Rosie Revisited:

A U.S.-Led Solution to Global Warming

By Steve Nelson

GlobalWarmingSolution.org

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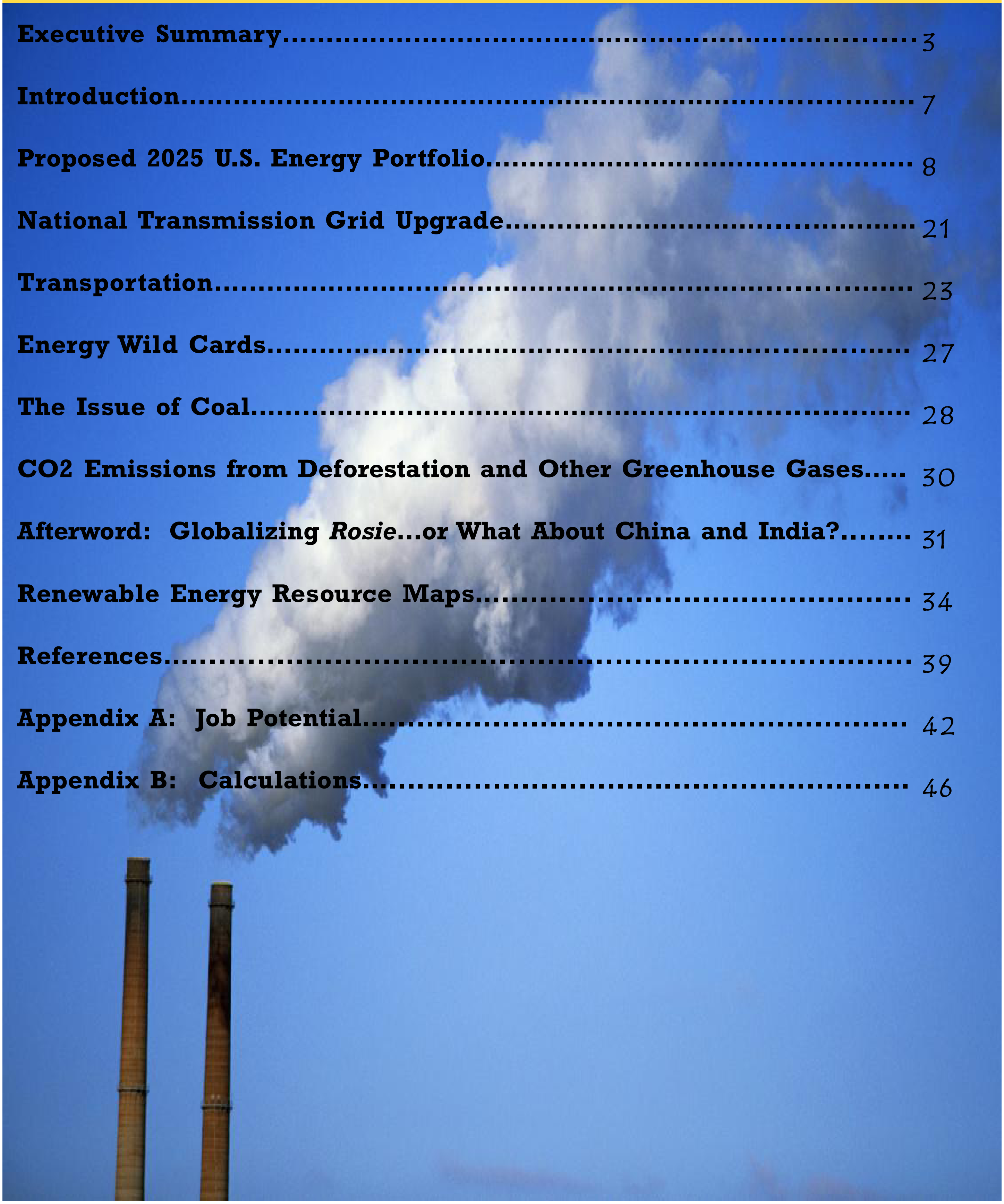


Executive Summary

The gravity of the global warming threat can no longer be denied. Skeptics have been marginalized or converted, the public is aroused, industry is repositioning and Congress is awakening from its long stupor of inaction. For these reasons the following statement may be most unwelcome or even appear out-of-touch. Nonetheless, GlobalWarmingSolution.org stands by it:

Despite much activity, the U.S. Congress is currently contemplating no policies sufficient to address the rapidly growing global warming crisis.

The two strongest bills under consideration by Congress call for 80% reductions in greenhouse gas emissions by 2050, with the intent to keep atmospheric CO2 concentrations from rising no higher than 450 parts per million. Proponents of these bills make general references to "scientists that consider this the danger point." No such unified statement has come from the leading scientific body addressing global warming, the Intergovernmental Panel on Climate Change. In fact the IPCC is prohibited from taking a position on where the danger point lies, but leading scientists, such as NASA's James Hansen, has repeatedly said that he believes the danger point is below 450 parts per million, perhaps "substantially" so. Furthermore, NASA reported on May 31, 2007 that: "Only moderate additional climate forcing is likely to set in motion disintegration of the West Antarctic ice sheet." The complete melting of the West Antarctica ice sheet would raise sea levels 15 feet worldwide. Every coastal city in the world would be flooded well short of the maximum sea-level rise.

We are now faced with the fact that tomorrow is today. We are confronted with the fierce urgency of now. In this unfolding conundrum of life and history there is such a thing as being too late... We may cry out desperately for time to pause in her passage, but time is deaf to every plea and rushes on. Over the bleached bones and jumbled residue of numerous civilizations are written the pathetic words: "Too late."

—Martin Luther King, Jr.

GlobalWarmingSolution.org believes that the "danger point" was passed long ago. Our policy goal—reducing global greenhouse gas emissions 80% below 1990 levels by 2025—is based on the following recommendation issued by the IPCC in 1990:

"*In order to stabilize concentrations at present day concentrations (353 ppmv), an immediate reduction in globalanthropogenic emissions by 60-80 percent would be necessary.**"*** (IPCC First Scientific Assessment, 1990 (p.18)).

Major and intensifying global warming impacts are unfolding around the world, and have been for many years. We simply can not state with any precision what CO2 level is a danger point, and to continue in this futility is a criminal waste of time and scarce civic energy. The import is the same: *Clearly our focus should now be to reduce greenhouse gas emissions as rapidly as possible, in the United States, and globally.*

***Rosie Revisited* demonstrates how U.S. carbon dioxide emissions could be reduced 80% below 1990 levels by 2025.** Further, the report's methodology could and should be applied to the rest of the developed world and developing countries as well, in order that these deep and rapid cuts in emissions are *global. Rosie Revisited* is offered to the American public and their elected representatives in the U.S. Congress and the White House as a plan for a wartime-speed energy transition. More concretely, *Rosie Revisited* demonstrates:

1-U.S. greenhouse gas emissions could be reduced 80% below 1990 levels by 2025, a full generation before the strongest bills currently under consideration in the U.S. Congress. We recommend the transition begin in 2010.

2-Such a dramatic energy transition could be completed with currently existing technology. There are no technological barriers to planning and launching the transition immediately.

3-Investing only 3% of our GDP annually would be necessary to fund the 15-year transition, which could be accomplished with a combination of public and private investment.

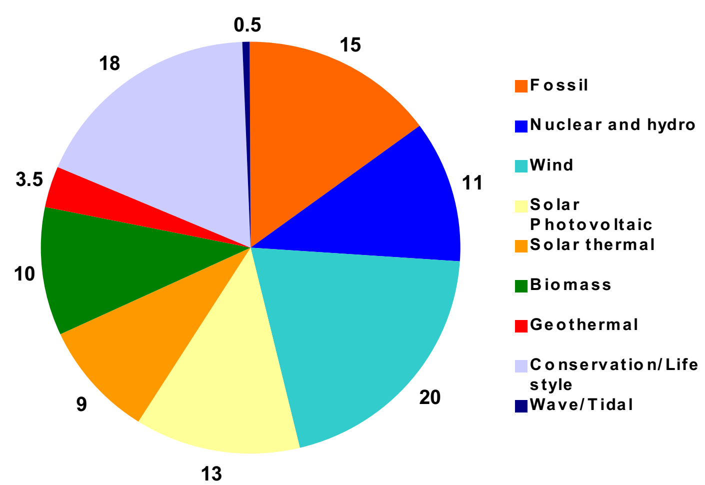
4-Such a transition would create far more jobs than staying on the current fossil fuels-intensive path.

5-An "Afterword," discusses applying the *Rosie Revisited* methodology to the rest of the developed world and developing countries, in order to reduce *global* greenhouse gas emissions 80% below 1990 levels by 2025.

Changing the Mix: A 15-Year Wartime-Speed Energy Transition

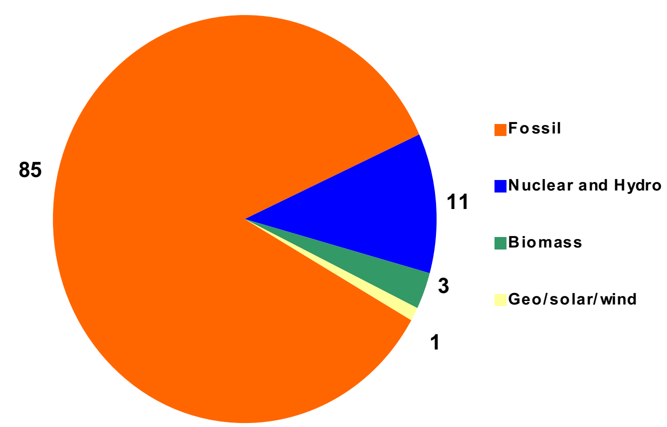
Rosie Revisited calls for making a shift from an energy system dominated by fossil fuels to a diverse portfolio of primarily renewable energy, a transition aided by enhanced energy efficiency and energy conservation.
The most aggressive bills currently under consideration in the U.S. Congress call for 80% greenhouse gas emissions cuts by 2050. This schedule is imprudent in the extreme considering the feasibility of the transition outlined in *Rosie Revisited.*

Proposed Energy Portfolio and Fossil Displacement Schedule 2025
(quadrillion BTUs)



CO2 emissions: 1,042,000,000 metric tons

2004 Energy Consumption by Source
(quadrillion Btus)



CO2 emissions: 5,903,000,000 metric tons (EIA est.)

Political leaders who underestimate the capacity of Americans to transform their energy system jeopardize the well-being of civilization with their lack of imagination and will, as well as missing the opportunity to energize a nation willing to work for a better future.

Technology That Already Exists Does Not Have to be Created

Achieving even the ambitious benchmarks set by *Rosie Revisited* will not require developing any new technology. The diverse renewable energy technologies upon which the *Rosie Revisited* transition is based are either commercialized already or on the brink of being so. And while further technological development is desirable and inevitable, *Rosie Revisited* argues that precious civic energy need not be spent on the false and dispiriting notion that making a sweeping energy transition is dependent on further, extensive technological development.

Maintain U.S. Energy Use at Current Levels through Efficiency Measures

Efficiency measures resulting in a 21% reduction in energy demand would eliminate the increase in U.S. energy use forecasted by the U.S. Department of Energy over the life of the transition contemplated by *Rosie Revisited.*

Conservation: Further Diminish Energy Demand

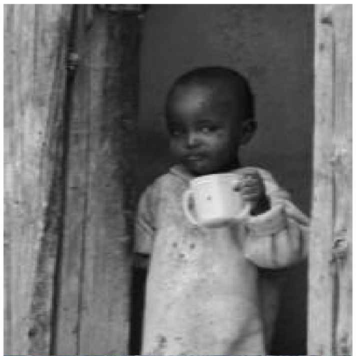
Depletion of natural resources, most of which are produced, delivered and consumed utilizing fossil fuels, drives global warming. Therefore we recommend that 18% of the proposed energy portfolio for 2025 come from conservation. The United States must learn to live with less consumption of material resources. High on the list of conservation priorities must be reworking the regulations, incentives, attitudes and traditions that encourage and even underwrite suburban sprawl. Another urgent national priority should be redirecting transportation funds toward the development of a world class public transit system, including extensive trolley and bike systems in every city, and the building of a spit-and-polish national intercity bullet train system such as those found in France and Japan. A host of other conservation strategies are available to government, business, and individuals.

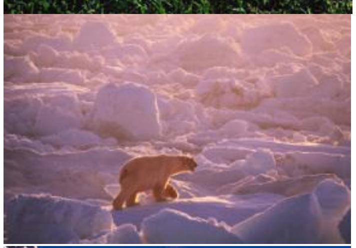
Indirect Conservation: Let's Talk About Global Population

In addition we must have a serious conversation about global population levels. More people means more burning of fossil fuels and more deforestation, direct causes of global warming. The United Nations Population Division describes three potential population scenarios for 2040 ranging from a low peaking at 7.9 billion to a high of 9.8 billion-and still rising- global population. We are on the medium trajectory which will lead to 8.8 billion by 2040. Clearly it is prudent to attempt to reach the lower level. According to Lester Brown of the Earth Policy Institute:

> *"Slowing world population growth means that all women who want to plan their families should have access to the family planning services they need. Unfortunately, at present 201 million couples cannot obtain the services they need to limit the size of their families. Filling the family planning gap may be the most urgent item on the global agenda. The benefits are enormous and the costs are minimal."*

Infinite growth of population and resource consumption on a finite planet is impossible. Similarly, pushing up against the carrying capacity of the biosphere, as humanity is today, is immoral and ruinous. We must stabilize population levels and learn to live with less consumption in the wealthy countries. This does not necessitate a reduction in the quality of life. In fact there is much evidence that these measures will greatly enhance our lives in both developed and developing countries, while securing a brighter future for ourselves and our children.



3% to Save Humanity

Rosie Revisited demonstrates that these sweeping changes to the U.S. energy infrastructure can be achieved by investing only 3% of our GDP, a paltry sum to pay for averting catastrophe. For comparison, in 1944 United States' spending on the war effort reached *38%* of GDP. Furthermore, much of the required capital would be in the form of profitable private investments.

A Huge Job-Creation Benefit

Many studies have confirmed that a renewable energy-intensive economy creates far more jobs than one based on fossil fuels. A 2004 University of California meta-study looked at 13 of these and concluded that the job-creating power of renewable energy is 3-5 times that of fossil fuels.

Global Warming Requires a Global Solution: The Question of China and India

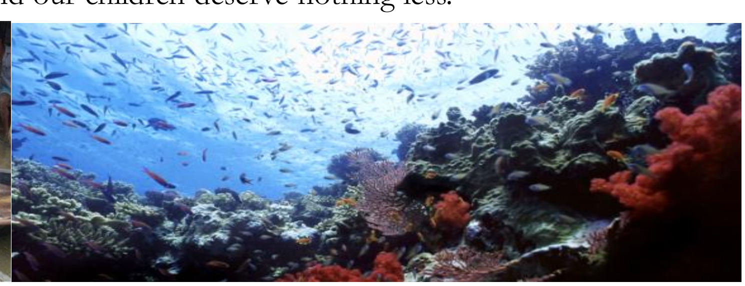
The United States should immediately draw up plans for its 15-year rapid energy transition and make that the starting point for negotiations at the United Nations Framework Convention on Climate Change in Bali, Indonesia in December, 2007. The goal should be to secure parallel commitments from the rest of the developed world and developing countries. in order that *global* greenhouse gas emissions be reduced 80% below 1990 levels by 2025 (See "Afterword" below). Because research for *Rosie Revisited* focused on the United States, our estimates for the cost of this rapid energy transition for the rest of the world can only be very general and speculative. But since the United States is one of the highest cost economies in the world, and the technologies employed will be in most cases identical, it seems reasonable to conclude that the transition could be achieved on average for about 3% GDP in the rest of the countries participating.

Now. Or never.

—Henry David Thoreau

Humanity has arrived at what political scientist William Ophuls called a genuine "civilizational crossroads" and our options are stark.: Continue to avoid a major energy transition and risk a permanent nightmare world for us and our children, or make a swift, resolute transition to a largely carbon-free U.S. and global energy infrastructure. *Rosie Revisited* is one path to the only morally justifiable option. Let's get on with with it. We and our children deserve nothing less.





Rosie Revisited:

A U.S.-Led Solution to Global Warming

Rosie Revisited is a bold but considered vision: The purpose of this paper is to present a framework for humanity's energy future: one which provides the hope of a clean, healthy future for our children, grandchildren and generations beyond; which reinvigorates the democratic process; which challenges us to shoulder our nations' role as a responsible world leader; and which plows the entrenched field of fossil fuels and cultivates a rich soil in which the seeds of a new energy generation may bear economic fruit. This paper is a global energy vision seen through a detailed analysis of how such an energy transformation could transpire in the United States. Discussion of the proposed energy transformation in the rest of the world's countries is included in an "Afterword" (below).

Energy

Energy is a cornerstone of all life, and most of our major decisions, when properly analyzed, are energy decisions.' The United States' energy use provides a high standard of living by historical global standards.

However, our consumption comes with costs. Cheap oil, which leads to expanded automobile use, has generated air pollution, congestion, increased road costs through construction and maintenance, urban sprawl, and an incipient exhaustion of the resource itself. Increased electrical demand and paltry conservation efforts produce greater need for coal-fired electrical generation, which itself generates strip mining, mercury contamination and air pollution. Low heating costs support inefficient building designs and spiraling consumer expectations for home sizes. Cheap transport costs have brought us a world of inexpensive consumables, whose point of production is far from the point of consumption, and we now take this "affordability" as a right to, rather than a privilege of cheap oil. Most importantly, our massive use of fossil fuels threatens the very climate that has made our civilization, and even existence, possible. Our culture has a massive energy addiction: the time to address our energy predicament is now.

Energy use in the US

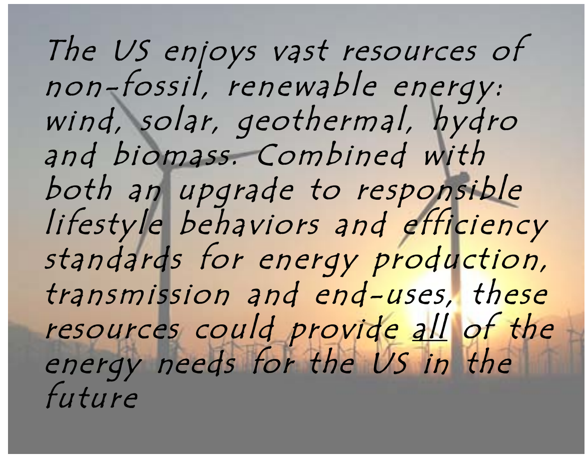
In 2004, the United States used **100** quadrillion British thermal units (BTU) of energy for all processes, including domestic production, heating, electricity and transportation. **1** quadrillion (1,000,000,000,000,000) BTU's is commonly referred to as a "quad", a name that gives little meaning to the magnitude of the consumption:

100 quads is the energy required to keep a 100-watt household bulb illuminated for 33,447,000,000 years (roughly <u>three times</u> the estimated age of the Universe). Using 100 quads of energy, a car with an average fuel economy of 20 mpg could cover a distance of 18,000,000,000,000 miles, or ¾ of the distance to the nearest star. 100 quads is the energy content of 5 billion tons of sub-bituminous coal, enough to fill 50 million railroad coal cars, creating a coal train that would stretch from the earth to the moon and back with enough left over to wind around the earth four times at the equator. The United States' energy consumption represents 24% of the total global energy use, a staggeringly large share for a country that represents only 4.6% of the world's population. Can the world afford this level of fossil fuel consumption for all of its' inhabitants? The increasingly apparent answer is no.

