RBR CONSULTANTS, INC.

A CALL TO ACTION

Herschel Specter

ABSTRACT

A Call to Action

The United States faces enormous energy related challenges. By many measures - a significant dependence on imported oil, half the balance of payments needed to pay for oil, high greenhouse gas (GHG) release levels, depletion of national oil reserves, and increases in demand from a growing population - the nation has failed to adequately address energy related issues for decades. There is no room to fail again.

There will be a persistent petroleum challenge. In 2008, when there was zero margin between demand for oil and world supply, oil prices to hit $147/barrel setting off a global recession. Unless we act now, in just a few years insufficient oil is likely to send the United States and others back into a deep recession. Goals of energy independence and mitigating climate change may never be realized unless the United States is "immunized" against all future zero margin petroleum situations.

The world's conventional oil appears to have peaked and started its irrevocable decline. Over the next two to three decades the oil supply will shift towards oil that has been discovered, but not developed, to undiscovered and undeveloped oil. Against this background of growing supply uncertainty there is a growing oil demand from China, India, Brazil and other developing nations. If China consumed, per person, as much as the average American it would need all the oil the world currently produces. Climate change is equally challenging and requires continuous reductions in GHG emissions. Both global issues, energy security and climate change, must be solved, but not one at the sacrifice of the other.

This report describes our energy problem, identifies failed legislation and shortcomings in energy analyses, and then offers a different way forward. This new way forward integrates national security and climate change goals and timetables, describes required major energy transformations, and then lays out an implementation plan.

Implementing this plan could lead to over $11.4 trillion (2008) dollars in oil savings by 2036, the re-industrialization of the United States, cleaner air, greater national security, and significant reductions in greenhouse gas emissions. By 2050 this country could have a low carbon, sustainable energy system, sufficient to meet all our needs. This report is meant to be a working document, a common starting point for all stakeholders, eventually leading to the creation of an enduring national energy plan.

A CALL TO ACTION

Executive Summary

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This report is a *call to action*, and it presents a multi-faceted national energy plan that would address the twin threats of petroleum usage and climate change that pose severe, imminent risk to the U.S. economy, environment and national security. It lays out specific goals and actionable approaches – both low-tech and high-tech – that would allow America to avert this looming crisis. By 2036, implementation of this plan should lead to over $11 trillion (2008) dollars in savings through reduced oil consumption and to the re-industrialization of the United States with cleaner air, greater national security, and significant reductions in GHG emissions. By 2050, or before, this country could have a low CO2, sustainable energy system, sufficient to meet all of our energy needs for centuries, at a price that is affordable.

This would require, of course, a nonpartisan recognition of the magnitude of the energy problems we face, and a concerted effort by our nation's government, business and environmental leaders to galvanize public support behind an ambitious effort to secure our energy future.

It is hoped that the fresh approach advocated here can serve as a common starting point for discussion and action by all stakeholders, eventually leading to the creation of an enduring national energy plan.

A PROBLEM OF WORLDWIDE MAGNITUDE

This is a call to action. The United States is headed into a perfect energy storm, requiring a fresh, clear-headed non-partisan approach to averting that storm. This paper proposes a different way of addressing the problem and a blueprint for adopting a strategy to solve it.

> When oil prices hit $147/barrel in 2008, it precipitated a global recession from which we have not yet fully recovered. Those occurred because there was a zero margin between the world's supply of oil and world demand.

The world economy was severely weakened in 2008 when oil prices hit $147/barrel, precipitating a global recession. Such high oil prices occurred when there was a <u>zero margin</u> between the world's supply of oil and world demand. The recession quickly suppressed demand, creating a temporary margin between supply and demand. However, this temporary margin is eroding and a number of energy experts now predict significant world oil shortages in the next few years. Economic recovery, and the associated increase in oil demand, will hasten the time when the next zero margin situation could occur.

The current and projected demand for oil is tremendous and increasing, as energy use in China, India, Brazil and other developing countries expands with their improving standards of living and growing urbanization. We face a serious threat of future zero margin situations because the world's total supply of conventional crude oil appears to have peaked and has started its irrevocable decline. Unlike past recessions where lowered oil prices speeded economic recovery, high oil prices are here to stay.

Complicating these zero oil margin challenges is climate change with its own set of major economic and environmental difficulties. Many climate scientists attribute worsening climate conditions to the burning of fossil fuels – mostly oil, natural gas, and coal – yet these fossil fuels represent a very large fraction of the energy used in the world today. Greenhouse gas (GHG) levels, as measured in parts per million (ppm) of CO_2 in the atmosphere, have increased from pre-industrial levels of about 280 ppm to 379 ppm in 2005. According to the International Panel on Climate Change (IPCC) the atmospheric concentration of CO_2 in 2005 exceeded the natural range of 180 to 300 ppm experienced over the last 650,000 years. Unless curtailed, climate change is predicted to bring excessive rains in some areas and droughts elsewhere—leading to tens of millions of refugees, dangerously unpredictable weather patterns, extinction of species, a significantly higher sea level, and many other effects.

We face a perfect energy storm: increasing world demand for oil, decreasing world supply of conventional crude oil, the need to significantly reduce the use of fossil fuels, and potentially crippling economic conditions every time the margin between oil demand and supply approaches zero.

Over the past decades, and despite warnings from every President from Nixon to Obama that the U.S. needs to reduce its dependence on oil, our political system has not worked in developing a sustainable national energy plan. In addition to the failure to address our ongoing energy challenges, the lack of a national energy plan also creates enormous uncertainty among those who need to make the large investments necessary to prepare us for a secure energy future.

> The absence of a comprehensive, bipartisan strategy to address our energy future has left the United States in a precarious position.

To address the challenges we face adequately, many simultaneous transformations in our energy system will have to take place. The initial emphasis must go to reducing the risks of oil usage, with greater emphasis on reducing the GHG releases phased in shortly afterwards. But our core strategy must focus on two overriding objectives:

I. The creation of a long lasting, affordable, low CO2 electric power system

II. The development of long lasting, affordable, and sufficient sources of low CO2 liquid fuels

CURRENT APPROACHES CANNOT SUCCEED

In the past few years there have been a number of approaches advocated to deal with our energy future. None have the broad, integrated components necessary to address the overall problem.

For example, the “Drill Baby, Drill” approach relies on the extraction of large amounts of oil from conventional and unconventional sources. The world’s supply of oil, however, is becoming increasingly uncertain. Despite a near tripling of world oil prices, non-OPEC production, which accounts for 60% of the world output, has not increased significantly since 2004. The largest worldwide oil find in the last 40 years, off the coast of Brazil, is estimated to contain 8.5 billion barrels of oil. At the present world consumption rate this would only be enough to last 100 days. According to the International Energy Agency (IEA) the world production of crude oil over the next two to three decades will shift away from today’s oil fields towards oil that has been discovered, but yet to be developed and then to oil that has not even been discovered, let alone developed, like oil wells in very deep water. By 2035, according to the IEA, conventional sources would only represent about 19% of the world’s oil production. Very deep water oil is estimated by some to have low recovery rates, in the 5% to 15% range, and is both risky and very expensive to develop.

> “Drill Baby, Drill” will not provide a sustainable energy future, nor one that would be environmentally acceptable.

While there is increasing supply uncertainty, there is a growing demand for oil from China, India, Brazil and other developing nations. If the Chinese consumed as much oil as the average American, it would need all the crude oil the world currently produces. All nations face the same global problem of increasing oil demand with decreasing certainty of supply. The leaders of tomorrow's world will be those nations that successfully made the transition from fossil based fuels to low CO2 sustainable fuels. The “Drill, Baby, Drill” scenario will not provide a sustainable energy future, nor one that is environmentally acceptable.

A different approach, "Repower America," depends almost exclusively on the rapid deployment of renewable energy. Repower America is a response to climate change concerns. It, too, will not work in and of itself, since it calls for the restructuring of our whole energy system in just 10 years. To illustrate some of its impractical recommendations, Repower America would have solar thermal energy with storage increase by a factor of over 3,300 in this short ten year time period. Repower America assumes that more wind power could be produced in ten years than the American Wind Energy Association says would take 23 years, under optimistic conditions. While the development of renewable energy is a critical piece of the puzzle, it can only be a small piece — at least for the foreseeable future.

> "Repower America" will not work, because it impractically calls for the restructuring of our entire energy system in just 10 years.

In between these extremes are studies by the National Academy of Sciences (NAS), the Department of Energy (DOE) and the Environmental Protection Agency (EPA), which might be thought of as "Business as Usual" approaches. Business as Usual analyses address incremental opportunities and challenges like increasing population levels, expected improvements in vehicular efficiencies, expected domestic petroleum production, etc. but avoid the extreme assumptions found in the "Drill Baby, Drill" and "Repower America" approaches. None of these reviews takes into account the need to simultaneously deal with the threats from insufficient liquid fuels and climate change in a practical, integrated, and timely manner.

For example, the EPA analysis of H.R. 2454, "The American Clean Energy and Security Act of 2009", which was passed by the House in 2009 but is now largely thought to be dormant, showed virtually no change in petroleum use from today through 2050. In a comparatively short time the GHG emissions from burning the EPA projected levels of petroleum would then exceed the limits that would have been allowable under H.R. 2454. Thus, it would not solve either the climate change challenge or the energy security threat.

Another example: The 2010 EIA Annual Energy Outlook (AEO) report projected 9.11 million barrels of oil imported in 2035, only down a small percentage compared to import levels in 2009. GHG emissions were projected to increase by 16% between now and 2035. Moreover, the EIA 2010 AEO projection of a steady supply of oil is at odds with a world which faces increasing oil uncertainty at a time of rapid growth in oil demand. The scenario projected by the 2010 AEO would result in the worsening of our economy and exacerbate the serious challenges of climate change. Like other Business as Usual analyses, the

> Business As Usual analyses are insufficiently incremental, and demonstrate the need to act comprehensively, and quickly.

EIA 2010 AEO projection simply underscores the need to act dramatically, comprehensively, and quickly.

A FRESH APPROACH

In order to deal with the magnitude of the coming energy crisis, this report recommends a different approach entirely to the problem. It was necessary to establish a set of goals, timetables, and plans, followed by a review of energy technologies and systems. The purpose of this approach to an implementation plan was to determine if the available and developing energy technologies could meet the established goals and timetables.

With respect to dependence on petroleum, this report recommends four goals:

1) *Immunize the United States, by 2016, against a near-term recession triggered by the next zero margin oil situation;*

2) *Eliminate all U.S. petroleum imports by 2026;*

3) *Reduce U.S. petroleum use to 3 million barrels per day by 2036;* and

4) *Phase out all U.S. petroleum use by 2050*

With respect to climate change, the report proposes two major goals:

1) *Limit U.S. GHG emissions to 3000 million metric tons/year of CO_2 equivalent by 2036;* and

2) *Re-evaluate and set new U.S. GHG emissions limits by considering the current state of technology and scientific advancements, in 2036.*

The report examines numerous energy technologies, including conservation options, which could be utilized to meet the above energy goals. Many energy sources would have to be redirected towards their long term priority uses. For example, coal's long term priority use is not in generating electricity but in producing liquid fuel, specifically methanol.

Building upon the analysis of available and developing technology, the report draws upon these various technologies to fit them into an implementation plan that would meet the national security and climate change goals and their timetables. This implementation plan includes both "no tech and low tech" ready solutions, in addition to advanced technologies. Actions like car pools, increased use of existing buses, better train schedules, and other steps were identified and their oil reduction potentials were calculated. Further, the role of coal in our energy mix would begin to change from producing electricity to supplying liquid fuel by capturing coal power plant CO_2 and converting it to methanol. This use of CO_2 turns an environmental liability into a national security asset. Excess natural gas power plant capacity would be used to replace coal generated electricity.

Each step along the way takes into account various studies that have evaluated how long it might take to develop certain industries, such as the production of tens of millions of plug-in hybrid vehicles and how quickly alternative fuels, such as ethanol and methanol, might be developed. In parallel with the technologies used at each step to reduce petroleum consumption, estimates are made of the associated GHG reductions.

A thorough analysis of the potential success of the initial implementation plan in meeting the established goals shows that it will fall materially short, an analysis presented at length in the report. In spite of all kinds of conservation actions like better home insulation, more use of public transportation, tens of millions of plug-in and hybrid vehicles, more energy storage, car pools, teleconferencing, converting decommissioned coal plants to make methanol, etc., additional action will be needed. This expansion focuses on the creation of a long lasting, affordable, low CO2 electric power system and the development of long lasting, affordable, and sufficient sources of low CO2 liquid fuels. The report details the steps required to meet the petroleum reduction and climate change objectives.

To illustrate, in a recent MIT study on natural gas, meeting long term GHG limits eventually means replacing natural gas electric power plants with low CO2 sources of electricity. The most promising way to do this is to build evolutionary nuclear power plants constructed in U.S. facilities, but with the low capital costs now available in South Korea and China. Where cost effective, renewable energy sources of electricity, including geothermal, should be part of the electricity mix.

With regard to sustainable low CO2 liquid fuels, converting biomass into ethanol deserves serious consideration, provided that it is agriculturally beneficial, does not complicate the GHG issue, avoids food/fuel conflicts, and is cost effective. This report describes an ethanol demonstration program that should be undertaken to prove that these criteria can be met. Methanol, which would be produced in large quantities by the conversion of CO2 effluent from former electricity producing coal plants, should be further expanded. Moreover, energy studies published by Columbia University have analyzed the use of nuclear energy to convert sea water into methanol. This has the potential to eliminate, worldwide, the need for petroleum with a near-zero CO2 release process. Advanced high temperature nuclear power plants, especially those that can utilize thorium or uranium, could be able to supply methanol from sea water for centuries.

NEED FOR DISCUSSION AND ACTION

The likelihood of severe disruption to our worldwide economy and climate is clear if we do not act quickly, boldly and comprehensively in dealing with the dependence on petroleum and CO_2 emissions. It is hoped that this report's new approach to addressing these issues will spark serious debate and lead to the kind of steps that must be taken.

Acknowledgment

The author of this document is a member of Our Energy Policy Foundation in which he is a Topic Director. The mission of this nonpartisan foundation is to use internet technology to facilitate a transformation in our national discourse on energy policy.

Our Energy Policy Foundation (OEPF) empowers knowledgeable energy experts representing every viewpoint from every sector - industry, academia, government, law, finance, non-profit organizations, think tanks, and more - to participate in and drive public dialogue that will sharpen distinctions, identify points of consensus, and stimulate innovative solutions.

The author wishes to thank the leadership of OEPF for their guidance and encouragement and acknowledge the considerable assistance he received from the large and diverse group of OEPF experts.

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Table of Contents

A Call to Action

Table of Contents

Table of Contents

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1.0 Introduction

The United States faces enormous challenges as it attempts to move towards a post-petroleum future. By many measures: a continuing significant dependence on imported oil, high greenhouse gas release levels, depletion of national oil reserves, and projected increases in demand for energy from a growing population, the nation has failed to adequately address energy related issues for decades. There is no room to fail again.

The United States faces a persistent petroleum threat. In 2008, when there was zero margin between demand for oil and world supply, oil prices hit $147/barrel, setting off a global recession. Unless we act now, in just a few years insufficient oil is likely to send the United States and other nations back into a deep recession. Our goals of energy independence and mitigating climate change may never be realized unless the United States is "immunized" against all future zero margin petroleum situations. Being the world's largest user of petroleum, we are especially vulnerable to oil prices and availability. Since petroleum consumption is the largest producer of GHG in the United States, it is also a major contributor to climate change. Energy security and climate change, both global issues, must be solved, but not one at the sacrifice of the other. However, this analysis shows that the strategy by which one accomplishes these goals is crucial. First emphasis must go to reducing the risks from oil usage which would also result in reducing significant abatement of GHG. Increased emphasis on reducing the release of GHG would come later, based on the best climate science of that time period. This is not a change in goals, but rather a change in strategy on how to achieve these goals.

According to the International Energy Agency (IEA) the world's production of crude oil from currently producing fields appears to have peaked and has started its irrevocable decline. Over the next two to three decades the supply of crude oil will increasingly shift towards oil that has been discovered, but yet to be developed, to oil that has not even been discovered, let alone developed. Against this background of increasing supply uncertainty there is a growing demand for oil from China, India, Brazil and other developing nations. If China consumed, per person, as much oil as the average American, it would need all the crude oil the world currently produces. Unless there is some kind of world order to deal with shrinking supplies of petroleum, much like world efforts to control GHG releases, armed conflict may occur.

Climate change is equally challenging and requires a continuous reduction in GHG emissions. GHG levels, as measured in parts per million (ppm) of carbon dioxide in the atmosphere, has increased from a pre-industrial revolution value of about 280 ppm to 379 ppm in 2005. According to the International Panel on Climate Change (IPCC), the atmospheric concentration of carbon dioxide in 2005 exceeded the natural range of 180 to 300 ppm experienced over the last 650,000 years, based on measurements of this GHG in ice cores. Unless mitigated, climate change is predicted to bring environmental disaster with excessive rains in some locations and droughts elsewhere leading to tens of millions of refugees, higher frequencies of class five hurricanes, loss of species, a significantly rising sea level, and many other effects. It is well to remember that most of New York City and vast areas around the globe are at sea level.

This report provides a comprehensive description of our energy problem, identifies legislation that has failed to solve this energy problem, analyzes the shortcomings of several key energy analyses, and then offers a different way forward. This new way forward establishes goals that address both national security and climate change issues, connects these goals to specific timetables, provides insights on major energy transformations, and then lays out a series of implementation steps. The ability of these implementation steps to meet specified goals is then evaluated. Where there are shortfalls in meeting these goals, remedial steps are offered.

Just as the present oil situation has caused a cascade of problems, its solution would present a cascade of benefits. Many of the issues that divide us today would either disappear or be greatly diminished with a national energy plan that effectively deals with both national security and climate change. This report is intended to be a working document for all stakeholders, leading to the creation of a national energy plan.

2.0 The Overall Energy Problem

There are two energy related pathways that can lead to environmental and human catastrophe. In some ways they seem to be opposites. One threat is the result of insufficient energy and the other threat comes from using energy, specifically from burning fossil fuels which supply about 80% of the energy used today in the United States and a large percentage of world energy use. Insufficient energy, especially liquid fuels, can lead to economic collapse and even armed conflict, while the over-use of fossil fuels can lead to worldwide damage from climate change effects. These twin energy dilemmas have been known for many years. Figure 1, which qualitatively integrates both of these energy threats, was first published in 1982 (reference [1]).

The left side of Figure 1 (energy security issues) was intentionally drawn higher and steeper than the right side (climate change issues). The justification for this is that energy security stresses can escalate far more quickly into global conflict than the build-up of greenhouse gases, leaving less time to take corrective actions, with fewer mitigative opportunities. It appears that the world is heading towards very disruptive petroleum shortages before the severe effects of climate change might be felt globally.

Insufficient energy has environmental effects as well as economic and national security effects. Figure 2 is a photograph of the famous Vienna, Austria woods (reference [2]). In 1919, shortly after the end of World War One, there was a shortage of coal coming into Vienna, Austria during the winter. Rather than freeze to death the Viennese cut down their revered woods. No one could have stopped them. Today insufficient energy has caused poor people to strip forests for their wood, which has led to fatal mud slides and floods during hurricanes, sometimes followed by the spread of cholera. Higher energy prices, principally increased cost for petroleum, drive higher food prices. The combination of higher fuel prices and higher food prices has been destabilizing in many poorer nations in the world.

Both of these pathways to environmental and human catastrophe must be dealt with: not one at the expense of the other. However, the sequence of actions selected to overcome these twin challenges is crucial. This report shows that for the United States, reducing petroleum use and therefore oil imports, should initially have the higher priority i.e., OIL FIRST. There are environmental, economic, and national security reasons that justify assigning a higher initial priority to reducing petroleum use than emphasizing actions that mainly or exclusively address climate change concerns.

Further justification for reducing our use of petroleum comes from the fact that in the United States burning petroleum releases more greenhouse gases (GHG) than burning coal or natural gas (See Figure 3 and (reference [3])). Reducing petroleum use therefore also abates the release of greenhouse gases.

Additionally, reducing GHG releases to very low levels while providing adequate energy will require trillions of dollars. A major source for much of this money could come through reduced importation of petroleum and by avoiding oil shortage initiated recessions and armed conflict. More to the point, unless the U.S. reduces its use of petroleum, it faces economic stagnation or collapse which would prevent it from making further progress on either GHG abatement or energy independence.

Figure 1: Two Pathways to Environmental Catastrophe

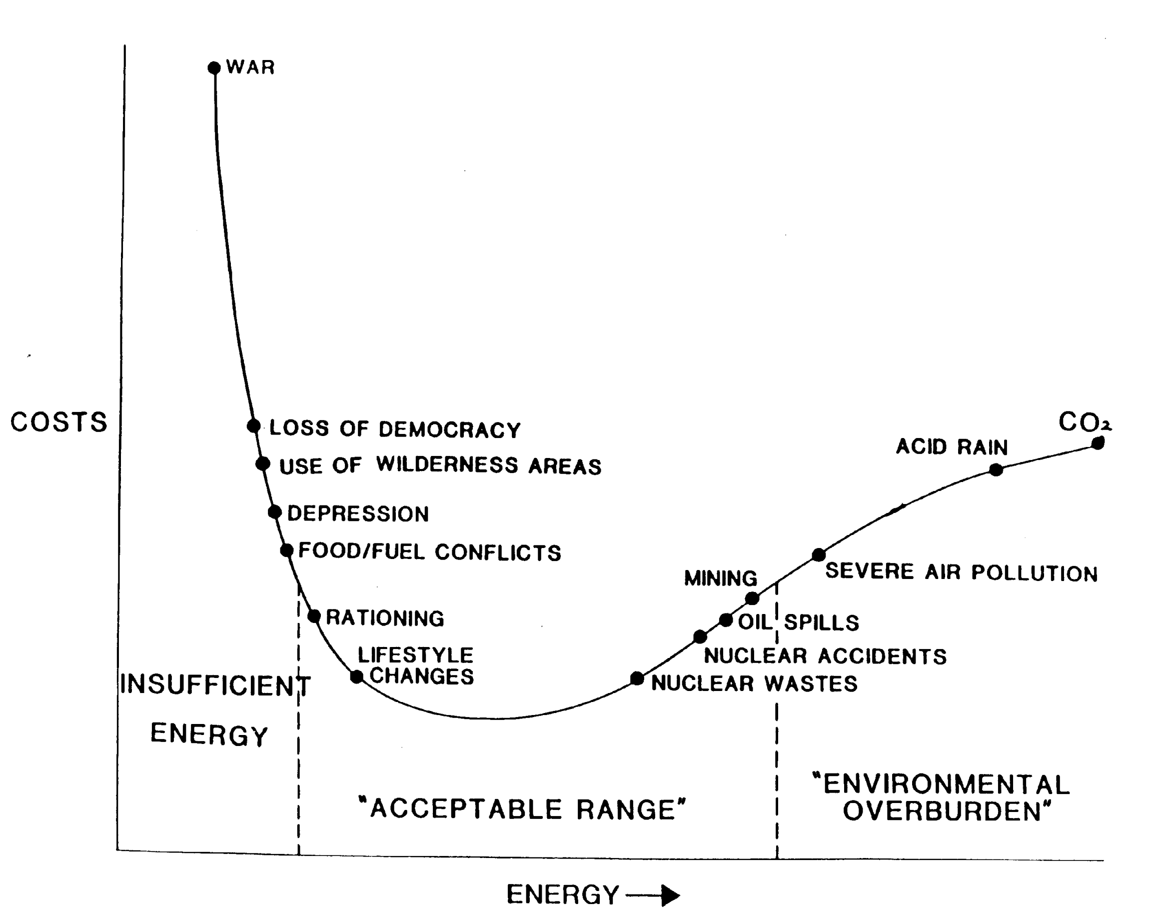


Figure 2: Sources of Greenhouse Gases, 2007

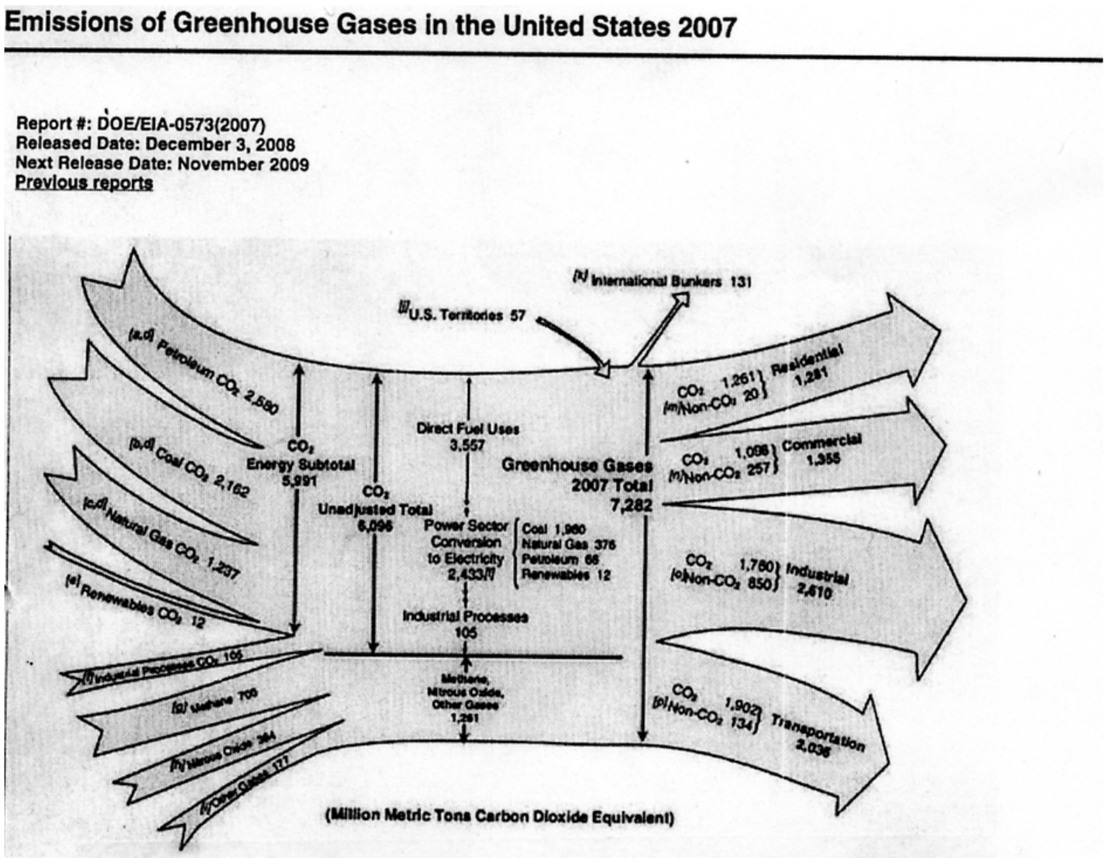


Figure 3: Vienna Woods, 1919

3.0 What Hasn't Worked

3.1 Past History

It is not as if the U.S. federal government has been inactive in passing energy legislation; quite the contrary. A partial list of such energy legislation is presented below:

A. The Synthetic Liquid Fuels Act of 1944

B. The Energy Policy and Conservation Act of 1975

C. The Energy Security Act of 1980

D. Alternative Motor Fuels Act of 1988

E. Energy Policy Act of 1992

F. American Jobs Creation Act of 2004 (Which provided a tax credit for ethanol)

G. Energy Policy Act of 2005

H. Energy Security and Independence Act of 2007

By many measures these acts have failed to protect the environment and the American people. Domestic oil reserves have steadily declined, oil dependency has climbed over the past several decades to a point where over half of the oil we use is imported. Greenhouse gas (GHG) levels, as measured in parts per million (ppm) of carbon dioxide in the atmosphere, has increased from a pre-industrial revolution value of about 280 ppm to 379 ppm in 2005. According to the International Panel on Climate Change the atmospheric concentration of carbon dioxide in 2005 exceeded the natural range of 180 to 300 ppm experienced over the last 650,000 years, based on measurements of this greenhouse gas in ice cores.

These legislative measures largely failed because they did not achieve sustainable bi-partisan support, especially during times of low oil prices, leaving in their wakes a string of started and cancelled energy projects. This inability to create a sustainable energy plan has raised fears in the minds of some who worry that this great democratic society can not compete with centrally controlled governments when it comes to effectively dealing with long term and divisive issues. Further, the lack of a national energy plan creates uncertainty. Uncertainty is an anathema to making the very large investments that are necessary to create a secure energy future for the nation. With such a legislative history it is understandable that energy companies would be very reluctant to invest tens of billions of dollars in projects that may never become operational or yield an acceptable return on their investments.

This lack of a national energy plan has left the nation in a very dangerous position. To illustrate how precarious the United States's position is, two tables are presented below. Table 1 lists the top seven countries in terms of oil consumption in 2007. Table 2 lists the 2007 oil and gas reserves of many companies. The contrast between Tables 1 and 2 is stark. The United States is, by far, the world's largest consumer of oil, yet American oil companies, ExxonMobil and Chevron, rank 17th and 21st, respectively, in total reserves of oil equivalents. The U.S. has become the Saudi Arabia of petroleum consumption.

Table 1: 2007 Oil Consumption, Top Seven Countries

Rank	Country	Barrels of oil/day
1	United States	20,680,000
2	China	7,578,000
3	Japan	5,007,000
4	Russia	2,858,000
5	India	2,722,000
6	Germany	2,456,000
7	Brazil	2,372,000

Table 2: 2007 Oil and Gas Reserves

Rank by 2007 Oil Equivalent Reserves	Company	Liquid Reserves, Millions of Barrels	Natural gas Reserves, Billions of Cubic Feet	Total Reserves (in Oil Equivalent), Millions of Barrels
1	Saudi Arabian Oil Company (Saudi Arabia)	259,900	253,800	303,285
2	National Iranian Oil Company (Iran)	138,400	948,200	300,485
3	Qater General Petroleum Corporation (Qatar)	15,207	905,300	169,959
4	Iraq National Oil Company (Iraq)	115,000	119,940	134,135
5	Petroleos de Venezuela, S.A. (Venezuela)	99,377	170,920	128,594
17	ExxonMobil Corporation (United States)	7,744	32,610	13,318
21	Chevron Corporation (United States)	7,087	22,140	10,870

3.2 Energy Future Analyses and Recent Congressional Legislation

3.2.1 Introduction

In the past few years there have been a number of "Energy Future" analyses and additional legislation has been passed by the House of Representatives to deal with our energy challenges. One such study, called "Repower America", promoted by former Vice President Gore, relies almost exclusively on renewable energy. An opposite approach has been called the "drill baby, drill" approach which would rely on the extraction of large amounts of oil from conventional and unconventional sources. Between these two extreme energy futures there is the National Academy of Sciences (NAS) report called "America's Energy Future" (AEF), studies by the Department of Energy, the Environmental Protection Agency (EPA), the International Energy Agency, and others. In addition to these energy future studies, the House of Representatives passed the "American Clean Energy and Security Act of 2009", also known as H.R. 2454. These energy future studies and legislative efforts appear to have one thing in common: not one addresses the need to deal with both climate change and energy sufficiency in a timely, practical, and integrated way.

3.2.2 The "Repower America" Approach

The Repower America proposal called for a huge energy transformation to a renewable energy future to be accomplished in just ten years, from 2010 to 2020. This study calls for a 3,300 fold increase in solar thermal electric facilities in just ten years. Not only is such a rapid growth rate highly unlikely, these electric power plants would be located in the desert and would not have water available to them to complete their thermodynamic cycle. Repower America assumes that more wind power could be produced in ten years than the American Wind Energy Association says would take 23 years, under optimistic conditions. A large number of other practical defects in this study that have been identified elsewhere (reference [4]) and no further discussion is presented here. While a low carbon sustainable future is most desirable and is a long term goal of this report, it is very doubtful that the Repower America plan would get us there and the price of failure would be extremely high.

3.2.3 The "Drill, Baby, Drill" Approach

The "drill baby, drill" approach is the opposite of the "Repower America" and is based on the assumption that continued exploration for unconventional oil plus advanced recovery methods for existing oil wells would provide sufficient oil for long periods of time. Even if such large amounts of oil were available, they could not be fully consumed without exceeding proposed GHG limits.

The United States will not solve its oil dependence problems by assuming that there will be massive increases in domestic oil supplies. The total U.S. crude oil proved reserves (lower 48 states onshore + federal offshore + Alaska) decreased between the years 1977 to 2008 from about 32 billion barrels to 19.1 billion barrels, as shown in Figure 4, or -1.9%/yr, on average. As stated by the Energy Information Administration (EIA) (reference [5]) "...even though discoveries of crude oil rose for the third year in a row, proved reserves of crude oil fell by more than 10 percent" (in the year between 2007 and 2008).

During this time period domestic oil production was also falling. According to Oak Ridge National Laboratories, the average annual decrease in domestic oil production between 1960 to 2008 was -3.2%/yr. Not only was the annual average production declining, the rate of decline was accelerating. If total petroleum consumption remains nearly constant for several decades, declining domestic crude oil reserves would inevitably lead to total U.S. dependency on imported oil. The lower 48 states have had thousands of oil wells drilled in it, so much so that the average distance between oil wells is now smaller than the size of a big oil field. This implies that finding many large new oil deposit within the lower 48 State's land area is unlikely.

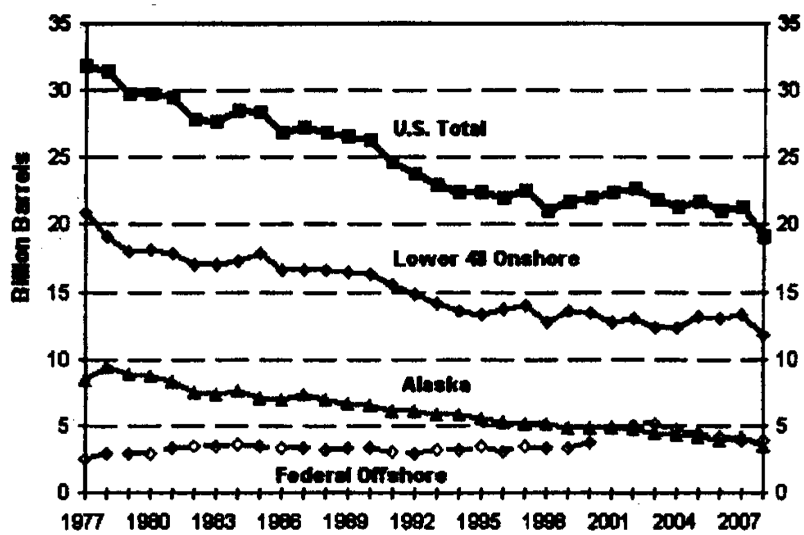
In 2009 there was an increase in the total proved reserves of 3.7 billion barrels of crude oil plus condensate of which 1.54 billion came from new discoveries.This brought the proved crude oil and condensate reserves up to 22.3 billion barrels, about where it was in 2006. Some of this increase was due to higher oil prices which made pursuing more expensive oil economic and some was due to improved technologies. Advanced recovery techniques have recently been successful in extracting more domestic oil, using drilling techniques similar to the shale gas drilling technologies.

While this additional domestic oil is welcome, to gain some perspective on this addition one can compare this increase in reserves of 3.7 billion barrels of oil to the reserves in the countries listed in Table 2. For example, the 2007 liquid reserves of Saudi Arabia, as shown in Table 2, was about 260 billion barrels of oil.

One bright spot in domestic oil production is the Bakken formation in North Dakota. Some have speculated that vast amounts of oil can be recovered from this area. However, the U.S.Geologic Survey estimates that there are 3.0 to 4.3 billion barrels of technically recoverable oil, with a mean value of around 3.65 billion barrels. At present rates of crude oil imports near 10 million barrels per day, or about 3.65 billion barrels per year, the Bakken formation would likely be equal to about one year's worth of imports.

Domestic enhanced recovery and developing unconventional oil will partially help but it will not overcome our energy dependence. The "drill baby, drill" scenario will not provide a sustainable energy future nor one that is environmentally acceptable.

Figure 4: U.S. Crude Oil Proved Reserves, 1977-2008



Source: EIA / U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 2008

3.2.4 The "Business-as-Usual" Approach-Environmental Issues

Then there are studies that avoid the above extremes. An example of a more balanced approach is the Annual Energy Outlook (AEO) published by the Department of Energy's Energy Information Administration (EIA). The 2010 AEO reference case projected 9.11 million barrels of imported oil per day (MB/D) by 2035 compared to 9.44 MB/D in 2009. With regard to CO_2 emissions, the 2010 AEO reference case prediction for 2035 actually exceeds present release levels. In one sense this analysis is worse than either extreme group's analysis, it doesn't address either energy security or climate change. Further, this "Business-as-Usual" type analysis is at odds with our actual energy history which has seen a series of economic recessions brought on by high oil prices. According to studies performed at the Oak Ridge National Laboratory, "Most of the oil price shocks were followed by an economic recession in the United States" The EIA 2010 AEO projection is also at odds with world conditions which faces increasing oil uncertainty at a time of rapid growth in oil demand from many developing nations and from the serious challenges of climate change.

Even if, somehow, a "Business-as-Usual" energy future could be achieved during the next 25 years, the cost for petroleum would come to an estimated $25 trillion (2008) dollars, based on an assumed constant price of $120 (2008 dollars)/barrel. This figure includes the cost for both domestic and imported oil, the cost of health effects due to burning oil, and the cost of using our armed forces to defend our oil supply, short of warfare. If one adds the additional costs associated with periods of oil related recessions, the total comes to, approximately, $34-35 trillion (2008) dollars. None of this money would be available for mitigating climate change threats or for investing in technologies that would reduce our oil usage.

The EIA 2010 AEO projection and others like it won't work either.

3.2.5 ANALYSIS OF CONGRESSIONAL CLIMATE CHANGE LEGISLATION

Because the two extreme energy futures of "Repower America" and "Drill Baby, Drill" and the more balanced "Business-as-Usual" futures do not look promising, attention now focusses on Congressional legislation, specifically H.R. 2454, the "American Clean Energy and Security Act of 2009".

