth, we will have to find a substitute. Notice that the substitutes here have very much less energy density. I would like to spend just a moment, Mr. Speaker, talking about energy density because it is really very important and presents a big challenge to us.

One barrel of oil, that is 42 gallons of oil, the refined product of which you can buy now for just a tenth of a penny under $2 at some stores now. So you can buy it for well less than $100. That will buy you the work output of 12 people working all year for you.

If you have some trouble getting your arms around that, Mr. Speaker, just imagine how far that gallon of gas or diesel fuel takes your pickup truck or your SUV or your car. By the way, that is still cheaper than water in the grocery store if you are buying it in the small bottles.

Now, you could pull your car or truck or SUV as far as that gallon of fuel takes you, how long would it take you to pull your truck there. Obviously, you cannot pull it, but you can use a come-along and guard rails and trees and so forth, and by and by you will get it there. But it would take you quite a while to take it the distance that that one gallon takes you.

Another little example of this energy density and the tremendous challenge we face of finding something that is equivalent to this: If you work all day real hard in your yard this weekend, I will get more work out of an electric motor with less than 25 cents worth of electricity.

□ 2115

That may be kind of humbling to recognize that in terms of fossil fuel energy we are worth less than 25 cents a day, but this incredible wealth that we found under the ground, how fast we have used it. How little concern we show for the future.

The next chart addresses the transportation challenge we have. Obviously, the oil will go further if we are using less of it, but what he says here is that we cannot conceive of any affordable, government-sponsored crash program to accelerate normal replacement schedules for our cars and trucks. The average car is on the road I think 16 years. That is the median. That does not mean it is the average because the last one is 18 years, that is the middle one, and the average light truck, about the same distance, 16 or 17 years. The average big truck, heavy truck, is on the road for 28 years.

So if you want to buy a Prius or an Insight or one of these hybrid cars now, we ought to be doing that. I am not discouraging us doing that. That will make a very small dent in oil use because the things that were bought just this year are going to be on the road 16 or 17 years for cars and light trucks and 28 years median for heavy trucks. So it will take a long time.

If you want to dramatically reduce oil use, you have got to get these gas hogs off the road and get some fuel efficient things on the road. What they are saying is they cannot conceive of any affordable here, and that is the key word here. Obviously, we could bribe all the people in the country to take their SUVs to the junkyard and give them enough money to get a new hybrid. That would not be affordable. That is the key word here.

What he is pointing out here is it is going take a long time to make this change from our present gas guzzling SUVs, big cars and trucks and so forth and go to these hybrids.

The next chart shows us the contribution that enhanced oil recovery can make. We have some really good techniques today, and some people will tell you do not worry. We are really good at getting oil out of the ground now, so do not worry about this peak. What this shows is it does not affect the peak. Indeed, if you think about it, it should not affect the peak, because up until this peak, the oil comes out of the ground easily. You do not need the enhanced recovery techniques to get it out because it comes out very easily anyhow. When you really need them is on the down slope, and this shows you get a little more oil out on the down slope.

The next chart shows a depiction that the authors use, and this is really a simplification. They will tell you that this should be a growth curve here, an exponential curve, but they are making it a wedge because it helps them to make their points. And this is a schematic one for any substitute that you want to have.

It takes awhile before you get anything out of it. You have got to build the plant and plan, and then you start producing some of whatever this is. The next chart will show us the variety of things that it is, and the longer you have, the more and more of it you produce a day, present this thing as a wedge.

The next chart shows us an addition of some of wedges that you might use to have more liquid fuels available.

Enhanced oil recovery, we looked at that. That will produce something.

Coal liquids. When I was a little boy, in our lamps we used coal oil. By and by that was substituted by kerosene, and Hitler ran his military in World War II on oil made from coal because he did not have any oil and we were not going to let him get any. So he had to make it from coal. They had a lot of coal.

Heavy oil. Heavy oil is what determines why it is heavy. It will most likely sink in water some of it. All the rest of oil floats on water, and some of it is what is called sour. When you see that sour crude, light sweet crude is the most valuable. Sour crude has a lot of sulfur in it. You have to take that sulfur out. You are really polluting the air.

Then gas to liquids, and then he shows something about efficient vehicles. It takes a while before you get this in the fleet, and notice in 15 years the trifling contribution that efficient vehicles have made.

The next chart is a composite here that makes a salient point that they make in their paper, and here they look at three different scenarios of when you start to address the problem and the consequences of that.

The first of these, you start your crash program when you peak out. You say, gee, we cannot get as much oil out of the ground today as we got yesterday. That will not literally be true. It will be this month compared to last month because day-to-day is probably not going to make that big a difference.

If you wait until you see peak oil, what they are saying here is that run as fast as you can. With mitigation, you are still going to have a big shortfall.

By the way, I would like to refer back to their simplification of the bell curve. They simply use a slope up and a slope down, and what they are saying here, when you reach peak oil, you would really like to keep on going and use more and more. This really, of course, is an exponential curve going up, but they show here for simplicity a straight line and what they are trying to do is fill the gap. I am going to come back to that in a couple of minutes, but I am not sure we ought to be trying to fill the gap.

The second curve here represents what happens if you anticipate it by 10 years, and notice that most of the people in that former chart thought you were going to have peak oil a lot sooner than 10 years from now, but if you have 10 years and start the mitigation, you are still going to have a shortfall.

To have no economic consequences, they say they are going to have to start 20 years ahead.

Now, almost nobody believes that we have 20 years ahead. So obviously, if we are trying to fill that gap, there is going to be some shortfall because it is either upon us or will shortly be upon us.

I would like to talk for just a moment about whether or not we ought to try to fill that gap. For two reasons I think that maybe we ought to be considering that that is not really a good idea.

One is there is a pretty widespread belief that the warm weather we are having and the more frequent and intense hurricanes, the melting of the icecaps and the glaciers may be due to global warming that may have resulted from an increase in greenhouse gases which are produced by burning these fossil fuels. Now, if that is true and you believe that is going to have a negative effect on our environment, our climate and so forth, which will ultimately affect us economically, then I am wondering why you would want to have more of this by trying to fill that gap.

Let me give you another maybe even better reason that you should not be thinking about filling the gap.

There is an old saying that if you are in a hole, stop digging. Now, a corollary to that would be, in this case, that if you are climbing a cliff, a hill, where you will come to a precipice and by and by fall off and have to uncomfortably go down the other side, the higher you climb, the further you have to fall. That is very germane to this because the more oil that we use, the more energy that we use, the higher we will have climbed up that cliff and the steeper will be the descent down the other side.

The next chart, and you should notice, Mr. Speaker, the page where you can find these on each one. This is from page 64 of their report, and let me read this because this is really significant and I suspect that not too many people know this.

World oil peaking is going to happen. That is a certainty. I think that everybody understands that oil cannot be forever. There is not an inexhaustible supply of oil. It is not going to last to forever. What does that mean?

They think that it means that we will shortly peak in oil production. I would like to emphasize that peaking does not mean that we are going to run out of oil. We will not run out of oil for a long time, maybe 100 years, but what we will have run out of is readily available, high quality oil that can be produced at the rate we would like to use it. It is oil peaking. It is not running out of oil.

A hundred years from now there will be some oil, some gas, some coal, that we can find in ever-decreasing amounts at ever-increasing cost. It will not be very much in 100 years, but there will still be some.

''World production of conventional oil will reach a maximum and decline thereafter. That maximum is called the peak.''

I would suggest, Mr. Speaker, that one can find a lot of information on this if you simply do a Google search for peak oil. Now, you get essentially the same information if you do a Google search for Hubbert's peak but peak oil will do. That is maybe easier to remember. You will find a lot of articles there relative to this.

''A number of competent forecasters,'' and we looked at that chart a few minutes ago, ''project peaking within a decade; others contend it will occur later. Prediction of the peaking is extremely difficult because of'' a number of things, ''geological complexities.''

Let me pause just a moment to talk a little bit about the geology here and why you do not find oil everywhere.

We believe that a very long time ago there were warm seas, and at that time, the world was warm up in northern Alaska and Siberia because there were warm seas there. In every sea there was life there that grew like algae on your pond. At the end of the season, it sank to the bottom, and then dirt was washed off of the adjoining hills and through a very long time that built up large deposits at the bottom of these warm seas.

Then the tectonic plates of the earth separated. As you know, Mr. Speaker, there are tectonic plates that ride on the molten core of the Earth, and then the crust of the Earth is above those. These separated somewhat so that the bottom of these ancient warm seas were submerged, covered by a lot of rock and dirt. They were warm enough to the molten core of the Earth that it was just the right amount of heat. They were under enough pressure, and with time in this pressure cooker, this organic material was converted to oil and gas. Gas is the volatile part of this oil.

Now, you do not only need that, Mr. Speaker, you need something else before you really have oil deposits and gas deposits. You need a dome of rock over top of this like a big umbrella that keeps the volatiles, the gas, from going up and escaping because, you see, if they can escape, you do not end up with the nice, light sweet crude oil that we value so much. You end up with something like the tar sands in the oil shales. It is a little bit like the asphalt roads you drive on.

Now, if you cook that stuff, it will flow, and it is pretty much what these tar sands in oil shales are, something like that. So they were a very unique series of events that occurred that provide the oil and the gas for us, and it is no argument that you should not find it, probably are not going to find it everywhere in the world.

By the way, when I was a little boy we lived near a coal mining town, and we got what was called Run-of-mine coal. In those days there was not a big mechanical thing on a coal face digging it off. It was a miner with a pick and his shovel and his wheelbarrow. He may have had a little cart and a mule inside the mine to help him in some of the bigger mines.

But that would come out of the mine, and we would buy it just as it came out, called Run-of-mine, just the way you mined it, some big lumps on down to dust. Some of those big lumps were so big I could not put them in the furnace. So there was a sledge hammer, and we would have to break the lump to put it in the furnace. I remember breaking some of those lumps and they would fall open and there would be a fern leaf. I remember the thoughts that I had, gee, how long ago did that thing grow. It was very obvious where coal came from. You can see the vegetation inside the coal.

''Geological complexities, measurement problems, pricing variations, demand elasticity,'' how much of it we are going to need, ''and political influences,'' are they really going to sell us the oil or not. ''Peaking will happen, but the timing is uncertain.'' But the fact that it will peak is not uncertain. It will peak.

''Oil peaking presents a unique challenge,'' they say. Then I emphasize this statement. ''The world has never faced a problem like this. Without massive mitigation more than a decade before the fact, the problem will be pervasive and will not be temporary. Previous energy transitions, wood to coal and coal to oil, were gradual and evolutionary; oil peaking will be abrupt and revolutionary.''

□ 2130

The next chart takes us back about 400 years in history. It would be nice to have one that took us back 5,000 years in history because that is about the extent of recorded history, about 5,000 years. But we go back here to the very beginning, a little bit before the beginning of the Industrial Revolution, and we notice that the Industrial Revolution began with wood and it ramped up, and we denuded largely the mountains of New England to make charcoal to take to England to make steel, and then we found coal. And the ordinate here is quadrillion BTUs. That was the amount of energy we got. Boy, did we get a lot more energy from coal than we did from wood. It is more dense. It is easier to get and haul large quantities of it. But notice what happened when we came to gas and oil. There was essentially an explosion in the amount of energy that we could produce. Notice up there at the top, Mr. Speaker, the recession of the 1970s produced by the Arab oil embargo.

There is a stunning statistic. Up until the Carter years, every decade, the world used as much oil as had been used in all of previous history. Now what that means is that when we had used half of all the oil that was there, we would have only one decade of oil remaining. Now, that slowed down after the Arab oil embargo. We got a lot more efficient. The refrigerator we have today probably uses a third of the electricity it did then; so we really slowed down in our use of oil, or this chart curve would have kept on going up.

There is another curve we might put on here, Mr. Speaker, and that is the world's population. And it might not be too surprising that the increase in population pretty much paralleled the increase in available energy. We started out with 1 billion, more or less, before the Industrial Revolution. Now we have almost 7 billion people.

Mr. Speaker, in terms of 5,000 years of recorded history, the age of oil will be but a brief blip. We have been in the age of oil about 150 years. It was about 150 years ago we first found oil in any quantities and started to use it. In another 150 years we will essentially be through the age of oil. What will our world look like when we have exhausted the fossil fuels? And they will be exhausted.

One of the writers in writing about this says that our great grandchildren, in looking at history and what we did with these fossil fuels, will say how could the monsters have done that. How could they have found this incredibly valuable resource buried in the ground, these riches buried in the ground, and used them wantonly with no regard that they might be finite, that they would one day run out. Matt Savinar, who wrote one of the articles that people will find when they do the Google search for peak oil, Matt Savinar begins his article by saying: ''Dear reader, civilization as we know it is coming to an end soon.'' I pulled it off the Web and gave it to my wife, and she read that first paragraph and said, The guy is crazy; I am not going to read any more.

I said, Please read on and reserve judgment.

She read on and was genuinely frightened when she had finished his article. Matt Savinar may be audacious, and I think that the future may not be so bleak as he presents it, but I will tell the Members, Mr. Speaker, if we do not do something meaningful in terms of trying to mitigate the damage, it could be, it could be as bad as Matt Savinar presents it. He may be audacious, but he is not an idiot; and I would suggest that Members read his article. It is very useful.

The next chart shows something really interesting that we have been talking about this evening. This is where we are now. We have been running up this side of Hubbert's peak. This, by the way, is worldwide. The question is now, When will the world do what the United States did in 1970? When will the world reach peak oil? I had a course in statistics when I was working for my doctorate in school maybe 55 or 60 years ago, and what they have done here, we have a probability of 95 percent. That is most likely what we will find. And then we have a 50 percent probability that it could be higher or it could be lower and then a 5 percent probability or it could be higher or it could be lower, and somehow they mysteriously take this as the expected value. It could be low just as well as high. That is not the expected value. The value that the statistician would tell us to expect is a 95 percent value. And, by the way, that is pretty much what the experts tell us.

A couple of Congresses ago, I was Chair of the Energy Subcommittee on the Science Committee, and I wanted to determine the dimensions of this problem. So we had a hearing and invited in the world's experts on oil reserves, and there was pretty unanimous agreement. I was surprised. It was somewhere like from 970 to 1,040, about 1,000 gigabarrels of oil that remained. Now, we have pumped about the same amount. We have pumped about 1,000 gigabarrels. That is 1,000 billion barrels. That is 1 trillion barrels, and that sounds like a lot.

But if we divide that 1,000 gigabarrels by the 84 million barrels that we use a day, 21 in our country alone, 63 in the rest of the world, 84 total, if we divide that 84 million barrels a day into the 1 trillion barrels that the experts told us are still out there, we come to about 40 years' remaining oil. Remember up until the Carter years, when we used half of it, which is about what we have used, we would have only 10 years remaining; so we have really slowed down, fortunately. We are using it much more efficiently now than we did then.

But they make two assumptions for this chart. One is that it peaks in 2016 and that there is 3,000 gigabarrels. That is not what the experts say. The experts say that there will be a total of about 2,000 gigabarrels, 1,000 already pumped, another 1,000 to be pumped. If that is true, then we would start downhill from this point.

But if we have another 1,000 gigabarrels, notice with this exponential curve how little that pushes peak oil out. Not very far. What is it? About 2017, 2016, something like that is all that it pushes out. Here it is: 2016. And if we now assume that there is more than that, it pushes it out further. But notice what happens. Notice what happens. Notice how quickly we fall.

I made the point before I am not sure we want to fill the gap because the analogy of if you are in a hole, stop digging is if you are climbing a hill and you are going to fall off a cliff on the other side, the lower the hill, the less you will fall. And they make exactly that point here in these predictions.

These are predictions of the Energy Information Agency. These are economists working for the Department of Energy. They are not oil experts. They are economists, and they do what economists do. They predict the future from the past. And they really study the past and know it, and they think that if they know the past well, they can predict the future. But what they do not take into account is that oil is finite and their predictions would be exactly right if market forces controlled and if oil were limitless, but oil is clearly not limitless.

In the last chart that I want to spend a few minutes on, where do we go from here? From where will we get our liquid fuels? From where will we get our energy as we run down the other side of Hubbert's peak? We have here some finite resources. By ''finite'' we mean they are not forever. Some of them are pretty big if we can get the energy out. Tar sands and oil shales. Some will tell us do not worry about the future of energy because there is 1½ trillion barrels of oil in the oil sands of Canada alone. That is true. But, Mr. Speaker, there is also an incredible amount of energy in the tides.

I pick up two 5-gallon buckets of water, and they are pretty heavy; and then I note that the Moon lifts the whole ocean about 2 feet. That is an incredible amount of energy. But because there is that incredible amount of energy out there does not mean that I can harness it and use it effectively. The same thing is pretty much true of these tar sands. Yes, there is potentially a lot of energy there, but how effectively, efficiently can we get it out?

The Canadians are now producing oil maybe even less than $30 a barrel. They are selling for $60. That is a good deal, and they are producing a lot of it. But when we look at the energy that it takes to get it out, there are better techniques than the one they are using; but the technique they are using, they use more energy from natural gas than they get out of oil so that the energy profit ratio is less than nothing. The oil is sought on the market and brings a good price. The gas is up there and they do not need it and it is hard to ship. So from a dollar-and-cents perspective, it may make sense to use that gas, even more energy and gas to produce the oil than they get out of the oil. But ultimately, of course, as we move to a more energy-efficient world, we will not be able to do that.

I was out at a conference in Denver, Colorado, just this past weekend; and the Shell Oil scientist that was doing some of the tests in the oil shales of Colorado emphasized that his work was just experimental, that he could not extrapolate from what he had now done to the future. And what they have done is kind of interesting, Mr. Speaker.

They have taken a small patch of Colorado desert out there, high desert, and they have drilled a lot of holes in a circle and frozen, put pipes down there, and they froze in the ground. What they have done is to make a vessel out of frozen ground because they do not want what they are doing inside that big vessel to contaminate groundwater outside, and then they cook the oil.

I hear from 2 years to 4 years, for some period of time, they cook the oil inside that vessel. They keep putting hot water down there, steam down there, and they cook the oil. By the way, they heat that with natural gas, which is why it takes so much energy. And then they pump on that. When they have heated it up, it will flow so they can pump it out. But this is pretty small. It is hard to scale up from that. And they put in one unit of energy from heat and they get out 3½ units of energy. That looks like a pretty good energy profit ratio, but it does not account for all the energy that goes in there: drilling the holes and refrigeration and the energy it took to make the equipment that they use and refining it when they get it out and so forth.