A Lean Green Energy Machine

GlobalWarmingSolution.org is dedicated to the rapid transition of our energy infrastructure from fossil fuels to renewable energy, consonant with the scientific consensus regarding climate change. One clear and consistent recommendation has been the deep and rapid reduction of carbon dioxide emissions, globally: ***"In order to stabilize concentrations at present day concentrations (353 ppmv), an immediate reduction in global anthropogenic emissions by 60-80 percent would be necessary."*** (IPCC First Scientific Assessment, 1990 (p.18).

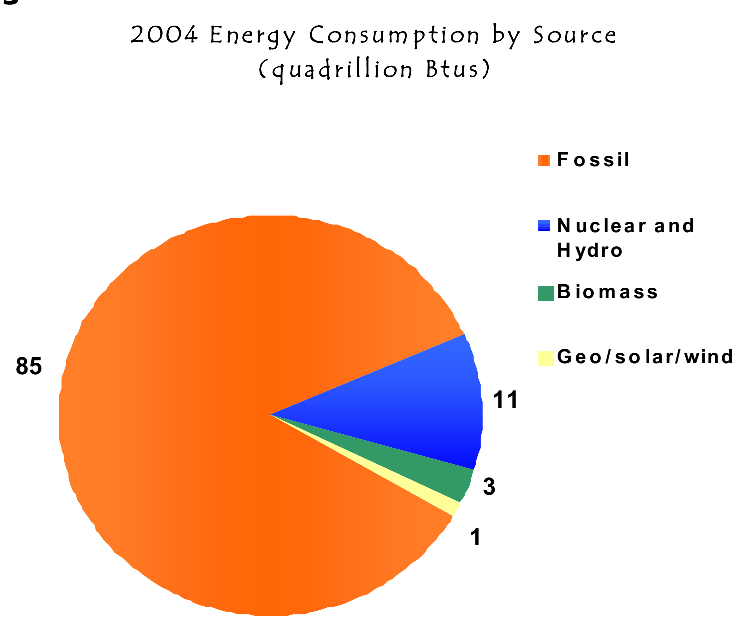
The evidence that an 80% reduction in carbon dioxide emissions is a reasonable goal to achieve over a 15-year time horizon is resounding. The difficulties and costs of this effort are obvious and immense; however, in comparison to the costs and impacts resulting from climate change—and considering the significant economic growth that will come from retooling the nation's infrastructure—the transition to renewable energy will have modest impacts and be viewed, in hindsight, as prudent, courageous and visionary.



Vast resources of non-fossil, renewable energy are available to the United States in the forms of wind, solar, geothermal, hydro and biomass. Combined with improved lifestyle choices by individuals and improved efficiency in energy production, transmission and end-uses, renewable resources could provide all of the United States' future energy needs. (Increased use of nuclear power is not a part of the reduction in carbon emissions because it is not necessary. In the ensuing calculations, the present nuclear capacity is merely held constant.)

With *Rosie Revisited*, how to integrate bountiful existing renewable resources into a strategic energy plan consistent with the promise of livable future is no longer a matter of technical feasibility. It is only a matter of political will.

Figure 1.[1]



CO_2 emissions: 5,903,000,000 metric tons[2]

GlobalWarmingSolution

Based on resource availability and technical feasibility, GlobalWarmingSolution.org proposes the following prudent transition of the US energy sector from predominantly fossil fuels resource (Figure 1) to a portfolio that taps the vast renewable energy resources available currently (Figure 2). (The transition would begin in concert with other nations in 2010).

Figure 1 depicts the total US primary energy usage for 2004. Primary fuels are those which are consumed in the original production of energy, before the energy is converted into useable forms (e.g. into steam, electricity, motion etc).

Figure 2

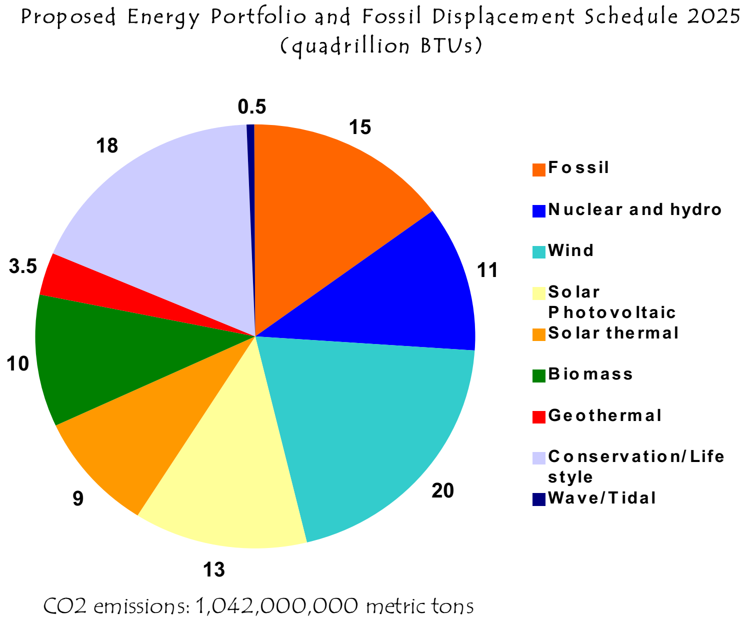


Figure 2 depicts the amount of fossil primary fuel that would be *displaced* by each resource by 2025. A note on the concept of displacement: due to inefficiencies in combustion, typically only 33% of primary fuel energy is available for use, meaning that around 67% of the energy represented by the orange area in Figure 1 is released to the surroundings as waste heat. Consequently, renewable resources must replace only the *useable* energy, not the entire primary quantity. For example, a (theoretical) 112,000 MW wind farm operating at standard 30% capacity will produce 293,000,000 MWh or 1.0 quad of electrical energy. To produce the same unit of electricity using fossil fuels would require 3.0 quads (1.0 useable + 2.0 waste) of primary energy (coal or natural gas). Thus, a unit of wind energy produced has the potential to displace three units of fossil primary energy. Our proposed portfolio includes 6.7 quads of wind-generated energy, which will *displace* the 20 quads of fossil fuels depicted.

This transition plan:

- provides the best hope of reducing greenhouse gases within a timeframe that both allows economic, manufacturing and consumer adjustment and seriously addresses the race-against-time that is global warming.
- constitutes a massive boost to a US economy already suffering from the cost of fossil fuel energy, costs that will only rise and therefore threaten future businesses' viability.
- propels the US back into a position of world leadership in terms of courage, vision, ingenuity and responsibility to humanity.

Figure 3

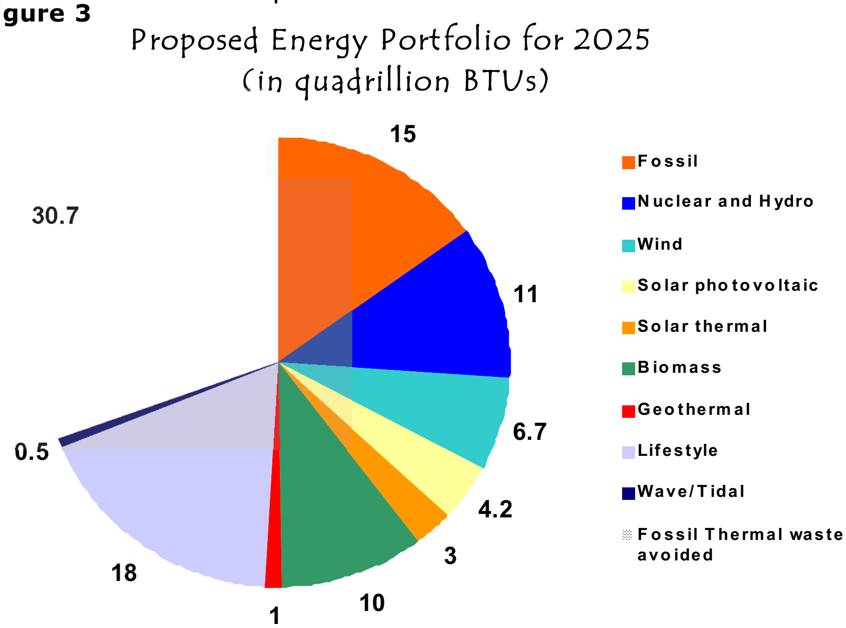


Figure 3 illustrates the actual amount of energy required by both fossil and renewable resources, and includes the amount of fossil thermal waste (energy that is exhausted and does no useable work) that will be avoided by using the proposed mix. Please note: We are including the thermal waste for illustration purposes only, such that the comparisons (present and future) add to 100 quads.

Costs:

The costs associated with *Rosie Revisited* are considerable. Significant investment capital will be needed to facilitate this transition, as well as government commitment to creating a supportive and rewarding economic environment. Firm federal regulation and coordination will be essential. *Rosie Revisited*, however, holds the promise of significant job creation potential.

Table 1 displays the capital investment required, the percent of gross domestic product it represents, and employment potentials (See Appendix A) for the various renewable energy developments outlined in this paper. Discussion of each resource follows this section. For comparison of the costs of a renewable energy transition to a business-as-usual scenario, table 2 illustrates a composite of select national energy costs/liabilities under current US energy policies.

Table 1: Cost and Employment Impact totals

Technology	Yearly Total Costs	% GDP (US)	Job Employment Range (yearly)	Overall 15-year cost
Wind	$75 billion	0.68	246,000 - 320,000	$1.12 trillion
Solar PV	$95 billion	0.86	100,000 - 460,000	$1.4 trillion
Biomass-electrical	$34 billion	0.3	168,000 - 611,000	$0.516 trillion
Biomass-transport	$9.2 billion	0.08	480,000 - 1,680,000	$0.138 trillion
Geothermal	$3.5 billion	0.03	11,000	$0.052 trillion
Solar Thermal	$37 billion	0.34	185,000	$0.555 trillion
Wave/Tidal	$3.3 billion	0.03	?	$50 billion
Grid costs	$90 billion	0.82	?	$1.35 trillion
Totals	**$347 billion**	**3.14%**	**1,190,000 - 3,267,000**	**$5.18 trillion**

Table 2. Business-as-usual Yearly Energy cost composite estimate (2006-2020)

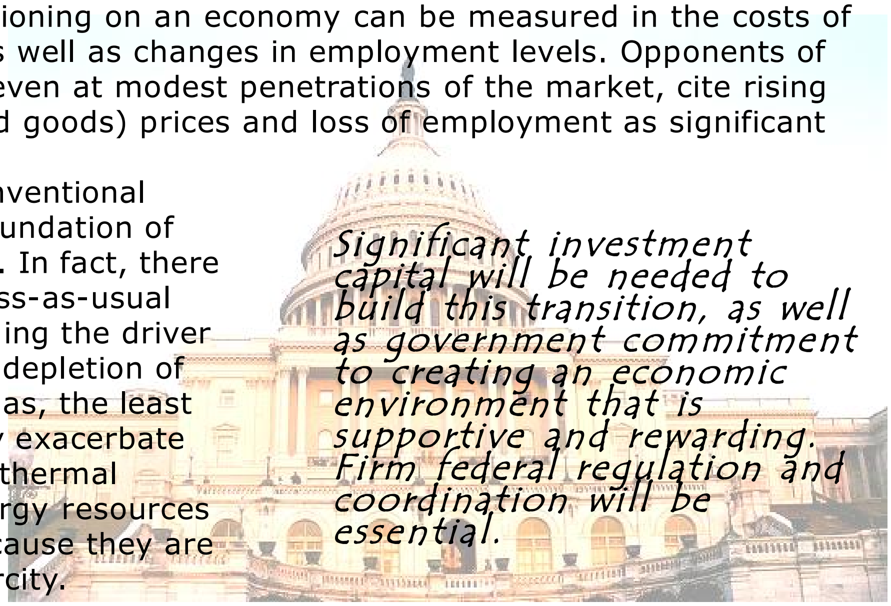
Cost source	Yearly cost	Source
Annual US petroleum imports	$280 billion	3
Annual Grid outage and power quality impacts to economy	$25–180 billion	4
Subsidies to fossil fuel industry	$2.6–121 billion	5
Coal investment costs		
New capital investments	$3 billion	6
External costs for new plants*	$15–40 billion	7
External costs for existing plants *	$73-190 billion	7
Total cost range	**$399-814 billion**	

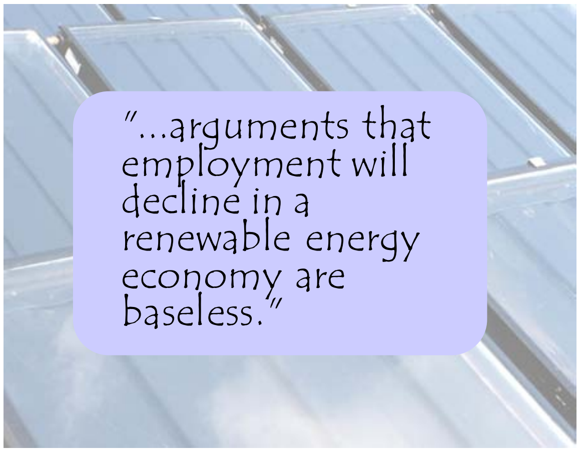
*includes estimated costs for global warming

Economic:

Two critical impacts of transitioning on an economy can be measured in the costs of raw materials and finished goods as well as changes in employment levels. Opponents of transitioning to renewable energy, even at modest penetrations of the market, cite rising energy (and therefore materials and goods) prices and loss of employment as significant drawbacks of change.

A critical look beyond this conventional wisdom reveals a rapidly eroding foundation of empirical evidence for their position. In fact, there is growing evidence that the business-as-usual fossil fuel economy is rapidly becoming the driver of increased costs. Impending local depletion of and global competition for natural gas, the least carbon-intensive fossil fuel, will only exacerbate this trend. Most (sun, wind and geothermal though not biofuels) renewable energy resources are immune from fuel-price risk because they are not resources characterized by scarcity.





Arguments that employment will decline in a renewable energy economy are similarly baseless. Preliminary studies of renewable energy employment potentials (see appendix A), bolstered by hard data from emerging industries, indicate the exact opposite: investment in a renewable energy economy will reap a substantial employment dividend. Conversely, the 2006 layoffs at Ford and General Motors demonstrate that business-as-usual practices can result in decreased employment. Adoption of innovative design, incorporating fuel economy and fuel alternatives, including electric cars, could re-invigorate the industry. In fact, some projections actually fuel a new concern: a concerted transition to renewables might be hampered by *lack* of a sufficient work force. Given the rate of outsourcing and the increasing numbers of people employed in low-wage jobs, the proposed transition offers new hope for economic stability for American workers and families.

GlobalWarmingSolution: Components of a sustainable energy policy

Efficiency: 21% overall reduction in demand

"The idea that our natural resources were inexhaustible still obtained, and there was as yet no real knowledge of their extent and condition. The relation of the conservation of natural resources to the problems of National welfare and National efficiency had not yet dawned on the public mind…"
THEODORE ROOSEVELT

Energy efficiency is an age-old concept: fish in a current make decisions based on whether the energy expended in capturing a submerged insect will be paid for by the energy stored in the insect. Trees shed leaves and limbs that, shaded or diseased, no longer yield enough photosynthetic energy to pay off their consumption debt. Mammals terminate nursing when the young's ability to gather their own energy exceeds the energy drain on the mother. Releasing the millennia of energy embedded in fossil fuels has permitted humanity a luxury unprecedented in nature: energy gluttony. We must rediscover efficiency.

Energy efficiency practices can be implemented in nearly every aspect of American life. A national commitment to increase fuel economy in cars and trucks, to adopt aggressive energy saving building codes, to apply Energy Star™ standards to all appliances, and to assess all industrial and manufacturing processes for energy saving measures would reap savings in both economic and environmental terms. The US Department of Energy (DOE)-facilitated National Action Plan for Energy Efficiency cites a potential for a 20% reduction in national energy use by 2025 through efficiency measures. The American Council for an Energy Efficient Economy estimates the ability to cut energy use by 18% in 2010 and 33% in 2020 through adoption of comprehensive policies for advancing energy efficiency, with savings to consumers and businesses totaling $500 billion net during 2000-2020[8].

Rosie Revisited proposes adopting a modest target of 21% efficiency, an amount that will offset the increase in energy demand predicted (between 1.3 and 1.5%/year) over a 15 year period, so that our total demand in 2025 will remain at the 100 quads we currently use, which will be our baseline for examining the distribution of sources in the US energy portfolio for 2025.

Jevons Paradox: In 1865, the English economists Stanley Jevons observed that England's consumption of coal skyrocketed after the introduction of James Watt's improved steam engine. Watt's engine's efficiency was significantly greater than that of Thomas Newcomens' earlier engine, and logically should have reduced the amount of coal used per unit of production, leading to an overall national reduction in coal use. Contrarily, coal use increased. Jevons observed that, while technological improvements in the efficiency with which a resource is used will decrease the amount of the resource used for a given task, the resulting decrease in cost of using the resource may foster new ways of using the resource, resulting in a net increase in resource consumption. In the British case, Watt's engine made coal a far more efficient power source, leading to expanded use of steam engines in a broad spectrum of industrial applications. As applied to this proposal, the Jevons paradox suggests that any reductions in energy use by efficiency may well be offset by an increase in consumption of the newly available (80% renewable) energy. Consequently, more resources and an increased portfolio of generating and transmission facilities will be required, driving up the costs and greenhouse gas emissions outlined by this scenario.

The real issue is one of consumption, dealt with later in the lifestyle section of this paper. However, there are several factors that might curb the effect posited by Jevons. First, Jevons paradox assumes an unrestrained (and therefore cheap) energy supply; however, energy in a carbon-constrained world will not always be cheap: if time-of-use rates are adopted, then peak-hour electricity will command a premium price, limiting its consumption. Further, some generation (e.g. solar PV) may be more expensive. Second, adoption of a carbon tax will place negative pressure on consumption. Third, awareness of the global climate issue will, at least for many, place a damper on consumption.

Wind: 20% displacement

Raise your sail one foot and you get ten feet of wind – Chinese proverb

Wind power, the fastest growing renewable energy technology (36%/yr) has achieved many milestones over the past 20 years: 90% reduction in costs, increased reliability of turbines, decreased avian mortality, demonstrated profitability, and electricity costs competitive with coal and gas. (When external costs are included, wind electricity is cheaper than coal and natural gas.) Development of wind power manufacturing has excellent job creation potential: export potential is enormous as developing countries seek alternatives to fossil fuels in post peak-oil markets.