H.R. 2454 is the legal embodiment of analyses performed by the IPCC. The IPCC performed various sensitivity studies with their climate change computer model to determine how different GHG release levels might affect the environment, such as different sea levels as a function of GHG releases. Reports by the International Panel on Climate Change and many others have lead to a world-wide concern that rising greenhouse gas (GHG) levels will lead to enormous environmental damage. As climate change occurs, many scientists predict it will threaten world catastrophe with huge areas of human habitat flooded by rising sea levels, accelerated loss of species, increased frequencies of category five hurricanes, droughts in some areas and excessive rainfall in other areas, food supply challenges, hundreds of millions of displaced persons, and other severe effects (reference [6]).

H.R.2454 seems to have set GHG limits based on those IPCC analyses on the low end of environmental damage.

The EPA was tasked with the analyzing this piece of legislation. Because the time allotted to EPA to perform this task was very short, EPA relied on sensitivity studies at hand from the EIA. The result of this was that the EPA analyses showed virtually no change in petroleum use through 2050 for the six scenarios it examined. However, if one calculates the GHG emissions due to just petroleum in any of these six scenarios, it becomes apparent that there is a disconnect between the purpose of H.R.2454 and the EPA analyses of H.R.2454. In a comparatively short time the GHG emissions from burning the EPA projected levels of petroleum would exceed the allowable limits in H.R.2454.

This report presents a similar analysis using the petroleum levels in the NAS document "America's Energy Future" and found that H.R.2454 GHG limits would be exceeded <u>by 2030,</u> even if one assumes that no GHG releases came from coal and from natural gas. A slightly more realistic analysis using just 20% of today's coal and natural gas advanced this cross-over time to 2025.

The EPA analyses of H.R. 2454 only dealt with the right half of Figure 1, i.e., the climate change half. Figure 6 is an EPA plot of the GHG limits contained in this energy bill and the projected GHG releases corresponding to the Department of Energy's Energy Information Administration's (EIA) Annual Energy Outlook report for 2009. The EIA projected release of GHG and those required in H.R.2454 are in conflict. The GHG release limits in H.R. 2454 are far below EIA's 2009 projected numbers, underscoring the difficulty faced by trying to achieve such large GHG reductions. Although it was Congress that called on EPA to analyze H.R.2454, which then showed a conflict between this legislation and GHG projections by the Department of Energy's EIA, it is not clear that any effort was made to resolve this conflict. To further compound this confusion, these EIA "Business-as-Usual" projections and more recent ones have their own difficulties in that they do not look to be implementable on environmental, economic, and national security grounds, as discussed later.

It is unlikely that H.R. 2454 will ever be put into practice as it is written now. H.R. 2454 calls for about an 80% decrease in CO_{2e} by 2050. Here the subscript "e" notation stands for the word "equivalent". Besides CO_2 there are a number of other gases, like methane, that are also contributors to greenhouse effects. Based on their comparative effect per molecule these other greenhouse gases are expressed in terms of equivalent CO_2 molecules. In 2007 these other gases contributed about 18% of the total CO_{2e} release. In order to get an 80% reduction in CO_{2e} without reducing these non-CO_2 greenhouse gases, the burning of virtually all fossil fuels would have to be eliminated.

The EPA is not alone in predicting a high consumption of petroleum for several decades by the United States. A study by the National Academy of Sciences' "America's Energy Future" (AEF) (see Reference 5) also predicts continuing high levels of petroleum use. To quote AEF's Figure 2.1, "Combining the projected growth in vehicle fleet size with potential savings results in only slightly higher gas (*gasoline*) consumption in vehicles in 2020 and 2030 than exists today". According to the AEF report, in 2007 a total 14 million barrels/day of gasoline equivalent consumed in the transportation sector. The AEF report's reference scenarios (Table 2.1.3) projected that the consumption of gasoline in the transportation sector would be 16 million barrels/day by 2020 and 17 million barrels/day by 2035. These projections are based on EIA projections. However, if significant efforts are made to improve light duty vehicles, gasoline use might be reduced to 11.6 million barrels/ day by 2020 and 10.4 million barrels/ day by 2035, according to the AEF. In other words, the AEF analyses show no to modest decreases compared to today through 2035 in oil consumption in the transportation sector. America's energy future, based on the AEF report, would mean continuing large oil imports through 2035 and likely well beyond that.

These EIA, EPA, and NAS energy studies all project a continuing high consumption of oil in the transportation sector because of our petroleum based individual internal combustion engine vehicle oriented society. In these studies expected significant improvements in vehicle efficiency would be offset by an increasing population, slow turnover of our fleet of vehicles, assumed more miles driven per year per person, lack of adequate public transportation, and other factors. A 2009 MIT transportation analysis of light duty vehicles (reference [7]) compared fuel consumption in year 2000 to that projected for year 2035. In 2000 some 503 billion liters of gasoline equivalent were consumed by light duty vehicles (LDVs). If no improvements in fuel efficiency were implemented, this MIT analysis projected a rise to 765 billion liters of gasoline equivalent by 2035. However, even with a number of efficiency improvements, this same analysis projected that 594 billion liters of gasoline equivalent would still be needed by 2035, thereby somewhat exceeding the year 2000 consumption. In this energy future analysis we would be working hard to just stand still.

Analyses presented here show that the GHG releases from such AEF predicted petroleum consumption would, **by 2030,** defeat the goals of H.R. 2454 even if 100% of the releases of GHG from coal and natural gas were eliminated and GHG abatements were achieved in non-transportation uses of petroleum and in non-CO_2 greenhouse gases. This analysis assumed, as others have, that the energy efficiency of U.S. vehicles would be significantly improved. A slightly more realistic analysis showed that even if just 20% of today's GHG releases from coal and natural gas were permitted, the limits set by H.R. 2454 would be overcome about five years sooner, by **2025**. If 50% of today's GHG releases from coal and gas were permitted, the limits in H.R. 2454 would be exceeded in **less than ten years**. In effect, the EPA analysis of H.R. 2454 showed that the goals of this climate change energy bill and continued high consumption of petroleum are incompatible.

One important ramification of this analysis is its effect on the policy debate about carbon taxes versus a cap and trade approach to reducing GHG releases from coal and gas electric power plants. Neither policy option has much value unless petroleum use is sharply reduced. Regardless of which climate change policy option or combination of options the nation chooses, if any, it would be overcome in a few years unless petroleum use is simultaneously reduced. Congressional actions limited to only reducing GHG emissions from fossil fueled electric power plants are doomed to fail to adequately address climate change issues. This observation underscores the need to work on both the left and right sides of Figure 1 in an integrated way.

Figure 5: EPA Analysis of H.R. 2454

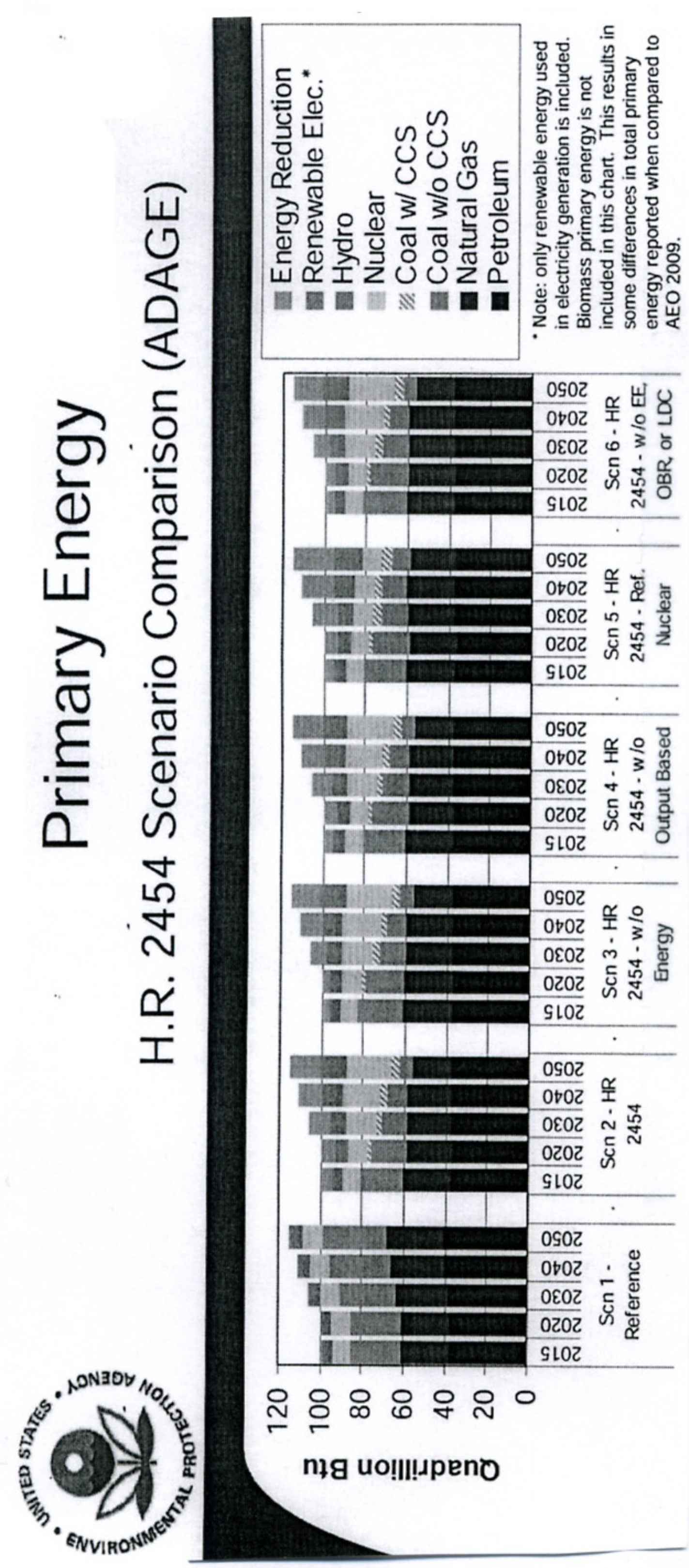
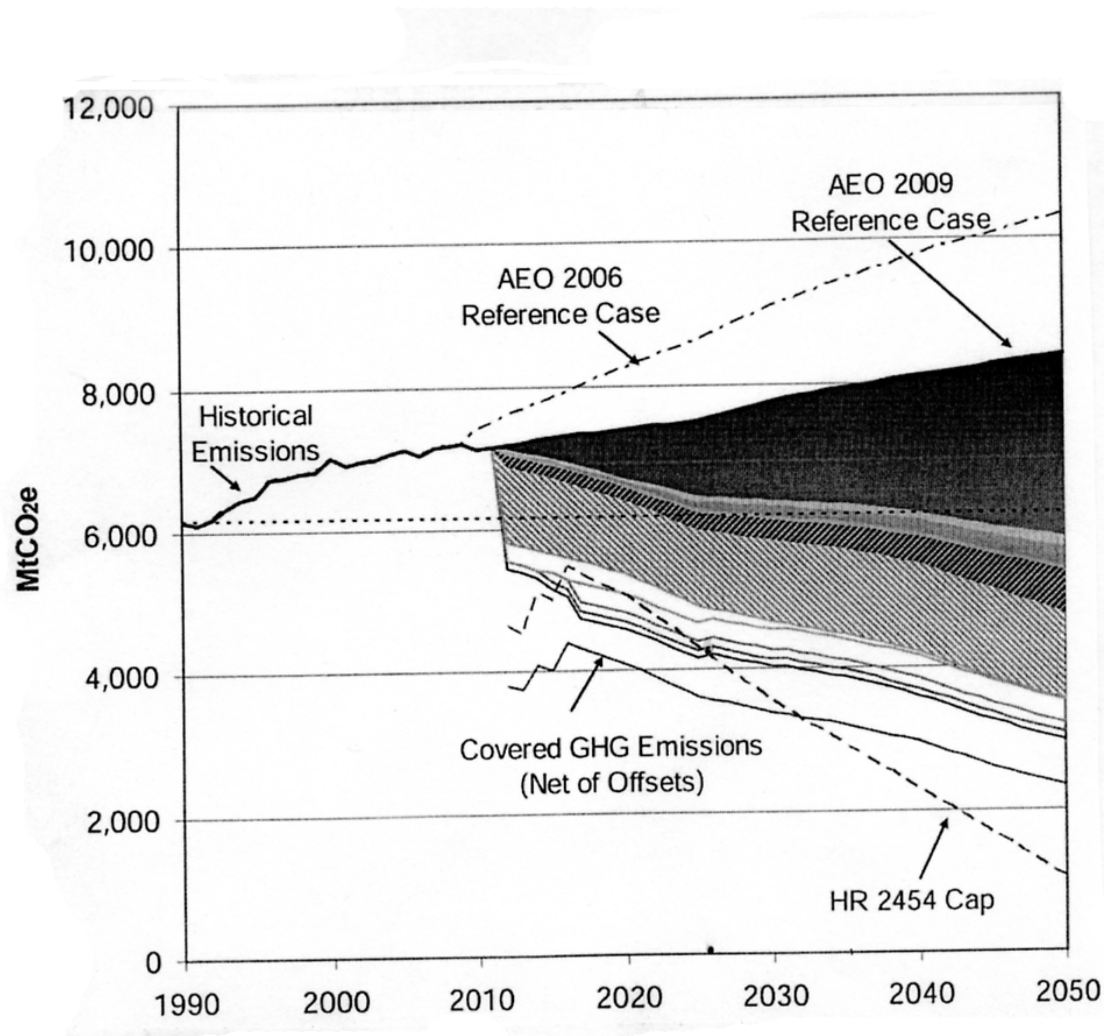


Figure 6: EPA Plot of GHG Limits vs. Time Based on H.R.2454

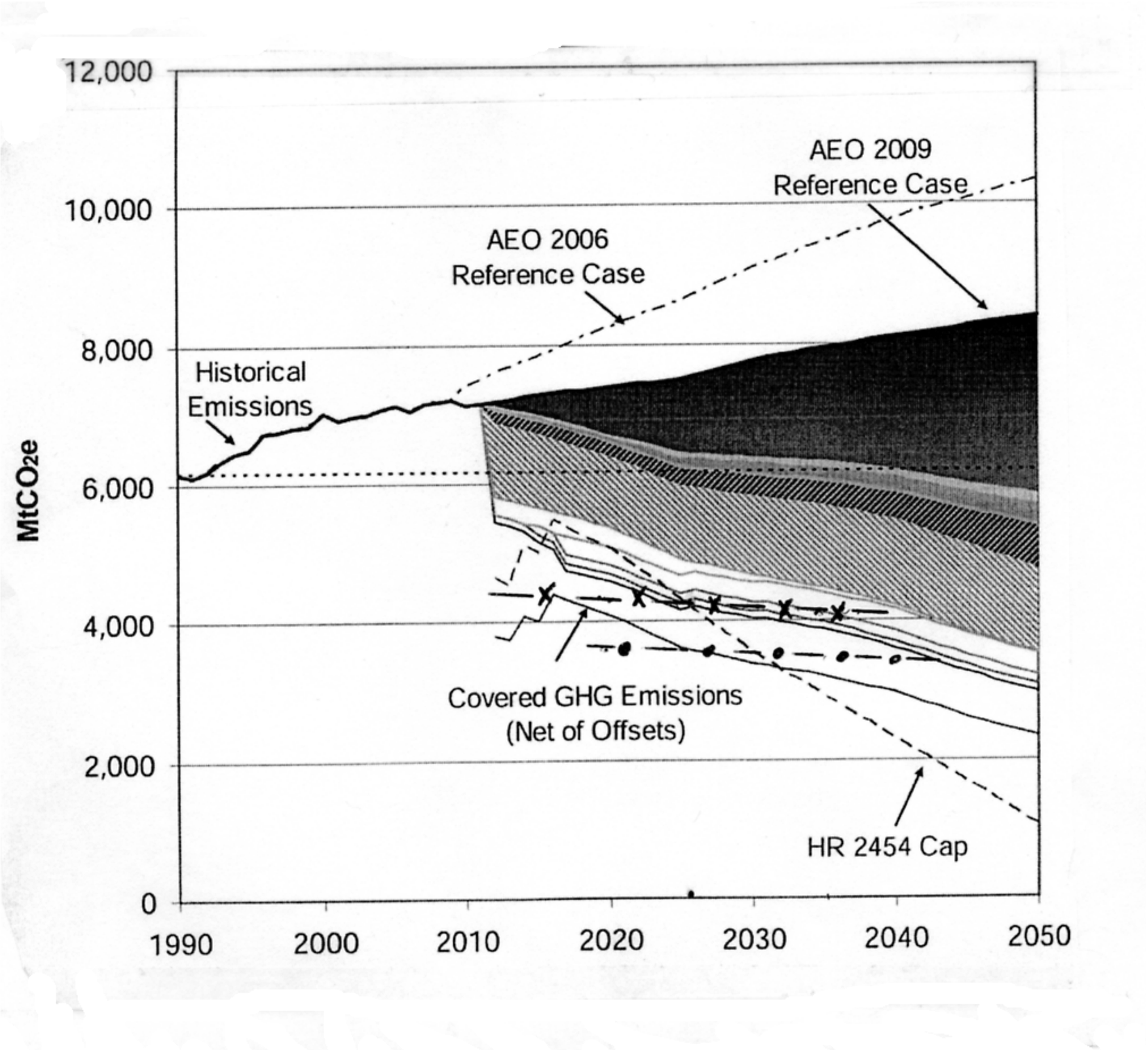


In addition to comparing H.R. 2454 to its EPA analysis, an environmental analysis of the AEF report was made by comparing its projected greenhouse gas releases to the limits set in H.R.2454. Table 3 displays measured releases of greenhouse gases in the United States from petroleum and from non-CO_2 greenhouse gases for 2007 and projected GHG values for 2020 and 2035 based on AEF Table 2.1.3 reference petroleum use projections. Using AEF figures, the 2020 petroleum consumption in transportation, and therefore releases of GHG, would be 1.14 times larger than those in 2007 and 1.21 times larger those in 2007 in year 2035. In 2007 some 2,025 million metric tons of CO_{2e} (carbon dioxide equivalent) were released from our transportation sector. (See Figure 2).

It was further assumed that progress was made on reducing the emission of GHG from non-transportation uses of petroleum and in reducing the releases of methane, nitrous oxide, and other non-CO_2 greenhouse gases. Specifically, it was assumed that by 2020 there would be a 20% decrease and by 2035 a 25% decrease, relative to 2007, of both non-transportation uses of petroleum and releases from non-CO_2 greenhouse gas sources. Table 3 then compares these GHG release rates to the limits set by H.R.2454. It is noted that even if greenhouse gases from <u>all coal and natural gas sources</u> were eliminated, even if significant actions were taken to make light and heavy duty vehicles far more energy efficient, and with 20% to 25% reductions in the release of GHG from the non-transportation uses of petroleum and from other non-CO_2 greenhouse gases, H.R. 2454 limits would be exceeded by around **2030**. (See Figure 7).

Today coal produces nearly half of our electricity. Natural gas produces close to 20% of the electricity and also provides space and hot water heating, etc., and is used in various industrial processes. As stated before, leaving just 20% of the 2007 coal and natural gas GHG release rate cause climate change legislation to be exceeded five years sooner, i.e., by about year **2025**. Leaving 50% of the GHG 2007 releases from coal and natural gas would result in H.R. 2454 limits being exceeded in less than ten years, if petroleum use matched that projected in the AEF or EPA analysis.

Figure 7: H.R. 2454 CO_{2e} Limits and AEF Petroleum Releases



LEGEND

Table 3, No Coal or Gas	—— • ——
Table 3, 20% Coal and Gas	—— x ——

Table 3: Millions of Metric Tons/year of CO_{2e} Released

1. **No Coal or Natural Gas GHG Contribution**	Year 2007	Year 2020	Year 2035
From petroleum used in transportation sector. (2020 and 2035 GHG numbers based on AEF Table 2.1.3)	2025	2309	2450
From petroleum for non-transportation uses. Based on EIA 2007 petroleum data, with assumed 20% and 25% reductions by 2020 and 2035, respectively. [More detailed analyses in Section 6 gives a reduction of about 250 million metric tons/year by 2036]	545	436	409
Non-CO_2 greenhouse gases (Based on EIA 2007 data, with assumed 20% and 25% reductions, by 2020 and 2035, respectively.	1261	1009	946
Total CO_{2e} from petroleum and non-CO_2 GHG.	3831	3754	3805
H.R. 2454 CO_{2e} limit	N/A	5000	3000
Percent of H.R. 2454 limit, no coal or natural gas GHG contribution.	N/A	0.75	1.27
2. **With a coal and natural gas GHG contribution equal to 20% of the 2005 release amount.**	Year 2007	Year 2020	Year 2035
20% of 2007's coal and natural gas GHG releases.	N/A	680	680
Total CO_{2e} from petroleum and non-CO_2 gases + 20% of 2007's coal and natural gas GHG releases.	N/A	4434	4485
Percent of H.R. 2454 limit with 20% of coal and natural gas 2007 GHG releases.	N/A	0.89	1.50
3. **With a coal and natural gas GHG contribution equal to 50% of the 2005 release amount.**	Year 2007	Year 2020	Year 2035
50% of 2007's coal and natural gas GHG releases.	N/A	1700	1700
Total CO_{2e} from petroleum and non-CO_2 gases + 50% of 2007's coal and natural gas GHG releases.	N/A	5454	5505
Percent of H.R. 2454 limit with 50% of coal and natural gas 2007 GHG releases.	N/A	1.09	1.84

Those who seek to shut down coal plants on environmental grounds but do not account for the GHG releases from petroleum present an incomplete argument.

In conclusion, significant reductions in petroleum use are justified on environmental grounds in order to meet proposed GHG release limits, i.e. OIL FIRST.

3.2.6 The "Business -as-Usual" Approach-Economic Issues

3.2.6.1 Introduction

Section 3.2.5 showed that significant oil consumption reductions are required to meet proposed GHG release limits. This section shows that significant oil consumption reductions are also required to prevent economic collapse. The impact of oil consumption on the US economy is examined at three levels; a typical "Business-as-Usual" scenario, a much more difficult scenario with frequent and severe shortfalls in the availability of adequate oil supplies and a final, catastrophic scenario, where shortages are so acute that armed conflict breaks out.There may not be clear boundaries among these three scenarios since one scenario could readily evolve into a more challenging one.

Before discussing the economic impacts of petroleum consumption it is important to clarify some aspects of the world oil situation. Questions like "How long will it before the world runs out of oil?" and "When will conventional oil production peak?" have spurred debate. Yet these questions may be of secondary importance. Long before the world runs out of oil (conventional plus non-conventional) either a U.S. post-petroleum future will have to be in place or the effects of major climate changes and/or armed conflict over remaining critical resources would have occurred. Nature will not wait for people to cut back on their releases of GHG. People and nations will not wait until a critical resource is exhausted before they use force.

Many oil experts believe that conventional oil production has already peaked. The precise moment that conventional oil will or has peaked is not of central importance. We have already seen major recessions because of high oil prices prior to reaching peak oil production levels. This can be seen graphically in Figure 8 (reference [8]).The world has also seen armed conflict over oil shortages. An oil embargo by the United States on Japan, when the US was a major oil exporter, was a factor in the bombing of Pearl harbor, well in advance of conventional oil reaching its peak production. Conversely, if handled properly, dire consequences can be avoided in a post-peak conventional oil time period, provided there is a margin between supply and demand.

The time of peak conventional oil production is an interesting moment in history, but other parameters are more important. The most important parameter to watch is oil shortfalls: their possible frequency, duration, severity, and which nations are most affected by them. A shortfall is defined as the difference between supply and the demand. Demand here includes that which is met with available supply plus that which would have been met if supplies were fully adequate and affordable. Prior to a shortfall there may be a significant run-up in the price of oil.

3.2.6.2 A TYPICAL "BUSINESS-AS-USUAL" SCENARIO

A typical "Business-As-Usual" scenario assumes that adequate oil from conventional and unconventional sources is available at market prices, at least through 2035. No oil shocks from gaps between supply and demand are considered nor any armed conflict.

The EIA Annual Energy Outlook for 2010 reference case presented in Table 4 predicts a cost of $133/barrel (in 2008 dollars) by 2035. This would be about $224/barrel in nominal dollars. It is assumed in this report that for the 24 years between 2011 and 2035 the time averaged price of oil, in 2008 dollars, will be **$120/barrel**. In 2009 the U.S. petroleum consumption was 18.8 MB/D with 9.7 MB/D, 52%, of this petroleum imported.The percentage of oil supplied by imports today is now slightly below 50%, partially due to poor economic conditions and partially due to an uptick in domestic oil production. As the economy improves oil consumption is likely to rise. Table 2.1.3 of the AEF report projects that the United States would continue to consume oil, through 2035, at a rate similar to or higher than that of 2007. If this rate of imports were continued for 25 years at $120/barrel, the total cost would be, **approximately, $11 trillion (2008) dollars**. This is just for a constant import rate of 9.7 MB/D. The balance of the nation's oil bill would come to another $**10 trillion (2008) dollars**.

There are two other major costs that deserve to be considered. There is the national defense costs related to protecting our oil supplies. At a minimum this cost is about $67.5 to $83 billion (2008) dollars per year (reference [9]) not including the costs of actual warfare. What in not accounted for here is all the fuel consumed by the military, which is considerable and very expensive, estimated to cost about $400-500/gallon in combat zones. As the need for the militarily to protect our foreign sources of oil decreases, less oil would be consumed yielding further savings. Once no oil has to be imported considerable savings would occur. In addition to the savings from the military, estimates have been made by the National Academy of Sciences (reference [10]) of the cost of the 2005 health effects caused by our energy system. These health costs from energy use are estimated to be $132 billion (2008) dollars / year of which some $62 billion (2008) dollars/year are attributed to transportation, i.e., to the use of petroleum. The total cost of imported oil, the oil related portion of our national defense effort and transportation (petroleum) related health effects for the next 25 years would, conservatively, come to about **$14 to 15 trillion (2008) dollars**. The total oil bill from domestic and imported sources, plus national defense plus health effects would be a staggering **$25 trillion (2008) dollars for a typical "Business-as-Usual" scenario.**

An economic tipping point might be defined as when a person, business, or country has accrued such a large debt that the interest on this debt exceeds its ability to generate enough new revenue to pay off this interest. At that point the debt will grow regardless of any efforts and bankruptcy would have to be declared. The question here is would the cost of importing petroleum according to the AEF projections of petroleum use, plus other energy related costs, result in crossing an economic tipping point? On 9/30/2009 the national debt was slightly over $10 trillion dollars and a year later close to $12 trillion dollars. Since the present debt level has already put the US economy into jeopardy, petroleum costs around $25 trillion (2008) dollars over the next 25 years, could possibly cause an economic tipping point to be exceeded. Further, these $25 trillion (2008) dollars do nothing to reduce oil imports or decrease the release rate of GHG. On the other hand this $25 trillion (2008) dollar expense would be spread out over 25 years and one might argue that this could be tolerated. It comes to about a trillion dollars per year for the next 25 years if petroleum consumption remains essentially flat as predicted in a typical "Business-as-Usual" scenario.

The above analyses are based on comparatively modest increases in the price of oil. Since oil has briefly reached $147/ barrel already, it is plausible that oil might reach as high as $200 (2008) dollars /barrel between now and 2035. At $200/ barrel gasoline would cost between $8 to $10 dollars per gallon. If one assumes that a family of four with two drivers average a combined 20,000 miles per year (say with one driving a pickup truck and the other a small crossover), their fuel costs would come to about $8000/year. At these costs a mean income family could not afford to drive to work with such a use profile and price and other means for transportation, like car pools and mass transportation, would be necessary. In addition to the costs for gasoline, high oil prices directly affect the cost of food and other essential commodities. These additional costs have not been accounted for in this report.

Alan S.Blinder, former vice chairman of the Federal Reserve, estimated (reference [11]) that the large drop in oil prices from its 2008 peak of near $147/barrel saved Americans about $300 billion dollars in just one year. Blinder cautiously assumed a drop in oil price of about $60/barrel,i.e., from $100/barrel to $40/barrel. If a similar $60/barrel savings could be repeated each year it would be like an annual stimulus bill that did not add to the national debt. Another way to look at Blinder's analysis is that reducing our importation of oil would save the nation a vast sum of money which could then be dedicated to further oil reduction efforts and to GHG abatement actions. Reduced oil imports would not only save money directly because we would purchase fewer barrels of oil, it would also moderate the price of oil. The combined effect would be fewer imported barrels of oil at a lower price per barrel.

The Blinder comment raises other questions about costs. In many purchasing decisions comparisons are made between goods or services that compete, with the lower cost item usually chosen. However in a more complex situation where normally competing goods and services both reduce costs of a third item, then it might be advantageous to purchase both the lowest and the next lowest good or service. For example, suppose that both wind power and nuclear power compete to produce carbon free electricity that would be used by electric vehicles which then reduce oil usage. Suppose further that the cost of electricity from the nuclear plants was lower than from wind power. Under normal economic practices the nuclear plants would be chosen over the wind power sources. However, all systems have restraints on how quickly they can be put into place. If the combination of nuclear power and wind power reduces oil use more rapidly than using nuclear power alone, then purchasing electricity from the higher wind power sources is also justified, provided that the additional cost for windpower is offset by reduced costs for oil.

This report emphasizes OIL FIRST and this has ramifications for economic decision making. System A may be more economical when compared to System B, but is it more economical than implementing Systems A+B? Orienting decision making based on the most rapid reduction of oil use leads one to consider optimum combinations of systems and technologies and each system's implementation limitations. Further, the OIL FIRST strategy has implications for the use of government subsidies and loans. The distribution of government money into subsidies and loans should be influenced by the potential ability of a financially supported activity to reduce the cost of oil.

The AEF report is akin to a “Business-As-Usual” approach. In spite of accounting for projected vehicular efficiency improvements, the AEF bottom line is that oil dependence would continue at a high rate, and this in turn would prevent the achievement of GHG reduction goals. A “Business-As-Usual” approach is not sustainable and this could be a forerunner to economic collapse, discussed next. The AEF report is a valuable first assessment of our energy capabilities, but much more needs to be done.

Just as the AEF report was basically a “Business-As-Usual” type of analysis, so was the EPA analysis of H.R. 2454, as shown in Figure 5. The EPA analysis itself was also based on the Department of Energy’s Annual Energy Outlook (AEO) analyses. A synopsis of a sensitivity study performed by the EIA in its 2010 AEO is presented in Table 4, below, where three different economic scenarios are compared. One scenario represents low economic growth, another represents the EIA’s reference economic growth rate and the final scenario represents high economic growth. This tabular synopsis just lists the projected quantities of imported crude oil (converted from EIA’s units of quadrillions of BTU’s to MB/D) and the projected release of carbon dioxide equivalent. As points of reference, the 2009 crude oil imports came to 9.94 MB/D and the CO_2 releases were 5507 millions of metric tons (reference [12]). Note that Table 4 only includes the CO_2 component to the overall release of GHG. The CO_2 component was 83% of the total CO_{2e} in 2009.

The conclusions reached earlier for the AEF analyses that a “Business-As-Usual” view of our energy future would be prohibitively expensive and would undermine efforts to adequately limit the release of GHG, also apply to these EIA analyses. In spite of a range of economic models, all the results still fall into the “Business-As-Usual” classification. The 2035 reference case projected crude oil imports is hardly different from the measured value for 2009 and even the low economic growth scenario does not show enough of a reduction in the oil import level to avoid national security issues. These EIA analyses forecast a worsening release rate of greenhouse gases. At the heart of all these analyses is the assumption that transportation would largely be accomplished by somewhat improved versions of today’s petroleum based internal combustion engine vehicles. That won’t work.

Table 4: EIA AEO 2010 Projected Crude Oil Imports and GHG Releases

YEAR	Low Economic Growth Oil imports, MB/D	Reference Case Oil imports, MB/D	High Economic Growth Oil imports, MB/D	Reference Case Millions of Metric Tons of CO_{2e}
Actual 2009 value	N/A	9.44	N/A	5447
Projected 2015 value	8.84	9.26	9.78	5713
Projected 2025 value	8.48	9.05	10.05	6016
Projected 2035 value	7.84	9.11	10.49	6310

3.2.6.3 Increased Economic Strain

The "Business-As-Usual" approach described above, in spite of its high costs, is optimistic and inconsistent with our economic history. In the "Business-As-Usual" scenario, there was a sufficient and stable supply of oil. However the wealth and power transfer away from the United States would be very large. A more severe and more realistic scenario is one where there are frequent prolonged deep recessions, similar to the one the United States is experiencing now. Major oil price shocks have disrupted world energy markets five times since 1973 (1973-74,1979-80,1990-91,1999-2000 and 2008). According to studies performed at the Oak Ridge National Laboratory (reference [13]), "Most of the oil price shocks were followed by an economic recession in the United States". It has been estimated that over the last 30 years oil market upheavals have cost the United States in the vicinity of **$7 trillion (1998) dollars or about $9.2 trillion (2008) dollars.** Oak Ridge researchers have divided the cost of oil dependence into three categories: wealth transfer, dislocation losses, and loss of potential gross domestic product (GDP). Wealth transfer is the product of the total U.S. oil imports and the difference between the actual market price of oil (influenced by market power) and what the price would have been in a competitive market. Dislocation losses are temporary reductions in GDP as a result of oil price shocks. Loss of potential GDP results because a basic resource used by the economy to produce output becomes more expensive. This causes the economy to produce less. In 2008 alone the cost of oil dependence due to wealth transfer and GDP losses, combined, was calculated to be about half a trillion dollars, about 3.5% of the 2008 GDP. (See Figure 8). A still higher figure has been calculated for 2009 by the United States Bureau of Economic Analysis who found that Americans spent $900 billion dollars on gasoline, diesel, and other refined petroleum products, or 6.4% of the GDP (reference [14]).

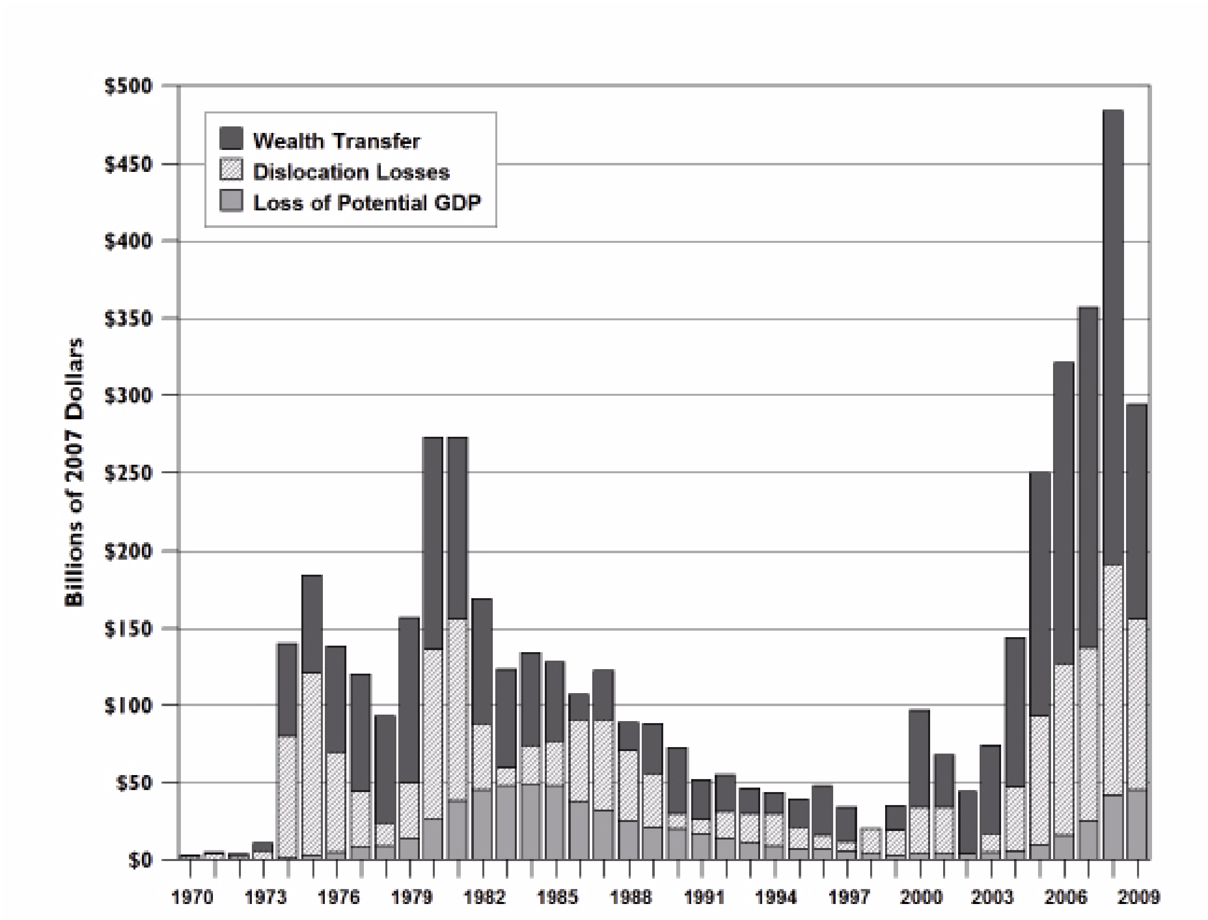
If one assumes that there will be similar oil shocks in the next 20 to 30 years, with a "Business-As-Usual" type situation in between these shocks, the $14 to 15 trillion (2008) dollars discussed previously. plus the $9.2 trillion (2008) dollars described here comes to a total of about **$23-24 trillion (2008) dollars over the next quarter century, once again raising the economic tipping point issue. These huge figures do not include another $10 trillion (2008) dollars for purchasing oil from domestic sources.** None of this money would go towards lowering our dependence on imported oil or reducing GHG emissions. There could well be additional trillions of dollars of losses due to the effects of climate change in the latter part of this time period because there were not sufficient funds to take actions to abate GHG emissions.

The perspective of the International Energy Agency on this issue is interesting. The IEA uses an "oil burden" concept. Oil burden is defined as nominal oil expenditures (demand multiplied by the price of crude oil) divided by nominal GDP. According to the IEA "This is not to say that rising oil burden will necessary *cause* an economic recession (with the clear exception of the 1970s), but it can greatly compound the effect of other economic and financial shocks. Indeed, the economic activity in the OECD had already been stagnating *before* oil prices began their final assent from roughly $90/barrel in late 2007 to$147/barrel by July, 2008. Thus, as much as the Great Recession can be attributed to financial factors, high oil prices were the final nail in the coffin for advanced economies at that time" (reference [15]). Considering the high national debt, high unemployment rates, millions of houses facing foreclosure, state governments overwhelmed by unfunded financial obligations, etc., the United States and many other nations are in a much weaker financial condition than they were prior to July, 2008. High oil prices that precipitate a second, back-to-back Great Recession, could put the nation beyond the point of no return.