So we are not yet sure how positive that is going to be. It may be that we will use the energy from four barrels of oil and have one net plus.

By the way, that would not be all that bad because that is about the ratio in producing ethanol. We have to put in about three-fourths as much energy into the ethanol as we get out of it, about 750,000 BTUs of energy to get 1 million units of energy in producing ethanol; and that is for efficient production. Many of our ethanol production facilities now are producing ethanol, Dr. Pimental believes, with a negative energy profit ratio: the more fossil fuel energy goes in to producing it than we get out of it.

Coal: we have about 250 years of coal remaining in our country. That is the current use rate. If we increase the use only 2 percent exponentially, that 250 years shrinks to 85 years. For many uses like our car, we cannot use coal. We are going to have to use gas or a liquid, and we are going to have to take some energy to make that conversion. Now it shrinks to 50 years. So we have got about 50 years of effective coal remaining at only a 2 percent increase. We may need to increase its use much more than 2 percent. It is there. We need to husband it and use it wisely.

Nuclear: we produce 8 percent of our electricity in this country from nuclear. That is 20 percent of our electricity.

□ 2145

That can and maybe should grow. But the kind of plants we use, the light water reactor plants, cannot be expanded indefinitely because there is a limited supply of fissionable uranium in the world. I get wildly divergent estimates, from 30 years to 200 years. That is at current-use rates. As soon as you start exponentially increasing the rate of use, whatever that time is, it shrinks very rapidly.

That means if we really wanted to go big-scale nuclear, we need to go to breeder reactors. With breeder reactors, you borrow a lot of problems, like transporting the fuel for enrichment. You have weapons-grade plutonium produced, and you may in the future be making a choice between buying these problems and shivering in the dark because in an energy-deficient world, that may be the choice that you come to.

Nuclear fusion. Oh, how I hope we get there because then we are home-free. But planning to solve our energy problems in this country of the world with fusion is a bit like you or me planning to solve our personal economic problems by winning the lottery. It would be nice if it happened; it probably will not, and I certainly would not count on it.

And then we come to the truly renewable sources. About half of those, a little more than half comes from nuclear up here as compared to what is down here. Solar, wind, they now represent about a quarter of a percent of our total energy. A bit more than that of electricity, but about a quarter of a percent of our total electricity.

Geothermal, that is tapping into the molten core of the earth. Where we can do that, we ought to do it because that will last a very long time.

I mentioned ocean energy. Lots of energy there. The tides, the waves, thermal gradients in the ocean. There is a lot of potential energy there, but there is an old axiom that says energy to be effective must be concentrated. It is so diffuse in the ocean. We have been trying for a very long time to capture some of that energy, and it is very, very difficult.

And then we come to agricultural resources. A lot of people have high hopes for what we can get from agriculture. We can get energy from agriculture in two different ways: One by producing fuels like ethanol and methanol by fermenting the product; and the other is by burning the product.

There are limits to both of these. We now are barely able to feed the world. Tonight a fair number of people will go to bed hungry. We could free up more of this energy if we would be content to eat the soybeans and corn rather than the pig and the cow and the chicken eating the corn and the soybeans.

To take biomass from the soil, that is what makes topsoil different from subsoil is organic material, biomass. I am sure we can get some energy from that. But we have to be careful how much to tend to get from that.

Waste energy, instead of putting it in the landfill, burn it. There is a really good plant here in Montgomery County very near. I would be proud to have that next to my church. I cannot even see that it is burning trash because trash comes in inside a big container. It is inside before it is emptied, and it looks like a nice brick office building.

The last thing is hydrogen from renewables. Hydrogen is not an energy source. You cannot mine it or suck it out of the air. The only way you get hydrogen is to use energy from some other source like natural gas. This is where we get most of it or like splitting water with electrolysis. You will always use more energy in getting the hydrogen than you get out of hydrogen, or else you are going to have to repeal the second law of thermodynamics, and that is not going to happen. It is still a good idea because hydrogen burns very cleanly. You get only water. You can burn it in a fuel cell where you have at least twice the efficiency of reciprocating engine, but it is not a solution to our energy problem. Think of it as an energy carrier which is exactly what your battery is.

If you think of this as being a hydrogen battery as opposed to an electron battery that you have in your car, you will get it right as far as hydrogen is concerned.

There is a lot of talk about a hydrogen future. That is not going to happen in the next decade or two or even three. It is going to take a very long time to ramp up, and we will always have to have some bigger energy source from which we make the hydrogen because it will always be made with an energy deficit because we are not going to repeal the second law of thermodynamics.

Mr. Speaker, I want to submit for the RECORD this report because it is not available anywhere else for the public to review.

PEAKING OF WORLD OIL PRODUCTION: IMPACTS, MITIGATION, & RISK MANAGEMENT

(By Robert L. Hirsch, SAIC, Project Leader; Roger Bezdek, MISI; Robert Wendling, MISI)

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EXECUTIVE SUMMARY

The peaking of world oil production presents the U.S. and the world with an unprecedented risk management problem. As peaking is approached, liquid fuel prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented. Viable mitigation options exist on both the supply and demand sides, but to have substantial impact, they must be initiated more than a decade in advance of peaking.

In 2003, the world consumed just under 80 million barrels per day (MM bpd) of oil. U.S. consumption was almost 20 MM bpd, two-thirds of which was in the transportation sector. The U.S. has a fleet of about 210 million automobiles and light trucks (vans, pick-ups, and SUVs). The average age of U.S. automobiles is nine years. Under normal conditions, replacement of only half the automobile fleet will require 10–15 years. The average age of light trucks is seven years.

Under normal conditions, replacement of one-half of the stock of light trucks will require 9–14 years. While significant improvements in fuel efficiency are possible in automobiles and light trucks, any affordable approach to upgrading will be inherently time-consuming, requiring more than a decade to achieve significant overall fuel efficiency improvement.

Besides further oil exploration, there are commercial options for increasing world oil supply and for the production of substitute liquid fuels: (1) Improved Oil Recovery (IOR) can marginally increase production from existing reservoirs; one of the largest of the IOR opportunities is Enhanced Oil Recovery (EaR), which can help moderate oil production declines from reservoirs that are past their peak production: (2) Heavy oil/oil sands represents a large resource of lower grade oils, now primarily produced in Canada and Venezuela; those resources are capable of significant production increases;. (3) Coal liquefaction is a well established technique for producing clean substitute fuels from the world's abundant coal reserves; and finally, (4) Clean substitute fuels can be produced from remotely located natural gas, but exploitation must compete with the world's growing demand for liquefied natural gas. However, world-scale contributions from these options will require 10–20 years of accelerated effort.

Dealing with world oil production peaking will be extremely complex, involve literally trillions of dollars and require many years of intense effort. To explore these complexities, three alternative mitigation scenarios were analyzed: Scenario I assumed that action is not initiated until peaking occurs. Scenario II assumed that action is initiated 10 years before peaking. Scenario III assumed action is initiated 20 years before peaking.

For this analysis estimates of the possible contributions of each mitigation option were developed, based on an assumed crash program rate of implementation.

Our approach was simplified in order to provide transparency and promote understanding. Our estimates are approximate, but the mitigation envelope that results is believed to be directionally indicative of the realities of such an enormous undertaking. The inescapable conclusion is that more than a decade will be required for the collective contributions to produce results that significantly impact world supply and demand for liquid fuels.

Important observations and conclusions from this study are as follows:

1. When world oil peaking will occur is not known with certainty. A fundamental problem in predicting oil peaking is the poor quality of and possible political biases in world oil reserves data. Some experts believe peaking may occur soon. This study indicates that ''soon'' is within 20 years.

2. The problems associated with world oil production peaking will not be temporary, and past ''energy crisis'' experience will provide relatively little guidance. The challenge of oil peaking deserves immediate, serious attention, if risks are to be fully understood and mitigation begun on a timely basis.

3. Oil peaking will create a severe liquid fuels problem for the transportation sector, not an ''energy crisis'' in the usual sense that term has been used.

4. Peaking will result in dramatically higher oil prices, which will cause protracted economic hardship in the United States and the world. However, the problems are not insoluble. Timely, aggressive mitigation initiatives addressing both the supply and the demand sides of the issue will be required.

5. In the developed nations, the problems will be especially serious. In the developing nations peaking problems have the potential to be much worse.

6. Mitigation will require a minimum of a decade of intense, expensive effort, because the scale of liquid fuels mitigation is inherently extremely large.

7. While greater end-use efficiency is essential, increased efficiency alone will be neither sufficient nor timely enough to solve the problem. Production of large amounts of substitute liquid fuels will be required. A number of commercial or near-commercial substitute fuel production technologies are currently available for deployment, so the production of vast amounts of substitute liquid fuels is feasible with existing technology.

8. Intervention by governments will be required, because the economic and social implications of oil peaking would otherwise be chaotic. The experiences of the 1970s and 1980s offer important guides as to government actions that are desirable and those that are undesirable, but the process will not be easy.

Mitigating the peaking of world conventional oil production presents a classic risk management problem: Mitigation initiated earlier than required may turn out to be premature, if peaking is long delayed. If peaking is imminent, failure to initiate timely mitigation could be extremely damaging.

Prudent risk management requires the planning and implementation of mitigation well before peaking. Early mitigation will almost certainly be less expensive than delayed mitigation. A unique aspect of the world oil peaking problem is that its timing is uncertain, because of inadequate and potentially biased reserves data from elsewhere around the world. In addition, the onset of peaking may be obscured by the volatile nature of oil prices. Since the potential economic impact of peaking is immense and the uncertainties relating to all facets of the problem are large, detailed quantitative studies to address the uncertainties and to explore mitigation strategies are a critical need.

The purpose of this analysis was to identify the critical issues surrounding the occurrence and mitigation of world oil production peaking. We simplified many of the complexities in an effort to provide a transparent analysis. Nevertheless, our study is neither simple nor brief. We recognize that when oil prices escalate dramatically, there will be demand and economic impacts that will alter our simplified assumptions. Consideration of those feedbacks will be a daunting task but one that should be undertaken.

Our study required that we make a number of assumptions and estimates. We well recognize that in-depth analyses may yield different numbers. Nevertheless, this analysis clearly demonstrates that the key to mitigation of world oil production peaking will be the construction of a large number of substitute fuel production facilities, coupled to significant increases in transportation fuel efficiency. The time required to mitigate world oil production peaking is measured on a decade time-scale. Related production facility size is large and capital intensive. How and when governments decide to address these challenges is yet to be determined.

Our focus on existing commercial and near-commercial mitigation technologies illustrates that a number of technologies are currently ready for immediate and extensive implementation. Our analysis was not meant to be limiting. We believe that future research will provide additional mitigation options, some possibly superior to those we considered. Indeed, it would be appropriate to greatly accelerate public and private oil peaking mitigation research. However, the reader must recognize that doing the research required to bring new technologies to commercial readiness takes time under the best of circumstances. Thereafter, more than a decade of intense implementation will be required for world scale impact, because of the inherently large scale of world oil consumption.

In summary, the problem of the peaking of world conventional oil production is unlike any yet faced by modern industrial society. The challenges and uncertainties need to be much better understood. Technologies exist to mitigate the problem. Timely, aggressive risk management will be essential.

I. INTRODUCTION

Oil is the lifeblood of modern civilization. It fuels the vast majority of the world's mechanized transportation equipment—Automobiles, trucks, airplanes, trains, ships, farm equipment, the military, etc. Oil is also the primary feedstock for many of the chemicals that are essential to modern life. This study deals with the upcoming physical shortage of world conventional oil—an event that has the potential to inflict disruptions and hardships on the economies of every country.

The earth's endowment of oil is finite and demand for oil continues to increase with time. Accordingly, geologists know that at some future date, conventional oil supply will no longer be capable of satisfying world demand. At that point world conventional oil production will have peaked and begin to decline.

A number of experts project that world production of conventional oil could occur in the relatively near future, as summarized in Table I–1. Such projections are fraught with uncertainties because of poor data, political and institutional self-interest, and other complicating factors. The bottom line is that no one knows with certainty when world oil production will reach a peak, but geologists have no doubt that it will happen.

TABLE I–1.—PREDICTIONS OF WORLD OIL PRODUCTION PEAKING

Projected date	Source of projection
2006–2007	Bakhitari
2007–2009	Simmons
After 2007	Skrebowski
Before 2009	Deffeyes
Before 2010	Goodstein
Around 2010	Campbell
After 2010	World Energy Council
2010–2020	Laherrere
2016	EIA (Nominal)
After 2020	CERA
2025 or later	Shell
No visible Peak	Lynch

Our aim in this study is to summarize the difficulties of oil production forecasting; identify the fundamentals that show why world oil production peaking is such a unique challenge; show why mitigation will take a decade or more of intense effort; examine the potential economic effects of oil peaking; describe what might be accomplished under three example mitigation scenarios; and stimulate serious discussion of the problem, suggest more definitive studies, and engender interest in timely action to mitigate its impacts.

In Chapter II we describe the basics of oil production, the meaning of world conventional oil production peaking, the challenge of making accurate forecasts, and the effects that higher prices and advanced technology might have on oil production.

Because of the massive scale of oil use around the world, mitigation of oil shortages will be difficult, time consuming, and expensive. In Chapter III we describe the extensive and critical uses of U.S. oil and the long economic and mechanical lifetimes of existing liquid fuel consuming vehicles and equipment.

While it is impossible to predict the impact of world oil production peaking with any certainty, much can be learned from past oil disruptions, particularly the 1973 oil embargo and the 1979 Iranian oil shortage, as discussed in Chapter IV. In Chapter V we describe the developing shortages of U.S. natural gas, shortages that are occurring in spite of assurances of abundant supply provided just a few years ago. The parallels to world oil supply are disconcerting.

In Chapter VI we describe available mitigation options and related implementation issues. We limit our considerations to technologies that are near ready or currently commercially available for immediate deployment. Clearly, accelerated research and development holds promise for other options. However, the challenge related to extensive near-term oil shortages will require deployment of currently viable technologies, which is our focus.

Oil is a commodity found in over 90 countries, consumed in all countries, and traded on world markets. To illustrate and bracket the range of mitigation options, we developed three illustrative scenarios. Two assume action well in advance of the onset of world oil peaking—in one case, 20 years before peaking and in another case, 10 years in advance. Our third scenario assumes that no action is taken prior to the onset of peaking. Our findings illustrate the magnitude of the problem and the importance of prudent risk management.

Finally, we touch on possible market signals that might foretell the onset of peaking and possible wildcards that might change the timing of world conventional oil production peaking. In conclusion, we frame the challenge of an unknown date for peaking, its potentially extensive economic impacts, and available mitigation options as a matter of risk management and prudent response. The reader is asked to contemplate three major questions: What are the risks of heavy reliance on optimistic world oil production peaking projections? Must we wait for the onset of oil shortages before actions are taken? What can be done to ensure that prudent mitigation is initiated on a timely basis?

II. Peaking of World Oil Production

A. BACKGROUND

Oil was formed by geological processes millions of years ago and is typically found in underground reservoirs of dramatically different sizes, at varying depths, and with widely varying characteristics. The largest oil reservoirs are called ''Super Giants,'' many of which were discovered in the Middle East. Because of their size and other characteristics, Super Giant reservoirs are generally the easiest to find, the most economic to develop, and the longest lived. The last Super Giant oil reservoirs discovered worldwide were found in 1967 and 1968. Since then, smaller reservoirs of varying sizes have been discovered in what are called ''oil prone'' locations worldwide—oil is not found everywhere.

Geologists understand that oil is a finite resource in the earth's crust, and at some future date, world oil production will reach a maximum—a peak—after which production will decline. This logic follows from the well-established fact that the output of individual oil reservoirs rises after discovery, reaches a peak and declines thereafter. Oil reservoirs have lifetimes typically measured in decades, and peak production often occurs roughly a decade or so after discovery. It is important to recognize that oil production peaking is not ''running out.'' Peaking is a reservoir's maximum oil production rate, which typically occurs after roughly half of the recoverable oil in a reservoir has been produced. In many ways, what is likely to happen on a world scale is similar to what happens to individual reservoirs, because world production is the sum total of production from many different reservoirs.

Because oil is usually found thousands of feet below the surface and because oil reservoirs normally do not have an obvious surface signature, oil is very difficult to find. Advancing technology has greatly improved the discovery process and reduced exploration failures. Nevertheless, oil exploration is still inexact and expensive.

Once oil has been discovered via an exploratory well, full-scale production requires many more wells across the reservoir to provide multiple paths that facilitate the flow of oil to the surface. This multitude of wells also helps to define the total recoverable oil in a reservoir—its so-called ''reserves.''

B. OIL RESERVES

The concept of reserves is generally not well understood. ''Reserves'' is an estimate of the amount of oil in a reservoir that can be extracted at an assumed cost. Thus, a higher oil price outlook often means that more oil can be produced, but geology places an upper limit on price-dependent reserves growth; in well managed oil fields, it is often 10–20 percent more than what is available at lower prices.

Reserves estimates are revised periodically as a reservoir is developed and new information provides a basis for refinement. Reserves estimation is a matter of gauging how much extractable oil resides in complex rock formations that exist typically one to three miles below the surface of the ground, using inherently limited information. Reserves estimation is a bit like a blindfolded person trying to judge what the whole elephant looks like from touching it in just a few places. It is not like counting cars in a parking lot, where all the cars are in full view.

Specialists who estimate reserves use an array of methodologies and a great deal of judgment. Thus, different estimators might calculate different reserves from the same data. Sometimes politics or self-interest influences reserves estimates, e.g., an oil reservoir owner may want a higher estimate in order to attract outside investment or to influence other producers.

Reserves and production should not be confused. Reserves estimates are but one factor in estimating future oil production from a given reservoir. Other factors include production history, understanding of local geology, available technology, oil prices, etc. An oil field can have large estimated reserves, but if the field is past its maximum production, the remaining reserves will be produced at a declining rate. This concept is important because satisfying increasing oil demand not only requires continuing to produce older oil reservoirs with their declining production, it also requires finding new ones, capable of producing sufficient quantities of oil to both compensate for shrinking production from older fields and to provide the increases demanded by the market.