Total wind potential for the lower 48 states is equivalent to 1/3 of total US <u>energy</u> use (33 quads)[9]. Harnessing 20% of this potential will require construction of 1,120,000 megawatts (MW) of capacity within 15 years. This capacity will provide 6.7 quads of electricity, displace 20 quads of fossil fuels and eliminate 20% of US total greenhouse gas emission, a significant step toward our target reduction of 80%. Job creations potential is estimated at 3.7 to 4.8 million job-years employment over 15 years, which translates into between 246,000 and 320,000 jobs per year[I] (all Roman numeral superscripts refer to Appendix A, job potential document). Costs for this level of wind development will be steep: $1.12 trillion over 15 years ($75 billion/year), which is 0.7% GDP. However, taken in the context of:

- the costs of proposed new (fossil) electrical generating capacity which may harbor significant economic liability from future carbon taxes, and
- costs due to air pollution and impacts of coal mining and petroleum acquisition, and
- costs of retiring and replacing outdated coal plants, and
- the massive costs which will accrue from climate change over the next century, wind offers near-term profitability (as demonstrated repeatedly by existing wind parks) and long-term payoffs in stabilizing global atmospheric concentrations of greenhouse gases.

The US wind industry is currently growing at 36%/year. In order to reach the capacity target of 1,120,000 MW by 2025, the following expansion is proposed: starting in 2010, the wind industry growth rate is ramped up to 50%/year for seven years (2016 inclusive), after which time growth plateaus to zero. At this time industry production will be adding 105,470 MW per year to total capacity, which should create the necessary target potential[A] (All letter superscripts refer to Appendix B, calculations) . If the growth rate of the wind industry continues to climb (slowly) after 2016, additional production can be exported.

To put this planned expansion of the wind power industry into perspective, during 1944, after only four years of rapid industry growth, the US produced the equivalent of over 100,000 1.0MW windmills—powerful (and mechanically complex) aircraft engines that powered over 55,000 planes into the air that year[10,11].

Solar Photovoltaic: 13% displacement

In 1905, Albert Einstein published three papers that rocketed him from obscurity as a Swiss patent clerk to the forefront of physics. One of the papers revealed the physics behind a poorly understood phenomenon known as the photoelectric effect: when light was shone on plates of a given metal, electrons were ejected from the metal atoms in the plate. Since moving electrons are the basis of electrical current, Einstein had established the theoretical foundation for solar electrical generation—photovoltaics (PV).

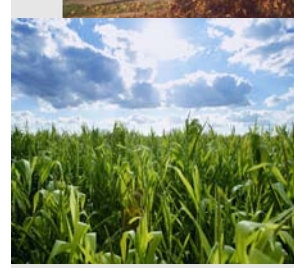
The entire US electricity demand could be met using 10,000 square miles of solar PV (a square 100 miles on a side), located in a high-sun area.

It is appropriate that, just after the 100th anniversary of Einstein's paper, the solar industry is poised to provide the world with clean, renewable energy at increasingly affordable costs. Solar energy provides the greatest potential for supplying energy sustainably into the future. Annually, the Sun radiates 220 million billion kilowatt-hours (750,000 quads) of energy onto Earth's surface, which is 1800 times the annual global energy use. Currently, only a tiny fraction of this energy is harvested to generate electricity. The entire US electricity demand could be met using 10,000 square miles of solar PV (a square 100 miles on a side), located in a high-sun area. A study released by the Energy Foundation estimates that there is sufficient (suitable) rooftop area in the US for 710,000MW of solar electrical capacity, equivalent to 4.2 quads of energy annually[12]. Currently, solar PV converts solar radiation into electricity with around 15% efficiency. If all rooftop area were utilized at this current efficiency, fossil fuel use could be reduced by 13%[B]. An increase in average panel efficiency to 20% (21% modules are already available) would boost energy production to 5.6 quads, with the potential to displace 17% annual fossil fuel use.

Costs for solar PV currently run from $4-$5/watt; increased production can reduce costs to $2/watt or less[13]. To overcome the obvious chicken-and-egg dilemma, solar PV must be supported initially with federal economic incentives, with an eye towards large long-term financial and environmental benefits. Assuming the industry achieves a $2/watt installed cost via improvements in efficiency and economies of scale, the cost for 710,000 MW will be $1.4 trillion dollars, or $95 billion/yr, which is 0.9%GDP. Achieving this goal will require the solar industry to begin an 80%/year growth rate starting in 2010 (assuming a 2006 production figure of 120MWp, and industry average growth rate of 25% per year till 2010) for 10 years, after which time production remains constant, producing 88,300 MW/year till 2025. Although the required growth rate is steep, again taking an example from WWII: the years 1941, 42, and 43 witnessed annual aircraft production growth rates of 411%, 154%, and 81%, respectively[14].

Job potentials range from 1.5 to 7 million job-years, or 100,000 to 460,000 jobs per year over a 15-year time frame[II]. Employment would be in raw material procurement, manufacturing, sales, installation and maintenance of both small and utility-scale facilities. Ranges are large in this industry due to a) lack of large-scale figures and b) the massive growth potential for this industry (current growth rate is 30% per year).

Biomass: 10% displacement



"In… [knowledge's] light, we must think and act not only for the moment but for our time. I am reminded of the great French Marshal Lyautey, who once asked his gardener to plant a tree. The gardener objected that the tree was slow-growing and would not reach maturity for a hundred years. The Marshal replied, "In that case, there is no time to lose, plant it this afternoon."

President JOHN F. KENNEDY, address at the University of California, Berkeley, California, March 23, 1962.

Biomass refers to "any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood residues, plants, grasses, animal residues, municipal residues and other residue material."[15] Biomass is important for its potential to displace fossil fuels, and is renewable by virtue of the continuous reduction of atmospheric carbon (as CO_2) into carbohydrates via photosynthesis. Unlike wind, solar, geothermal and hydropower resources, biomass use releases CO_2 through combustion; however, the CO_2 released to the atmosphere is balanced molecule for molecule by CO_2 absorbed from the atmosphere during photosynthesis. Thus the net change in atmospheric CO_2, considering the biomass fuel itself, is essentially zero (an in-depth discussion of life cycle energy for biomass is considered in the extended version of this paper).

A 2005 Oak Ridge National Laboratory (ORNL) feasibility study, sponsored by DOE and USDA, determined that there is sufficient sustainably harvested annual resource, in terms of cellulosic residue and grain feedstock, to displace 30% of US annual petroleum use[16]. Because 2004 US petroleum consumption totaled 40 quads, biomass could potentially displace 12 quads, or 12% of the US total energy requirement. The ORNL study determined both agricultural and forest biomass resources available for fuel after accounting for food, feed, industry and export requirements. Additionally, attention was paid to insuring that sufficient field residues remained to satisfy USDA soil conservation requirements, and an increasing percentage of fields incorporated no-till methods. Soil conservation and soil health are critical components of this vision, and improvements to US agricultural soils must not be sacrificed for transportation needs.

Biomass will be utilized for a) electrical and heating through combined heating and power (CHP) plants, b) biofuels production and c) in gasified form, powering electrical turbines that can "level" peaks and dips in intermittent power generation. Our proposed fossil displacement for biomass is 4.5 quads for electricity and 5.5 quads for fuels (note: biomass' potential to displace fossil fuels is 1:1; combustion efficiencies are assumed to be identical for both fuels).

Electrical: Current costs of biomass-generated electricity are just under 5 ¢/kWh (compare to national wholesale averages of 3-6¢/kWh), with installation costs running around $2.15/watt installed. To meet the 4.5 quad displacement target will require 215,000 MW of installed capacity, running with a 70% capacity factor (recent studies indicate biomass generation can have capacity factors of 85% or above, equal to conventional generation[17]). This system will cost $462 billion over 15 years ($30.8 billion/year), which is 0.3%GDP. Job potential for biomass CHP range from 168,000 to 611,000 jobs per year for plant operation and feedstock procurement[III]. Small (5MW) power plants employ ~34 people (16 operations, 18 feedstock procurement); larger plants (25MW) will require only 1 additional position for operations, but require ~54 people for the greater feedstock requirement. Thus smaller distributed generating systems may generally offer greater employment, offset by higher local electrical and heating rates.

Transportation fuels: The ORNL study projects a capacity to produce 20% (5.5 quads) of transportation fuels by 2030[18].. We optimistically predict a 10-year acceleration of this target through aggressive national policy. (This estimate is based on current CAFE standards (24 mpg[19]); if CAFE standards are raised to 36 mpg (some analyses indicate higher efficiencies[20]), then the projected 5.5 quads of energy will drive the US motor fleet 50% further, effectively displacing 7.3 quads of 24mpg-equivalent fossil fuels (see biofuels section in Transportation special section). Capital costs for ethanol production facilities are near $2/gallon of production capacity[21]; biodiesel capital costs are closer to $2.50/gallon capacity. Production capacities will need to reach 54 billion gallons of (predominantly cellulosic) ethanol/year; costs for this would be $108 billion dollars over 15 years ($7.2 billion/year); and 12 billion gallons of biodiesel/yr at a cost of $30 billion over 15 years ($2 billion/yr). Total biofuels capital investment of $9.2 billion/year represents 0.08%GDP. These projected capacities are based on current US consumption (160 billion gallons gasoline/diesel annually). Reducing consumption is the preferred option, but it is a hard sell without presidential leadership. Job potential ranges for ethanol are 360,000- to 930,000 jobs per year[IV]. Job potential ranges for biodiesel, including feedstock procurement, are 120,000 to 750,000 jobs per year[V].

Geothermal: 3.5% displacement

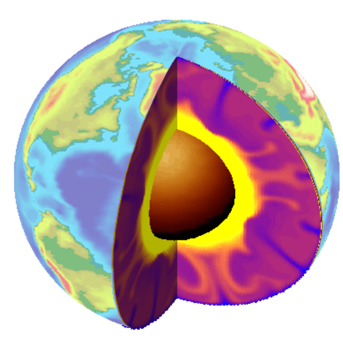
The Earth itself provides a valuable resource for renewable energy: every minute the Sun radiates Earth with 1.4 quads of energy, a portion of which is stored in surface rock and soils. Additionally, latent heat from Earth's formation and radioactive decay within the Earth both provide a steady flow of heat from the core to the surface. The result is a balmy 10°C (50°F) at a mere 2-meter depth in the crust, and a searing 100-250°C (212-482°F) at a depth of 6 kilometers (3.6 mi.). Geothermal technologies can harness this energy, either providing electrical generation and direct heating using deep sources, or providing heating and cooling utilizing surface sources.

Electrical: Currently, there are 2200MW of installed geothermal electrical capacity in the US generating electricity (around 0.06 quads per year) for 5 to 8 cents/KWh with near zero emissions and extremely low external costs. A report issued in 2000 by the National Renewable Energy Laboratory (NREL) concludes that there are 23,000MW of geothermal potential in the US and that undiscovered resources might increase the resource five-fold[23]. Development of this resource incurs large upfront costs due to resource exploration, drilling and construction costs, but pays out with low operating, and zero fuel, costs. Plants are extremely reliable, generating electricity more than 90% of the year (compared with coal's 65-75% capacity). Because of this stability, geothermal plants can provide utility planners with an energy supply "leveler" when used in conjunction with intermittent resources such as wind and solar.

Assuming a modest increase in geothermal potential to 26,000 MW, and using a conservative capacity factor of 0.85, 0.66 quads of electricity can be generated with this resource effectively displacing 2.0 quads[C] of fossil primary energy. At current installation costs of $2.00/watt, total capital investment for geothermal electrical development will be $52 billion over 15 years. Job potential, including exploration, drilling, construction, operational and maintenance is estimated at 170,000 job years[VI] (11,300 jobs/year).

Space heating and cooling: (ground source heat pumps) Currently in the US, 600,000 commercial and residential buildings are heated and cooled with ground source heat pumps, systems that transfer ground heat to buildings in the winter and building heat to the ground in summer. In spite of large upfront investments, these units save owners between 30 and 70% annually in energy consumption and between 20 and 50% annually in heating/cooling bills and can pay for themselves in 3 to 7 years, with a 95% customer satisfaction rating[24]. Reduction in greenhouse gas emissions can reach 77% when compared with emissions from conventional heating systems[25]. If 40 million homes and/or businesses utilized geothermal heat pumps, a displacement of 1.5 quads[D] of fossil fuels could be achieved. Costs for this would be generally borne by home and business owners; monthly additions of the installations costs to mortgage payments would be offset immediately by monthly energy savings. Achieving this level of utilization could create up to 80,000 jobs each year.[VII]

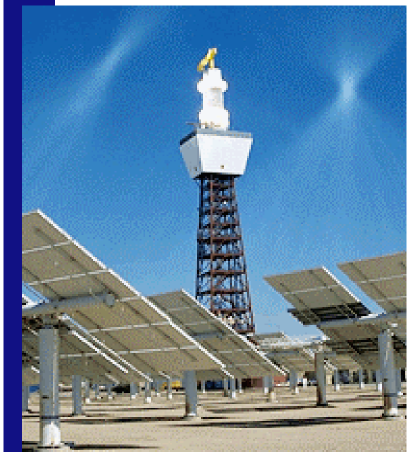
Thus the combined contribution of geothermal energy to our energy portfolio totals 3.5 quads fossil fuels displaced.



Source: Goddard Space Flight Center [22]

Solar Thermal: 9% displacement

In the early eighties, in an attempt to utilize the sun's energy in a radically different way, a consortium of ten companies and DOE designed and built a large scale solar power plant near Barstow, CA, capable of generating 10 megawatts of electricity. Dubbed Solar I, the system utilized an array of nearly 2000 mirrors (called heliostats) which tracked the sun throughout the day, focusing the energy on the top of a 300 ft. tower. In an upgraded version (Solar II), the enormous amount of heat thus generated was stored in molten salt at 1050°F. This heat energy was then utilized over a 24-hour period, creating steam that drove a turbine coupled to an electrical generator. This experimental system was shut down after meeting or exceeding all of its design objectives.



Power Tower II
(source: Solarpaces.org)

Solar Thermal technologies differ from solar photovoltaic in that PV converts solar radiation into electrical energy, whereas solar thermal systems capture solar radiation directly as heat energy, then use the heat energy either for space and water heating, or to drive electrical generating turbines or engines. Solar thermal systems can be as simple as water filled black pipe placed in direct sunlight, a well designed passive solar home or solar concentrators which use reflective surfaces to focus the sun's energy for specific tasks (cooking, drying, driving chemical reactions, generating electricity). Solar thermal space and water heating systems are durable and generally the most cost-effective form of renewable energy, ideal for remote or developing regions where they provide an energy option that leapfrogs fossil fuel development.

Electrical generation: Utility-scale electrical generation utilizes concentrating solar thermal power (CSP): parabolic reflectors focus solar radiation on collectors located at the parabola's focal point, where a liquid or gas is heated to temperatures sufficient to drive turbines or Stirling engines coupled to generators. Most systems' installation costs are projected to be $2-3/watt for the first installations[26]. Although these represent large upfront costs, two points may be considered: first, economies of scale drive costs down; second, coal's costs are rising as environmental concerns over coal are addressed: clean coal technologies, including carbon sequestration, drive coal installation costs up to between $1.80 and $3.00/ watt installed, with wholesale electricity costs rising by 25 to 100%.[27] Given this, CSP installation costs compare favorably.

The southwest region, including California, Nevada, New Mexico, Arizona, Utah and Texas combined, consume 2.2 quads of electricity annually, derived in part from 4.2 quads of primary fossil energy (63% coal, 37% natural gas)[28]. There is sufficient minimum solar resource in the region to replace this entire fossil fuel requirement utilizing CSP.[29]. Additionally, we are proposing that the future US

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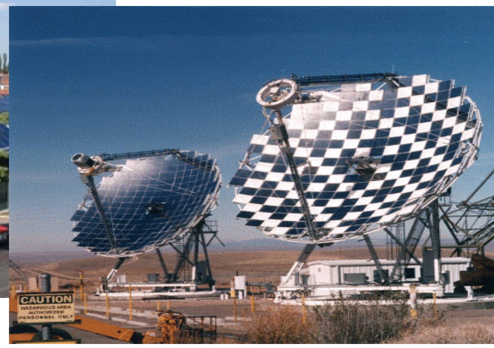
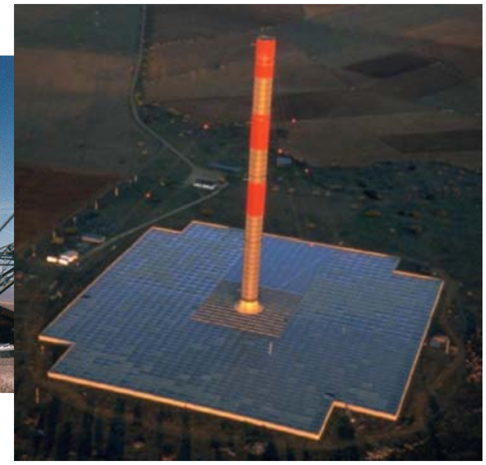




transportation sector should include sufficient electric vehicles to displace 2.7 quads of petroleum. Given that 25% of the US population lives in the southwest, an additional 0.7 quads of electrical primary energy would be required (under a business-as-usual scenario) to charge this fleet. Assuming a mixture of CSP with thermal storage and CSP without storage for peak load supply, with an average capacity factor of 40%, replacing the electricity produced by 4.9 (4.2 + 0.7) quads of primary energy will require 135,500 MW of installed CSP capacity[E]. Furthermore, as economies of scale bring costs down, and the cost associated with carbon-based fuels rise, CSP developed in regions of lower intensity solar radiation in Colorado, Wyoming and Southeastern Oregon will approach cost-competitiveness, with the potential to generate at least 0.3 quads of electricity, displacing 1.0 quad fossil fuels (total CSP will be 5.9 quads displaced). Assuming a lower capacity factor of 20%, 50,000 MW of CSP will need to be developed in these areas. Using the higher projected value of $3.00/watt installed, total cost for 185,000 MW of CSP will be $555 billion over 15 years, or $37 billion/year (0.34%GDP). Job creation potential will be around 185,000 jobs/year[VIII].

Space and water heating: Solar water heating provides a cost-effective solution for reducing fossil fuel use in residential, commercial and industrial applications. Used in 1.5 million homes, solar water heating systems are reliable in all climates. Costs range from $1500 to $4000 for an average household, and energy saving estimates range from 50-80%. When added to a 30-year mortgage, monthly system payments are generally offset by reductions in energy bills, resulting in a positive net cash benefit immediately[30]. We propose that 50% of American households (53 million) will utilize solar water heating, realizing a displacement of 0.8 quad of primary fossil fuels[G]. Commercial water heating (1995 figure) consumed 1.0 quad; if we assume a proportional displacement as realized in residential applications, another 0.5 quads could be displaced[H]. Data for industrial water heating were not available; however, industrial energy consumption is 1.5 times residential, and water heating is a major part of industrial processes. A conservative assumption that industrial water heating can achieve proportional energy conservation yields a savings of 1.2 quads[I]. Achieving the 50% benchmark for installations will generate manufacturing, installation and maintenance revenues nationwide, create tens of thousands of jobs and provide critical economic support for communities and small businesses.

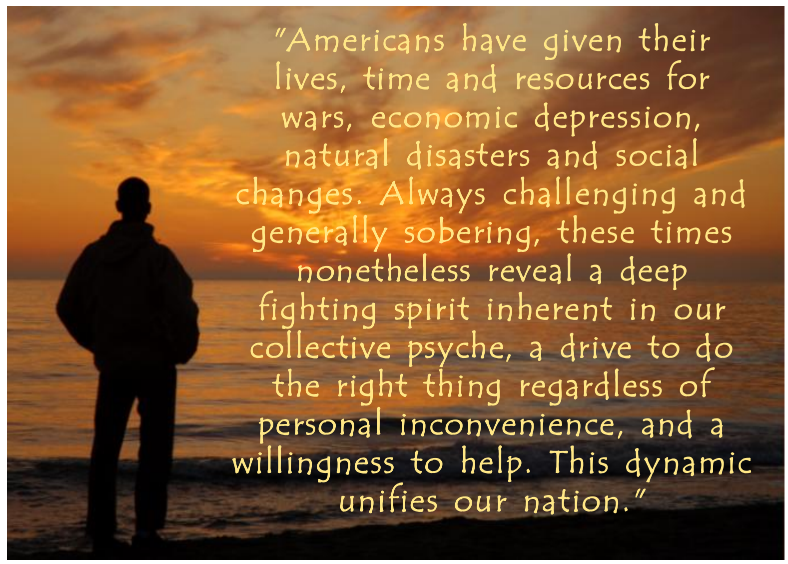
Solar thermal space heating: Energy savings estimates are difficult to make at this time. Given that 10% of residential energy use is for space heating, and that combined use of energy by residential, commercial and industrial sectors totals 73 quads, we make an estimate of a 10% across-the-board space heating requirement (7.3 quads) for these three sectors. If, as seems reasonable, a 10% savings in energy could be achieved via passive solar space heating, 0.7 quad of energy could be saved.

The total displacement of primary fossil fuel energy by solar thermal technology will be 5.9(CSP)+2.5(solar water heating)+0.7(solar space heating)=9.1 quads.

Conservation/Lifestyle: 18% displacement

"You are not here merely to make a living. You are here in order to enable the world to live more amply, with greater vision, with a finer spirit of hope and achievement. You are here to enrich the world, and you impoverish yourself if you forget the errand."
-Woodrow Wilson

Throughout American history, national crises have spurred citizens to serve and sacrifice for the benefit of their nation and their neighbors. Americans have given their lives, time and resources during wars, economic depression, natural disasters and social changes. Always challenging and generally sobering, these times nonetheless reveal a deep fighting spirit inherent in our collective psyche, a drive to do the right thing regardless of personal inconvenience, and a willingness to help. This dynamic unifies our nation.



Global warming may be the greatest threat currently facing humanity in general and our nation in particular. Countering its effects will demand participation from each citizen, requiring changes in habits and moderation of energy use. We may choose to do this now or be forced to later; let us be proactive. We must first embrace a simple truth: Americans consume more energy *per capita* than any other industrialized or large nation (China and India are not even close). By comparison, France, Germany, Japan, the UK and Spain all enjoy high standards of living, yet per capita energy consumption is half or less that of the U.S.[31] The longer we deny this fact, or rationalize it, the longer we delay finding new means to live full, rich lives that accommodate responsible energy use.

Rosie Revisited calls on Americans to reduce personal energy consumption by 18%. While this may initially seem like a substantial cut, Americans need to know that they can maintain their standard of living *easily* with 18% less energy use. We feel that the trade-off of 18% for the opportunity to be actively involved in a real solution will be attractive to all but the most entrenched American consumer. Sanguinely termed "Yankee ingenuity", American imagination will surely present us with a multitude of energy saving practices. Depending on individuals' and families' abilities, needs and resources, bold actions taken could add up to greater than 18% reduction in use.

"A man is rich in proportion to the number of things he can let alone."
-Henry David Thoreau, Walden

Of grave concern is the overall economic impact of reducing consumption. We are aware that an economic downturn would decrease public support for environmental safeguards, and would erode households' ability to afford many of the changes we suggest. Several points are worth considering in this context:

- Rather than a downturn in consumption, there will likely be a redistribution in types of goods consumed. Purchase of fewer high quality, longer lasting and energy efficient goods of higher dollar value would replace purchase of many disposable, energy inefficient and often marginally useful goods. As an example, organic foods and products, bearing USDA organic certification, command a higher dollar value, and people choose to pay more for the ecological and health benefits that these goods bring. Similarly, consumer goods in a carbon-constrained economy, bearing ecological certification guaranteeing lower ecological impact, can be expected to bear a higher purchase price. Thus, consumers may be expected to trade *quantity* of goods consumed for *quality*, with the dollars spent remaining relatively constant.

- Increased employment opportunities in the manufacturing, distribution and installation sector will provide increased income.
- Impacts of climate change will also exact an economic toll; the effect of this toll on consumer confidence will be impossible to predict.

Therefore, the importance of a national dialogue and leadership cannot be stressed enough, especially when wrestling with the dynamics of consumption and economic growth in an energy-constrained world. Only proactive planning provides a hedge against inevitable challenges.

Wave/Tidal Power: 0.5% Displacement

For anyone who has contemplated the formation of the Grand Canyon, fought currents in a boat, or witnessed the destructive power of flooding during storms, moving water represents a powerful force of nature. The Earth's oceans are an enormous reservoir of moving water, and as such, are an as-yet untapped energy resource. Each day, uneven heating of the oceans by solar radiation create powerful winds which, traveling thousands of kilometers over the surface, generate waves that eventually collide with the continents along coastal regions. Additionally, the combined gravitational pull of both the sun and the moon create tides which ebb and flow at continental boundaries. Both of these forms of fluid motion can be converted into electrical energy, and a wide variety of experimental and demonstration projects (see http://www.bwea.com/marine/devices.html) are laying the foundation for developments with no greenhouse gas emissions, minimal environmental impact, and a negligible visual toll. A 240 MW tidal facility in France and a 20 MW facility in Nova Scotia have been in successful continuous operation since the 1960's and 1984, respectively. This year, Ocean Power Delivery Systems (UK) signed a contract with a Portuguese consortium to build the first phase of the world's first wave farm (22.5 MW) off the coast of Portugal.

Tidal currents typically have power densities (quantity of power moving through a square meter per unit time) similar to wind, on the order of 0.1 to 1.0 kW/m^2 in good locations. Wave power, by comparison, can be from ten to seventy times as powerful as tidal currents, having power densities from 40 to 70 kW per meter of wave crest (or meter of shoreline).[34,35] Given the extensive coastal regions in the US and globally, these resources are under intense study.

Wave power globally has been estimated at a staggering 2,000,000 MW (total global installed electrical capacity from all energy source is 3,500,000 MW). Economically recoverable wave energy (global) using existing mature technologies range from

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140 to 750 Terawatt-hours/year (0.5 to 2.5 quads)[36]. The US' portion of global wave energy is estimated at 2,300 terawatt-hours/yr, or 7.8 quads[37]. How much of this is economically recoverable is not yet known; however, even a small fraction of this potential could displace a respectable amount of fossil energy. Given the enormous potential, the flood of wave energy conversion technologies under construction and the interesting fact that speculators are already applying for permits in regions of good to excellent tidal resources, we predict that wave/tidal technologies will mature to a level of competitiveness in certain niche markets within 15 years, with the capability of displacing 0.5 quads of fossil fuels. If we assume a capacity factor of 0.33, this level of generation will require 16,700 MW of tidal and wave capacity (2% of the estimated US wave resource). Costs for these systems are rough estimates, due to their being in the experimental stages. Various manufacturers of wave energy conversion devices put cost estimates in the range of $3-4/watt[38]; tidal power cost estimates are around $2.50/ watt installed[39]. These are for demonstration units; costs for full-scale commercial applications would enjoy cost-reductions. If we assume a cost of $3.00 per watt installed, this level of development will cost $50 billion over 15 years, or $3.3 billion per year (0.03% GDP). Job potential figures are presently unavailable.

> Addressing the problems of global warming and peak oil, utilizing a diverse portfolio of renewable energy resources, presents one of the greatest challenges: integration of these resources into a reliable, robust national energy system. Perhaps no single component of the energy infrastructure underscores the need for comprehensive national planning and leadership more than the national energy transmission system—the grid.

National Transmission Grid Upgrade

Utilizing a diverse portfolio of renewable energy resources to address the problems of global warming and peak oil raises the challenges of integrating these resources into a reliable, robust national energy system. Perhaps no single component of the energy infrastructure underscores the need for comprehensive national planning and leadership more than the national energy transmission system—the grid. It is one thing to advocate for harvesting the vast wind energy potential in the Great Plains to power large metropolitan centers; it is quite another to actually get that energy reliably from the wind generator to the customers.

Called the "most complex and tightly coupled system ever constructed for use in daily life"[40], the grid connects several thousand power plants (coal-fired, gas-fired, hydroelectric dams, nuclear and a small but increasing number of wind, solar and biomass generators), through a 156,000 mile web of high voltage cross-country power lines and lower voltage distribution lines, controlled by transforming stations to increase or decrease the voltage (so that you don't accidentally switch 500,000 volts into your toaster) and governed by an assemblage of regulatory instruments whose paperwork probably rivals the US tax code. Power operators who control electricity on the grid must supply electricity to customers when they need it, immediately available, 24 hours, day in and day out. The grid itself cannot store electricity; consequently, power controllers must exactly balance each kilowatt-hour of demand ("load") with a kilowatt-hour of electricity, utilizing an armada of power plants capable of meeting peak demand. Because electrical load varies over time (see figure 4), operators must plan ahead (days and weeks) to match demand with supply. Consequently, power operators rely on two critical tools: on-demand energy sources and a highly reliable grid. If either of these operates less than optimally, costly blackouts occur, incurring losses of $25 to 180 billion[41] annually.

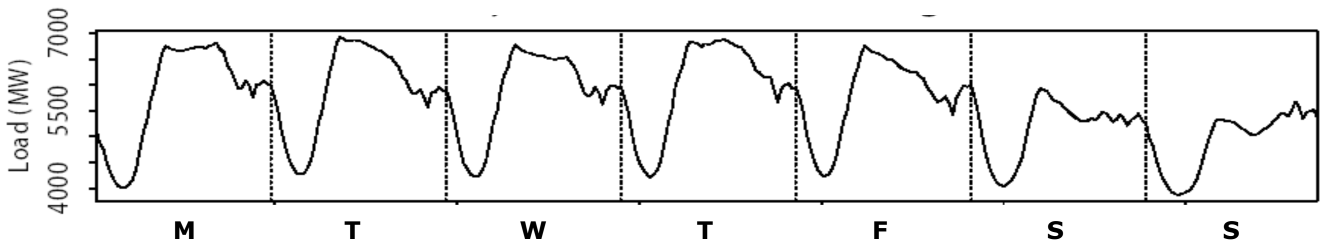


Figure 4: Sample electrical load fluctuation for a one-week period[42]

With respect to the grid, two major challenges face the large-scale incorporation of renewable energy: First, large distances often separate the resource (e.g., wind energy from the Great Plains or solar from the deserts) from demand centers. Many renewable power systems will require extensive development of transmission capacity to carry the energy from resource to consumers. Second, many renewable resources (e.g. wind, solar and eventually wave power) are not available on demand, but vary in strength over weekly, hourly or even minute by minute time frames, governed by the caprice of nature. As a result, operators must use new strategies when planning supply. Both of these factors will incur substantial costs to a revamped national energy system. Given the costs associated with climate change and volatile conventional fuel prices, and the essentially nonexistent fuel costs of renewable resources, as well as the merits of improving electrical infrastructure as a stand-alone goal, the costs of improving the grid are merited.

Future grid development is an opportunity to break with outmoded business-as-usual planning, and encourage long-term thinking and innovation: "System engineers, who have been weaned on centrally dispatched technologies, see the challenge as making (intermittent resources) fit into the existing system, when the emphasis, rather, needs to be on re-engineering the electricity production-delivery process to accommodate a variety of 21st century needs, including the integration of wind and other variable-output sources."[43] Capitalizing on renewables' strengths can yield dividends: for instance, solar power (both photovoltaic and concentrating solar power) have peak output in the middle of the day, which coincides with peak demand in a majority of southwestern, western and southern states. Peak electrical power in many of these regions commands a premium value; solar power in these markets thus has a high value and can displace a larger proportion of conventional generation than in an area with a peak load in the evening. Studies on the effect of interconnecting wind farms across diverse geographic regions show that wind patterns are complementary: that when one farm is becalmed, the likelihood that a distant interconnected farm is experiencing good wind is high: enough so that such an interconnect can reliably supply a percentage of power round the clock (baseload power)[43.1]. Other studies demonstrate that the reliability of intermittent resources increases when several different resources are integrated into one system: Wind and solar in a given region may complement each other in terms of peak output periods; when neither are producing, a gasified biomass combined heat and power plant can fill in as backup[43.2]. Other strategies involve:

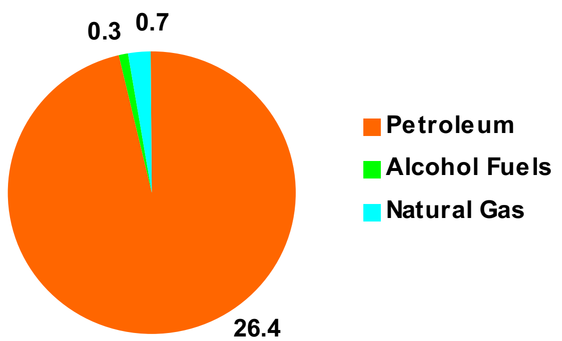
- Time-of-use rates, wherein the rate structure of electricity is changed, with peak hour rates being higher than off-peak rates; this change will encourage consumers to modify use to take advantage of off-peak electricity, reducing their contribution to peak load.
- Using efficiency to reduce the amount of electricity that is required at any time.
- Improving forecasting of wind and solar events in order to plan for both their peak and low output periods.
- Support research and development of storage technologies, such that surplus energy produced in off peak hours can be utilized during on-peak periods, increasing the value of intermittent energy.

Conservative estimates for upgrading the grid and adding transmission capacity simply to manage the current system range from 26 to 120 billion dollars[44,45] (these costs could be absorbed into the larger upgrade that would result from a high-penetration renewable scenario, thereby increasing the effectiveness of such costs). The cost of adding transmission capacity for renewables will depend in large part on the proportion of distributed versus centralized power that is planned: the more decentralized the system, the less additional transmission capacity, and therefore cost, required. However, assuming large-scale development of the Great Plains wind and Southwest solar resources, increased high-voltage line capacity costs could run to over $156 billion over 15 years[L]. Additional costs incurred from incorporating intermittent resources (planning costs, backup power costs, power purchases) could add $50 billion annually. Storage technologies would add an additional $30 billion annually. Total grid costs for a high renewable energy scenario could run $90 billion per year, which is 0.9% GDP. When compared to the annual power outage costs to the economy mentioned ($25-180 billion, or 0.2-1.6% GDP), the grid costs for renewable energy appear to be within reasonable parameters.

Transportation

Figure 5

2004 Transportation Sector Energy Consumption (quadrillion BTUs)[47]



The US transportation sector consumed 27.5 quads of primary energy in 2004 (figure 5). Consumption of 130 billion gallons of gasoline and 40 billion gallons of petroleum diesel released 1.7 billion tons of CO_2 into the atmosphere, roughly 7%[M] of the world total CO_2 emissions. Petroleum imports total 12 million barrels per day at a cost to the US consumer of **$500,000 *per minute* ($263 billion/year)**[46]**.** Transportation's large energy share, coupled with petroleum's desirable high energy density (comparatively high BTUs/kilogram of fuel) presents a challenge to any carbon reduction scenario. However, we believe this goal may be achieved utilizing a diverse portfolio of transportation fuel options (figure 6). The actual fossil fuel displacement achieved by each option is illustrated in figure 7; a discussion of each fuel option follows.

Figure 6

Proposed Transportation Energy Portfolio (percent contribution)

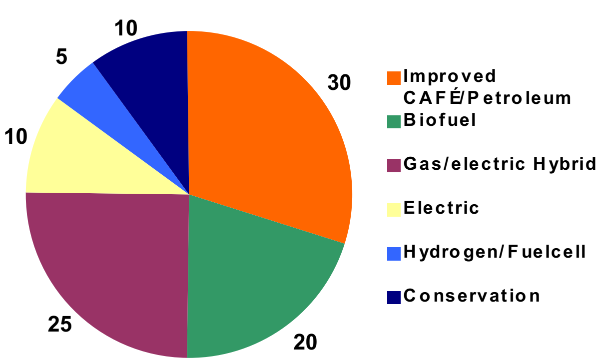
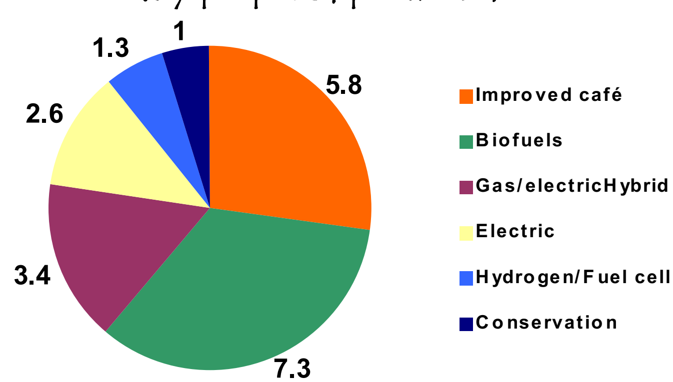


Figure 7

Quads Fossil Fuels Displaced (by proposed portfolio)



Conservation

A clear choice for all Americans is conservation. This does not mean simply demanding everyone give up their cars and walk or forcing people to purchase a one-size-fits-all minicar. Rather, it means presenting a simple challenge: there are typically 30 days in a month, 20 of them workdays. Can we creatively reduce our driving by 3 car-days per month—2 workdays and 1 weekend day, for the sake of our children's future? Options are varied: carpooling, public transportation, walking, biking, organizing errands/shopping to reduce trips throughout the month, switching to a more fuel efficient car (such that accumulated savings equals 3 days of driving the lower mpg vehicle)…even transportation credit trading: finding someone who will reduce their driving by an amount equivalent to theirs + your driving days, in exchange for a service you offer (at no increase in energy cost, of course!) The result of this single step: a reduction of 500,000 barrels of oil consumed per day, equivalent to a savings of $30 million per day; a reduction of 220,000 tons of emitted CO_2 per day, and a respectable reduction of 3% of our total transportation energy budget: 3%, 3 days/month.

