RBR CONSULTANTS, INC.

Analysis of the National Academy of Sciences' Report "America's Energy Future" and Proposed Congressional Energy Legislation

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DRAFT FOR COMMENT

February, 2010,

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1.0 Executive Summary

Various studies, such as the those by the Department of Energy's Energy Information Administration, the EPA analysis of the House of Representatives energy bill H.R. 2454 (See Figure 2), and the recent report by the National Academy of Science's "America's Energy Future" (AEF) all project very high levels of U.S. petroleum use for several more decades. However, such high levels of petroleum consumption would prevent the greenhouse gas (GHG) limits in present Congressional legislation from being achieved (See Figure 4). Further, the majority of the projected petroleum consumption comes from imported oil and presents a severe national security threat. Neither H.R. 2454, nor its Senate counterpart S.1733, call for reductions in imported petroleum according to a specific timetable. Yet both of these energy bills are quite specific when dealing with the issue of climate change: both energy bills proposed a timetable by which specific GHG reductions must be achieved. Both of these energy bills claim to address the issue of energy independence and national security, yet no specific actions to accomplish this are incorporated into the text of these energy bills. This analysis shows that: **Continuing our high levels of petroleum use, particularly imported petroleum, would defeat the climate change intentions of both Congressional energy bills while increasing threats to our national economy and security. However, by placing first emphasis on energy independence, national economy and security goals could be achieved as well as climate change goals. The nation needs to restructure its energy priorities.**

It appears that we have been so focussed on climate change we have underestimated the importance of phasing out imported petroleum. Climate change, the national economy, and national security must be addressed, but not one at the expense of another. Petroleum today produces more greenhouse gases than coal does (See Figure 1) and has all kinds of national security and economic issues that domestic coal does not have. Coal plants that emit GHG will have to be phased out over time. However, even if all greenhouse gases were eliminated from burning coal by shutting down all coal fired electric plants or by developing a technology that captures and stores all of coal's greenhouse gases, that would not be enough to prevent eventually exceeding proposed Congressional GHG limits. If, besides coal, all uses of natural gas including gas fired electric power plants, which together with coal produce about 70% of today's electricity, were also shut down, in time this too would not be enough. Even if we went further and reduced by 20% to 25% the GHG releases from methane, nitrous oxide and other non-CO_2 greenhouse gases, greatly improved the efficiency of our light and heavy duty vehicle fleets, and reduced releases from burning non-transportation uses of petroleum, it still would not be enough. In spite of these draconian steps, the GHG limits in H.R. 2454 would still be exceeded by around **2030**. If a somewhat less drastic approach were used where 20% of today's GHG releases from coal and natural gas were allowed to occur, the limits in H.R.2454 would be exceeded sooner, by about **2025**. These insights also show that the debate over which legal mechanism should be used to reduce GHG emissions, a carbon tax or a cap and trade approach, is of limited importance. If the GHG limits of H.R. 2454 are eventually exceeded, in spite of zero GHG emissions from both coal and natural gas, then the choice of which legal mechanism gets us to this end point is less significant than arriving at an unacceptable end point.

As described in the AEF report and elsewhere, high levels of petroleum importation are a result of a transportation system that today is almost totally dominated by the use of petroleum. According to the AEF, significant improvements in the efficiency of light duty vehicles will not be enough to materially reduce gasoline consumption below present levels for several decades. This is a profound conclusion and unless a different transportation future is put in place in a timely manner the consequences would be catastrophic. Fortunately there are answers. Significantly lowering petroleum consumption in the transportation sector requires much greater use of electrically driven transportation, particularly electrically driven <u>mass</u> transportation. This in turn would require major increases in our capacity to produce electricity, even after all practical steps are taken to reduce the consumption of electricity. Today only about one percent of our passenger miles is accomplished electrically. If our future transportation had but half of its passenger miles accomplished electrically, that would require a 50 fold increase in this form of travel compared to today; a huge undertaking. Where might all of this future electricity for transportation come from? The AEF report does not quantify how much electricity would be needed to power a much greater electrically driven transportation future.

The concept of a race against time to avoid severe environmental damage from climate change, global warfare, or both appears to be largely absent in the AEF report. Instead the AEF report places various sources of electricity in a somewhat competitive structure by attempting to compare costs. Not only are there specific issues about this cost comparison, it seems to miss a much larger point. The AEF report has not shown how to integrate all practical sources of electricity rapidly enough to avoid severe environmental damage and a great toll on humanity.

This review concludes that we will need all forms of environmentally acceptable and practical sources of electricity, but that much of the additional electricity would have to be supplied by nuclear power. This greatly expanded role for nuclear power is consistent with the rapid construction of nuclear plants in many world locations, but differs from AEF recommendations which suggest a very modest expansion of nuclear power at this time. This large increase in electrical capacity would have to be matched with electrically actuated, oil-displacing end uses, especially in the transportation sector. Much greater use of electrified transportation already exists in Europe, Japan and elsewhere. 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 high speed train in 2014 which would only travel the 84 mile route between Tampa and Orlando, Florida.

Even with more electrification, we would still have to provide large quantities of liquid fuel as alternatives to gasoline and diesel fuel. Some of this could come from converting biomass to biofuel, subject to food/fuel limits, water constraints, soil erosion concerns, and high conversion costs (See Appendix B). However, the bulk of the liquid fuels likely would have to come from a coal-to-liquid (CTL) process, using some non-carbon heat source to supply process heat or hydrogen. If, instead of using coal both as a heat source and a feedstock a carbon-free heat source were used, far less GHG would be released. High temperature nuclear power plants could be developed that would be able to provide the process heat and/or hydrogen used in the CTL process.

All the above means that an unusual opportunity for bipartisan cooperation on energy is possible, but barely recognized. Everyone gets something out of cooperation. Those dedicated to climate change issues need carbon free nuclear power to supply lots of electricity to run much of the future transportation system. People in the coal industry need to concentrate on building a new CTL industry, using process heat or hydrogen from nuclear plants, and possibly biomass, to keep GHG releases to low values and to stretch out the remaining lifetime of our coal reserves. Such a nuclear/biomass/coal combination means that coal would have a critical place in our future energy mix, even if carbon capture and storage (CCS) technology fails to be attractive. With a secure CTL future, coal advocates might be less inclined to oppose what we have learned from climate change science.

Those in the renewable energy camp would benefit from energy storage systems that are essential if renewable energy is to be more than a niche contributor. Energy storage is essential for wind power if it is to overcome issues of its intermittence and variability and the possibility that this variability could initiate electric grid instabilities or grid collapse. Major energy storage facilities need to be built by utilities to benefit their present operations. With energy storage, up to twice as much energy could be extracted from our present electrical power system. Many of these energy storage systems could be used to replace oil used in space and water heating while others could be used in systems that could displace oil in the transportation sector. Grid supplied electricity stored in the batteries in plug-in hybrid cars is an example of an electrically actuated, oil-displacing end use device. There are other examples of electrically actuated, oil-displacing end use devices that are already in use. Many of these energy storage facilities would be funded by centralized electric utilities. However, these energy storage facilities could be shared with renewable energy sources like wind power, reducing wind power costs while increasing wind power’s reliability and market share. Renewable energy already has gained by working with the coal and nuclear energy industries. The transmission system that renewable energy depends upon today was built by these industries and the backup electricity needed to overcome variability in renewable energy systems comes from these same industries and from hydropower.

The transition to a post-petroleum future will take many trillions of dollars and several decades. As one example, the National Renewable Energy Laboratory estimates that to supply 20% of our 2024 electricity with wind power would cost $1.1 trillion dollars and this does not include the cost of 15,000 miles of new extra-high voltage lines or the costs of energy storage systems to prevent potential grid instabilities. Nuclear power plants are very expensive to build and constructing a large CTL industry is not cheap.

Where will all this money come from? It has been estimated (1) that by investing $520 billion dollars between now and 2020, about $1.2 trillion dollars could be saved in non-transportation energy costs, for a net gain of about $700 billion dollars. Much of this money would be saved by simple conservation efforts, like better house insulation and more efficient light bulbs and appliances. These conservation steps would reduce GHG emissions and some amount of petroleum use.

Reducing the release of GHG and their associated pollutants should improve air quality in urban areas which would then reduce health costs. One estimate (2) of energy's health costs places monetized damages at $120 billion for 2005, of which $56 billion in health damages/year are calculated to be caused by transportation.

As our transportation system became less dependent on petroleum we should realize important savings from a reduced military force which no longer would be needed to protect petroleum delivery routes and oil producing countries. Over $500 billion dollars is now spent on defense programs, much of which is related to protecting oil supplies.

In theory we could about double the electrical energy delivered by our present electrical system.This large increase in electrical output, without increasing the number of power plants or increasing the electrical grid, would be accomplished by particular end use energy storage devices, which themselves would be used to displace oil in space heating, hot water heating, and in transportation, often with a net reduction in GHG emissions.

However, the truly large money-saver would be in reducing our national oil bill. Alan S.Blinder, former vice chairman of the Federal Reserve, estimated (3) that the large drop in oil prices from its recent peak of near $145/barrel saved Americans about $300 billion dollars in just one year. Blinder cautiously assumed a drop in oil price of about $60/barrel, from $100/barrel to $40/barrel. If similar savings could be repeated each year it would be like an annual stimulus bill that did not add to the national debt. As shown later, if the United States actually consumed the amount of petroleum projected in the AEF report through 2035, it could cost about $11 trillion (2008) dollars, about the size of our present national debt. Fewer dollars shipped overseas to pay for our huge oil bill would go a long way in funding wind turbines, nuclear plants, biomass, high speed trains, plug-in hybrids, home insulation, and much more. However, the opposite situation is also true. Our oil bill could become so massive that we will not have the means to extricate ourselves from a downward economic spiral.

To achieve a much smaller oil we must rethink how we will accomplish transportation. Unless we learn to move about without importing petroleum, no acceptable energy future is possible. The sooner we can reduce petroleum consumption in transportation and elsewhere, the more money we would save and the less GHG we will release.

Two things must end: our over dependence on imported petroleum and partisan bickering over a national energy plan. As a first step, our political leaders should work together to expand the proposed energy legislation to include a timetable for reducing petroleum imports and to place a higher carbon tax per ton of GHG released on imported oil than from domestic coal.

2.0 Introduction

The highly regarded National Academy of Sciences (NAS) has assembled a large group of energy and economic experts with the enormous task of estimating what the energy future of the United States might look like.Their efforts are integrated into an important, recently published, NAS report titled "America's Energy Future" (AEF). The AEF report is a significant improvement over another well known recent energy study that claimed that in just ten years the United States could completely function on renewable energy. To its credit AEF makes it clear that it will take decades and trillions of dollars to establish an acceptable energy future in the United States. Further, the AEF report utilizes conservation and a number of energy sources, some renewable and others not, to estimate what the United States' energy future might look like.

The AEF report represents a major step forward in developing a national energy plan. Yet major questions remain about the implications of the AEF report. Among these questions are:

1. How does the projected AEF releases of greenhouse gases (GHG) compare to the limits proposed by legislation now moving through Congress?
2. What are the national security implications of the AEF report?
3. While focusing on cost differences between different sources of electricity, has the AEF report ignored the very high costs of insufficient electricity?
4. Has the need for nuclear power been underestimated in the AEF report?

The present issue of the AEF report might be considered as a first phase in addressing a major technological issue of our time. It is suggested that the above fundamental questions be addressed in a revised edition of the AEF report which utilizes specific goals and timetables for actions to limit both climate change and the importation of petroleum.