C. PRODUCTION PEAKING

World oil demand is expected to grow 50 percent by 2025. To meet that demand, ever-larger volumes of oil will have to be produced. Since oil production from individual reservoirs grows to a peak and then declines, new reservoirs must be continually discovered and brought into production to compensate for the depletion of older reservoirs. If large quantities of new oil are not discovered and brought into production somewhere in the world, then world oil production will no longer satisfy demand. That point is called the peaking of world conventional oil production.

When world oil production peaks, there will still be large reserves remaining. Peaking means that the rate of world oil production cannot increase: it also means that production will thereafter decrease with time.

The peaking of world oil production has been a matter of speculation from the beginning of the modern oil era in the mid 1800s. In the early days, little was known about petroleum geology, so predictions of peaking were no more than guesses without basis. Over time, geological understanding improved dramatically and guessing gave way to more informed projections, although the knowledge base involves numerous uncertainties even today.

Past predictions typically fixed peaking in the succeeding 10–20 year period. Most such predictions were wrong, which does not negate that peaking will someday occur. Obviously, we cannot know if recent forecasts are wrong until predicted dates of peaking pass without incident.

With a history of failed forecasts, why revisit the issue now? The reasons are as follows:

1. Extensive drilling for oil and gas has provided a massive worldwide database; current geological knowledge is much more extensive than in years past, i.e., we have the knowledge to make much better estimates than previously.

2. Seismic and other exploration technologies have advanced dramatically in recent decades, greatly improving our ability to discover new oil reservoirs. Nevertheless, the oil reserves discovered per exploratory well began dropping worldwide over a decade ago. We are finding less and less oil in spite of vigorous efforts, suggesting that nature may not have much more to provide.

3. Many credible analysts have recently become much more pessimistic about the possibility of finding the huge new reserves needed to meet growing world demand.

4. Even the most optimistic forecasts suggest that world oil peaking will occur in less than 25 years.

5. The peaking of world oil production could create enormous economic disruption, as only glimpsed during the 1973 oil embargo and the 1979 Iranian oil cut-off.

Accordingly, there are compelling reasons for in-depth, unbiased reconsideration.

D. TYPES OF OIL

Oil is classified as ''Conventional'' and ''Unconventional.'' Conventional oil is typically the highest quality, lightest oil, which flows from underground reservoirs with comparative ease. Unconventional oils are heavy, often tar-like. They are not readily recovered since production typically requires a great deal of capital investment and supplemental energy in various forms. For that reason, most current world oil production is conventional oil. (Unconventional oil production will be discussed in Chapter VI).

E. OIL RESOURCES

Consider the world resource of conventional oil. In the past, higher prices led to increased estimates of conventional oil reserves worldwide. However, this price-reserves relationship has its limits, because oil is found in discrete packages (reservoirs) as opposed to the varying concentrations characteristic of many minerals. Thus, at some price, world reserves of recoverable conventional oil will reach a maximum because of geological fundamentals. Beyond that point, insufficient additional conventional oil will be recoverable at any realistic price. This is a geological fact that is often misunderstood by people accustomed to dealing with hard minerals, whose geology is fundamentally different. This misunderstanding often clouds rational discussion of oil peaking.

Future world recoverable reserves are the sum of the oil remaining in existing reservoirs plus the reserves to be added by future oil discoveries. Future oil production will be the sum of production from older reservoirs in decline, newer reservoirs from which production is increasing, and yet-to-be discovered reservoirs.

Because oil prices have been relatively high for the past decade, oil companies have conducted extensive exploration over that period, but their results have been disappointing. If recent trends hold, there is little reason to expect that exploration success will dramatically improve in the future. This situation is evident in Figure 11–1, which shows the difference between annual world oil reserves additions minus annual consumption. The image is one of a world moving from a long period in which reserves additions were much greater than consumption, to an era in which annual additions are falling increasingly short of annual consumption. This is but one of a number of trends that suggest the world is fast approaching the inevitable peaking of conventional world oil production.

F. IMPACT OF HIGHER PRICES AND NEW TECHNOLOGY

Conventional oil has been the mainstay of modern civilization for more than a century, because it is most easily brought to the surface from deep underground reservoirs, and it is the most easily refined into finished fuels. The U.S. was endowed with huge reserves of petroleum, which underpinned U.S. economic growth in the early and mid twentieth century. However, U.S. oil resources, like those in the world, are finite, and growing U.S. demand resulted in the peaking of U.S. oil production in the Lower 48 states in the early 1970s. With relatively minor exceptions, U.S. Lower 48 oil production has been in continuing decline ever since. Because U.S. demand for petroleum products continued to increase, the U.S. became an oil importer. Today, the U.S. depends on foreign sources for almost 60 percent of its needs, and future U.S. imports are projected to rise to 70 percent of demand by 2025.

Over the past 50 years, exploration for and production of petroleum has been an increasingly more technological enterprise, benefiting from more sophisticated engineering capabilities, advanced geological understanding, improved instrumentation, greatly expanded computing power, more durable materials, etc. Today's technology allows oil reservoirs to be more readily discovered and better understood sooner than heretofore. Accordingly, reservoirs can be produced more rapidly, which provides significant economic advantages to the operators but also hastens peaking and depletion.

Some economists expect higher oil prices and improved technologies to continue to provide ever-increasing oil production for the foreseeable future. Most geologists disagree because they do not believe that there are many huge new oil reservoirs left to be found. Accordingly, geologists and other observers believe that supply will eventually fall short of growing world demand—and result in the peaking of world conventional oil production.

To gain some insight into the effects of higher oil prices and improved technology on oil production, let us briefly examine related impacts in the U.S. Lower 48 states. This region is a useful surrogate for the world, because it was one of the world's richest, most geologically varied, and most productive up until 1970, when production peaked and started into decline. While the U.S. is the best available surrogate, it should be remembered that the decline rate in US production was in part impacted by the availability of large volumes of relatively low cost oil from the Middle East.

The trend lines show a relatively symmetric, triangular pattern. For reference, four notable petroleum market events are noted in the figure: the 1973 OPEC oil embargo, the 1979 Iranian oil crisis, the 1986 oil price collapse, and the 1991 Iraq war.

In constant dollars, oil prices increased by roughly a factor of three in 1973–74 and another factor of two in 1979–80. The modest production up-ticks in the mid 1980s and early 1990s are likely responses to the 1973 and 1979 oil price spikes, both of which spurred a major increase in U.S exploration and production investments. The delays in production response are inherent to the implementation of large-scale oil field investments. The fact that the production up-ticks were moderate was due to the absence of attractive exploration and production opportunities, because of geological realities. Beyond oil price increases, the 1980s and 1990s were a golden age of oil field technology development, including practical 3–D seismic, economic horizontal drilling, and dramatically improved geological understanding. Nevertheless, Lower 48 production still trended downward, showing no pronounced response to either price or technology. In light of this experience, there is good reason to expect that an analogous situation will exist worldwide after world oil production peaks: Higher prices and improved technology are unlikely to yield dramatically higher conventional oil production.

G. PROJECTIONS OF THE PEAKING OF WORLD OIL PRODUCTION

Projections of future world oil production will be the sum total of (1) output from all of the world's then existing producing oil reservoirs, which will be in various stages of development, and (2) all the yet-to-be discovered reservoirs in their various states of development. This is an extremely complex summation problem, because of the variability and possible biases in publicly available data. In practice, estimators use various approximations to predict future world oil production. The remarkable complexity of the problem can easily lead to incorrect conclusions, either positive or negative.

Various individuals and groups have used available information and geological estimates to develop projections for when world oil production might peak. A sampling of recent projections is shown in Table II–1.

TABLE II–1.—PROJECTIONS OF THE PEAKING OF WORLD OIL PRODUCTION

Projected date	Source of projection	Background and reference
2006–2007	Bakhitari, A.M.S.	Iranian Oil Executive
2007–2009	Simmons, M.R.	Investment banker
After 2007	Skrebowski, C.	Petroleum journal Editor
Before 2009	Deffeyes, K.S.	Oil company geologist (ret.)
Before 2010	Goodstein, D.	Vice Provost, Cal Tech
Around 2010	Campbell, C.J.	Oil company geologist (ret.)
After 2010	World Energy Council	World Non-Government Org.
2010–2020	Laherrere, J.	Oil company geologist (ret.)
2016	EIA nominal case	DOE analysis/information
After 2020	CERA	Energy consultants
2025 or later	Shell	Major oil company
No visible peak	Lynch, M.C.	Energy economist

III. WHY THE TRANSITION WILL BE SO TIME CONSUMING

A. INTRODUCTION

Use of petroleum is pervasive throughout the U.S. economy. It is directly linked to all market sectors because all depend on oil-consuming capital stock. Oil price shocks and supply constraints can often be mitigated by temporary decreases in consumption; however, long term price increases resulting from oil peaking will cause more serious impacts. Here we examine historical oil usage patterns by market sector, provide a summary of current consumption patterns, identify the most important markets, examine the relationship between oil and capital stock, and provide estimates of the time and costs required to transition to more energy efficient technologies that can play a role in mitigating the adverse effects of world oil peaking.

B. HISTORICAL U.S. OIL CONSUMPTION PATTERNS

After the two oil price shocks and supply disruptions in 1973–74 and 1979, oil consumption in the U.S. decreased 13 percent, declining from nearly 35 quads in 1973 to 30 quads in 1983. However, overall consumption continued to grow after the 1983 low and has continuously increased over the last 20 years, reaching over 39 quads in 2003, as shown in Figure 111–1. Of particular note are changes in three U.S. market sectors: (1) Oil consumption in the residential sector declined from eight percent of total oil consumption in 1973 to four percent in 2003, a decrease of 50 percent; (2) Oil consumption in the commercial sector declined from five percent to two percent, decreasing 58 percent; and (3) Consumption in the electric power sector fell from 10 percent in 1973 to three percent in 2003, decreasing 70 percent. These three market sectors currently account for 1.3 quads of oil consumption annually, representing nine percent of U.S. oil demand in 2003.

Oil consumption in other market sectors did not decrease. A 140 percent growth in GDP over the 1973–2003 period made it difficult to decrease oil consumption in the industrial and transportation sectors. In particular, personal transportation grew significantly over the past three decades, and total vehicle miles traveled for cars and light trucks more than doubled over the period. From 1973 to 2003, consumption of oil in the industrial sector stayed relatively flat at just over nine quads, and the industrial sector's share of total U.S. consumption remained between 24 and 26 percent. In sharp contrast to all other sectors, U.S. oil consumption for transportation purposes has increased steadily every year, rising from just over 17 quads in 1973 to 26 quads in 2003. By 2003, the transportation sector accounted for two-thirds of the oil consumed in the U.S.

C. PETROLEUM IN THE CURRENT U.S. ECONOMY

The 39 quad consumption of oil in the U.S. in 2003 is equivalent to 19.7 million barrels of oil per day (MM bpd), including almost 13.1 MM bpd consumed by the transportation sector and 4.9 MM bpd by the industrial sector, as shown in Table III–1. This table also shows the petroleum fuel types consumed by each sector. Motor gasoline consumption accounted for 45 percent of U.S. daily petroleum consumption, nearly 9 MM bpd, almost all of which was used in autos and light trucks. Distillate fuel oil was the second-most consumed oil product at almost 3.8 MM bpd (19 percent of consumption), and most was used as diesel fuel for medium and heavy trucks. Finally, the third most consumed oil product was liquefied petroleum gases, at 2.2 MM bpd equivalent (11 percent of total consumption), most of which was used in the industrial sector as feedstock by the chemicals industry. Only two other consuming areas exceeded the 1 MM bpd level: kerosene and jet fuel in the transportation sector, primarily for airplanes, and ''other petroleum'' by the industrial sector, primarily petroleum feedstocks used to produce non-fuel products in the petroleum and chemical industries.

TABLE III–1.—DETAILED CONSUMPTION OF PETROLEUM IN THE U.S. BY FUEL TYPE AND SECTOR—2003

[Thousand of barrels per day]

	Residential	Commercial	Industrial	Transportation	Electric Power	Total
Motor Gasoline	....	20	159	8,665	....	8,844
Distillate Fuel Oil	421	236	603	2,455	51	3,766
LPG	429	76	1,648	10	....	2,163
Kerosene/Jet Fuel	27	9	7	1,608	....	1,651
Residual	....	30	87	250	291	658
Asphalt & Road Oil	....	....	513	....	....	513
Petroleum Coke	....	....	398	....	61	459
Lubricants	....	....	78	73	....	151
Aviation Gas	....	....	....	18	....	18
Other Petroleum	....	....	1,435	....	....	1,435
Total	877	371	4,928	13,079	403	19,658

D. CAPITAL STOCK CHARACTERISTICS IN THE LARGEST CONSUMING SECTORS

Energy efficiency improvements and technological changes are typically incorporated into products and services slowly, and their rate of market penetration is based on customer preferences and costs. In the 1974–1983 period, oil prices ratcheted up to newer, higher levels, which led to significant energy efficiency improvements, energy fuel switching, and other more general technological changes. Some changes came about due to legislative mandates (corporate average fuel economy standards, CAFE) or subsidies (solar energy and energy efficiency tax credits), but many were the result of economic decisions to reduce long-term costs. Under a normal course of replacement based on historical trends, oil-consuming capital stock has been replaced in the U.S. over a period of 15 to 50 years and has cost consumers and businesses trillions of dollars, as discussed below.

Automobiles represent the largest single oil-consuming capital stock in the U.S. 130 million autos consume 4.9 MM bpd, or 25 percent of total consumption, as shown in Table III–2. Autos remain in the U.S. transportation fleet, or rolling stock, for a long time. While the financial-based current-cost, average age of autos is only 3.4 years, the average age of the stock is currently nine years.

Recent studies show that one half of the 1990-model year cars will remain on the road 17 years later in 2007. At normal replacement rates, consumers will spend an estimated $1.3 trillion (constant 2003 dollars) over the next 10–15 years just to replace one-half the stock of automobiles.

TABLE III–2.—U.S. CAPITAL STOCK PROFILES

	Autos	Light Trucks	Heavy Trucks	Air Carriers
Oil consumption (MM bpd)	4.9	3.6	3.0	1.1
Share of the U.S. total	25%	18%	16%	6%
Current cost of net capital stock (billion $)	$571 B	$435 B	$686 B	$110 B
Fleet size	130 MM	80 MM	7 MM	8,500
Number of annual purchases	8.5 MM	8.5 MM	500,000	400
Average age of stock (years)	9	7	9	13
Median lifetime (years)	17	16	28	22

A similar situation exists with light trucks (vans, pick-ups, and SUVs), which consume 3.6 MM bpd of oil, accounting for 18 percent of total oil consumption. Light trucks are depreciated on a faster schedule, and their financial-based current-cost average age is 2.9 years. However, the average physical age of the rolling stock is seven years, and the median lifetime of light trucks is 16 years. At current replacement rates, one-half of the 80 million light trucks will be replaced in the next 9–14 years at a cost of $1 trillion.

Seven million heavy trucks (including buses, highway trucks, and off-highway trucks) represent the third largest consumer of oil at 3.0 MM bpd, 16 percent of total consumption. The current-cost average age of heavy trucks is 5.0 years, but the median lifetime of this equipment is 28 years. The disparity in the average age and the median lifetime estimates indicate that a significant number of vehicles are 40–60 years old. At normal replacement levels, one-half of the heavy truck stock will be replaced by businesses in the next 15–20 years at a cost of $1.5 trillion.

The fourth-largest consumer of oil is the airlines, which consume the equivalent of 1.1 MM bpd, representing six percent of U.S. consumption. The 8,500 aircraft have a current-cost average age of 9.1 years, and a median lifetime of 22 years. Airline deregulation and the events of September 11, 2001, have had significant effects on the industry, its ownership, and recent business decisions. At recent rates, airlines will replace one-half of their stock over the next 15–20 years at a cost of $250 billion.

These four capital stock categories cover most transportation modes and represent 65 percent of the consumption of oil in the U.S. The three largest categories of autos, light trucks, and heavy trucks all utilize the internal combustion engine, whether gasoline- or diesel-burning. Clearly, advancements in energy efficiency and replacement in this capital stock (for instance, electric-hybrid engines) would help mitigate the economic impacts of rising oil prices caused by world oil peaking. However, as described, the normal replacement rates of this equipment will require 10–20 years and cost trillions of dollars. We cannot conceive of any affordable government-sponsored ''crash proqram'' to accelerate normal replacement schedules so as to incorporate higher energy efficiency technologies into the privately-owned transportation sector; significant improvements in energy efficiency will thus be inherently time-consuming (of the order of a decade or more).

When oil prices increase associated with oil peaking, consumers and businesses will attempt to reduce their exposure by substitution or by decreases in consumption. In the short run, there may be interest in the substitution of natural gas for oil in some applications, but the current outlook for natural gas availability and price is cloudy for a decade or more. An increase in demand for electricity in rail transportation would increase the need for more electric power plants. In the short run, much of the burden of adjustment will likely be borne by decreases in consumption from discretionary decisions, since 67 percent of personal automobile travel and nearly 50 percent of airplane travel are discretionary.

E. CONSUMPTION OUTSIDE THE U.S.

Oil consumption patterns differ in other countries. While two-thirds of U.S. oil use is in the transportation sector, worldwide that share is estimated about 55 percent. However, that difference is narrowing as world economic development is expanding transportation demands at an even faster pace. A portion of nontransportation oil consumption is switchable. As stated by EIA, ''Oil's importance in other end-use sectors is likely to decline where other fuels are competitive, such as natural gas, coal, and nuclear, in the electric sector, but currently there are no alternative energy sources that compete economically with oil in the transportation sector.'' Because sector-by-sector oil consumption data for many counties is unavailable, a detailed analysis of world consumption was beyond the scope of this report. Nevertheless, it is clear that transportation is the primary market for oil worldwide.

F. TRANSITION CONCLUSIONS

Any transition of liquid fueled, end-use equipment following oil peaking will be time consuming. The depreciated value of existing U.S. transportation capital stock is nearly $2 trillion and would normally require 25–30 years to replace. At that rate, significantly more energy efficient equipment will only be slowly phased into the marketplace as new capital stock gradually replaces existing stock. Oil peaking will likely accelerate replacement rates, but the transition will still require decades and cost trillions of dollars.

IV. LESSONS AND IMPLICATIONS FROM PREVIOUS OIL SUPPLY DISRUPTIONS

A. PREVIOUS OIL SUPPLY SHORTFALL AND DISRUPTIONS

There have been over a dozen global oil supply disruptions over the past half-century.