Biofuels

Scratching the surface of biofuels initially produces an intoxicating scent of simple solutions. Biofuels are liquid fuels that are plant-derived, can be burned in standard and advanced/hybrid internal combustion engines (ICE), thus providing a replacement fuel which would work well in the existing fuel infrastructure. Biofuels are produced from regional agricultural feedstocks: as homegrown fuel, it addresses the issue of fuel supply security and price volatility as petroleum resources come under increasing demand from developing nations. Biofuels offer the potential for major greenhouse gas emission reductions: the CO_2 released to the atmosphere through combustion of such fuels was originally removed from the atmosphere via photosynthesis in the feedstock plant, resulting in a theoretical net zero CO_2 emission. However, the environmental and energy benefits derived from biofuels depend strongly on types of feedstocks used to produce the fuels (e.g. corn vs. waste cellulose for ethanol, soybean vs. rapeseed for biodiesel). Lifecycle assessments are increasingly shedding light on the cost-to-benefit ratio for biofuels, and must be included when determining which agricultural crops are slated for large-scale development. At present, ethanol from cellulose (as opposed to grains. corn, wheat) offers the greatest greenhouse gas (ghg) reduction (75-95%) and fossil energy reduction (85-95%)[48], although cost competitiveness has not been demonstrated. Biodiesel from rapeseed or sunflower oils offer reductions of up to 78% in ghg and 75% in fossil energy use.[49]

To what extent can biofuels displace fossil energy and ghg reductions in an aggressive national plan? The DOE/USDA feasibility study (ORNL 2005) indicates a potential to replace 5.5 quads of fossil fuels nationally with 5.5 quads of biofuels. How far can we stretch this energy, and what fossil fuel displacement can be realized? As long as

CAFE standards remain stuck at low levels, expect minimal impact on fossil fuel use by biofuels. If CAFE standards are increased to 36 mpg, thereby easing demand on a relatively modest supply of biofuels, the use of such fuels, in conventional internal combustion engines, should be capable of displacing 7.3[N] quads of fossil energy. Utilization of biofuels in advanced hybrids, especially plug-in (see below), has the potential to displace more than 10 quads[O] of fossil fuels.

Hybrid Gasoline/electric

Hybrid vehicles use an integrated gasoline engine/electric motor drive with regenerative braking. This is a current, state-of-the-art technology which is economically and technically viable, currently enjoying an annual growth rate of 88%/ year. Typically, mileages for true hybrids range from 30 to 60 mpg. Modest industry predictions, assuming an accelerated growth to 2020, give hybrids 25% of the auto market by that date. In our scenario, we have assumed these to all be gasoline hybrids, although there is potential for biofuels or hydrogen hybrids. We also assume a modest fuel economy of 50 mpg (already achieved by current standards) by 2020 for the American hybrid fleet (cars, light trucks and SUVs). This is a 100% increase in fuel economy over the current 24 mpg, and translates into a 50% reduction in fuel requirement. If hybrids comprise 25% of the transportation sector, then the amount of petroleum displaced will be 3.4[P] quads. (If technology can achieve a 75 mpg CAFE standard for hybrids, the 200% increase in fuel economy would translate into a 66% reduction in fuel requirement, with a realized displacement of 4.5 quads of fossil fuel. This is currently achievable via plug-in hybrid technology: hybrid cars with larger battery capacity that can plug in for home or at-work recharging. Here, we are assuming the electricity required will be from a grid which is 80% renewable. However, we will use the conservative CAFE standard of 50 mpg across the entire hybrid fleet).

General Motors built 800 EV1 electric vehicles for lease between 1996 to 2002; owners' responses were generally positive to militantly supportive[50]

Electric vehicles

Electric vehicles offer an excellent, long-range solution for GHG reductions. A national fleet of urban and suburban electric commuters, recharged using renewable energy, offer the only true near-term zero emission transportation option. Both vehicle and recharging technologies are available, but production and public acceptance are currently lacking.

State-of-the-art production electric vehicles have demonstrated a range of 75 to 130 miles on a full charge, reaching (governor-limited) speeds of 80 mph, carrying two people and recharging in 4 to 8 hours. General Motors built 800 EV1 electric vehicles for lease between 1996 to 2002; owners' responses were generally positive to militantly supportive[50]. Unfortunately, and controversially, GM scrapped this program in spite of public outcry. Toyota's RAV4EV posted similar performance figures. Again, production was discontinued, but many vehicles remain on the road. Critics argue that electric vehicles are impractical for average Americans' needs. Comparing a 60-80 mi/ charge electric vehicle to a standard gasoline vehicle with a two to three hundred mile range is valid only for cases wherein a longer-range capability is required, and an electric vehicle cannot fill this need (yet). However, when compared to an urban gasoline vehicle that commutes to work, ferries the kids or goes to the store, an electric vehicle can provide comparable performance with greatly reduced fuel costs and emissions. Given that 50% of Americans live within 13 miles of work[51], one must ask if a 250-mile range (gasoline) vehicle is appropriate? Since 60% of US households own 2 cars[52] and, for the first time, there are more cars than drivers to operate them[53], it is entirely appropriate that automobile-commuting households choose to own both a long-range and a (short-range) electric commuter vehicle. As wind and solar begin to penetrate the energy market, a greater proportion of renewable electricity used for vehicle recharging will displace fossil fuel–derived electricity.   Our transportation portfolio posits that 10% of current vehicle type will be replaced by electric vehicles (representing 2.7 quads of fuel). The actual fossil-fuel displacement, assuming recharging electricity is 80% renewable grid-based, would be 2.6 quads[Q]

Hydrogen and Fuel Cell Vehicles

Considerable interest, research and investment are currently focused on both fuel cells as automotive power plants and hydrogen as the energy carrier to power them. Many questions remain regarding hydrogen's future as a universal fuel. Among these are sources (fossil reforming vs. renewable electrolysis from water), storage and transportation, potential environmental effects from leakage, costs, and safety and suitability in various power plants. Similarly, fuel cells have not reached the reliability and durability required for general automotive use. However, it is likely that a decreasing supply, and increasing cost, of petroleum, as well as potential limits on biofuels, will drive hydrogen development in the US forward. Based on prototypes from General Motors, Toyota and Honda[53.1] we conservatively, yet optimistically project that a hydrogen-powered fuel cell vehicle will be ready within fifteen years and will command approximately 5% of market share by 2020. Particular attention should be focused on regional electrolysis centers that utilize either local (distributed) wind or solar generating capacity and/or excess renewable grid-electricity generated during off-peak hours. As hydrogen can replace fossil fuels, 5% of the market translates into 1.3 quads displaced (provided hydrogen is generated from renewable resources).

Improved CAFE Standards

In 1975, the federal government enacted Corporate Average Fuel Economy (CAFE) standards, resulting in nearly doubling of the fuel economy for cars over the next decade. Most of these improvements were accomplished through cost-effective measures (engine efficiency and weight reductions), without compromising vehicle safety or interior volume. However, CAFE standards for cars have crept up dismally since 1985, then fallen slightly with the popularity of the inefficient SUV, in spite of technological advancements, and the combined light duty fleet average now stands at 24 mpg, compared to the 25.9 mpg average achieved by 1986 (decrease due to larger SUV market share). According to the American Council for an Energy Efficient Economy, engineering analyses show that raising CAFE standards by 5% per year for 10 years and 3% thereafter "..is feasible and could be achieved using "conventional" (non-hybrid) technologies through a combination of streamlining, reduced tire rolling resistance, engine improvements, optimized transmission, and effective use of the upcoming transition to higher voltage automotive electrical systems."[54] This schedule would improve fuel economies to 50 mpg by 2020, with a savings of 4.7 million barrels of oil per day[55] ($280 million/day at $60/barrel). The increased retail cost for vehicles would be recouped by consumers as savings at the gas pump. Perhaps one of the most cost-effective and technologically immediate solutions, implementing aggressive CAFÉ standards of 50 mpg by 2020 will translate into a savings of 5.8 quads of fossil fuels[R].

Energy Wild Cards

Throughout the course of a given technology's evolution and maturity, serendipitous discoveries have pushed advancement in often-spectacular runs, leaps and spikes. With renewable energy, we might expect technological breakthroughs that will provide unexpected benefits; some of these are reviewed here. We make no predictions regarding how each will fare: however, based on past examples, there is a reasonable probability of a new technology emerging that is economically competitive. How much fossil fuel may be displaced is equally difficult to predict; however, we conservatively posit that these "wild cards" will provide a buffer to unexpected failures in the emerging renewable energy industry, increasing the probability of a net overall success (fossil fuel reduction at economical rates).

Railroad rebirth: moving freight by rail is three times more energy efficient than by heavy truck. One option is to shift long-haul freight from trucking to rail, using trucking for local deliveries from railheads. In 2001, 3.5 quads of petroleum were consumed by combination trucks[56]; shifting half of this freight to rail would reduce fossil fuel consumption by 1.2 quad[S]

Carbon sequestration: removing CO_2 from exhaust gases (post-combustion) or from fuels (pre-combustion) is termed "carbon capture." Burying resultant CO2 into stable reservoirs is called carbon sequestration [carbon sequestration occurs in nature via photosynthesis ($CO_{2atmospheric}$ convert to sugars) and marine shell formation ($CO_{2atmospheric}$ convert to calcium carbonate)]. Research into carbon sequestration is at the forefront of "clean coal" technology. Its success would effectively reduce coal's greenhouse gas emissions, and it is thus becoming the poster child of the coal industry's attempt to move a 19th century fuel into the 21st century climate debate. Many uncertainties surround carbon sequestration. Long-term studies for carbon's stability and ability to stay put, as well as environmental impacts to sequestration, are lacking; additionally, cost-effectiveness of this technology remains uncertain. Cost estimates for capture, transportation and sequestration of carbon dioxide range from $50 to $300 per ton. To put this cost in perspective, in 1999, the US emitted 1.8 billion metric tons of CO_2 from coal combustion[57]. The resulting costs for sequestration would range from $90 billion to half a trillion dollars annually, a dollar value which would completely underwrite the development of sufficient wind, solar PV and solar thermal power plants to displace all current coal generation in 15 years.

> moving freight by rail is three times more energy- efficient than by heavy truck.

Until proven economically, technologically and environmentally viable, we consider carbon sequestration to be a wild card. GlobalWarmingSolution.org envisions the eventual phase-out of coal plants by virtue of market forces, as renewables' costs decrease and external cost assessments unveil the actual cost of fossil fuel use. However, new coal plants that stay on-line to fulfill financial obligations will provide a smooth transition to renewable energy, provide (marginal) firming for intermittent power sources (wind and solar), and will be the electrical generating workhorses during the initial phases of the transition. Given coal's consumption of 21 quads of primary energy for electrical generation, and given the eventual reduction of coal's market share by 80% by 2025, the remaining online generation could conceivably still be using 4.2 quads of primary energy, the emissions for which could all be eliminated by carbon sequestration, if successful.

Nuclear Fusion: Although considerable funding continues to ply the mysteries of the nuclear strong force and the conversion of abundant hydrogen into helium with virtually no hazardous wastes, sustained fusion reactions that generate net positive energy tenaciously evade researchers. This is perhaps the wildest card of all; if it happens, the energy benefit will defy comprehension. At this juncture, we must suspend judgment.

The Issue of Coal

As natural gas prices flare up and petroleum bloats to $70 a barrel and beyond, coal is re-emerging as a front-runner fuel to satisfy an America desperate for cheap energy, whatever the cost. As of November 2005, 129 new coal plants have been proposed nationwide as utilities scramble to fill the gap between electrical demand and generating capacity. The combined proposed capacity is 77,000 MW, which will provide the electricity equivalence of 77 million homes, carrying a reported price tag of $104 billion for capital investments[58]. Given coal's potential environmental impacts, magnified now through the lens of climate change, we must demand to know what actual costs this figure represents, and what does it fail to represent?

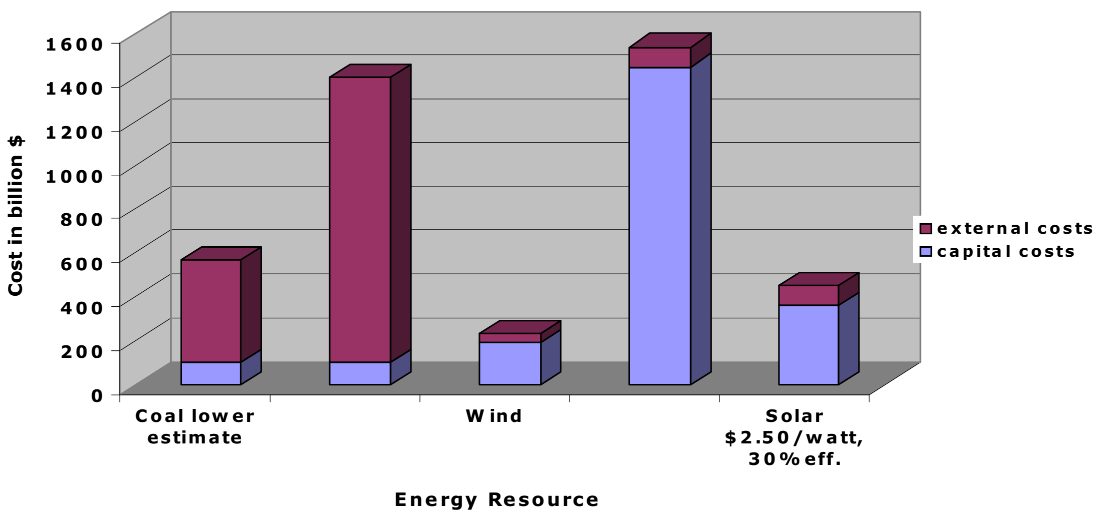
One hundred four billion dollars would cover the costs of leases, permits, environmental assessments, development and construction costs for 129 plants. Although estimates vary, the job potential ranges from 70,000 to 150,000 construction and 6,000 to 15,000 permanent (operation and maintenance) jobs offer needed employment. These plants might be expected to pay $250 million in local, state and federal taxes. All of this, and we can still expect to pay a national average of around 8 cents a kilowatt-hour (kWh) for electricity.

The $104 billion capital outlay, plus ongoing operation and maintenance costs (fuel, labor, taxes, insurance, environmental reclamation, etc.), all exist within certain spatial, economic and temporal boundaries: They begin at the time and location from which the coal is removed from the ground, through transportation of coal, operation of the plants, mitigation of regulated environmental impacts, and ending in retail distribution of the electricity and disposal of wastes. These costs are the *internal* costs of energy production and are part of a standard economic accounting for any business. Beyond these spatial and temporal boundaries, however, are other costs, directly attributable to the activity but generally ignored by cost-accounting. These, ultimately, are borne by the American consumer's pocketbook. Such *external* costs come from air and

water pollution, land degradation from mining and waste disposal, health impacts, and impacts on communities once a mine or power plant closes. In the case of coal, external costs , if accounted for, would increase the cost of coal-fired electricity by 50 to 100%, above the cost of wind, and approaching the range of some solar applications.

Typical external costs for coal are estimated between 3-8 cents/kWh[59,60,61]. This range assigns a dollar value to impacts on health care, environment, global warming and communities from coal on a per kWh basis. If these external costs are added to utility bills, then the increased revenue thus generated should be used by the industry to mitigate impacts. Although it does raise the rate for electricity, it does finally link the burden of reparation to the correct source, and begins to level the playing field for electricity producers utilizing more benign technologies. How does this assessment impact the cost of the 129 proposed plants? The stated capacity will be 77,000MW total. If plants operate at 75% capacity (typical), then 129 plants will produce 506 billion kWh/year. Assuming a 30-year life span average for all plants, the total 30-year external cost range for the entire proposal will be between $455 billion and $1.2 trillion. (If we extend the assessment of external costs to current plants *plus* projected plants, the total external costs over 30 years will be a staggering $2.2 to $5.7 trillion). These costs dwarf the original value of the plants, and focus sharply the true economics of our electricity choices. It should by now be obvious that a) the hidden costs must be discussed prior to decisions regarding any of the plants; b) the hidden costs will be largely shouldered by the next generation; and c) a transition away from coal and toward renewable energy capacity will yield a savings in terms of avoided external costs. In fact, to a first approximation, the avoided costs are equal to, and would finance, the costs of development of a national grid of wind, solar, geothermal and biomass (Figure 8)

Figure 8: Total Cost Comparisons (30 yr) for Coal, Wind, and Solar [T]



Author's Note: As of this final draft, the National Energy Technology Laboratory's Report, "Tracking New Coal-Fired Power Plants; Coal's Resurgence in Electric Power Generation" dated September 2006, updated from the previous report of February 2004, lists over double the number of plants, 309 at 500 MW each (154 GW total capacity). This report lists, of the 309 plants, the following which will be new technology units: compressed fluidized bed (CFB), 23; supercritical, 13; ultracritical, 2; integrated gasification combined cycle (IGCC), 28. The total, 66 is only 21% advance technology, leaving 79% utilizing 19th century technology. The 2004 report indicated 32% advanced technology.

Beyond the issue of external costs lies an economic time bomb that is almost entirely obscured beneath the $104 billion price tag— built-in inefficiency. Most current coal plants burn pulverized coal, a 19th century technology that is only around 35% efficient, (for every 100 BTUs of energy available in a sample of coal, 35 BTUs are converted to electricity and 65 BTUs are released as waste heat energy, doing no useful work). There are more advanced technologies in coal combustion. Integrated gasification combined cycle (IGCC) plants convert solid coal to a gaseous fuel that is burned in a gas turbine, turning a generator. The hot exhaust gases from the turbine are directed through a heat recovery system that creates sufficient steam to turn a second generator. These plants are capable of removing contaminants (mercury, arsenic, particulates, sulfur and carbon), although these removal steps are energy-parasitic, reducing overall power plant efficiency from a maximum of 50% to 40-45%.[62] Compressed fluidized bed (CFB) technology suspends solid fuels on upward-directed jets of air, resulting in a turbulent, floating region of combusting fuel. This configuration facilitates easier mitigation of nitrous and sulfur oxides (compared to pulverized coal) and is around 42% efficient. IGCC and CFB plants, however, are more costly than pulverized coal plants (by 30 to 90%), and of the 129 plants proposed, only 41 use advanced technologies, leaving 88 "new" coal plants to be built on dirty, archaic technology[63]. If carbon is regulated as a pollutant (which it eventually must be), the net economics of these plants will change overnight from assets to liabilities.

In the case of coal, external costs, if specifically accounted, would increase the cost of coal-fired electricity by 50 to 100%, above the cost of wind, and approaching the range of some solar applications.

We are at a crossroads in energy policy: future development of electrical generating capacity without accounting for efficiency, external costs and greenhouse gas emissions will incur future economic liabilities and adversely affect consumers, owners, investors and communities, while guaranteeing increasing impacts from global warming. The California Public Utilities Commission's recent decision, requiring that electricity purchased by investor-owned utilities come from sources whose greenhouse gas emissions are no higher that those of a combined-cycle natural gas power plant, notifies utilities that coal's business-as-usual stance is now a liability.

CO2 Emissions from Forest Destruction

Although the burning of fossil fuels is by far the largest source of carbon dioxide emissions, deforestation also causes major releases of carbon dioxide. Largely due to the destruction of its forests and peat bogs, Indonesia, for example, is now the world's third largest producer of carbon dioxide emissions, according to a World Bank study released in March, 2007. For this reason it is imperative that the world move promptly to a global eco-forestry system, a transition that is beyond the scope of this white paper.

The Five Other Regulated Greenhouse Gases

Emissions of the five other greenhouse gases regulated under the Kyoto Protocol also need to be sharply and rapidly reduced or eliminated.

Methane emissions will be addressed by phasing out fossil fuels, ending methane escapes from landfills, and making a shift to a global organic agriculture system, another urgent transition that is beyond the scope of this white paper.

Nitrous Oxide emissions will be addressed by phasing out fossil fuels and shifting to a global organic agriculture system (which will eliminate the use of nitrogen fertilizers).

Emissions of the ***industrial gases-hydrofluorocarbons (HFC's), perfluorocarbons (PFC's), and sulfur hexafluoride (SF6)-*** can be eliminated entirely because alternatives exist.

Afterword:
Globalizing Rosie... or What About China and India?

by David Merrill
GlobalWarmingSolution.org Executive Director

Global warming can only truly be addressed by a global solution.

Over the next decade, for example, 1200 new coal plants are slated to come online world-wide, mostly in China, India, and the United States. If this happens, humanity's fate will be all but sealed in a cascade of environmental calamities.

Although *Rosie Revisited* received much inspiration from the U.S. World War II home front mobilization, it is important to bear in mind that the final victory in that war resulted from a joint effort by Allied forces. Similarly, global warming can only be addressed by an international binding treaty mandating clear emissions reductions percentages and firm deadlines for attaining them. This is the only plausible method of ensuring that societal resources and efforts are properly channeled and maximized and that sufficient progress is being made towards the global emissions reduction goal. Only national governments and international bodies have the authority and resources to set and enforce such a regime, optimizing market forces in the process.

We have just laid out in detail how the U.S. can achieve emissions reductions of 80% below 1990 levels between 2010-2025. Yet the IPCC called for immediate, global, 60-80% carbon dioxide emissions cuts in 1990. How are the 80% emissions reductions to be achieved in the rest of the world?

Generally speaking, similar or identical renewable energy and energy efficiency technologies and conservation measures would be employed to achieve emissions reduction targets in both industrialized and developing countries. Furthermore, the costs would be comparable, or perhaps even less in developing countries, than the *Rosie Revisited* costs that we calculated for the United States, one of the highest-cost economies in the world. This "Afterword" is a rough sketch of how global 80% emissions reductions would be assigned, carried out and paid for.

We're Headed for a Big Global Energy Bill, Regardless

The International Energy Agency projects that globally, 550 billion dollars will be need to be invested in energy development, each year, through 2030. The sum would be roughly split evenly between the industrialized countries and the developing countries, or 275 billion dollars for each group of countries, per year.

How much would it cost to provide the same level of energy service, over a 15 year period, from largely renewable sources, and how could this be financed?

Leapfrogging Fossil Fuel Development: *International Renewable Energy Transfer Fund*

"Globalizing Rosie" to the 80% of the world economy outside of the United States, assuming a 4.5 % average economic growth rate for the non-U.S. portion, and 3% of gross world product capital investment per year, would require 2.8 trillion dollars global energy investment each year for 15 years (including U.S. expenditures). However, since the United States is one of the highest cost economies in the world, the expenditures for the remainder of the world economy could be much less. Bear in mind that in World War II, the United States spent 7% of US GDP on the war effort, reaching a one-year high of 38% in 1944. (Humanity currently spends $1.2 trillion per year on the military). Such investment costs would be offset by dramatic reductions in the staggering environmental and health costs of fossil fuel combustion, including the rapidly mounting costs from global warming impacts. This could be the greatest bargain humanity has ever seen…and unlike warfare it would not entail killing people.

About half of this global total, 1.4 trillion dollars, would need to be spent in developing countries. As was stated above, 275 billion dollars per year is projected to be invested in developing countries as a group on the current fossil fuels-intensive energy path. But to get to "Rosie Globally" these countries will need to invest 1.4 trillion. Where will those extra billions come from?

A large proportion of the needed capital would be in the form of profitable private investment. For needed public funds that exceed developing countries financial resources, other revenue sources would need to be developed.

Ross Gelbspan, author of *The Heat is On* and *Boiling Point* has long advocated a small tax on international currency transactions—currently running about 1.9 trillion dollars a day—to fund renewable energy projects in the developing world. Such a tax could cover the shortfall. A tax on international air travel is another potential revenue source.

Of course the developing countries would welcome the assistance available through this "International Renewable Energy Transfer Fund." The harmful ecological side effects of fossil fuel development are often more pronounced in developing countries. In addition, developing countries, like the rest of the world, are already suffering from global warming, and are generally more vulnerable to these impacts as well. We can be confident that an international plan that aims to truly address global warming, and via a method that provides funds for developing countries to leapfrog fossil fuel development, would be met largely with open arms. The aggressive emissions reduction schedule would have to be agreed to, but as this paper has demonstrated, the moral, environmental, and economic case for such a transformation can be made quite convincingly.

Channeling such substantial economic resources towards renewable energy would lead to economies of scale in that industry that would ultimately accelerate cost reductions. And as Greg Easterbrook points out in *The Progress Paradox*, environmental regulations very often end up costing far less than originally projected.

In short, generating sufficient investment capital for the global energy transition is not an insurmountable obstacle.

The second, related challenge is to ensure that humanity makes sufficiently rapid and demonstrable progress toward the global 80% emissions reduction goal. To that end, GlobalWarmingSolution.org proposes the following timetable.

Deep Emissions Reduction Schedule:
Fifteen Years to Secure Humanity's Future

GlobalWarmingSolution.org proposes that in December, 2007 the United States brings a proposal to the United Nations Framework Convention on Climate Change meeting in Bali, Indonesia, that global greenhouse gas emissions be reduced 80% below 1990 levels by 2025. The reductions would be binding on developed and developing countries. Before the end of 2009 the agreement would have to be finalized and agreed upon by the world community. National governments would then have to secure ratification in their home countries so that the treaty would go into force in 2010. (Although the Kyoto Treaty regime runs out in 2012, an aggressive emissions reduction program should start as soon as possible. NASA's May, 2007 warning that we are close to triggering the disintegration of the West Antarctica Ice Sheet alone justifies this). Each developed country, and the developing countries, could apply the *Rosie Revisited* methodology, flexibly, to their unique circumstances, in formulating national plans for reducing their greenhouse gas emissions 80% below 1990 levels between 2010 and 2025.

Starting in 2010 each country would commence reducing their greenhouse gas emissions roughly 6% each year, ultimately reducing them 80% below 1990 levels by 2025.

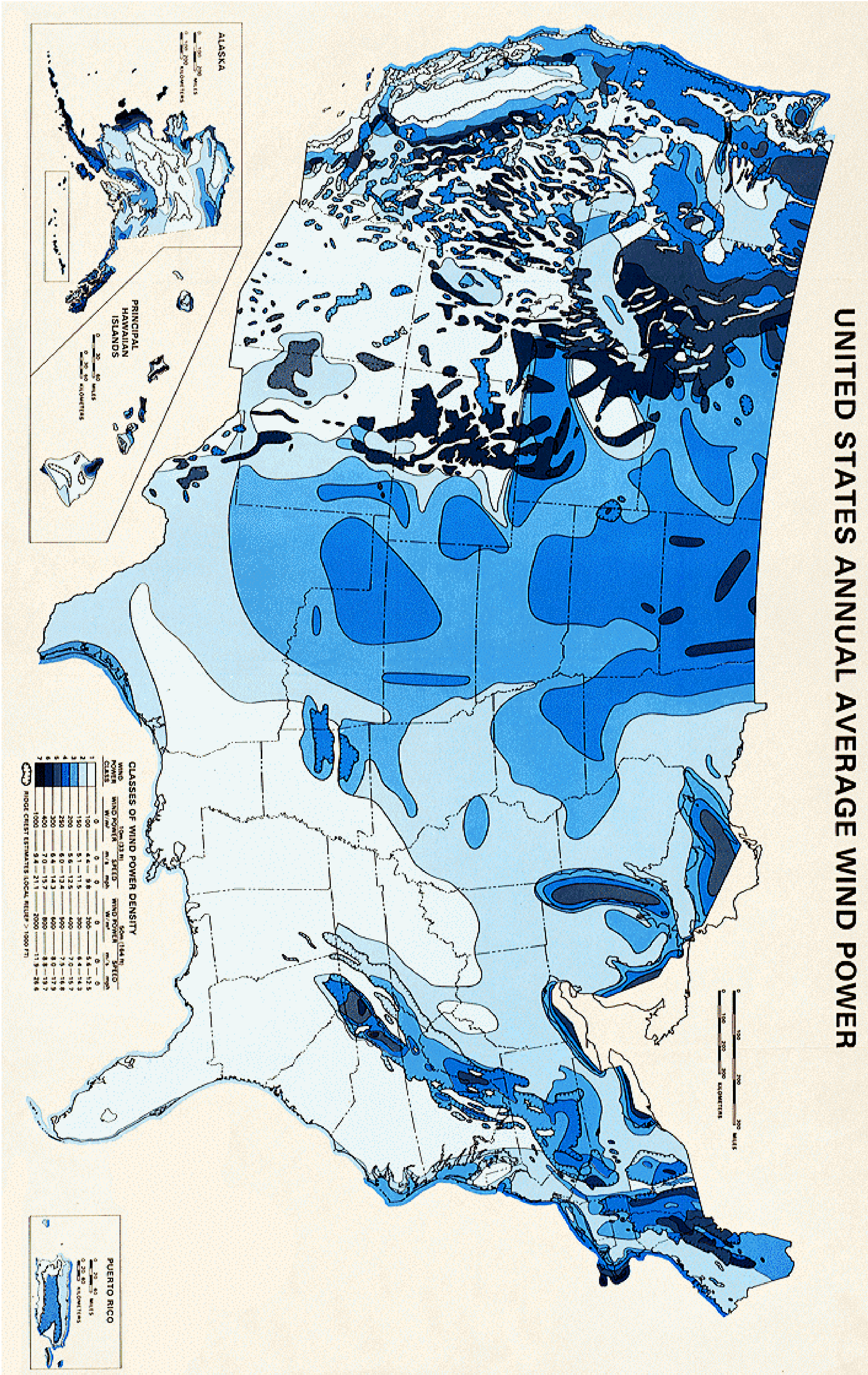
Some argue that wealthy countries should be required to reduce their fossil fuel use at a more rapid rate because they largely triggered the global warming crisis and are disproportionately perpetuating it. GlobalWarmingSolution.org disagrees.

Wealthy, developed countries could be required to decrease their fossil fuel use at a more rapid rate. However, this would probably disadvantage developing countries because they would retain a higher dependency on fossil fuels at the end of the energy transition. Furthermore, since 75% of the greenhouse gases causing global warming were produced by wealthy countries, the payments from the international renewable energy transfer fund can be viewed as payment of damages by the wealthy nations to all of humanity, and most of all, developing countries.

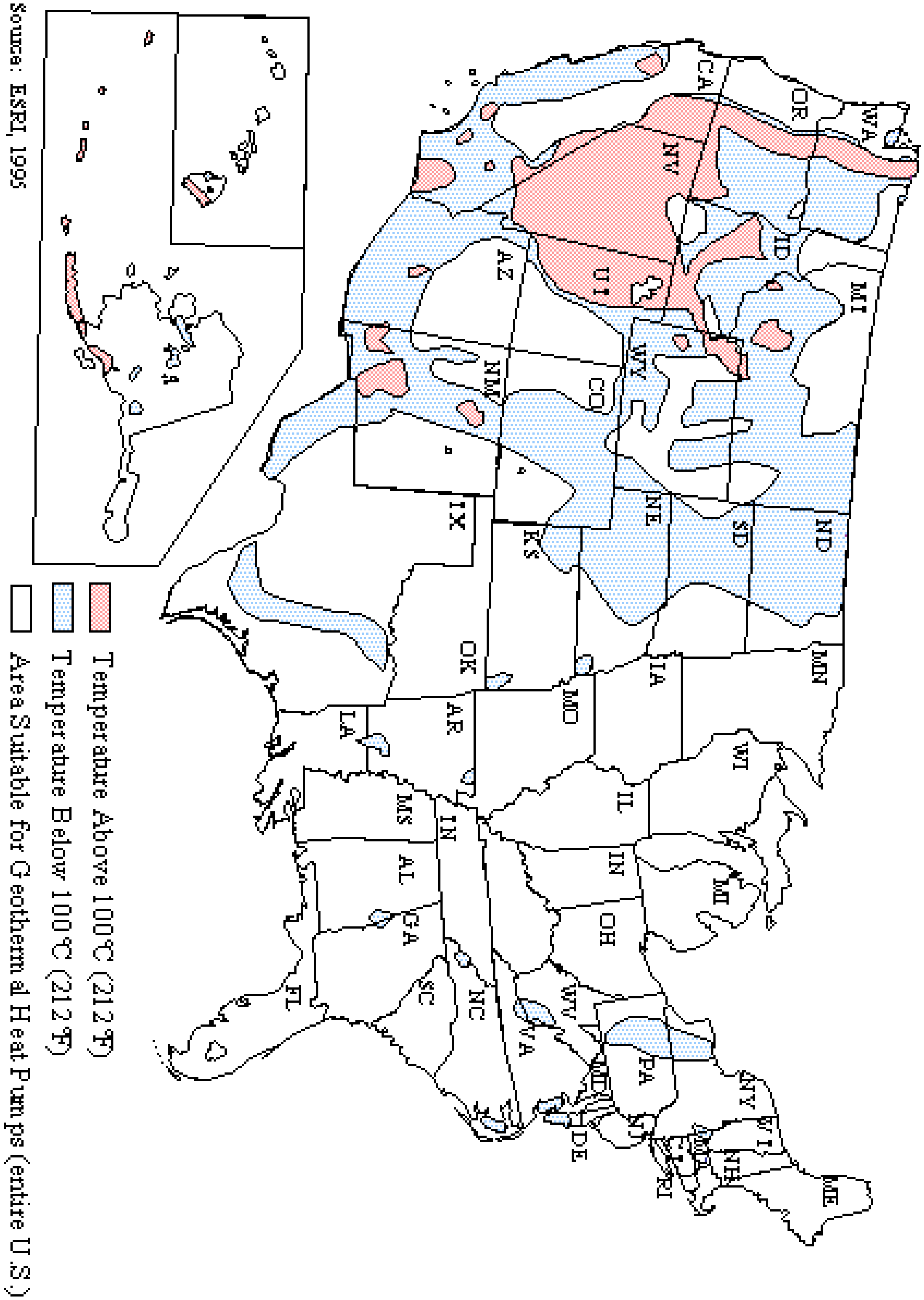
Clearly our proposal entails a high-speed transformation of our global energy infrastructure. But remember, every major industry in the United States was transformed in twelve months in the opening stages of World War II. Why should we cravenly assume that an inspired humanity could not achieve a less dramatic transformation of the energy infrastructure of our global economy in fifteen years?

"Rosie Revisited" would engage all humanity in an inspiring, hopeful mobilization and— in blessed contrast to World War II— it wouldn't involve killing people. Someone once said that "high morale is the touchstone of efficiency". The immensely proactive, positive international project described in this white paper would mean thankfully putting the fossil fuel era behind us and joyfully embracing the Age of the Environment. We would thereby secure our children's future as we watch the dark threat of global warming recede before our eyes. A rationally conceived project that benefited from harnessing the power of the human spirit around the globe has great prospects for success. But we had better get started on it before Nature takes matters out of our hands.