It is likely that economic analyses like those described above underestimate the effects of oil shortfalls in that they do not address other decreases in societal productivity. When people stand in a long line to get a limited amount of gasoline, as they did in past oil embargoes, they are not being productive. When businesses can not operate in a steady manner, as they do when energy is always available, this lowers productivity. When college graduates can not enter the workforce because of an economic slowdown, this affects their whole careers and reduces the long term productivity of the nation.

The “Business-As-Usual” analyses assumes a sufficient amount of oil is always available, if one can pay the price. More realistically, going forward there can be times when oil/gasoline is not available regardless of the price people would pay for it. Insufficient energy has a very high cost. One can get a deeper appreciation for this by looking at a parallel situation that exists in the electric power industry. The U.S. has an electrical system that is 99% reliable.The small decrease in reliability, one percent, due to power outages and degraded voltage, costs the nation between $119 billion to $188 billion dollars annually (reference [16]). The cost of unavailable electricity far exceeds the cost of purchasing this needed electricity. Similarly, oil shortages, like “out of gas” signs at service stations that prevent normal functions from proceeding, are far more expensive than the gasoline one would purchase, if it were available.

Figure 8: Costs of Oil Dependence to the U.S. Economy, 1970-2009



3.2.6.4 Economic Collapse

Back-to-back severe recessions could result in economic collapse in the United States. Up to now the more severe oil related recessions have been fairly far apart in time with the more recent ones occurring around 1974, then another in 1980-81 and a third in 2008-11 (or longer). However, there are fundamental shifts going on in the oil market that are likely to affect the frequency and severity of oil related global recessions. In the past, world oil stability, the balancing of supply and demand, was largely in the hands of OPEC, with Saudi Arabia taking a major position. As long as there was some margin between supply and demand, world energy stability might be obtained. If demand dropped too low and oil prices fell too much, OPEC could decrease production, causing prices to rise again. If oil prices rose too high this could precipitate world recessions and which would cause a drop in oil demand. Saudi Arabia, with its huge reserves, comparatively low costs for oil recovery, and large production capability, was in a strong position to bring about some semblance of stability between supply and demand, if it chose to, by modifying its oil output. This has proven to have been less than a perfect balancing act, but it did provide some degree of stability. Unfortunately, this large influence on the global economy by OPEC nations has retarded the development of alternatives to oil. Low oil prices, while a temporary stimulus to the economy, especially to the United States- the largest consumer of oil, undercut sustaining interest in alternatives to oil. As oil prices rose, the interest in oil alternatives also rose, only to be dashed again by recessions, dropping demand, and lower oil prices. At times when oil demand and prices were high Congress passed more legislation, only to be set aside in the next oil economic cycle. This kind of reactive posture is no substitute for a proactive sustainable energy plan.

The lack of a sustainable energy policy has put the United States and others into great jeopardy. First there has been a shift in world buying power (reference [17]) as the United States exported vast amounts of money east and west. Using the data from Table 2, the Saudi Arabian oil equivalent reserve of 303 billion barrels at an assumed value of only $80/barrel is equal to $24 trillion dollars. The total value of all the companies in the stock market in the U.S. is about $10-12 trillion dollars (combined market cap of the Wilshire 5000). In theory, the Saudis could buy every US company outright at today's oil prices and still have trillions of dollars left over.

The rise in oil demand from China has reshaped the geopolitics of oil, with Saudi Arabia now exporting more oil to China than to the United States. According to the

NY Times (reference [18]),- “The Chinese military is seeking to project naval power well beyond the Chinese coast, from the oil ports of the Middle East to the shipping lanes of the Pacific, where the United States Navy has long reigned as the dominant force, military analysts say.” Further evidence of growing energy related friction between China, its neighbors, and the United States recently occurred when the U.S. challenged China on its dispute with its smaller Asian neighbors over a string of islands in the south China sea. These islands are rich in oil and natural gas deposits (reference [19]). Comparisons between China’s economy and that of the United States often predict that it will take China another ten to twenty years before their GDP equals that of the United States. However, recently, a new calculus has been made by comparing the purchasing power of these two nations. When such comparisons are made some claim that China is already on a par with the United States. As China has grown economically and militarily stronger, it has flexed its muscles in a number of ways. For example, after a dispute about a Chinese fishing boat entering Japanese territories, the Chinese have cut off the delivery of rare earths to Japan, key materials to the high tech economy of Japan. China’s weak response to North Korean aggression has alarmed South Korea, the United States, Russia, Japan, and others. There are voices in Japan today calling for an end to its post-WWII pacifism and to start to develop nuclear weapons. With China’s financial arrangements between oil suppliers like Saudi Arabia, Iran, Venezuela, and Sudan and very large financial reserves, even purchasing power equality comparisons seem optimistic. One needs to compare how these two nations have fared during the recent and ongoing recession to project how they would likely do during future oil shocks. The United States, with its great dependency on imported petroleum and large national debt, is far less likely than China is to ride out the next oil crisis.

The very nature of oil shortfalls is changing. Reviews of the effects of past imbalances between supply and demand on the United States, such as the oil embargo in 1973 and the Iranian Revolution in 1979, show that only a few percent of the oil production was removed from the world market. These earlier shortfalls were often politically motivated. However, oil demand has risen to the point where there is little spare production capacity, i.e., only a small margin. In the future there could be two causes of oil shortfalls: politically initiated shortfalls, like past oil embargoes and civil wars in oil exporting countries, and physically initiated shortfalls whenever demand exceeds supply, like that which initiated the Great Recession in 2008. Permanant high oil prices and frequent shortfalls present a different set of conditions from those we have experienced and could bring about long term economic difficulties and international stresses.

In the past, oil-initiated recessions could end when the political dynamics changed so that full oil flow was again possible, like at the end of an oil embargo. In the case of physical shortfalls where demand exceeds supply, it is not clear how they might end. They are materially different from shortfalls initiated by political actions. One can not quickly find new sources of oil and bring that oil to market. Demand can rise far more quickly than creating new supplies. With a fixed amount of oil available in the world marketplace, times when demand exceeds supply means that some nations will have to get by with less oil than they want, while weaker nations will get less oil than they need. Supply and demand may only come back into a temporary equilibrium when some nations do with less. This equilibrium would be temporary if demand continues to rise and supplies can't keep up.

In this new era of politically and physically initiated shortfalls, the ability to maintain price and supply stability becomes more difficult. Major oil suppliers, like Saudi Arabia, will likely have a decreasing ability to influence world stability and could logically look to the needs of their most important customers. There is the possibility, if not the likelihood, that the oil market as we have known it will largely disappear as suppliers give preferential treatment to their most financially secure customers. Achieving world stability now requires co-operation among major suppliers and major consumers, but this co-operation is not in place at this time.

The frailty in maintaining oil stability has been nicely presented in The Electrification Roadmap (reference [20]), "...even small perturbations can cause massive price swings. A hurricane in the Gulf of Mexico, violence in the Niger Delta, or an oil worker strike in Venezuela, can lead to sudden and calamitous swings in the price of oil as markets adjust their expectations about the supply-demand balance and risks to future deliveries of crude oil." The above list of perturbations is incomplete in that it does not include acts of terrorism, such as attacks on Saudi Arabian oil refineries, possible blockage of critical pinch points in oil supply routes, territorial conflicts over sources of oil, human error or the ongoing enormous upheavals across many arab nations. Figure 9, below, published in The Electrification Roadmap clearly shows an oil shortfall (see A Global Financial Crisis, marked by a vertical dashed line in Figure 9), occurred in 2008 when demand temporarily exceeded supply and the price of oil hit $147/ barrel. This was a physical oil shortfall, not a political one. Prior to that historic moment oil prices were steadily rising from $33.75/

barrel in 2003 to $75.14/barrel in 2007 to $97.26 in 2008. Note that prior to 2003 there was considerable margin between the sum of OPEC spare capacity and world oil production. This margin largely eroded between 2003 and by the time it temporarily disappeared in 2008, prices had reached $147/barrel.

The margin between consumption and the sum of OPEC spare capacity and world oil production has been restored, at least temporarily, when demand dropped sharply in the present severe recession. U.S. oil consumption decreased 8.5% in the third quarter of 2008 compared to the same time period in 2007, the largest such decrease since 1980. Such a decrease in consumption was not the result of major structural changes in the U.S. energy system, but the result of a battered economy. Assuming that the United States does recover from the present recession, consumption will again begin to rise. In the meanwhile oil consumption is rising apace in China and elsewhere. The International Energy Agency (IEA), in its10 February 2011 Oil Market Report, concluded that in December, 2010 China's year-on-year increase in oil demand was 17.7%. China's total oil demand averaged 10.4 MB/D, according to IEA figures.This is a sharp increase from the 2007 demand figure in Table 5 which lists a demand of 7.6 MB/D. Even though China is now taking steps to curb the growth in its oil demand, these figures portend future shortfalls, as many have already predicted.

Most of the future increase in oil demand will not come from OECD nations or the United States, but from emerging nations like China, India, and Brazil. China is the fastest growing oil market in the world, even though the United States at this time remains the top consumer. The potential demand for oil from China alone is tremendous. The China Association of Automobile Manufacturers recently announced that in 2010 that overall vehicle sales, including trucks and buses, came to 18.1 million units, up 32.4 percent from a year ago. By comparison, US auto sales rose more than 11 percent in 2010 to nearly 11.6 million vehicles.

Nations may increasingly look to the United States to help maintain stability by reducing its demand and perhaps punish it during shortfalls because of its long history of dominating oil consumption. Being the "Saudi Arabia of oil demand" may take on new meaning and responsibilities for the United States in the years ahead.

Figure 9: World Oil Production Capacity vs. Demand

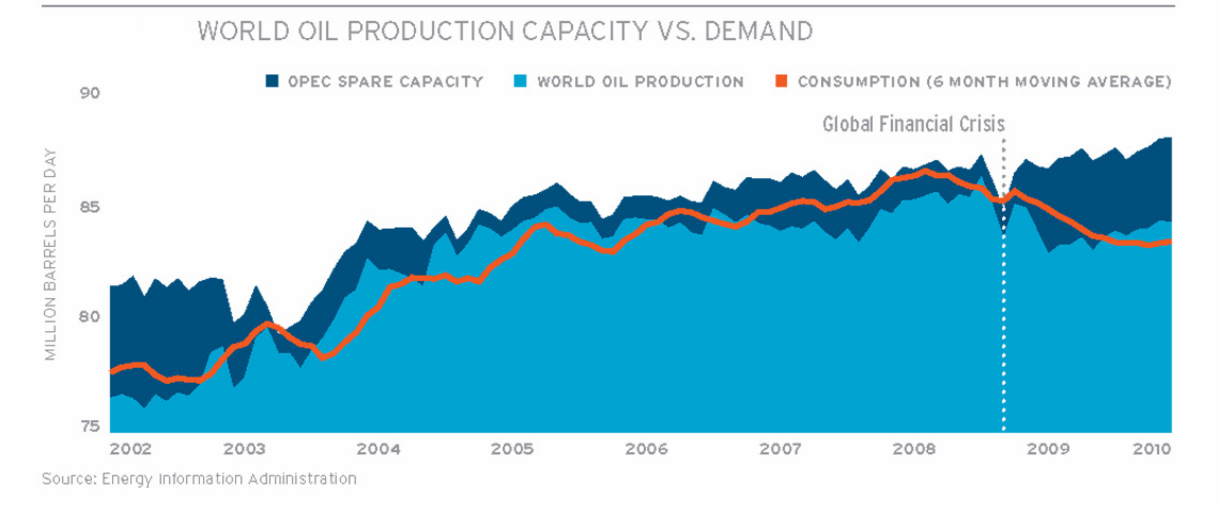


Table 5 presents a few comparisons that illustrate the potential for oil competition among a few leading nations.

Table 5: Oil Consumption Per Person

Country	2007 consumption, barrels per day	Population (2010)	Barrels/day per person
United States	20,680,000	309,556,000	0.0668
China	7,578,000	1,338,240,000	0.0057
India	2,722,000	1,182,487,000	0.0023
Brazil	2,372,000	193,117,000	0.0123
Russia	2,858,000	141,927,300	0.0201
Total	36,210,000	3,165,327,000	0.0114 (average)

The above six nations represent about half the world's population. If these six nations consumed, per person, the same level as in the United States did in 2007 it would require 211 million barrels of oil burned each day (MB/D). By comparison, in 2010 the world production of oil around 86.5 (MB/D). Based on Figure 10, the International Energy Agency (reference [21]) expects the world output of crude oil to rise to about 95 MB/D in 2035. So, even if the oil needs of the other half of the world's population were totally ignored, these six nations would still be far short of what would be needed to match U.S. consumption rates. In 2009 each American consumed almost twelve times what the average Chinese person consumed. If the consumption of today's production of 86.5(MB/D) were evenly distributed among these six nations, then the average per person consumption would only be enough to meet about 41% of the average American's consumption rate, again leaving nothing for the rest of the world.

If China alone grew to the point that the average gasoline consumption was half that of the average American, or 0.0334 barrels/day per person, then China's consumption would be about 44.4 MB/D, essentially half of the world's present production rate. It is projected that China will produce about 250 million new cars over the next ten years, roughly the same size of the whole fleet of vehicles now in the United States. Such a massive buildup of vehicles in China, supplemented by large increases in demand elsewhere, effectively guarantee great strains on world oil supplies. The major lesson from Table 5 is that the potential demand for oil is huge and far exceeds expected oil reserves, both conventional and non-conventional.

The IEA projection in Figure 10 also shows is the very large transformation in the expected sources of oil. Whereas most of the crude oil produced today comes from currently producing fields, this type of conventional oil production is predicted to sharply decline with a projected contribution of about only 19% of the total 2035 production. Far more dependence would be placed on crude oil fields yet to be developed and crude oil from fields yet to be found and then developed. Even without increasing demand, the changing nature of future oil means higher environmental impacts and higher costs per barrel. This would be accompanied by greater uncertainty, especially as oil is sought in deep offshore water. When this uncertain oil production future is coupled with rapidly increasing world demand it virtually guarantees higher prices and greater national security pressures. What nation would want to bet its energy future on oil that is yet to be discovered and then developed?

Since the 1970s the United States, as a national security measure, has taken steps to diversify its supplies of imported oil. However, maintaining a diversity of supplies will become increasingly difficult as more and more previously oil exporting countries switch over and become oil importing nations. The United States will not be able to maintain its present diversity of supplies indefinitely. The world is headed towards an increasing dependence on a few remaining oil producing countries, many of whom may not be particularly friendly towards the U.S.

With both politically initiated and physically initiated shortfalls, the time between recessions may shrink. As stated before, there are fewer mechanisms available to recover from a shortfall of oil supply and bring demand and supply back into equilibrium. Therefore recessions initiated by physical shortfalls may last longer than previous politically initiated shortfalls. In between recessions there would periods of high oil prices. In other words, an economic collapse could be brought about by prolonged recessions caused by oil shortages.

3.2.6.5 Timing of Oil Shortfalls

The exact timing and severity of the next oil shortfall is unknown. Nonetheless a reasonable estimate must be made for planning purposes.

It is instructive to compare the views of different energy experts on this subject. A February, 2010 report from the UK predicts that conventional oil will not exceed 92 MB/D. This is projected to occur 5 to 10 years from now (reference [22]). This same UK report warns of impending threats to their national security and calls for transformative actions to avoid this, such as more electrified mass transportation. The United States also must emphasize more electrified mass transportation in urban areas.

Others have voiced their concerns about world oil prospects. Many are concerned that about half of the U.S. current trade deficit is due to importing oil. In January, 2008 the CEO of Royal Dutch/Shell wrote; "Shell estimates that after 2015 supplies of easy-to-access oil and gas will no longer keep up with demand". About the same time the chairman of Hess Corporation said "An oil crisis is coming in the next 10 years. It is not a matter of demand. It is not a matter of supplies. It is both".

Richard A.Kerr reviewed (reference [23]) the International Energy Agency's (IEA) *World Energy Outlook, 2008* report. Kerr notes the IEA concern that world oil production could plateau sometime around **2030** if demand continues to rise. Kerr states "Unless oil-consuming countries enact crash programs to slash demand, analysts say, **2030** could bring on a permanent global oil crunch that will make the recent squeeze look like a picnic." There has been a recent statement (reference [24]) that conventional oil will peak ten years sooner, i.e., in 2020. Fatih Birol, the chief economist of the International Energy Agency, believes that if no big new discoveries are made, "the output of conventional oil will peak in 2020 if oil demand grows on a business-as-usual basis." Even though the above comments are not that old, more recent comments are less optimistic. IEA analyses now show conventional oil already at or near peak production.

One energy forecast, the Department of Defense's "JOE/2010" report, predicts that by 2012 surplus oil production capacity could disappear entirely and as early as 2015 there may be a 10 MB/D shortfall (reference [25]).

Rune Likvern writes in the August, 2010 edition of the Energy Bulletin that OPEC's spare capacity may be completely eroded during 2011. While these estimates differ somewhat on the time to arrive at the next zero oil margin situation, all are in the near term.

In 2010 world oil consumption grew by an estimated 2.2 MB/D, significantly reducing the margin between supply and demand. Petroleum consumption projections by EIA indicate that supply growth from non-OPEC countries to be quite limited, about 160,000 barrels/day in 2011 and only about 20,000 barrels/day in 2012. The increase in OPEC production is also projected to be rather small, 500,000 barrels/day in 2011 and about 1.1 MB/D in 2012. Using these recent EIA data on increased world oil consumption and on oil production from OPEC and non-OPEC nations, one oil expert estimated that all the world spare capacity will be used up by **2013** (reference [26]).

The United States should consider setting a target of reducing its annual oil consumption by 5.0 MB/D below 2009 consumption levels by the end of 2016. Such a reduction in oil consumption by the United States may not be enough to prevent a world shortfall in petroleum if world demand for oil continues at its present pace. It would be necessary for other nations to slow down their petroleum consumption so that, together, some margin between supply and demand could be maintained. However, it might prevent back-to-back recessions in the United States. How this petroleum reduction might be achieved by 2016 is the subject of Section 6. A second reduction of about 7.0 MB/D might be achieved by 2026 and a third reduction of about 3.0 MB/D by 2036. Note that these projected reductions are based on no increase in demand due to a growing population. How to offset the increase in demand due to a growing population is discussed in Section 6.

It is possible to make a rough estimate of the savings that might be generated if the above petroleum reductions were achieved. Two types of savings are possible. First there is the savings that would be the result of using less oil. Second there is the savings that might occur through lower oil prices per barrel of oil. Lower world prices per barrel of oil might be the result of a reduced demand for oil from the United States and other nations seeking to avoid a zero margin situation between supply and demand. The additional saving from a lower price per barrel are not credited in this analysis.

Table 6 compares the cost of continuing to consume oil for the next 25 years at the 2009 petroleum use level of 18.8 MB/D to the petroleum consumption levels consistent with those calculated in Section 6. An assumed time averaged price of $120 (2008 dollars)/ barrel was chosen, consistent with the previous “Business-As-Usual” analysis.

This analysis assumes no increase in demand for oil because of an increasing population in the United States. If higher demand for oil occurs because of population growth or any other cause, savings would be reduced. Oil related defense costs are not included in this simple economic comparison nor are the oil related health costs due to burning petroleum. Over the next 25 years savings on health costs and national defense because of reduced use of petroleum could add several more trillion dollars to the total estimated in Table 6.

The full $11.4 trillion 2008 dollars savings by 2036 shown in Table 6 can not be achieved because it is not possible for the United States to continue to burn petroleum for 25 more years at 2009 rates for the environmental and economic reasons presented before. Nonetheless, Table 6 shows that a great deal of savings could be obtained through petroleum use reduction, perhaps enough to pay for the whole energy transformation that lies ahead. A few examples are useful. In the first year the projected savings of 24.5 billion 2008 dollars would be sufficient to buy about 12 new 1000 megawatt nuclear power plants in just one year at nuclear power plant prices now being offered by China and South Korea (about $2000/KWe), or provide a 50% subsidy for about 25 such nuclear plants. Twelve new nuclear plants would roughly be equivalent to increasing the nation’s nuclear power electricity production by about 11%, assuming a 90% capacity factor. If these 12 new nuclear plants replaced coal or gas electric power plants the GHG abatement would be significant. In the second year of such an oil importation reduction plan, year 2015, some $70.1 additional billion dollars savings would occur, relative to a “Business-as-Usual” scenario where oil consumption remains equal to today’s usage. If plug-in and electric vehicles were subsidized at a rate of $7500 per vehicle, the second year’s $70.1 billion dollar savings on the national oil bill alone would be enough to subsidize 9.3 million new energy plug-ins and electric vehicles in just that year. If such a subsidy arrangement continued for another two years an additional 36.2 million plug-ins and electric vehicles could be subsidized at $7500 per vehicle. In just three years of petroleum savings 12 new nuclear plants and $7500 subsidies for about 45.5 million such advanced electric vehicles could be provided, far more than the manufacturing infrastructure and imports could accommodate. The combination of these carbon free nuclear power plants and these subsidized plug-ins and electric vehicles would continue to reduce oil use and the release of GHG releases throughout their useful lives. Further, these subsidies would not add to the national debt. To accomplish all this a mechanism would have to be established whereby savings in the nation's oil bill would have to end up in the Treasury so that these federally subsidized programs could go forward.

Table 6: Estimated Savings Through Reduced Use of Petroleum

Year	Reference oil use (2009 value), MB/D	Projected oil use due to reductions described in Section 6, MB/D	Annual savings based on a cost of $120/barrel, billions of 2008 U.S. Dollars	Cumulative savings, billions of 2008 U.S. dollars
2011	18.8	18.2	24.5	24.5
2012	18.8	17.2	70.1	94.6
2013	18.8	16.2	113.9	208.5
2014	18.8	15.2	157.8	366.3
2015	18.8	14.2	201.5	567.8
2016	18.8	13.2	245.3	813.1
2017	18.8	12.5	275.9	1,089.0
2018	18.8	11.8	306.6	1,395.6
2019	18.8	11.0	341.2	1,736.8
2020	18.8	10.3	372.3	2,109.1
2021	18.8	9.6	403.0	2,512.1
2022	18.8	8.9	433.6	2,945.7
2023	18.8	8.2	464.3	3,410.0
2024	18.8	7.4	499.3	3,909.3
2025	18.8	6.7	530.0	4,439.3
2026	18.8	6.0	560.6	4,999.9
2027	18.8	5.7	573.8	5,573.7
2028	18.8	5.4	586.9	6,160.6
2029	18.8	5.0	604.4	6,765.0
2030	18.8	4.7	617.6	7,382.6
2031	18.8	4.4	630.7	8,013.3
2032	18.8	4.1	643.9	8,657.2

2033	18.8	3.8	657.0	9,314.2
2034	18.8	3.5	670.1	9,984.3
2035	18.8	3.2	683.3	10,667.6
2036	18.8	2.8	700.8	11,368.4
Total	N/A	N/A	N/A	11.4 trillion 2008 dollars

The above nuclear plants and plug-ins and electric vehicles examples are meant to be illustrative. The larger point here is that the potential national cost savings from a reduced oil bill is large and opens the door for supporting many additional oil displacing activities. How many trillions of dollars would be needed to pay for the full re-industrialization of the United States to arrive at a post-petroleum future has not been determined.

3.2.6.6 After 2016

The petroleum reductions that are the basis for Table 6 may be sufficient to "immunize" the United States from world oil shortfalls for a few years. However, even with reduced petroleum usage by the United States, the possibility of situations where world supply and world demand leave a zero margin will persist. As shown in Table 5, the potential oil demand from China, India, and Brazil is tremendous if they are to even partially consume oil per person like that now in the United States. Moreover, this uncertain oil demand situation is not the only uncertainty. There also is a growing uncertainty about the supply of oil in future years.

Peak conventional oil production may have already occurred.As recently reported by Richard Kerr in Science, "Despite a near tripling of world oil prices, non-OPEC production, which accounts for 60% of the world output, hasn't increased significantly since 2004" (reference [27]). This indicates that in non-OPEC countries conventional oil production had peaked, or at least reached a plateau, since these countries could not take advantage of higher prices by producing more oil. This observation has geopolitical implications for the United States because it signals that the diversity of supply that the United States has worked for will slip away as the remaining oil is increasingly in the hands of a few OPEC countries. This observation also sheds light on the economic model assumption that higher oil prices would, over time, result in greater oil production. This seems to be partially true and improved technology has also resulted in greater production in some locations. However, in spite of higher prices and improved technology, oil reserves are finite and eventually geologic constraints set production limits. Therefore computer models which project greater domestic production because of higher oil prices should be viewed with caution.

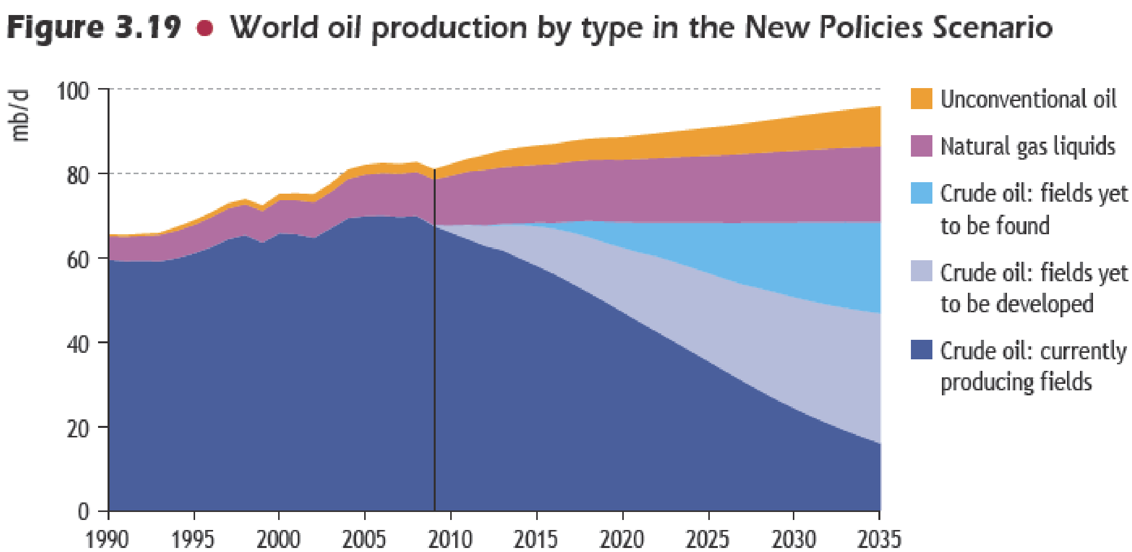
Analyses published by the International Energy Agency, (IEA), predict an increasing reliance on new discoveries and non-conventional oil to compensate for the loss of production from conventional oil, as shown in Figure 10 (reference [28]). This IEA figure indicates that conventional oil production has already peaked and has begun a long, irreversible decline. By 2035, according to this IEA figure, these conventional sources of oil would only represent about 19% of the world's oil production.

It would be prudent to recognize the uncertainties in this IEA projection, especially in the latter years.The largest worldwide oil find in the last 40 years, off the coast of Brazil, is estimated to contain 8.5 billion barrels of oil. At present world consumption rates this would only be enough to last 100 days (reference [29]).

Unconventional oil, such as from Canadian tar sands has come at a high environmental price and can be very expensive to develop. Recent improvements in technology that result in lowering the tar sand's viscosity should help reduce water consumption and costs. There has been severe environmental problems associated with the BP rig failure offshore from Louisiana. Further, there are important geological restraints that bear on the recovery of offshore oil, particularly in very deep water. The earth's crust is much thinner under oceans than under the continents. Because of this, deep water sites are closer to the earth's upper mantle which has temperatures in the 1400 degrees Centigrade and higher range. These deep water sites are hot, which can have several effects. If temperatures are too high, this can preclude the formation of oil at these locations in the first place. In areas where oil might be found, the hot temperatures in the thin crust area can destroy expensive drill bits. Recovery rates are low. Andrew McKillon (reference [30]) has estimated oil recovery rates for such deep water sites in the range of 5% to 15%. At such rates most of the deep water sites will not be able to recover the majority of the oil thought to be there. Shallow water and conventional oil sites have recovery rates closer to 50% and advanced recovery technology should be able to raise this number further. In deep water locations a single "dry hole" can lead to a loss of $200 million dollars and this may make it difficult to justify such large and risky investments.

Integrating these observations, it is not enough to "immunize" the nation against the near term challenge of oil shocks and oil related recessions. The nation must move as rapidly as possible to achieve energy independence, starting with transportation energy independence or face repeated situations of zero oil margins.

Figure 10: IEA's 2010 World Oil Production Projection



3.2.7 The Armed Conflict Scenario

Sections 3.2.4.2 through 3.2.4.6 show increasing stresses on the economy through rising oil prices which can also limit our ability to abate the release of GHG. These stresses would become acute if there is not sufficient energy to meet a nation's basic needs, such as having the ability to deliver an adequate food supply. The loss of ability to meet basic needs could lead to armed conflict to secure sufficient oil. In a world filled with weapons of mass destruction, global armed conflict would be the end of civilization a we know it. Armed conflict over oil must be avoided.

Well before the more technically advanced nations might themselves resort to armed conflict there is the possibility that major problems will first erupt in the economically weaker nations. Since food prices correlate closely with energy prices, higher oil prices, especially during shortfall periods, means that many tens of millions of people may not have enough to eat. Higher food prices has been a contributing factor in the unrest in North Africa. Higher oil prices and restricted oil availability means that weaker nations may not be able to buy sufficient oil-based herbicides, fuel for their tractors, or oil to run their irrigation pumps. Even if these critical farm commodities could be purchased or donated, there might not be a viable transportation system within these countries to deliver them because of oil shortages. Today 42 African nations are net oil importers. Of these nations, some 20 or so may effectively end up with no oil sometime in this decade. This could very well start as civil unrest and then mass starvation and regional wars. Tens of millions of lives might be lost. This too must be avoided.

3.3 Conclusions

Section 3 explained what has not worked. Many energy studies seem to fall into two groups: ideologically driven studies and more balanced studies that are variations on a "Business-As-Usual" model. The ideologically driven extreme energy futures often fail to pass common sense critiques. One can not trade energy security for environmental protection or the other way around. Both of these energy challenges must be dealt with in an integrated way. More balanced approaches that hardly change the status quo also end up in failure. They don't solve the climate change challenge or the economic challenge or the national security challenge. Legislation based on any of these analyses are also bound to fail one way or another. What is needed is a plan that is not ideologically driven, is not "Business-As-Usual", and addresses both sides of Figure One.

The remaining sections are dedicated to what might work.The starting point is to identify specific goals and their associated timetables. It is recognized that since fossil fuels, particularly oil and coal, would have to undergo huge transformations, this must be responded to by other huge transformations, specifically how we produce energy, how it is distributed, and how it is to be used to enable all critical functions, like transportation, to remain functional.

The overall transformation to a post-petroleum future requires near, middle and long term solutions. Identifying which actions are appropriate for each of these time periods requires some sense of the implementation difficulties throughout a whole new energy system. One can not hope to establish an energy policy framework until these goals and their timetables are matched to specific actions, which themselves take into account infrastructure limitations. Today these implementation difficulties are imperfectly known. Section 4 suggests specific goals and timetables. Section 5 describes many energy transformations that must take place. Reaching our energy goals will take energy innovation, but perhaps more important it will take reorienting our energy sources so that each is performing in its priority applications.

4.0 Goals and Timetables

4.1 Introduction

In two to three generations United States may have vastly restructured its energy system from one that is about 80% dependent on fossil fuels to one that is far less dependent on fossil fuels and capable of providing comparatively clean energy for hundreds of years or more. To accomplish this, specific quantitative liquid fuel and climate change goals and timetables must be established. These quantitative goals are then supplemented by qualitative goals.

How these goals might be achieved is discussed in Section 6, An Implementation Plan.

4.2 Quantitative Liquid Fuel Goals

Step One, 2011-2016: Immunize the nation against a back-to-back recession brought on by high oil prices and/or shortages. Reduce petroleum use by at least 4.7 MB/D by 2016. Lay the groundwork for further savings.

Step Two, 2016- 2026: Reduce petroleum usage by another 7.0 MB/D by 2026. Create a National Liquid Fuel Reserve storing a minimum of about 685 million barrels of petroleum equivalent. End all importation of petroleum.

Step Three, 2026-2036: As a minimum, reduce petroleum use by 3.0 MB/D. Initiate actions that would further decrease petroleum use during this time period and then totally end petroleum use during Step Four.

Step Four, 2036-2050: Phase out fossil-based liquid fuels, as dictated by national security considerations and by climate change requirements determined by using 2036, or earlier, climate change science.

4.3 Quantitative Climate Change Goals

4.3.1 Introduction

Figure 6 displays the CO_{2e} goals in H.R. 2454 which, it is assumed, were based on scientific analyses performed by the International Panel on Climate Change. In 2007 the total CO_{2e} released came to 7282 million metric tons of CO_{2e}, of which fossil fuels, i.e., coal, petroleum, and natural gas, produced 5,990 million metric tons. The other large group of GHG contributors are gases that are not CO_2, but are methane, nitrous oxide, chlorofluorocarbons, hydro fluorocarbons, and others. This latter group of gases, in 2007, was equivalent to 1281 to million metric tons of CO_2 or 17.7% of the total CO_{2e}.

There are two immediate challenges are apparent within Figure 6. First, it is noted that the Energy Information Administration's AEO 2009 projection of GHG releases and those in H.R. 2454 differ significantly. Even if the EIA projection of GHG production had turned out to be flat, the difference between a flat projection and the H.R. 2454 goals would still be very large. It is not clear what practical steps can be implemented that would decrease the emission rate of greenhouse gases from 7,282 million metric tons/year down to about 5,500 million metric tons/year by around 2016, i.e., within just a few years. It is not clear if this GHG reduction could be done without greatly disrupting power supplies and transportation. Second, this H.R. 2 454 figure calls for about an 80% reduction in GHG by 2050. This is an emissions rate around 1450 million metric tons/year, scarcely more than the emissions rate of present non-CO_2 gases. If the capability to reduce non-CO_2 sources of GHG is limited, then almost all fossil fuels would have to be phased out by 2050 if the long term limits of H.R. 2454 are to be met. These difficulties with H.R. 2454, on both the near term and on the long term, call for a restructuring of its CO_{2e} limits, as described below.

4.3.2 Specific Climate Change Goals

Step One: 2011-2016: Lower CO_{2e} emissions by at least 1,300 million metric tons per year by 2016.

Step Two: 2016-2026: Further reduce CO_{2e} emissions by at least 1,400 million metric tons per year.

Step Three: 2026-2036: In 2036,or before, make a major re-evaluation, using up-to-date climate change science, to determine if the present CO_{2e} limit for 2050 needs to be changed either higher or lower. It is noted that about 17.7% of the CO_{2e} contribution comes from non-CO_2 gases. If CO_{2e} release rates are to be reduced by 80% relative to today's emissions, then these non-CO2 gases must also be abated to permit some use of remaining fossil fuels. This may be difficult because some of these gases, like some methane seepage through the earth's surface,e.g., marsh gas. Other sources of methane include those from livestock and reducing these sources would require large scale dietary changes.

Step Three calls for a major reduction in the CO_{2e} release rate so not to exceed 3000 million metric tons per year by 2036. If this can be achieved, the GHG release rate would be a decrease of about 4280 million metric tons/year relative to 2007 release rates and would be consistent with limits in H.R.2454 for 2036. Achieving the goal of a 3000 million metric tons per year release rate will require the accelerated use of carbon neutral sources of liquid fuels to displace the remaining petroleum and methanol made from fossil fuels would be necessary. It would also be necessary to start to replace gas electric plants with carbon free nuclear power plants and renewable energy sources of electricity. Step Three also calls for the lowering of non-CO_2 GHG, where practical.

Note that present debate about whether climate change is caused by humans or is actually the result of long natural cycles is largely unimportant through 2036. Up until 2036 CO_2 abatement would be a consequence of money saving actions that reduce energy demand like better home insulation, from second generation conservation where the use of energy storage encourages more efficient use of our electricity production system (which also abates GHG releases), and by numerous steps to end the use of petroleum.

Step Four: 2036-2050: By 2036 there would be experience in reducing non-CO_2 sources of GHG which would help project practical limits in reducing these gases. Based on an updated review of CO_{2e} limits for 2050, continue to replace methanol made from fossil fuels with carbon neutral liquid fuels. Replace natural gas used for making electricity with low carbon sources.

4.4 Qualitative Energy Future Goals

4.4.1 Introduction

A desirable energy future should meet the priority quantitative petroleum and climate change goals described above. However, there are several other supportive, qualitative goals that need to be considered.

4.4.1.1 Sufficiency

A desirable energy future should reliably generate enough energy to meet the needs of all the necessary functions of a modern society.

4.4.1.2 Other Critical Resources

A desirable energy future should not create other crises such as food or water shortages, overuse of land, financial crises, or cause security threats to ourselves or others.

4.4.1.3 Resiliency

A desirable energy future should be resilient enough to withstand natural and man-made challenges with a high degree of confidence that all critical functions would continue to be met.

4.4.1.4 Flexibility

A desirable energy future should flexible enough so that it had handle the loss or phasing out of a basic resource, such as coal, and flexible enough to absorb new technologies, such as fusion, as they become available.

4.4.1.5 Cost Effective

A desirable energy future should cost effective so that goods and services can be available to the general public and industry at affordable prices.

4.4.1.6 Air Pollution

A desirable energy future should have far less air pollution, especially in urban areas.

4.4.1.7 Military

A desirable energy future should place far smaller requirements on the military to protect sources of energy and their supply lines.

5.0 Technological Transformations

5.1 Introduction

Eliminating imported petroleum from the American energy diet while reducing GHG releases represents two huge transformations. In order to achieve these critical transformations other major transformations must take place. This section describes a number of necessary technological transformations.