Briefly, disruptions ranged in duration from one to 44 months. Supply shortfalls were 0.3–4.6 MM bpd, and eight resulted in average gross supply shortfalls of at least 2 MM bpd. Percentage supply shortfalls varied from roughly one percent to nearly 14 percent of world production. The most traumatic disruption, 1973–74, was not the most severe, but it nevertheless lead to greatly increased oil prices and significant worldwide economic damage. The second most traumatic disruption, 1979, was also neither the longest nor the most severe.

For purposes of this study, the 1973–74 and 1979 disruptions are taken as the most relevant, because they are believed to offer the best insights into what miqht occur when world oil production peaks.

B. DIFFICULTIES IN DERIVING IMPLICATIONS FROM PAST EXPERIENCE

Over the past 30 years, most economic studies of the impact of oil supply disruptions assumed that the interruptions were temporary and that each situation would shortly return to ''normal'' Thus, the major focus of most studies was determination of the appropriate fiscal and monetary policies required to minimize negative economic impacts and the development of policies to help the economy and labor market adjust until the disruption ended. Few economists considered a situation where the oil supply shortfall may be long-lived (a decade or more).

Since 1970, most large oil price increases were eventually followed by oil price declines, and, since these cycles were expected to be repeated, it was generally felt that ''the problem will take care of itself as long at the government does nothing and does not interfere. The frequent and incorrect predictions of oil shortfalls have been often used to discredit future predictions of a longer-term problem and to discredit the need for appropriate long-term U.S. energy policies.

C. HOW OIL SUPPLY SHORTFALLS AFFECT THE GLOBAL ECONOMY

Oil prices playa key role in the global economy, since the major impact of an oil supply disruption is higher oil prices. Oil price increases transfer income from oil importing to oil exporting countries, and the net impact on world economic growth is negative. For oil importing countries, increased oil prices reduce national income because spending on oil rises, and there is less available to spend on other goods and services. Not surprisingly, the larger the oil price increase and the longer higher prices are sustained, the more severe is the macroeconomic impact.

Higher oil prices result in increased costs for the production of goods and services, as well as inflation, unemployment, reduced demand for products other than oil, and lower capital investment. Tax revenues decline and budget deficits increase, driving up interest rates. These effects will be greater the more abrupt and severe the oil price increase and will be exacerbated by the impact on consumer and business confidence.

Government policies cannot eliminate the adverse impacts of sudden, severe oil disruptions, but they can minimize them. On the other hand, contradictory monetary and fiscal policies to control inflation can exacerbate recessionary income and unemployment effects. (See Appendix II for further discussion of past government actions).

D. THE U.S. EXPERIENCE

Oil price increases have preceded most U.S. recessions since 1969, and virtually every serious oil price shock was followed by a recession. Thus, *while oil price spikes may not be necessary to trigger a recession in the U.S., they have proven to be sufficient over the past 30 years.*

E. THE EXPERIENCE OF OTHER COUNTRIES

1. The developed (OECD) economies

Estimates of the damage caused by past oil price disruptions vary substantially, but without a doubt, the effects were significant. Economic growth decreased in most oil importing countries following the disruptions of 1973–74 and 1979–80, and the impact of the first oil shock was accentuated by inappropriate policy responses. Despite a decline in the ratio of oil consumption to GDP over the past three decades, oil remains vital, and there is considerable empirical evidence regarding the effects of oil price shocks:

The loss suffered by the OECD countries in the 1974/–75 recession amounted to $350 billion (current dollars) / $1.1 trillion 2003 dollars, althouh part of this loss was related to factors other than oil price. The loss resulting from the 1979 oil disruption was about three percent of GDP ($350 billion in current dollars) in 1980 rising to 4.25 percent ($570 billion) in 1981, and accounted for much of the decline in economic growth and the increase in inflation and unemployment in the OECD in 1981–82. The effect of the 1990–91 oil price upsurge was more modest, because price increases were smaller; they did not persist; and oil intensity in OECD countries had declined. Although oil intensity and the share of oil in total imports have declined in recent years, OECD economies remain vulnerable to higher oil prices, because of the ''life blood'' nature of liquid fuel use.

2. Developing countries

Developing countries suffer more than the developed countries from oil price increases because they generally use energy less efficiently and because energy-intensive manufacturing accounts for a larger share of their GDP. On average, developing countries use more than twice as much oil to produce a unit of output as developed countries, and oil intensity is increasing in developing countries as commercial fuels replace traditional fuels and industrialization/urbanization continues.

The vulnerability of developing countries is exacerbated by their limited ability to switch to alternative fuels. In addition, an increase in oil import costs also can destabilize trade balances and increase inflation more in developing countries, where financial institutions and monetary authorities are often relatively unsophisticated. This problem is most pronounced for the poorest developing countries.

F. IMPLICATIONS

1. The world economy

A shortfall of oil supplies caused by world conventional oil production peaking will sharply increase oil prices and oil price volatility. As oil peaking is approached, relatively minor events will likely have more pronounced impacts on oil prices and futures markets.

Oil prices remain a key determinant of global economic performance, and world economic growth over the past 50 years has been negatively impacted in the wake of increased oil prices. The greater the supply shortfall, the higher the price increases; the longer the shortfall, the greater will be the adverse economic affects.

The long-run impact of sustained, significantly increased oil prices associated with oil peaking will be severe. Virtually certain are increases in inflation and unemployment, declines in the output of goods and services, and a degradation of living standards. Without timely mitigation, the long-run impact on the developed economies will almost certainly be extremely damaging, while many developing nationsly be even worse off.

The impact of oil price changes will likely be asymmetric. The negative economic effects of oil price increases are usually not offset by the economic stimulus resulting from a fall in oil prices. The increase in economic growth in oil exporting countries provided by higher oil prices has been less than the loss of economic growth in importing countries, and these effects will likely continue in the future.

2. The United States

For the U.S., each 50 percent sustained increase in the price of oil will lower real U.S. GDP by about 0.5 percent, and a doubling of oil prices would reduce GDP by a full percentage point. Depending on the U.S. economic growth rate at the time, this could be a sufficient negative impact to drive the country into recession. Thus, assuming an oil price in the $25 per barrel range—the 2002–2003 average, an increase of the price of oil to $50 per barrel would cost the economy a reduction in GDP of around $125 billion.

If the shortfall persisted or worsened (as is likely in the case of peaking), the economic impacts would be much greater. Oil supply disruptions over the past three decades have cost the U.S. economy about $4 trillion, so supply shortfalls associated with the approach of peaking could cost the U.S. as much as all of the oil supply disruptions since the early 1970s combined.

The effects of oil shortages on the U.S. are also likely to be asymmetric. Oil supply disruptions and oil price increases reduce economic activity, but oil price declines have a less beneficial impact. Oil shortfalls and price increases will cause larger responses in job destruction than job creation, and many more jobs may be lost in response to oil price increases than will be regained if oil prices were to decrease. These effects will be more pronounced when oil price volatility increases as peaking is approached. The repeated economic and job losses experienced during price spikes will not be replaced as prices decrease. As these cycles continue, the net economic and job losses will increase.

Sectoral shifts will likely be pronounced. Even moderate oil disruptions could cause shifts among sectors and industries of ten percent or more of the labor force. Continuing oil shortages will likely have disruptive inter- industry, and inter-regional effects, and the sectors that are (both directly and indirectly) oil-dependant could be severely impacted.

Monetary policy is more effective in controlling the inflationary effects of a supply disruption than in averting related recessionary effects. Thus, while appropriate monetary policy may be successful in lessening the inflationary impacts of oil price increases, it may do so at the cost of recession and increased unemployment. Monetary policies tend to be used to increase interest rates to control inflation, and it is the high interest rates that cause most of the economic damage. As peaking is approached, devising appropriate offsetting fiscal, monetary, and energy policies will become more difficult. Economically, the decade following peaking may resemble the 1970s, only worse, with dramatic increases in inflation, long-term recession, high unemployment, and declining living standards.

V. LEARNING FROM THE NATURAL GAS EXPERIENCE

A. INTRODUCTION

A dramatic example of the risks of over-reliance on geological resource projections is the experience with North American natural gas. Natural gas supplies roughly 20 percent of U.S. energy demand. It has been plentiful at real prices of roughly $2/Mcf for almost two decades. Over the past 10 years, natural gas has become the fuel of choice for new electric power generation plants and, at present, virtually all new electric power generation plants use natural gas.

Part of the attractiveness of natural gas was resource estimates for the U.S. and Canada that promised growing supply at reasonable prices for the foreseeable future. That optimism turns out to have been misplaced, and the U.S. is now experiencing supply constraints and high natural gas prices. Supply difficulties are almost certain for at least the remainder of the decade. The North American natural gas situation provides some useful lessons relevant to the peaking of conventional world oil production.

B. THE OPTIMISM

As recently as 2001, a number of credible groups were optimistic about the ready availability of natural gas in North America. For example:

In 1999 the National Petroleum Council stated ''U.S. production is projected to increase from 19 trillion cubic feet (Tcf) in 1998 to 25 Tcf in 2010 and could approach 27 Tcf in 2015 . . . Imports from Canada are projected to increase from 3 Tcf in 1998 to almost 4 Tcf in 2010.''

In 2001 Cambridge Energy Research Associates (CERA) stated ''The rebound in North American gas supply has begun and is expected to be maintained at least through 2005. In total, we expect a combination of US lower–48 activity, growth in Canadian supply, and growth in LNG imports to add 8.95 Bcf per day of production by 2005.''

The U.S. Energy Department's Energy Information Administration (EIA) in 1999 projected that U.S. natural gas production would grow continuously from a level of 19.4 Tcf in 1998 to 27.1 Tcf in 2020.

C. TODAY'S PERSPECTIVES

The current natural gas supply outlook has changed dramatically. Among those that believe the situation has changed for the worse are the following:

CERA now finds that ''The North American natural gas market is set for the longest period of sustained high prices in its history, even adjusting for inflation. Disappointing drilling results . . . have caused CERA to revise the outlook for North American supply downward . . . The downward revisions represent additional disappointing supply news, painting a more constrained picture for continental supply. Gas production in the United States (excluding Alaska) now appears to be in permanent decline, and modest gains in Canadian supply will not overcome the US downturn.

Raymond James & Associates finds that ''Natural gas production continues to drop despite a 20 percent increase in U.S. drilling activity since April 2003. ''U.S. natural gas production is heading firmly downwards . . .''

''Lehman now expects full-year U.S. production to decline by 4% following a 6% decline in 2003. . . . Domestic production is forecast to fall to 41.0 billion cubic feet a day by 2008 from 46.8 in 2003 and 52.1 in 1998. After a sharp 12% fall in 2003, Canadian imports are seen dropping.''

The NPC now contends that ''Current higher gas prices are the result of a fundamental shift in the supply and demand balance. North America is moving to a period in its history in which it will no longer be self-reliant in meeting its growing natural gas needs; production from traditional U.S. and Canadian basins has plateaued.''

Canada has been a reliable U.S. source of natural gas imports for decades. However, the Canadian situation has recently changed for the worse. For example: ''Natural gas production in Alberta, the largest exporter to the huge U.S. market, slipped 2 percent last year despite record drilling and may have peaked in 2001, the Canadian province's energy regulator said on Thursday . . . Production peaked at 5.1 trillion cubic feet in 2001. . . . (EUB) forecast flat production in 2004 and an annual decline of 2.5 percent through at least 2013.''

D. U.S. NATURAL GAS PRICE HISTORY

EIA data show that U.S. natural gas prices were relatively stable in constant dollars from 1987 through 1998. However, beginning in 2000, prices began to escalate—they were roughly 50 percent higher in 2000 compared to 1998. Skipping over the recession years of 2001 and 2002, prices in late 2003 and early 2004 further increased roughly 25 percent over 2000.

While it is often inappropriate to extrapolate gas or oil prices into the future based on short term experience, a number of organizations are now projecting increased U.S. natural gas prices for a number of years. For example, CERA now expects natural gas prices to rise steadily through 2007.

E. LNG—DELAYED SALVATION

With North American natural gas production suddenly changed, hopes of meeting future demand have turned to imports of liquefied natural gas (LNG). The U.S. has four operating LNG terminals, and a number of proposals for new terminals have been advanced. Indeed, the Secretary of Energy and the Chairman of the Federal Reserve Board recently called for a massive buildup in LNG imports to meet growing U.S. natural gas demand.

But the construction of new terminals demands state and local approvals. Because of NIMBYism and fear of terrorism at LNG facilities, a number of the proposed terminals have been rejected. There are also objections from Mexico, which has been proposed as a host for LNG terminals to support west coast natural gas demands. In the Boston area there is an ongoing debate as to whether the nation's largest LNG terminal in Everett, Massachusetts, ought to be shut down, because of terrorist concerns. Decommissioning of that terminal would exacerbate an already tight national natural gas supply situation. Public fears about LNG safety were heightened by an explosion at an LNG liquefaction plant in Algeria that killed 27 people in January 2004. Alternatively, some are considering locating LNG terminals offshore with gas pipelined underwater to land; related costs will be higher, but safety would be enhanced.

F. THE U.S. CURRENT NATURAL GAS SITUATION

U.S. natural gas demand is increasing; North American natural gas production is declining or poised for decline as indicated in references 53, 54, and 55. The planned U.S. expansion of LNG imports is experiencing delays. U.S. natural gas supply shows every sign of deteriorating significantly before mitigation provides an adequate supply of low cost natural gas. Because of the time required to make major changes in the U.S. natural gas infrastructure and marketplace, forecasts of a decade of high prices and shortages are credible.

G. LESSONS LEARNED

A full discussion of the complex dimensions of the current U.S. natural gas situation is beyond the scope of this study; such an effort would require careful consideration of geology, reserves estimation, natural gas exploration and production, government land restrictions, storage, weather, futures markets, etc. Nevertheless, we believe that the foregoing provides a basis for the following observations: Like oil reserves estimation, natural gas reserves estimation is subject to enormous uncertainty. North American natural gas reserves estimates now appear to have been excessively optimistic and North American natural gas production is now almost certainly in decline. High prices do not a priori lead to greater production. Geology is ultimately the limiting factor, and geological realities are clearest after the fact.Even when urgent, nation-scale energy problems arise, business-as-usual mitigation activities can be dramatically delayed or stopped by state and local opposition and other factors.

If experts were so wrong on their assessment of North American natural gas, are we really comfortable risking that the optimists are correct on world conventional oil production, which involves similar geological and technological issues?

If higher prices did not bring forth vast new supplies of North American natural gas, are we really comfortable that higher oil prices will bring forth huge new oil reserves and production, when similar geology and technologies are involved?

VI. MITIGATION OPTIONS AND ISSUES

A. CONSERVATION

Practical mitigation of the problems associated with world oil peaking must include fuel efficiency technologies that could impact on a large scale. Technologies that may offer significant fuel efficiency improvements fall into two categories: retrofits, which could improve the efficiency of existing equipment, and displacement technologies, which could replace existing, less efficient oil consuming equipment. A comprehensive discussion of this subject is beyond the scope of this study, so we focus on what we believe to be the highest impact, existing technologies. Clearly, other technologies might contribute on a lesser scale.

From our prior discussion of current liquid fuel usage (Chapter III), it is clear that automobiles and light trucks (light duty vehicles or LDVs) represent the largest targets for consumption reduction. This should not be surprising: Auto and LDV fuel use is large, and fuel efficiency has not been a consumer priority for decades, largely due to the historically low cost of gasoline. An established but relatively little-used engine technology for LDVs in the U.S. is the diesel engine, which is up to 30 percent more efficient than comparable gasoline engines. Future U.S. use of diesels in LDVs has been problematic due to increasingly more stringent U.S. air emission requirements. European regulations are not as restrictive, so Europe has a high population of diesel LDVs—between 55 and 70 percent in some countries.

A new technology in early commercial deployment is the hybrid system, based on either gasoline or diesel engines and batteries. In all-around driving tests, gasoline hybrids have been found to be 40 percent more efficient in small cars and 80 percent more efficient in family sedans.

For retrofit application, neither diesel nor hybrid engines appear to have significant potential, so their use will likely be limited to new vehicles. Under business-as-usual market conditions, hybrids might reach roughly 10 percent on-the-road U.S. market share by 2015. That penetration rate is based on the fact that the technology has met many of the performance demands of a significant number of today's consumers and that gasoline hybrids use readily available fuel.

Government-mandated vehicle fuel efficiency requirements are virtually certain to be an element in the mitigation of world oil peaking. One result would almost certainly be the more rapid deployment of diesel and/or hybrid engines. Market penetration of these technologies cannot happen rapidly, because of the time and effort required for manufacturers to retool their factories for large-scale production and because of the slow turnover of existing stock. In addition, a shift from gasoline to diesel fuel would require a major refitting of refineries, which would take time.

Nation-scale retrofit of existing LDVs to provide improved fuel economy has not received much attention. One retrofit technology that might prove attractive for the existing LDV fleet is ''displacement on demand'' in which a number of cylinders in an engine are disabled when energy demand is low. The technology is now available on new cars, and fuel economy savings of roughly 20 percent have been claimed. The feasibility and cost of such retrofits are not known, so we consider this option to be speculative.

It is difficult to project what the fuel economy benefits of hybrid or diesel LDVs might be on a national scale, because consumer preferences will likely change once the public understands the potential impacts of the peaking of world oil production. For example, the current emphasis on large vehicles and SUVs might well give way to preferences for smaller, much more fuel-efficient vehicles.

The fuel efficiency benefits that hybrids might provide for heavy-duty trucks and buses are likely smaller than for LDVs for a number of reasons, including the fact that there has long been a commercial demand for higher efficiency technologies in order to minimize fuel costs for these fleets.

Hybrids can also impact the medium duty truck fleet, which is now heavily populated with diesel engines. For example, road testing of diesel hybrids in FedEx trucks recently began, with fuel economy benefits of 33 percent claimed. On the other hand, there appears to be limits to the fuel economy benefits of hybrid engines in large vehicles; for example, the fuel savings in hybrid buses might only be in the 10 percent range.

On the distant horizon, innovations in aircraft design may result in large fuel economy improvements. For example, a 25 to 50 percent fuel efficiency improvement may be possible with a new, blended wing aircraft. Such benefits would require the purchase of entirely new equipment, requiring a decade or more for significant market penetration. Innovations for major liquid fuel savings for trains and ships may exist but are not widely publicized.