Resource maps follow:
WindResource

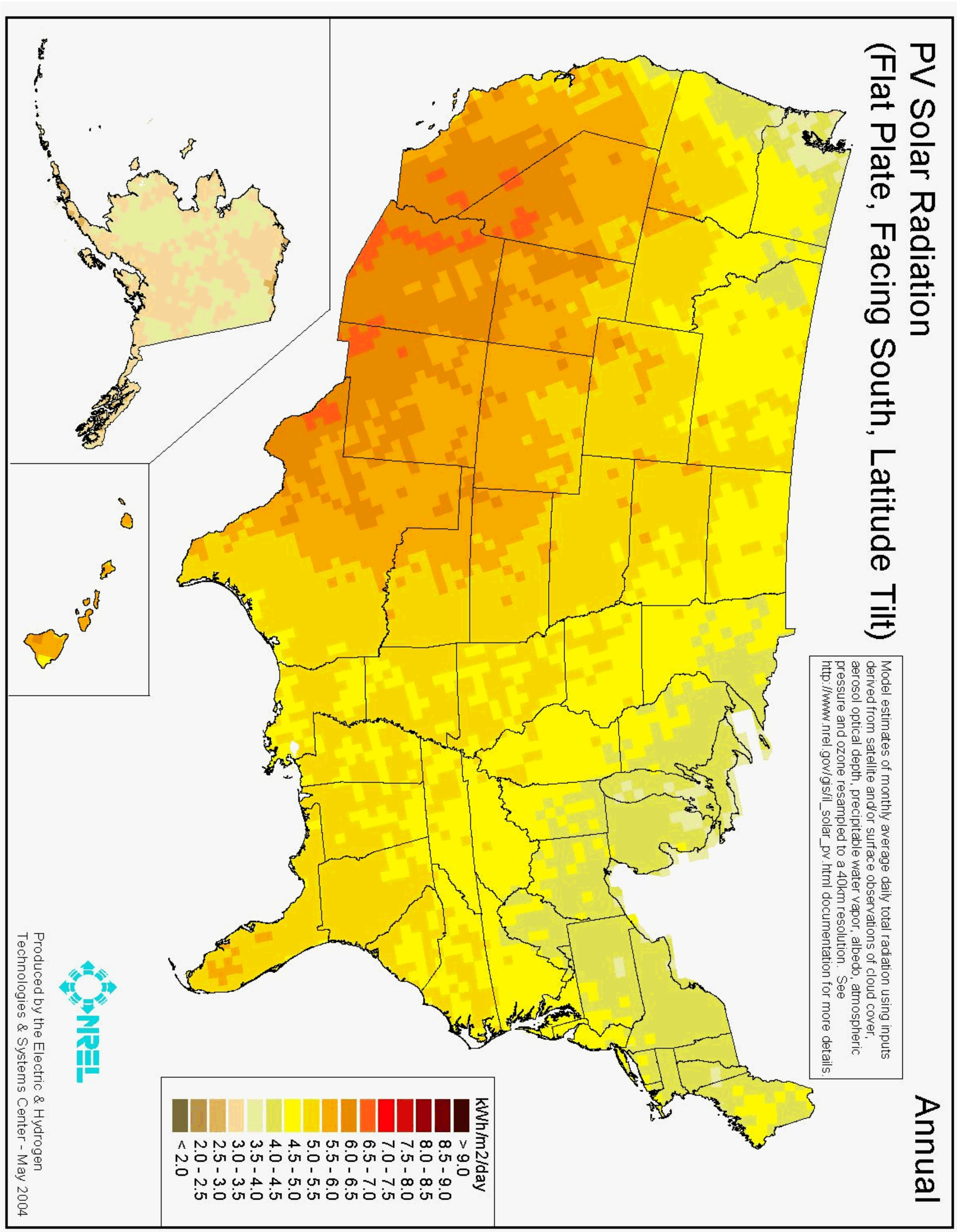


Geothermal Resource



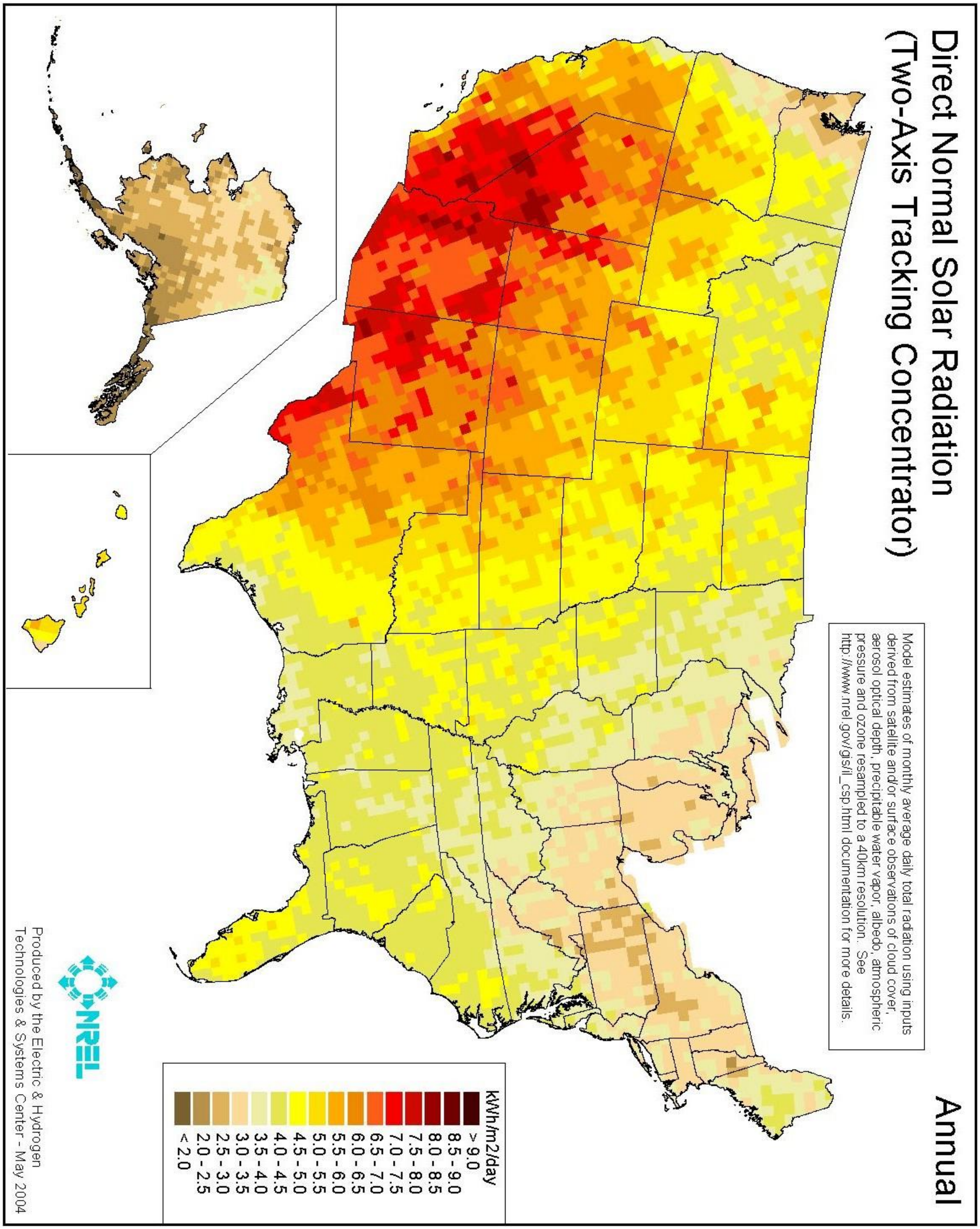
Source: Geoheat Center http://geoheat.oit.edu/images/usmap1.gif

Solar PV Resource



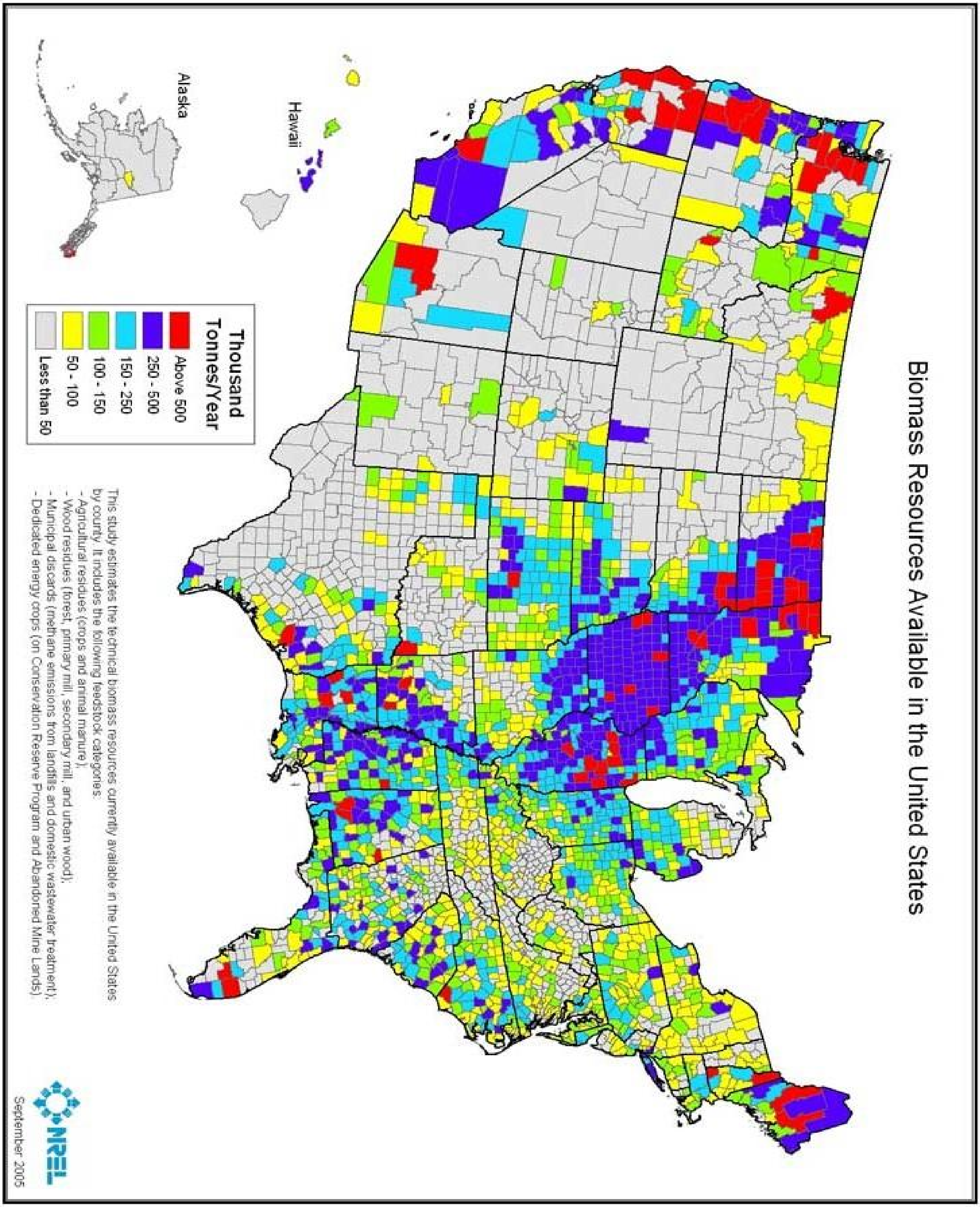
Source: NREL http://www.nrel.gov/gis/images/us_pv_annual_may2004.jpg

Solar Thermal Resource:



Source: NREL http://www.nrel.gov/gis/images/us_csp_annual_may2004.jpg

Biomass Resource



Source: NREL http://www.nrel.gov/gis/images/biomass.jpg

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29. Annual Direct Normal Solar Radiation map http://www.nrel.gov/gis/images/us_csp_annual_may2004.jpg http://www.eia.doe.gov/emeu/international/energyconsumption.html
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33. “Leaking Electricity: Standby and Off-Mode Power Consumption in Consumer Electronics and Household Appliances” Jennifer Thorne and Margaret Suozzo American Council for an Energy-Efficient Economy February, 1998 http://www.aceee.org/pubs/a981.htm
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40. “Getting a Grip on the Grid” Vahid Madani and Damir Novosel
41. “Grid 2030” US DOE Office of Electric Transmission and Distribution publication June 2003 http://www.ferc.gov/eventcalendar/Files/20050608125055-grid-2030.pdf
42. Source: Electricity Load and Price Forecasting Using Statistical Methods and Models Posted by Dr. Michael Smith on Second Moment (the news and business resource for applied analytics) http://www.secondmoment.org/articles/electricity-fig.pdf
43. “Restructuring our Electricity Networks” Shimon Awerbuch March 2004
43.1 "Supplying baseload power and reducing transmission requirements by interconnecting wind farms" C. Archer and M. Jacobson June 25, 2006.

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44. “US Transmission Capacity: Present Status and Future Prospects” E. Hirst, Report Prepared for Edison Electric and DOE Aug 2004
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50. http://www.saveev1.org , http://www.generationev.com/ General Motors EV1 consumer statement
51**.** “Are travel times and distances to work greater for residents of poor urban neighborhoods” A. Khattak, V.Amerlynck and R. Quercia U of NC 1999
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53.1 "Hydrogen fuel cell cars in dealer showrooms by 2015, say industry experts" Canadian Press, April 29, 2007.
54. “Vehicle Fuel Economy Standards: Big Energy Savings at a Modest Cost” ACEEE fact sheet (**http://www.aceee.org/energy/cafe.htm**)
55. Ibid
56. Bureau of Transportation Statistics Table 4-6: Energy Consumption by Mode of Transportation http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_04_06
57. “Carbon Dioxide Emissions from Generation of Electric Power in the United States” July 2000 Table 1 DOE/EPA document http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html
58. National Energy Technology Laboratory report “ “Tracking New Coal-Fired Power Plants: Coal’s Resurgence in Electric Power Generation,” feb 2004
59. (source: European commission, ExternE study, revised 2003 edition: “External Costs-Research results on socio-environmental damages due to electricity and transport.” See also http://www.externe.info).
60. DOE/Fossil Energy Carbon Sequestration Program briefing to President’s Council of Advisors on Science and Technology Sept. 20,2005 Jay Braitsch http://www.ostp.gov/PCAST/agenda_9_20_05_files/Braitsch_DOECsequest_PCAST_20Sep05.pdf
61**.** “Energy Subsidies and External Costs” UIC Nuclear Issues Briefing Paper # 71 November 2005 **http://www.uic.com.au/nip71.htm**
62.Op.cit. Braitsch
63. National Energy Technology Laboratory report “ “Tracking New Coal-Fired Power Plants: Coal’s Resurgence in Electric Power Generation,” feb 2004

Appendix A: Job potential

I. Wind Ranges:

1. 1000 MW creates 3000 manufacturing, 700 installation and 600 operation jobs. (4.3 jobs/MW)
Source: "Wind Turbine Development: Location of Manufacturing Activity" Sept 2004 Renewable Energy Policy Project (http://www.repp.org/articles/static/1/binaries/WindLocatorShort.pdf)

2. 12 jobs/MW
Source: European Wind Energy Association "The Current Status of the Wind Industry" report on industry overview, market data and employment. 2004
http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/factsheet_industry2.pdf

3. 3.3 jobs/MW Source: Donald Aitken "Germany Launches Its Transition to All Renewables" Solar Today Magazine Mar 31 2005

4. 5.7 jobs/MW
Source: Cited in Trends Alert "Renewable Energy and State Economies" May 2003 Barry Hopkins from "The Work That Goes Into Renewable Energy" Renewable Energy Policy Project (2001)

5. Each megawatt of installed capacity creates around 2.5 direct employment (construction and operations/maintenance) and 5.5 years indirect.
Source: American Wind Energy Association, "The Most Frequently Asked Question About Wind Energy" May 2002 http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF

Given Germany's demonstrated job creation via their aggressive wind program, we will adopt Aitken's figure of 3.3 jobs/MW as the lower bound and the REPP's 2004 figure of 4.3 jobs/MW as the upper bound for job creation potential.

II. PV ranges:

1. 30-185/MW (CanSIA used 35/MW)
Source: "The Job Creation Potential of Solar Energy in Canada" Canadian Solar Industry Association Issues Report v3.0 Jan 2005 Rob McMonagal

2. 7.41 jobs/MW_a (Renewable Energy Policy Project) *
10.56 jobs/MW_a (Greenpeace, 2001) *

* These job estimates are based on the average installed capacity de-rated by the capacity factor of the technology: for a 1 MW solar facility operating an average of 21% of the time, the power output would be 0.21 MW_a . This exemplifies one of the problems plaguing discussion amongst us reasonably-educated masses: all quantities can be expressed in numerous units (60 mph is 100 kilometers per hour or 88 ft/sec or…). Energy industry units can be complex, and efforts are made to standardize them; however, it still requires patience and diligence on the part of the reader. For the purposes of this paper, we have made every attempt to take into account reasonable capacity factors for each technology. In the case of solar, we used 0.2. When estimating what will be required in terms of installed capacity, we have always corrected for capacity factors. E.g., if 100MW_a of (average)

electrical output is required of a solar installation, then 100/0.20 or 500$MW_{installed}$ will be required.
Source: DanielM Kammen, Kamal Kapadia and Matthias Fripp (2004) "Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?" RAEL Report, University of California, Berkeley, CA

3. 3.8 jobs/$million (est. $4/watt, this translates to around 15 jobs /$MW_{installed}$
Source: Donald Aitken "Germany Launches Its Transition to All Renewables" Solar Today Magazine Mar 31 2005

4. 5.65 jobs/$million (est. $4/watt, this translates to 23 jobs/MW)
Source: Cited in Trends Alert "Renewable Energy and State Economies" May 2003 Barry Hopkins from "The Work That Goes Into Renewable Energy" Renewable Energy Policy Project

Again, given Germany's demonstrated job creation, we will use their figure of 15 jobs/MW (which is by far the most conservative) as the basis for our estimation of US jobs potential. However, we also recognize that actual figures may be higher (Canadian Solar Industry Association used 35jobs/MW, which we will adopt as an upper bound)

III. Biomass (Electrical Generation) Ranges:

1. 0.78 jobs/MW (lower bound) to 2.84 (upper bound)
Source: Source: DanielM Kammen, Kamal Kapadia and Matthias Fripp (2004) "Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?" RAEL Report, University of California, Berkeley, CA

2. 66,000 rural jobs for 75 GW biopower and 40,000 biofuel jobs (0.88 jobs/MW plant, 0.53 jobs/MW fuel, 1.41 jobs/MW total).
http://www.greenjobs.com/Public/info/industry_background.aspx?id=13

3. 5 MW biopower plant: 16 jobs, $600,000 payroll and benefits; fuel procurement for 5MW:
18 people (3.2 jobs/MW plant, 3.6 jobs/MW fuel, 6.8 jobs/MW total)

25 MW biopower plant: 17 jobs $641,250 payroll and benefits; fuel procurement for 25 MW: 54 people (0.68 jobs/MW plant, 2.1 jobs/MW fuel, 2.78 jobs/MW total)

We adopt the values proposed by Kammen et.al. as 0.78 to 2.84 jobs/MW for electrical generation and fuel procurement.

IV. Biomass (Ethanol Production) Ranges:

1. A 15-million-gallon per year biomass ethanol facility would employ approximately 30 people at the plant. Approximately 70 people would be employed in feedstock supply and delivery systems, bringing the total economic impact to approximately 100 new jobs.
Average: 2.0 jobs plant, 6.7 jobs total per million gallons
"Biomass Resource Assessment and Utilization Options for Three Counties in Eastern Oregon" Oregon DOE, USDA ,USFS Prepared by McNeil Technologies, Lakewood, CO Dec 31 2003
http://www.oregon.gov/ENERGY/RENEW/Biomass/docs/EOBRA/Part1.pdf

2. The industry average for constructing an ethanol plant is less than $2.00 per gallon of annual

production (Van Dyne, Braschler, and Blase 1996),

Table 1. Job Creation Impact from Ethanol Plant (15 million gallon/year)

Description During	Construction	Plant Operation
Increase in jobs	388	206
Increase in personal income (million $)	$34.3	$27.9
Increase in total economic activity (million $)	$36.6	$30.9

Source: Based on inputs of Van Dyne and Braschler 1996; Van Dyne, Braschler, and Blase 1996.

Average: 25.9 jobs construction, 13.7 jobs operation per million gallon/yr capacity

Source: Golden Triangle Energy Cooperative, Inc. Ethanol Plant
by Rodney Fink
http://www.iira.org/pubsnew/publications/IVARDC_CS_184.pdf

3. A recent study found that an average 40 million gallon per year ethanol plant will have the following positive economic impacts on a local community:

-1 time boost of $142 million during construction
-Expand the local economic base to the community by $110 million each
-year through the direct spending of $56 million
-create 41 full time jobs at the plant and 694 jobs throughout the entire economy
-increase household income for the community by $19.6 million annually
-provide an average 13.3% annual return on investment over 10 years to a farmer who invests $20000 in an ethanol production facility

Average: 1.0 jobs plant, 17.3 jobs entire economy (incl fuel procurement?) per mgy

Source: "Ethanol and the Local Community," John Urbanchuk,
AUS Consultants and Jeff Kapell, SJH & Company, June 2002
Photo credit: Ethanol Producer Magazine
Cited from "Building a Secure Energy Future" Renewable Fuels Association report 2003
http://www.ethanolrfa.org/objects/pdf/outlook2003.pdf

Ethanol studies vary in how they break down jobs (plant, construction, operations which may include fuel procurement, and total economy). Using only the total economy and plant operation ranges give values of 6.7 to 17.3 jobs per million gallons, which translates to 362,000 to 934,000 jobs/year based on projected 54 billion gallon production capacity.

V. Biomass (Biodiesel) Ranges:

1. "Biodiesel Feasibility Study: An evaluation of Biodiesel Feasibility in Wisconsin" T.Randall Fortenbery Aug 2004
4 million gallon per year plant employs 12 people directly, total job creation in Wisconsin would be ~50. (3 plant jobs/mgy, 12 total/mgy)
http://www.aae.wisc.edu/pubs/sps/pdf/stpap481.pdf

2. $12 million factory in Ralston Iowa produces 6 million gallons annually at $1.50 gallon. Investment costs are around $1/gallon
http://www.choicesmagazine.org/scripts/printVersion.php?ID=2003-3-03
Cole Gustafson is a professor in the Agribusiness and Applied Economics Department at North Dakota State University, Fargo.