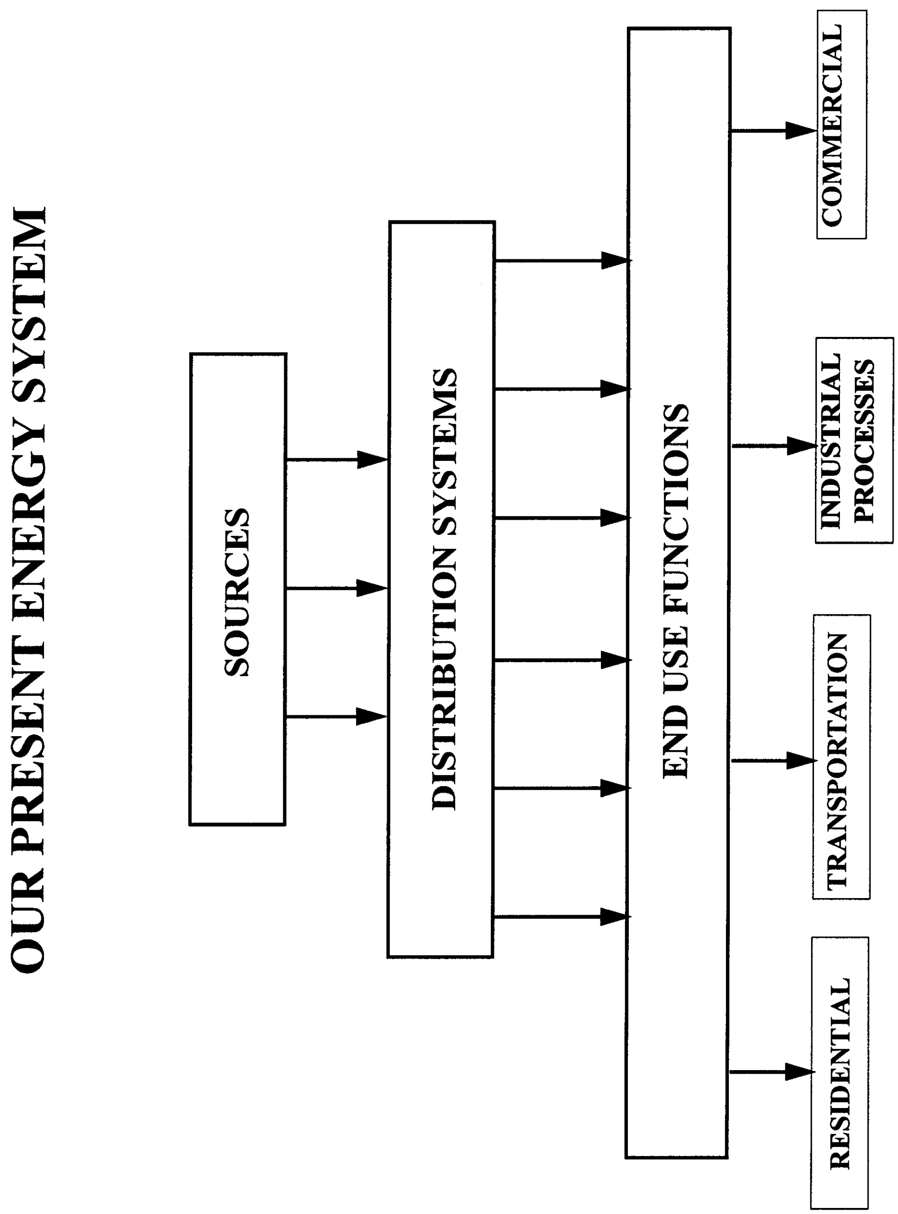
5.2 The Overall Energy System

The overall energy system consists of sources of energy, distribution networks that deliver this energy to billions of end use devices like cars, light bulbs, washing machines, and farm tractors. These end use devices serve four principle energy sectors: Residential, Transportation, Industrial Processes, and Commercial, as shown in Figure 11. The transformation to a post-petroleum future would affect every portion of our present energy system; the energy sources, the distribution networks and hundreds of millions, if not billions, of end use devices. A broad description of many of these changes follows.

One major area of transformation would be in the electric power system. This report first concentrates on the transmission portion of the electric power system. Following the discussion of the electrical grid there is a discussion of the transformations that are expected in various energy sources, transformations in many end use devices, and transformations in the transportation sector.

The largest increase in the demand for electricity is expected to come from a much more electrified transportation system, be it high speed electric trains, plug-in and all-electric vehicles (evs), light rail, or electric buses and trams. Today only about one percent of the U.S. passenger miles is accomplished by electricity. If half of tomorrow's passenger miles were accomplished electrically, this would be a huge fifty-fold increase.

Figure 11: Our Present Energy System



5.3 Transforming the Electricity Distribution System

5.3.1 Introduction

Although there are several major energy distribution networks such as the electricity grid, natural gas pipelines, gasoline delivery pipelines and trucks, coal trains, etc., only the electrical grid is discussed here since its transformation is likely to be the largest and most important.

Major transformations must be implemented in our electrical energy system in order to achieve the goals set out in Section 4. First, this system must be utilized far more efficiently, second it must become far less carbon intensive, and third it may have to grow to meet the demands of a growing population with much more reliance on electrified transportation. Section 5.3.2 addresses what can be done to improve its efficiency. Becoming less carbon intensive is discussed later under Energy Sources and End Use Devices.

5.3.2 Greater Efficiency

Greater efficiency in our electrical system has many benefits. First, the more efficient our electrical system is, the more competitive U.S. products will be in the world marketplace. Greater efficiency should result in a smaller GHG release per unit of GDP. The demand for electricity is likely to grow in the future because of a growing population, possible greater use of electricity per person than today as more people use computers, buy air conditioners, replace space heating oil burners with electricity, and use electrified transportation and teleconferencing. Greater efficiency means restructuring the electric power system so that fewer new power plants would have to be constructed to meet growing demand and to replace older and/or more polluting power plants.

5.3.2.1 Greater Transmission Efficiency

There are several large opportunities to increase the efficiency of our electrical system. One opportunity is the greater use of high voltage direct current in the electrical grid, provided AC-DC-AC conversion costs are not excessive. Another area where the electric energy system might be used more efficiently is through a "smart grid". Basically a "smart grid" is an information and control system. Such an information system would monitor all major aspects of the electric energy system, including energy storage facilities. When coupled with time-of-day pricing, customers may benefit from shifting their electricity usage from higher cost times to lower cost times, like running one's electric clothes dryer at night or on the weekends. A smart grid system should be able to fine tune the whole electric power system to travel a least cost path, thereby achieving further savings. In peak demand periods a smart grid system may drop major industrial loads in order to prevent a blackout condition from arising. This has already been done where the utility and large industrial consumers have agreed to this and these customers receive a financial benefit from permitting this arrangement. A combination of significant and well placed energy storage and a smart grid might be an even better solution to handling peak demands for electricity than dropping large electrical loads. First, the smart grid would activate energy storage devices. If energy storage was insufficient and electrical reserves became too low, then the smart grid would step in again and discontinue the supply of electricity to large consumers as per prior contractual arrangements. This staged approach of first storage, then cutting off selected supplies might be more economical and more appealing than an all smart grid approach.

The combination of energy storage/smart grid opens up other opportunities. With energy storage at the energy sources, within the distribution system, and in multiple end use devices, a smart grid could control how much energy goes into and out of these distributed storage devices, when, and where. This highly flexible type of control system lends itself to an economically optimized electric power system. Centralizing the control of the whole electric power system with a smart grid requires additional protection against cyberterrorism and other system wide challenges.

While on the subject of electrical transmission lines, one note of caution seems appropriate. Some sources of electricity, such as some wind farms, may be located far from the electrical loads they would serve. Getting approval to build transmission lines between these wind farms and the load centers they would serve can cause jurisdictional disputes. This may be especially aggravated by the fact that the benefactors of these new and lengthy transmission lines may not be the same people who have these lines cross near or through their properties. Further complicating this issue are different rules and regulations from state-to-state that govern the permitting processes for such power lines. Some have suggested that the Federal Energy Regulatory Commission be empowered to override State decisions in these matters.

A lesson might be learned from the history of Yucca Mountain, Nevada where nuclear wastes were to be buried for long term disposal. A majority in the U.S. Congress years ago imposed its will on Nevada to place the national nuclear waste repository there, thereby avoiding having their states from being selected. Now, after many years of work and after billions of dollars have been spent, Yucca Mountain may never be completed; another political decision. Other countries with nuclear wastes appear to be more successful because they first seek support from the people directly affected by a proposed repository. This lesson should not be lost on the wind energy community. It would seem that before prolonged jurisdictional disputes are initiated, those that wish to build such lengthy transmission lines should seek local support. One way of garnering local support might be to bury the power lines, although this would appreciably increase costs. Another possibility might be to provide a financial benefit for property owners that have transmission lines crossing through their property.

5.3.2.2 Use of "Waste Heat"

Far more energy can be extracted from the present U.S. electrical power system. About two thirds of the energy that thermal power plants produce is low temperature heat. This energy is often wasted because it is discharged into nearby rivers, lakes, oceans or into the atmosphere through cooling towers. Yet others have made use of this energy by having carbon free district heating, by growing food in greenhouses, and other uses. Many thermal electric power plants have the potential to sell both electricity and "waste" heat. In Korea, the Korean District Heating Corporation reported a 53 percent reduction in fuel consumption in their service area in 2002 because of the use of district heating, a $342 million dollars saving in fuel costs, and a 23 percent reduction in the emission of greenhouse gases compared to conventional systems (reference [31]). If power plants were co-located near biorefineries perhaps their "waste heat" might be an energy input to these refineries. In Civitavecchia, Italy the effluent water from the power plant there is used to heat a fish farm, one of Italy's largest. Denmark "ladders" the "waste" heat from power plants by first using this energy for district heating and then uses the district heating return line water to heat greenhouses. In Canada greenhouses are heated by warm water from the discharge canals of the Bruce Nuclear Power Plants.

5.3.2.3 Use of Energy Storage

A major transformation of our electric energy system would be much greater use of energy storage. Energy storage already exists in our overall energy system in the form of unburned fuel, in water stored upstream of dams, in pumped storage facilities, compressed air, etc. In the future the use of energy storage would expand beyond these present examples.

One benefit to energy storage is its potential to reduce the number of older, more expensive and more polluting power plants that are kept in reserve in order to meet peak demands and to respond to unplanned plant shut downs due to a mechanical failure or some other difficulty such as extreme weather conditions. Instead of keeping this inventory of older plants in reserve, energy storage might achieve much of the same purpose.

Energy storage is also connected to Homeland Security. It would be beneficial to establish energy storage depots within the electric distribution network, particularly in and/or near more populated areas. Since these energy depots would be located near their point of use and highly distributed, they would be very valuable during emergencies where there were grid blackouts due to equipment failure, human error, severe weather events, or acts of terrorism. Emergency electrical loads "downstream" of the energy depots might still be served for a period of time because only that local portion of grid need be operative. Since they would be highly distributed, it would be very unlikely that deliberate destructive acts would be able to eliminate most of them. Energy storage might be considered as an element in meeting national energy security goals.

Energy storage serves the same purpose as the Strategic Petroleum Reserve by providing essential energy for a fixed period of time when there are emergencies. Electricity might be stored in the form of compressed hydrogen which can be recombined with oxygen to produce electricity. This electricity could then be put on the grid during national emergencies to supply critical services, such as electrified transportation used to deliver food.

5.3.2.4 Energy Storage and a Flat Production Profile

Another major way to extract far more energy out of our existing fleet of electric power plants is to strive for a "flat" electricity production profile, i.e., to run all thermal plants at full power every hour of every day, except when shut down for maintenance, repair, or refueling. An ideal "flat" production profile is not possible today because power plants are operated in a manner that tracks the demand for electricity. So when demand is low, like at night, during weekends, and seasonally, some plants are not operated fully. The result of demand tracking operation is that, on average, only about half (46.2%) of the full electricity production potential is realized[1], based on 2006 data from the EIA (reference [32]).

The key to a flatter production profile is energy storage. Energy storage can be utilized throughout the whole energy system; at the energy sources, within the electrical distribution network, and at the points of end use. Energy storage systems help to meet peak demands in electricity production by shifting power production to off-peak time periods. Electric energy can be stored in the form of heated materials or as ice, in batteries, in pumped hydro storage, in compressed air, in the chemical bonds and in hydrocarbon liquid fuels. In this section only energy storage that applies to the electrical distribution portion of our overall electric system is discussed, leaving further energy storage discussions for the energy sources and end use devices sections. Improved transmission capabilities (See Section 5.3.2.1) is another way to enhance a flatter production profile.

5.3.2.5 Energy Storage and Electrified Transportation- Individual Vehicles

As stated before, on average, only about 46% of the national electricity production capacity is used. To get a more precise understanding of this unused capacity than taking an annual average, one has to compare supply and demand on an hour-by-hour basis throughout the whole year to determine the time dependent amount of excess capacity. A partial answer to this question can be found in a study by Pacific Northwest National Laboratory (PNNL) which analyzed the impact of plug-in hybrid vehicles on the U.S. power grid (reference [33]).

PPNL made a stylized load shape for one day during the peak season, as reproduced below in Figure 12. Here the area labeled "valley filling" provides opportunities to extract more electricity from our present electrical system without needing to increase the number of power plants or make nationwide improvements to the transmission grid, although some local adjustments to the grid may be necessary where there would be a concentration of plug-in or electric vehicles that might require recharging at the same time.

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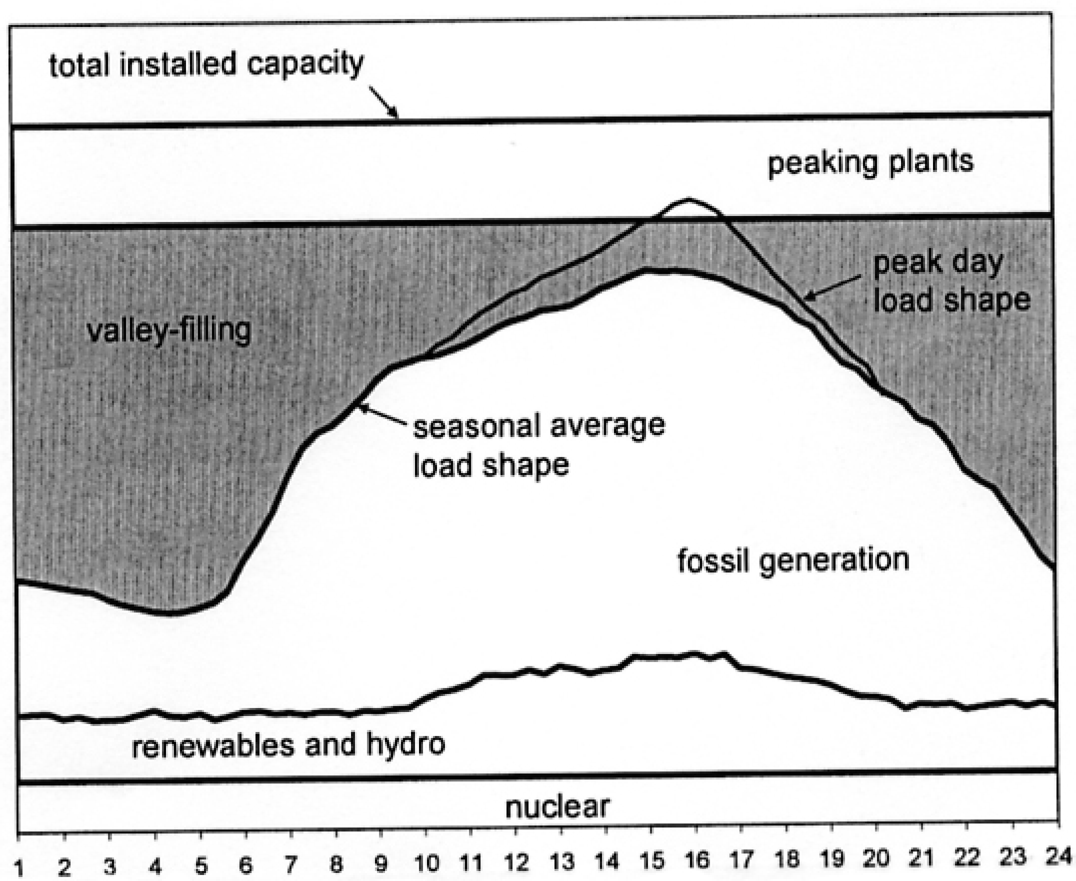
1 EIA 2006 data: Net Summer Capacity + Net Winter Capacity = 1,988,562 Megawatts. If run all year at 100% net capacity, 8,797,501, 560 megawatt-hours would have been produced. Actual consumption in 2006 =4,064,702,000 megawatt-hours. Actual consumption/maximum possible net production = 0.462

The purpose of the PPNL study was to estimate how many plug-in hybrids could have their batteries recharged from the present grid without having to increase the number of power plants or the transmission network. According to the U.S. Bureau of Transit Statistics in 2006 there were about 251 million vehicles in the United States of which about 135 million were classified as automobiles and another 100 million as SUVs and pickup trucks.The PPNL analysis concluded that about 73% of the nation's 2007 stock of about 235 million light duty vehicles (LDVs) could be replaced by plug-in hybrids without requiring additions to our electricity production and distribution capabilities. However, in order to achieve the 73% figure, the plug-ins would have to have access to the grid's underutilized capacity 24 hours a day. Using an assumption that would better match likely plug-in recharging times, from 6:00 P.M. to 6:00 A.M., PPNL calculated that the percentage of present LDVs that could be replaced by plug-ins without expanding our electrical system for that purpose would be 43%. If 43% of today's LDVs were replaced by plug-ins, this would require about 100 million plug-ins or all electric vehicles (EVs).

This 43% figure may be too low. Even more use of idle electric capacity would be possible if regional energy transfers over an improved grid system made more electricity available in the 12 hour time span listed above. The 100 million plug-in/electric vehicle figure may also be too low. If high voltage recharging stands were placed at transportation hubs and elsewhere, they might be energized during time periods between 6:00 A.M. to 6:00 P.M. Even if electricity was purchased by plug-in or EV owners to charge their batteries during times of higher cost electricity per kilowatt-hour, this may only be a small economic penalty, especially when compared to the cost per mile from using gasoline. With the use of recharging stands, plug-ins could replace somewhere between 43% and 73% of the nation's LDVs during the most limiting day, i.e., during peak demand time periods. One method of rapidly recharging plug-ins and EVs is to have drive through stations where drivers could exchange depleted batteries for fully charged ones. This effectively turns the batteries into rental items, not purchased ones, which further affects the implementation rate of such gasoline-displacing vehicles. The batteries installed at these drive through stations could have been recharged previously during off-peak time periods. The time to switch out batteries in such drive through stations is likely no longer than it now takes to refill the gas tank of an internal combustion engine vehicle. National standards on battery holding brackets would need to be developed.

It is clear from the above analyses that a very large number of plug-ins and electric vehicles could be accommodated with the present electrical system without the need for major increases in the total electrical capacity.

Figure 12: PNNL - One Day Load Shape During Peak Season



5.3.2.6 Energy Storage and Electrified Transportation- Mass Transportation

In the above discussion energy storage in energy depots was described as one method of shifting electricity to approach a “flat grid” configuration. Normally these proposed energy depots would store energy from off-peak electricity production and return this energy to the grid during times of higher demand, typically during regular working hours. However, energy storage can do more than shifting electricity use. If the energy storage medium is hydrogen or methanol, then this stored energy could be used as transportation fuel. An example of this follows.

One concept is to use compressed hydrogen as the storage medium. Present gasoline service stations might be modified to store liquid fuels like ethanol and methanol in underground tanks, much like gasoline is stored today. Additional underground storage would be for hydrogen where large pressurized tanks would replace former gasoline storage tanks. Since this underground hydrogen storage tank would be stationary, its heavy weight would not be a problem. The technology for storing and handling hydrogen seems to be well advanced in Germany. There the Linde Group has opened a hydrogen filling station for zero emissions fuel cell passenger ships (reference [34]). BMW is using hydrogen at its manufacturing facilities in order to reduce its GHG footprint.

The hydrogen stored in these renovated gas stations would be generated by electrolysis of water right at the stations, using lower cost off peak electricity. Such an application that would help flatten the nation’s electricity production profile. Using the present electrical grid to make hydrogen at a large number of distributed locations eliminates the leakage and metal embrittlement concerns associated with trying to distribute pure hydrogen over long distances through metal pipelines. The electrical requirements of such future hydrogen storage depots might be met by the present electrical capabilities at present gas stations. Another benefit of such an arrangement is that it largely uses existing gas stations, thereby reducing the costs to build new energy depots. In addition to using hydrogen as a storage medium to help “flatten” the electrical grid, this hydrogen might be used as an energy source in clean city buses. Such an application would reduce air pollution in urban areas, thereby reducing the $120 billion dollars/year health costs identified by the NAS. This potential application is discussed in Section 5.6 on Transportation.

Energy storage depots might be shared by a number of sources of electricity. There already is a mix of sources of electricity on the electric grid that could use the same energy storage facilities. If the stored energy medium is methanol there are further opportunities to share these energy storage facilities. As described later, methanol might be produced by offshore wind turbines and nuclear power plants that use electricity to convert the CO_2 in seawater to methanol. Also described later is the possible use of existing coal plants to convert their "waste" CO_2 into methanol. Methanol can also be generated from natural gas and from coal. By sharing storage facilities for multiple sources of methanol, cost savings might be achieved.

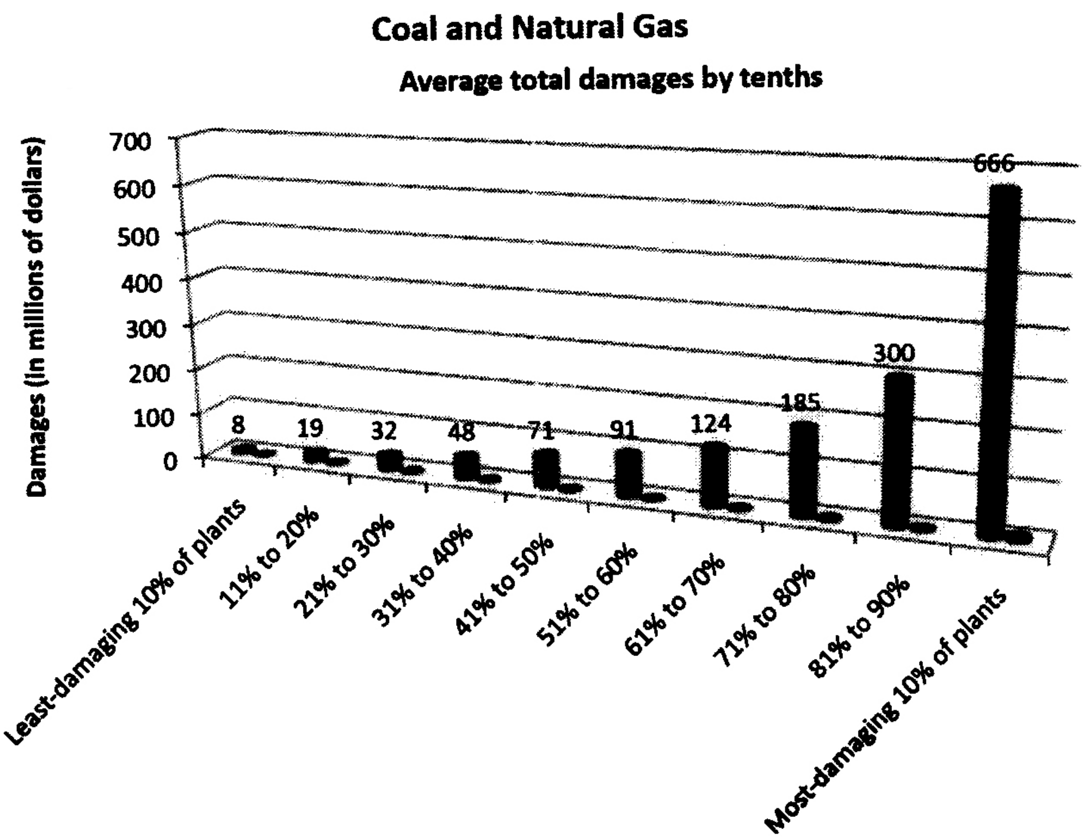
5.3.2.7 Ranking of Power Plants

Another energy strategy is to rank thermal power plants in terms of their GHG emissions per kilowatt-hour of electricity production. A similar ranking is shown in Figure 13, "Damages From Coal and Natural Gas Plants", reproduced from a National Academies of Sciences' report "Hidden Costs of Energy" (reference [35]). This figure relates to health damages caused by pollution intensity, principally SO_2 and NO_x. Ten percent of the plants with the highest damages produced 43%, of the aggregate damages from all plants; while 50% of the plants with the lowest damages produced only 12% of the aggregate damages, according to the NAS. This NAS report estimated that the hidden health costs of energy amounted to more than $120 billion dollars in 2005. There are important secondary effects of operating these fossil plants that likely are not covered by this 2005 $120 billion dollar NAS figure, such as causing chronic bronchitis or asthma. Asthma is a major cause of absenteeism among school children.

Although Figure 13 does not rank GHG releases from different deciles of power plants, there are lessons to be learned from this figure. Different power plants will emit different amounts of GHG per kw-hr because they have different thermal efficiencies. It may be possible to produce more kw-hrs from the more efficient power plants and cut back on the less efficient power plants. This should result in no decrease in the production of electricity, but with a net decrease in GHG emissions. If there are times when the more efficient power plants can produce electricity in excess of the demand, this excess electricity production might be put into storage (such as making and storing ice in the summer in the basements of large buildings to pre-cool air fed into the air-conditioning system, thereby reduce air-conditioning electrical loads during the day).

Energy storage permits a utility to sell the same number of kw-hrs per year, but with a smaller carbon footprint and, likely, at a somewhat lower cost for electricity. Energy storage within the distribution networks permits economic optimization among a whole fleet of power plants and offers more flexibility than energy actions taken at a single power plant. This ranking approach could be tied to using the CO_2 from coal plants to make methanol, as discussed in Section 5.4.3.2 on the transformation of the use of coal. Less efficient coal plants would be taken off the grid first and their output replaced by less carbon intensive sources.

Figure 13: Damages From Coal and Natural Gas Plants



5.4 Transforming The Energy Sources

5.4.1 Introduction

Section 5.4 discusses a limited number of energy sources and energy conservation. Omitted from this discussion are other energy sources such as geothermal energy, liquid fuels from algae, fusion, wave power, and others. It is thought that these possible sources of energy are unlikely to be major contributors in the time frame of this report, now until 2050. However research on many of these energy sources should continue in that they also have the potential to be sustainable, low carbon sources.

Many of the energy sources left out of this report have great potential. Section 4.4.1.4 identifies flexibility as a supportive energy goal and many of the actions recommended to reach a post-petroleum future would enhance flexibility. for example, fusion and geothermal energy might eventually be significant producers of electricity. Should fusion or geothermal energy become practical and widespread sources of electricity sometime in the future the improved electric distribution system and the vast number of electrically driven end uses discussed here would enable these possible energy sources to contribute more quickly. Similarly, steps proposed in this report to provide liquid fuels to displace petroleum would enhance the deployment of liquid fuels from algae, should that become a practical source.

5.4.2 Renewable Energy

5.4.2.1 Ethanol from Biomass

Biomass, usually corn in the United States and sugar cane in Brazil and elsewhere, is used today to make ethanol which is either used directly or blended with other liquid fuels, such as gasoline, for use in automobiles. There are a variety of sources of biomass that can be used to make liquid fuels besides corn and sugar cane, such as switchgrass, corn stover, and wood. Soybeans have been used in the production of biodiesel.

The major benefit of ethanol from biomass is the potential for a sustainable source of liquid fuel. However, there are major issues with biomass that need to be favorably resolved. Rather than attempting to address all of these points of controversy, the approach here is to discuss some fundamental aspects of biomass, how they affect the future of ethanol production, and to propose a way that might replace controversy with data from actual operating experience, using a different way to have farmland produce ethanol.

The most fundamental characteristic of biomass is its low energy density. Although solar energy is a huge source of energy, it is very spread out. Further, the portion of the sun's net energy that is annually converted to biomass is only a small fraction of the solar insolation, in the range 0.1% for trees, based on U.S. Forest Service measurements. On an annual average, trees absorb about 1% of the incident sunlight energy, but about 90% of that energy is utilized as a "house load", i.e., to grow leaves, move water/fluids from the soil to higher elevations, etc. The remaining 10% is used to grow new biomass, i.e. just 0.1% of the incident solar radiation energy has the potential to be converted to liquid fuels. Similar figures have been reported, such as 0.05% of the solar energy absorbed by plants and trees ends up as biomass that may be useful in making ethanol (reference [36]). This low energy density means that significant land areas must be used to produce sizeable quantities of ethanol from biomass.

The low energy density of many biofuels before processing also affects the gathering of biomass. The range over which vehicles, like trucks, can gather these energy sources is limited. At some point the energy it takes to drive the truck on a round trip will exceed the energy content of the biomass in the truck. This zero net energy point is the maximum distance that the truck should travel from the biorefinery. Because of energy density considerations, steps are taken to densify the biomass near its point of origin, i.e., near the growing fields themselves. Work is underway to accomplish this localized densification of biomass (reference [37]).

The ability to find more land to grow biomass for ethanol production, beyond what is now dedicated to farming and forests, is constrained. One suggestion is to make cellulosic ethanol from switchgrass grown on land in the Conservation Reserve Program (CRP), using modern farming techniques. The CRP might be the first place to consider because use of its land would not be in competition with food or forestry production, although some people want to preserve this land as is since they hunt there. There are about 34.6 million acres (13.8 million hectares) in this program, but some of this land is so isolated that it would not be practical to attempt to use it. As indicated before, there would be a net energy loss if biomass was gathered over widely spread out locations (See Figure 14). If one assumes that 9.6 million hectares are available for switchgrass and the switchgrass to ethanol production rate is 2700 liters per hectare per year, this CRP land area might yield about 25.9 billion liters of ethanol per year, not counting processing losses in converting switchgrass to ethanol. As a point of comparison the annual production of ethanol from corn today is about 18 billion liters and requires about 5.7 million hectares, using about 20% of the land area now used to grow corn in the U.S. Converting liters to gallons, the 25.9 billion liters from CRP land is equivalent to producing about 6.5 billion gallons of ethanol, again without accounting for processing losses. Ethanol has a 38% lower energy density than gasoline, so 6.5 billion gallons of ethanol is the energy equivalent of 4 billion gallons of gasoline. In 2009 the United States consumed about 138 billion gallons of gasoline.

Although ethanol has a lower energy content per gallon than gasoline, its higher octane number produces a higher compression ratio in vehicles than gasoline. Even if the higher compression ratio completely offset the lower volumetric energy content of ethanol and if all the practical CRP land was dedicated to growing switchgrass, this would, at most, only displace a few percent of the gasoline now used in American vehicles.

Since the CRP land would, at best, only produce a few percent of the energy equivalent of today's gasoline, additional land needs to be used for growing biomass for fuel if ethanol is to be a major future liquid fuel. However there are cautions here too. If ecosystems are cleared directly or indirectly to produce biomass for biofuels, the resulting release of sequestered carbon in the soil of the cleared lands could negate decades to centuries any greenhouse benefits from using biofuels (reference [38]). So one important criterion for growing biomass to produce ethanol is that it should be GHG neutral, or better.

With regard to using land to grow energy crops, some basic principles must be established in addition to being GHG neutral, or better. First, no action should be taken that degrades the land such as excessively increasing erosion of the soil or stripping the soil of necessary nutrients, i.e., growing of energy crops should be sustainable. Second, using land for energy crops should not result in having an insufficient amount of food for the nation and those that depend upon our food exports[2]. Third, growing energy crops should not cause shortages of other critical resources, such as water.

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2 Earlier claims that growing corn to make ethanol has caused food shortages have been challenged. The counter-argument is that recent food shortages appear to be a more of a result of high oil prices and less so from producing ethanol.

Perhaps the most promising way to increase the biomass contribution to liquid fuels is a basic rethinking of how land should be used. (reference [39]). Some 85% of the land used for agriculture in the U.S. does not directly go into making food for humans. Rather, this land is used to make food for animals which are later consumed in our food chain. However, we could feed cows more digestible grass or crop residues and less grain so that the land formerly devoted to feeding them grain can then grow grass for biofuels and animal feed. Other means to increase the amount of biomass is to use double cropping. It is argued that the presence of a double crop would permit greater removal of corn stover without excessive soil erosion. Finally, a larger contribution from biomass would entail increasing the grass yield from pasture land, perhaps from 3 tons per acre to about 6. Achieving this increase in pasture yield is considered to be plausible based on the fourfold increase in the yield of corn over the past 50 years which was accomplished by better seeds and better agronomic practices. It is estimated that this approach would require about 280 million acres of land and might produce about 100 billion gallons of ethanol per year after accounting for losses in the biorefineries, somewhat less than half of the energy equivalent of today's gasoline used in transportation in the United States. In addition to growing biomass to make ethanol in the United States, energy farms might be encouraged in other locations, like Central America.

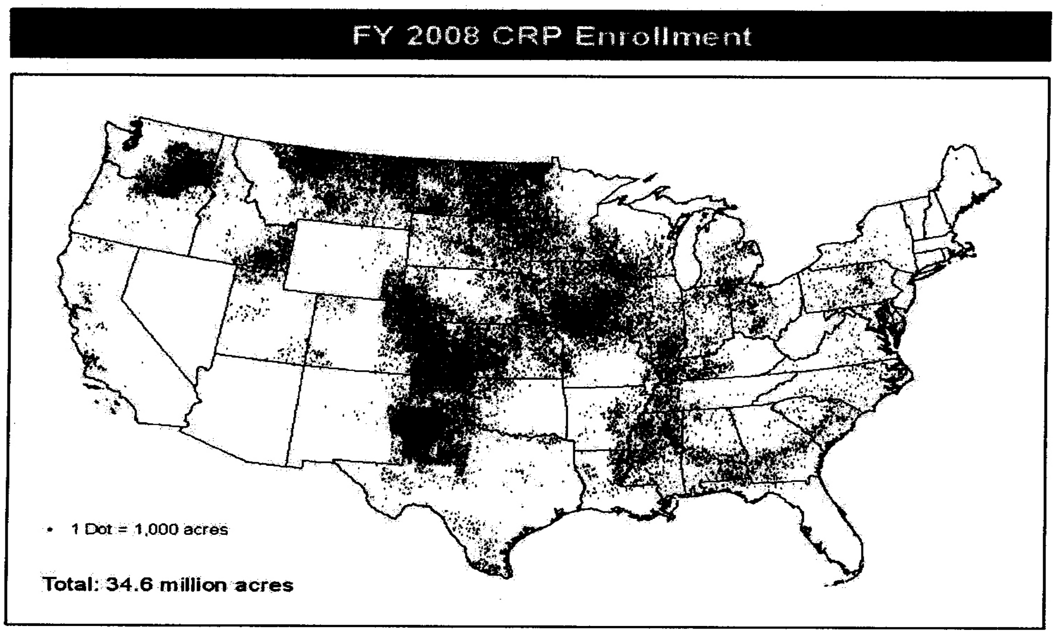
The pace at which liquids from biomass enter the transportation market might not be set by the ability to grow the requisite amount of biomass, but more by the time it takes to build the accompanying infrastructure. Estimates are that it would take decades to build enough biorefineries to convert the biomass into 100 billion gallons of ethanol per year. One estimate is that about 1000 biorefineries might be needed. Even if a new biorefinery became operational every week, it would still take about 20 years to build 1000 refineries.

Producing ethanol on this scale is a mammoth undertaking and using farmland to grow fuel is subject to considerable controversy. Some earlier claims about the yield of ethanol per hectare from switchgrass have been shown to be significantly overstated. These earlier switchgrass ethanol estimates were based on very small research plots, typically less than five square meters in size. These small research plots were hand-sown, hand-weeded, and hand-harvested which maximized their output. Much more realistic results have been reported (reference [40]) by Schmer, et al, based on multi-year experiments in ten farms in several locations in mid-America. These recent results show that the ethanol yield per hectare for switchgrass is similar to that from corn, provided modern farming techniques are applied.

Conversion technologies for corn-to-ethanol are far more mature than switchgrass-to-ethanol technologies. The sugars and starches in switchgrass are more tightly bound than those in corn and will result in higher conversion costs and smaller net energy. However, advanced technologies to extract ethanol from cellulosic material are under investigation and may prove to be effective (reference [41]).

In conclusion, some experts believe that over several decades a large fraction of today's liquid fuels could come from biomass. Implementing such an agricultural change to produce all this ethanol would be a profound transformation of our farm system. It seems essential to first test this important idea by demonstrating that the projected biomass yields can be obtained in a sustainable way that does not create water shortages, cause soil degradation, create a net increase in GHG, or reduce the amount of food the nation now produces, all at a price that is affordable. If making liquid fuels from biomass can be accomplished in a way that decreases the release of GHG in transportation, biomass derived liquid fuels could be an important mechanism to meet the long term GHG release limits. A significant demonstration project of appropriate scale and duration seems to be justified to generate actual production data and to demonstrate that the criticisms of biomass can be overcome by using farmland in a more grass oriented way. When establishing such a biomass demonstration program an independent scientific body should establish goals, performance criteria, boundary conditions, etc., and monitor results to prove that present criticisms of using biomass to make ethanol can be effectively resolved.

Figure 14: Conservation Reserve Program



5.4.2.2 Offshore Windpower

Offshore windpower has some advantages over onshore windpower. Offshore wind speeds are often higher and the wind blows a higher fraction of the time. Offshore wind farms may be placed closer to their electrical loads along the nation's coastlines, than some land based wind farms. Such offshore sites would avoid some NIMBY (Not in my back yard) resistance and possible legal controversies associated with running very long new transmission lines through many different jurisdictions. It may be easier to erect very large wind turbines offshore, in the 5 megawatt or larger range, than attempting similar sized wind turbines on land. Being offshore, there are no land use conflicts. On the other hand, the cost for underwater electric cables is high and even some offshore facilities have run into public resistance, often for aesthetic reasons. Both onshore and offshore wind farms have to deal with grid instability issues, their intermittent operation, and possible temporal mismatches between demand and supply. Both onshore and offshore wind farms must be built to withstand severe weather conditions such as hurricanes and ice storms.