B. IMPROVED OIL RECOVERY

Management of an oil reservoir over its multi-decade life is influenced by a range of factors, including (1) actual and expected future oil prices; (2) production history, geology, and status of the reservoir; (3) cost and character of production-enhancing technologies; (4) timing of enhancements; (5) the financial condition of the operator; (6) political and environmental circumstances; (7) an operator's other investment opportunities, etc.

Improved Oil Recovery (IOR) is used to varying degrees on all oil reservoirs. IOR encompasses a variety of methods to increase oil production and to expand the volume of recoverable oil from reservoirs. Options include in-fill drilling, hydraulic fracturing, horizontal drilling, advanced reservoir characterization, enhanced oil recovery (EOR), and a myriad of other methods that can increase the flow and recovery of liquid hydrocarbons. IOR can also include many seemingly mundane efficiencies introduced in daily operations.

IOR technologies are adapted on a case-by-case basis. It is not possible to estimate what IOR techniques or processes might be applied to a specific reservoir without having detailed knowledge of that reservoir. Such knowledge is rarely in the public domain for the large conventional oil reservoirs in the world; if it were, then a more accurate estimate of the timing of world oil peaking would be possible.

A particularly notable opportunity to increase production from existing oil reservoirs is the use of enhanced oil recovery technology (EOR), also known as tertiary recovery. EOR is usually initiated after primary and secondary recovery have provided most of what they can provide. Primary production is the process by which oil naturally flows to the surface because oil is under pressure underground. Secondary recovery involves the injection of water into a reservoir to force additional oil to the surface.

EOR has been practiced since the 1950s in various conventional oil reservoirs, particularly in the United States. The process that likely has the largest worldwide potential is miscible flooding wherein carbon dioxide (CO_2), nitrogen or light hydrocarbons are injected into oil reservoirs where they act as solvents to move residual oil. Of the three options, CO_2 flooding has proven to be the most frequently useful. Indeed, naturally occurring, geologically sourced CO_2 has been produced in Colorado and shipped via pipeline to west Texas and New Mexico for decades for EOR. CO_2 flooding can increase oil recovery by 7–15 percent of original oil in place (OOIP). Because EOR is relatively expensive, it has not been widely deployed in the past. However, in a world dealing with peak conventional oil production and higher oil prices, it has significant potential.

Because of various cost considerations, enhanced oil recovery processes are typically not applied to a conventional oil reservoir until after oil production has peaked. Therefore, EOR is not likely to increase reservoir peak production. However, EOR can increase total recoverable conventional oil, and production from the reservoirs to which it is applied does not decline as rapidly as would otherwise be the case.

C. HEAVY OIL AND OIL SANDS

This category of unconventional oil includes a variety of viscous oils that are called heavy oil, bitumen, oil sands, and tar sands. These oils have potential to play a much larger role in satisfying the world's needs for liquid fuels in the future.

The largest deposits of these oils exist in Canada and Venezuela, with smaller resources in Russia, Europe and the U.S. While the size of the Canadian and Venezuela resources are enormous, 3–4 trillion barrels in total, the amount of oil estimated to be economically recoverable is of the order of 600 billion barrels. This relatively low fraction is in large part due to the extremely difficult task of extracting these oils.

Canadian oil sands production results in a range of products, only a part of which can be refined into finished fuels that can substitute for petroleum-based fuels. These high quality oil-sands-derived products are called synthetic crude oil (SCO). Other products from oil sands processing are Dilbit, a blend of diluent and bitumen, Synbit, a blend of synthetic crude oil and bitumen, and Syndilbit, a blend of Synbit and diluent. Current Canadian production is approximately 1 million bpd of which 600,000 bpd is synthetic crude oil and 400,000 bpd is lower grade bitumen.

The reasons why the production of unconventional oils has not been more extensive is as follows: (1) Production costs for unconventional oils are typically much higher than for conventional oil; (2) Significant quantities of energy are required to recover and transport unconventional oils; and (3) Unconventional oils are of lower quality and, therefore, are more expensive to refine into clean transportation fuels than conventional oils.

Canadian oil sands have been in commercial production for decades. During that time, production costs have been reduced considerably, but costs are still substantially higher than conventional oil production. Canadian oil sands production currently uses large amounts of natural gas for heating and processing. Canada recently recognized that it no longer has the large natural gas resources once thought, so oil sands producers are considering building coal or nuclear plants as substitute energy sources to replace natural gas. The overall efficiency of Canadian oil sands production is not publicly available but has been estimated to be less than 70 percent for total product, only a part of which is a high-quality substitute transport fuel.

In addition to needing a substitute for natural gas for processing oil sands, there are a number of other major challenges facing the expansion of Canadian oil sands production, including water and diluent availability, financial capital, and environmental issues, such as SO_X and NO_X emissions, waste water cleanup, and brine, coke, and sulfur disposition. In addition, because Canada is a signatory to the Kyoto Protocol and because oil sands production results in significant CO_2 emissions per barrel, there may be related constraints yet to be fully evaluated.

The current Canadian vision is to produce a total of about 5 MM bpd of products from oil sands by 2030. This is to include about 3 MM bpd of synthetic crude oil from which refined fuels can be produced, with the remainder being poorer quality bitumen that could be used for energy, power, and/or hydrogen and petrochemicals production. 5 MM bpd would represent a five-fold increase from current levels of production. Another estimate of future production states that if all proposed oil sands projects proceed on schedule, industry could produce 3.5 MM bpd by 2017, representing 2 MM bpd of synthetic crude and 1.5 MM bpd of unprocessed lower-grade bitumen. It should be noted that not everyone supports this expansion. For example, the executive director of the Sierra Club of Canada, calls tar sands''. . . the world's dirtiest source of oil.

Venezuela's extra-heavy crude oil and bitumen deposits are situated in the Orinoco Belt, located in Central Venezuela. There are currently a number of joint ventures between the Venezuelan oil company, PdVSA, and foreign partners to develop and produce this oil. In 2003, production was about 500,000 bpd of synthetic crude oil. That is expected to increase to 600,000 bpd by 2005. While the weather in tropical Venezuela is more conducive to oil production operations than the bitter winters of Alberta, Canada, the political climate in Venezuela has been particularly unsettled in recent years, which could impact future production.

In closing, it is also worth noting that the bitumen yield from oil sands surface mining operations is about 0.6 barrels per ton of mined material, excluding overburden removal. This is similar to the yield from a good quality oil shale, but is less than Fisher-Tropsch liquid yields from coal, which is about 2.6 barrels per ton of coal.

D. GAS-TO-LIQUIDS (GTL)

Very large reservoirs of natural gas exist around the world, many in locations isolated from gas-consuming markets. Significant quantities of this ''stranded gas'' have been liquefied and transported to various markets in refrigerated, pressurized ships in the form of liquefied natural gas (LNG). Japan, followed by Korea, Spain and the U.S. were the largest importers of LNG in 2003. LNG accounted for an important fraction of all traded gas volumes in 2003, and that fraction is projected to continue to grow considerably in the future.

Another method of bringing stranded natural gas to world markets is to disassociate the methane molecules, add steam, and convert the resultant mixture to high quality liquid fuels via the Fisher-Tropsch (F-T) process. As with coal liquefaction, F-T based GTL results in clean, finished fuels, ready for use in existing end-use equipment with only modest finishing and blending. This Gas-To-Liquids process has undergone significant development over the past decade. Shell now operates a 14,500 bpd GTL plant in Malaysia. A number of large, new commercial plants recently announced include three large units in Qatar—a 140,000 bpd Shell facility, a 160,000 bpd ConocoPhillips facility, and a 120,000 bpd Marathon Oil plant. Projects under development and consideration total roughly 1.7 MM bpd, but not all will come to fruition. Under business-as-usual conditions, 1.0 MM bpd may be produced by 2015, in line with a recent estimate of 600,000 bpd of GTL diesel fuel by 2015—the remaining 400,000 bpd being gasolin and other products.

E. LIQUID FUELS FROM U.S. DOMESTIC RESOURCES

The U.S. has three types of natural resource from which substitute liquid fuels can be manufactured: coal, oil shale, and biomass. All have been shown capable of producing high quality liquid fuels that can supplement or substitute for the fuels ow produced from petroleum.

To derive liquid fuels from coal, the leading process involves gasification of the coal, removal of impurities from the resultant gas, and then synthesis of liquid fuels using t1e Fisher-Tropsch process. Modern gasification technologies have been dramatically improved over the years, with the result that over 150 gasifiers are in commercial operation around the world, a number operating on coal. Gas cleanup technologies are well developed and utilized in refineries worldwide. F-T synthesis is also well developed and commercially practiced. A number of coal liquefaction plants were built and operated during World War II, and the Sasol Company in South Africa subsequently built a number of larger, more modern facilities. The U.S. has huge coal reserves that are now being utilized for the production of electricity; those resources could also provide feedstock for large-scale liquid fuel production. Lastly, coal liquids from gasification/F-T synthesis are of such high quality that they do not need to be refined. When co-producing electricity, coal liquefaction is a developed technology, currently believed capable of providing clean substitute fuels at $30–35 per barrel.

The U.S. is endowed with a vast resource of oil shale, located primarily in the western part of the Lower 48 states with lesser quantities in the mid Atlantic region. Processes for mining shale and retorting it at high temperatures were developed in intensively in the late 1970s and early 1980s. However, when oil prices decreased in the mid 1980s, all large-scale oil shale R&D was terminated.

The oil shale processing technologies that were pursued in the past required large volumes of water, which is now increasingly scarce in the western states. Also, air emissions regulations have become much stricter in the ensuing years, presenting additional challenges for shale mining and processing. Finally, it should be noted that the oil produced from shale retorting requires refining before it can be used as transportation fuels.

In recent years, Shell has been developing a new shale oil recovery process that uses in situ heating and avoids mining and massive materials handling. Little is known about the process and its economics, so its potential cannot now be evaluated. (See Appendix VI for notes on shale oil).

Biomass can be grown, collected and converted to substitute liquid fuels by a number of processes. Currently, biomass-to-ethanol is produced on a large scale to provide a gasoline additive. The market for ethanol derived from biomass is influenced by federal requirements and facilitated by generous federal and state tax subsidies. Research holds promise of more economical ethanol production from cellulosic (''woody'') biomass, but related processes are far from economical. Reducing the cost of growing, harvesting, and converting biomass crops will be necessary. In other parts of the world, biomass-to-liquid fuels might be more attractive, depending on a myriad of factors, including local labor costs. Related projections for large-scale production would be strictly speculative. In summary, there are no developed biomass-to-fuels technologies that are now near cost competitive. (See Appendix VI for notes on biomass).

F. FUEL SWITCHING TO ELECTRICITY

Electricity is only used to a limited extent in the transportation sector. Diesel fuels (mid-distillates) power most rail trains in the U.S.; only a modest fraction are electric powered. Other electric transportation is limited to special situations, such as forklifts, in-factory transporters, etc.

In the 1990s electric automobiles were introduced to the market, spurred by a California clean vehicle requirement. The effort was a failure because existing batteries did not provide the vehicle range and performance that customers demanded. In the future, electricity storage may improve enough to win consumer acceptance of electric automobiles. In addition, extremely high gasoline prices may cause some consumers to find electric automobiles more acceptable, especially for around-town use. Such a shift in public preferences is unpredictable, so electric vehicles cannot now be projected as a significant offset to future gasoline use.

A larger number of train routes could be outfitted for electric trains, but such a transition would likely be slow, because of the need to build additional electric power plants, transmission lines, and electric train cars. Since existing diesel locomotives use electric drive, their retrofit might be feasible. However, since diesel fuel use in trains is only roughly 0.3 MM bpd, electrification of trains would not have a major impact on U.S liquid fuel consumption.

There are no known near-commercial means for electrifying heavy trucks or aircraft, so related conversions are not now foreseeable.

G. OTHER FUEL SWITCHING

It is conceivable that consumers who now use mid-distillates and LPG (Liquefied Petroleum Gas) for heating could switch to natural gas or electricity, thereby freeing up liquid fuels for transportation. Analysis of this path is beyond the scope of this study, but it should be noted that these uses represent only a few percent of U.S. liquid fuel consumption. Such switching on a large scale would require the construction of compensating natural gas and/or electric power facilities and infrastructure, which would not happen quickly. In addition, freed-up liquids would likely require further refining to meet market and environmental requirements. Related refining would require refinery construction, which would also be time consuming.

H. HYDROGEN

Hydrogen has potential as a long-term alternative to petroleum-based liquid fuels in some transportation applications. Like electricity, hydrogen is an energy carrier; hydrogen production requires an energy source for its production. Energy sources for hydrogen production include natural gas, coal, nuclear power, and renewables. Hydrogen can be used in internal combustion engines, similar to those in current use, or via chemical reactions in fuel cells.

The Department of Energy is currently conducting a high profile program aimed at developing a ''hydrogen economy.'' DOE's primary emphasis is on hydrogen for light duty vehicle application (automobiles and light duty trucks). Recently, the National Research Council (NRC) completed a study that included an evaluation of the technical, economic and societal challenges associated with the development of a hydrogen economy. That study is the basis for the following highlights.

A lynchpin of the current DOE hydrogen program is fuel cells. In order for fuel cells to compete with existing petroleum-based internal combustion engines, particularly for light duty vehicles, the NRC concluded that fuel cells must improve by (1) a factor of 10–20 in cost, (2) a factor of five in lifetime, and (3) roughly a factor of two in efficiency. The NRC did not believe that such improvements could be achieved by technology development alone; instead, new concepts (breakthroughs) will be required. In other words, today's technologies do not appear practically viable.

Because of the need for unpredictable inventions in fuel cells, as well as viable means for on-board hydrogen storage, the introduction of commercial hydrogen vehicles cannot be predicted.

I. FACTORS THAT CAN CAUSE DELAY

It is extremely difficult, expensive, and time consuming to construct any type of major energy-related facility in the U.S. today. Even assuming the expenditure of substantial time and money, it is not certain that many proposed facilities will ever be constructed. The construction of transmission lines, interim and permanent nuclear waste disposal facilities, electric generation plants, waste incinerators, oil refineries, LNG terminals, waste recycling facilities, petrochemical plants, etc. is increasingly problematic.

What used to be termed the ''not-in-my-back-yard'' (NIMBY) principle has evolved into the ''build-absolutely-nothing-anywhere-near-anything'' (BANANA) principle, which is increasingly being applied to facilities of any type, including low-income housing, cellular phone towers, prisons, sports stadiums, water treatment facilities, airports, hazardous waste facilities, and even new fire houses. Construction of even a single, relatively innocuous, urgently needed facility can easily take more than a decade. For example, in 1999, King County, Washington, initiated the siting process for the Brightwater wastewater treatment plant, which it hopes to have operational in 2010.

The routine processes required for siting energy facilities can be daunting, expensive, and time consuming, and if a facility is at all controversial, which is almost invariably the case, opponents can often extend the permitting process until sponsors terminate their plans. For example, approval for new, small, distributed energy systems requires a minimum of 18 separate steps, requiring approval from four federal agencies, 11 state government agencies, and 14 local government agencies. Opponents of energy facilities routinely exercise their right to raise objections and offer alternatives. Intervenors in permitting processes may delay decisions and in some cases force outright cancellations, although cases do exist in which facilities have been sited quickly.

The implications for U.S. homeland-based mitigation of world oil peaking are troubling. To replace dwindling supplies of conventional oil, large numbers of expensive and environmentally intrusive substitute fuel production facilities will be required. Under current conditions, it could easily require more than a decade to construct a large coal liquefaction plant in the U.S. The prospects for constructing 25–50, with the first ones coming into operation within a three year time window are essentially nil. Absent change, the U.S. may end up on the path of least resistance, allowing only a few substitute fuels plants to be built on U.S. soil; in the process the U.S. would be adding substitute fuel imports to its increasing dependence on imports of conventional oil.

For the U.S. to attain a lower level of dependence on liquid fuel imports after the advent of world oil peaking, a major paradigm shift will be required in the current approach to the construction of capital-intensive energy facilities. Federal and state governments will have to adopt legislation allowing the acceleration of the development of substitute fuels projects from current decade time-scales. During World War II, facilities of all types were constructed on a scale and schedules that would have previously been inconceivable. In the face of the 1973 energy crisis, the Alaska oil pipeline was approved and constructed in record time.

While world oil peaking poses many dangers for the U.S., it also offers substantial opportunities. The U.S. could emerge as the world's largest producer of substitute liquid fuels, if it were to undertake a massive program to construct substitute fuel production facilities on a timely basis. The nation is ideally positioned to do so because it has the world's largest coal reserves, and it could muster the required capital, technology, and labor to implement such a program. However, unless a process is developed to expedite plant construction, this opportunity could easily slip away. Other nations, such as China, India, Japan, Korea, and others also have the capabilities needed to construct and operate such plants. Under current conditions, other countries are able to bring such large energy projects on-line much more rapidly than the U.S. Such countries could conceivably even import U.S. coal, convert it to liquid fuels products, and then export finished product back to the U.S. and elsewhere.

The U.S. has well-developed coal mining, transportation, and shipping systems that move coal to the highest bidders, be they domestic or international. As recently as 1981, 14 percent of U.S. coal production was exported. While that number has declined in recent years, the U.S. could easily expand its current coal exports many fold to provide feedstock for coal liquefaction plants in other nations. Not only would the U.S. be dependent on foreign sources for conventional oil, which will continue to dwindle in volume after peaking, but it could also become dependent on foreign sources for substitute fuels derived from U.S. coal.

VII. A World Problem

Oil is essential to all countries. In 2002 daily consumption ranged from almost 20 million barrels in the U.S. to 20 barrels in the tiny South Pacific island of Niue, population 2,400.

Oil is produced in 123 countries. The top 20 producing countries provide over 83 percent of total world oil. Production by the largest producers is shown in Table VII–1. The table also lists the top 20 oil-consuming countries and their respective consumption. In total, the top 20 countries consume over 75 percent of the average daily production. Beyond these larger consumers, oil is also utilized in all the world's 194 remaining countries.