In parallel with this NAS effort there has been energy legislation slowly moving through Congress. Such proposed legislation includes H.R. 2454 (The Waxman-Markey bill) and its Senate counterpart, S.1733 (The Kerry-Boxer bill). Both the Senate and House energy bills present specific timetables by which U.S. levels of released greenhouse gases must be reduced to. However, neither energy bill provides comparable timetables to limit petroleum import levels.

This critique discusses the above four questions and key aspects of current Congressional energy legislation. Suggestions are offered, where appropriate.

3.0 Conclusions Drawn From a Review of the AEF Report

1. If the AEF energy path is followed, the United States could experience an increasing dependence on imported petroleum. Additionally, **starting around 2030 or sooner**, the United States may not be able to meet the climate change goals set forth in H.R. 2454 and S.1733. Failure to meet these climate change goals might lead to worldwide environmental damage.
2. The inability to meet proposed Congressional climate change legislation by about **2030** might occur even if greenhouse gases (GHG) from <u>all coal and natural gas sources</u> (100%) were eliminated, even if significant actions were taken to make light duty vehicles (vehicles weighing less than 10,000 pounds) and heavy duty vehicles far more energy efficient, even if appreciable reductions were made in the release of GHG from the non-transportation uses of petroleum and also reductions from other greenhouse gases such as methane, nitrous oxide, and others. If coal and gas, which together produce about 70% of today's electricity, were not completely phased out or if significant reductions in non-transportation uses of petroleum or other non-CO_2 greenhouse gases were not achieved, then the inability to meet proposed Congressional climate change legislation would occur sooner than **2030**. For example, with an 80% reduction in the GHG released from burning coal and natural gas relative to today's release level, Congressional climate change legislation would be exceeded by about **2025**. The AEF projected GHG releases are well below the 2008/2009 Energy Information Administration's (EIA) reference case. However, this improvement over the EIA reference case is not good enough. In 15 to 20 years decreases in GHG releases would not be happening fast enough to meet the shrinking limits proposed in Congressional legislation. **The most important reason for this inability to meet Congressional climate goals would be the continuing high use of petroleum in our transportation sector.**
3. The types of results that are observed for the AEF report are also true for an EPA analysis of H.R. 2454. The EPA examined six different scenarios in its analysis of H.R. 2454. All six EPA scenarios exhibited continuing high levels of petroleum use, all of which would result in GHG releases that would exceed the limits proposed in the very law that it was analyzing (See Figure 3). Both the AEF report and the EPA analysis have their roots in the 2008, 2009 EIA reference cases.

These EIA reference cases would also fail to meet the proposed Congressional energy legislation GHG limits.

4. In addition to possibility crossing a climate change tipping point where human corrective actions would no longer be sufficient to prevent huge climate change effects, the possibility also exists that another tipping point might be crossed. This is an economic tipping point where the U.S. economy would not be able to acquire sufficient petroleum to meet all of its transportation needs, even with improved vehicle fuel economy. The U.S. economy without adequate transportation would then likely be near collapse and armed conflict to secure sufficient petroleum cannot be ruled out.
5. To prevent these multiple catastrophes there must be far more electrified mass transportation. Today about one percent of the U.S. passenger miles are accomplished electrically. If, in the future, just half of our passenger miles were accomplished electrically, this would require about a 50 fold increase over what exists today. Such a huge transformation to electrified mass transportation would require large investments in environmentally acceptable sources of electricity, starting now and using proven technology. The AEF report recognizes the importance of electrified transportation in both reducing petroleum imports and in abating the release of GHG and states (4) that "Rail is about 10 times more energy-efficient than trucking, so shifting freight from trucks to rail can offer considerable energy savings". In addition to transporting freight, large energy savings also apply to greater use of electrically driven mass transportation for passenger travel. Not only is there far less energy needed per passenger mile, this energy would come from electricity, not petroleum. There is a secondary benefit in shifting to mass transportation. With fewer cars on the road there is less congestion. This saves time, lowers oil use, less air pollution and smaller GHG emissions. Electrically driven mass transportation is proven technology which is undergoing further energy saving improvements in other countries through the use of regenerative braking, similar to the regenerative braking used in hybrid cars. Even though AEF recognized the important energy savings from greater electrified mass transportation it did not identify this as a priority action, as other countries have.
6. Once it is clear that avoiding unacceptable levels of GHG releases and minimizing national security threats requires significant growth in electrified transportation, the central issue becomes "Where might the electricity come from?" The AEF recommends, perhaps five, evolutionary nuclear power plants be built over the next decade and then their costs and construction times would be used to

decide nuclear power's future role. However, the AEF's approach to establishing the future role of nuclear power, would not be determined by some <u>future</u> cost analysis after these nuclear plants would be up and running, but nuclear power's future would be determined <u>today</u> if such a modest AEF approach were used. There appears to be several inconsistencies and omissions in the AEF cost comparisons that invalidates it as a basis for determining the future of nuclear power, as elaborated in Appendix A. Even more important, there is no need to wait for nuclear power plant costs or construction time data for evolutionary plants. They are being built all around the world. South Korea recently secured a $20 billion dollar contract to build four nuclear power plants in the tiny United Arab Emirates (UAE). This UAE effort is about the same size of the whole AEF nuclear decision-making recommendation and it is proceeding now. Russia and Turkey have reached an agreement to cooperate on building nuclear power plants in Turkey. Russia has also signed a memorandum of understanding with Argentina to possibly build Russian nuclear plants there. China plans a huge expansion of nuclear power by adding 10 new plants annually, reaching as much as 400 gigawatts by 2050. It has 11 operating nuclear plants, 20 more under construction, and 37 more in the advanced planning/licensing stage. South Korea aims to export 80 nuclear reactors by 2030 according to South Korean government officials. South Korea has 20 nuclear plants in operation, six under construction and six in the licensing phase. They plan to build these nuclear plants rapidly, around 40 months from the first safety-related concrete pour to fuel load. India intends to boost its nuclear energy capacity by 12,000 percent by 2050. Prime Minister Singh recently predicted that India could produce 470 gigawatts of nuclear electricity. Today India has 18 plants operating, five under construction, and 23 more in the licensing phase. Other examples exist in Europe, North America, and in South America. All this nuclear activity is happening around the world today, often using technology that originated in the United States. The United States today produces about 101 gigawatts of nuclear energy and no new nuclear plants have been constructed in over 30 years. If the NAS wants to have a range of nuclear construction costs <u>now</u>, it can refer to actual data from plants now under construction, even including the expensive plant under construction in Finland. Where costs are very high an analysis could be made to determine why this has happened and how such high costs might be avoided in the United States. Unlike the modest role for nuclear power recommended in AEF, many more evolutionary nuclear power plants would need to be built on an accelerated basis to meet the growing demand for electrified transportation, even after all practical efforts are made to use electricity more efficiently.

7. Advanced (also called alternative) nuclear power plants that are expected to be more resistant to proliferation, use nuclear fuel more sparingly, consume far less water in several designs, and produce far less nuclear waste, need to be built and tested. These advanced nuclear power demonstration plants can be used to make high temperature carbon-free process heat and/or hydrogen, both of which would be very valuable in converting coal to a liquid fuel (CTL), while eliminating greenhouse gas production in the conversion process. High temperature process heat and/or hydrogen would be very valuable in many other industrial processes. Unlike large solar facilities scheduled for operation in high solar insolation areas like southern California, high temperature nuclear power plants could be built in many locations throughout the country. They might be placed close to load centers or they might be co-located near coal mines. If they used the surrounding air as their heat sink they need not be located near a body of water because they would not be consuming water. The AEF report did not stress the need to develop these advanced nuclear plants on an accelerated basis. Suggestion: Instead of AEF's recommendation that 4-5 evolutionary plants to be constructed during this decade, 4-5 demonstration plants of advanced design should be started now.
8. A critical issue in our transportation future is the availability and the environmental impacts of producing and using liquid fuels. The AEF report supports a CTL process using coal as both the heat source and the feedstock material, provided that the carbon capture and storage (CCS) can be successfully developed. CCS could be used to capture the GHG released when using coal as the heat source in a CTL process. However, the AEF report (5) states that "There is uncertainty associated with the technical potential for carbon capture and storage." Even if CCS actually worked and was not too great an economic penalty, it would mean that far more coal would have to be mined to support coal's multiple roles as both a heat source and as a feedstock in the CTL process plus being used in advanced coal electric plants with CCS. The AEF report did not address how adequate liquid fuels might be obtained in the future if CCS technology proves to be unworkable.At the very least, developing advanced nuclear power plants for generating high temperature steam and/or hydrogen seems like a good hedge against possible inadequacies in developing CCS, the environmental impacts of increased coal mining, and possible shortages if coal reserves are more limited than assumed in the AEF report.

9. Theoretically, up to twice as much electrical energy could be extracted from our existing electrical energy structure. This can be accomplished comparatively quickly through the extensive use of energy storage and without the need to add to our electrical generation capacity or require extensive improvements in our transmission and distribution systems. Although the AEF report supports energy storage it does not appear to recognize its full value. Energy storage is essential for significant development of renewable energy, but is also extremely valuable for other energy sources and for advanced forms of conservation. Energy storage can be used to reduce GHG emissions. Using energy storage to make much greater utilization of our existing electrical structure would compliment other conservation actions such as more efficient light bulbs, better insulation, etc. Together, these two conservation efforts would buy time to expand the nation's overall electrical capacity to meet the growing demands from a transportation future that uses far more electricity.
10. Energy storage is but one example of how the technology developed for one energy source or conservation can benefit other sources of energy. The AEF report seems to segregate the many different energy sources and conservation into a somewhat competitive structure, rather than examining how they might be used to help one another. Since we are in a race against time to prevent environmental disaster, we need to focus on determining which practical mix of energy sources, distribution networks, end use devices, and conservation can be put into place that would reduce our oil usage most rapidly. This integrated approach to our nation's energy future seems to be absent from the AEF report.

4.0 Conclusions Drawn From a Review of Congressional Energy Legislation

1. Present proposed Congressional energy legislation is inadequate and out of balance. H.R.2454 claims to "Increase our national security by reducing our dependence on foreign oil" and S.1733 bill claims to "promote energy independence". Unlike the specific goals and timetables for GHG reductions contained in these energy bills, neither energy bill sets any goals or timetables for the reduction of imported petroleum. It has not been demonstrated by the EIA 2008/2009 reference cases, nor by the EPA analysis of H.R.2454, nor by the AEF report that either of these energy bills can meet their stated, but unquantified, national security objectives. In fact, all of these analyses describe a continuing high petroleum import dependence for the next 25 years or more.

2. Suggestion: These energy bills should incorporate the a national security goal such as: **By 2030 there should be zero imported petroleum or natural gas from countries beyond North, South, and Central America and the Caribbean.**
3. As described in Section 5 below, the GHG limits in these energy bills are likely to be exceeded by 2030 or sooner if any of the energy futures in the EIA, EPA, and the NAS analyses is pursued. The common problem of all these analyses is in their treatment of oil. More GHG are released per year in the United States from burning petroleum than from burning coal. Further, releasing a gigaton of CO_2 from burning coal or a gigaton of CO_2 from burning petroleum would have the same environmental effect. However, domestically produced coal does not have the national security baggage that imported petroleum has.
4. Suggestion: A premium should be put on burning imported petroleum, such as a higher carbon tax per gigaton of CO_2 than on domestic coal. Such a premium would affect in a positive way the energy strategies the nation develops to reduce GHG releases. **H.R. 2454 and S. 1733 need to have a two tier carbon tax or cap and trade structure, with a higher cost per gigaton of CO_2 released placed on imported petroleum.**

5.0 Where the AEF Report and Congressional Legislation Intersect

5.1 Introduction

An environmental analysis of the AEF report was made by comparing its projected greenhouse gas releases to the limits set in H.R.2454 (S.1733 has similar GHG limits).

5.2 Comparison of AEF Report to H.R. 2454

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 10 million barrels of gasoline per day were consumed in the United States. This amount is just for light duty vehicles (LDVs). Heavy duty vehicles (HDVs) consumed about another 4 million barrels per day of gasoline equivalent in 2007, or 28.6% of the total 14 million barrels/day of gasoline equivalent consumed in transportation sector. The AEF report projects the consumption of gasoline in LDVs will increase to 13 million barrels/day by 2020 and 16 million barrels/day by 2035. 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. Table 1 displays the releases of greenhouse gases in the United States from petroleum and from non-CO_2 greenhouse gases for the years 2007, 2020, and 2035. Table 1 was constructed assuming that efficiency improvements in HDVs were comparable to those projected for LDVs. Using these AEF figures, the 2020 petroleum consumption in transportation would be 11.6/10 times larger than the petroleum use in 2007and 10.4/10 times larger by 2035.

In 2007 some 2,035 million metric tons of CO_{2e} were released from our transportation sector. (See Figure 1). These transportation releases of GHG can be separated into those from light duty vehicles (LDVs) and heavy duty vehicles (HDVs). The LDV portion of these 2,035 million metric tons is 71.4% or 1455 million metric tons. The HDV 2007 GHG releases are 28.6% of the 2035 million metric tons released in the transportation sector, or 580 million metric tons.

Using the AEF year 2020 projected increase of 1.16 in gasoline consumption relative to 2007, LDVs would release 1,686 million metric tons and HDVs 675 million metric tons. In 2035, with a 1.04 projected increase relative to 2007, LDVs would release 1,511 million metric tons and HDVs 605 million metric tons.

It was further assumed that conservation 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 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 of methane, nitrous oxide, and other greenhouse gases (6). Table 1 also compares these AEF based GHG release rates to the limits set by H.R.2454. It is noted 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 greenhouse gases such as methane, nitrous oxide, and others, H.R. 2454 limits would be exceeded around **2030**. (See Figure 4).

Today coal produces nearly half of our electricity. Natural gas produces close to 20% of the electricity and also provides space heating and is used in various industrial processes. Instead of assuming that all coal and natural gas were eliminated, as analyzed above, it was assumed that an 80% reduction in coal and natural gas took place. This would add more GHG to the atmosphere and shorten the time when the limits set by the above energy bills would be exceeded. Even with an 80% reduction in the GHG released from burning coal and natural gas relative to today's release level, Congressional climate change legislation would be exceeded by about year **2025**. (See Figure 4).

Figure 4 does not include the effects of biofuels which may reduce the need to burn petroleum without significantly adding to the release of GHG. However the contribution of biofuels in this time frame are calculated to be rather small and might only extend the time to exceed H.R.2454 limits by about one year or less. See Appendix B.

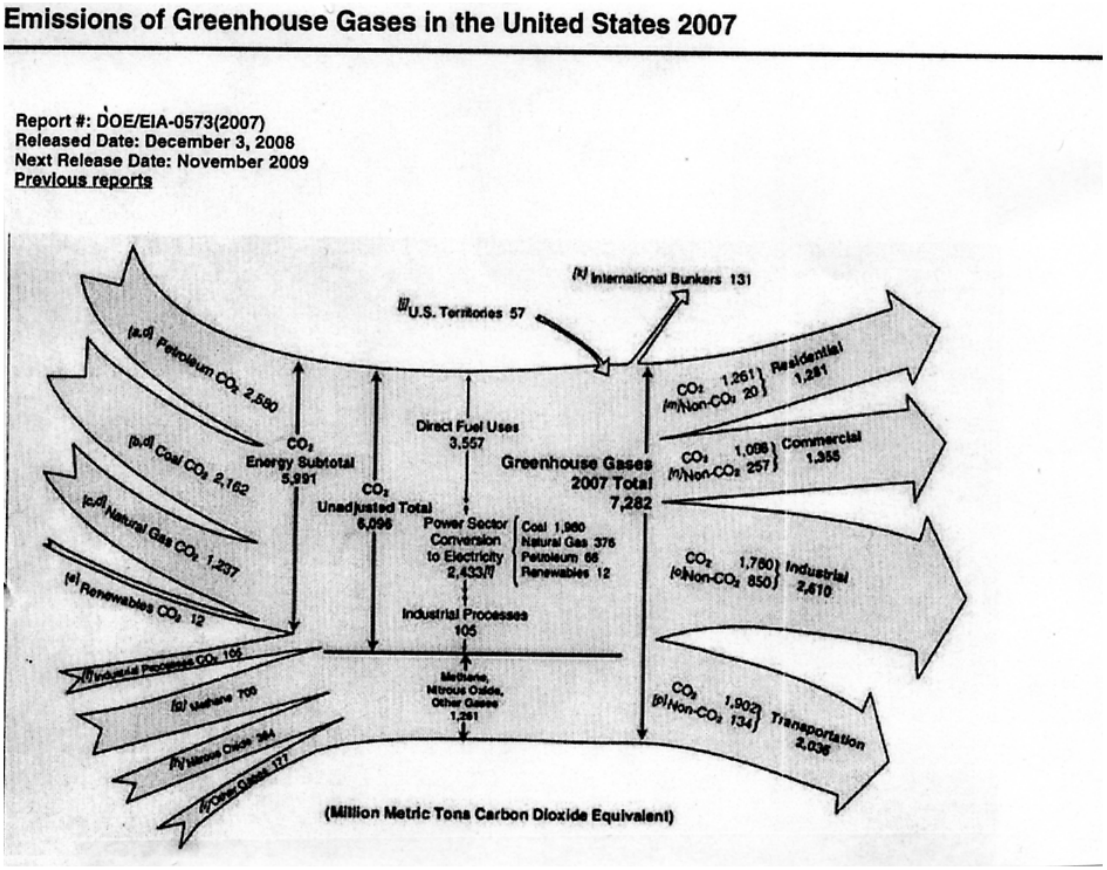
5.3 Conclusion

If the actual consumption of petroleum in the United States matched those projected in the AEF report, it would defeat the intent of current Congressional legislation.

Table 1: Millions of Tonnes/year of CO_{2e} Released From Petroleum and non-CO_2 Gases

1. No coal or natural gas	2007	2020	2035
Petroleum for LDVs.(2020 and 2035 amounts derived from AEF numbers).	1455	1686	1511
Petroleum for HDVs.(2020 and 2035 amounts derived from AEF numbers).	580	675	605
Petroleum for non-transportation uses (Based on EIA 2007 petroleum data, with 20% and 25% reductions by 2020 and 2035, respectively)	545	436	409
Non-CO_2 greenhouse gases (Based on EIA 2007 data and assumed 20% and 25% reductions, by 2020 and 2035, respectively).	1261	1009	946
Total **CO_{2e} just from petroleum and non-CO_2 gases.**	3841	3806	3471
H.R. 2454 **CO_{2e} limit**	N/A	5000	3000
Percent of H.R. 2454 limit	N/A	0.76	1.16
2.Addition in 2020 and 2035 of 20% of 2007's coal and natural gas GHG releases.	N/A	680	680
Total **CO_{2e} just from petroleum and non-CO_2 gases + 20%** of 2007's coal and natural gas.	N/A	4486	4151
Percent of H.R. 2454 limit	N/A	0.90	1.38

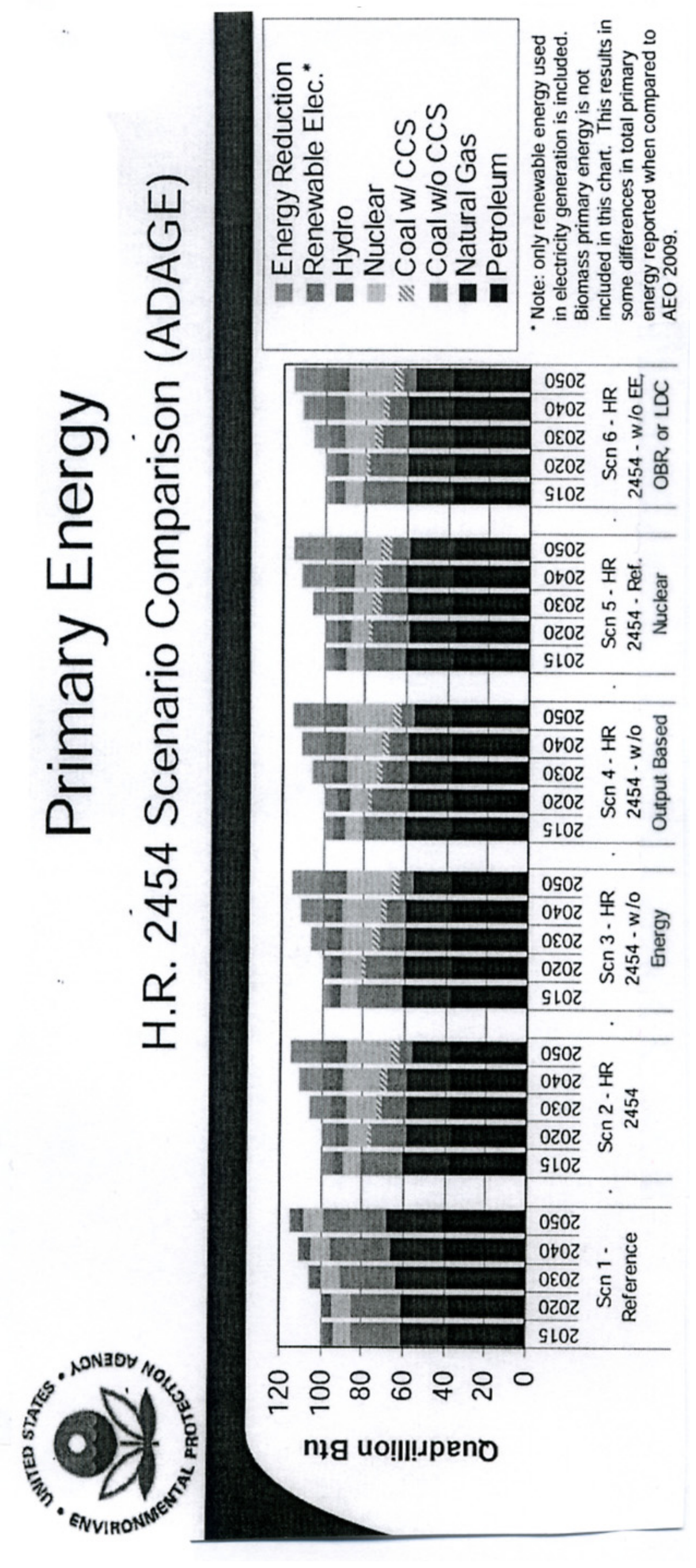
Figure 1: Sources of GHG, 2007



Emissions of Greenhouse Gases in the United States 2007

Report #: DOE/EIA-0573(2007)
Released Date: December 3, 2008
Next Release Date: November 2009
Previous reports

Figure 2: EPA Analysis of H.R. 2454



Primary Energy

H.R. 2454 Scenario Comparison (ADAGE)

* Note: only renewable energy used in electricity generation is included. Biomass primary energy is not included in this chart. This results in some differences in total primary energy reported when compared to AEO 2009.

Figure 3: EPA Plot of $C0_{2e}$ Release limits in H.R.2454

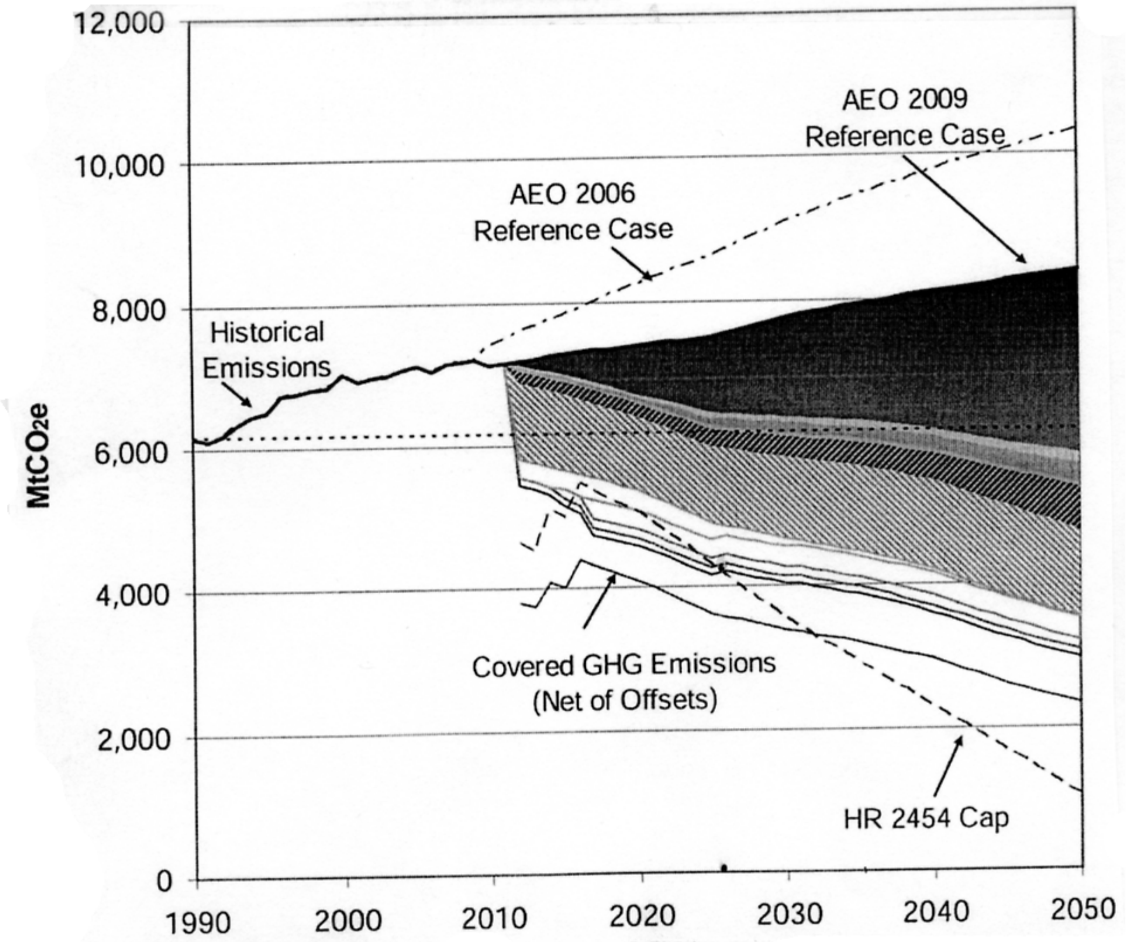
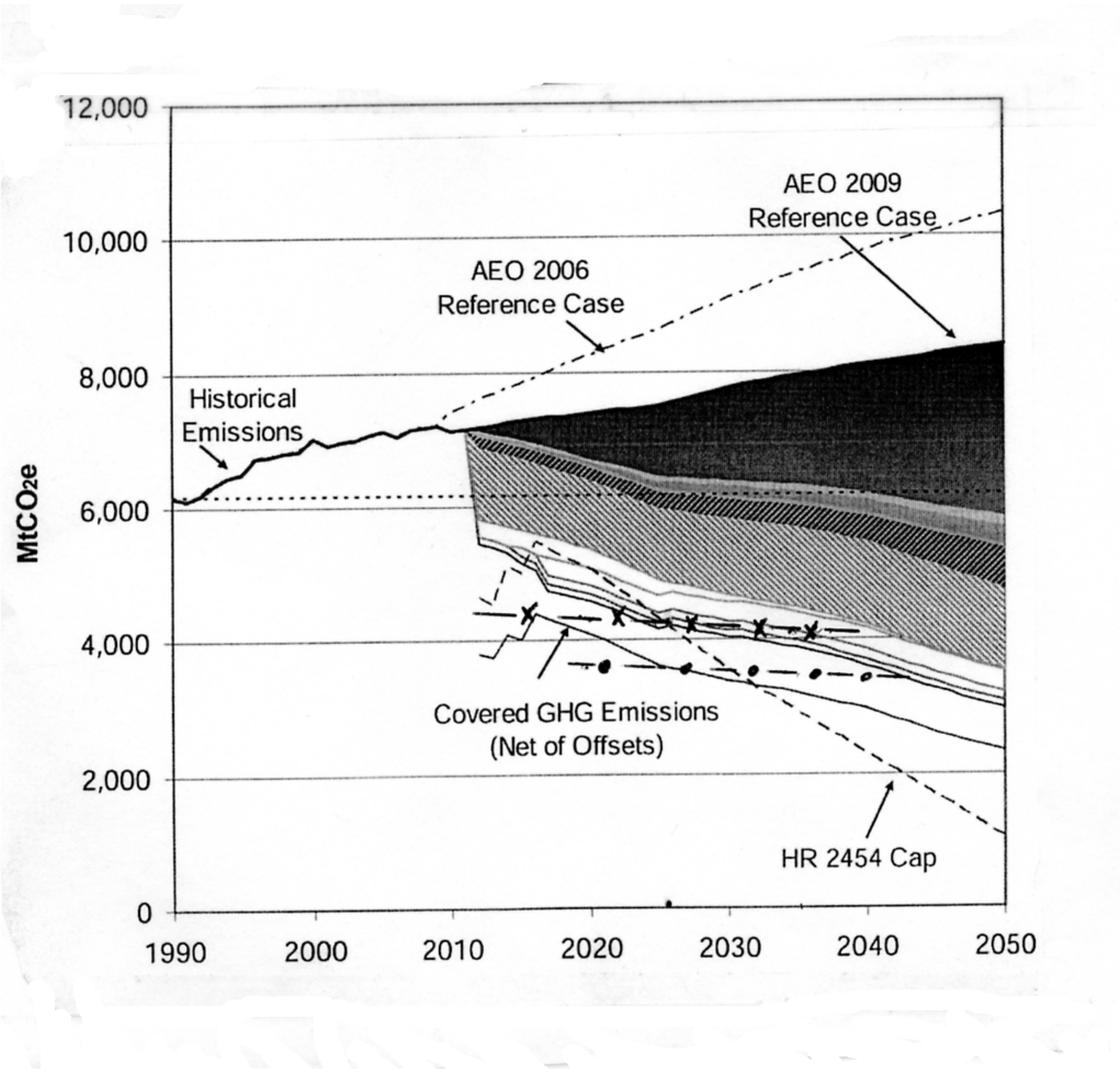


Figure 4: Intersection of H.R. 2454 CO_{2e} Limits with AEF Petroleum Releases



LEGEND

Table 1, No Coal or Gas	—— ● ——
Table 1, 20% Coal and Gas	—— x ——

6.0 National Security Implications of the AEF Report

6.1 World Petroleum Reserves and Consumption

Today, with 4.5% of the world's population, the United States consumes about a quarter of the world's oil. Table 2 lists the top 20 oil consumers in 2007. United States is the "Saudi Arabia" of oil consumption. The top 20 oil consuming nations in Table 2 can be compared the 2007 oil and gas reserves of the top 21 companies in the world, as shown in Table 3. Note that the top ten companies in Table 3, printed in bold, are all members of OPEC.

Table 2: 2007 Oil Consumption by Country

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
8	Canada	2,371,000
9	Saudi Arabia	2,311,000
10	South Korea	2,214,000
11	Mexico	2,119,000
12	France	1,960,000
13	United Kingdom	1,763,000
14	Italy	1,702,000
15	Iran	1,679,000
16	Spain	1,611,000
17	Indonesia	1,219,000
18	Netherlands	984,200
19	Australia	966,200
20	Taiwan	950,000

Table 3: Reserves of Leading Oil and Gas Companies Around the World

Rank by 2007 Oil Equivalent Reserves	Company	Worldwide Liquids Reserves, Millions of Barrels	Worldwide 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
6	**Abu Dhabi National Oil Company (UAE)**	92,200	198,500	126,132
7	**Kuwait Petroleum Corporation (Kuwait)**	101,500	55,515	110,990
8	**Nigerian National Petroleum Corporation (Nigeria)**	36,220	183,990	67,671
9	**National Oil Company (Libya)**	41,464	50,100	50,028
10	**Sonatrach (Algeria)**	12,200	159,000	39, 379
11	Gazprom (Russia)	0	171,176	29, 261
12	OAO Rosneft (Russia)	17,513	25,108	21,805
13	PetroChina Co. Ltd. (China)	11,706	57,111	21,469
14	Petronas (Malaysia)	5,360	82,992	19, 547
15	OAO Lukoil (Russia)	15,715	28	15,720
16	Egyptian General Petroleum Corp. (Egypt)	3,700	58,500	13,700
17	ExxonMobil Corporation (United States)	7,744	32,610	13,318
18	Petroleos Mexicanos (Mexico)	11,048	12, 578	13, 198
19	BP Corporation (United Kingdom)	5,492	41,130	12,523
20	Petroleo Brasilerio (Brazil)	9,613	12,547	11,578
21	Chevron Corporation (United States)	7,087	22,140	10,870

The contrast between Tables 2 and 3 is stark. The United States is, by far, the world's largest consumer of oil, but its two native oil companies, ExxonMobil and Chevron, ranked seventeenth and twenty first, respectively, in world reserves of oil and gas equivalent. This huge imbalance between United States consumption and its own oil equivalent reserves is a grave national security issue. Over 50% of our 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 (7) 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." According to the January 10, 2010 issue of the NY Times, China has surged past the United States to become the world's largest automobile market. This alone would seem to guarantee a continuing high demand for oil and rising oil prices.

There appears to be a number of recent statements (8) 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."

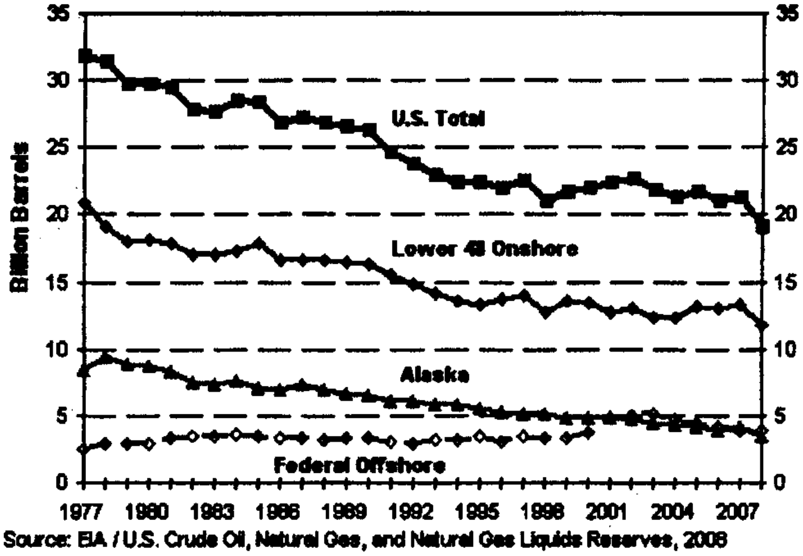
Outside of OPEC, oil production did not rise between 2004 and 2008, even though prices for oil increased considerably. This indicates that in non-OPEC countries conventional oil production had peaked, or at least reached a plateau, and these countries could not take advantage of higher prices by producing more oil. This observation has geopolitical implications for the United States because it implies 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.

There is essentially no discussion in the AEF report about the IEA prediction of an oil production plateau around 2030 (and now perhaps in 2020) or China's and other countries' rapid increases in oil demand. Further, we must recognize that we are a debtor nation and we will not be able to outbid China with its deep pockets in an open market for oil. Nor could we or should we challenge China's growing military strength with its military bases built along its oil supply routes. The AEF report, like the EIA and EPA reports, with projections of high consumption of oil out to 2035 and beyond, seems to be in conflict with the analyses made by the International Energy Agency and the statements of corporate leaders of major oil companies.

6.2 Domestic Oil Reserves and Oil Import Dependence

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 5.

Figure 5: U.S.Crude Oil Proved Reserves, 1977-2008



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

As stated by the EIA (9) "...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). The average annual decrease in domestic oil production between 1977 and 2008 was -1.4%/yr. If this average decrease continues to 2020 there might be another 14% decrease in the domestic reserve to about 16.4 billion barrels and by 2035 the reserves might be as low as 12.4 billion barrels. Decreasing petroleum reserves will likely mean decreasing domestic petroleum production. If total petroleum consumption remains nearly constant between now and 2035, as suggested in the AEF report, declining domestic crude oil reserves would lead to an increase in the U.S. dependency on imported oil, which is already unacceptably high. The declining domestic oil production appears to be consistent with the oil predictions of geophysicist Dr. M. King Hubbert. Dr. Hubbert's logistical model included projected new discoveries, yet once past peak production, the rate of discoveries could not keep pace with the rate of the drawdown in reserves, resulting in a net decrease in oil reserves over time. The United States has 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 a large new oil deposit within the U.S. land area is unlikely.

The Energy Information Administration offers a different projection (10) of future domestic oil production than the above extrapolation of historical domestic oil reserves. The EIA projects domestic production actually increasing somewhat, assumedly due to rising petroleum prices. This EIA prediction has domestic crude oil production, measured in quadrillions of BTUs per year, at 10.75 for 2007, 13.19 by 2020 and 13.50 by 2035. This is consistent with economic models that predict that known reserves will increase as prices rise. It is noted that this did not occur in non-OPEC oil producing countries during recent very high oil prices. These non-OPEC countries, like the United States, have already passed their production peaks and do not appear to be capable of measurably responding to higher prices. This same EIA analysis predicts a declining level of oil imports from 21.91 quadrillion BTUs per year in 2007 to 18.95 in 2020 to 19.34 by year 2035. Using EIA data, the ratios of imported amounts of crude oil to the sum of domestic and imported amounts for the years 2007, 2020 and 2035 are, respectively, 0.67, 0.59 and 0.59. These ratios represent a measure of our petroleum dependence, i.e., the 0.59 figure for 2035 means that 59% of our oil would have to be imported even as late as 2035. Such high import percentages are hardly "promoting energy independence" as called for by the Senate energy bill. If the geophysical model turns out to be more accurate that the economics model, the above import percentages for 2020 and for 2035 will be even higher.

Regardless of which forecast turns out to be more accurate, geophysical or economic, both indicate an unacceptable level of energy dependence for decades. Similarly, the AEF analysis projects an unacceptable national security situation. **The postulated AEF, EPA and EIA continuing petroleum import dependence levels are inconsistent with the national security goals of proposed Congressional energy legislation.**

6.3 Economic Tipping Point

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 revenue to pay off this interest. At that point the debt will grow regardless of efforts to reduce it. The question here is would the cost of importing petroleum according to the AEF projections of petroleum use result in crossing an economic tipping point?

The EIA Annual Energy Outlook for 2010 predicts a cost of $133/barrel (in 2008 dollars) by 2035. This would be about $224/barrel in nominal dollars. Since we have already briefly experienced a price of $147/barrel, the EIA projected prices may be low. In 2007 the U.S. imported about 10,000,000 barrels of oil/day or about 3,650,000,000 barrels/year. If this rate of imports were continued for the 25 years between 2010 and 2035, similar to the AEF projection, at an assumed average price of $120/barrel (2008 dollars), the total cost would be, **approximately, $11 trillion (2008) dollars**. 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, an additional $11 trillion dollars, although distributed over 25 years, could possibly cause an economic tipping point to be exceeded.

6.4 Multiple Choices, Two of Which are Catastrophic

Three different scenarios are possible, based on the above analyses of the AEF report:

1. The United States continues to consume petroleum in its transportation sector according to the AEF analysis. Military expenses connected with securing this level of petroleum remain high and there are significant energy related health effects due to air pollution, etc. Such a scenario leads to GHG releases that eventually exceed proposed Congressional legislation while possibly putting the

nation in to such an impoverished state it crosses the economic tipping point. National security risks remain very high because of the continuing high level of petroleum imports, or,

2. The United States is unable to compete in the world market for sufficient oil because of its debtor status and the much larger assets held by China and others. Insufficient petroleum leads to a collapse of our individual vehicle intensive economy. Without adequate transportation enough food can not be grown and delivered. Global warfare to secure more petroleum may be initiated, or,
3. Congress works in a bipartisan manner to simultaneously reduce the threats of global warming and national security. Congress expands proposed energy legislation by establishing a two tier carbon tax system where a premium is placed on imported oil. Congress also expands energy legislation to establish a timetable and schedule to restrict oil imports and to limit such importation to North, South, and Central America and to the Caribbean.The United States immediately enlarges easier conservation efforts to reduce energy consumed in lighting, heating, etc. This is followed by supporting petroleum-displacing end uses that run off of off peak electricity directly or run off of energy stored as heat, hydrogen, compressed air, electricity, chemical compounds, and other storage means. A large mass transportation system is initiated, using domestic energy sources as the basis of its electricity generation and its liquid fuels. First emphasis would be on electrified buses for use in urban and suburban locations. Congress mandates that the reduced petroleum import bill, reduced health costs due to less pollution from our transportation system, and the savings in our military which would no longer need to protect energy supply routes, would largely fund this major energy use and source transformation. A major increase in electrical capacity would be needed for a much larger electrified transportation system. All practical sources of electricity are harnessed together to meet this large demand for electricity, however much of this would have to be supplied by evolutionary nuclear power plants. Several different advanced nuclear power plant demonstration plants should be built and tested. CCS technology should be tested with demonstration facilities. A large CTL effort should be initiated where high temperature nuclear plants supply much of the carbon free process heat and/or hydrogen. Unless there are sufficient coal reserves and unless CCS is shown to be affordable and practical, coal use gradually shifts from our being our main source of electricity to supplying liquid fuels in a CTL process. Biomass is used as much as practical subject to avoiding food/fuel conflicts, excessive use of land or water, soil erosion that

threatens soil sustainability, or causing a net increase in the release of GHG or a net increase in fossil fuel usage.

7.0 Conclusions

The NAS should revise the AEF report to take into account:

1. The national security implications of continuing a high level of petroleum imports. (An estimate of the savings that might be obtained by reducing petroleum imports should be made).
2. The observation that even if all the AEF's projected petroleum use were both obtainable and the nation could afford it, burning that level of petroleum would result in exceeding GHG limits in present proposed legislation.
3. That construction of an electrified mass transportation system should be given priority status. This mass transportation system should first emphasize electrified buses for urban and suburban areas because they can be built and deployed faster than a large intercity electrified rail system. To maximize their use, such electric buses should be designed to easily go from a passenger commuting mode to a local freight delivery mode during off-peak commuting times. The energy to power these electrified urban and suburban buses could come from off peak electricity converted to hydrogen and stored in community energy storage stations for later use in buses with fuel cells or buses with motor/generators that burn hydrogen to make electricity. A very large number of such buses could be energized without the need to build more power plants to increase the transmission network. The manufacture of such buses would take place at present automobile factories, modified as necessary. This would create many jobs. An intercity high speed electrified mass transportation system would take a long time to construct, but should also be started now. The intercity rail system should be integrated with the urban electrified bus system, local subways, etc.
4. That the long term priority use of coal is as a feedstock in a CTL process, not in the production of electricity. This CTL process should use carbon free energy sources for process heat and/or hydrogen production. Coal would then continue to be a very valuable energy source, even if CCS was not found to be technologically or economically successful.
5. That far more nuclear power plants are needed. Progress on nuclear power plants should proceed on two parallel tracks. Many more nuclear power plants using evolutionary designs should be built to replace older coal plants without CCS and to provide electricity for more electrified transportation and for a growing popu-

lation. The licensing and construction methods used by the South Koreans and others to keep capital costs down should be examined for possible utilization in the United States.

6. Four to five advanced design high temperature nuclear power plants should be brought to the demonstration stage. Greater use of carbon free nuclear power plants means that end use devices that displace petroleum, such as plug-in hybrid cars, would also become increasingly effective in reducing GHG emissions as the carbon intensity per kilowatt-hour of grid based electricity decreased. There should be much more emphasis on energy storage to enhance conservation, to increase the contribution of renewable energy, and to make better use of non-renewable energy sources.
7. The NAS, if they revise the AEF report, should emphasize the nation is in a race against time and that it is essential that all practical energy sources and conservation work together to reduce the time it takes to displace imported oil. This approach could be further refined by modeling of our whole energy system: energy sources, distribution networks, and end use devices to determine which series of actions (sequences) throughout the whole system results in the least cost path towards ending oil imports from the Mideast.

8.0 Appendix A: Review of the AEF Cost Analyses

8.1 Introduction

This appendix reviews the AEF cost analysis as presented in Figure 2.10 and its supporting documentation. More specifically, the use of Figure 2.10 to recommend a very modest nuclear power program is questioned. The third bullet on page 32 of the AEF report states “The committee has not made judgements about the relative desirability of the supply options described in this report or about their appropriate pace and scale of deployment.” However, it appears that exactly this kind of judgement was made when the committee elected to recommend limiting nuclear power to a “suite of about five plants in this country during the next decade” so that the commercial viability of evolutionary nuclear power plants can be demonstrated (11). As discussed before, the data to determine the commercial viability of evolutionary nuclear power plants are already at hand. Just between China, India, and South Korea there are 31 nuclear plants under construction and another 66 plants undergoing licensing review. In light of all this actual cost information the NAS should re-evaluate its basis for suggesting an evolutionary nuclear program that significantly differs from those in other technologically advanced countries.

Nuclear power plants are expensive to build, but inexpensive to operate. This has become quite evident where many of today's nuclear power plants are the least cost electricity producers in a utility's portfolio. This situation has turned many existing nuclear power plants into "cash cows", so much so that some governments are seeking some kind of rebate from the utilities that own these plants. Over the next 60 to 80 year lifetimes of evolutionary nuclear power plants we may experience steep increases in the price for fossil fuels and/or shortages, whereas the cost for fuel at a nuclear power plant is but a small percentage of its total cost and several year's worth of unused nuclear fuel can be safely stored at nuclear sites. The long design lifetimes, low fuel costs, and ample supplies of uranium mean that a fleet of evolutionary nuclear plants could help form a stable economic backbone for the United States for decades to come.

To further demonstrate that the AEF cost analysis comparison is an inappropriate basis to recommend such a modest nuclear program, energy costs are examined at three levels: a global level, a national level, and a detailed level.

8.2 Examining Nuclear Power Costs From a Global Perspective

It has been previously shown that continuing to consume petroleum at or near present rates would cause GHG limits to be exceeded which could bring on climate change. It was also shown that such high rates of petroleum consumption threaten our national economy. However, if obtaining the needed petroleum, as forecast in the AEF report, were not possible this could create a severe national security issue with the possibility of armed conflict. Any result, economic collapse, climate change, or global conflict, or possibly all three at one time, have costs that are immeasurably large.

The root of the AEF projection of continued high petroleum consumption is in the huge volume of petroleum used in our transportation system. Because improving the efficiencies of individual vehicles is insufficient to cause large reductions in petroleum use for several decades, a significantly and timely expansion of electrified mass transportation is strongly recommended.

In order to have a much larger electrified mass transport system, there must be a corresponding increase in new sources of electricity. All practical sources of electricity would be valuable in meeting the energy needs of large expansion of electrical capacity. However, the bulk of this new electrical capacity would likely come from evolutionary nuclear power plants. This is because there is a need to use our limited coal resources in an optimum way, i.e., in making liquid fuels. So even if CCS proves to be technologically feasible and the cost penalty is bearable, the primary use of coal would still be in making liquid fuels, not electricity. Renewable electric energy sources will contribute to our future portfolio of sources of electricity. However, it is very unlikely that all the renewable energy sources together could reliably supply enough electricity to meet future transportation needs at a reasonable price, as discussed in more detail in Section 8.4.Therefore it is necessary to build a sufficient number of evolutionary nuclear plants to meet the anticipated large growth in electricity as electrically driven transportation grows.

8.2.1 GLOBAL CONCLUSION

The cost of enough nuclear power plants needed to help arrest climate change and help prevent global warfare over petroleum is insignificant compared to the risks imposed by these two global threats.

8.3 Examining Nuclear Power Costs From a National Perspective

Before getting into the details of AEF Figure 2.10, there are two cost considerations that lie outside of this figure that provide a broader perspective on costs.

1. Paying for evolutionary nuclear power plants through a smaller oil import bill.

It was previously estimated that if the AEF projected level of oil imports could actually be paid for through 2035, this could cost an estimated $11trillion (2008) dollars. If nuclear power plants only reduced this overall oil bill by 5% by providing electricity to a future electrified transportation system and if each nuclear plant cost $5 billion dollars (similar to South Korea’s $20 billion dollars for four nuclear power plants for the United Arab Emirates), this reduction in the nation’s oil bill would be enough to pay for about 114 nuclear power plants. This would be quite a bargain since the nuclear plants would likely operate for 80 years or more, well beyond the 25 years between 2010 and 2035. Actually, 114 large nuclear plants may be able to displace more than 5% of the oil import bill. Forsberg (12) estimates that 30-35 large nuclear power plants could reduce America’s <u>total energy demand</u> by 5% when used to replace present ground transportation of freight with electrified trains.

2. Actual electrical grid operating experience

The U.S. electrical grid operates with a very high reliability, over 99%, each year. However, the National Renewable Energy Laboratory (NREL) reports (13) that this small, about one percent, unreliability is very expensive, far more than the cost of the missing one percent of the kilowatt-hours. The U.S. economy is losing between $119 billion and $188 billion annually from power outages and power-quality issues, according to the NREL.

Suppose that without an adequate contribution from nuclear power overall reliability slips half a percent to 98.5%/year. This might increase our annual losses due to power outages and poor power quality by about $60 billion to $94 billion per year, based on extrapolating the NREL numbers. This additional cost might be avoided by bringing more nuclear power plants on line to prevent power outages or poor power quality. If so, in just one year of operation there could be enough avoided costs to pay for 12 to 18 nuclear power plants at a cost of $5 billion dollars each. This might be thought of as very inexpensive insurance because these nuclear power plants should continue to operate up to another 60 to 80 years.

8.3.1 NATIONAL CONCLUSION

The cost of constructing many nuclear power plants may be justified on the basis of avoiding financial losses because of decreased overall system reliability. Insufficient energy is the most expensive form of energy.

8.4 Detailed Review of AEF's Figure 2.10

8.4.1 INTRODUCTION

There are several structural difficulties with Figure 2.10. First, evolutionary nuclear power and coal are mature technologies whereas coal-CCS, biopower, and all the intermittent renewable energy sources are not. It is not clear that one can make meaningful cost comparisons between mature industries and those that are still in their early stages. For example, many wind turbines have unexpectedly experienced broken gear boxes. The NREL has established a program to solve this issue, but it does illustrate that there are unforeseen cost issues that all technologies experience when in the early stages of development. Another example of the difference between mature industries and those still developing is in their design lifetimes. As AEF acknowledges, evolutionary nuclear plants are expected to operate 60 to 80 years. This nuclear lifetime expectation is based on actual operating experience. Today, the design lifetimes of wind turbines is about 20 years, with some Danish utilities pressing wind turbine manufacturers to redesign wind power facilities to last 50 years. Replacing wind turbines more frequently than evolutionary nuclear plants is a cost factor. It is not clear if Figure 2.10 captures the difference between the longer design lifetimes mature industries and the unproven lifetimes of those energy sources that are still in the early stages of their development.

Another structural question about AEF's Figure 2.10 is in their financial assumptions. There are important financing differences that separate evolutionary nuclear power plants from other new sources of electricity. Those nuclear plants that get federal loan guarantees have to repay all financial benefits they receive back to the federal government. Loan guarantees do not represent a cost to the taxpayer if the project is successfully completed. If the best construction practices of other countries, like South Korea, are adapted for use in the United States, the risk of cost overruns should be minimal. It might even be advantageous to purchase a few nuclear plants from South Korea on a fixed cost basis. However, many renewable energy sources are subsidized at the federal and state levels and/or built because of some mandated requirement; all of which are burdens carried by the tax payer. To be consistent, AEF Figure 2.10 should compare technologies using the total costs to all stakeholders, such as costs to taxpayers plus to rate payers.

It does not seem that nuclear power plant costs were always compared to renewable energy sources on a equivalent basis. For example, many renewable energy sources of electricity, such as wind farms and solar facilities in the desert, are located far from their load centers. Therefore their dedicated transmission line costs should be included in their total costs. NREL estimates that 15,000 miles of new transmission lines would be necessary for wind power if in the future it provides 20% of the nation's electricity. Further, the cost for dedicated energy storage for renewable energy sources should also be included in Figure 2.10. In contrast, there is ample space to accommodate many additional evolutionary nuclear plants on existing nuclear sites. These nuclear sites are comparatively near their load centers and the connecting transmission network is already there and may only require upgrading to serve the additional evolutionary nuclear power plants.

The NAS might benefit by comparing AEF's Figure 2.10 to a study (14) completed by McKinsey & Company who investigated the costs to abate greenhouse gas releases from non-transportation sources. Exhibit 1 from this McKinsey & Company report is reproduced below as Figure 6. In this cost analysis new nuclear build was calculated to be more cost effective per gigaton of GHG abated than onshore wind (medium penetration), onshore wind (high penetration), biomass power-confining, distributed solar photovoltaics, concentrated solar power facilities, and a variety of coal power plant configurations with CCS.

Figure 6: McKinsey & Company, Exhibit B

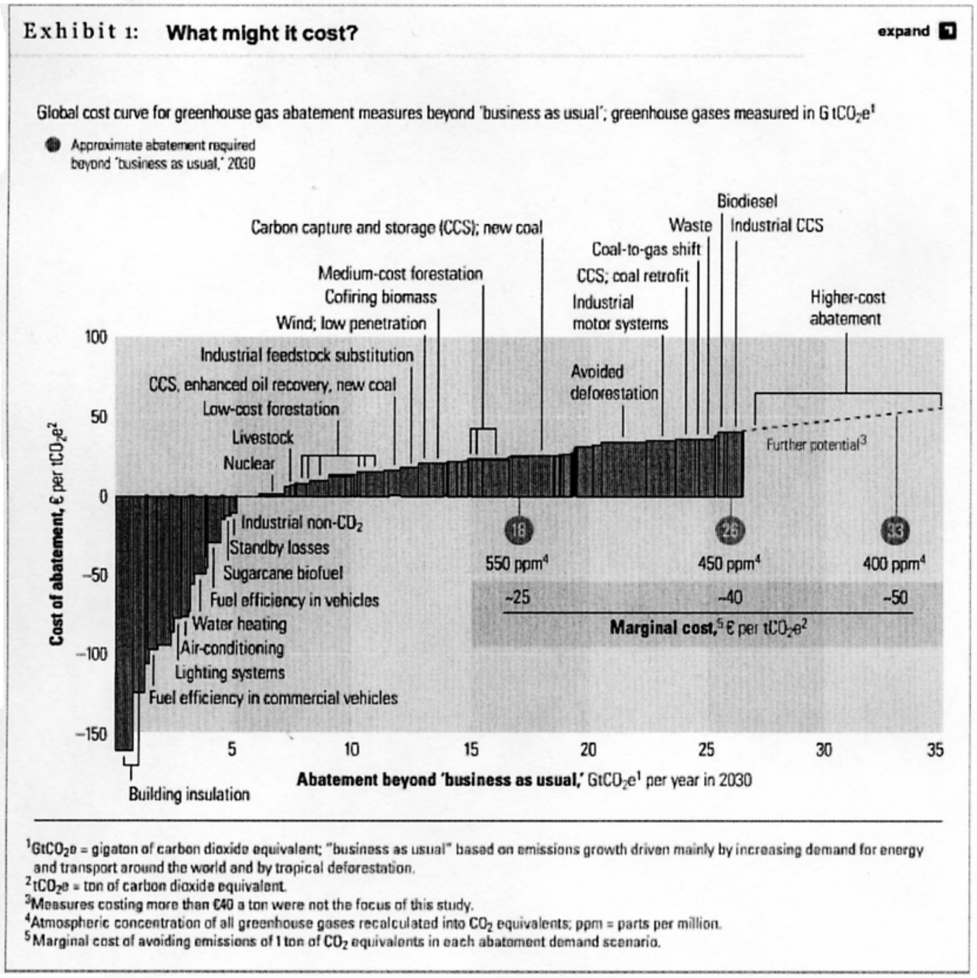


Exhibit 1: **What might it cost?**

Global cost curve for greenhouse gas abatement measures beyond 'business as usual'; greenhouse gases measured in G tCO_2e[1]

[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.

[2] tCO_2e = ton of carbon dioxide equivalent.

[3] Measures costing more than €40 a ton were not the focus of this study.

[4] Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.

[5] Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

8.4.2 BACKUP POWER AND CONSERVATION

Intermittent sources of electricity need either an energy storage system or a backup source of electricity to assure an adequate supply of electricity at all times. A very limited analysis was made by examining the cost of backup electricity in the Consolidated Edison of New York service area. Ten months of data were collected on the cost of electricity in 2009 for a single apartment in this service area. The total residential cost for 2596 kilowatt-hours came to $658.83, giving an average cost of 25.38 cents per kilowatt-hour. Of this hourly cost, 8.65 cents per kilowatt-hour was the cost of the delivered electricity and 16.73 cents per kilowatt-hour was the cost of taxes, fees, maintaining the system, etc. Of the total bill of $658.83 some $434.31 (66%) can be attributed to the system's costs, independent of the cost of electricity or the source(s) of electricity. The cost for the electricity was $224.52 for ten months.

Several lessons can be learned from this limited cost analysis. The cost of the electricity itself was only 34% of the total cost per kilowatt-hour. Because the cost of the electricity is only about a third of the total cost, cost differences between different sources of electricity of a few cents/kilowatt -hour have a limited effect on the total electric bill. In this service area, a difference of 4 cents/kilowatt-hour would only affect the overall costs by about 16% in the example that was used.

As customers begin to use electricity more sparingly through more energy efficient appliances, better lighting, "smart grids", etc., the electricity usage component of the overall bill will decrease. One effect of implementing conservation measures is to make cost differences among different sources of electricity an even smaller effect on overall costs. Overall utility bills are affected by different energy sources, but only in a limited manner because of overall costs are dominated by non-electricity factors. For equal consumption, electricity bills may show more variation due to customers living in different service areas, than the fuel choice.

The AEF report states on page 59 "However, when installed at the point of energy use, such as on a residential rooftop, PV competes with the retail cost of electricity and are therefore more cost competitive for a purchasing customer". This may not be the case because of the need to continue to pay for backup costs to the utility to supply electricity when the output from the PV system is inadequate to match demand. To show this more clearly, assume that during the course of a year a PV system returns to the grid as many kilowatt-hours as is purchased from the grid when the PV system output is smaller than the demand. If the homeowner is credited by the utility with the full value of the PV electricity returned to the grid, the net cost for the electricity consumed per year would be zero. However, the customer would still have to pay the backup costs. In the above Consolidated Edison of New York example, this amounted to $434.31 for 10 months. In order for a roof top PV system to have a continuous supply of electricity at no net cost for either the purchased electricity of the cost of the backup system, the PV system would have to be far more than a zero net electricity use system. It would have to generate excess electricity to pay for the backup costs as well. At 8.65 cents per kilowatt-hour the excess electricity needed to offset the 10 month backup cost of $434.31 is 5020 kw-hours. These 5020 kilowatt-hours would be added to the 2596 kilowatt-hours used by the customer, for a total output of 7616 kilowatt-hours per ten months or about 9139 kilowatt hours/year, a very large PV system. Even if a PV system were capable of producing 9139 kilowatt-hours per year and therefore had zero net utility costs, this arrangement does not provide any funds to pay for the very large PV system itself. Note that zero net electricity use and zero net cost for reliable electricity are two very different economic analyses.

Those customers who do not have a PV system they would also have to pay for all the system charges. So the most direct analysis of the cost competitiveness of PV systems would be to determine its payback period. Its payback period, without considering interest on the cost of the PV system or maintenance costs, would be the cost of the PV system divided by the savings on the utility's electric bill. Assuming the PV system would produce electricity eight hours/day on average and an installed 2010 cost of ~ $7.00 per watt (15), it would take about 28 years to recover one's investment in the PV system in the above example. The price of $7.00/watt is the cost prior to receiving any direct financial incentives or tax credits. A recovery period of about 28 or more years may exceed the design lifetime of the PV system.

It is suggested that a more useful comparison of PV costs to utility charges for electricity would be the case where the customer is not connected to the utility at all. Many such systems have been built, especially in low population density areas and cost data from such systems could be used. Further PV cost insights are given in Sections 8.4.3 and 8.4.4.

8.4.3 SOLAR ENERGY

Figures 7 and 8 present solar insolation data collected by NOAA. Figure 7 plots the monthly means, measured in watts per meter squared, for 2008 at Fort Peck, Montana. Figure 8 is the 2008 record of the solar insolation monthly means at Desert

Rock, Nevada. When Figures 7 and 8 are compared it shows that there are large differences in the collected solar energy between these two sites, as expected. For two comparable solar installations, the Fort Peck, Montana site would collect considerably less solar energy than the Desert Rock, Nevada site. All other things being equal, solar electricity generated at the Fort Peck site would be more expensive than the same facility installed at Desert Rock, roughly in proportion to their different solar insolations throughout the year. This implies that large centralized solar energy facilities may not economically be located everywhere throughout the country. However, sunny areas like Desert Rock, Nevada generally are further from the load centers compared to present day power plant sites. In order to maximize on the solar insolation a trade-off is made where the benefits of greater sunlight results in higher transmission line costs.

Desert locations make a second trade off in that their ultimate heat sink will have to be the surrounding atmosphere, not a body of water. Using air as the ultimate heat sink carries some economic penalty compared to using a body of water, especially during very hot days in the desert.

At night a different challenge has to be addressed, that of freezing. One desert solar design will use a molten salt as its working fluid. The freezing point for this molten salt is about the same temperature at which water boils. In order to prevent this molten salt from freezing during the cold desert nights, the molten salt would have to be drained from the system each night and refilled each following morning.

Like wind power, solar energy is an intermittent source of electricity. Solar energy varies during the day and there is no energy collection at night. This variable collection rate can be “smoothed over” by energy storage so that the solar plants can produce a steady level of electric power for more hours than just between dawn and dusk. Present designs with storage do not provide electricity 24 hours a day. As stated before, energy storage is an essential aspect to greater use of renewable energy and this is an example. The cost for energy storage in renewable energy sources needs to be included in AEF Figure 2.10.

Figure 8 provides additional information about solar economics. Not only are there diurnal variations in the solar insolation, there are large seasonal variations. The data show that the January solar energy that a power plant might collect is less than half that of the peak values in the summer. Whereas some “smoothing over” of diurnal solar insolation is possible through energy storage, it would appear to be very uneconomical to try to “smooth over” seasonal variations. More likely the shortfall of solar electricity production in winter months would have to be made up by other facilities and this raises its own economic issues (See Section 8.4.2). If the backup source of electricity to the solar plant is an otherwise idle fossil plant, this solar/fossil combination would then compromise one of solar energy’s main attractions as a source of energy that does not emit GHG. A solar/nuclear combination would retain the GHG advantage, but at this time all existing nuclear plants are running “full out” and there is no spare capacity. Implementing the AEF recommendation of a very modest increase in nuclear power would limit solar energy to solar/fossil combinations.

Some have suggested that shortfalls in electricity production from solar plants could be offset by importing wind power from other locations in the country. This too seems economically unattractive. These two renewable energy sources have very different geographical distributions with the best wind sites in the plain states and off shore whereas the best solar sites are in the southwest deserts. Putting two variable sources of electricity together that are geographically separated so that they could match variable demand may be very difficult without massive amounts of energy storage. Again, storage costs would have to be added to the renewable energy costs in AEF Figure 2.10. Without energy storage there is a very high probability that power outages and power quality issues would arise from a solar/wind combination. The solar facilities do not produce electricity at night and have reduced output during winter seasons. If there is insufficient wind energy to compensate for the loss of solar electricity this could cause a blackout situation. As described in Section 8.3, it is already known that power outages and quality issues are the cause of very large economic losses. To prevent such blackouts one might overbuild the wind facilities to assure that its minimum output is sufficient to make up for the drop in output from the solar plants, daily and seasonally. This too is economically unattractive in that it would lead to idle wind power capability during times of solar production.

Figure 7: 2008 Monthly Means Solar Insolation, Fort Peck, Montana

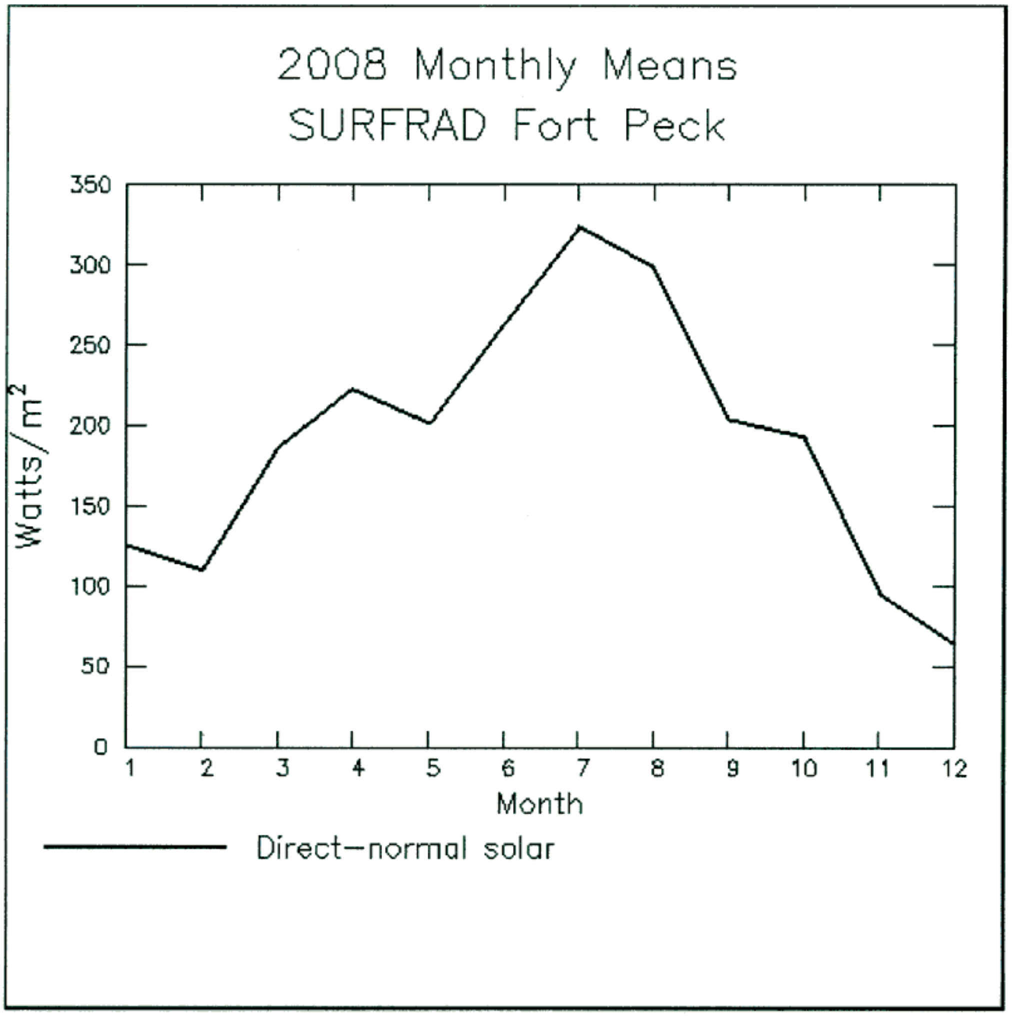
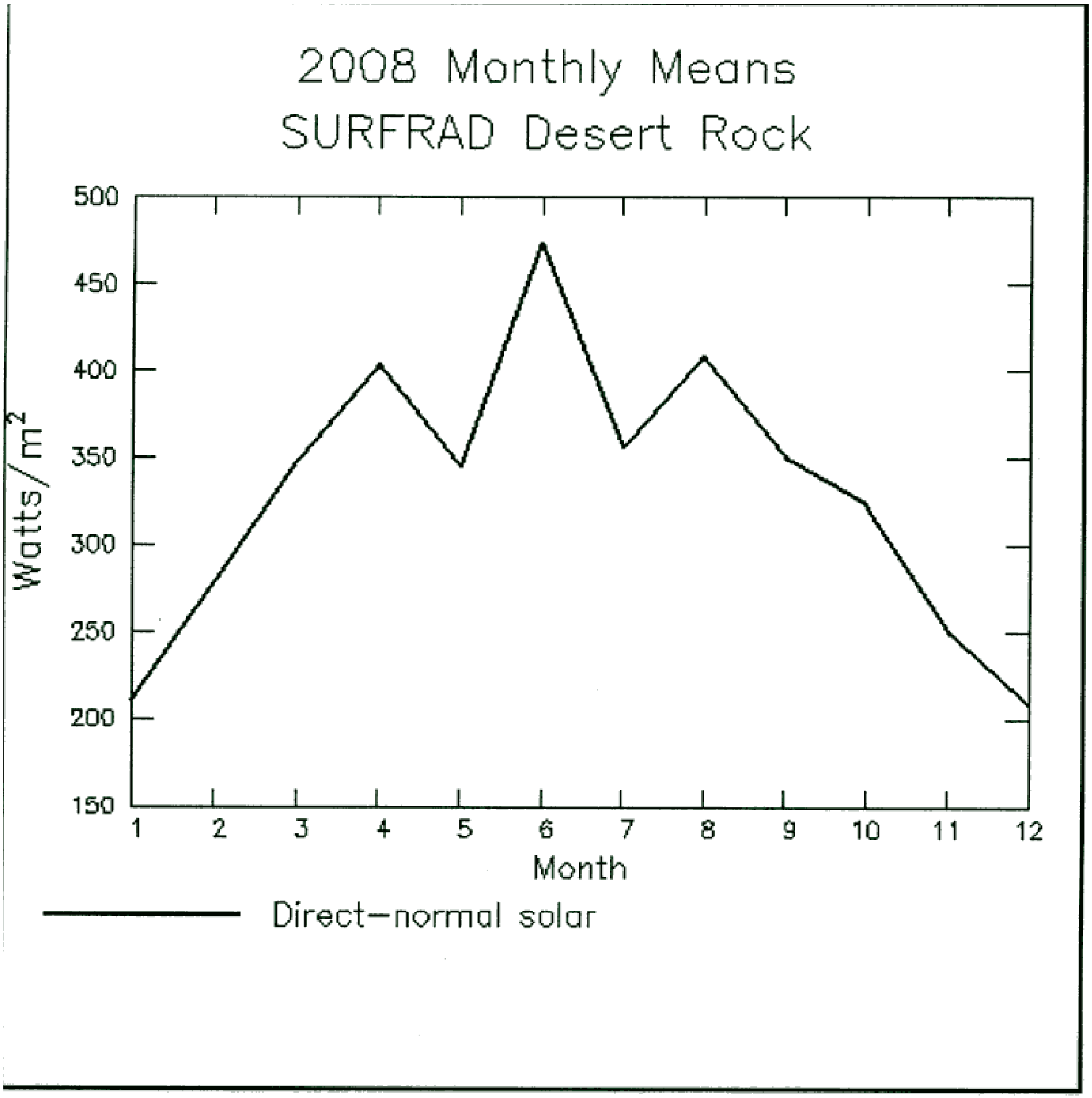