The levelized cost of electricity from offshore wind farms is estimated to be higher than nuclear power plants (reference [42]). New nuclear plants built in China and South Korea now being offered at very attractive capital costs. How would offshore wind power compete in the carbon free electricity market if such low cost nuclear plants begin to be built in the United States or against natural gas plants now that large amounts of shale gas are coming on line? One possible answer to this question is that offshore wind farms might be better off in the liquid fuels market, not the electricity market.

It is possible to make methanol, CH_3OH, and other hydrocarbons, such as kerosene, out of seawater by combining the products of the electrolysis of CO_2 and the electrolysis of H_2O (reference [43]). The concentration of CO_2 in seawater is much higher than in air, making seawater a more attractive source for this gas than air.

Using the electricity from offshore windpower to make methanol in situ would solve a number of problems. First, the offshore wind turbines could be placed far enough away from the land so that they would not be visible, which should minimize aesthetic objections, and would avoid noise concerns. Deepwater locations can be chosen to avoid shipping lanes, aircraft flight paths, commercial and sport fishing, and known migratory paths of birds and marine animals. There would be some cost reduction because no power cables from the wind turbine site to the onshore grid would be necessary. The intermittent nature of the wind turbine would not be a concern with methanol as the final product, not electricity. There is no need to try to match supply and demand. Methanol would be generated at the wind turbine site and stored in nearby tanks as it is produced. These tanks would be emptied periodically by ships specifically designed to take this methanol from its offshore origin to an onshore storage location or possibly towed ashore to be emptied there. Storing energy in the form of chemical bonds, i.e., as a liquid fuel, requires far less volume than storing energy using “mechanical” means, like pumped storage. This means that the methanol storage systems at sea could be comparatively compact. Because these offshore wind turbines methanol producers would not be tied to the onshore electric grid, there is no concern about causing grid instabilities. Finally, there are many excellent ways to make electricity, but only limited ways to make liquid fuels that also reduce GHG levels in the atmosphere.

This arrangement could produce methanol with no net CO_2 buildup in the atmosphere. As this system operates, CO_2 would first be depleted from the seawater.

This would cause an equal amount of CO_2 in the atmosphere to be rapidly absorbed in the upper layers of the seawater. Until such time as this seawater derived methanol is burned, this operation would lead to a decrease in the CO_2 in the atmosphere. Later, when this seawater generated methanol is burned, CO_2 would be released back into the atmosphere equal to the amount first depleted from the atmosphere. Since this seawater/wind turbine methanol would be used to displace gasoline, there would be a net decrease of CO_2 generated in the transportation sector, while simultaneously reducing our dependence on petroleum. This net decrease in CO_2 would continue until such time as there would not be any gasoline to displace, at which time this seawater process would become CO_2 neutral. This is an advantage over using methanol to displace gasoline where the methanol comes from fossil fuels like coal or natural gas. Methanol that comes from fossil fuels initially can be made to be essentially GHG neutral. This is because the GHG abated from burning gasoline is matched when the methanol itself is burned as a liquid fuel. Once there is no gasoline for fossil generated methanol to displace, this route to liquid fuels becomes a net source of GHG. Another advantage that the WTG mode of making methanol has over using fossil fuels is that it is sustainable, whereas methanol producing fossil fuels, coal and natural gas, is not. In the next twenty years or so all practical means of producing methanol would be of interest as a means to displace imported petroleum, but in the long term GHG neutral sources of methanol would be preferred. More generally, ethanol from biomass and methanol from seawater, both renewable energy carriers, could be the dominant sources of liquid fuels in the long term post-petroleum era in that both are sustainable and GHG neutral.

An estimate has been made of how much methanol 10,000 offshore 2.3 megawatt electric WTGs might produce in a year, assuming a capacity factor of 40%. Based on these assumptions about 0.28 MB/D of methanol would be made and 17.6 million metric tonnes of CO_2 would be removed from the atmosphere per year until such time that the methanol is burned (reference [44]). Section 4.2 recommends a goal of storing a minimum of about 685 million barrels of petroleum equivalent in a strategic National Liquid Fuel Reserve. Since methanol has about half of the energy content of gasoline per unit volume, 685 million barrels of crude oil after refining is roughly the energy equivalent of about 1370 million barrels of methanol. Assuming that 1000 WTGs, 2.3 MWe in size, could be operational in one year, another 2000 WTGs in the second year, then 3000 and 4000 WTGs added in the third and fourth years, respectively, it would take about 15 years of operation from inception to accumulate about 1370 million barrels of methanol. An additional benefit to this program is that it would generate operational data for other large seawater to methanol projects that would come later.

In June, 2009 Norway's giant oil and gas company Statoil installed the world's first full-scale floating wind turbine (reference [45]). This 2.3 megawatt generator is moored six miles off the Norwegian coast in 700 feet of water and started to supply electricity to the Norwegian grid in September, 2009.

The American Wind Energy Association (AWEA) has called for about 100,000 wind turbines by 2030, of which 20,000 would be placed offshore (reference [46]). The AWEA estimates that these 100,000 wind machines would cost of about $500 billion dollars, not including the additional cost for the transmission lines. One cost estimate, made by the University of Maine's Advanced Structures and Composites Center, is that a 5 gigawatt deepwater wind farm would require about a $20 billion dollar investment. Based on these cost estimates 10,000 offshore wind turbines in the 2.3 megawatt range might cost about $25-50 billion dollars.

It is expected that costs for offshore wind turbines would decrease over time if a large order to build these machines were placed. This would help sustain the offshore wind power industry. The industrial base and technology development of such a large offshore effort would likely benefit onshore windpower, as well.

There are other potential benefits to developing a wind turbine industry, as discussed in Section 5.4.2.8.

5.4.2.3 Onshore Windpower

Onshore windpower is growing in the United States, often driven by state mandates to have a certain amount of renewable energy by a specific date and by a variety of subsidies. Public acceptance is divided where some people are unhappy with noise and aesthetic issues and others are generally quite supportive.

In the longer term, the contribution of onshore wind power will likely be determined by costs. On the positive side this source of electricity is sustainable and carbon free. Onshore windpower does not consume water. This could be increasingly important as adequate water resources become less available. If a carbon tax is enacted wind power would benefit, as well as other renewable energy forms and nuclear power. On the negative side there can be the expense of long transmission lines between wind farms and electric load centers, possible underutilization of dedicated transmission lines, and the need to have backup sources of electricity (often fossil fuel sources) when wind power is insufficient to meet the demand for electricity.

One area of debate is the level of wind power penetration in the overall electrical power system that can be tolerated before grid stability issues become important. One report, by the North American Electric Reliability Corporation, warns that "adding electricity from the wind and the sun could increase the frequency of blackouts and reduce the reliability of the nation's electrical grid" (reference [47]).

Some analyses indicate that wind power could reach a penetration of 20% or more before grid stability becomes an issue. However, this level seems to be at odds with actual experience. On February 26, 2008 a drop in frequency on Texas's transmission grid caused the Electric Reliability Council of Texas (ERCOT) to activate an Emergency Electric Curtailment Plan. ERCOT reported that wind production dropped from over 1700 megawatts three hours before the event, down to 300 megawatts at which point the emergency procedures were implemented. These emergency procedures included temporarily dropping large industrial electrical loads off the grid where the utility and these industrial customers had contracts in place to have their electricity cut off under emergency conditions.

The February 26, 2008 event clearly happened at wind power penetration was less than 20% in the ERCOT service area. It appears that the determination of grid stability is a local configuration issue where the location and size of wind energy sources, the location and size of electrical loads, the capabilities of different transmission lines that connect sources and sinks, and the availability of ancillary services (such as generation resources held in reserve to address loss of generation resources and unexpected large changes in generation requirements, and non-spinning reserves) all play a part. Perhaps the resolution of the grid stability/ percent penetration of wind power on a national basis will be the sum of achieving grid stability in many local areas.

The issue of grid stability must be resolved. The national renewable energy reports that the US economy loses between $119 and $188 billion dollars annually from power outages and power quality issues (reference [48]). Yet the U.S. electrical system is at least 99% reliable. If a small decrease in reliability (1%) costs the nation between $119 and $188 billion dollars annually, what are the economic risks introduced by onshore wind power because of grid stability issues?

Tied to the grid stability issue, and also the need to optimize transmission line utilization, is the use of energy storage. Energy storage can accomplish many things, such as acting as a buffer between wind farms and the electrical grid, thereby eliminating grid stability issues. With energy storage, electricity can be dispatched from the storage system upon command, such as by a command signal from a smart grid. This creates a wind farm/energy storage/transmission system that is optimized for least cost wind generated electricity. Such a system can be used as a base load source of electricity or can be used to provide electricity when demand is at its highest and when the value of each kilowatt-hour electric would also be at its highest. A number of storage media have been proposed such as compressed air, pumped hydro, and batteries. The National Renewable Energy Laboratory is also sponsoring research looking into using hydrogen as an energy storage medium. The hydrogen would be generated by electrolysis of water, using the electricity from wind power. Electricity can be regenerated by running the hydrogen through a fuel cell or by burning the hydrogen to drive a small gas turbine-generator.

It is recommended that wind power cost estimates be determined on a whole system basis by including the costs for energy storage and dedicated transmission lines.

5.4.2.4 Solar Thermal

Solar energy can be collected and concentrated to raise the temperature of a working fluid, typically a molten salt, which then is used to produce steam to drive turbine-generators that make electricity. Such concentrated solar power (CSP) systems have the advantage of being essentially GHG and pollution free during operation and sustainable. In order to get maximum sunshine such power plants are/would be located in sunny southern U.S. desert areas where there is low relative humidity.

However there are significant economic penalties associated with such desert locations. First, there is an economic penalty if they are far from their electric load centers, much like some onshore wind farms that are located far from their electric load centers. CSP demonstation plants can use limited amounts of water in the desert as their ultimate heat sinks, but further expansion of this concept means that future solar thermal plants would have to use the surrounding air as the ultimate heat sink. Desert air temperatures are high during the day, thereby reducing the efficiency of air cooling, which already is less economical than using a body of water as the ultimate heat sink.

Like all solar systems they can only collect solar energy during daylight hours. The use of a molten salt as both cooling medium and an energy storage medium extends the time during which a solar thermal plant can continue to produce electric power. In effect, some electricity production during daylight hours is shifted to hours after sunset through energy storage. Present solar thermal designs do not produce electricity 24 hours per day. Since molten salt freezes at about the same temperature that water boils, this salt must be drained from the solar thermal plant each evening and kept above its freezing point. Subsequent operation during daylight hours then requires refilling of the solar thermal plant with its molten salt working fluid.

In addition to diurnal variations in the availability of solar energy there are significant seasonal variations as well. Insolation data collected at Desert Rock, Nevada, which is in the same general area as these solar thermal plants, show that the available solar energy in winter months ia about half that of peak summer months. So the electrical output from solar thermal plants would be correspondingly smaller in winter months. This electricity production seasonal profile plus the diurnal variations impacts the economics of the transmission lines from the solar thermal plants to their distant load centers. If the transmission lines are only partially used, particularly in winter months, this is an economic disadvantage.

Some have expressed concern that sand storms might be destructive of the highly polished concentrating reflectors used in these CSP plants.

It may be difficult for these solar thermal plants to economically compete with new gas electric and new nuclear plants that would be built much closer to their load centers, can produce electricity a very high percentage of the time and can be located throughout the country and not just in dry, sunny, low humidity areas.

5.4.2.5 Photovoltaics

Photovoltaic plants have a distinct advantage over solar thermal plants because they directly convert solar energy into electricity. Because of this they avoid the problems of having an ultimate heat sink as all thermal plants require. There is no need to drain and refill molten salt working fluids daily. However, large photovoltaic plants in the desert have some of the same drawbacks as solar thermal plants: far from their load centers, and diurnal and seasonal variations in electrical output, unless large storage systems are built.

Unlike large solar thermal machines, small scale photovoltaic systems exist today in large numbers. Small scale photovoltaic systems have been immensely useful in countries with large rural populations with no significant service from an electrical grid. While such electric loads are is much smaller than the typical usage of people on the grid in urban areas, it has been profoundly beneficial to people in rural areas who have had no electricity. It has enabled them to recharge their cell phones, has cut down on the fire wood they have to gather for cooking, and has been the source of electricity for limited lighting.

Extending the positive experience of photovoltaics to developed countries has its challenges where grid based electricity is available virtually all the time. Costs for photovoltaic systems have been high, but the efficiency of converting sunlight directly into electricity have been improving. However the cost of the balance of these photovoltaic systems, such as inverters, represents a large portion of the total system costs. Since the technologies of the balance of these photovoltaic systems are well developed, it is less likely that major cost reductions in this portion of the overall costs will be achievable. It is expected that the contribution from photovoltaics will continue to increase because of subsidies and renewable energy mandates. The ultimate limit on the photovoltaic contribution is likely to be set by cost factors.

It is valuable to recognize that we are in the very early stages of solar electricity. Data collected by the Energy Information Administration indicate that the combined output for solar thermal and photovoltaics for 2009 was 0.8 billion kilowatt-hours out of a national electric production of 3,652.7 billion kilowatt-hours.

5.4.2.6 Geothermal

Geothermal energy has the potential to produce large amounts of low carbon electricity and could possibly supplement nuclear power in the long term. If so, this would add diversity to our long term sources of electricity. It is even possible to visualize geothermal energy as a long term land based source of electricity with nuclear power more concentrated on offshore locations and dedicated to producing methanol (see Section 5.4.4). In order to advance the status of geothermal energy a prototype commercial scale enhanced geothermal facility needs to be constructed and field tested (reference [49]), (reference [50]).

5.4.2.7 Algae Sources

Microalgae biofuels may eventually be a source of liquid fuels but will require long-term R&D, including the development of strains that achieve very high productivities. Algae production systems are limited by the need to be located in favorable climates where flat land, water and CO_2 sources are all simultaneously available (reference [51]). Favorable climates are necessary to avoid situations where energy would have to be added to the algal ponds during cold weather to protect the algae from freezing. Since algae are cultivated using photosynthetic processes it has similar complications as solar thermal systems with both diurnal and seasonal variations in the energy available from sunlight. On a more positive side, liquid fuel can be easily stored and unlike solar thermal systems there is less need to temporally match supply and demand.

Some DOE sponsored efforts have been made to use the CO_2 effluent from coal power plants as the CO_2 input to algal systems. This was a fairly land intensive effort and points to the difficulty in finding locations that would meet the requirement of co-locating sources of CO_2, water, and flat land.

5.4.2.8 Population Density and Laddering

The significant benefits of photovoltaics to rural off-grid areas in the world contains broader lessons for renewable energy. Whereas it is difficult for photovoltaic systems to be economically viable without subsidies in a country like the United States where even rural areas are already electrified, the opposite is true in rural off-grid areas in developing nations. In such rural off-grid areas it is far less economically attractive to install large centralized facilities, such as 1000 MWe nuclear plants. The cost for such large plants is often beyond the means of rural populations, they take long times to be installed and the required transmission and local distribution network does not exist, and the electrical loads may be too small to justify such a large source of electricity.

Placing the right technology in the right location is often influenced by population density. Lower population density areas, especially rural off-grid areas, are a better fit for distributed renewable energy systems, such as the photovoltaic system described in Section 5.4.2.5. Higher population density areas, such as urban areas are better served by large centralized facilities, such as large nuclear plants. We see this today where lower population density areas often have homes with their own water wells, septic fields, individual oil or propane tanks or wood piles for heating, i.e., they have a far more decentralized lifestyle than in urban areas. In more highly populated areas one needs centralized systems to deliver services such as water, electricity, sewers, trash removal, and grocery stores. So there is a correlation between population density and the degree of decentralization that is practical. Distributed renewable energy sources are a better fit for low population density areas while large centralized facilities, such as nuclear power plants, are a better fit for urban areas.

There may also be a "laddering" effect. Rural off-grid areas may start with photovoltaics in a home-by-home situation. In time, a larger, village sized, system might be justified such as a wind turbine with energy storage to assure a constant or demand controlled output. This wind turbine would have a local distribution system, not a full sized transmission grid, and might primarily serve larger electrical loads such as from irrigation and refrigeration systems. Since wind turbines do not use water and are non-polluting they would fit well in a rural agricultural area.The home-by-home photovoltaic and the village sized wind turbine systems would likely overlap each other in terms of the consumers they would serve. It is also conceivable that further laddering situations might evolve as one considers the electricity needs beyond village sized settings and into larger communities. An example of "laddering" might be if rural off-grid areas develop into larger communities with a demand for electricity exceeding what could be provided by photovoltaics and wind turbines. In such a case the next step up the ladder might be a small nuclear plant as described in Section 5.4.4.

If a national commitment is made to 10,000 offshore wind turbines (See Section 5.4.2.2) which has the purpose of making methanol and/or reducing atmospheric GHG levels, this would help sustain a U.S. manufacturing base for onshore wind turbine systems with energy storage, which then would be designed to meet the basic first "ladder steps" of rural off-grid areas in developing countries.

5.4.3 Fossil fuels

5.4.3.1 Oil

The major points about the transformation of oil have already been made. Conventional oil has likely seen its peak. Many of the projected sources of oil would come at both high market and high environmental costs. The uncertainty about future oil supply is likely to increase as the world becomes more and more dependent on oil fields yet to be developed and oil fields yet to be discovered. Not only are there increasing uncertainties about oil supply going forward, there are uncertainties in the demand for oil. Therefore the margin between oil supply and oil demand is uncertain on both sides of the equation. Yet the trigger for economic crises is the loss of this margin, as seen in 2008 when the margin effectively was zero and oil prices briefly hit $147/barrel precipitating a world wide recession. This section adds further insights to the oil transformation now going on.

One result of oil becoming a much smaller fraction of a future energy mix is the reduced need for oil refineries. Petroleum refining is the most energy- intensive manufacturing industry in the United States and accounts for about 7% of the total US energy consumption (reference [52]). Limiting oil use in transportation and space heating would reduce the amount of oil to be refined and the release of GHG from refineries. Refineries release about 200 million tonnes of GHG per year and the EPA has announced plans to regulate these emissions (reference [53]). These EPA plans have met with Congressional resistance. However, much of the EPA goal to reduce GHG emissions from refineries could be accomplished just by reducing the nation's use of petroleum. The conflict between some Congressional members and the EPA might be reduced if this alternative way to reduce the environmental impact of oil refineries were more widely known. A similar opportunity to reduce conflict between the EPA and some congressional members arises in the curtailment of GHG emissions from coal power plants. The proposed replacement of existing coal generated electricity with natural gas would reduce GHG emissions. Then using these coal fired power plants to make methanol reduces petroleum use. Less petroleum use means a reduction in GHG from refineries in addition to all the national security and economic benefits. Figure 13 displays a ranking of coal and gas plants according their health damage effects. It should also be possible to rank the 149 or so oil refineries in the United States, according to their efficiencies. As oil refineries are phased out, those that are least efficient should be considered for earliest retirement.

An alternative to phasing out today's refineries would be to upgrade them so that they could handle all refining needs in the United States plus refine imported crude oil for other countries, selling back the refined products to them and others. If US refining capacity was maintained in order to market refined products, improvements would be in order. Today's refineries burn between 10% and 20% of the crude oil delivered to the refineries as a heat source. This is rather like heating your home by burning 100 dollar bills. Not only is this expensive, today's refineries are major sources of air pollution and greenhouse gases.

What if the heat source in a modern refinery was a High Temperature Gas Cooled Nuclear Reactor (HTGR) instead of burning crude oil as the heat source? HTGRs are ultrasafe power plants capable of reaching 900 degrees centigrade or more, quite sufficient to refine crude oil. These nuclear reactors, long neglected in the United States where their technology was started, are under development in Japan, China, and South Africa, with some research going on in the United States including some recent funding by the DOE on high temperature nuclear power plants. High temperature nuclear plants could use air as the ultimate heat sink instead of relying on a body of water, e.g., a river, lake, or the ocean, as the heat sink. This air cooling capability permits such high temperature plants to be co-located with many types of facilities that would benefit from a no-carbon heat source that would not add to water availability issues. Saving oil by supplying high temperature heat to oil refineries from HTGRs would be the equivalent of a major oil discovery in the United States, without having to drill a single well or build one pipeline to transport the crude oil.

The Chinese have a small 10 megawatt high temperature research reactor that is planned to be operational this year. South Africa is concentrating on a 165 megawatt Pebble Bed Modular reactor they hope to develop and export to the world (reference [54]). These highly efficient machines produce both high temperature heat and electricity without producing any greenhouse gases. Any excess electricity from a HTGR at an oil refinery could be placed on the electrical grid.

The high energy density of gasoline makes it attractive for aviation and other applications where weight and space are at a premium. Oil will still be valuable for other applications beyond transportation, such as in petrochemicals and other non-transportation applications (See Table 10). Domestic oil will continue to be in demand as long as its price is competitive and environmental effects are acceptable.

Looking at the world oil situation more broadly, it seems plausible that the roles of China and the United States may become reversed over time. In order to survive as a nation, the United States must greatly reduce its usage of petroleum. On the other hand, if China continues to grow, its need for petroleum will also grow as witnessed by its recent sharp increase in demand. China's oil demand will continue to rise if it implements its plans to greatly increase its fleet of automobiles. As shown in Table

5, China's very large population and low oil consumption per person are indicators that China's demand for oil may continue to rise for many years. Since there will be increasing uncertainty in the world's available oil, China will have to take a course similar to that now required of the United States and seek its own post-petroleum future.

Instead of possible conflict between these two great nations, the world oil situation could be the basis for mutual interdependence. For example, China has shown a willingness to invest in America's energy future by offering to help build and finance high speed trains (See Section 5.6.4). As the United States succeeds in reducing its petroleum use, it provides more petroleum on the world market and stretches out the time China would have to complete its own energy transformation. Further, a stronger America protects the U.S. currency and China has very large investments in U.S. debt. Finally, having succeeded in transforming itself to a post-petroleum future, the United States may have products and technologies that would assist China in making its own energy transformation.

5.4.3.2 Coal

Coal is a major resource in the United States. The dominant use of coal today is in coal fired electric power plants with about half of the electricity generated in the United States coming from coal. Because coal, after petroleum, is the largest source of GHG in the USA and the source of many other environmental and health issues, there is significant pressure to curtail its use. Since GHG are now considered as covered by the Clean Air Act, EPA will issue regulations that impact on the use of coal in electric power generation. Further, coal faces growing competition from abundant shale gas (natural gas) and low cost nuclear plants being built outside of the United States which likely will find their way to the US energy market, plus challenges from renewable energy and conservation. Natural gas releases about half the GHG per kilowatt-hour of electricity than coal and nuclear power, renewable energy, and conservation are all essentially "carbon-free".

In order to protect the future of coal use in electric power plants in the United States there has been interest in carbon capture and storage (CCS), a technology with considerable uncertainties. One concept is to run pipelines from the smokestacks of coal plants to some underground storage location, then compressing the CO_2 to high pressures, around 1000 pounds per square inch, before injecting it into underground storage caverns. It is difficult to accept that present coal plants could economically run piping systems from their plants to underground caverns and sequester huge volumes of CO_2 effluent over long periods of time. It has been estimated that as much as 28% of the electricity output from a typical coal power plant would be needed to achieve this form of CCS. The volume of CO_2 that would have to be captured and stored is huge. New undergound locations equivalent to the volume of 41 oil supertankers would be needed every day of the year to store this compressed CO_2 according to Robert Bryce (reference [55]).

A leak rate of 2%/year might return much of this CO_2 to the atmosphere in 50 years where it would remain for very long time periods. Reference is made in the AEF report to successful CO_2 sequestering offshore from Norway (in the Utsira Sand at Sleipner). However, this underwater CO_2 sequestering was carried out at a depth of 1012 meters below sea level (reference [56]). This implies that the CO_2 had to be compressed to very high pressures on land to overcome the seawater hydrostatic pressure. This opens up the possibility of important leakage at the point of compression and along the pathway to this underwater sand reservoir. Obviously, deep water CO_2 storage could not be used in inland locations.

Consequently people have been looking for alternative ways to sequester CO_2 and some promising ideas are now coming forward. One idea is to combine CO_2 with seawater to make calcium carbonate which can then be spray-dried into cement or shaped into pellets for later use in construction jobs (reference [57]). If this approach to capturing carbon and sequestering it as calcium carbonate proves to be attractive it might have an important effect on coal's energy future in the United States and elsewhere. Not only might this technology be applied to present coal plants, but could possibly be used in CTL processes. Further, it might be something that would be of interest to other countries with large coal resources, like China.

An even more attractive way to deal with CO_2 releases from coal power plants (and other major sources of CO_2 releases such as cement factories, crop wastes, and natural gas power plants) is to use this "waste" product as input to making methanol. This would convert a liability into an asset. Methanol can be made from anything that is, or ever was, a plant. This production of methanol would reduce our usage of petroleum and should be GHG neutral; the CO_2 released by burning methanol in transportation would be offset by not releasing CO_2 from the gasoline it would displace. There would be an additional GHG benefit if methanol reduced gasoline use resulted in cutting back on the production of gasoline at refineries. Methanol is a basic building block for hundreds of essential chemical commodities and would be an excellent replacement for oil used in non-transportation applications.

An estimate has been made on how much methanol might be produced if all the electricity produced at the nation's coal power plants was removed from the grid and used instead to convert the CO_2 in the flue gases from these coal plants. Here the electricity would be used in the co-electrolysis of CO_2 and H_2O to make methanol, CH_3OH. (reference [58]). In 2009 the coal plants in the United States produced 1867 million metric tons of CO_2, enough to produce 3.72 million tonnes/day of methanol or about 2.95 MB/D of methanol. Methanol has about half the volumetric energy content of gasoline (15.6 MJ/L vs. 32.4 MJ/L), so 2.95 MB/D of methanol is the energy equivalent of about 1.42 MB/D of gasoline. Methanol has a higher octane rating than gasoline. According to Bromberg and Cheng "With a dedicated methanol engine, the vehicle can be as efficient as a diesel, or about 25-30% more efficient than conventional vehicles operating on gasoline. The range of dedicated high efficiency methanol vehicles is about 30% lower than conventional gasoline vehicles."

The figure of 2.95 MB/D of methanol can be further increased because it was based on the CO_2 output from coal plants in 2009. However, in 2009 only a fraction of the coal capacity was used, some 59.2% of the nameplate capacity. Assuming that 15% of the nameplate capacity can not be used because of water or other limitations and the remaining methanol producing plants operated 90% of the time, about 3.81 MB/D of methanol could be produced from existing coal power plants. From a driving range this would be about the same distance 2.7 MB/D of gasoline would be able to achieve in conventional automobiles. However, another 10-20% must be added to this amount to account for the crude oil used as a heat source in the refineries. Using a mid-range figure of 15%, some (2.7)(1,150) =3.1 MB/D of crude oil would have to be consumed. Therefore if all the CO_2 from coal plants were converted to methanol, this would be sufficient to reduce our petroleum consumption by about 3.1 MB/D.

Therefore converting present coal plants to be methanol producers represents a significant way to reducing petroleum usage. This would be a boon to the coal industry because it would mean an increase of about 29% in the amount of coal needed per year, no need to spend money on CCS, and a new market for coal that would be independent of competition from lower cost producers of electricity. Further, the coal plants are already built as are their coal delivery systems.

The technology of converting CO_2 from power plants and factory emissions is not new; it has already been done. However, producing methanol from power plants at the above scale would be a very large increase. In 2009 only 5.3 million tons of methanol were consumed in the United States, according to the Methanol Institute. In order to fully take advantage of the great potential of existing coal plants to displace petroleum emphasis would have to be placed on the methanol conversion aspect of this major transformation and the sources of electricity needed to replace present coal generated electricity. More information is provided later on these replacement sources of electricity. This calculation about using coal plants to produce liquid fuels also emphasizes the need to make cars that can use methanol, or a blend of methanol with other liquid fuels. A priority governmental action then would be the passage of the **Open Fuel Standard**.

There are other ways to make liquid fuels from coal besides using the CO_2 effluent from coal power plants. Converting coal into a liquid (CTL) fuel via the Fischer - Tropsch (FT) process is a long established technology. Coal supplies in the United States are thought to be very large and the cost per barrel of gasoline equivalent from coal using the FT process is attractive. A shown in AEF's Figure 2.14, CTL would be competitive with gasoline if oil prices remain above $65/barrel (2007 dollars).

A major drawback to the FT process to convert coal to a liquid fuel is in the GHG it produces. In some CTL processes today coal is used both as a heat source and as a feedstock. GHG are emitted when coal is burned as a heat source and more GHG are emitted when the liquid fuel, such as methanol, is burned in transportation.

A number of alternative CTL processes have been suggested that would prevent GHG from entering the environment during the heat addition step. The AEF report identifies two such schemes: Using biomass instead of coal as the heat source and using a carbon capture and storage (CCS) process to capture coal's GHG releases. However, the AEF report correctly points out that using biomass as a heat source is not attractive in that this same biomass might be used to make ethanol. This then would leave the CTL process completely dependent on a successfully developed CCS process, which has considerable technical challenges of its own. If CCS is not feasible and large CO_2 releases in the FT process are to be avoided, then the major sources of liquid fuels would be biomass converted to ethanol, natural gas converted to methanol, the conversion of CO_2 in air or in seawater to methanol, and the conversion of CO_2 from coal power plants into methanol. Methanol might also be made near coal mine mouths where adequate supplies of water exist.

However, an alternative to using coal with CCS in the FT process is to use some non-carbon heat source. Several scientists have written papers on using nuclear power in a CTL process, either as a source of hydrogen or as a high temperature heat source (reference [59]), (reference [60]), (reference [61]). High temperature nuclear power plants have the additional advantage over the CCS approach in that it would stretch out coal reserves. The AEF report, on page 66, estimates that to supply 3 million barrels of gasoline equivalent/day would require huge amount of coal, up to 50% of the coal we extract today, assuming coal is both the heat source (with CCS) and the feedstock. Forsberg (reference [62]) has studied coupling a nuclear hydrogen plant with a coal liquefaction plant and concludes that this would convert almost all of the carbon in the coal to liquid fuels and eliminate carbon dioxide releases from the coal liquefaction plant. Three times as much liquid fuel would then be produced per ton of coal. It would be prudent to develop high temperature nuclear technology to have greater assurance that we will have the liquid fuels we need. High temperature nuclear power plants of the same or similar design could be used to generate methanol from seawater.

One attractive idea that needs further development is to use high temperature heat from a nuclear power plant to convert soft coal into solid high-carbon char, hydrocarbons, and gases. This would be accomplished by adding nuclear heat to a large undergound deposit of coal, i.e., to create an underground refining option. This process would have a number of benefits compared to using the CO_2 from coal electric plants. It would replace the coal carrying unit trains that transport massive amounts of coal to the power plants with a liquid distribution system that carried methanol from the underground coal site. It would also avoid issues like the accumulation of coal ash at power plants. A failure of the coal ash retaining dike at the Kingston, Tennessee coal plant led to extensive environmental damage, costing about a billion dollars. While this underground nuclear heating process does not eliminate the release of GHG when the methanol is burned, it has the potential to drastically reduce such emissions during the production process (reference [63]).

Coal can be converted to alcohols, ethanol and methanol, through a gasification process. Coal is used to make syngas which, after passing through a catalyst, becomes methanol.The cost per gallon of methanol using this technology is comparatively low.

In summary, the coal industry, now under attack, could have a very bright future if it underwent a number of major changes. First, it should move away from making electricity to making methanol. Second, as high temperature sources of energy become available, the generation of liquid fuels should relocate from many existing coal fired plants to liquid fuel generating plants mainly placed in the coal fields. Advances in technology could further benefit the coal industry by producing valuable products by in situ heating of coal, thereby avoiding the need for coal trains, old power plants and all the hazards associated with coal wastes, such as ash retaining ponds that have failed, causing extensive damages. Lastly, coal can be converted into various feedstocks for use in a multitude of chemical products.

Energy planners are understandably interested in how many years of coal are left at current consumption rates. (reference [64]), (reference [65]). There are differing opinions on how much coal remains in the United States. Some have used a logistics model similar to that developed by M. King Hubbert, who first used his method to estimate U.S. oil production. This logistics model has now been used by some to estimate the remaining coal reserves in the United States. The Hubbert model fits the U.S oil production and the U.K. coal production histories quite well.

One estimate is that the U.S. will run out of coal in about 100 years, considerably shorter than previousestimates of 250 years. Another estimate by Mikael Hook of Upsula University in Sweden is that world coal production will peak around 2020, enter a 30- year- long plateau, and then decline.

Since coal would be a major source of liquid fuels it is important to stretch out this important energy reserve by transforming the coal industry towards this priority application of making methanol. In time methanol from coal would be replaced by methanol from seawater, as described before.

5.4.3.3 Natural Gas

After many years of decline the reserves of natural gas in the United States has increased dramatically. The reason for this turn around is the ability to extract natural gas from shale using new technologies and the realization that there are vast amounts of shale gas in the country from Texas to New York.

The price of natural gas fell in 2009 to roughly half the 2008 level. In 2009, annual average gas wellhead prices reached their lowest level in 7 years. (reference [66]).

The status of natural gas has been well researched (reference [67]) and will not be repeated here. Instead, this section concentrates on how natural gas can be used to achieve goals of reduced usage of petroleum and limiting climate change.

Natural gas can be used to reduce greenhouse gases by replacing coal in electric power plants. Natural gas can be used to displace petroleum by using compressed natural gas in larger vehicles, like buses, and by making methanol to displace petroleum in other vehicles and in non-transportation applications.

There is a third possibility that is particularly attractive. Excess natural gas electric power plant capacity can be used to replace an equal number of kilowatt-hours normally generated by coal power plants. Replacing petroleum with methanol derived from CO_2 from coal plants was discussed in the previous section. This earlier discussion is continued here and in Section 6.3.2.1. from the perspective of how such an action might affect the natural gas industry. In theory, replacing coal power plants with gas electric power should proceed rapidly because the natural gas plants are already operational and have significant excess capacity during much of the year. In practice, however, there are peak demand times, especially during hot summer months, where both coal and natural gas electricity is needed to meet high demands. Section 6.3.2.1 offers ways to reduce peak demands for electricity thereby liberating more gas megawatt-hours to replace an equivalent amount of electric energy that would otherwise be generated by the coal plants.

In 2009 there was more than enough unused natural gas capacity to completely replace all coal generated electricity. This excess gas capacity would gradually become available to replace coal plants as the actions described in Section 6.3.2.1 to deal with peak demands are implemented. If coal generated electricity was completely replaced by gas power plants, there would be a 930 million metric ton net reduction in greenhouse gas emissions because, on average, coal produces about 2.14 pounds of CO_2 per kilowatt-hour while natural gas produces about 1.22 pounds of CO_2 per kilowatt-hour.

In 2009 1,755,904 thousands of megawatt-hours of electricity were generated by coal power plants and gas power plants produced 920,797 thousands of megawatt-hours of electricity. If excess gas power plant capacity completely replaced coal power plants this would result in a 91% increase in natural gas usage in the generation of electric power. This large increase in gas usage would be further increased by using much more compressed gas in buses and other large vehicles and in the production of methanol.

5.4.4 Nuclear Power

5.4.4.1 Growth in Nuclear Power

Although there is slow progress in United States in building new nuclear power plants, this is not true elsewhere. A very large worldwide transformation is underway in nuclear power, although it has slowed down as nations reassess nuclear power in the wake of the Fukushima accident. There are now over 440 nuclear plants worldwide. Other nations, such as South Korea, Russia, China, France, Japan, and India, are significantly increasing their domestic nuclear construction programs. Many of these countries are also selling nuclear power plants to other countries, uranium mining is increasing and advanced nuclear designs are being brought forward. As the threat of climate change increases, the acceptance of carbon free nuclear power has also increased. According to Michael Kruse of Arthur D. Little, China will spend $511 Billion dollars to build 245 nuclear reactors (reference [68]).

Not only are many light water reactors under construction or in the pipeline, there has been a reawakening of many nuclear designs/ideas that have been shelved for years. India, with its large thorium deposits, is exploring thorium fueled nuclear plants. Other countries are exploring thorium cycle designs. South Korea wants to develop its own spent nuclear fuel reprocessing capability. Only about 1% of the uranium in present once-through fuel cycles is used and reprocessing offers the opportunity to increase the amount of available fuel significantly. The Japanese are exploring extracting uranium from seawater. A by-product of their seawater design is the extraction of vanadium.

Many large nuclear power plants are in the 1000 to 1400 Megawatt-electric (MWe) range. However there is considerable interest in smaller, modular designs with lower up-front capital costs. Holtech International has designed a 140 megawatt underground passive plant that does not need pumps and does not rely on an outside electric grid. This is a modular design that would be mostly manufactured in a factory. It is claimed that the construction cycle of such plants would be just 24 months.The Hyperion Power Module uses a uranium nitride fuel and a lead-bismuth eutectic as the coolant. The 25 megawatt-electric plant is intended to be buried 33 feet underground and would be refueled every eight to ten years. NuScale is a small, light-water reactor, of modular design. A single nuclear site could have between one and 24 such modules, each operating at 45 megawatts-electric (MWe). Babcock & Wilcox has a 125 MWe design, General Electric-Hitachi has a 311 MWe Prism design, Toshiba the 10 MWe 4S design and Westinghouse has its 335 MWe IRIS design. South Korea is also developing a design that would produce about 100 MWe or process heat for water desalination. Dr. Steven Chu, head of the Department of Energy, has pointed out that small reactors are to be sold as ready-made, turnkey devices, which will keep construction costs down and minimize price uncertainties. Other efforts are going forward with high temperature molten salt nuclear reactors, breeder reactors, and high temperature gas cooled reactors, etc., designs.

5.4.4.2 A Modern Licensing Process

One challenge for these small modular reactors is the very long times it takes to get through the Nuclear Regulatory Commission licensing process. The need to modernize the nuclear licensing process is evident and is recognized by the NRC itself.

One area that would benefit from modernization is in the licensing of new light water reactors in the United States. During all the years that the over 100 nuclear power plants have operated in the United States, no member of the public has ever been exposed to high levels radiation from these power plants. Even if there were a severe accident, long term consequences would be extremely small, far smaller than normal background causes of cancer fatalities. Years of operational experience combined with sophisticated analyses show that the probability of a release of radioactive material into the environment from an accident is low. New insights on nuclear accidents have come from ongoing work at the Sandia National Laboratory in its SOARCA program[3]. Sandia has reviewed and analyzed nuclear experiments from around the world and improved its analysis of postulated severe accidents by using much more detailed descriptions of actual nuclear power plants. The following can be derived from the Sandia SOARCA program and other studies:

1. Nuclear accidents which lead to a reactor meltdown are highly unlikely.
2. Of these meltdowns, the majority would not lead to radioactive material entering the environment.