TABLE VII.1—TOP WORLD OIL PRODUCING AND CONSUMING COUNTRIES—2002

Rank	Country	MM bpd	Percent
	Producers		
1	United States	9.0	11.7
2	Saudi Arabia	8.7	11.3
3	Russia	7.7	10.0
4	Mexico	3.6	4.7
5	Iran	3.5	4.6
6	China	3.5	4.6
7	Norway	3.3	4.3
8	Canada	2.9	3.8
9	Venezuela	2.9	3.8
10	United Kingdom	2.6	3.3
11	United Arab Emirates	2.4	3.1
12	Nigeria	2.1	2.8
13	Iraq	2.0	2.7
14	Kuwait	2.0	2.6
15	Brazil	1.8	2.3
16	Algeria	1.6	2.0
17	Libya	1.4	1.8
18	Indonesia	1.4	1.8
19	Kazakhstan	0.9	1.2
20	Oman	0.9	1.2
	103 other countries	12.6	16.3
	Consumers		
1	United States	19.8	25.3
2	Japan	5.3	6.8
3	China	5.2	6.6
4	Germany	2.7	3.5
5	Russia	2.6	3.3
6	India	2.2	2.8
7	Korea, South	2.2	2.8
8	Brazil	2.2	2.8
9	Canada	2.1	2.7
10	France	2.0	2.5
11	Mexico	2.0	2.5
12	Italy	1.8	2.4
13	United Kingdom	1.7	2.2
14	Saudi Arabia	1.5	1.9
15	Spain	1.5	1.9
16	Iran	1.3	1.7
17	Indonesia	1.1	1.4
18	Taiwan	0.9	1.2
19	Netherlands	0.9	1.1
20	Australia	0.9	1.1
	194 other countries	18.4	23.5

VIII. Three Mitigation Scenarios

A. INTRODUCTION

Issues related to the peaking of world oil production are extremely complex, involve literally trillions of dollars and are very time-dependent. To explore these matters, we selected three mitigation scenarios for analysis: Scenario I assumes that action is not initiated until peaking occurs. Scenario II assumes that action is initiated 10 years before peaking. Scenario III assumes action is initiated 20 years before peaking.

Our approach is simplified in order to provide transparency and promote understanding. Our estimates are approximate, but the mitigation envelope that results is believed to be indicative of the realities of such an enormous undertaking.

B. MITIGATION OPTIONS

Our focus is on large-scale, physical mitigation, as opposed to policy actions, e.g. tax credits, rationing, automobile speed restrictions, etc. We define physical mitigation as (1) implementation of technologies that can substantially reduce the consumption of liquid fuels (improved fuel efficiency) while still delivering comparable service and (2) the construction and operation of facilities that yield large quantities of liquid fuels.

C. MITIGATION PHASE-IN

The pace that governments and industry chose to mitigate the negative impacts of the peaking of world oil production is to be determined. As a limiting case, we choose overnight go-ahead decision-making for all actions, i.e., crash programs. Our rationale is that in a sudden disaster situation, crash programs are most likely to be quickly implemented. Overnight go-ahead decision-making is most probable in our Scenario I, which assumes no action prior to the onset of peaking. By assuming overnight implementation in all three of our scenarios, we avoid the arduous and potentially arbitrary challenge of developing a more likely, real world decision-making sequence. This is obviously an optimistic assumption because government and corporate decision-making is never instantaneous.

D. THE USE OF WEDGES

The model chosen to illustrate the possible effects of likely mitigation actions involves the use of ''delayed wedges'' to approximate the scale and pace of each action. The use of wedges was effectively utilized in a recent paper by Pacala and Socolow.

Our wedges are composed of two parts. The first is the preparation time needed prior to tangible market penetration. In the case of efficient transportation, this time is required to redesign vehicles and retool factories to produce more efficient vehicles. In the case of the production of substitute fuels, the delay is associated with planning and construction of relevant facilities.

After the preparation phase, our wedges then approximate the penetration of mitigation effects into the marketplace. This might be the growing sales of more fuel-efficient vehicles or the growing production of substitute fuels. We assume our wedges continue to expand for a few decades, which simplifies illustration but is increasingly less realistic over time because markets will adjust and impact rates will change.

Our aim is to approximate reality in a simple manner. Greater detail is beyond the scope of this study and would require in-depth analysis.

E. CRITERIA FOR WEDGE SELECTION

Our criteria for selecting candidates for our energy saving and substitute oil production wedges were as follows:

1. The option must produce liquid fuels that can, as produced or as refined, substitute for liquid fuels currently in widespread use, e.g. gasoline, jet fuel, diesel, etc. The end products will thus be compatible with existing distribution systems and end-use equipment.
2. The option must be capable of liquid fuels savings or production on a massive scale—ultimately millions to tens of millions of barrels per day worldwide.
3. The option must include technology that is commercial or near commercial, which at a minimum requires that the process has been demonstrated at commercial scale. For production technologies, this means that at least one plant has operated at greater than 10,000 bpd for at least two years, and product prices from the process are less than $50/barrel in 2004 dollars. For fuels efficiency technologies, the technology must have at least entered the commercial market by 2004.
4. Substitute fuel production technologies must be inherently energy efficient, which we assume to mean that greater than 50 percent of process energy input is contained in the clean liquid fuels product.
5. The option must be environmentally clean by 2004 standards.
6. While domestic resources are of greatest interest to the U.S., the oil market is international, so substitute fuel feedstocks not abundantly available in the U.S. must also be considered, e.g. heavy oil/tar sands and gas-to-liquids.
7. Energy sources or energy efficiency technologies that produce or save electricity are not of interest in this context because commercial processes to convert electricity to clean hydrocarbon fuels do not currently exist.

F. WEDGES SELECTED AND REJECTED

The combination of technologies, processes, and feedstocks that meet these criteria are as follows: 1. Fuel efficient transportation; 2. Heavy oil/Oil sands; 3. Coal liquefaction; 4. Enhanced oil recovery; 5. Gas-to-liquids.

In the end-use category, a dramatic increase in the efficiency of petroleum-based fuel equipment is one attractive option. As previously described, the imposition of CAFE requirements for automobiles in 1975 was one of the most effective of the government mandates initiated in response to the 1973–74 oil embargo. In recent years, fuel economy for automobiles has not been a high national priority in the U.S. Nevertheless, a new hybrid engine technology has been phasing into the automobile and truck markets. In a period of national oil emergency, hybrid technology could be massively implemented for new vehicle applications. Hybrid technologies offer fuel economy improvements of 40 percent or more for automobiles and light-medium trucks—no other engine technologies offer such large, near-term fuel economy benefits.

The fuels production options that we chose are heavy oil/tar sands, coal liquefaction, improved oil recovery, and gas-to-liquids. Our rationale was as follows: 1. Enhanced Oil Recovery is applicable worldwide; 2. Heavy oil/tar sands is currently commercial in Canada and Venezuela; 3. Coal liquefaction is a well-developed, near-commercial technology; 4. Gas-To-Liquids is commercially applicable where natural gas is remote from markets.

We excluded a number of options for various reasons. While the U.S. has a huge resource of shale oil that could be processed into substitute liquid fuels, the technology to accomplish that task is not now ready for deployment. Because various shale oil processing prototypes were developed in years past and because shale oil processing is likely to be economically attractive, a concerted effort to develop shale oil technology could well lead to shale oil becoming a contributor in Scenarios II or III. However, that would require the initiation of a major R&D program in the near future.

Biomass options capable of producing liquid fuels were also excluded. Ethanol from biomass is currently utilized in the transportation market, not because it is commercially competitive, but because it is mandated and highly subsidized. Biodiesel fuel is a subject of considerable current interest but it too is not yet commercially viable. Again, a major R&D effort might change the biomass outlook, if initiated in the near future.

Over 45 percent of world oil consumption is for non-transportation uses. Fuel switching away from non-transportation uses of liquid fuels is likely to occur, mimicking shifts that have already taken place in the U.S. The time frame for such shifts is uncertain. For significant world scale impact, alternate large energy facilities would have to be constructed to provide the substitute energy, and that facility construction would require the kind of decade-scale time periods required for oil peaking mitigation.

Nuclear power, wind and photovoltaics produce electric power, which is not a near-term substitute fuel in transportation equipment that requires liquid fuels. In the many-decade future after oil peaking, it is conceivable that a massive shift from liquid fuels to electricity might occur in some applications. However, consideration of such changes would be speculative at this time.

It is possible that technology innovations resulting from aggressive future research may well change the outlook for various technologies in the future. Our focus on the currently viable is in no way intended to prejudice other future options. We have chosen not to add a wedge for undefined technologies that might result from accelerated research, because such a wedge would be purely speculative. No matter what the new technology(ies), implementation delay times and contribution growth rates will inherently be of the same order of magnitude of the technologies that we have considered, because of the inherent scale of all physical mitigation.

G. MODELING WORLD OIL SUPPLY/DEMAND

It is not possible to predict with certainty when world conventional oil peaking will occur or how rapidly production will decline after the peak. To develop our scenarios, we utilize the U.S. Lower 48 production pattern as a surrogate for the world. This assumption is justified on the basis that Lower 48 oil production represents what really happened in a large, complex oil province over the course of decades of modern oil production development.

Our horizontal axis is centered on the year of peaking (the date is not specified) and spans plus and minus two decades. For this study, our vertical axis is pegged at a peak world oil production of 100 MM bpd, which is 18 MM bpd above the current 82 MM bpd world production. If peaking were to occur soon, 100 MM bpd might be high by 20 percent. If peaking were to occur at 125 MM bpd at some future date, the 100 MM bpd assumption would be low by 20 percent. Since the estimates in our wedges are rough under any conditions, a 100 MM bpd peak represents a credible assumption for this kind of analysis. The selection of 100 MM bpd is not intended as a prediction of magnitude or timing; its use is for illustration purposes only.

Next is the important issue of the slopes of the production profile showing the rate of growth of production/demand before peaking and the subsequent decline in production. The World Energy Council stated: ''Oil demand is projected to increase at about 1.9 percent per year rising from about 75.7 million b/d in 2000 (actual) to 113–115 million b/d in 2020—an increase of about 37.5–39.5 million b/d.'' Recent trends indicate a 3+ percent world oil demand growth, driven in part by rapidly increasing oil consumption in China and India. However, a 3+ percent growth rate on a continuing basis seems excessive. On this basis, we assume a two percent demand growth before peaking, and we assume an intrinsic two percent long-run hypothetical, healthy economy demand after peaking. This extrapolation of demand after peaking provides a reference that facilitates calculation of supply shortfalls. The assumption has the benefit of simplicity, but it ignores the real-world feedback of oil price escalation on demand, which is sure to happen but the calculation thereof will be complicated and was beyond the scope of this study.

Estimating a decline rate after world oil production peaking is a difficult issue. While human activity dominates the demand for oil, the ''rocks'' (geology) will dominate the decline of world conventional oil production after peaking. Referring to U.S. Lower 48 production history, the decline after the 1970 peaking was roughly 1.7 percent per year, which we have chosen to round off to two percent per year as our estimated world conventional oil decline rate. It should be noted that other analysts have projected decline rates of 3–8%, which would make the mitigation problem much more difficult.

H. OUR WEDGES

In Appendix IV we develop the sizes of the wedges that we believe appropriate for our trends analysis. Once again, bear in mind that these are rough approximations aimed at illustrating the inherently large scale of mitigation.

I. THE THREE SCENARIOS

As noted, our three scenarios are benchmarked to the unknown date of peaking: Scenario I: Mitigation begins at the time of peaking; Scenario II: Mitigation starts 10 years before peaking; Scenario III: Mitigation starts 20 years before peaking.

Our mitigation choices then map onto our assumed world oil peaking pattern.

OBSERVATIONS AND CONCLUSIONS ON SCENARIOS

This exercise was conducted bottom-up; we estimated reasonable potential contributions from each viable option, summed them, and then applied them to our assumed world oil peaking pattern.

While our option contribution estimates are clearly approximate, in total they probably represent a realistic portrayal of what might be achieved with an array of physical mitigation options. Together, implementation of all of the specified options would provide 15–20 MM bpd impact, ten years after simultaneous initiation. Roughly 90 percent would result from substitute liquid fuel production and roughly ten percent would come from transportation fuel efficiency improvements.

Our results are congruent with the fundamentals of the problem: Waiting until world oil production peaks before taking crash program action leaves the world with a significant liquid fuel deficit for more than two decades. Initiating a mitigation crash program 10 years before world oil peaking helps considerably but still leaves a liquid fuels shortfall roughly a decade after the time that oil would have peaked. Initiating a mitigation crash program 20 years before peaking appears to offer the possibility of avoiding a world liquid fuels shortfall for the forecast period.

The obvious conclusion from this analysis is that with adequate, timely mitigation, the costs of peaking can be minimized. If mitigation were to be too little, too late, world supply/demand balance will be achieved through massive demand destruction (shortages), which would translate to significant economic hardship, as discussed earlier.

K. RISK MANAGEMENT

It is possible that peaking may not occur for several decades, but it is also possible that peaking may occur in the near future. We are thus faced with a daunting risk management problem:

On the one hand, mitigation initiated soon would be premature if peaking is still several decades away.

On the other hand, if peaking is imminent, failure to initiate mitigation quickly will have significant economic and social costs to the U.S. and the world.

The two risks are asymmetric: Mitigation actions initiated prematurely will be costly and could result in a poor use of resources. Late initiation of mitigation may result in severe consequences.

The world has never confronted a problem like this, and the failure to act on a timely basis could have debilitating impacts on the world economy. Risk minimization requires the implementation of mitigation measures well prior to peaking. Since it is uncertain when peaking will occur, the challenge is indeed significant.

IX. MARKET SIGNALS AS PEAKING IS APPROACHED

As world oil peaking is approached and demand for conventional oil begins to exceed supply, oil prices will rise steeply. As discussed in Chapter IV, related price increases are almost certain to have negative impacts on the U.S. and world economies. Another likely signal is substantially increased oil price volatility.

Oil prices have traditionally been volatile. Causes include political events, weather, labor strikes, infrastructure problems, and fears of terrorism. In an era where supply was adequate to meet demand and where there was excess production capacity in OPEC, those effects were relatively short-lived. However, as world oil peaking is approached, excess production capacity by definition will disappear, so that even minor supply disruptions will cause increased price volatility as traders, speculators, and other market participants react to supply/demand events. Simultaneously, oil storage inventories are likely to decrease, further eroding security of supply, aggravating price volatility, and further stimulating speculation.

While it is recognized that high oil prices will have adverse effects, the effects of increased price volatility may not be sufficiently appreciated. Higher oil price volatility can lead to reduction in investment in other parts of the economy, leading in turn to a long-term reduction in supply of various goods, higher prices, and further reduced macroeconomic activity. Increasing volatility has the potential to increase both economic disruption and transaction costs for both consumers and producers, adding to inflation and reducing economic growth rates.

The most relevant experience was during the 1970s and early 1980s, when oil prices increased roughly six-fold and oil price volatility was aggravated. Those reactions have often been dismissed as a ''panic response,'' but that experience may nevertheless be a good indicator of the oil price volatility to be expected when demand exceeds supply after oil peaking.

The factors that cause oil price escalation and volatility could be further exacerbated by terrorism. For example, in the summer of 2004, it was estimated that the threat of terrorism had added a premium of 25–33 percent to the price of a barrel of oil. As world oil peaking is approached, it is not difficult to imagine that the terrorism premium could increase even more.

In conclusion, oil peaking will not only lead to higher oil prices but also to increased oil price volatility. In the process, oil could become the price setter in the broader energy market, in which case other energy prices could well become increasingly volatile and unpredictable.

X. WILDCARDS

There are a number of factors that could conceivably impact the peaking of world oil production. Here is a list of possible upsides and downsides.

A. UPSIDES—THINGS THAT MIGHT EASE THE PROBLEM OF WORLD OIL PEAKING

The pessimists are wrong again and peaking does not occur for many decades.

Middle East oil reserves are much higher than publicly stated.

A number of new super-giant oil fields are found and brought into production, well before oil peaking might otherwise have occurred.

High world oil prices over a sustained period (a decade or more) induce a higher level of structural conservation and energy efficiency.

The U.S. and other nations decide to institute significantly more stringent fuel efficiency standards well before world oil peaking.

World economic and population growth slows and future demand is much less than anticipated.

China and India decide to institute vehicle efficiency standards and other energy efficiency requirements, reducing the rate of growth of their oil requirements.

Oil prices stay at a high enough level on a sustained basis so that industry begins construction of substitute fuels plants well before oil peaking.

Huge new reserves of natural gas are discovered, a portion of which is converted to liquid fuels.

Some kind of scientific breakthrough comes into commercial use, mitigating oil demand well before oil production peaks.

B. DOWNSIDES—THINGS THAT MIGHT EXACERBATE THE PROBLEM OF WORLD OIL PEAKING

World oil production peaking is occurring now or will happen soon.

Middle East reserves are much less than stated.

Terrorism stays at current levels or increases and concentrates on damaging oil production, transportation, refining and distribution.

Political instability in major oil producing countries results in unexpected, sustained world-scale oil shortages.

Market signals and terrorism delay the realization of peaking, delaying the initiation of mitigation.

Large-scale, sustained Middle East political instability hinders oil production.

Consumers demand even larger, less fuel-efficient cars and SUVs.

Expansion of energy production is hindered by increasing environmental challenges, creating shortages beyond just liquid fuels.

XI. SUMMARY AND CONCLUDING REMARKS

Our analysis leads to the following conclusions and final thoughts.

1. WORLD OIL PEAKING IS GOING TO HAPPEN

World production of conventional oil will reach a maximum and decline thereafter. That maximum is called the peak. A number of competent forecasters project peaking within a decade; others contend it will occur later. Prediction of the peaking is extremely difficult because of geological complexities, measurement problems, pricing variations, demand elasticity, and political influences. Peaking will happen, but the timing is uncertain.

2. OIL PEAKING COULD COST THE U.S. ECONOMY DEARLY

Over the past century the development of the U.S. economy and lifestyle has been fundamentally shaped by the availability of abundant, low-cost oil. Oil scarcity and several-fold oil price increases due to world oil production peaking could have dramatic impacts. The decade after the onset of world oil peaking may resemble the period after the 1973–74 oil embargo, and the economic loss to the United States could be measured on a trillion-dollar scale. Aggressive, appropriately timed fuel efficiency and substitute fuel production could provide substantial mitigation.

3. OIL PEAKING PRESENTS A UNIQUE CHALLENGE

The world has never faced a problem like this. Without massive mitigation more than a decade before the fact, the problem will be pervasive and will not be temporary. Previous energy transitions (wood to coal and coal to oil) were gradual and evolutionary; oil peaking will be abrupt and revolutionary.