3. 50,000ton RME plant (approx. 14 million gallons) would employ 17 full time jobs, but the impact on agricultural jobs could range from 250 to 966 jobs (1.2 plant jobs/mgy, 17-69 total jobs/mgy)

cited from "Rationale and Economics of a British Biodiesel Industry" prepared by the British Association for Biofuels and Oils, Kerr C. Walker, Agro-Industrial Research Services and Werner Korbitz, Korbitz Consulting April 1994
http://www.biodiesel.org/resources/reportsdatabase/reports/gen/19940401_gen-294.pdf

4. 4 million gallon (hypothetical) soy-based biodiesel plant in Buchanan County Missouri would employ 81 direct and 243 total jobs (20 jobs/mgy, 60 total jobs/mgy)
"Soy Diesel Processing in Buchanan County, Missouri: Potential Impacts" Jian C. Ma, James K. Scott and Thomas G. Johnson University of Missouri 1996
http://www.ssu.missouri.edu/Faculty/JScott/soydsl.htm

Job potential ranges for biodiesel, including feedstock procurement, are 1.2 to 3 jobs/mgy plant operations and 9 to 60 jobs/mgy for feedstock procurement, yielding a total job potential of 120,000 to 750,000 jobs per year (Based on a 12 billion gallon/year production figure).

VI. Geothermal (Electrical Generation) Ranges:

1. Cited from Trends Alert: Critical information for state decision makers: Renewable Energy and State Economies Barry Hopkins May 2003, sponsored by the Council of State Governments pp.15-18

VII. Geothermal (Ground Source Heat Pump) Ranges:

Labor estimate:

Labor for GSHP installation vary with installation type, local geology, location and existing landscape, and local labor costs; therefore, labor estimates for 40 million installations are rough. Most GSHP information sites indicate systems can be installed "typically" in one to two days. I estimated two installations per week for a three person crew, over a year period. This tallies to 3 jobs per year for 100 installations. Installing 40 million systems would thus require 400,000 x 3 job-years, or 1.4 million job-years over the entire 15 years, or 80,000 jobs per year.

VIII. Solar Thermal:

Solar thermal job potential for 10 100 MW plants over 11 year period: average annual employment is 4900 construction for 11 years, O&M 1800 jobs
4.9 jobs/MW construction over 11 years (0.44 jobs/MW-year) and 1.8 jobs/MW operations, totaling 2.2 jobs/MW annual
Source: "The Potential Economic Impact of Constructing and Operating Solar Power Generation Facilities in Nevada" R.K.Schwer and M. Riddel NREL/SR-550-35037 Feb.2004

Given the lack of data on solar thermal employment impacts, we will adopt a low value of 1.0 job/MW annually

Appendix B: Calculations

A. Wind power calculation:
Assumptions:

1. GE is the largest US manufacturer, constituting 60% of the US installation figures in 2005: GE's contribution: 1433MW
2. Total US installations in 2005: 2431MW
3. Growth rate: 35%+ (http://www.awea.org/newsroom/releases/Annual_Industry_Rankings_Continued_Growth_031506.html)
4. GE produced 1005 turbines for use in US in 2005; average turbine is then 1433/1005=1.42MW

5. GE delivered 1346 turbines worldwide; assuming an average of 1.42 MW, this is a total production capacity of 1911 MW
(GE Energy Completes Record Year in Wind Energy Sales; GE's Global Wind Revenue Up 200% Over 2004**Business Wire**, **Feb 27, 2006**) http://www.findarticles.com/p/articles/mi_m0EIN/is_2006_Feb_27/ai_n16086199
We assume that the US can produce this level of capacity (1911MW) by itself starting in 2005. We further assume some imports will be added. We start with an assumed installation capability of 2454MW per year*, beginning in 2006, driven by a 35% growth rate to 2012.Thereafter, for five years, a 43% growth rate is enacted, followed by a plateau to zero growth.
http://www.awea.org/newsroom/releases/Wind_Power_Capacity_012307.html

B. Solar power calculations:
Industry growth calculations:
Solar capacity produced (assume total shipments-imports=dom.production)
1999-2000: 72MW
2000-2001: 79MW 10%
2001-2002: 87MW 10%
2002-2003: 104MW 19%
2003-2004: 99MW -5%
2004-2005: 133MW 34%
2005-2006: 135MW 2%
source: Table 47. Annual Shipments of Photovoltaic Cells and Modules, 1996-2005
www.eia.gov/cneaf/solar.renewables/page/solarreport/solar.html

total installed US capacity:

year	96	97	98	99	00	01	02	03	04	05	06
capacity	77	88	100	117	139	168	212	275	365	(475)*	(617)*
growth	14%	14	17	19	21	26	30	33			

*assuming 30% growth rate for 05 and 06
source: Cumulative installed solar PV
http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2006/STAGING/local_assets/downloads/pdf/table_of_cumulative_inst_solar_photovoltaic_pwr_2006.pdf

Geothermal calculations:

Geothermal electrical generation:
Data and sources:

1. Geothermal potential:
   a. current: 2200MW, future 23,000MW (possibly100,000) (C. Kutscher *The Status and Future of Geothermal Electric Power* NREL/CP-550-28204 June 2000)
2. Costs:
   a. Installation: $1400-1500/kW for steam plants; $2100/kW for binary plants
   b. Generation 5 to 8 cents/kWh (Ibid.)
3. Capacity factors:
   a. 0.95 (Ibid.); 0.83 (Lund, J.; Boyd, T.; Sifford, A. and R. Bloomquist *Geothermal Energy Utilization in the United States-2000* Oregon Institute of Technology

C. If 26,000MW of resource can be utilized at a capacity factor of 0.85, then total electrical production is:

$26{,}000MW_{potential}$ x 8760 hr/year x 0.85 = 1.93×10^8 MWh = 0.66 quads

Assuming a 33% efficiency of primary energy to electrical conversion, total primary displacement is:

0.66 quads/. 0.33 =2.00 quads displaced

Ground Source Heat Pump:
Data and sources:
1. Energy savings:
   a. GSHP energy savings range: 31 to 71% (. Lienau,P.; Boyd, T. and R. Rogers *Ground Source Heat Pump Case Studies and Utility Programs* Report prepared for US DOE Geothermal Division Oregon Institute of Technology April 1995
   b. Ground source heat pumps can reduce energy consumption by 25 to50% when compared to conventional HVAC (Geoexchange fact sheet for builders and developers)
   c. 100,000 units will displace 37.5 trillion Btus (0.038 quads), 2.18 million tons of carbon equivalent and save consumers $750 million over 20 year lifetime of units. (Geoexchange fact sheet)
2. Costs:
   a. GSHP savings range: 18 to 54% ($) (Op cit. Lienau et al.)
3. Annual household energy use and source data: Energy Information Administration Annual Energy Review 2004 Table 2.5: "Household Energy Consumption and Expenditures by End Use and Energy Source, Selected Years 1978-2001"
4. US Household electricity data: US Household Electricity Report July 2005 www.eia.doe.gov/emeu/reps/enduse/er01_us.html
5. The distribution of space heating fuel sources in 2001 in the US was: 57% natural gas, 41% electric, 8% fuel oil, 6% propane and 2% wood/kerosene* (Residential Energy Consumption Survey 2001 Consumption and Expenditures Fuel Tables http://www.eia.doe.gov/emeu/recs/byfuels/2001/byfuels_2001.html)
   * percentages do not total 100 due to overlap of primary and secondary heating sources reflected in the values

Shaded area represents portion of household energy used for space heating

D. Calculations:

Residential electrical consumption in 2001, for 107 million households, was 1,140 billion kWh of electricity; of this, HVAC accounted for 356 billion kWh (3327 kWh/household ave). Proposing 40 million households converting to GSHP with an average 50% reduction in energy usage:

$(40 \times 10^6) \times .5 \times 3327 = 66.5$ billion kWh saved (0.23 quads electricity)
Given that electrical generation and transmission is approximately 33% efficient, the corrected displacement of primary energy used for electrical generation would be 0.23/.33 = 0.70 quads electrical primary energy displaced

Residential natural gas usage in 2001 totaled 3.32 quads for space heating; 57% of 107 million households yields as average usage of 54 million Btus. If we assume a fraction of 40 million households converting to GSHP that is proportional to current fuel source distribution, then the savings in natural gas will be (again at 50% energy reduction):
$[0.57 \times (40 \times 10^6)] \times .5 \times (54 \times 10^6) = 6.16 \times 10^{14}$ Btus = 0.62 quads natural gas displaced

Residential fuel oil usage in 2001 totaled 0.62 quads for space heating; fuel oil represents 8% of household heating; average fuel oil consumption was 72 million Btus/houshold. Using a proportional conversion to GSHP, at 50% energy reduction:
$[0.08 \times (40 \times 10^6)] \times .5 \times (72 \times 10^6) = 1.15 \times 10^{14}$ Btus = 0.12 quads fuel oil displaced

Residential propane usage in 2001 totaled 0.28 quads for space heating, averaging 43.6 million Btus per household. Similar analysis yields a reduction in energy use of:
$[0.06 \times (40 \times 10^6) \times .5 \times (43.6 \times 10^6) = 5.2 \times 10^{13}$ Btus = 0.05 quads LPG displaced

Total energy savings projected from utilization of ground source heat pumps in residential applications will be 1.5 quads

Solar thermal calculations:

E. Assuming a combustion efficiency of 33%, 4.9 quads of primary energy will produce 1.62 quads of electricity. Generating 1.62 quads of electricity from CSP at 0.4 capacity factor will require
1.62 quads x 293 $\times 10^6$MWh/quad x 1yr/8760 hrs x 1/0.4 capy factor = 135,500 MW capacity

F. 135,500 MW (40% capacity factor) will produce 474,800,000 MWh/year; 50,000MW (20%cf) will produce 87,600,000 MWh/year. @ $0.08/kWh retail, revenues should be
5.62×10^8 MWh/year x 10^3 kWh/MWh x $0.08/kWh = $45 billion/year

G. Residential water heating in the US in 2001: total 1.51 quads; by energy source: 41 million households, electricity (0.36 quads total, 8.8 million Btus/houshold) and 58 million households, natural gas (1.15 quads total, 19.8 million Btus/houshold). If 53 million households incorporated solar water heating into their existing systems, and assuming a modest average 60% energy savings, the total displacement of fossil energy would be:
electrical:
58×10^6 househld x 41/99(proportion of electrical users) x 8.8×10^6Btus/household x 0.6savings = 0.126 quads
primary fuel displacement: 0.126 quads/.33 efficiency = 0.38 quads
natural gas:
58×10^6 x 58/99(proportion of n.g. users) x 19.8×10^6Btus/household x 0.6 = 0.40 quads
primary fuel displacement: solar is directly displacing natural gas, so displacement is 0.40 quads
Total fossil fuel displaced by solar water heating: 0.78 quads

H. Residential primary ff. displacement as a proportion of delivered energy: 0.78/1.51

Equivalent industrial ff. displ :   0.52/1.00

I. Industrial energy use in 2004 was 33.8 quads, or 1.5 times residential use (21.4 quads). We assume a proportional savings in water heating via solar for industrial applications:

0.8 quads residential x 1.5 = 1.2 quads

Lifestyle calculations:

J. Total 2004 residential electrical consumption: 4.4 quads   Total residential energy use: 21.4 quads (EIA Monthly Energy Review March 2005)
5% electrical savings: .05 x 4.4 quads = 0.22 quads. Primary displacement (33% efficiency) would be 0.22 quads/0.33 = 0.66 quads; as a percentage of total energy use: 0.66/21.4 = 0.03 or 3%

K. Energy use each appliance as a percent of total taken from USDOE EERE Energy Savers Tips page. Average residential use is 11,000 kWh; Dryer is 850kWh (7.7%); dishwasher is 575(5%)
http://www.eere.energy.gov/consumer/tips/appliances.html

Transmission Grid Summary Calculations

L. Calculations for grid costs for renewable addition:

Cost basis for transmission:

Jacobson and Masters (2001) eletters (referring to "The Real Cost of Wind Energy", J Decorolis and D Keith, Science 2001; 294:1000-1003) 11/28/01
http://www.sciencemag.org/cgi/eletters/294/5544/1000#357
0.000345 cents/kWh/km (amortized over 50 years)
Cavallo (1995) 2000km HVDC line: $0.0275/kWh or 0.00138 cents/kWh/km (same eletter)
DeCorolis and Keith: 1.5 cents/kWh

Distances from wind resource to existing transmission lines

Jacobson and Masters (above eletters): 840,000 MW within 20 km
NREL: 175,000MW within 5 miles existing 230kV or lower lines, 284,000MW within 10 miles and 401,000MW within 20 miles.   "Wind Energy Issue Brief" M Shaheen (Oct 1997) http://www.nationalwind.org/pubs/wes/ibrief09.htm

Calculation for 1,120 GW of wind energy (assuming capacity factor of .35) over a 50 year period (lifetime of the transmission lines)

1. 0.00345 cents/kWh/km:
estimating 401,000MW within 32 km, remaining 719,000MW within 100 km:
401 x 10^6kW x 8760hr/yr x .35 x 0.000345cents/kWh/km x 32km x 50yr =
$6.8 billion
719 x 10^6kW x 8760hr/yr x .35 x 0.000345cents/kWh/km x 100km x 50yr =
$38 billion
Total = $45 billion

2. Cavallo's value is four times Jacobson and Masters, therefore total cost would be $180 billion

3. 1.5 cents/kWh:
1.12 x 10^9kW x 8760hrs/yr x.35 x $0.015/kWh x 50yr = $51.5 billion/yr x 50 yr = $2.6 trillion

4. Assuming 840,000MW within 20 miles (Jacobson and Master), remaining 280,000 within 500 miles. Average wind farm is 200MW using 2.5MW turbines:
840,000MW x 1 farm/200MW x 20mi/farm =   84,000 mi

280,000MW x 1 farm/200MW x 500mi/farm = 700,000 mi
Total = 784,000 mi

This figure is clearly unlikely, given that the entire grid currently stands at some 156,000 miles. If we assume a need to double the grid, then we will add 156,000 miles of new transmission, at a cost of $1 million/mile:

$156 billion

5. In a communication between Jacobson and Howard Gruenspecht, a discussion of carrying capacity of lines yields a range of 30 to 163 km/GW; the higher value is assuming a carrying capacity of 2GW actual power, which translates to 5.5GW installed power. Using this value,

1,120GW x 1 line/5.5GW x 163 km/line = 33,193 km = 20,000 miles

20,000 miles x $1 million/mile = $20 billion

Using the argument in #4 above, the value of $156 billion seems reasonable as an upper limit to costs for new (wind) transmission lines.

Transportation calculations

M. Fuel calculation: gasoline produces 8.82 kg of CO_2 per gallon; diesel produces 9.98 kg CO_2 per gallon. World production of CO_2 (2000): 24.2 billion tons.

N. Calculations for biofuels:
increasing CAFÉ from 24 to 36 mpg stretches a gallon of fuel by 50%; thus, 5.5 quads (36mpg biofuels) has the potential to displace 8.3 quads of (24 mpg) fossil fuels. However, fossil fuels will be required for biofuels production, transport and processing.
Calculations for fossil requirements for biofuels:
Ethanol: assuming 54 billion gallons production per year, 76000 Btus/gallon and a requirement of 5 to15% fossil energy use (on a $Btus_{fossil}$-to-$Btus_{ethanol}$ basis) yields a range:

54×10^9 gal x 76000Btu/gal x 0.05 to 0.15 = 2.1 to 6.2 x 10^{14} Btus =
0.21 to 0.62 quads fossil fuel requirement

Biodiesel: assuming 12 billion gallons production per year, 120000Btus/gal and a requirement of 25% fossil energy use ($Btus_{fossil}$-to-$Btus_{biodiesel}$ basis) yields

12×10^9 gal x 120000Btu/gal x .25 = 3.6 x 10^{14} Btus =
0.36 quads fossil fuel requirement

Using the upper values, around 1 quad of fossil fuel will be required to produce 5.5 quads of biofuels; the net fossil fuel reduction, assuming increased CAFÉ to 36 mpg, will be 8.3-1 or 7.3 quads displaced.

O. assuming a 75 mpg plug-in hybrid utilizing primarily renewable electricity yields a 200% increase in fuel economy over a 24 mpg CAFÉ standard; at this efficiency, 5.5 quads could theoretically displace 17 quads

P. Using 27.5 quads as our base transportation fuel consumption, savings achieved will be

27.5 quads x .25(%market) x .5(fuel saving) = 3.4 quads f.f. displaced

Q. Calculation for electric vehicle

The GM EV1 provides data from 800 production vehicles with several years and tens of thousands of miles; we will utilize this data as our baseline:

The GM EV1 was rated by the EPA as requiring 30 kWh/100 miles city driving, or 0.3 kWh/mi for charging (1 kwh=3412 Btus) or 1024 Btu/mi. For comparison, a 24 mpg vehicle using 130,000 Btu/gal gasoline requires 5400 Btu/mi. Thus, replacing gasoline with electric vehicles represents an 80% savings in energy.

2.7 quads of fossil fuels at the above rate (5400 Btu/mi) is equivalent to 500 x 10^9 miles @ 24 mpg ave. The electrical energy requirement for 500 billion miles for an EV will be
500 x 10^9 mi x 1024 Btu/mi = 5.1 x 10^{14} Btus (0.51 quads)

If the electricity used to recharge these vehicles is 80% renewable (carbon neutral) by 2020, then only 20% of 0.51 quads, or 0.10 quad, will be fossil fuel based. Therefore the total fossil fuel displacement will be 2.7 – 0.10 = 2.6 quads

R. calculation: total transportation fuel displacement by other technologies represents 57.6%, leaving 42.4% ICE/fossil vehicles, or 11.7 quads. If CAFÉ increased to 50 mpg (100% increase), consumption reduced by 50% (5.8 quads)
S. calculation rail:
3.5 $\text{quads}_{\textbf{trucking}}$ x $.5_{\textbf{rail replacement}}$ x $0.66_{\textbf{fuel reduction percentage}}$ = 1.16 quads

<u>Coal section calculations:</u>

T. <u>Coal:</u> 30-year cost range, (including external costs) $572 billion to $1.3 trillion

<u>Wind</u>: Using a capacity factor of 0.3, producing the equivalent of 77,000MW of 75% capacity coal will require 193,000 MW of wind capacity. At $1 million/MW, this will cost $193 billion…65% more than the equivalent best available technology coal plants. However, when the minimal external costs for wind (up to 0.25 cents/kWh) are added, the external cost over 30 years will be only $38 billion, making wind's grand total over 30 years $231 billion…60% lower than coal's *lower* cost bound.

<u>Solar photovoltaic</u>: Using a capacity factor of 0.2, producing the equivalent energy of coal will require 289,000 MW capacity. At the current rate of $5/watt installed, total cost will be $1.4 trillion; with external costs (0.6 cents/kWh), external cost over 30 years will be $91 billion. Solar PV's 30-year total cost would be roughly $1.45 trillion. This cost, based on current solar costs (which have not yet benefited from economy of scale cost reductions) is very close to coal's upper cost bound. If prices in PV fall to $2.50/watt, and/or PV achieves a doubling of efficiency, total
30-year costs could be equivalent to coal's lower cost bound.