3 SOARCA, State-of-the-Art Reactor Consequence Analysis

3. For those extremely unlikely accidents that could lead to a release into the environment, the calculated radioactive releases would be far smaller and much delayed, compared to what was thought prior to the SOARCA program.
4. These low release values would be achieved without the benefit of any plant operator taking steps to mitigate the accident and without operation of any plant engineered safety feature. This is a very important observation because these Sandia analyses examined station blackout conditions without recovery of the electric grid or the use of large emergency diesels, the Fukushima accident condition.
5. It appears that these nuclear power plants act like big, complex, passive filters of radioactive material. This filtering process is completely accomplished by natural chemical and physical processes without the intervention of safety equipment or actions of plant personnel.
6. In the United States additional safety capabilities were implemented at nuclear power plants following the 2001 terrorist attack to deal with a variety of challenges including station blackout conditions. This additional capability further reduces the likelihood of station blackout conditions leading to reactor damage. If, nonetheless, a situation arose where there was reactor damage, the chemical and physical processes identified above would greatly limit releases of radioactive material to the environment. These natural chemical and physical filtering processes would be unaffected by acts of terrorism.

The implications of the operating experience, probabilistic risk assessments, and now the Sandia studies, is that the licensing of very safe light water reactors could be significantly simplified. What evolves out of all this safety effort is that, for light water reactors, the dominant public protection comes from having a sturdy barrier between the reactor vessel and the outside environment, a low core melt frequency, a physics design that precludes increases in plant power level if reactor cooling water is lost, and the protection of spent fuel. By meeting these design criteria and having an emergency plan that uses evacuation for the inner two miles from the point of release and sheltering downwind beyond two miles, any light water reactor would present very low public health risks regardless of which country it is located in. Had these design criteria been applied to the Chernobyl power plant, its accident could not have occurred and if a different severe accident occurred it would have been contained, as the accident at the U.S. Three Mile Island plant was. The Chernobyl design did not include a sturdy barrier, such as a containment building, and during the accident the power level increased one hundredfold in just four seconds because of a design that caused rapid power increases upon loss of cooling water. It also appears that had the U.S. station blackout safety enhancements installed post September, 2001 been incorporated into the Fukushima plants, plant damage would have been far less. Full verification of this last statement awaits detailed reviews of the Fukushima accident.

The Nuclear Regulatory Commission should greatly accelerate its light water reactor licensing process by concentrating on these design criteria, plus a simplified emergency planning process that emphasizing downwind sheltering at distances more than two miles from the plant site. Many of today's engineered safety features or their equivalent would remain in modern LWR designs because there is a great economic incentive to prevent reactor damage.

With the advent of many new reactor designs, many of which are not light water designs, the Nuclear Regulatory staff should begin to shift its emphasis to reviewing their safety characteristics. Many of these new designs also have inherent safety characteristics.

5.4.4.3 The Fukushima Accident in Japan

The nuclear accident at the Fukushima nuclear station in Japan is being thoroughly analyzed for lessons learned, as is the practice with all large accidents, nuclear and non-nuclear. Although it will be some time before all the facts are in, some preliminary insights are available; some of which are positive, others negative.

On the positive side, two of the most important safety features withstood this unprecedented Richter 9.0 earthquake and continued to function as designed. It appears that the passive containment structure retained its integrity and the active emergency diesels started up and ran for about an hour, until the enormous tsunami washed away the fuel storage systems that these emergency diesels depended upon. Since it was the tsunami, not the earthquake itself, that lead to this destruction at the Fukushima station, the implication is that other nuclear plants not struck by a huge tsunami are likely to survive very large earthquakes, even earthquakes beyond those that they were designed to cope with. In addition to tsunamis, other large natural forces may challenge nuclear plants. there already have been instances where nuclear plants have been subjected to very large natural forces and safely shut down, as designed. The Turkey Point plant in the Florida withstood Hurricane Andrew, a category 5 hurricane, and more recently the Surrey plant and the Brown's Ferry plants survived extreme tornadoes, without incident. Nuclear plants subject to large tsunamis need to be focused on, but there does not appear to be any nuclear sites in the United States where this would be an issue.

Also on the positive side of the Fukushima accident was many of the off site emergency responses. The best response to nuclear emergencies, where the release of radioactive material into the environment may happen or is already happening, is to evacuate citizens near the damaged plant(s) within about two miles and have downwind sheltering for others beyond this distance. The Japanese offsite emergency response, properly, was a mix of in-close evacuation followed by sheltering. If anything, the initial emergency response may have evacuated an area was larger than necessary, thereby placing an additional burden on the already stressed emergency shelters. Nonetheless, a mix of in-close evacuation followed by sheltering virtually eliminates early radiological health effects, even for radioactive releases much larger than those being experienced at Fukushima. Also, to the credit of the Japanese officials conducting the emergency response, steps have been being taken to interdict contaminated food and water from entering the food chain. In the case of the Chernobyl accident 90% of the thyroid cancers, the only major detected radiological health effect from that accident, came from children drinking contaminated milk in a situation described by the WHO as a case of drink the milk or starve to death. This will not happen in Japan or in any other country which has a food interdiction program in their emergency plan. Finally, considering that multiple reactor cores and several spent fuel pools have been damaged, the offsite dose readings are rather low in most areas. This seems to be consistent with the results of Sandia's SOARCA analyses for the Peach Bottom Nuclear Power Plant. This Sandia study is particularly relevant because the Peach Bottom Plant has a design quite similar to the Fukushima plant, including a Mark I containment, and because Sandia analyzed a long term station blackout sequence for Peach Bottom, precisely the event at the Fukushima reactors, regardless of how the accident was initiated.

For the Japanese general public no early health effects from radiation are expected and long term health effects are expected to be too small to be detectable compared to normal background latent cancer fatalities. Economic losses are significant since all the damaged plants will have to be scrapped and there may be large offsite costs. The amount of land that might be contaminated from the release of Cesium-137 is likely to be far smaller than that at Chernobyl. The data that are available so far indicate that the Cesium-137 release from Fukushima has been about one third that from Chernobyl and much of this cesium was transported by wind currents into the Pacific Ocean.

There appears to have been some misrepresent of the Fukushima accident with claims that one or more of the spent fuel pools failed. More recent information refutes this. However, the Fukushima accident pointed out the difficulties in preventing the water in spent fuel pools from eventually evaporating when all electric power is lost for more than a day or two if access to these pools is difficult because of local high radiation levels and fallen debris. This accident appears to indicate that the containment venting system was not properly designed or operated in that hydrogen, an expected by-product of a core melt accident, was not transported through a hardened vent and safely released outside of the reactor building. The subsequent hydrogen explosions significantly complicated the recovery from this accident.The design of these vents will have to be reviewed to determine if they differ from those used in similar plants in the United States as well as comparing venting procedures.

In the long run the largest negative effect of the Fukushima accident may be the slowing down the growth of nuclear power and possible substitution of coal electricity for nuclear power in some countries. This would only worsen the world GHG situation. Germany has embarked on a very ambitious program to replace its nuclear plants, largely with renewable energy. Germany is a highly advanced technological country, but with limited sunshine. Time will tell whether this can be done without harming the environment or being too expensive.

5.4.4.4 Applications

Not only are multiple nuclear reactor designs coming forward, both large sized and small, and not only are different uranium fuels and fuel cycles being developed, different and/or expanded applications of nuclear energy are being considered. These applications can be separated into three main areas: production of electricity, production of process heat, and production of hydrogen. Evolutionary light water reactors (LWRs), modern versions of the types now in operation in the United States, would principally be used for electricity production and some process heat applications, such as desalination of sea water, district heating, and aquaponics. High temperature reactors can also generate electricity and more readily provide high temperature process heat and hydrogen than present LWRs. High temperature process heat and hydrogen can be very important contributors to producing liquid fuels. Examples of high temperature process heat from nuclear power plants to increase liquid fuel include replacing oil as the heat source in refineries, replacing coal as a heat source in Fisher-Tropsch coal conversion to liquid fuels, in situ conversion of coal to liquid fuels, possibly as a heat source for biorefineries, and as a heat source to boost methanol production from seawater, as discussed below.

A very interesting application of nuclear power would be in the generation of methanol. The discussion on generating methanol from sea water using wind turbine generators, while reducing CO_2 concentrations in the atmosphere, presented in Section 5.4.2.2 would also apply to offshore nuclear power plants. The same output as 10,000 2.3 MWe WTGs operating at a 40% capacity factor could be obtained by about 10 offshore 1000 MWe nuclear plants operating at a 90% capacity factor. If these nuclear power plants are also sources of high temperature thermal energy then approximately three times as much methanol could be produced and three times as much CO_2 removed. This large increase in methanol (and CO_2 removal) would be the result of high temperature co-electrolysis of mixed CO2 and steam directly in a solid oxide electrolyzer cell (reference [69]).

There are other features of sea based liquid fuel centers that are attractive. These locations could produce carbon neutral liquid fuels without having issues like food/fuel conflicts, land use and water use constraints, or the need for thousands of miles of new transmission lines and the conflicts this can produce.

What makes this process so valuable is the combination of renewable energy, chemistry, and nuclear power could provide all the methanol the US might need, virtually indefinitely, without causing a net increase in atmospheric or ocean carbon dioxide concentrations. **This process alone has the potential to solve the future U.S. liquid fuels needs for centuries. Equally important, this same approach could be applied world wide, wherever there was an ocean.**

The issue about the availability of sufficient uranium has been thrashed out elsewhere. An excellent analysis of many forms of energy, including nuclear power, has been written by Dr. David J.C. MacKay (reference [70]). MacKay also demonstrates that the amount of uranium and thorium worldwide and in the oceans is sufficient to meet the needs of a very large nuclear power industry for many centuries, especially if fast breeder reactors are used. Fast breeder reactors would use uranium 60 times more efficiently than present once-through LWRs. In the more immediate future before fast breeder reactors are developed, some have argued that there hasn't really been an extensive effort to develop uranium mines and that a far larger reserve of uranium could exist than can be proven on today's limited mining data. Because uranium fuel costs are such a small fraction of the cost of nuclear power, the cost for uranium ore could increase many times without having a major impact on the cost of nuclear energy.

5.4.4.5 Capital Costs

One of the most important issues for new nuclear power plants in the United States is the initial capital costs. Even though many operating nuclear plants are the least cost producers in their service areas, with high reliability and low fuel costs, building a new nuclear power plant can be very expensive. Because of assumed high capital costs, many energy projections predict a rather limited role for nuclear power plants. For example, the AEF report in Figure 2.10 gives a levelized cost for nuclear power in the 6-13 cents per kilowatt-hour. Table 3.1 of MIT's natural gas report gives a cost of 8.8 cents per kilowatt-hour (2005 dollars) and the energy forecasts by the Energy Information Administration put new nuclear power plant costs at 11.4 cents per kilowatt-hour (2009 dollars), of which 78% is attributed to capital costs.

The above cost estimates are significantly different from those published by the OECD (reference [71]). The OECD reports a range of levelized costs from 4.9 cents per kilowatt-hour to 7.7 cents per kilowatt-hour for nuclear power plants built in the United States. The lower cost estimate is based on 5% discount rate and the higher cost figure on a 10% discount rate, which illustrates the great importance of discount rates in projecting nuclear power plant costs and other capital intensive projects, such as oil exploration in deep offshore locations. In the OECD example the difference for nuclear electricity in the United States between a 10% discount rate and a 5% discount rate was 2.8 cents per kilowatt-hour, or about 36% of the overall costs.

Most important, however, are the levelized cost of electricity from nuclear power plants offered by South Korea and China. The OECD nuclear levelized cost figure for South Korea for their APR-1400 design is 2.9 and 4.2 cents per kilowatt-hour, at the 5% and 10% discount rates, respectively. OECD prices for Chinese nuclear power plants are very similar to those from South Korea. South Korean nuclear officials have announced that in the future they expect to make as much money selling nuclear plants to other countries as they expect to make selling their new cars, like their Hyundai vehicles.

5.4.4.6 A Different Nuclear Power Business Model

Considering the enormous importance of low cost electricity to the US economy, the need to maintain international competitiveness and to deal with climate change, a new approach to controlling costs of new nuclear plants in the US must be taken. The move to produce small modular designs is one type of response. Another possibility for larger nuclear plants would be to use a business model already established by South Korea's Hyundai cars and other foreign car producers. Some Hyundai cars sold in the United States use American workers in US factories earning U.S. wages and protected by US and state regulations. About half of the components of some Hyundai cars are manufactured in South Korea and the other half in North America.

The construction of modern nuclear power plants will entail a shift towards assembling many more components, systems, and structures in factories than at the construction sites. This shift towards greater prefabrication makes the comparison to the automobile business model valid. One financial arrangement that might be attractive to all parties is to guarantee a purchase of a set number of nuclear power plants at a fixed price, then have the South Koreans build a nuclear manufacturing facility in the United States, using their funds to purchase half of this facility. The United States government would purchase the other half of such a nuclear power plant production facility, using funds now designated for loans to individual utilities who are interested in buying new nuclear plants. The federal government would then get commitments from various U.S. utilities to purchase one or more of these nuclear plants, as well as agreeing to purchase, over time, a share of the money invested by the federal government in this manufacturing facility. Since the South Koreans would guarantee a fixed price purchase price, the lower 5% discount rate should apply because much of the financial uncertainty would have been removed. An initial order of 20 South Korean 1000 MWe nuclear power plants built in America might be an appropriate place to start. **Alternatively, a consortium of nuclear utilities could broker a fixed price contract with South Korea without requiring investments from the U.S. government.** In addition to using American workers in these manufacturing facilities, American workers would be used during the power plants' construction and operational phases.

Such an arrangement with the South Koreans is an example of the path to reindustrialization of the United States where both countries benefit.

Creative financial arrangements in the world nuclear scene are now fairly common. One example of this is the arrangement between Russia and Turkey. Not only will

Russia build nuclear power plants for Turkey, they will supply the technical staff to operate and maintain these plants. Other financial arrangements include plant manufacturers that also sell new fuel elements and later take possession of the spent fuel.

5.4.4.7 Long Term GHG Abatement

Many operating nuclear plants in the United States are having their operating licenses extended from 40 to 60 years. These power plants were built using the nuclear technology of the 1960s. New nuclear power plants are likely to have a useful life from 80 to 100 years. It has been reported that Russia has developed nanosteel that can improve nuclear reactors and other applications. It has been stated that this nanosteel would extend the life of nuclear reactors to 100 years or permit 60-80 year reactors to run with 30-40% higher power levels (reference [72]).

Such long nuclear power plant lifetimes are important in addressing long term GHG limits. In the United States, H.R. 2454 calls for an 80% reduction in GHG emissions by 2050, relative to 2005 emissions. The time to achieve this low emissions level falls within the expected lifetimes of new nuclear power plants. Figure 3.9 from the MIT Future Gas Interim study[4], reproduced here as Figure 15, also examines an 80% reduction of GHG emissions, but with a time frame for reaching this low value 50 years later than H.R. 2454, in 2100. As shown in this long term projection, the need for nuclear power becomes very large, about two thirds of the projected energy mix. However, this MIT analysis was based on a 2005 levelized cost of electricity of 8.8 cents per kwh electric for nuclear power. If the cost of electricity from nuclear power plants at a levelized cost of 2.9 cents per kwh electric it would be less expensive than the electricity from Advanced Natural Gas power plants, estimated to be 5.6 cents per kwh electric (reference [73]). Using this lower levelized nuclear cost, a recalculated MIT Figure 3.9 would show a much larger nuclear contribution appearing decades sooner. One consequence of this lower nuclear price is that projected GHG emissions would be much closer to those called for in H.R.2454. The MIT report states this well: "An implication to be drawn from this longer- term experiment is that plentiful supplies of domestic gas in the near term should not detract from preparation for the longer-term emissions challenge."

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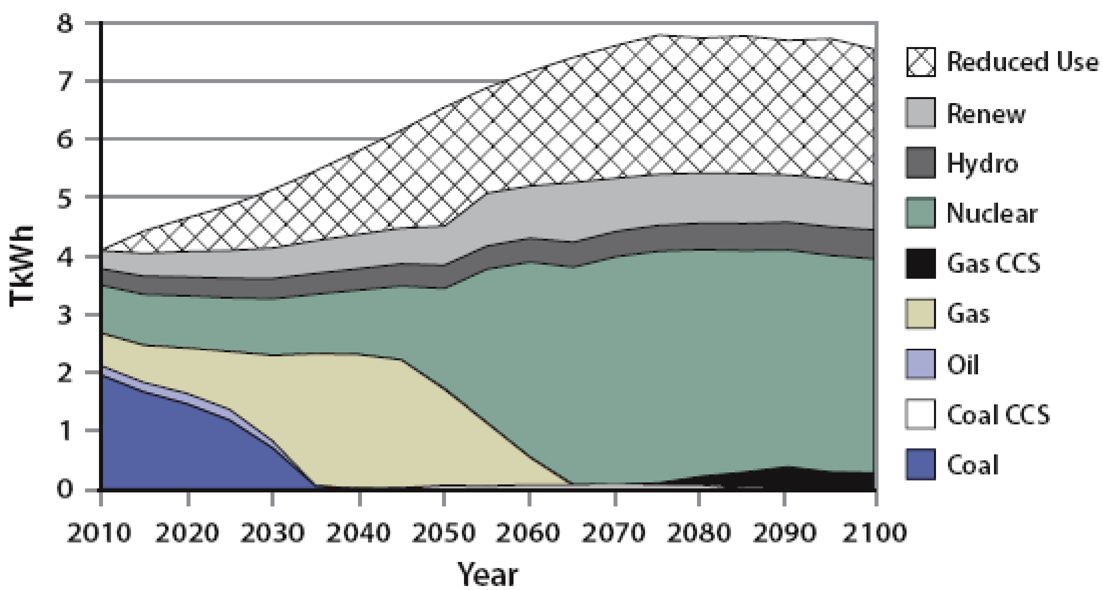
4 Figure 3.9 "Energy Mix in Electric generation under a Price-Based Climate Policy, Mean Natural Gas Resources and Regional Natural Gas Markets (Tkwh)", See reference 70.

Some have claimed that producing natural gas from shale results in releasing significant amounts of methane gas as well. Others have claimed that the magnitude of this methane issue has been overstated. To the extent that methane is released into the atmosphere from mining shale gas, the need to phase out natural gas would come sooner than that displayed in Figure 15.

This observation is also important to the development of electric transportation. At this time the electric grid is highly carbonized because so much electricity comes from coal and natural gas. This means that while electric vehicles, such as plug-ins, would be quite effective in reducing petroleum usage, but would be rather limited in reducing GHG emissions. The reduced GHG emissions at the tailpipes can be offset by increased GHG emissions at the fossil fueled power plant. Substituting natural gas for coal would be a major improvement in making electric vehicles more effective in reducing overall GHG emissions. However, to really achieve a low carbon future "carbon free" sources of electricity, such as nuclear power and some forms of renewable energy, must be used to power electrified transportation.

Figure 15: MIT Long Term Energy Mix Projection

Figure 3.9 Energy Mix in Electric Generation under a Price-Based Climate Policy, Mean Natural Gas Resources and Regional Natural Gas Markets (TkWh)



5.4.5 Conservation

As shown in Figure 2, burning petroleum is the largest source of GHG and coal fired power plants are the second largest source of GHG. Steps taken to eliminate petroleum from our transportation future and other steps to transform the use of coal are essential to meeting the climate change goals described in Section 4.3. More can and must be done to reduce GHG emissions. Those actions that relate to reducing the release of GHG, but not including a modified transportation future, have been studied by McKinsey and Company. Their conclusions are displayed in Figure 16 (reference [74]).

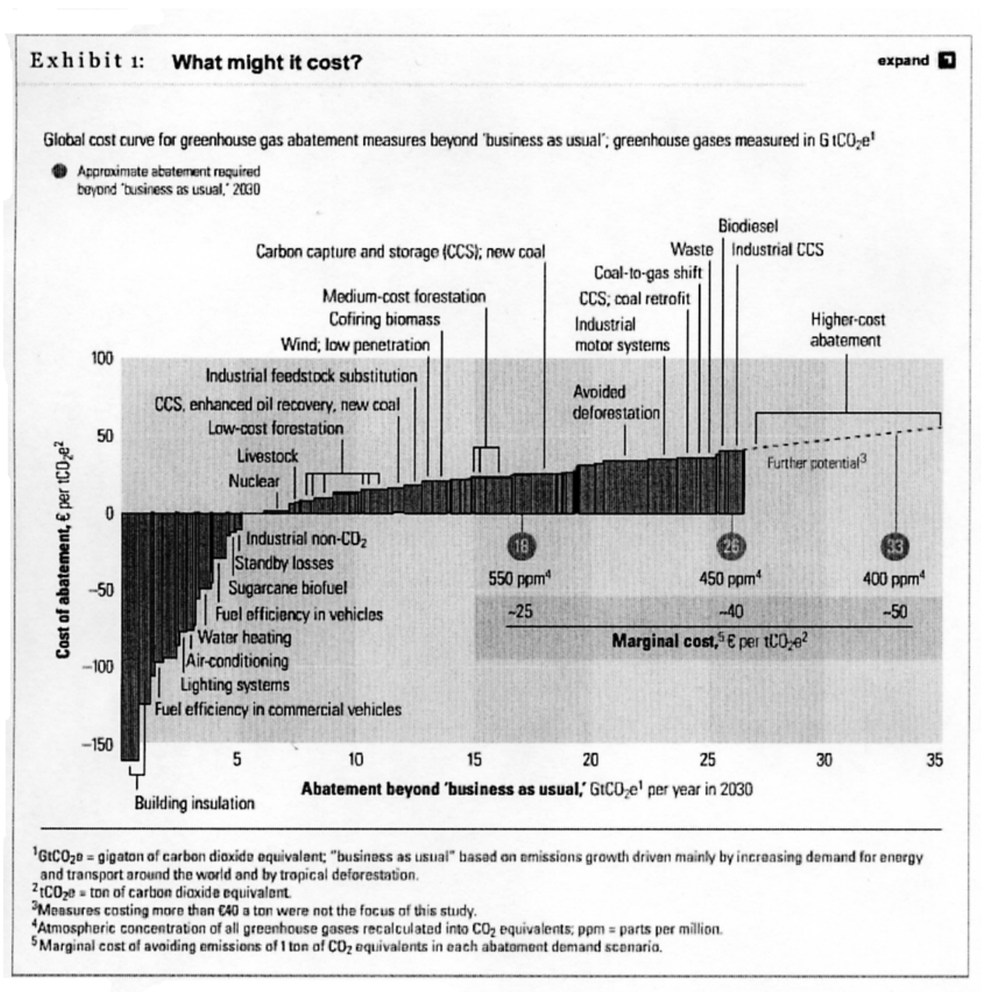
Energy conservation has multiple benefits beyond saving money and reducing the release of GHG. Many conservation actions, like home insulation, are long lasting and would not require further use of resources. Further, conservation actions usually depend on different supply chains and infrastructure support than other energy actions. A hypothetical example would be concerns about the availability of large amounts of lithium that may be needed in the batteries if tens of millions of electric vehicles are eventually put on the road. It is not likely that conservation actions would rely on lithium and therefore conservation would not act to slow the implementation of electric vehicles. The conservation actions recommended here are based on mature technologies. This means that they can be implemented rather quickly and with far less uncertainty about costs or effectiveness. The quicker the abatement of GHG gases, the greater the GHG reduction over time.

McKinsey and Company have calculated that about 1.1 gigatons/year (Gt/yr) of greenhouse gases can be abated by 2020 through actions like home insulation, with a net savings in money. It is estimated that for a $520 billion dollar investment, about $1.2 trillion dollars in energy costs could be saved, yielding a net surplus of about $680 billion dollars. Further reductions in the release of GHG requires investments that would have a net cost. It could be argued that this projected surplus of $680 billion dollars should be used to take additional GHG abatement actions.

The steps outlined in Figure 16 might be called “first generation conservation” and are well known. There is also a “second generation conservation” that is at least as important. This “second generation conservation” is based on extracting far more electricity out of our electric power plants by moving away from our sinosoidal-like diurnal electricity production profile. By creating a power production profile that is closer to a flat distribution we could generate many more megawatt-hours of electricity for the same number of power plants and transmission lines. Getting more production out of our existing power plants and the transmission grid can be considered a second form of conservation. Energy storage, in its many forms, and smart grids are key aspects needed to achieve this flatter power production profile.

There are further benefits to this "second generation conservation" with its flatter power production profile. Such a profile would mean that fewer gas electric power plants would be needed to handle peak electric loads, such as during hot summer days. Those gas fired plants not needed for peak demands would enable removing more coal fired electric plants from the grid. As discussed later, these coal plants removed from the electric grid would then be used to make methanol.

Figure 16: McKinsey & Company, Exhibit 1



5.4.6 Long term Priority Uses and Markets of Energy Sources

Table 7 is an attempt to rank the long term uses of different energy sources so that oil use might be reduced most rapidly and to limit climate change. It is intended that this table serve as an approximate guide to how to best utilize these energy sources and what energy markets they are best suited for. Near term uses and markets for these energy sources might have different higher priorities than those in the long term.

It is noted that space and hot water heating and other gas appliances were chosen as the highest long term priority use/market for natural gas. This was done because of the huge number of end use devices like hot water heaters, gas driers, gas ranges, and gas furnaces, that would have to be replaced if these services were completely accomplished with electricity. This would require very large capital, energy, and GHG investments to first expand the industrial base to manufacture a massive number of electrically driven end uses and then to replace these gas supplied end use devices one-by-one. The preservation of the present gas infrastructure eliminates a concern that for many years there would be a negative net energy and a negative net GHG if huge numbers of gas operated end uses had to be replaced with electrically driven ones. Further, it reduces the possibility of straining the capacity of the electric generation system which already would have greatly increased loads from electrified transportation. This arrangement also maintains diversity of supplies for specific end use functions.

Table 7: Long Term Priority Uses/Markets of Different Energy Sources

Energy Source	*Long Term Highest Priority Use*	*Secondmost important*	*Thirdmost important*
RENEWABLE ENERGY			
Biomass, algae	**Liquid fuels (e.g., ethanol).**	---------------	--------------------
Offshore Wind	**Liquid fuels (methanol) and GHG reduction.**	**Electricity**	--------------------
Onshore Wind	**Electricity.**	---------------	--------------------
Solar thermal, photovoltaics, other renewables	**Electricity in rural areas in developing countries.**	---------------	--------------------
Geothermal	**Electricity.**	**Low temperature applications**	--------------------
FOSSIL FUELS			
Oil	**Petrochemicals and other industrial applications.**	**High energy density applications, e.g., air travel.**	-------------------
Coal	**Liquid fuel (methanol).**	**Replace oil in petrochemical and in other industrial applications.**	**Electricity, assuming CCS.**
Natural Gas	**Space, hot water heating, gas ranges, gas furnaces.**	**Electricity and transportation fuels (methanol and compressed gas).**	**Replace oil in petrochemical and in other non-transportation applications.**

NUCLEAR ENERGY			
LWRs	**Electricity.**	**Low temperature process heat, for desalination, district heating, aquaponics.**	**Energy input to bio-refineries**
High Temperature Reactors, Breeders	**High temperature steam and hydrogen used to make liquid fuels and other industrial applications.**	**Electricity.**	**Breed new nuclear fuel, reduce existing nuclear wastes.**
Fusion	**Electricity.**	**---------------**	**------------------**

5.5 Transforming End Use Devices

The largest transformation in end use devices would be in the Transportation Sector and is discussed in Section 5.6. Other end use transformations, such as more efficient lighting, can be found in Section 5.4.5 on energy conservation. There are additional end use opportunities to reduce petroleum usage and GHG production discussed below.

5.5.1 Heating and Cooling

One place where there can be reductions in the consumption of petroleum is in space heating. A well established space heating technology uses compact electric storage systems. These passive systems are energized with off-peak electricity and can replace oil burning furnaces in homes, apartments, and in businesses. Lower cost off-peak electricity is used to heat a block of steel or a ceramic brick to very high temperatures. The air that flows over these hot surfaces picks up energy and then goes on to heat a home, apartment, school or office building. This strategy would be particularly useful in the northeast section of the U.S. where many homes and buildings are oil heated. Table 10 shows that 3% of the oil consumed in the United States goes into these oil burning space heaters. If all oil burning space heaters were replaced with compact electric storage systems this would reduce oil consumption by about 0.56 MB/D, not counting the additional petroleum savings at the oil refineries. Eliminating oil heated furnaces would also remove a source of air pollution in urban and suburban locations. China already uses a system like this, but for a different purpose. It uses electric storage systems to replace home coal burning furnaces, thereby lowering local air pollution. The electric power to these home heaters is controlled with a timer so that it would not draw energy during peak demand periods - a very simple version of a smart grid approach. Beyond applying this proven technology to existing homes and apartments, it would be valuable in new home construction. Since there is no combustion of fossil fuels with these compact electric storage devices, there is no need to have a chimney to draw off poisonous exhaust fumes. This can save several thousands of dollars in a new home construction while providing "an extra closet" within the same overall house dimensions.

This existing technology may be capable of further development so that it could also provide cooling for the summer months. High temperature sources, like a propane flame, combined with an ammonia cycle is the basis of a long established refrigeration technology and is still used today as an air conditioning system in recreational vehicles. Perhaps the high surface temperature of the steel or ceramic blocks in compact electric storage systems can substitute for the propane flame in driving the ammonia cycle. Extending the operation of these compact electric storage systems into the warmer months of the year would amortize their costs more effectively. This extended use could be particularly attractive since its use of off-peak electricity would shift the peak demands for electricity during the hottest portions of the day to off-peak time periods. Another version of this might combine compact electric storage furnaces with heat pumps. This would have the advantage of getting the energy multiplying effect of heat pumps during the day and the off-peak cost advantage of compact energy storage systems at night. The United States should create new jobs by expanding its compact electric storage manufacturing capability.

Still gas is used at the refineries as a heat source and feedstock and also represents about 3% of the oil used in the U.S. Major portions of still gas could be replaced for further savings as petroleum refining itself is decreased.

Another established technology uses off peak electricity is to make ice that is stored in large buildings. This stored ice is then used to reduce the demands on air conditioning systems in subsequent hot days. While this ice-making process reduces peak demands for electricity which, in turn, lowers costs and reduces the emissions of

GHG. As discussed elsewhere, shifting peak demands towards a flatter electricity production profile would make more gas fired electricity available to replace coal plants.

Energy Information Administration 2001 data on electricity consumption in U.S. households showed that refrigerators consumed about 13.3% of the total use of electricity and home air-conditioning another 16%. Perhaps ice storage can be increased in advanced refrigerators where the ice compartment is enlarged to have two additional hours worth of cooling tied up in the ice's heat of fusion. Using a smart grid or a simple timer, the compressor in the refrigerator would be turned off for two hours or so during summer peak demand times and cooling would be accomplished by circulating air inside the refrigerator over the stored ice. Two benefits would result from this extra ice storage. First there would be a decrease in the peak demand on the grid because refrigerator compressors would be turned off. Second, there would be less of a load on the air conditioning in the house that had this type of a refrigerator. The heat rejected from the refrigerator during normal operation would be absent when the compressor is shut off. Less load on the air conditioner also means less of a demand on the grid. The smart grid or a simple timer would signal these advanced refrigerators when peak demands had subsided to restart the compressor and later when to start the process to restore ice in the ice storage bin for the next hot day. During the cooler seasons this additional ice storage scheme would not be necessary and the "waste" heat from the refrigerator would be a supplemental heat source for the house.

5.6 Transforming The Transportation Sector

5.6.1 "No tech" and "Low tech" Transportation Actions to Rapidly Reduce Oil Consumption

Steps need to be taken now to prevent a looming back-to-back recession brought on by high oil prices, similar to what occurred in 2008 when there was no margin between oil supply and demand. Because the next zero margin situation is thought to be in the near future, it is essential to utilize what is at hand. Concentrating on the transportation sector makes sense because it is the largest consumer of petroleum.

Recently the President announced a new fuel economy standard of 54.5 miles per gallon for cars and light trucks by 2025. This would be a significant fuel efficiency improvement for the longer term. Passing Open Fuel Standard (flex fuel) legislation also would be a major step in the right direction. Many vehicles already have flex fuel capability, and the cost to retrofit a car to have flex fuel capability is not too high. Factory installation for new vehicles is not expensive.

However, unless having flex fuel capability is made a national priority, it will take years to have major effects on petroleum consumption unless alternative fuels soon become available in much larger quantities and the infrastructure to deliver these alternative fuels, right down to the pumps and hoses in gasoline stations, is rapidly expanded. All this can and should be done, but will take time.

On an even longer time scale, it is going to take many years to build up the kind of transportation infrastructure, like more efficient cars, electric vehicles, advanced buses, and high speed trains needed to make major reductions in both GHG releases and oil imports. These important actions need to be started, but the short term challenge of back-to-back recessions must be overcome first.

Because time is short we need actions that could be implemented quickly at comparatively low costs. To do this we turn to "no tech" and "low tech" methods to reduce petroleum consumption and would also reduce emissions of GHG. Implementing such "no tech" and "low tech" solutions means major changes and some public sacrifice for a number of years. This, then, is as much a political challenge as a technical one. It will take political leadership to gather sufficient public support for these approaches. A number of "no tech" and "low tech" solutions are provided below.

The least cost trip is the one you didn't have to take. In this regard, working at home and walking to short term rental offices with teleconferencing (telecommuting) services would save energy and reduce GHG emissions. Greater government emphasis needs to be placed on true virtual presence high definition bi-directional video. This means greatly increasing the band width to homes. The rest of the world is much further along on this than the U.S.

For the more hardy, short trips can be accomplished on foot and on bicycles. Huge numbers of electric bicycles are being utilized in China. Important improvements in train transportation have been reported. Scheduling optimizations using advanced mathematical algorithms have been reported to shorten 60 minute train rides to just 48 minutes. Not only does this make commuting by train more attractive, it could result in getting more service out of a fixed number of trains.

For those that would still use motor vehicles, there can be petroleum savings here too. A major example of a “no tech” improvement is higher ridership in individual vehicles using car pools and in public transportation. Table 8, below, adapted from Table 2.12 of ORNL-6984, sheds light on the relationship between ridership (load factor) and energy use for cars, buses, airplanes, and trains.

Table 8: Passenger Travel and Energy Use, 2007

Vehicle Type	Load factor (persons/vehicle)	Btus per vehicle-mile	Btus per passenger- mile
Cars	1.57	5,517	3,514
Buses	9.1	39, 408	4, 315
Airplanes	97.2	301,684	3,103
Amtrak	21.7	54,585	2,516

One “no tech” practice that could have a very large effect on energy use and GHG releases would be greater use of car pools. If the average number of persons per vehicle were around three, oil use in individual vehicles would be cut in about half. Of course car pools and more energy efficient vehicles can be used together to further increase energy savings. Public apathy and resistance to forming car pools is expected and political leadership is needed here. It may be necessary to implement some form of fuel rationing; at the very least the government should take actions to be ready to quickly implement rationing if this becomes necessary. Car pools might be implemented rather quickly without much government involvement, especially if fuel prices rise sharply or if people again began to experience gas stations with “out of gas” signs because of oil shortfalls. State and local governments have encouraged greater use of car pools by providing designated parking areas for car pool vehicles and by giving car pools preferred high occupancy lanes on interstate highways and other major roads.

As shown in Table 8 the energy use per passenger-mile was the highest for travel by bus. The problem is not with the buses. This is directly attributable to the very low load factor for buses because of our car oriented society. Travel by air in 2007 had a very high energy use per vehicle-mile, but because the load factor was also quite high, the Btus per passenger-mile was actually less than those for both cars and buses. If efforts are made to increase bus ridership to an average load factor of, say 50, the Btus per passenger-mile would drop to about 785, or almost five times better than the efficiency of 2007 internal combustion engine automobiles with a low ridership of 1.57. The more drivers that switch from cars to buses, the fewer the cars on the road. This smaller inventory of vehicles on the road should reduce traffic congestion, thereby further reducing petroleum consumption and GHG emissions from the vehicles that are still in use.

State and local governments need to establish which bus routes would be crucial if there were a rapid shortfall in imported oil and people began to use this form of public transportation much more extensively. Many exciting new bus designs have recently been put into practice, as will be discussed later in this section, but getting large numbers of these modern buses on the street takes time. If pressed hard by shortages of petroleum, it might be practical to temporarily use idle school buses, which are available in large numbers when not used to transport school children. Adjustments might have to be made to co-ordinate school related transport with commuter transport, if school buses are pressed into this additional service.

If 10% more of the passenger miles were accomplished by three person car pools and 10% more of the passenger miles were accomplished by high occupancy buses, the estimated reduction in petroleum use in the United States would be, approximately, 1.21 MB/D with increased use of car pools the source of a saving of about 0.43 MB/D and increased use of buses the source of about a 0.78 MB/D saving.

Another “no tech” strategy is to encourage business to modify their working hours. If more people could work “off peak” the existing bus infrastructure could be expanded into these off peak time periods without having to buy more buses. This too would reduce petroleum consumption and GHG emissions. Forty hour work weeks with four days per week at ten hours a day might reduce energy consumption.

So well before people would be able to use tens of millions of electric vehicles or build a high speed train system, using today’s ordinary petroleum driven buses could cause a large reduction in gasoline use relative to individual light duty vehicles, provided high ridership is achieved. Building many tens of thousands of new buses in the United States would create many new jobs. To the extent that natural gas, converted to methanol or as compressed natural gas, can be used as the fuel for such buses, this should happen. All new buses should be hybrids with regenerative braking.

Table 8 also shows that increased ridership for Amtrak trains could significantly decrease its energy use per passenger-mile. Mass transportation with high ridership has the potential to reduce oil use far more than all the projected improvements in internal combustion vehicles that are not plug-ins.

Success here is not a matter of finding a breakthrough in battery technology or discovering a way for algae to produce liquid fuels. All the above increases in ridership were observed during previous oil shortages and just faded away as oil became available again and gasoline prices dropped. Similarly, any of the older technologies (streetcars, buses with overhead power lines, etc.) can be used in the United States to cut oil consumption. Again, no technological breakthroughs are needed. What is mostly required here is political leadership that the public has confidence in. People will make sacrifices if they believe that they are effective and fair. Perhaps the lesson here is that in the transportation sector is that the U.S. should consider "going backward in time" to reduce the likelihood of back-to-back recessions, while working on higher tech solutions to go "forward in time".

5.6.2 Hybrids, Plug-in Hybrids, and EVs for Individual Transportation

Hybrid vehicles are now being offered by many automobile manufacturers and represent a well accepted and effective way to reduce the petroleum use. For example, the 2010 Toyota Prius has a fuel efficiency rating of about 50 MPG. Such hybrids have regenerative braking and a rather compact battery system that typically limits their electric- only range to a mile or two. Regenerative braking converts the vehicle's kinetic energy back into electricity and stores this electricity in an on-board battery for subsequent use. There already have been interesting developments and proposals. It is claimed that new Hyundai Sonata hybrid demonstrates a valuable battery energy density improvement by using lithium polymer technology instead of nickel-metal hydride technology.

Plug-in hybrids (PHEVs) are individual vehicles that have the potential to displace a considerable amount of imported oil. Their fuel efficiency ratings generally exceed those of hybrid vehicles. These plug-in hybrid vehicles are composed of a battery system that can be recharged from the electric grid and, possibly, from off-grid wind turbines or photovoltaic systems in rural areas. A liquid fuel driven engine enables these plug-ins to increase their range well beyond the range of the electric-only mode. Plug-in hybrids would also use regenerative braking to increase their efficiency. The benefits of regenerative braking accrue in both the battery-only mode of travel and in the liquid fuel-only mode of travel.

One of the main benefits for plug-in hybrids in a future transportation plan is to have local travel in the electric-only mode and then link up with the other modes of travel that use electrified mass transportation. Such travel would be petroleum free. Many plug-in vehicles would be mainly recharged from the 110 volt electric outlets at residential locations at off-peak times when the cost for electricity should be lower. Those plug-ins recharged at off-peak times represent an important step towards a flatter electricity demand profile.Charging times at this voltage can be long, up to eight hours. Home electrical outlets at 220 volts or so would significantly shorten this recharging time. This higher voltage level is available in many households, especially those that have large electrical loads like electric dryers.

Level II charging, between 208 and 240 volts, would shorten battery recharging times. Level III chargers would be capable of providing very high voltage can recharge batteries in minutes, not hours. Higher voltage recharging stations where plug-ins are going to be parked for several hours, such as in parking garages near work locations, train stations, or other transportation hubs, are being tested today. Such chargers might also be located along intercity roads to accommodate longer trips (reference [75]). Israel is establishing many quick electric charge locations throughout the country. This Israeli technology will also be explored in Denmark and Australia. Such an approach is well suited for high population density areas, particularly in smaller area countries. Therefore it is of interest to see how this technology might work in a very large country like Australia or if it would be limited to urban areas.

The effect of using recharging stations at transportation hubs would be to effectively double the maximum electric only range of plug-ins, for some commuters. Some commuters could drive to the transportation hubs or parking garages with batteries charged at night at home and return home with batteries recharged while they were at work. Considering the transportation hub as the center of a circle, by doubling the radius which can be totally served by battery power, this increases the fully electrified area by a factor of four. Thus, potentially many more commuting plug-in drivers would be capable of getting to and from these transportation hubs or offices in the electric-only mode if recharging stands are available. Although purchasing electricity during the day would be more expensive per kilowatt-hour than off peak purchases, the cost of electricity per mile traveled would still be considerably less than paying for gasoline per mile traveled.

A rough estimate can be made of the potential benefits of the recharging station/ plug-in hybrid combination by using Table 9, below. Assume that all plug-ins have a battery system with a 10 mile all-electric range. Based on Table 9 this would be sufficient to travel 23.3% of our miles in the electric-only mode, leaving 76.8% of our miles to be traveled using liquid fuels. If the availability of recharging stations at transportation hubs and business parking lots doubles the range of the electric-only travel mode, then 44% of the plug-in miles could be achieved in this manner, leaving 56% of the plug-in miles to be accomplished by liquid fuels. If half of the trips performed by plug-ins take advantage of recharging stations, then the overall liquid fuel savings would be 0.5 (76.8%-56.0%) ~10% reduction in national LDV liquid fuel use for the plug-in mode of travel. The implication of this very approximate estimate is that the cost of building many recharging locations would easily be offset by a reduced national oil bill.

Additionally, fully charged plug-ins might be available for rent at major mass transportation hubs, again using parking lot recharging stands to energize these rental vehicles. Rentals could extend the number of electrically driven miles in a combined electric mass transportation/plug-in hybrid trip. Taxis, which often queue-up waiting for passengers disembarking from trains, could also be plug-in vehicles which are recharged to some degree as they wait for new fares. Level III chargers might be the best match for taxis. Some plug-in hybrid owners, like apartment dwellers, may not have easy access to an electric outlet to gradually recharge their batteries over night. The availability of recharging stands at transportation hubs and at parking areas near work could ease this problem. In fact, this group of commuters could do the opposite of those commuters that live in private homes and have ready access to an electrical outlet at night. Apartment dwellers might charge their plug-in batteries in transportation hub or work parking areas while they are at work and then use this stored energy to drive home to their apartments and then back to the transportation hub the following day using their plug-in’s electric-only mode. This approach would only have half the all electric range of a combined home and hub recharging process, but could potentially increase the number of plug-in owners by including those that live in apartment buildings.

Federal subsidies for plug-in hybrids reduce the cost of ownership of such vehicles. Subsidizing plug-in hybrid recharging stands at transportation hubs and work locations is an additional way of investing tax dollars for a more secure energy future.

Plug-in hybrids are also capable of travelling long distances in a liquid fuel mode. The liquid fuel portion of plug-in vehicles should be designed to use a variety of liquid fuels that cover a range of ethanol/methanol/gasoline mixtures, i.e., to be a flex-fuel engine. This capability could be particularly important on longer trips because the type of liquid fuel that might be available could differ from one region of the country to another, such as methanol mixes mostly in one area and ethanol mixes in another.

Another approach to plug-ins and EVs that is being tried out is to have drive-through stations along major highways where drivers would quickly replace their batteries in about the same time it takes to fill a gas tank. In this arrangement batteries are not owned by the drivers, but rented. Batteries would be recharged at these drive through stations at off peak times. Renting batteries instead of owning them increases the number of financial options to people and could result in a more rapid growth in plug-in use. Refueling stations with Level III recharging capability would be even simpler. While refilling the liquid fuel tank, the plug-in's battery could simultaneously be recharged.

There has been some confusion about the percent of trips that plug-ins can achieve in the electric-only mode and the percent of miles that these trips entail. Table 9, based on light duty vehicle data for cars with internal combustion engines (ICE) from the Department of Transportation, can be used to clarify this difference.

Table 9: Trip Length vs. Cumulative% of Trips Taken and Miles Traveled

Trip Length (in miles)	Cumulative Percent of Trips Taken	Cumulative Percent of Miles Travelled
0-0.9	9.7	0.4
1-4.9	49.7	9.5
5-9.9	71.4	23.2
10-19.9	87.6	44.0
20-49.9	97.3	70.9
50-99.9	99.2	82.9
100 +	100.0	100.0

Most of our trips are short ranged. A plug-in hybrid with a 20 mile all-electric range would be sufficient for 87.6% of our trips. However, 56% of the miles we drive are on trips that are longer than 20 miles. This means that even if all vehicles in the country were plug-ins with a 20 mile battery range, we would still need 56% of the gasoline, or its energy equivalent, that we consume today, unless we also use other modes of electrified mass transportation to a much greater degree. Actually, since 20 miles out of such trips would be accomplished using battery power the balance of the trip requiring gasoline would be less than in the ICE case. Here the remaining distance to be accomplished in a plug-in and the associated fuel required is conservatively set equal to ICE values. A plug-in hybrid like the Chevy Volt with its 40 mile range in the electric-only mode would be capable of accomplishing 94.1% of our trips, but 38% of the miles would still remain to be accomplished through liquid fuels for the remaining 5.9% of our trips. To put this into perspective, 38% of the oil the U.S used in 2007 is 7,858,400 barrels per day, of which about two thirds was used for transportation, or about 5.2 million barrels per day. In 2007, France, the UK, and Italy, combined, consumed about 5.4 million barrels of oil per day for all their purposes; transportation and otherwise. Even if a 100 mile battery could be developed at an acceptable cost, weight, and size, some 17.1% of the miles to be travelled would need liquid fuels. Unless there are additional modes of electrically driven transportation,e.g., electrically driven mass transportation, completely replacing present internal combustion engine vehicles with plug-ins would still require large amounts of liquid fuels.

Then there are vehicles, called EVs, that are fully electric; they do not have a gasoline or diesel engine and strictly depend on battery power. A very high priced EV has been produced by the TESLA company and recently Nissan Motor Company has produced a much lower cost EV, named the Leaf, which has a large battery and a range of about 100 miles, depending on the weather (battery power decreases at lower temperatures). The main challenges for EVs are their limited range and long recharging times.

At this time the cost for batteries in plug-in vehicles and EVs is high. As reported by the National Research Council (NRC) (reference [76]) the Chevy Volt with its 40 mile battery system will cost about $18,000 more to manufacture than a similar-sized conventionally powered vehicle. Because of these high battery costs and the normally slow turnover rate for automobiles, the NRC predicts a rather slow penetration rate for plug-in. Specifically, the NRC has made two projections: Its “more probable" scenario estimates about 13 million plug-ins by 2030 while its "maximum practical scenario" predicts about 40 million plug-ins by 2030.

The Chevy Volt will have to compete with vehicles, like the recently released plug-in version of Toyota's Prius which has a smaller battery than the VOLT and an all-electric range of 13 miles and a range of 475 miles. This plug-in version of the Prius is expected to have an overall gas mileage efficiency of around 134 m.p.g. It is estimated to cost $3000-$5000 dollars more than a conventional Prius. Toyota claims that its lithium-ion battery pack can be recharged in 180 minutes at 120 volts or in 90 minutes at 240 volts.

The NRC's report may be overly cautious, as demonstrated by the new plug-in Toyota Prius and others. Tata Motors has revealed the four passenger Indica Vista electric car with a claim of a 150 mile range on one charge and with a price around $10,000. It is claimed that it can reach 0 to 60 m.p.h. in about 10 seconds.This is an EV with a super-polymer lithium-ion battery (reference [77]). China plans to introduce its own plug-in hybrid to the American market with its BYD F3DM model which has the capability to travel 31 miles on electricity alone, plus another 300 miles using its gasoline engine. The F3DM is expected to sell for less than $29,000 and incentives may drop the price closer to $20,000 (reference [78]). In Japan, SIM-Drive claims over 200 mile range for its EV (reference [79]). It has been reported that Sumitomo Electric Industries, Ltd. has developed a lower temperature molten salt rechargable battery that promises to cost about 10% as much as lithium ion batteries (reference [80]). The NRC analyses is based on a gasoline price of $4.00 per gallon, but this figure is being exceeded now in many parts of the country. Virtually every car company, domestic and foreign, is coming out with one or more versions of a plug-in and/or EV design. The race is on.

There is a perceived need to have batteries with higher energy densities and other improvements. The present administration has allocated $2.4 billion dollars into developing and subsidizing next generation plug-in hybrids and fully electric vehicles. Better batteries would extend the electric- only range of plug-ins and EVs, thereby reducing the demand for liquid fuels like petroleum. However, if sufficient low carbon, affordable liquid fuel alternatives to petroleum can be produced, then the need for very high energy density batteries is reduced. The minimum cost per mile traveled would be determined by a combination of battery and liquid fuel costs per mile traveled.

Federal subsidies for plug-in hybrids and EVs might directly be used to reduce the cost of ownership of such vehicles. However, the concept of placing recharging stands at transportation hubs and parking areas near work locations might be another way of investing tax dollars since it could encourage commuters to utilize various forms of mass transportation. With recharging stands at transportation hubs plug-in purchasers might more frequently opt for lower cost plug-ins with the smaller batteries because this transportation hub arrangement would significantly increase their electric-only range when commuting. This in turn would encourage a more rapid market penetration of the lower cost plug-in version. A more rapid market penetration of lower cost plug-ins would serve the national interest by more rapidly reducing the amount of oil that need be imported. Electric Transportation Engineering Corporation was recently awarded a stimulus grant of nearly $100 million to build 12,800 charging stations in five different states. In his 2011 State of the Union President Obama called for a million electric vehicles on the road by 2015. In a recent report that expanded on the President's State of the Union speech, the Department of Energy stated that Recovery Act funds have support 22,000 electric charging points in more than 20 cities across the country. These are commendable actions, but are too modest.

Although having a million electric vehicles on the road by 2015 is a worthy and ambitious goal, it must be recognized that in a country with about 250- 300 million vehicles achieving this goal would only affect less than 0.5% of the nation's fleet of vehicles. Therefore the major benefit of electric vehicles in terms of oil use reduction would not be felt for many years later. Using Figure S.2 of the NRC report, gasoline consumption would decrease from about 138,000 millions of gallons/year in 2010 to about 100,000 millions of gallons/year by 2030 and 60,000 millions of gallons/year by 2050, under the maximum practical penetration scenario, because of the increased use of plug-ins.

Although much of the discussion about plug-ins centers around battery technology, it is important to seek high efficiencies in the liquid fuel mode of travel. Plug-ins with diesel engines may be a very effective mix. Engines specifically designed to run on methanol are reported to have a 25to 30% increase in efficiency compared to conventional gasoline engines. Such vehicles are said to have about 70% of the range of a conventional ICE vehicle, assuming equal volume fuel tanks. When the additional range available from the battery is considered this 70% figure would be exceeded. A combination of a plug-in vehicle with a methanol based engine might be a particularly attractive step forward.To effectively reduce national petroleum consumption, one might combine plug-in hybrids with car pools. Perhaps the federal government could encourage this arrangement by supporting companies that rent plug-in hybrids to car pools that connect with transportation hubs.

5.6.3 Local Mass Transportation

Local mass transportation vehicles can be divided into two types: those that follow a fixed route and those that have the capability to alter their route, as necessary. In the latter situation, some form of stored energy within the vehicle is necessary to give it the flexibility to alter its route. Local mass transportation can be further subdivided into electrified and non-electrified carriers.

There is no question that electrified mass transportation can be accomplished. It has been done for many decades using old technology, such as subways, electric streetcars, and buses which draw electricity from fixed position sources like overhead power lines.Whereas electrified mass transportation without on-board energy storage is simpler, less costly, and can be accomplished with mature technologies, following a fixed route is a series process: an interruption along the route that can not be by-passed might cause the whole route to be shut down until the cause of the interruption is removed.

In addition to long established forms of electrified mass transportation like streetcars, there are modern variations of this. In Seoul, Korea there is now a short distance electric tram system that draws its electricity from power strips imbedded into the road (reference [81]). In between these power strips this electric tram uses onboard batteries.The use of imbedded power strips reduces the need for on-board batteries by 80%. It is thought that this form of electric vehicle travel might be a model for much wider use in urban areas.

China is experimenting with a different kind of electric bus called a capabus. Instead of using batteries, these vehicles store electricity in electrical double layered capacitors (EDLCs). Capacitors have some distinct advantages over batteries. They can be very quickly recharged. They have a long life and can be put through far more charge/ discharge cycles than ordinary batteries (millions or more compared to 200 to 1000 for most commercially available batteries). These characteristics make capacitors ideally suited for the stop-and-go of city buses and streetcars that use regenerative braking. As a capabus goes to one of its stops it can be quickly recharged under what is called an “electric umbrella”. In 2006 two commercial bus routes began to use EDLCs, one of which is in Shanghai. Ioxus, manufacturer of ultra capacitors for transportation recently announced a hybrid capacitor, a combination of an ultra capacitor and lithium-ion battery with an energy density 115 percent higher than standard electric double-layered capacitors (reference [82]). Capacitors have drawbacks as well. Perhaps the most important drawback is the amount of energy stored per unit weight, about a tenth of a typical lead-acid battery.

Brazil uses “Bus Rapid Transit” or a BRT system that appears to be very cost effective. Capital and infrastructure costs are extremely low compared to rail and subway systems and utilization has been high (reference [83]). BRT systems use “transit stations” in place of bus stops. These are elevated platforms where passengers pay to enter the transit station or use passes to enter, thereby eliminating any waiting for fare collection. These buses have wide doors to speed up passenger entry and exit times. Because the BRT system uses supercapacitors, these buses can be quickly recharged at the transit stations. Similar BRTs have also been used in the United States and in Europe, however the user-friendly transit stations seem to be predominantly in South America.

The South Korean, Chinese, and Brazilian approaches to electrified transportation have an important characteristic in common. They all use sources of electricity along the vehicle’s pathway, thereby reducing or eliminating the need for batteries. An approach similar to this might be explored in the United States using our present interstate road system and along major arteries in cities. Assuming issues of safety and the effects of weather are resolved, electrified strips might be embedded into one or more lanes of these major highways. If this were feasible, then a plug-in hybrid or EV could drive to such a embedded highway on its own battery power. At that point the electricity in the road’s power strips would both propel the plug-in and recharge its battery to some extent. Once off the embedded highway the plug-in hybrid would revert to its normal modes of travel. People who have envisioned such technology have taken it even further. It is possible to have the control of the plug-in on such electric highways done automatically where safe distances are kept electronically between fast moving vehicles. The driver need not be actively engaged at this time and the exit that he wants could be logged in to the highway’s monitoring and control system. Each vehicle could be identified by an “Easy Pass” technology and the driver’s bank account would be charged according to the kilowatt-hours consumed on a particular trip. It seems likely that it would take many years to develop this kind of technology.

In addition to these electrified local mass transportation options, there are other possibilities. Hyundai Motor Company has unveiled a compressed natural gas (CNG) hybrid, called the "Blue-City" bus, using a lithium- polymer battery pack (reference [84]). This bus has a range of 211 miles and emits 24% less CO_2 than conventional CNG buses and 35% less than diesel buses and has a maximum speed of about 62 m.p.h.

Any of the older local mass transportation technologies (streetcars, buses with overhead power lines, etc.) can be used in the United States, as well as newer designs similar to those coming into greater use in South Korea, China, Brazil and elsewhere. However, there may be a local mass transportation design that would be particularly attractive to the United States in the longer term because it would build upon two existing infrastructures: our electric power system and our petroleum distribution system. This U.S. design would also use supercapacitors, thereby eliminating/ minimizing the need for batteries. This design could operate under both a fixed route and variable route conditions and would be pollution free at the point of use. As the electrical grid becomes less carbon intensive, this form of transportation would also become a smaller and smaller source of greenhouse gases.

What is envisioned here is a bus with both a supercapacitor system and hydrogen storage which would be major components of the buses' propulsion system. This bus would employ regenerative braking and the electricity that is generated during braking would be stored in the supercapacitors for later use. The purpose of the hydrogen would be to extend the range of this hydrogen/supercapacitor bus and to permit travel outside of a fixed route. The hydrogen stored on the bus might be placed in high pressure cylinders or pipes. It is possible that these strong pipes could also be used as structural support members for the bus. Rather than running the on-board hydrogen through a fuel cell to generate electricity, one might use an approach under development at the National Renewable Energy Laboratory for hydrogen storage use at wind farms. In this application the on-board hydrogen is burned in a small motor/generator that produces electricity. This electricity and that from the supercapacitors would be sent to electric motors directly attached to the wheels of the bus. Using a small motor/generator should save money compared to using a fuel cell and likely could be deployed more rapidly.

A variation on this design is to use solid oxide fuel cells (SOFCs) (reference [85]). These fuel cells are considered impractical for cars and light trucks because they only operate at high temperatures. They have to be brought up to operating temperatures slowly via external heaters of some sort and thermal stresses of each start-up and shut down cycle takes a big toll on their working lifetimes. Although thought to be impractical for cars and light trucks, SOFCs might be useful in heavy trucks and in buses. With good insulation these SOFCs could be kept hot continuously. At truck stops and bus barns these larger vehicles could be plugged in, not to draw power, but to deliver it. The reason that is attractive is that the combination of a SOFC and a gas turbine running on its "waste heat" is by far the most efficient means we have to convert fuel into electricity (reference [86]). The fuel could be hydrogen from renewable energy sources or nuclear power or it can be natural gas or volatile hydrocarbons; it could even be de-mineralized coal or wood charcoal feeding an on-board gasifier. Such fuel cells would be combined with supercapacitors, regenerative braking and possibly some energy storage in batteries for prolonged power on uphill grades and for storing the excess electricity made via regenerative braking during prolonged downhill grades.

Use might be made of present gasoline stations, as they would take on a somewhat different role in the future. These stations are ubiquitous, have or could have 220 volt electrical service or higher and already have underground storage tanks used to hold gasoline or diesel fuel. In the future many of these gas stations could be transformed to serve future vehicles. A portion of the underground storage at these stations would hold liquid fuels, such as methanol, ethanol, or any petroleum-like product that comes from biomass, coal, or natural gas. This liquid fuel would be used by vehicles, like plug-in hybrids and buses, that need liquid fuel for longer distance trips. The remaining underground storage would be for hydrogen where large pressurized tanks would replace former gasoline storage tanks. Since this underground hydrogen storage tank would be stationary, its heavy weight would not be a problem. The technology for storing and handling hydrogen seems to be well advanced in Germany. There the Linde Group has opened a hydrogen filling station for zero emissions fuel cell passenger ships (reference [87]).

The hydrogen stored in these renovated gas stations would be generated by electrolysis right at the stations, using lower cost off peak electricity: another application that would help flatten the nation's electricity production profile. Using the present electrical grid to make hydrogen at a large number of distributed locations eliminates the leakage and metal embrittlement concerns associated of trying to distribute pure hydrogen over long distances through metal pipes. The electrical requirements of such future gas stations might fit into their present capabilities because they would only be servicing the electrical needs of buses and would be generating the stored hydrogen over many off-peak hours. Even with the build-up of many end use devices: hydrogen propelled buses, plug-in hybrids, and compact electric space heaters it would be a long time before there might be shortages in electricity to meet all these off-peak demands for electricity. During this time period new low or no carbon sources of electricity would be built and they would be available to supply electricity to new demands that peak during normal working hours, such as electrified mass transportation and then be able to supply electricity at off-peak times for those end uses that have energy storage capabilities.

The use of hydrogen and supercapacitors in these buses permits rapid refueling. Both the on-board hydrogen storage system and the supercapacitors could be rapidly recharged, simultaneously, at a converted gasoline service station.

There are other aspects of this hydrogen/supercapacitor concept that are attractive. Distributed energy storage systems are less vulnerable to system failures, like widespread blackouts, and to terrorist attacks on transmission grids or power plants. Even if there were some large scale loss of electric power, the hydrogen/supercapacitor bus system could continue to operate until the stored hydrogen was depleted. Even during blackouts the supercapacitors could be recharged by burning hydrogen to make electricity. Burning hydrogen to make electricity would be a capability at these future "gas stations" and could put some electricity back on the grid in an emergency. Hydrogen storage should be shared by both renewable and non-renewable sources of electricity.

5.6.4 Long Distance Electrified Transportation

Because of its great emphasis on individual automobiles the United States has fallen far behind Europe and other countries in the use of high speed trains. China recently became the world leader in manufacturing high speed electric trains. China has 42 high-speed trains recently opened or set to open by 2012 with an average speed of 215 miles per hour. According to the New York Times, the U.S. hopes to build its first federally sponsored high speed train in 2014 which would only travel the 84 mile route between Tampa and Orlando, Florida. Some increase in train transportation is being developed in Los Angeles. This modest effort in building a high speed train system is woefully inadequate. A better answer is coming out of the State of California which plans to build its own high speed rail system. This has gained widespread interest in that China, Japan, Germany, South Korea, Spain, France, and Italy have approached California to build this train system. Of particular interest is China's offer. China is not just offering to build a railroad in California, but to help finance its construction. “We are the most advanced in many fields, and we are willing to share with the United States” said Zheng Jian, the former chief planner and director at China’s railway ministry (reference [88]). This form of financing and co-operation is discussed later.

If the nation were to build a substantial high speed rail system it should look for routes that might have the greatest impact on reducing gasoline usage as rapidly as possible. For example, a high speed route between Miami, Florida and Portland, Maine could well be a top choice because of the high population density in this important area. Conversely, there is little incentive for replacing diesel driven freight trains with electric ones in sparsely populated areas because the oil savings would be too small and the costs too high (reference [89]).

Significant liquid fuel savings, as well as reductions in GHG emissions, may be achieved by modifying our ground freight shipments. According to Forsberg (reference [90]) “Liquid fuel consumption in the ground freight transport system could be reduced by 80% by the combination of electrification of railroads, as in Europe, and large scale intermodal rail truck systems. Most of the long distance truck transport would be replaced by containerized freight that travels long distances by rail, with local delivery by truck.” Modifying ground freight transport by using electrified trains is estimated to reduce America’s energy demand by 5%. To accomplish this, Forsberg estimates that 50,000 megawatts-electrical would be required or about 30-35 large nuclear power plants.

Forsberg also points out “In the 1970s, the French Government decided to build an electrified high-speed super train system to connect major metropolitan areas and to reduce consumption of liquid fuels. The system has demonstrated that high-speed trains can replace air travel for distances up to 500 miles because of lower costs, higher point-to-point speeds and greater comfort. Simultaneously, rail stations have been built at major airports to provide point-to-point transport.”

Greater use of such trains have secondary benefits, as well. Almost half of the aircraft flight delays in the country were directly or indirectly a result of the three New York and two Washington, D.C. airports. If one wants to fix the U.S. airline system, including long aircraft taxi lines that burn jet fuel, high speed rail along the east coast corridor would decrease the load on these airports. This would reduce the release of GHG, lower air pollution, reduce the use of oil, and increase customer satisfaction.

Modern high speed trains also save energy by using regenerative braking. The Japanese (reference [91]) are using regenerative braking on their trains and store the electricity these brakes generate in lithium batteries. The East Japan Railway expects significant energy savings and a 60% reduction in particulates released into the environment. British operators have embraced regenerative braking as a means of saving energy and reducing maintenance costs (reference [92]). Economic savings are being made because trains with regenerative braking have far less brake pad wear. Comparisons conducted in Britain showed that with regenerative braking, brake pad life was 18 months and without regenerative braking, only 18 days. While this is an extreme example, the role of regenerative braking in reducing downtimes, maintenance costs and air pollution is clear.

6.0 An Implementation Plan

6.1 A Missing Analytical Tool

The technical community needs to develop an advanced dynamic analytical tool to deal with our energy future. The whole subject of our energy future is complex, is subject to both positive events (e.g., new discoveries and inventions) and negative ones (e.g., less coal reserves than once thought), and the energy technical information is huge, growing, and dispersed. We need to answer, in a more sophisticated and transparent way, a whole host of questions, such as "What is the least cost pathway to reducing oil dependence and GHG releases and what infrastructure needs to be improved first?" We need to address questions like these in a broad based, transparent, interactive manner that invites constructive comment and where decisions are posted and justified. We need consistency among different elements of this analytical tool so that meaningful comparisons can be made. One example of this is a consistent economic analysis that applies the same cost of money to all aspects of this tool and another example is to recognize the difference between subsidies and loans.

Such an advanced analytical tool might be placed in DOE's Energy Information Agency and posted on the internet. This would be an extension of EIA's annual energy outlook series. The EIA would maintain and update this tool and make it available to all countries and internet users. It should be possible for the EIA to run many kinds of "what if" scenarios to determine their postulated effect on oil imports, GHG releases, costs, etc. With such a tool the results of different scenarios can be meaningfully compared since they were computed on a uniform basis. Such comparisons permit the ranking of different scenarios to determine which ones look most promising. The results of such postulated scenarios should be periodically made available on the internet by the EIA.

Individual elements of this analysis, such as the cost of steel, have their own uncertainty bands. Individual element uncertainty bands need to built into this system so that the overall uncertainty of different energy scenarios could be estimated in a consistent manner. Mathematical techniques already exist that permit the incorporation of many smaller uncertainties into the creation of an overall uncertainty band. This would help when comparing one scenario with another.

Users should be able to search this tool to identify bottlenecks to making energy progress. Overcoming such bottlenecks might promote a wellspring of ideas from new and existing entrepreneurs.

The availability of such an analytical tool should bring greater coherence within and outside of the government. Personnel at the DOE, EPA, Department of Transportation, Congressional Staff members, industry, and academia alike should all be able to “read off of the same page”. Internet users should be able to track down a wide range of energy information and communicate back to the EIA with new ideas/ questions.Various publishers of technical documents, such as the National Academy of Sciences, should be able to identify where their technical articles should be linked to locations within this analytical tool, leaving it up to the EIA to link these new sources of information.

Creating such a broad, sophisticated analytical tool is well within present technology and seems to be less of a task than producing probabilistic risk assessments that are routinely used for safety analyses at nuclear power plants. Figures 17 describes in broad terms our present energy system with its energy sources, distribution networks and end use functions. Not displayed are the billions of end use devices which implement these energy functions like cars, refrigerators, farm tractors and many more. Figure 17 is an evolution of Figure 11. Energy storage is partially displayed here in the end use device of a compact electric storage system and at community energy depots. Additional energy storage systems would be placed at wind farms, solar thermal systems, at hydrogen producing nuclear power plants and built into various transportation vehicles and trains. Also not shown in Figure 17 is the whole natural gas network that would supply liquid fuels, provide electricity, and perform space heating functions.

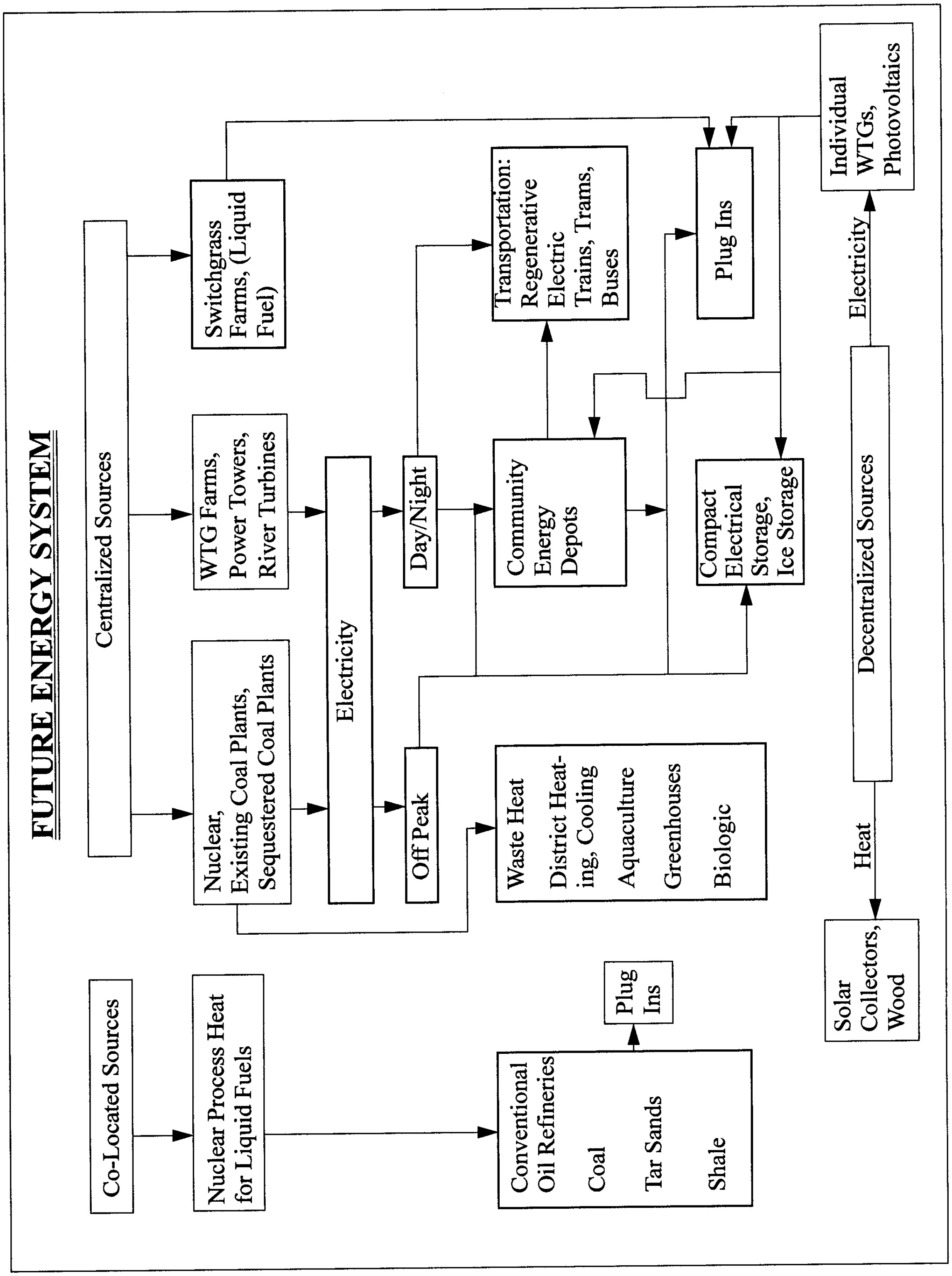
Figure 17 needs to include a level of detail which describes the time dependent evolution of supporting infrastructure (factories, materials, manpower, etc.), cost figures, GHG release figures and petroleum use figures. Implicit in this much more detailed figure would be the modeling of transmission networks and CTL, bio-refineries, and CSS systems. Creating this next level of detail would need the input from many people with diverse fields of expertise.

Not included in Figure 17 is some kind of gasoline affordability index which displays what percentage of the population would be unable to pay for gasoline as a function of price. Such an index would be an important indicator of social and political stress. Some work has been done in this area in 2008 by the CATO Institute (reference [93]).

This advanced analytical tool should be able to identify critical paths for each scenario it analyzes and be able to rank and compare the results from different scenarios, like GHG releases versus time, or to make cost comparisons, or uncertainty band comparisons.

While the availability of this analytical tool won't fully answer all complex energy/ political/ environmental issues, it might be able to provide useful insights that would help shape decision making in a consistent and transparent manner.

Figure 17: Future Energy System



6.2 Overview

The development of this implementation plan resulted in some broad insights.

With regard to ending challenges from overdependence on petroleum, it was observed that, in the early stages, reliance would be placed on other fossil fuels, principally natural gas and coal, to diminish the role of petroleum. In the later years further petroleum use reductions could be achieved as nuclear power and renewables took over from natural gas and coal as the sources of low carbon liquid fuels and by low carbon sources of electricity.

With regard to dealing with climate change, early GHG abatements could mainly be achieved by a combination of money saving conservation, minimizing methane releases from municipal solid waste facilities, capturing flared natural gas, reduced demand for petroleum through several “no tech” and “low tech” actions, by using surplus natural gas electric power plant capacity to replace all coal fired electric power plants, and by reducing GHG emissions from petroleum refineries. In the mid term GHG emissions would be further reduced by greater electrification of transportation through increased use of electrified individual vehicles and more efficient mass transportation including high speed trains. In the long term, achieving long term energy security and bringing GHG emissions down to low levels will require two main actions:

1. Use of affordable, carbon neutral, and sustainable sources of liquid fuels, and
2. Replacement of fossil fueled sources of electricity with affordable, low carbon sources.

The sources of sustainable carbon neutral sources of liquid fuels could be ethanol from biomass, and methanol derived by the co-electrolysis of H_2O and CO_2 from seawater, using high temperature nuclear reactors as the energy source, and from municipal solid waste systems. Factory built, lower cost evolutionary nuclear plants (LWRs) would, over time, have to replace many of the natural gas electric power plants in order to meet ever tightening GHG release limits. Some contribution of low carbon electricity from geothermal energy may be possible in this time frame.

Achieving both the petroleum use transformation and GHG abatement transformation would require a very large financial investment. This includes saving money through energy conservation, by reducing the nation’s oil bill (see Table 6), by reducing health costs through cleaner air...particularly in urban areas, by lowering costs for electricity by replacing natural gas power plants with lower cost nuclear plants, and by reducing military expenditures because of reduced foreign threats over our oil supply. Were this accomplished, the United States would become reindustrialized, employment would be higher, air pollution greatly reduced, the balance of payments shifted from large losses to large gains, the risks from climate change greatly diminished, and petroleum related threats to our national security largely ended.

Our energy future could be sustainable, flexible, and diverse. Sustainable because carbon neutral ethanol would be derived from solar energy via biomass and from carbon neutral methanol derived from seawater/high temperature nuclear energy sources and methanol from municipal solid wastes. Our energy future would be flexible because this would be a highly electrified world. As new sources of electricity, such as from geothermal energy and fusion energy, become available the electrical end uses they would actuate and their distribution systems would already be in place. This future would be diverse because there would be multiple sources of carbon neutral liquid fuels and sources of electricity. This future energy system would also be more secure against acts of terrorism or the impact of large natural phenomena through the use of distributed energy storage systems in energy depots and energy storage in many end use devices.

What follows is a multi-step quantitative implementation plan that is meant to determine if the petroleum usage and greenhouse emission goals established in Section 4 can be achieved. Whenever possible, quantitative petroleum reduction and GHG abatement values come from identified references. When such references are not available, estimates are made based on simple analyses. This implementation plan was developed in two phases. First, an optimistic analysis was made that did not account for an increase in demand for energy and increased GHG releases, both because of a growing population. The results of this optimistic analysis was then compared to the goals presented in Section 4. This comparison showed that the optimistic analysis results came close to meeting the petroleum usage goal but was far off in terms of meeting GHG release objectives. In order to also meet the GHG goal, eliminate the remaining petroleum dependence, and account for a growing population, more would have to be done. Two additional, and major actions would have to be taken, as identified above. These additional efforts include the eventual phasing out gas fired electrical plants and the development of sustainable carbon neutral liquid fuels in sizeable quantities. The final step in this implementation plan describes how to accomplish these last two efforts.

First priority was placed on preventing a back-to-back recession in the next few years due to a global shortfall between petroleum supplies and the growing demands for oil. Even if successful in the short term, this challenge is not going to go away as world oil supplies tighten and demand for oil from developing countries continues to rise. The possibility of future recessions and even armed conflict beyond achieving this short term goal can not be ruled out. So the next step has a goal of ending petroleum imports. Should we achieve the goal of ending petroleum imports, this would still leave sizable quantities of petroleum consumption which would be dependent on domestic sources. Much of our petroleum reduction emphasis has been on passenger vehicles which consume about half of the petroleum the nation uses. However, in order to eliminate all use of petroleum one would also have to eliminate petroleum from heavy duty vehicles and from non-transportation uses of petroleum. This latter category, non-transportation uses of petroleum, consumes about 28% of today's petroleum use. Reducing petroleum use in the non-transportation sector and in the heavy vehicle sector may prove to be more difficult than dealing with the challenges of reducing petroleum use in our automobiles.

In parallel with these petroleum consumption reducing actions are actions to abate the release of GHG. These GHG abatement achievements, through 2036, were compared to the GHG limits for 2036 incorporated into H.R. 2454 and repeated as a goal in Section 4.

As already stated, this initial implementation attempt failed to meet the GHG goal. What was also observed was that it will become increasingly difficult over time to prevent slipping back into a petroleum dependence posture or to meet the tightening GHG limits of H.R.2454. This first implementation trial failed in spite of assuming that there would be tens of millions of plug-ins, plus EVs and HEVs, increased public transportation, offshore oil exploration, and conservation, all of which are used to reduce petroleum usage and/or the release of GHG. Worse, this first attempt failed even though it optimistically assumed a flat demand profile, i.e., it did not account for a growing population.

It became apparent that far more would have to be done if the goals of Section 4 were to be achieved.

6.3 A Multi-Step Energy Plan

6.3.1 INTRODUCTION

Since the more precise analytical tool described in Section 6.1 is not available at this time an attempt is made here to provide a first draft of an energy plan that would address national security issues, economic, and climate change issues. This proposed plan is divided into four steps. Although many assumptions and approximations had to be made, the overall results provide valuable insights and guidance.

This first attempt intentionally assumed no increase in energy demand even though the size of the is population a growing. An assessment was then made of how successful we might be in meeting national security and climate change goals by 2036, the end of Step Three. It is shown that, even under the no population growth assumption, meeting long term goals is questionable and that further steps must be taken. Several further steps were then identified.

6.3.2 STEP ONE, 2011-2016

6.3.2.1 Prevent Back-to-Back Recessions

The following actions should be taken during the five year period ending in 2016 to reduce our dependence on imported petroleum. None of them require technological innovation.

Because of the gravity of a second long and deep recession brought on by high petroleum prices or shortages, the actions recommended in Section 6.3.2 should be considered a national priority and treated as an emergency condition. Even though Step One would only last five years and much has to be done, it should be remembered that, for the United States, WWII was about five years long and great accomplishments were achieved.

First, coal plants that are now shut down but could become operational should be retrofitted to capture their CO_2 to make methanol. These plants, no longer on the electric grid, should be operated near their name plate capacity for as many hours per year as practical. Next, other coal plants, still operational, but on the low end of efficiency rankings, should be taken off the grid and converted to methanol producers if their electricity production can be replaced. Ranking of power plants is discussed in Section 5.3.2.7. It is possible that the electric power normally produced by these less efficient power plants would be taken up by the more efficient coal plants, if some level of energy storage is available and/or if smart grid technology permits this. In the meanwhile other, non-power plant sources of methanol from waste CO_2 need to be developed, where practical. Examples of other sources of CO_2 is the effluent from cement factories, from flared off natural gas, and from municipal solid waste facilities. Direct conversion of solid wastes to fuels and eventually to CO_2 through combustion can result in a decreased impact on climate change (reference [94]). This is because these waste facilities generate methane (under anaerobic conditions) and, per molecule, methane is many times more heat trapping than a CO_2 molecule. This source of methanol, although small, can be considered as sustainable.

As these initial steps are taking place, consideration might be given to modifying existing coal power plants to have a dual capability. These power plants would first produce electricity as they do now. However, when demands for coal- based electricity are down and these plants are not needed to add electricity to the grid, they would continue to operate at full power, but in a methanol producing mode. In time, as the need for coal produced electricity decreases, these dual capability plants would increasingly be used to produce methanol. This arrangement gives greater assurance that adequate supplies of electricity would be at hand during this transition and the money invested in installing a methanol capability at these coal plants would not be wasted.

The next major step would be replacing the remaining coal fired electricity with other sources of electricity and by reducing overall demand for electricity through conservation. With regard to replacing coal fired electricity with gas fired electricity, more emphasis on energy storage needs to be taken. For example, in urban areas peak summer demands of air conditioning is usually met by gas and coal fired electricity. However, if large air conditioning loads in specific buildings can be met by storing ice, in situ, then these peak air conditioning loads could be decreased. (See Sections 5.3.2.3 and 5.3.2.4). Like using ice for energy storage to decrease peak electric loads, compact electric storage with the additional capability to act as cooling systems might be attractive. (See Section 5.5.1).

Conservation, such as building insulation and more energy efficient appliances, would also accomplish the same objectives as energy storage. The combination of conservation and energy storage would be very cost effective.

In parallel with using natural gas to help the transformation of coal electric plants to be methanol producers, natural gas should be used to make methanol directly.

Greater use of natural gas power plants to replace coal plants may require a review of existing natural gas pipelines to assure that these gas plants will have adequate gas supplies. The adequacy of the national electrical grid may also need to be reviewed to determine if the additional electricity from gas fired plants is sufficient to meet the needs of present consumers of electricity from existing coal fired plants who may be located in areas rather far from these gas fired electric plants. Where necessary, additional gas pipelines and improved electrical grids should be constructed. Improved electrical grids may also benefit onshore wind power. The rate at which gas plant capacity replaces coal fired electricity should be such that temporary shortages in electric capacity do not occur and this can be accomplished by using dual capability coal plants, as described earlier. Alternatively, evolutionary nuclear power plants could be used to replace some of the coal plants. This would have the advantages of greater GHG reductions per kilowatt-hour than gas generated electricity and would avoid any need to expand the electrical grid or lay new gas pipelines, which itself has been controversial in some locations. Wind turbine farms, especially those with energy storage capabilities, might also provide part of the answer where economical.

Since the production of methanol consumes significant amounts of water it should be determined if there are locations where water availability or other factors limit the conversion of particular coal plants from making methanol. The ability to distribute and utilize methanol from these converted coal plants to present gasoline service stations should be determined and expanded where necessary. Further, Open Fuel Standard legislation should be enacted by Congress on a priority basis so that all new passenger vehicles would have this capability. The federal government should determine if financial assistance should be given to owners of existing vehicles so that the installation of a flex-fuel capability in these vehicles would proceed at a pace that matches the availability of methanol and ethanol mixes at service stations. As methanol is added to the nation's liquid fuel mix, its energy equivalent in gasoline should be reduced. As gasoline usage is reduced there would be a reduction in the amount of petroleum processed at oil refineries. Between 10% to 20% of the petroleum used in refineries is used as a heat source rather than as a feedstock. Every reduction in petroleum demand would also produce a further saving in petroleum at the refineries because less petroleum would be used as a heat source.

In just five years, if these sequences of actions can be fully implemented, the following reductions in petroleum use and GHG emissions might be possible:

1. Existing excess capacity at natural gas electric generation plants would replace all coal fired plants.This action would require a 91% increase in natural gas usage in electric power generation. (See Section 5.4.3.3). In 2009 natural gas produced 373 million metric tons of CO_2/ year in the electric power sector. An increase in use of natural gas by 91% would raise this to 712 million metric tons of CO_2/ year. However, in 2009 coal electric power plants produced 1733 million metric tons of CO_2. Eliminating coal plants taken from the electrical grid by substituting natural gas would result in a net GHG abatement of about 1021 million metric tons /year.
2. Existing coal plants would be converted to make methanol from CO_2 generated at these plants. Assuming that 85% of all existing name plate coal power plant capacity is converted to methanol production and that these converted power plants operate at full power 90% of the time, some 3.1 MB/D of petroleum could be displaced. This would require a 29% increase in coal usage. (See Section 5.4.3.2). Substituting energy equivalent amounts of methanol for gasoline is treated as GHG neutral. Over time the production of methanol from coal might shift from the many coal power plant sites to the coal fields themselves. The potential exists to produce liquid fuels without mining the coal or producing coal ash and other difficult wastes, using high temperature steam from nearby high temperature nuclear power plants. This relocation to the coal fields would also greatly reduce the need for coal trains/barges to deliver coal to the coal power plants.
3. Using the 2009 value of 18.8 MB/D for total U.S. petroleum consumption, this reduction in oil use would be 3.1/18.8 =0.165 or about a 17% decrease of the 2009 petroleum consumption rate. Almost one fifth of all U.S. petroleum use could be eliminated by fully implementing this natural gas to coal to methanol to petroleum sequence. In 2009 there were 9.0 MB/D of imported petroleum. A reduction of 3.1 MB/D from this one sequence would cut 2009 levels of petroleum imports by about a third. Since refineries produce about 200 million metric tons of GHG per year, a reduction in petroleum consumption of this size should abate GHG emissions by about 33 million metric tons/year. If it is assumed that the least efficient refineries are shut down first, perhaps the GHG abatement from reduced usage of refineries would come to 57 million metric tons/year. If so, the replacement sequence of natural gas to coal to petroleum to petroleum refineries

would result in a total decrease of about 1021+ 57 = 1078 million metric tons of GHG emissions per year.

4. Additional methanol from natural gas would be made directly. At this time this source has not been quantified in terms of petroleum displacement or its additional demands on the natural gas industry.
5. With a dedicated methanol engine, a vehicle as efficient as a diesel, or about 25-30% more efficient than a conventional gasoline driven vehicle. This is a very significant benefit from using methanol.
6. A combination of a plug-in vehicle with a dedicated methanol engine might be a very effective way to reduce petroleum use in our transportation sector.

Second, there are a number of “no tech” and “low tech” near term opportunities to reduce petroleum consumption. It has been estimated that if ten percent of today’s passenger miles were accomplished by three person car pools, a petroleum reduction of about 0.43 MB/D would be achieved.

Third, a petroleum use reduction of about 0.56 MB/D would be achieved if ten percent of today’s passenger miles were accomplished by buses with an average ridership of 50 persons/bus. This petroleum reduction is based on just using today’s buses, not advanced models like South Korea’s “Blue-City” hybrid bus that uses compressed natural gas and electricity (See Section 5.6.3) or the Chinese “capabus”. However, a major effort would be initiated in Step One to build such advanced buses, along with their supporting infrastructure. These advanced buses could be partially or totally manufactured in the United States in a business arrangement similar to those used by car companies of foreign origin who have manufacturing facilities in the United States. This is one example out of many that supports the notion that creating a new energy future for the United States would lead to a reindustrialization of this country and a long term answer to unacceptable levels of unemployment.

Fourth, if the 3% of today’s oil use in home heating were replaced by compact electric storage systems an additional petroleum reduction of 0.56 MB/D could be achieved. (See Section 5.5.1).

Fifth, as discussed in Section 5.4.2.2, it is recommended that work begins on manufacturing 10,000 offshore wind turbines to make methanol from seawater and to abate GHG releases. If the buildup of WTGs is similar to that described in Section 5.4.2.2, then these 10,000 WTGs might be fully operational by 2016. By 2016 these

10,000 WTGs might produce about 0.28 MB/D of methanol and abate about 18 million metric tons/ year. Cumulatively, these WTGs would abate 36 million metric tons between 2012 and 2016 since the methanol they produce would not be burned, but stored in a National Liquid Fuel Reserve.

One purpose for committing to build 10,000 offshore WTGs would be to maintain the viability of the wind turbine industry. The most recent EIA projections of the growth in windpower shows a large decline. As discussed in Section 5.4.2.3 there may be a large market for onshore WTGs in rural, off-grid, areas in developing countries. Further, these offshore WTGs would be the beginning of an offshore methanol industry. As such, they could provide useful operational experience for a much larger future off shore methanol industry. Offshore methanol complexes using floating nuclear plants surrounded by wind turbines might be an attractive design.

The petroleum reduction actions 2, 3, and 4 total 1.55 MB/D, assuming that WTG methanol production is dedicated to the National Liquid Fuel Reserve. These last three actions would reduce GHG emissions by about 213 million metric tons/year.

The combination of these first four actions would result in a petroleum reduction of about 4.7 MB/D, about half of the oil imported in 2009. At this level, the nation should be "immunized" against back-to-back deep recessions brought on by world oil market instabilities during the 2011-2016 time frame.

Large sums of money would be saved by reducing petroleum consumption. This might be considered as an annual stimulus package and/or as a major means to drive down the national debt. The most effective use of this money, however, might be to invest in further petroleum reducing projects.

Other actions, such as the increased use of telecommunications, electric bikes, shifts in working hours, and avoiding unnecessary trips, were conservatively not credited here for reducing petroleum consumption or abating GHG. Nonetheless, these additional near term actions should be encouraged.

6.3.2.2 Status of Greenhouse Abatement by 2016

The Step One actions would collectively reduce GHG emissions by about 1,327 million metric tons/year. No GHG or petroleum reduction credits were given in this short time frame for vehicles specifically designed to operate just on methanol, even though such vehicles would be more efficient than gasoline engines.

6.3.2.3 Lay the Groundwork for Further Savings

In addition to the actions to be taken to immunize the nation against back-to-back recessions due to high oil prices, a large number of programs would be initiated during 2011-2016. The full benefits of these programs would not be felt until after 2016.

One high priority program is the energy conservation program discussed in Section 5.4.5. which is aimed at abating GHG releases. One reason to give this program a high priority is because it is a net money saver. Based on Figure 16, it has been estimated that about 1.1 gigatons/year (1100 million metric tons/year) of greenhouse gases/year could be abated with a net savings of about $680 billion dollars between now and about 2020. If coal fired plants were replaced by natural gas and if home heating with oil is replaced by compact electric storage systems, then the net GHG and dollar savings in Figure 16 would be less. To avoid double counting these conservation benefits, it is assumed that only about 80% of Figure 16's benefits in GHG abatement and dollar savings could be achieved. This leaves, by 2020, a GHG reduction of about 880 million metric tons/year and an overall cost savings of about $540 billion dollars. These reductions are credited in Step Two, although some of the GHG abatement would occur within Step One. No credit is given in this conservation program for petroleum reduction.

With regard to electric vehicles, it is assumed that the President's goal of one million electric vehicles by 2015 would be started and achieved. At this level the impact on petroleum consumption and on GHG abatement would be very small. Similarly, during this short time frame other forms of electrified transportation, such as high speed trains, would have a negligible impact. However, these programs should be started for longer term benefits. It is recommended that work would begin on three high speed train corridors in high population areas. One corridor might serve the east coast from Portland, Maine to Miami, Florida. A second corridor might run between Buffalo, New York, through Chicago, and on to St. Louis. A third corridor might serve the major cities in California. Additional high speed train corridors would likely be built in the longer term to serve other large cities.

There is a need to start a demonstration program of sufficient scale to assess new ways of producing ethanol from biomass. Prior to starting this important program an independent and knowledgeable group of scientists and administrators should develop a set of criteria that need to be met to determine the success of such a program. Even if the demonstration program is successful, the rate at which ethanol might enter the liquid fuel market might be gradual and set by the pace of building biorefinery capacity. The biomass-to-ethanol process recommended in Section 5.4.2.1 should be agriculturally beneficial, independent of producing ethanol. No new credit is given for ethanol in this 2011-2016 time period for displacing petroleum.

During this Step One five year period a number of actions need to be initiated in the nuclear energy field. First, the licensing process at the Nuclear Regulatory Commission (NRC) for new nuclear power plants should be divided into two different review pathways, one dealing with evolutionary light water reactors (LWRs) and the other with advanced designs, such as high temperature nuclear plants. With regard to LWRs, a much more rapid mechanism to obtain an operating license appears to be justified. Given the many reactor-years of safe LWR operation in the United States, the insights from many modern probabilistic risk assessments, and the inherent risk reducing chemical and physical actions that all LWRs have, as shown in Sandia's SOARCA program, LWR licensing should mainly focus on designs that have a low core melt frequency, minimize the likelihood of unwanted power excursions, protect the spent fuel, have a substantial barrier (e.g. a containment building, or placed below ground or submerged under water, etc.) between the reactor core and the spent fuel pool and the environment, have an effective emergency plan, are resistant to terrorist attacks and sabotage, and have applied the lessons learned from the Fukushima nuclear accident. If feasible, further verification of the results of the SOARCA program should be made by comparing recent tragic events at several Japanese nuclear power plants at Fukushima to SOARCA analyses.

It should take less than one year for LWRs that meet these broad safety categories to become licensed for operation, especially if they are of a standard design that has already been reviewed and approved. The balance of the licensing activities at the NRC should concentrate on how to license advanced high temperature nuclear power plants.

6.3.3 STEP TWO, 2016-2026

6.3.3.1 Introduction

Step One was directed at immunizing the nation in the near term against back-to-back recessions brought on by world oil shortages. Even though a successful Step One would solve the near term petroleum problem, it is likely that the world petroleum condition would continue to deteriorate as demand for petroleum from China, India, Brazil and other nations continues to expand and world supply becomes increasingly uncertain. As shown in Figure 10, the International Energy Agency is projecting a major shift in oil supply as conventional oil sources continue to shrink and there is increasing dependence on oil fields that have yet to be developed and oil that hasn't even been discovered. Further, this IEA projection may not account for an increasing use of oil by the oil producing nations themselves, leaving less oil on the world market. This is a very uncertain future. Therefore Step Two introduces actions to continue to make the nation immune to another world condition after 2016 where again there was no margin between supply and demand. By the end of Step Two the nation would have eliminated all petroleum imports and would then only rely on domestic sources, again based on the no population growth model.

6.3.3.2 Reduce Non-transportation Petroleum Usage

As shown in Table 10 about 28% of our 2009 use of petroleum, 5.3 MB/D, goes into non-transportation applications. The goal established in Section 4.2 is to reduce this 28% figure down to around 10% by 2026. If this were accomplished there would be a reduction in petroleum usage by about 3.4 MB/D.

For the purposes of this report items 6-11 in Table 10 are assumed to be unchanged and made from petroleum, as is half of item 4. Together they constitute 10% of the total national petroleum consumption. The remaining 18% of the non-transportation petroleum consumption is to be eliminated. Some of this petroleum elimination would already be implemented in Step One where the 3% dedicated to oil heating would be replaced by compact electric storage devices.

Assuming items 6-10 in Table 10 remain unchanged is conservative. Studies have been conducted that have identified other oil reducing opportunities beyond cars and trucks. There are many such smaller possibilities and they are distributed across the commercial, industrial, and residential energy sectors. They are too numerous to identify here, but include actions like reducing oil usage in the manufacturing of asphalt and road oils which are mainly used in paving roads. "By recycling existing pavement combined with the addition of crumb rubber from recycled tires, the amount of new petroleum products can be dramatically reduced" (reference [95]).

Items 1 and 2 in Table 10, propane/propolene and natural gas liquids and liquid refinery gases, can be made without petroleum via ethanol from biomass or methanol from coal or natural gas based processes. Together they represent an 11%, or 2.1

MB/D reduction in petroleum usage. If the ethanol piece of this 11% is 3% and ethanol from biomass is assumed to be GHG neutral, then this would cause a GHG reduction of about 77 million metric tons/year. No GHG reduction is given for the other 8% which would come from coal or natural gas based methanol.

Some items in Table 10 would automatically be reduced as the throughput in refineries is scaled back due to less demand for oil. Other cleaner heat sources for refineries, such as High Temperature Gas Cooled Nuclear Power Plants, would further reduce the need for petroleum based heat sources at refineries. Between reduced oil and alternative heat sources, it is assumed that the need for still gas is eliminated. This would be a 3% or 0.56 MB/D reduction, worth about a GHG reduction of 77 million metric tons/year.

Table 10 shows that about 3% of our oil use is tied to residual oil. This heavy, viscous oil is often used to propel large ships and is quite polluting. Perhaps half of this could be phased out by 2026 with hydrogen propelled zero emissions vessels, as described in Section 5.3.2.6. This would be a 1.5% reduction in oil use, worth a 0.28 MB/D reduction in petroleum use and about a GHG reduction of 38 million metric tons/year. It is assumed that the electricity or natural gas used to make the above hydrogen itself produces GHG and that the net GHG abatement is 19 million metric tons/year.

Table 10: Non-Transportation Uses of Petroleum in 2009

1	Propane/propolene	6%
2	Natural gas liquids and liquid refinery gases	5%
3	Still gas	3%
4	Residual/heavy oil	3%
5	Heating oil	3%
6	Petrochemical feedstocks	3%
7	Petroleum coke	2%
8	Asphalt and road oil	2%
9	Lubricants	1%
10	Miscellaneous products and unfinished oils	0.2%
11	Special napthas, aviation gasoline, kerosene, and waxes	0.33%

6.3.3.3 Conservation

Many of the actions recommended in Section 6.3.2 would begin to bear fruit in the ten year span of Step Two. Previously the GHG reduction due to conservation actions, like better home insulation, was estimated to be 880 million metric tons/year with a net savings of about $540 billion dollars. It is estimated that this effort could be completed by 2020 or so.

6.3.3.4 Create a National Liquid Fuel Reserve

By 2026 the 10,000 offshore WTGs would have filled its portion of the National Liquid Fuel Reserve and would then begin to add about 0.32 MB/D of petroleum equivalent to the nation's fuel mix. This WTG portion of the National Liquid Fuel Reserve would be sufficient to meet the liquid fuel needs for one year of a reduced non-transportation sector. During the time period from 2016 to 2026 these 10,000 WTGs would abate about 180 million metric tons of GHG.

6.3.3.5 Improvements in the Transportation Sector

In addition to reducing non-transportation uses of petroleum from 28% to 10% there would be a number of petroleum savings in the transportation sector.

It was also argued in this report that recent progress in batteries, rising costs for gasoline, and many new vehicles being offered that run partially or completely on electricity justify the use of the National Research Council's "maximum practical scenario". If anything, the newly announced Toyota Plug-in Prius indicates that the NRC's projections may be too conservative. Based on Figure S.2 of the NRC report (reference [96]) by 2026 gasoline consumption would have decreased to about 120,000 millions gallons of gasoline per year from about 130,000 millions gallons per year used in 2010. This would be equivalent to a reduction in petroleum use of about 1.3 MB/D since it takes about two gallons of petroleum to produce one gallon of gasoline, assuming previously mentioned actions are taken to deal with the non-gasoline uses of petroleum. This expansion would require about 25 million electrified vehicles like plug-ins by 2026, far larger than the President's recent goal of a million electric vehicles by 2015. A fleet of 25 million electric vehicles by this date would not exceed today's capability to have this many vehicles recharged during electric grid off-peak time periods and is well within the manufacturing capability of domestic auto manufacturers.

In parallel with the build-up of electric vehicles like plug-ins, more hybrid electric vehicles (HEVs) like the conventional Toyota Prius are likely to be on the road by 2026. The 2010 Prius model gets about 50 MPG and future HEVs are expected to achieve 60 MPG. Both HEVs and PHEVs would save considerable gasoline compared to today's vehicles but the difference between the two types is not expected to be large. The National Research Council estimates that this difference would be about 0.2 MB/D if 40 million PHEV-10s[5] and an equal number of HEVs were on the road. It seems plausible that the future passenger fleet of cars would be a mix of HEVs, PHEVs, and EVs. For the purposes of this report it is assumed that by 2026 there would be enough HEVs on the road (about 13 million) to reduce petroleum usage by another <u>0.52 MB/D</u>. Even with 25 million PHEVs/EVs and another 13 million HEVs this would still be less than 15% of the vehicles now on the road in the United States. This rather low percentage of 15% further supports the conclusion that the nation should act more aggressively in producing petroleum displacing vehicles. Further, this underscores the need to also concentrate on more than advanced batteries, regenerative braking, and the other elements of the electrical portion of advanced automobiles and begin to also focus on low carbon liquid fuels like ethanol and methanol.

The National Research Council's Figure S.3 was used to estimate the GHG reduction for 25 million PHEVs. A reduction of about <u>100 million metric tons/year</u> was read from this figure. Since the fuel consumption of HEVs is almost as good as the PHEVs according to the National Research Council, it was assumed that the 13 million HEVs would reduce GHG by about <u>40 million metric tons relative to today.</u> The total reduction for these high efficiency vehicles is then <u>140 million metric tons/year</u>.

If there were 25 million PHEVs and EVs by 2026 and another 13 million HEVs this would come to 38 million vehicles. Spread out over the 15 years between 2011 and 2026 this averages out to be about 2.5 million such vehicles sold per year. With rising gasoline prices this annual average sales rate of high efficiency vehicles seems reasonable. Many of these sales would likely occur in the latter part of this 15 year span.

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5 A PHEV-10 is a plug-in electric vehicle with a range of 10 miles using only the electricity from its battery.

During this time period, because of actions taken in Step One, some improvements in mass transportation would be expected, such as replacing less efficient diesel buses with new compressed natural gas hybrid buses and/or with new buses that use ultra capacitors. It is assumed that these more energy efficient buses reduce petroleum usage by about another 0.52 MB/D with a corresponding GHG emission reduction of about 40 million metric tons/ year.

Finally, it is assumed that petroleum usage in trucks is reduced from 17% to 10% of our total present use of petroleum, a reduction of 1.32 MB/D. This reduction would be the result of using compressed natural gas in these heavier vehicles and greater use of putting truck cargoes on freight trains, using an intermodal travel configuration. (See Section 5.6.4). The GHG abatement for this form of truck travel is estimated to have a gross GHG reduction of 181 million metric tons/ year. Since the use of compressed natural gas releases GHG and the source of electricity for trains used in intermodal travel would be partly fossil fuel based, only a GHG abatement of 90 million metric tons/year is credited.

6.3.3.6 Other Reductions

About one percent of the electricity produced in the United States is petroleum based. If this were totally eliminated this would save about 0.19 MB/D and would reduce GHG by about 26 million metric tons/ year.

It is assumed that advances in materials, such as in nanotechnology with better strength to weight ratios, and other conservation measures reduce the use of jet fuel from 7% to 5% with a petroleum savings around 0.38 MB/D with a GHG abatement of 52 million metric tons/ year.

6.3.3.7 Ending Petroleum Imports?

For Step Two the total estimated petroleum reduction came to about 7.2 MB/D. By 2026, the Step One and Two petroleum reduction might be around 11.9 MB/D, relative to 2009 petroleum usage. In 2009 about 9.7 MB/D were imported. With a reduction of 11.9 MB/D this would be sufficient to eliminate all oil imports. Starting with a petroleum consumption of 18.8 MB/D, followed by a reduction of 11.9 MB/D, the balance to be provided in 2026 by domestic oil production would have to be about 6.9 MB/D, if all imports were eliminated.

Based on the assumptions used in Steps One and Two, petroleum imports might be avoided by 2026, provided domestic supplies equaled 6.9 MB/D. This domestic petroleum supply might be used for activities that are best served by petroleum. Specifically, this analysis assumes that we would still need about 1.9 MB/D of petroleum for heavy trucks, about 1.4 MB/D for PHEVs when they are on longer trips beyond the range of their batteries, about 0.6 MB/D for HEVs, another 0.28 MB/D for residual oil on large ships, another 1.88 MB/D for non-transportation uses of petroleum, about 0.9 MB/D for jet fuel, and a small portion for bus trips that still rely on petroleum. These higher priority uses of petroleum total 6.9 MB/D,

The amount of domestic oil that the United States might be able to produce by 2026 is unlikely to be 6.9 MB/D. In 2009 U.S. petroleum production (crude oil, NGPL, and other oils) was about 7.3 MB/D of which 5.4 MB/D was crude oil. Seventeen years later, in 2026, domestic oil production would most likely be less, declining, and may not be able to meet the 6.9 MB/D needed for priority uses. By the end of Step Three, 2036, the gap between domestic supplies and the remaining priority uses for petroleum would likely widen further. If preventing oil importation is desirable, then additional petroleum reducing actions are needed. Therefore the purpose of Step Three is to plan for a situation where domestic oil supplies might not be sufficient to prevent the U.S. from returning to the world oil market.

6.3.3.8 Status of Greenhouse Gas Abatement by 2026

By 2026 the combination of energy conservation and various GHG reductions due to less usage of petroleum comes to about 1,419 million metric tons/ year. Therefore Steps One and Two would together reduce CO_2 emissions by about 2,746 million metric tons/year by 2026. Total GHG abatement would also include reductions in the release of non-CO_2 greenhouse gases.

6.3.4 STEP THREE, 2026 - 2036

6.3.4.1 End All Use of Petroleum?

During this ten year time period between 2026 to 2036 the National Research Council predicts a significant increase in the number of electric vehicles on the road in their Maximum Practical Penetration model. Referring again to Figure S.2 of the National Research Council's report on electric vehicles, by 2036 gasoline consumption is projected to decrease to about 90,000 millions of gallons/year. This would be a further decrease of about 30,000 millions of gallons/year of gasoline from 2026 and an increase in electric vehicles from 25 million to 75 million. Since it takes about 2 gallons of petroleum to produce one gallon of gasoline this would be a decrease of about 60,000 million gallons per year of petroleum or about 3.9 MB/D, with an additional GHG abatement of about 300 million metric tons/year. This 3.9 MB/D reduction in petroleum consumption again assumes that actions are taken to replace the non-gasoline products in petroleum.The number of electric vehicles this corresponds to is around 75 million and could exceed the off-peak charging capability of the electrical grid. However, since there would be many situations where it would be beneficial to recharge electric vehicles during daylight hours, this many electric vehicles might not overly strain the nation's off peak electric capacity. If new HEVs numbered around 20 million vehicles, an increase of 7 million HEVs during this time period, this would lead to a further petroleum reduction of about 0.26 MB/D and a GHG reduction of about 20 million metric tons/year. The total petroleum reduction, would then come to about 4.2 MB/D. At this level of fuel efficient cars, 95 million, it is assumed that the three person carpool reverts back to 1.57 passengers/vehicle. This would cause an increase in petroleum consumption of about 0.43 MB/D and GHG by 59 million metric tons/year. The large increase in fuel efficient individual vehicles may also decrease mass transportation ridership, mainly buses, thereby possibly increasing petroleum usage by an estimated by 0.56 MB/D and a GHG increase by 77 million metric tons/year. If these actions take place, this would limit the overall petroleum reduction in Step Three to a net of 3.2 MB/D from transportation and a net decrease in GHG of 184 million metric tons/year. It is not clear if there could be a reduction in mass transportation, especially in urban areas. This issue is reviewed later in a more comprehensive discussion of population growth.

Steps One and Two had a combined petroleum reduction of about 11.9 MB/D. With an additional reduction of 3.2 MB/D in Step Three, this comes to about 15.1 MB/D leaving a possible shortfall of about 3.6 MB/D of the assumed total consumption of 18.7 MB/d. This, 3.6 MB/D difference, by 2036, is unlikely to be made up by domestic oil production. If the United States' domestic oil supply is nearly exhausted by 2036 and becoming an oil importer again is unacceptable, then supplemental supplies of liquid fuel must be produced. These supplemental supplies might be carbon neutral ethanol from biomass and sea water based methanol and some methanol from converting methane now released from municipal solid waste facilities.

6.3.4.2 Status of Greenhouse Gas Abatement by 2036

The total GHG abatement from Steps 1,2, and 3 came to 2932 million metric tons per year. Further reductions in greenhouse gases may be achieved by reducing non-CO_2 greenhouse gases. However, the GHG goal for year 2036 was an abatement of 4280 million metric tons of CO_{2e} per year. so the first three steps would be insufficient. A further abatement equal to 1348 million metric tons of CO_{2e} per year would be necessary to meet the goals of Section 4.3. Non-CO_2 greenhouse gases in 2007 were released at a rate of 1281 million metric tons of CO_{2e} per year, so even if half of these more difficult gases were somehow eliminated, additional CO_2 abatement would have to be done.

6.3.5 STEP FOUR, 2036-2050

6.3.5.1 Introduction

The analyses presented in Steps One, Two, and Three indicate that significant progress could be made in reducing our use of petroleum by 2036. These three steps also show that significant GHG abatement could take place just from conservation and reducing our use of petroleum. However, even with all this progress, the liquid fuel goal beyond 2036 of total elimination of petroleum is unlikely to be met and would worsen over time due to the diminishing supply of domestic oil. The climate change goals in Section 4 were not met in spite of all the actions taken through 2036 and the gap between performance and goals would worsen over time because of tightening GHG release limits.

Furthermore this analysis did not account for a growing population. Based on U.S. Census Bureau estimates, the population is expected to increase from today's 308 million to 363 million by 2030 and 420 million by 2050. To meet the demands of this growing population somewhat more liquid fuels, domestic ethanol and methanol, and/or more petroleum imports might be necessary. However, the larger impact of a growing population would be the need more electricity and, if this is supplied by a fossil fuel, more greenhouse gases will be released into the atmosphere. The expected growth in population would be also characterized by a shift of the population towards urban areas and away from rural areas. Urban areas rely more on mass transportation and consume fewer gallons of gasoline per passenger mile, especially if the urban transportation becomes increasingly electrified. In 2010 the percentage of the population residing in urban areas in developed countries was about 78%.

This percentage is projected to rise to about 88% by 2050. For the United States the growth in total population between now and 2050, projected to be about 112 million, is actually less than the projected shift towards urban areas, about 130 million people. Such growth could not be absorbed by existing urban areas if the use of individual vehicles keeps up at the present pace without totally jamming the streets. Because of this greater mass transportation in urban areas appears to be inevitable and much of this would be electrified. This implies that more power plants and other sources of electricity will be needed.

Since the actions proposed in Steps One, Two, and Three barely keep up with the petroleum reduction goals and significantly fall short of the GHG abatement goals for 2036, even under the flat demand situation (no population increase), more will have to be done to achieve the goals set out in Section 4.

6.3.5.2 Towards a Sustainable Energy Future

It may be possible to have a much cleaner and sustainable energy future, yet one that is flexible enough to continue to evolve as new technology enters the marketplace. Such a future might be the natural outcome of reducing the remaining GHG in order to meet long term GHG limits and minimizing any remaining use of petroleum.The four major sources of greenhouse gases in 2036 would be:

1. The remaining non-CO_2 greenhouse gases, such as from methane bubbles that percolate up through swamps, lakes, and other locations, and from livestock. If global temperatures continue to rise and presently frozen methane compounds thaw and are released into the atmosphere, then these many steps to curb greenhouse gases would be undone.
2. From burning methanol made from coal and natural gas.
3. From natural gas used to generate electricity, from compressed natural gas used in transportation, and from the hundreds of millions of end use devices run on natural gas.
4. From any remaining petroleum that gets oxidized.

In order to further reduce GHG down to levels that are indicated in the climate change reanalysis described above, the following might be considered:

1. Liquid Fuels: Use ethanol from biomass to replace methanol from fossil fuels provided, this process is agriculturally beneficial. Use high temperature nuclear

power plants to convert sea water into methanol that would replace the methanol derived from coal.

2. Electricity: Replace natural gas electric power plants with evolutionary LWR nuclear plants and with renewable energy sources, where cost effective.
3. Transportation: Increase the amount of transportation that is energized with electricity. This includes high speed trains and placing trucks on more intermodal travel configurations. Electrified transportation should use a low carbon based electrical grid.
4. Nuclear energy: Nuclear energy is central to accomplishing the above three actions. Efforts need to be made to modernize the nuclear fuel cycle to make more efficient use of uranium and thorium while reducing proliferation issues, to reduce nuclear wastes, to encourage designs with passive core cooling systems, and to modernize the regulatory review process. Nuclear capital costs need to be sharply reduced by shifting to standardized factory made pre-assembled structures and systems and by reducing the cost of money by minimizing financial uncertainties through fixed price orders.

Figure 15 is reprinted from the report "The Future of Natural Gas", Interim Report, MIT, 2010 and addresses the long term GHG issue. It concludes that a significant increase in the use of nuclear power would be necessary to replace gas fired electric plants to meet climate change GHG release limits. However, it appears that in this MIT analysis, very low GHG limits would not be achieved until 2100, some 50 years later than the time to reach such low values as in H.R. 2454. This implies that the build-up of carbon free nuclear power should start sooner than that shown in Figure 15 if it is desirable to meet the GHG limits proposed in this report and in H.R.2454.

6.3.5.3 Ethanol and Methanol

This report encourages the development of both ethanol from biomass as long as this produces an agricultural benefit and the development of methanol from the extraction of CO_2 from seawater. Both sources of liquid fuels would be sustainable for centuries and would have a low carbon fuel cycle. Diversity of supply is beneficial. Ethanol from biomass has been a wide subject of discussion, but making methanol from seawater is far less well known. Therefore some of the benefits of methanol from seawater are given here.

Methanol from seawater avoids land use and water use issues. There would not be any need for cooling towers.There wouldn't even be a hint of a food/fuel conflict. There are no concerns about fertilizer run-off or possible release of GHG from carbon sequestered in soil (The Indirect Land Use Change issue) that had been dug up to make more area for biomass farms. This sustainable source of a carbon neutral liquid fuel is not restricted to specific areas where farming is feasible, but could be distributed worldwide, wherever there is an ocean. Therefore there is an "endless" number of potential sites, but most likely these facilities would be located near coastal cities, far enough off shore to be out of sight. There would be no need for refineries or connections to electrical grids and very few waste products would be generated. Even if there were a methanol spill, it would be quickly dispersed. Methanol produced at such facilities could be stored in partially submerged barges that could be disconnected from the power plant and towed to onshore methanol storage facilities where they would be emptied before returning to the offshore methanol facility.

The nuclear power plant that would energize a seawater methanol facility would use the seawater as its ultimate heat sink. Being offshore, no member of the public need be evacuated in the event of an accident, nor would there be any significant land contamination if there were a release of radioactive cesium. It may be advantageous to somewhat submerge the reactor system underwater, using technology already established for nuclear submarines. Advanced nuclear designs that do not rely on active cooling systems could be employed to reduce maintenance tasks. Those advanced passive nuclear designs that only need refueling every eight to ten years, might permit controls to be located onshore, thereby minimizing the size of the operating crew.

The development of a "methanol economy" within the larger context of a post-petroleum future could start with producing methanol from coal plants, supplementing this with direct production of methanol from natural gas, and ending up with carbon neutral offshore derived methanol. So by the time that seawater based methanol would begin to be produced in large quantities, a major methanol industry would already be in place.

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