4. THE PROBLEM IS LIQUID FUELS

Under business-as-usual conditions, world oil demand will continue to grow, increasing approximately two percent per year for the next few decades. This growth will be driven primarily by the transportation sector. The economic and physical lifetimes of existing transportation equipment are measured on decade time-scales. Since turnover rates are low, rapid changeover in transportation end-use equipment is inherently impossible.

Oil peaking represents a liquid fuels problem, not an ''energy crisis'' in the sense that term has been used. Motor vehicles, aircraft, trains, and ships simply have no ready alternative to liquid fuels. Non-hydrocarbon-based energy sources, such as solar, wind, photovoltaics, nuclear power, geothermal, fusion, etc. produce electricity, not liquid fuels, so their widespread use in transportation is at best decades away. Accordingly, mitigation of declining world oil production must be narrowly focused.

5. MITIGATION EFFORTS WILL REQUIRE SUBSTANTIAL TIME

Mitigation will require an intense effort over decades. This inescapable conclusion is based on the time required to replace vast numbers of liquid fuel consuming vehicles and the time required to build a substantial number of substitute fuel production facilities. Our scenarios analysis shows:

Waiting until world oil production peaks before taking crash program action would leave the world with a significant liquid fuel deficit for more than two decades.

Initiating a mitigation crash program 10 years before world oil peaking helps considerably but still leaves a liquid fuels shortfall roughly a decade after the time that oil would have peaked.

Initiating a mitigation crash program 20 years before peaking appears to offer the possibility of avoiding a world liquid fuels shortfall for the forecast period.

The obvious conclusion from this analysis is that with adequate, timely mitigation, the economic costs to the world can be minimized. If mitigation were to be too little, too late, world supply/demand balance will be achieved through massive demand destruction (shortages), which would translate to significant economic hardship.

There will be no quick fixes. Even crash programs will require more than a decade to yield substantial relief.

6. BOTH SUPPLY AND DEMAND WILL REQUIRE ATTENTION

Sustained high oil prices will stimulate some level of forced demand reduction. Stricter end-use efficiency requirements can further reduce embedded demand, but substantial, world-scale change will require a decade or more. Production of large amounts of substitute liquid fuels can and must be provided. A number of commercial or near-commercial substitute fuel production technologies are currently available, so the production of large amounts of substitute liquid fuels is technically and economically feasible, albeit time-consuming and expensive.

7. IT IS A MATTER OF RISK MANAGEMENT

The peaking of world conventional oil production presents a classic risk management problem: Mitigation efforts initiated earlier than required may turn out to be premature, if peaking is long delayed. On the other hand, if peaking is imminent, failure to initiate timely mitigation could be extremely damaging.

Prudent risk management requires the planning and implementation of mitigation well before peaking. Early mitigation will almost certainly be less expensive and less damaging to the world's economies than delayed mitigation.

8. GOVERNMENT INTERVENTION WILL BE REQUIRED

Intervention by governments will be required, because the economic and social implications of oil peaking would otherwise be chaotic. The experiences of the 1970s and 1980s offer important lessons and guidance as to government actions that might be more or less desirable. But the process will not be easy. Expediency may require major changes to existing administrative and regulatory procedures such as lengthy environmental reviews and lengthy public involvement.

9. ECONOMIC UPHEAVAL IS NOT INEVITABLE

Without mitigation, the peaking of world oil production will almost certainly cause major economic upheaval. However, given enough lead-time, the problems are soluble with existing technologies. New technologies are certain to help but on a longer time scale. Appropriately executed risk management could dramatically minimize the damages that might otherwise occur.

10. MORE INFORMATION IS NEEDED

The most effective action to combat the peaking of world oil production requires better understanding of a number of issues. Is it possible to have relatively clear signals as to when peaking might occur? It would be desirable to have potential mitigation actions better defined with respect to cost, potential capacity, timing, etc. Various risks and possible benefits of possible mitigation actions need to be examined. (See Appendix V for a list of possible follow-on studies).

The purpose of this analysis was to identify the critical issues surrounding the occurrence and mitigation of world oil production peaking. We simplified many of the complexities in an effort to provide a transparent analysis. Nevertheless, our study is neither simple nor brief. We recognize that when oil prices escalate dramatically, there will be demand and economic impacts that will alter our simplified analysis. Consideration of those feedbacks will be a daunting task but one that should be undertaken.

Our study required that we make a number of assumptions and estimates. We well recognize that in-depth analyses may yield different numbers. Nevertheless, this analysis clearly demonstrates that the key to mitigation of world oil production peaking will be the construction a large number of substitute fuel production facilities, coupled to significant increases in transportation fuel efficiency. The time required to mitigate world oil production peaking is measured on a decade time-scale, and related production facility size is large and capital intensive. How and when governments decide to address these challenges is yet to be determined.

Our focus on existing commercial and near-commercial mitigation technologies illustrates that a number of technologies are currently ready for immediate and extensive implementation. Our analysis was not meant to be limiting. We believe that future research will provide additional mitigation options, some possibly superior to those we considered. Indeed, it would be appropriate to greatly accelerate public and private oil peaking mitigation research. However, the reader must recognize that doing the research required to bring new technologies to commercial readiness takes time under the best of circumstances. Thereafter, more than a decade of intense implementation will be required for world scale impact, because of the inherently large scale of world oil consumption.

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APPENDIX I. MOST MEANINGFUL EIA OIL PEAKING CASE

In the year 2000, EIA developed 12 scenarios for world oil production peaking using three U.S. Geological Survey (USGS) estimates of the world conventional oil resource base (Low, Expected, and High) and four annual world oil demand growth rates (0, 1, 2, and 3 percent per year). We believe the most likely of the EIA scenarios is the one based on the USGS expected ultimate world recoverable oil of 3.003 billion barrels coupled with 2% annual world oil demand escalation.

The difference between the two profiles is attributable to two assumed production decay rates following peak production. Both curves assume a 2 percent per year growth from the year 2000 until the peak. One scenario assumes a 2 percent decline after the world oil production peak, while the other assumes a steeper drop after the world oil production peak. Because the areas under both curves must equal the projected 3,003 billion barrels of recoverable conventional oil from the year 2000 forward, the rapid decay curve will inherently yield the later occurring, higher world oil production peak.

The EIA scenario that peaks in 2016 looks like the relatively symmetric U.S. Lower 48 production profile. The EIA scenario that peaks in 2037 not only differs dramatically from the U.S. experience, it differs from typical individual oil reservoir experience, which often displays a relatively symmetric production profile, not the sharp drop illustrated in the alternate EIA case. On this basis, we believe that the EIA 2016 peaking case appears much more credible than the 2037 peaking case. The associated 21-year difference between the two predicted production peaks clearly would have profound implications for the time available for mitigation.

It is worth noting that the USGS mean estimate for the remaining recoverable world oil resource is much higher than estimates made by other investigators, according to K.S. Deffeyes, retired Shell geologist and emeritus Princeton geology professor. Deffeyes also opined '' . . . in 2000 the USGS again released implausibly large estimates of world oil.'' A lower total reserves estimate would of course mean a world oil production peak earlier than 2016.

APPENDIX II. MORE HISTORICAL OIL CRISIS CONSIDERATIONS

Economists have debated whether the economic problems of the 1970s were due to the oil supply disruptions or to inappropriate fiscal, monetary, and energy policies implemented to deal with them. The consensus is that the disruptions would have caused economic problems irrespective of fiscal, monetary, and energy policies, but that price and allocation controls exacerbated the impacts in the U.S. during the 1970s. There is general consensus on the following:

Appropriate actions taken included CAFE, the 55 mph speed limit, reorganization of the Federal energy bureaucracy, greatly increased energy R&D, establishment of the Strategic Petroleum Reserve (SPR), energy efficiency standards and building codes, establishment of IEA and EIA, and burden sharing agreements among nations.

Inadvisable actions included price and allocation controls, excessive regulations, de-facto gasoline rationing, ''excess profits'' taxes, policies targeting ''greedy energy companies,'' prohibitions on energy use, and subsidy programs.

Some actions that seemed to be inappropriate may have been desirable if the problem had not been short-lived. For example, synthetic fuel initiatives may have looked prescient had oil prices not collapsed in the mid 1980s.

Estimated costs to the U.S. of oil supply disruptions range from $25 billion to $75 billion per year, and the cumulative costs since 1973–74 total about $4 trillion. Nevertheless, except for several serious disruptions (and then only temporarily), oil prices have risen little in real terms over the past century.

Cost of living adjustment clauses imbedded in many contracts, labor agreements, and government programs (e.g., Social Security) are less visible but important inflation drivers. Price increases generated by oil supply disruptions automatically trigger successive inflationary adjustments throughout the economy, and these complicate monetary policies designed to counter the inflationary effects of the disruption.

The U.S. is currently less oil-dependent (in terms of oil/GDP ratios) than during the 1970s. However, the U.S. is now importing twice as much oil (in percentage terms) as 30 years ago and its transportation sector consumes a larger portion of total oil consumption. Further, by 2000 most of the energy saving trends resulting from the 1970s disruptions (increased energy efficiency and conservation, increased vehicle mpg, etc.) had been captured.

The primary effect of the 1973–74 disruption was oil price increases. The real price of oil peaked in 1981 and has never again reached similar levels.

At present, oil would have to be nearly $80 per barrel and gasoline would have to exceed $3 per gallon to equal real 1981 prices. Even then, however, energy would still be a less significant factor in the U.S. economy because average U.S. per capita incomes have doubled since 1981 and energy is a much smaller component of expenditures.

Nevertheless, over the past 50 years, oil prices have been extremely volatile—more volatile than virtually any other commodity.

APPENDIX III. LIKELY FUTURE OIL DEMAND

Petroleum consumption has been inexorably linked to population growth, industrial development, and economic growth for the past century. This relationship is expected to continue worldwide for the foreseeable future. While the U.S. consumes more oil than any other country—about 20 MM bpd, it represents only 26 percent of world production, compared to the 46 percent of world oil production the U.S. consumed in 1960. Western Europe currently consumes the second largest amount (18 percent) followed by Japan (7 percent), China (6 percent), and the FSU (5 percent), with over 150 other countries accounting for the remaining 38 percent of production.

Energy forecasting is difficult due to the numerous complex factors that influence energy supply and demand. Here we utilize the U.S. Energy Department's Energy Information Administration forecasts of future world oil requirements.

Table A–1 presents summary statistics for the EIA 2001–2025 forecast including 24-year country or country group projections for petroleum consumption, gross domestic product (GDP), and population.

TABLE A–1.—REFERENCE CASE PROJECTIONS, 2001–2025

[Average annual percentage change]

	Petroleum Consumption	GDP (Con. $)	Population
U.S.	1.5	3.0	0.8
W. Europe	0.5	2.0	0.1
China	4.0	6.1	0.5
FSU	2.1	4.2	−0.2
Japan	0.3	1.7	−0.1
Other	2.0	4.0	1.3
World	1.9	3.0	1.0

Oil consumption in China is expected to increase 4 percent a year, and by 2025 China is projected to be the second largest oil consuming country in the world, accounting for 11 percent of total world consumption. The second fastest growing market is projected to be the FSU countries, where petroleum consumption is forecast to increase an average of over 2 percent per year.

The remaining large consumers, including the U.S., Western Europe, and Japan are forecast to experience consumption growth over the 24-year period at or below the world average. The U.S. is forecast to increase oil consumption at a rate of 1.5 percent per year, and by 2025 the U.S. share of world oil consumption is forecast to decline to 23 percent (29.7 MM bpd), while Western Europe's share decreases to 13 percent (14.4 MM bpd). The many countries grouped as ''Other'' above, including India, Mexico, and Brazil, are expected to experience oil consumption growth rates 10 to 30 percent higher than the world average. By 2025, this group is forecast to account for 43 percent of world oil consumption.

In sum, in the EIA reference case, world oil consumption of 80 MM bpd in 2003 is projected to increase to 121 MM bpd in 2025, with the most rapid increases occurring in nations other than the U.S., Japan, or those in

Western Europe. Average annual world oil demand growth is projected as 1.9 percent over the period.

APPENDIX IV. RATIONALES FOR THE WEDGES

A. VEHICLE FUEL EFFICIENCY

The original U.S. Corporate Average Fuel Efficiency (CAFE) timetable, enacted in 1975, mandated a 53 percent increase in vehicle fuel efficiency, from 18 mpg to 27.5 mpg, over the seven years between 1978 and 1985. Average on-road vehicle fuel efficiency began to improve markedly in the early 1980s and continued to improve substantially every year through 1995. It showed little change between 1995 and 1999, and then began to decline gradually due to the shift to greater purchases of light trucks and SUVs. Between 1982 and 1995, average on-road vehicle fuel efficiency increased from about 14 mpg to 20 mpg. In other words, the first major U.S. oil disruption occurred in the fall of 1973; CAFE was not enacted until two years later; the increased mpg requirements did not begin until 1978, and were phased in through 1985; and significant increases in average on-road vehicle fuel efficiency did not occur until the mid- to late 1980s.

From the time world oil peaking occurs or is recognized, it may thus take as long as 15 years until strengthened vehicle fuel efficiency standards significantly increase average on-road fleet fuel efficiency. However, care must be exercised in making extrapolations. Most ''realistic'' enhanced vehicle fuel efficiency standards might not actually decrease future total gasoline consumed in the U.S. due to the anticipated continued increase in numbers of drivers and vehicles. Thus, a new CAFE mandate might decrease the rate at which future gasoline consumption increases, but not necessarily reduce total consumption. Only aggressive vehicle fuel efficiency standards legislation that ''pushes the envelope'' of fuel efficiency technologies over the next two decades (as determined, for example, in the study by the National Research Council of the National Academy of Sciences is likely to actually reduce total U.S. gasoline consumption.

Savings in the U.S. Assuming a crisis atmosphere, we hypothesize an aggressive vehicle fuel efficiency scenario, based on the NRC CAFE report and other studies that estimate the fuel efficiency gains possible from incremental technologies available or likely to be available within the next decade. We assume that legislation is enacted on the action date in each scenario. We further assume that vehicle fuel efficiency standards are increased 30 percent three years later—for cars from 27.5 mpg to 35.75 mpg and for light trucks from 20.7 mpg to 26.9—and then increased to 50 percent above the base eight years later—for cars from 27.5 mpg to 41.25 mpg and for light trucks from 20.7 mpg to 31 mpg; finally, we assume full implementation is assumed 12 years after the legislation is enacted. These assumptions ''push the envelope'' on the fuel efficiency gains possible from current or impending technologies.

On the basis of our assumptions, the U.S. would save 500 thousand barrels per day of liquid fuels 10 ten years after legislation is enacted; 1.5 million barrels per day of liquid fuels at year 15; and 3 million barrels per day of liquid fuels at year 20.

Worldwide Savings. The U.S. currently has about 25 percent of total world vehicle registrations, but consumes nearly 40 percent of the liquid fuels used in transportation worldwide. Since we could not find credible forecasts of the potential impacts of increased worldwide vehicle fuel efficiency standards, we assumed that the impact in the rest of the world of enhanced vehicle fuel efficiency standards will be about equal to that in the U.S. In total, the worldwide impact of increased vehicle fuel efficiency standards would thus yield a savings of 1 million barrels per day of liquid fuels 10 years after legislation is enacted; 3 million barrels per day 15 years after legislation is enacted; and 6 million barrels per day 20 years after legislation is enacted.

Increased vehicle fuel efficiency standards are a powerful way to reduce liquid fuels consumption. However, they required long lead-times to enact, implement, and become effective in the past. On the other hand, their importance and contributions continue to grow over time as older vehicles are retired. We note that a detailed study of these issues and opportunities would be of great value.

B. COAL LIQUIDS

High quality liquid fuels can be made from coal via direct liquefaction or via gasification followed by Fisher-Tropsch synthesis. A number of coal liquefaction plants were built and operated during World War II, and the Sasol Company in South Africa subsequently built a number of larger, more modern gasification based facilities.

While the first two Sasol coal liquids production plants were built under normal business conditions, the Sasol Three facility was designed and constructed on a crash basis in response to the Iranian revolution of 1978–79. The project was completed in just over three years after the decision to proceed. Sasol Three was essentially a duplicate of Sasol Two on the same site using a large cadre of experienced personnel. Sasol Three was brought ''up to speed almost immediately.''

The Sasol Three example represents the lower bound on what might be accomplished in a twenty-first century crash program to build coal liquefaction plants. This is because the South African government made a quick decision to replicate an existing plant on an existing, coal mine-mouth site without the delays associated with site selection, environmental reviews, public comment periods, etc. In addition, engineering and construction personnel were readily available, and there were a number of manufacturers capable of providing the required heavy process vessels, pumps, and other auxiliary equipment. While we have not done a survey of worldwide capabilities to perform similar tasks today, it is our belief that such capabilities are now in much shorter supply—a situation that will worsen dramatically with the advent of a worldwide crash program to build alternate fuels plants. We have therefore attempted to strike a balance between what we believe could be a somewhat slow startup of a worldwide coal liquefaction industry and a later speed up as experience is gained and new plants are built as essentially duplicates of previous plants.

Our coal liquefaction wedge thus assumes that the first coal liquefaction plants in a worldwide crash program would begin operation four years after a decision to proceed. We assume plant sizes of 100,000 bpd of finished, refined product, and we assume that five such plants could be brought into operation each year. We cannot predict where in the world these coal liquefaction plants might be built. Candidate countries with large coal reserves include the U.S. and the Former Soviet Union with the largest, followed in descending order by China, India and Australia. We note that a consortium of Chinese companies has recently signed a letter of intent with Sasol for feasibility studies on the construction of two new coal-to-liquids plants in China.

If U.S. siting and environmental reviews of new energy facilities were to continue to be as time consuming as they are today, few coal liquefaction plants would likely be built in the U.S. On the other hand, China has been quick to approve major new facilities, so coal liquefaction plants in that country might well be built expeditiously and economically. Because there is presently a large international trade in coal, it is not inconceivable that coal-poor countries might become the sites of many coal liquefaction plants using imported coal, possibly even from the U.S.