Figure 8: 2008 Monthly Means Solar Insolation, Desert Rock, Nevada



8.4.4 PHOTOVOLTAICS

The economics of photovoltaic systems are subject to the same backup costs described in Section 8.4.2 and the daily and seasonal variations in solar insolation as described in Section 8.4.3.

Much of our attention has been directed towards increasing the efficiency at which photovoltaic systems convert incoming solar energy into electricity. However, as pointed out by Skumanich, et al, in a recent article in Photovoltaics World (16) one has to consider the costs of a PV's balance of system (BOS). A typical BOS includes hardware, planning, and labor costs. Among the hardware costs are mounting frames, support elements, ground support structures, base blocks, connecting wiring and conduits, the inverter, and the power interface-breakers, transformer, protective switches, etc. In one case study of a 30 kw installation the BOS represented about 44% of the total costs. As Skumawich, et al, point out some components of the BOS such as frame materials and copper wiring are subject to price increases.

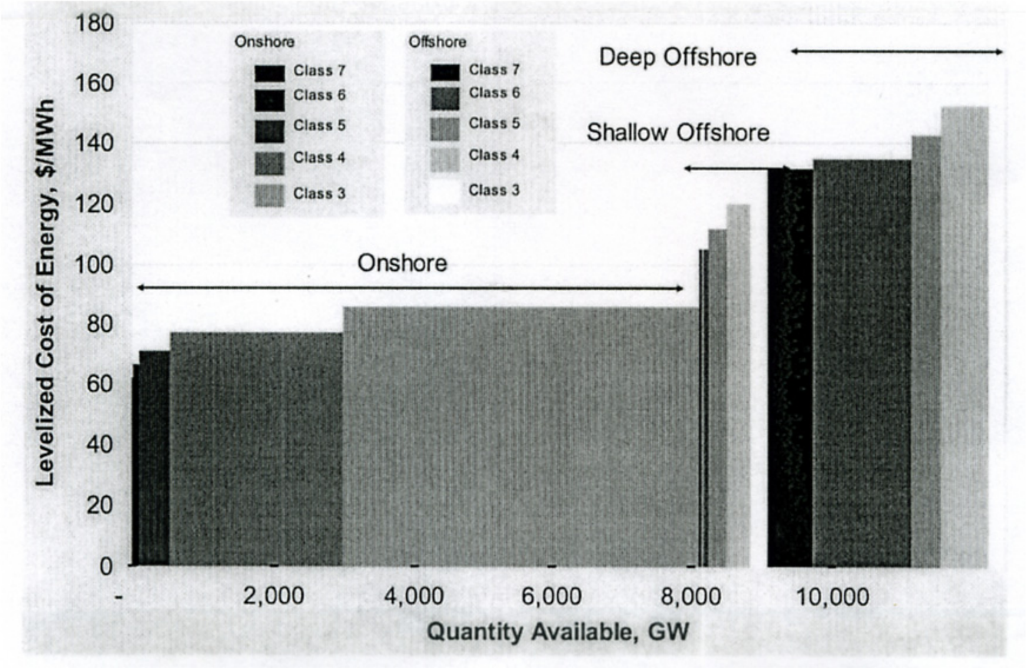
Even if the cost of the PV panel module, now about 56% of the total cost in the 30 kw installation, were reduced by a factor of two by greatly increasing the conversion efficiency, the overall costs would then be 28% + 44% = 72% of present costs. Based on AEF Figure 2.10 a reduction in costs of this size would still leave PV costs in an uncompetitive range. PV costs may not become competitive until BOS costs are significantly reduced.

Using the same cost considerations applied to nuclear power, would the NAS recommend a very limited PV effort? Would the national investment in PV and, perhaps concentrated solar plants, be better spent on high speed electric trains?

8.4.5 WIND POWER

On page 58 of the AEF report it is stated that "The bottom of the LCOE range for wind, corresponding to class 7 wind sites, extends below the range for nuclear". This statement may be true, but it is unimportant. This is because there are very few class 7 wind sites as shown in Figure 9, derived from a study (17) by the American Wind Energy Association. Costs in this figure do not include the production tax credit.

Figure 9: U.S. Wind Energy Supply Curve



To expand upon the AEF wind class site discussion, Table 4 describes the seven wind classes and their power densities and wind speeds at an elevation of 50 meters, as published by the Energy Information Administration in April, 2008. The energy available from a wind stream is proportional to the cube of the wind speed. Normalizing the theoretical energy from a class 7 location to 1.0, the fraction of class 7's wind energy is given in Table 4 for other wind classes by taking the cube of the ratio of a class's wind speed to 11.9 meters/second the wind speed EIA has listed for wind class 7. Wind power density is also provided as it is a useful way to evaluate wind resources at a potential site. Because of the rapid decrease in theoretical wind energy at lower wind speeds much of the nation's wind resource would not be economical. The American Wind Energy Association recommends wind class 4 or higher for large scale wind plants.

Offshore wind power enjoys higher wind speeds and likely higher wind persistence than many onshore locations. Nonetheless, offshore sites generally have higher projected costs for their electricity. As wind technology matures interest has grown in establishing design criteria, such as being able to withstand a once in a hundred year wind storm. This would likely be a category 5 hurricane that could envelope a whole wind farm. Since large hurricanes have already shown that they can severely damage off shore oil rigs, wind turbines built to such a criterion would have to be especially sturdy. Recent climate change analyses predict that the frequency of higher category hurricanes will increase in the years ahead. Cost estimates for wind power in AEF Figure 2.10 should reflect the costs of protecting wind turbines from extreme wind and wave effects.

Table 4: Classes of Wind Power Density at 50 meters, Rankings

Wind Class	Power density, watts/ meter^2	Wind Speed, meters/second	Relative ranking of theoretical wind energy, normalized to wind class 7
7	2000	11.9	1.0
6	800	8.8	0.404
5	600	8.0	0.304
4	500	7.5	0.240
3	400	7.0	0.203
2	300	6.4	0.156
1	0-200	5.6	0.104

8.5 Conclusion

The above review of a number of renewable energy systems is not intended to diminish their importance, but is intended to introduce important factors that affect their costs. Should the nation turn to more electrified transportation all practical and environmentally acceptable sources of electricity would be needed.

The cost of insufficient energy greatly overshadows the small differences between different electrical energy sources. Should NAS produce an updated AEF report, it might examine what constraints limit the rate at which electrical capacity can be expanded. This analysis of the rate of expansion of electrical capacity should apply to all electrical energy sources, their distribution systems, and to oil-displacing electrically driven end use devices. That mix of electrical energy sources, distribution systems and end uses that reduces oil imports most rapidly will likely be the most ecnomical approach because of oil's huge price tag. With this approach the NAS would be examining the benefits of different mixes of whole energy systems, not just individual cost projections. The NAS could then recommend the development that mix of energy sources, distribution systems, and end uses that appears to be most cost effective in meeting the nation's climate change and national security goals. Such a product would be far superior and useful than the approach taken in the AEF report.

9.0 Appendix B: Cellulosic Ethanol

Figure 4 of this critique of the AEF report was re-examined to determine the potential benefits of cellulosic ethanol using the information in AEF Figure 2.11 where a potential supply of 0.5 million barrels of gasoline equivalent per day were forecast for 2020 and 1.7 million barrels of gasoline equivalent per day for 2035. If these levels of cellulosic oil equivalents were available this would delay the time that the GHG limits in H.R. 2454 were exceeded by **about one year**.

Some caution is advised on estimating the amount of ethanol that might be derived from cellulosic sources, such as switchgrass. Some earlier claims about the amount of ethanol per hectare from switchgrass has 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 (18) 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. Switchgrass ethanol yields from areas, such as man-made prairies where there was a low energy input, were considerable less than the ethanol yields from areas using modern farming techniques based on the use of fertilizers, herbicides, diesel fuel, etc.

Schmer cautions that 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.

One estimate (19) for the potential of cellulosic ethanol assumes that all 34.7 million acres in the Conservation Reserve Program were used to grow switchgrass, using modern farming techniques. This estimate, which considered the greater difficulty in converting switchgrass to ethanol, is that around 2.5% of today's petroleum use might be displaced by such a switchgrass program.

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