C. HEAVY OILS/OIL SANDS

As noted, significant heavy oil production currently exists in Canada and Venezuela. While their total resource is estimated to be 3–4 trillion barrels, recoverable oil reserves are estimated to be roughly 600 billion barrels. Such reserves could support a massive expansion in production of these unconventional oils.

In the case of Canadian oil sands, a number of factors would challenge a crash program expansion, such as the need for massive supplies of auxiliary energy, huge land and water requirements, environmental management, and the harsh climate in the region. In the case of Venezuela, large amounts of supplemental energy, inherently low well productivity and other factors will likely pose significant challenges.

We know of no comprehensive analysis of how fast the Canadian and Venezuelan heavy oil production might be accelerated in a world suddenly short of conventional oil. Recent statements by the World Energy Council (WEC) guided our wedge estimates:

''Unconventional oil is unlikely to fill the gap (associated with conventional oil peaking). Although the resource base is large and technological progress has been able to bring costs down to competitive levels, the dynamics do not suggest a rapid increase in supply but, rather, a long, slow growth over several decades.''

''(Extrapolating expectations of TOTAL Oil Company in the Orinoco, Venezuela) overall reserves today would be only ~60 Gb over 30 years, allowing at best 6 MM bpd of production in 2030 if the entire area were put into production.''

''Current estimates put the additional production of Canada (heavy oil) . . . at less than 2 MM bpd in 2015–2025.''

In line with the WEC, we assume the following for our Venezuelan Heavy Oils wedge:

1. Accelerated production might begin three years after a decision to proceed with a crash program. This delay is based on the fact that the country already has significant production underway. Starting from scratch would require much more time.

2. Under business-as-usual conditions assumed by the WEC, Venezuela would have production of 6 MM bpd in 2030—5.5 MM bpd beyond production of 0.5 MM bpd in 2003. If we assume this level of production is achieved 10 years after initiation of a crash program, rather than the roughly 25 years estimated by WEC, then roughly 5.5 MM bpd of incremental production might be achieved 13 years from a decision to accelerate.

3. In contrast to the WEC, we assume that Venezuelan production is not capped at 6 MM bpd but continues to expand for the period covered by our approximations. Note: We ignore the currently extremely unstable political environment in Venezuela and assume that scale-up timing is not hindered by local politics.

Our assumptions for Canadian oil sands are as follows:

1. Again, accelerated production might begin three years after a decision to proceed with a crash program, based in large part on the fact that the country already has significant production underway.

2. Current plans are for production of 3 MM bpd of synthetic crude oil from which refined fuels can be produced by 2030. This is above

current production of 0.6 MM bpd. If we assume this level of production is achieved 10 years after initiation of a crash program, rather than the roughly 25 years targeted by the Canadians, then roughly 2.5 MM bpd of incremental production might be achieved 13 years from a decision to accelerate.

3a. We know of no upper limit on Canadian oil sands production, so for purposes of this order-of-magnitude illustration, we do not assume one.

D. ENHANCED OIL RECOVERY

Because it is impossible to evaluate the worldwide impact of Improved Oil Recovery (IOR) techniques, we can only provide a rough estimate of what might be achieved. We focus on a major subset of IOR technologies—Enhanced Oil Recovery (EOR). While EOR can add significantly to reserves, it is normally not applied to a conventional oil reservoir until after production has peaked. As discussed earlier, the most widely applicable EOR process involves the injection of CO_2 into conventional oil reservoirs to dissolve and move residual oil. Because EOR processes require extensive planning, large capital expenditures, procurement of very large volumes of CO_2, and major equipment for large reservoirs, our simplified assumptions parallel those for our heavy oil and coal liquids wedges.

We assume that the massive application of EOR worldwide will not begin to show production enhancement until 5 years after the peaking of world oil production, paced primarily by the difficulties of procuring CO_2. We further assume that world oil production enhancement due to such a crash effort worldwide will increase world oil production by roughly 3 percent after 10 years. We translate the 3 percent to 3 MM bpd, based on our assumed world oil peaking level of roughly 100 MM bpd.

E. GAS-TO-LIQUIDS

Estimating how fast world Gas-To-Liquids (GTL) production might grow as a result of the peaking of world oil production is an extremely complex undertaking because of the need to consider the total world energy system, its likely growth by country, future energy economics, other resources that compete with natural gas, etc. In a crash program, GTL plants might be built in a number of counties that have large reserves of stranded gas. Once operational, GTL product could be moved to markets around the world by conventional oil product tankers.

Our estimates for a crash program of world GTL production are tempered by the conflicting world demand for Liquefied Natural Gas (LNG), whose export volumes are currently growing at a rapid pace. The tradeoffs involved in estimating the future LNG/GTL balance are complex, and a world crash program in GTL could yield higher or lower volumes than our estimates. Note also that seven countries currently account for almost 80 percent of the world gas export market, and it is not inconceivable that the recently formed Gas Exporting Countries Forum (GECF) might well evolve into a future OPEC-like cartel.

Again, we assume a startup delay of three years before crash program GTL plants might come into operation. Using a base case, business-as-usual production forecast of 1.0 MM bpd in 2015 from the current level of essentially zero, we assume that a crash program might yield the 1.0 MM bpd in 5 years.

F. SUM OF THE WEDGES

A summary of the estimates from the foregoing is presented in Table A–2.

TABLE A–2.—SUMMARY OF CONSUMPTION AND PRODUCTION WEDGE ESTIMATES

Category	Delay until first impact (years)	Impact 10 years later (MM bpd)
Vehicle Efficiency	3	3
Gas-To-Liquids	3	2
heavy Oils/Oil Sands	3	8
Coal Liquids	4	5
Enhanced Oil Recovery	5	3

APPENDIX V. NOTES ON SHALE OIL AND BIOMASS

A. OIL SHALE BY GILBERT MCGURL, NETL

Worldwide resources of oil shale comprise an estimated 2.6 trillion barrels, of which two trillion are located within the United States. The richest deposits, 1.5 trillion bbl with high concentrations of kerogen, lie in Colorado, Utah, and Wyoming. An additional 16 billion barrels of rich but physically different oil shale is found in Kentucky, Indiana, and Ohio. A recent estimate is that, from the Green River deposits, 130 billion barrels of oil may be produced. Technology development on oil shale 'retorting' reached a high point in the late 1970s, with the major oil companies leading the way. The oil price collapse of the 1980s, the dissolution of the synfuels program, and the termination of the Unocal project in 1991 led to the demise of oil shale production in the United States.

A recent study performed by the DOE Office of Naval Petroleum and Oil Shale Reserves advocates a research and development program with a production goal of two million barrels per day by 2020. Production would be initiated by 2011. Traditional technologies for mining and preparation of oil shale ores and for aboveground upgrading have been 'proven' at less-than-commercial scale. Newer Canadian technologies have been tested at demonstration projects in Australia. However, that project, the Stuart upgrading project, is currently suspended pending project re-design. Nonetheless, the same technology has been licensed by operators in Estonia. Technologies for in-situ recovery are newer and less developed. In 2000, Shell revived an oil shale project called ''Mahogany'' in Colorado. Shell aims to test its process until 2010. If successful, the in-situ method would leave heavier hydrocarbons in the shale while producing lighter hydrocarbons and using much less water than traditional methods.

Most Estonian processing of oil shale has been for boiler fuel for electricity production. Small liquids facilities have been operating at ''full capacity'' given recent market oil prices. There are no solid figures for cost in large-scale plants since none have been built. The aborted Australian project estimated $8.50/bbl in operating costs once a commercial plant had been built. The Estonians estimate a break-even point at $21 Brent price (app $23 WTI) and low capacity factor. At higher capacity factors, plants may operate profitably even with prices in the mid-teens.

Besides water use and production, environmental concerns include fine particulates and carbon dioxide emissions. Since the last US oil shale project ceased operation before the implementation of the 1990 Clean Air Act amendments, new emission-control equipment would need to be tested on US shales.

B. BIOFUELS BY PETER BALASH, NETL

Bioethanol is produced as a transportation fuel largely in only two countries. In 2003 the US produced about 2.8 billion gallons and Brazil produced 3.5 billion gallons. All of this ethanol is produced by conversion of starch to sugar and fermentation to ethanol. In the US ethanol represents about 1.4% of the BTU content (2.0% by volume) of gasoline used in transportation. Current costs for ethanol production in the US are said to be $0.90 per gallon, which is equivalent to a gasoline price of $1.35 per gallon. Because of recent increases in energy costs current costs will be somewhat higher. Grain ethanol provides only a modest net energy gain because of the energy required to produce it. USDA calculated a net energy gain of 34% for a modern corn to ethanol plant, but there is considerable controversy over the real efficiency of the process. Most of the energy used to produce ethanol comes from natural gas and electricity. The production of ethanol uses only about 5% of the corn crop in the US. Significant expansion is possible but at some point there might be an impact on food prices.

Cellulosic ethanol is currently being produced only in two rather small pilot plants but is capable of producing about 40% conversion of cellulosic biomass to ethanol while providing all the energy needed for the process and exporting a modest amount of energy as electricity. It is anticipated that successful research may reduce the cost of cellulosic ethanol to about $1.10 per gallon by 2010. If this occurs the potential ethanol to mitigate peaking is high. Using only waste biomass and grass grown on land currently in the conservation reserve could produce 50 billion gallons of ethanol which would be equivalent to 35 billion gallons of gasoline or 17% of current US consumption. This could be achieved without any impact on current food production and at prices only $0.35 per gallon higher than refinery prices for gasoline. Since ethanol has an RON of 130 and a MON of 96 it raises the octane of the gasoline to which it is added and has a premium value as a result.

APPENDIX VI: AREAS FOR FURTHER STUDY

1. ECONOMIC BENEFITS TO THE U.S. ASSOCIATED WITH AN AGGRESSIVE MITIGATION INITIATIVE

Important economic and jobs benefits could result from a concerted U.S. effort to develop substitute fuels plants based on U.S. coal and shale resources and scale up of EOR. The impacts might include hundreds of billions of dollars of investment, hundreds of thousands of jobs, a rejuvenation of various domestic industries, and increased tax revenues for the Federal, state, and local governments. The identification and analysis of such benefits require analysis.

In the short run, the U.S. would be hard-pressed to find adequate physical and human resources to plan, develop, construct, and operate the required facilities. Given that oil peaking is a world problem, it is virtually certain that at the same time the U.S. embarked on an aggressive mitigation program, other major initiatives would likely be undertaken elsewhere in the world. All would require similar types of capital, technology, and human resources, generating additional constraints and inflationary pressures on the U.S. program. Assessment of the impacts of these constraints on the feasibility, costs, and timing of a major U.S. mitigation program merits investigation.

2. OIL PEAKING RISK ANALYSIS: COST OF PREMATURE MITIGATION VERSUS WAITING

The date of world oil production peaking is unknowable, but it may occur in the not too distant future. Large-scale mitigation is needed more than a decade before the onset of peaking if economic hardship is to be avoided. If major efforts were initiated early and peaking was to occur decades later, there might be an unproductive use of resources. On the other hand, mitigation initiated at the time of peaking will not spare the world from a decade or more of devastating economic impacts. A careful analysis of the benefits/costs of early versus late mitigation could provide valuable insights.

3. U.S. NATURAL GAS PRODUCTION AS A PARADIGM FOR VIEWING WORLD OIL PEAKING

The history of U.S. natural gas production is cited as an example of the perils of over-optimistic resource forecasts. A detailed analysis of the North American natural gas history, status, and outlook might provide lessons useful in addressing world oil production peaking.

4. POTENTIAL FOR NON-TRANSPORTATION OIL FUEL-SWITCHING

World non-transportation liquid fuel usage is amenable to fuel switching, thereby freeing up liquids for transportation. If switching were to occur on a large-scale, it would likely take place gradually because other energy substitutes would have to be scaled up to meet the new demands associated with a major shift, e.g., electric power plants built, refineries expanded to produce a different product slate, etc. A detailed study would provide an understanding of how difficult, expensive, time-consuming and productive worldwide non-transportation fuel switching might be.

5. WORLD COAL-TO-LIQUIDS POTENTIAL

Sasol has operational coal-to-liquids (CTL) production plants and is under contract to study the construction of similar facilities in China. An analysis of worldwide large-scale CTL potential could yield a useful estimate of complexity, timing and potential.

6. WORLD HEAVY OIL/OIL SANDS POTENTIAL

Canada, Venezuela, and, to a lesser degree, other countries have potential to massively scale up their unconventional oil production. A better understanding of how quickly scale-up might be implemented, the related barriers, and ultimate potential would help in the understanding the potential contribution of these resources.

7. WORLD EOR POTENTIAL

An analysis of worldwide large-scale EOR potential could provide an estimate of complexity, timing and potential.

8. WORLD GTL POTENTIAL

An analysis of worldwide large-scale GTL potential could yield a useful estimate of complexity, timing and potential. In particular, the likely conflicts between GTL and LNG production could provide a quantitative estimate of likely future use of world stranded gas.

9. WORLD TRANSPORTATION FUEL EFFICIENCY IMPROVEMENT POTENTIAL

It is important that we have the best possible understanding of the U.S. and worldwide potential for the upgrading of transportation fuel efficiency, including possible timing, cost, and savings as a function of time. Excellent data is available on U.S. transportation fleets, but fleets elsewhere in the world are less well described. A careful study is needed.

10. IMPACTS OF OIL PRICES AND TECHNOLOGY ON U.S. LOWER 48 OIL PRODUCTION

Analysis of U.S. Lower 48 oil production since the 1970 peak strongly suggests that oil prices and advancing technology had little impact on the production decline. However, a number of institutional factors also impacted Lower 48 oil production, e.g., allowables (Texas Railroad Commission), price and allocation controls (1970s), free market pricing (since 1981), foreign opportunities for multi-national oil companies, etc. An in-depth understanding of these various influences might provide useful guidance for the future.

11. TECHNOLOGICAL OPTIONS FOR COAL LIQUEFACTION

Current world coal liquefaction R & D is focused on gasification of coal followed by the Fischer-Tropsch synthesis. Other coal-to-liquids processes have been proposed, some of which were tested at relatively large scale. It may be worthwhile to revisit the various options in light of today's technology and environmental requirements to determine if any of them might also have competitive potential.

12. PERFORMANCE OF OIL PROVINCES OUTSIDE OF THE U.S.

There is a strong rationale for using U.S Lower 48 oil production as a surrogate pattern for future world oil production peaking and decline. Other large oil province histories could also yield valuable insights and alternate patterns. Related analysis might provide an improved basis for modeling future world oil production.

13. HOW THE U.S. COULD AGAIN BECOME THE WORLD'S LARGEST OIL PRODUCER.

After the peaking of world conventional oil production, there will be a major world transition from the current world liquid fuel infrastructure. Over time, major conservation and energy switching initiatives will almost certainly be implemented, but the need for liquid fuels will not disappear for at least the remainder of this century because there are no known alternatives for a number of transportation applications. An analysis of the major factors required for the U.S. to return to a position of oil supremacy and oil independence would be enlightening.

14. MARKET SIGNALS IN ADVANCE OF PEAKING

Increases in oil prices and oil price volatility have been identified as two precursors of world oil peaking, but both are likely short-term signals. The identification and character of longer-term signals, if they exist, could be of significant value.

15. RISK OF REPEATING THE SYNTHETIC FUELS EXPERIENCE OF 1970S AND 1980S

One risk of embarking on aggressive oil peaking mitigation is that OPEC might undermine such efforts by dramatically increasing conventional oil production. This could only happen if excess capacity were to exist, which could happen if world oil peaking was many decades away. Were such a dramatic increase in OPEC production to occur, governments would be under pressure to terminate support for their mitigation programs. Related scenarios might worthy of study.

16. EFFECTS OF OIL PRICE SPIKES IN CAUSING U.S. RECESSIONS

Oil price spike have been followed by U.S. recessions, but they are not the only cause of recessions. A detailed study of the role of oil prices and other factors in causing recessions might be worth further study.

UNITED STATES-BAHRAIN FREE TRADE AGREEMENT—MESSAGE FROM THE PRESIDENT OF THE UNITED STATES (H. DOC. NO. 109–71)

The SPEAKER pro tempore (Mr. JINDAL) laid before the House the following message from the President of the United States; which was read and, together with the accompanying papers, without objection, referred to the Committee on Ways and Means and ordered to be printed:

To the Congress of the United States:

I am pleased to transmit legislation and supporting documents to implement the United States-Bahrain Free Trade Agreement (the ''Agreement''). This Agreement enhances our bilateral relationship with a strategic friend and ally in the Middle East region and will promote economic growth and prosperity in both nations.

In negotiating this Agreement, my Administration was guided by the objectives set out in the Trade Act of 2002. The Agreement reflects my Administration's commitment to opening markets and expanding opportunities for American workers, farmers, ranchers, and businesses. The Agreement will open Bahrain's market for U.S. manufactured goods, agricultural products, and services. As soon as it enters into force, the Agreement will eliminate tariffs on all manufactured goods that the United States sells to Bahrain and immediately remove Bahrain's import duties on over 80 percent of U.S. agricultural products. The Agreement is also one of the most comprehensive ever negotiated to reduce barriers to trade in services and will create new opportunities for U.S. services firms.

The Agreement contains procedures that will facilitate cooperation between the United States and Bahrain on environmental and labor matters. The labor chapter of the Agreement reinforces Bahrain's recent legislative actions to expand democracy and improve the protection of worker rights, including trade union rights. Provisions in the Agreement requiring effective enforcement of environmental laws will contribute to high levels of environmental protection.

The approval of this Agreement will be another significant step towards creating a Middle East Free Trade Area by 2013. This Agreement offers the United States yet another opportunity to encourage economic reform in a moderate Muslim nation as we have done through our free trade agreements with Jordan and Morocco. Leaders in Bahrain are supporting the pursuit of social and economic reforms in the region, encouraging foreign investment connected to broad-based development, and providing better protection for women and workers. It is strongly in our national interest to embrace and encourage these reforms, and passing this legislation is a crucial step toward that end.

GEORGE W. BUSH.

THE WHITE HOUSE, *November 16, 2005.*

RECESS

The SPEAKER pro tempore. Pursuant to clause 12(a) of rule I, the Chair declares the House in recess subject to the call of the Chair.

Accordingly (at 9 o'clock and 51 minutes p.m.), the House stood in recess subject to the call of the Chair.

EXECUTIVE COMMUNICATIONS, ETC.

Under clause 8 of rule XII, executive communications were taken from the Speaker's table and referred as follows: