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Executive Summary

Carbon-Free and Nuclear-Free: A Road-Map for U.S. Energy Policy[1]

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A three-fold global energy crisis has emerged since the 1970s; it is now acute on all three fronts:

1. **Climate disruption:** Carbon dioxide (CO_2) emissions due to fossil fuel combustion are the main anthropogenic cause of severe climate disruption, whose continuation portends grievous, irreparable harm to the global economy, society, and current ecosystems.
2. **Insecurity of oil supply:** Rapid increases in global oil consumption and conflict in and about oil exporting regions make prices volatile and supplies insecure.
3. **Nuclear proliferation:** Non-proliferation of nuclear weapons is being undermined in part by the spread of commercial nuclear power technology, which is being put forth as a major solution for reducing CO_2 emissions.

After a decade of global division, the necessity for drastic action to reduce CO_2 emissions is now widely recognized, including in the United States, as indicated by the April 2007 opinion by the U.S. Supreme Court[3] that CO_2 is a pollutant and by the plethora of bills in the U.S. Congress. Many of the solutions offered would point the United States in the right direction, by recognizing and codifying into law and regulations the need to reduce CO_2 emissions. But much more will be needed. Moreover, most of the solutions being offered are likely to be inadequate to the task and some, such as the expansion of nuclear power or the widespread use of food crops for making fuel, are likely to compound the world's social, political, and security ills. Some, like production of biofuels from Indonesian palm oil, may even aggravate the emissions of CO_2.

This present report examines the technical and economic feasibility of achieving a U.S. economy in the with zero-CO_2 emissions without nuclear power. This is interpreted as an elimination of all but a few percent of CO_2 emissions or complete elimination with the possibility of removing from the atmosphere some CO_2 that has already been emitted. We set out to answer three questions:

- Is it possible to physically eliminate CO_2 emissions from the U.S. energy sector without resort to nuclear power, which has serious security and other vulnerabilities?

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[1] This summary is based on a draft report and subsequent research in response to reviews. This report is a joint project of the Nuclear Policy Research Institute and the Institute for Energy and Environmental Research (IEER). A book with the same title will be published by RDR Books in September 2007. The report considers only CO_2 emissions from fossil fuels, which constitute about 85% of U.S. greenhouse gas emissions.

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[3] On the Internet at http://www.supremecourtus.gov/opinions/06pdf/05-1120.pdf

- Is a zero-CO2 economy possible without purchasing offsets from other countries – that is, without purchasing from other countries the right to continue emitting CO_2 in the United States?
- Is it possible to accomplish the above at reasonable cost?

Central Finding

The overarching finding of this study is that a zero-CO_2 economy can be achieved within the next thirty to fifty years without the use of nuclear power and without acquiring carbon credits from other countries. In other words, actual physical emissions of CO_2 from the energy sector can be eliminated with technologies that are now available or foreseeable. This can be done at reasonable cost while creating a much more secure energy supply than at present. Net U.S. oil imports can be eliminated in about twenty-five years. All three insecurities – severe climate disruption, oil supply and price insecurity, and nuclear proliferation via commercial nuclear energy – will thereby be addressed. In addition, there will be large ancillary health benefits from the elimination of most regional and local air pollution, such as high ozone and particulate levels in cities, which is due to fossil fuel combustion.

The most critical policies that need to be enacted as urgently as possible for achieving a zero-CO_2 economy without nuclear power are:

1) Enact a physical limit of CO_2 emissions for all large users of fossil fuels (a "hard cap") that steadily declines to zero prior to 2060, with the time schedule being assessed periodically for tightening according to climate, technological, and economic developments. The cap should be set at the level of some year prior to 2007, so that early implementers of CO_2 reductions benefit from the setting of the cap. Emission allowances would be sold by the U.S. government for use in the United States only. There would be no free allowances, no offsets and no international sale or purchase of CO_2 allowances. The estimated revenues ~$30 to $50 billion per year would be used for demonstration plants, research and development, and worker and community transition.
2) Eliminate all subsidies and tax breaks for fossil fuels and nuclear power (including guarantees for nuclear waste disposal from new power plants, loan guarantees, and subsidized insurance).
3) Eliminate subsidies for biofuels from food crops.
4) Build demonstration plants for key supply technologies, including central station solar thermal with heat storage, large and intermediate scale solar photovoltaics, and CO_2 capture in microalgae for liquid fuel production.
5) Leverage federal, state, and local purchasing power to create markets for critical advanced technologies, including plug-in hybrids.
6) Ban new coal-fired power plants that do not have carbon storage.
7) Enact high efficiency standards for appliances at the federal level
8) Enact stringent building efficiency standards at the state and local levels, with federal incentives to adopt them.
9) Enact stringent efficiency standards for vehicles
10) Put in place federal contracting procedures to reward early adopters of CO_2 reductions.
11) Adopt vigorous research, development, and pilot plant construction programs for technologies that could accelerate the elimination of CO_2, such as direct solar hydrogen production (both the photosynthetic and photoelectrochemical approaches), hot rock

geothermal power, and integrated gasification combined cycle plants using biomass with a capacity to sequester the CO_2.

12) Establish a standing committee on Energy and Climate under the Environmental Protection Agency's Science Advisory Board.

The achievement of a zero-CO_2 economy without nuclear power will require unprecedented foresight and coordination in policies from the local to the national, across all sectors of the energy system. Much of the ferment at the state and local level, as well as some of the proposals in Congress, is already pointed in the right direction. But a clear long-term goal is necessary to provide overall policy coherence and establish a yardstick against which progress can be measured. A zero-CO_2 U.S. economy without nuclear power is not only achievable – it is necessary for environmental protection and security. *Even the process of the United States setting a goal of a zero-CO_2, nuclear-free economy and taking initial firm steps towards it will transform global energy politics in the immediate future and establish United States as a country that leads by example rather than preaches temperance from a barstool.*

Tables ES-3 and ES-4 at the end of this executive summary provide a sketch of the road-map with estimates of dates at which technologies can be deployed as well as research, development, and demonstration recommendations.

Summary of Main Findings

Finding 1: A goal of a zero-CO_2 economy is necessary to minimize harm related to climate change.

Global CO_2 emissions per person need to be about 1 to 1.5 metric tons per person per year, possibly less, to stabilize atmospheric concentrations at 450 parts per million (ppm). A reduction of 80% in total U.S. CO_2 emissions by 2050 relative to 2005, would still leave per person U.S. emissions at about 2.5 to 3 metric tons per person.[4] A global norm of emissions at this rate would leave worldwide CO_2 emissions essentially unchanged from the present. Further, the capacity of the oceans to absorb CO_2 may diminish, for instance, due to acidification from atmospheric CO_2 buildup; making the same level of emissions more damaging. Such problems may necessitate removal of CO_2 from the atmosphere ni the future. A goal of zero-CO_2, defined as being a few percent on either side of zero relative to the present, is both necessary and prudent. It is also achievable at reasonable cost (see below for details).

Finding 2: A hard cap on CO_2 emissions -- that is a fixed emissions limit that declines year by year until it reaches zero – would provide large users of fossil fuels with a flexible way to phase out CO_2 emissions. However, free allowances, offsets that permit emissions by third party reductions[5], or international trading of allowances, notably with developing countries that have no CO_2 cap, would undermine and defeat the purpose of the system. A measurement based physical limit, with appropriate enforcement, should be put into place.

A hard cap in CO_2 emissions is recommended for large users of fossil fuels, defined as an annual use of 100 billion Btu or more – equal to the use of about 1,000 households. At this level, the users have sufficient financial resources to be able to track the market, make purchases and sales, and evaluate when it is most beneficial to invest in CO_2 reduction technologies relative to purchasing credits. This would cover about

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[4] Based on a global population of 8 to 9 billion and a U.S. population of 400 to 420 million by 2050.

[5] Offsets allow a purchaser to continue emitting CO_2, while paying for reductions in CO_2 by the party from whom the offsets are purchased. These may or may not result in actual CO_2 reductions. Even when they do, the emissions may be immediate while reductions may be long-term. Verification is difficult and expensive.

two-thirds of fossil fuel use. Private vehicles, residential and small commercial use of natural gas and oil for heating, and other similar small-scale uses would not be covered by the cap. The transition in these areas would be achieved through efficiency standards, tailpipe emissions standards, and other standards set and enforced by federal, state, and local governments. Taxes are not envisaged in this study, except possibly on new vehicles that fall far below the average efficiency or emissions standards. The hard cap would decline annually and be set to go to zero before 2060. Acceleration of the schedule would be possible, based on developments in climate impacts and technology.

The annual revenues that would be generated by the government from the sale of allowances would be on the order of $30 billion to $50 billion per year throughout the period, since the price of CO_2 emission allowances would tend to increase as supply goes down. These revenues would be devoted to ease the transition at all levels – local, state, and federal – as well as for demonstration projects and research and development.

Finding 3: A reliable U.S. electricity sector with zero-CO_2 emissions can be achieved without the use of nuclear power or fossil fuels.

The U.S. renewable energy resource base is vast and practically untapped. Available wind energy resources in 12 Midwestern and Rocky Mountain states equal about two and a half times the entire electricity production of the United States in 2004, which is thermodynamically equivalent to the petroleum output of all the members of OPEC. Solar energy resources on just one percent of the area of the United States are about three times as large as wind energy, if production is focused in the high insolation areas in the Southwest and West. One intriguing resource is the sunlight over the 19 billion square meters of parking lots in the United States, [6] which could be used to generate a significant amount of electricity, while avoiding the need for transmission line expansion, though some strengthening of the distribution infrastructure may be needed in some cases. A start has been made. The U.S. Navy has a 750 kW installation in one of its parking lots in San Diego. Figure ES-1 shows a U.S. Navy solar PV parking lot installation that provides shaded parking spots for over 400 vehicles, with plenty of room to spare for expansion of electricity generation.

Figure ES-1: U.S. Navy 750 kW Parking Lot Solar PV Installation near San Diego

Courtesy of PowerLight Corporation.

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[6] A square meter is almost 11 square feet.

Wind energy is already more economical than nuclear power. In the past two years, the costs of solar cells have come down to the point that medium scale installations, such as the one shown above, are economical in sunny areas, since they supply electricity mainly during peak hours.

The main problem with wind and solar energy is intermittency. This can be reduced by integrating wind and solar energy together into the grid – for instance, wind energy is often more plentiful at night. Geographic diversity also reduces the intermittency of each source and for both combined. Integration into the grid of these two sources up to about 15 percent of total generation (not far short of the contribution of nuclear electricity today) can be done without serious cost or technical difficulty with available technology, provided appropriate optimization steps are taken.

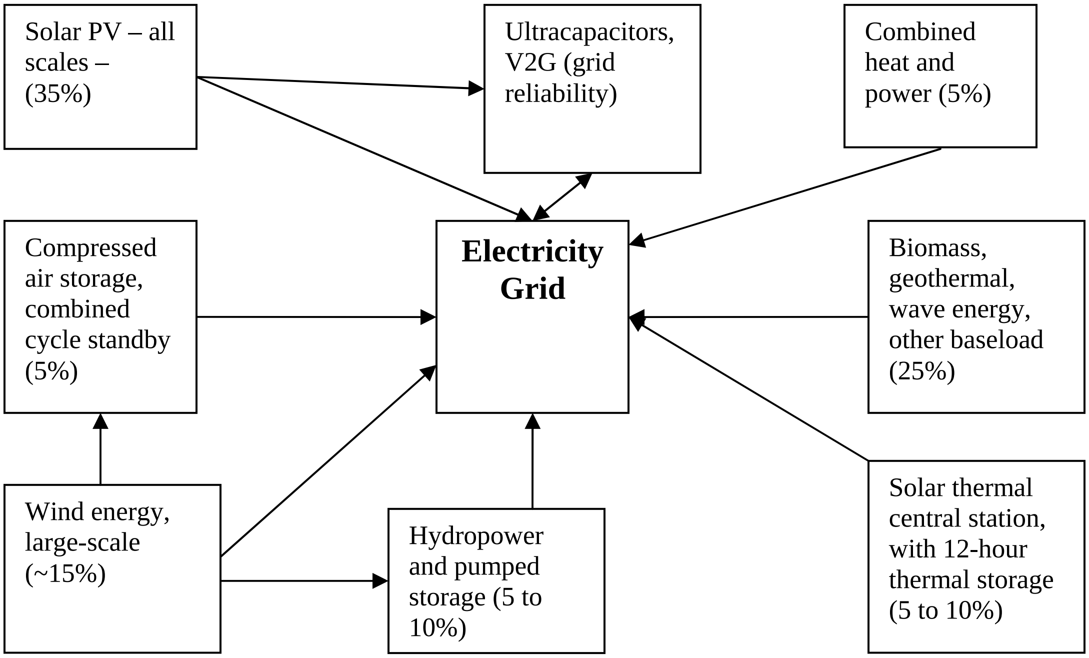
Solar and wind should also be combined with hydropower – with the latter being used when the wind generation is low or zero. This is already being done in the Northwest. Conflicts with water releases for fish management can be addressed by combining these three sources with natural gas standby. The high cost of natural gas makes it economical to use combined cycle power plants as standby capacity and spinning reserve for wind rather than for intermediate or baseload generation. In other words, given the high price of natural gas, these plants could be economically idled for some of the time and be available as a complement to wind power. Compressed air can also be used for energy storage in combination with these sources. No new technologies are required for any of these generation or storage methods.

Baseload power can be provided by geothermal and biomass-fueled generating stations and intermediate loads in the evening can be powered by solar thermal power plants which have a few hours of thermal energy storage built in. Finally, new batteries can enable plug-in hybrids and electric vehicles owned by fleets or parked in large parking lots to provide relatively cheap storage. Nanotechnology-based lithium ion batteries, which have begun to be produced by Altairnano, can be deep discharged far more times than needed simply to operate the vehicle over its lifetime (10,000 to 15,000 times compared to about 2,000 times respectively). Since the performance of the battery is far in excess of the cycles of charging and discharging needed for the vehicle itself, vehicular batteries could become a very low-cost source of electricity storage that can be used in a vehicle-to-grid (V2G) system. In such a system, parked cars would be connected to the grid and charged and discharged according to the state of the requirements of the grid and the charge of the battery in the vehicle. Communication technology to accomplish this is essentially the same as that used for cell phone systems. A small fraction of the total number of road vehicles (~ five percent) could provide sufficient backup capacity to stabilize a well designed electric grid based on renewable energy sources (including biomass and geothermal).

Figure ES-2 shows one possible configuration of the electric power grid. A large amount of standby power is made available. This allows a combination of wind and solar electricity to supply half or more of the electricity without affecting reliability. Most of the standby power would be supplied by stationary storage and/or V2G and by combined cycle power plants for which the fuel is derived from biomass. Additional storage would be provided by thermal storage associated with central station solar thermal plants. Hydropower use would be optimized with the other sources of storage and standby capacity. Wind energy can also be complemented by compressed air storage, with the compressed air being used to reduce methane consumption in combined cycle power plants.

With the right combination of technologies, it is likely that even the use of coal can be phased out, along with nuclear electricity. However, we recognize that the particular technologies that are on the cutting edge today may not develop as now appears likely. It therefore appears prudent to have a backup strategy. The carbon dioxide from coal-fired power plants can be captured at moderate cost if the plants are used with a technology called integrated gasification combined cycle (IGCC). Carbon capture and sequestration may also be needed for removing CO_2 from the atmosphere via biomass should that be necessary.[7]

Figure ES-2: One possible future U.S. electric grid configuration without coal or nuclear power in the year 2050



Tables ES-3 and ES-4 provide the details and estimated technological schedules, along with some cost notes for key components of the IEER reference scenario, which describes the overall combinations of technologies and policies that would enable the achievement of a zero-CO_2 economy without any fossil fuels or nuclear power by 2050. We recommend that new coal-fired power plants without carbon capture be banned since constructing new plants at this stage will create pressures to increase CO_2 emission allowances and/or higher costs for capturing the CO_2 later.

Complete elimination of CO_2 could occur as early as 2040. Elimination of nuclear power could also occur in that time frame, possibly sooner, depending on nuclear spent fuel management, costs of maintenance of aging power plants, etc. If there are major obstacles in the technological assumptions – for instance, if V2G cannot be implemented in the time frame anticipated here (on a large scale after about15 to 20 years) – then technologies such as co-firing of natural gas with biomass or even some coal with biomass and CO_2 sequestration may be needed.

Figure ES-3 shows the delivered energy to end uses in the IEER reference scenario (that is losses in electricity and biofuels production are not included), indicating the approximate pattern of phasing in of

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[7] Integrated gasification of coal works as follows: Coal is reacted with steam, which yields a mixture of hydrogen and carbon monoxide. When burned, this yields CO_2 and water. The process can result in removal of heavy metals prior to combustion; nearly all the sulfur in the coal can also be captured, preventing almost all sulfur dioxide emissions. When nearly pure oxygen is used for combustion, capture of CO_2 becomes far less expensive. The CO_2 can then be injected into a deep geologic formation. Since biomass draws CO_2 from the atmosphere, sequestering CO_2 when biomass is the fuel results in a reduction of atmospheric CO_2, provided the biomass production process does not lead to significant CO2 emissions.

new fuels and phasing out fossil fuels and nuclear power. It also shows the role of energy efficiency relative to a business-as-usual approach. Figure ES-4 shows the corresponding structure of electricity production. The slight decreases followed by increases reflect the faster increase in efficiency envisioned followed by large-scale introduction of electric cars.

Figure ES-3: Delivered Energy IEER Reference Scenario, Btu

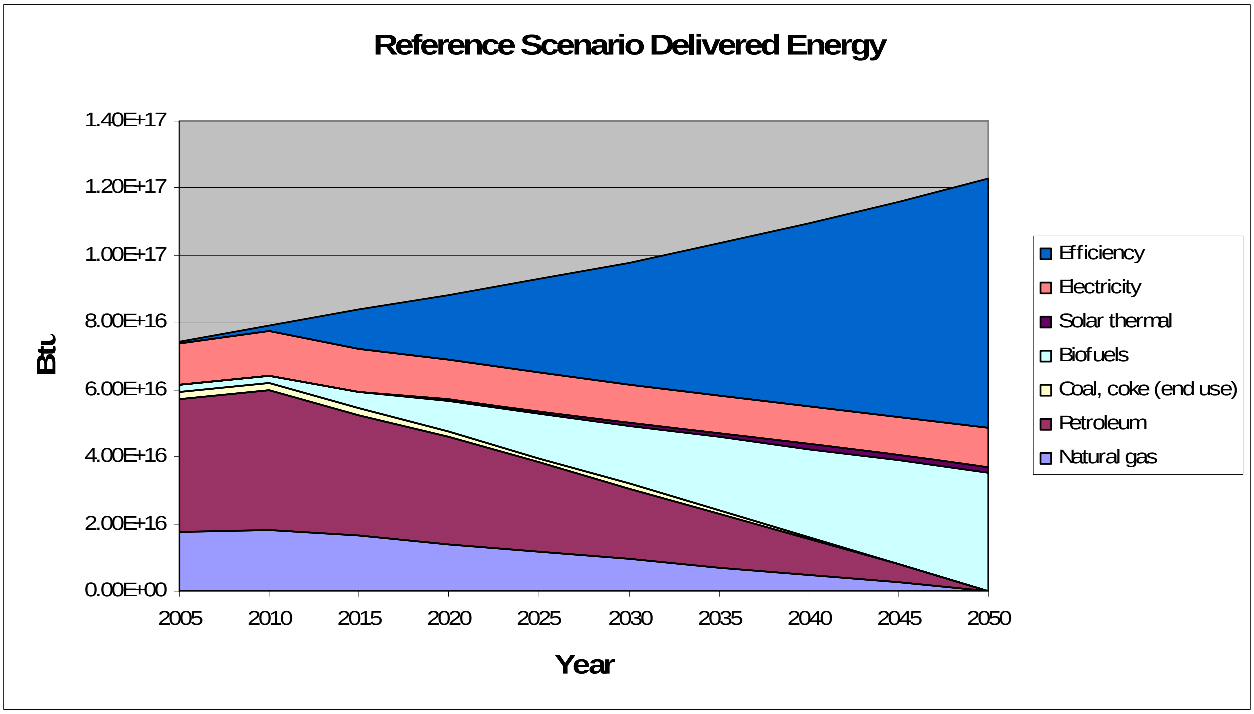
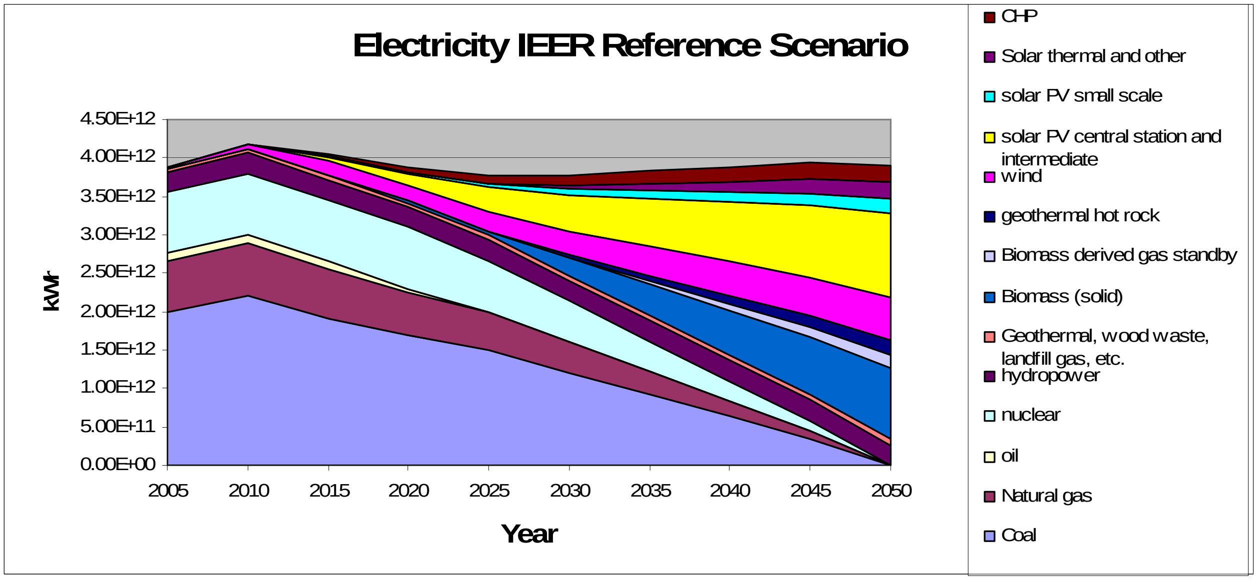


Figure ES-4: Electricity Supply, IEER Reference Scenario, kWh



Finding 4: The use of nuclear power to significantly reduce CO_2 emissions will result in increased risks of nuclear proliferation, terrorism, and accidents and will create new vulnerabilities and insecurities in the energy system.

The widespread use of nuclear power to reduce CO_2 emissions will require two to five nuclear power plants to built around the world every month for four or five decades. Fueling these plants would necessitate one to three large uranium enrichment plants to be built *each year*, when just one such plant in Iran has stoked global political-security tensions to a point that it is a major driver in spot market oil price fluctuations. Widespread use of nuclear power will convert the problem of nuclear non-proliferation from one that is difficult today to one that is intractable. For one thing, there would be three thousand terrorist targets worldwide, adding nuclear tensions to petroleum security problems.

Already, the Gulf Cooperation Council (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates), pointing to Iran and Israel, has stated that it will openly acquire civilian nuclear power technology. In making the announcement, the Saudi Foreign Minister Prince Saud Al-Faisal was quoted in the press as saying "It is not a threat….We are doing it openly." He also pointed to Israel's nuclear reactor, used for making plutonium for its nuclear arsenal, as the "original sin." At the same time he urged that the region be free of nuclear weapons.[8] No contortions of rhetoric can take away from the central facts – the pursuit of nuclear power is fueling proliferation.

To place nuclear in the electricity system comparable to the role that coal has today would necessitate building about 3,000 large nuclear power plants (1,000 megawatts each) by mid-century – more than one per week for over forty years. Protecting these power plants against terrorist attack would be a Herculean enterprise. The Federal Bureau of Investigation Director, Robert Mueller has noted that Al Qaeda has had and continues to have nuclear power plants as potential targets. Increasing potential terrorist from 400 plus to 3,000 would hardly be advisable.

The nuclear waste problem would grow as well, since a nuclear waste repository would be needed every few years. No country has so far been able to address the significant long-term health, environmental, and safety problems associated with spent fuel or high level waste disposal, even as official assessments of the risk of harm from exposure to radiation continue to increase.[9]

Such a large number of power plants would put pressure on uranium supplies and make commercial reprocessing more likely. The problems of reprocessing are already daunting. For instance, a commercial sector power plant and a reprocessing plant were used to provide the plutonium for North Korea's nuclear arsenal. The global increases in nuclear infrastructure, including nuclear materials processing and university education in nuclear engineering and related topics would make inspections and control very difficult, in a context in which the Nuclear Non-Proliferation Treaty (NPT) is fraying. A world in which a few countries assert the right to commercial nuclear technology while denying some aspects of this to others cannot be realized. It is too late for that. About three dozen countries, including Iran, Japan, Brazil, Argentina, Egypt, Taiwan, South Korea, and Turkey, have the technological capacity to make nuclear weapons. More can acquire it. It is critical therefore, to achieve the necessary reductions in CO_2 emissions without resorting to nuclear power. Finally, it is to be noted that Wall Street has been and remains skeptical of nuclear power due to its expense and risk.

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[8] http://www.saudi-us-relations.org/articles/2006/ioi/061213-gcc-summit.html

[9] See for instance, the most recent report of the National Academy of Sciences, published in 2006, at http://books.nap.edu/books/030909156X/html/28.html.

Finding 5: The use of highly efficient energy technologies and building design, generally available today, can greatly ease the transition to a zero-CO_2 economy and reduce its cost. A two percent annual increase in efficiency per unit of Gross Domestic Product relative to recent trends would result in a one percent decline in energy use per year, while providing three percent GDP annual growth. This is well within the capacity of available technological performance.

Before the first energy crisis in 1973, it was generally accepted that growth in energy use and economic growth, as expressed by Gross Domestic Product (GDP), went hand in hand. But soon after, the U.S. energy picture changed radically and economic growth was achieved for a decade without energy growth. Since the mid-1990s, the rate of energy growth has been about two percent less than the rate of GDP growth, despite the lack of national policies to greatly increase energy efficiency. For instance, residential and commercial buildings can be built with just one-third to one-tenth of the present-day average energy use per square foot with existing technology. As another example, we note that industrial energy use in the United States has stayed about the same since the mid-1970s, even as production has increased. The analysis in this report indicates that annual energy use can be reduced from the present 100 quadrillion Btu per year to about 60 quadrillion Btu per year, while maintaining the economic growth assumed in official energy projections.

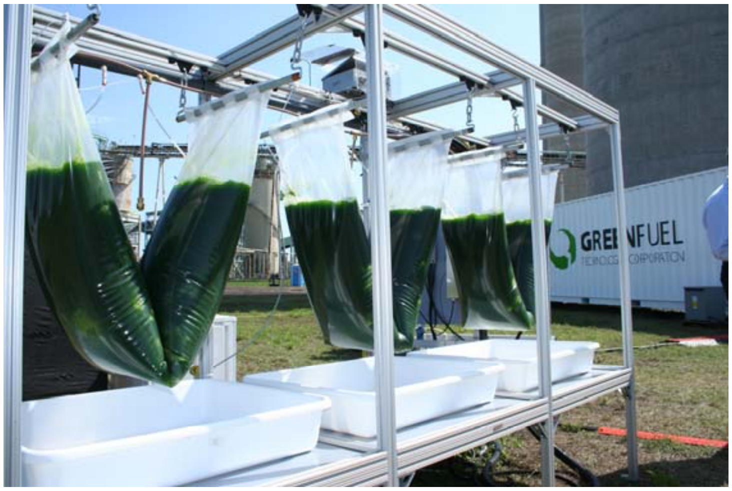
Finding 6: Biofuels, broadly defined, could be crucial to the transition to a zero-CO_2 economy without serious environmental side effects or, alternatively, they could produce considerable collateral damage or even be very harmful to the environment and impact greenhouse gas emissions negatively. The outcome will depend essentially on the policy choices, incentives, and research and development, both public and private.

Food crop-based biodiesel and ethanol can create and is creating social, economic, and environmental harm, including high food prices, pressure on land used by the poor in developing countries for subsistence farming or grazing, and emissions of greenhouse gases that largely or completely negate the effect of using the solar energy embodied in the biofuels. While they can reduce imports of petroleum, ethanol from corn and biodiesel from palm oil are two prominent examples of damaging biofuel approaches that have already created such problems even at moderate levels of production.

For instance, in the name of renewable energy, the use of palm oil production for European biodiesel use has worsened the problem of CO_2 emissions due to fires in peat bogs that are being destroyed in Indonesia, where much of the palm oil is produced. Rapid increases in ethanol from corn are already partly responsible for fueling increases in tortilla prices in Mexico. Further, while ethanol from corn would reduce petroleum imports, its impact on reducing greenhouse gas emissions would be small at best and may even be negative, due to energy intensity of both corn and ethanol production, as well as the use of large amounts of artificial fertilizers, which also result in emissions of other greenhouse gases (notably nitrous oxide). All subsidies for fuels derived from food crops should be eliminated.

In contrast, biomass that has high efficiency solar energy capture (~five percent), such as microalgae grown in a high CO_2 environment, can form a large part of the energy supply both for electricity production and for providing liquid and gaseous fuels for transport and industry. Microalgae have been demonstrated to capture over 80 percent of the daytime CO_2 emissions from power plants and can be used to produce up to 10,000 gallons of liquid fuel per acre per year. Some aquatic plants, such as water hyacinths, have similar efficiency of solar energy capture and can be grown in wastewater as part of combined water treatment and energy production systems. Figures ES-5 and ES-6 show two critical biomass examples that have the potential for about 5 percent solar energy capture – about ten times that of the corn plant, including the grain and the crop residues. The NRG Energy coal-fired power plant in Louisiana shown in Figure ES-5 is being used by GreenFuel Technologies Corporation for field tests. The plant is a potential site for a commercial scale algae bioreactor system that would recycle the plant's CO2 emissions into biodiesel or ethanol.

Figure ES-5: Operating demonstration algae bioreactor at a coal-fired power plant in Louisiana



Courtesy of GreenFuel Technologies Corporation

Figure ES-6: Water hyacinths can yield up to 250 metric tons per hectare in warm climates

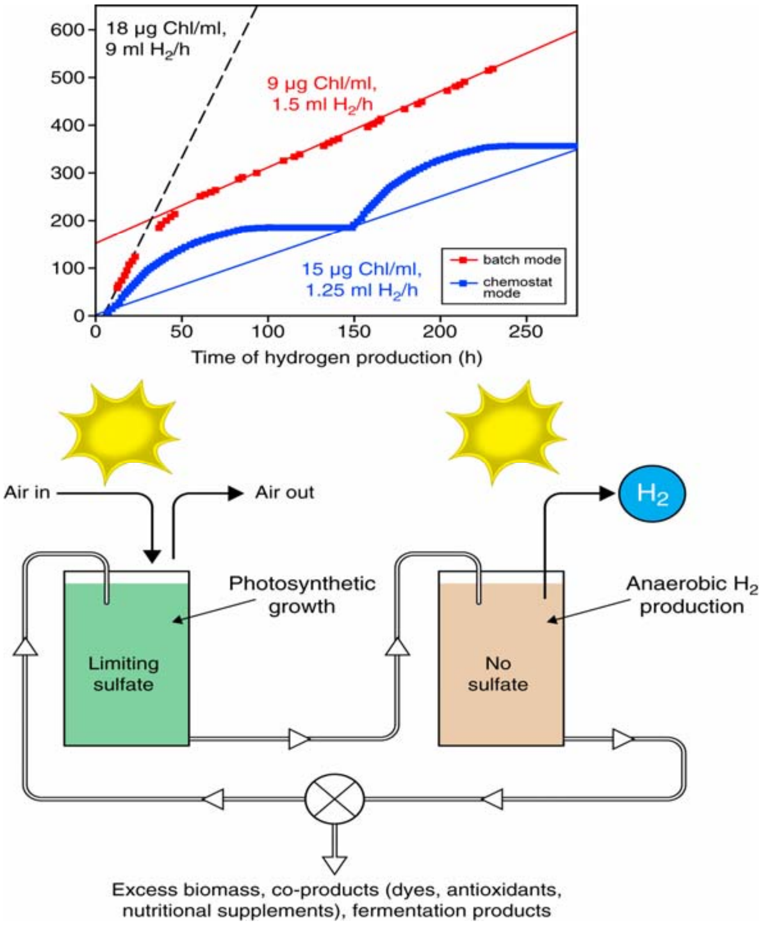
Courtesy of Center for Aquatic and Invasive Plants, Institute of Food and Agricultural Sciences, University of Florida

Prairie grasses have medium productivity, but can be grown on marginal lands in ways that allow carbon storage in the soil. This approach can therefore be used both to produce fuel renewably and to remove CO_2 from the atmosphere.

Finally, there are two approaches to hydrogen that could be very promising for a transition to hydrogen as a major energy source: photoelectrochemical hydrogen and hydrogen created from biological processes. In the former, solar cells, essentially similar to photovoltaic cells, use solar energy to directly split water into hydrogen and oxygen without first making electricity. A variety of biological processes can be used to make hydrogen; they include the use of algae within a sulfur-free environment, bacteria, and fermentation of biomass. Ten to fifteen percent conversion efficiencies have been achieved, but costs are still high and industrial-scale processes have not yet been developed. In some approaches, energy, food, and pharmaceuticals can be produced simultaneously. Progress has been far slower than it could be for lack of money.

Figure ES-7 shows direct hydrogen production from sunlight using algae deprived of sulfur in their diet. This technique is still in the laboratory stage but shows great promise for high efficient hydrogen production (10 to 15 percent solar energy capture).

Figure ES-7: Direct Solar Production of Hydrogen Using Algae



This diagram/graph was developed by the National Renewable Energy Laboratory for the U.S. Department of Energy. See Ghirardi and Seibert 2003. The Y axis in the graph above stands for hydrogen produced, in milliliters.

Finding 7: Much of the reduction in CO_2 emissions can be achieved without incurring any cost penalties (as, for instance, with efficient lighting and refrigerators). The cost of eliminating the rest of CO_2 emissions due to fossil fuel use is likely to be in the range of $10 to $30 per metric ton of CO_2.

Table ES-1 shows the estimated costs of eliminating CO_2 from the electricity sector using various approaches. It is based on 2004 costs of energy. At 2007 prices (about $8 per million Btu of natural gas and almost 9 cents per kWh electricity, averaged over all sectors) the costs would be lower.

Table ES-1: Summary of costs for CO_2 abatement (and implicit price of CO_2 emission allowances) – Electricity sector. (Based on 2004 costs of energy)

CO_2 source	Abatement method	Phasing	Cost per metric ton CO_2, $	Comments
Pulverized coal	Off-peak wind energy	Short-term	A few dollars to $15	Based on off-peak marginal cost of coal
Pulverized coal	Capture in microalgae	Short- and medium-term	Zero to negative	Assuming price of petroleum is >$30 per barrel
Pulverized coal	Wind power with natural gas standby	Medium- and long-term	Negative to $46	High costs corresponds to a low natural gas price ($4 per million Btu)
Pulverized coal	Nuclear power	Medium- to long-term	$20 to $30	Optimistic estimate for nuclear costs; unlikely to be economical compared to wind with natural gas standby
Pulverized coal	Integrated Gasification Combined Cycle (IGCC) with sequestration	Long-term	$10 to $40 or more	Many uncertainties in the estimate at present. Technology development remains.
Natural gas standby component of wind	Electric vehicle-to-grid	Long-term	Less than $26	Technology development remains. Estimate uncertain.

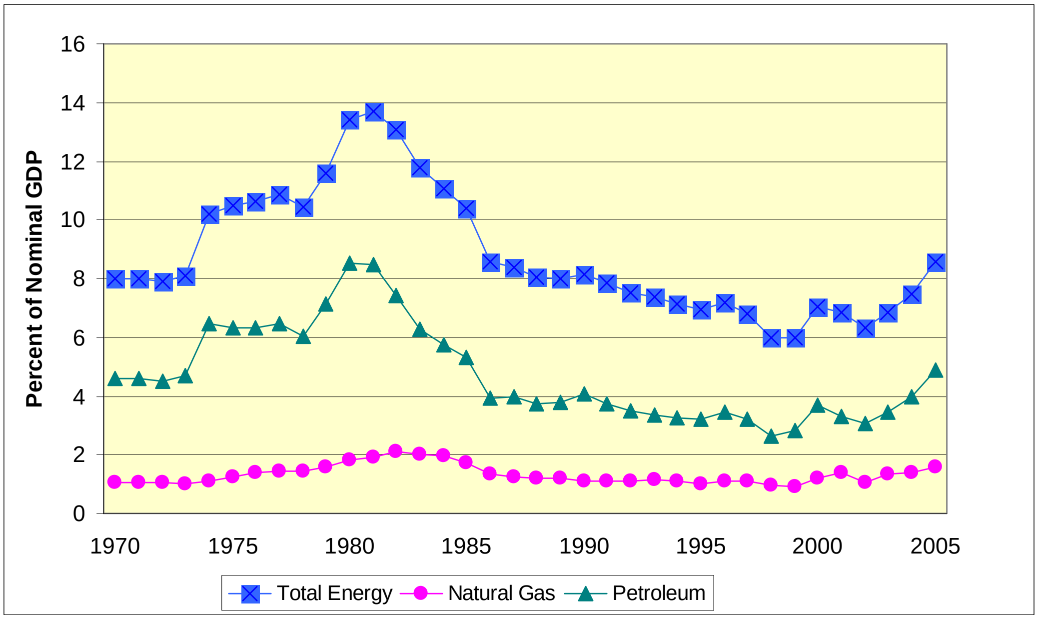
Notes:

1. Heat rate for pulverized coal = 10,000 Btu/kWh; for natural gas combined cycle = 7,000 Btu/kWh.
2. Wind-generated electricity costs = 5 cents/kWh; pulverized coal = 4 cents per kWh; nuclear = 6 to 7 cents per kWh.
3. Natural gas prices between $4 and $8 per million Btu.
4. Petroleum costs $30 per barrel or more.

CO_2 costs associated with wind energy related items can be reduced by optimized deployment of solar and wind together

Further, the impact of the any increases in costs on the total cost of energy services is low enough that the overall share of GDP devoted to such services would likely decline from the present level of about 8 percent (Figure ES-8)

Figure ES-8: Proportion of GDP spent on energy



Courtesy of the Energy Information Administration of the United States Department of Energy. Source: EIA' s spreadsheet: Energy Expenditure Share of the Economy.
Sources cited by EIA:
Energy data, 1970-2002; Petroleum, 2003-2004; Natural Gas, 2003: State Energy Price and Expenditure.
Nominal GDP, 1970-2005: Bureau of Economic Analysis;
Energy growth rates, 2003-2005: Short-term Energy Outlook, October 2006

Tables ES-2 and ES-3 show the total estimated annual energy and investment costs for the residential and commercial sectors in terms of the GDP impact. The lower energy use per house and per square foot, higher needed investment, and anticipated somewhat higher anticipated costs of electricity and fuels under the IEER reference scenario are taken into account. The net GDP impact of reducing residential and commercial sector energy use by efficiency improvements and converting entirely to renewable fuels is small or even slightly positive.

Table ES-2: Residential and Commercial Energy and Investment Costs, Annual, 2050, GDP basis, billion dollars (constant 2005 dollars)

Item	**IEER Reference Scenario**	**Business-as-Usual Scenario**
R + C Electricity	$326	$442
R + C Fuel	$150	$247
Sub-total energy cost	*$476*	*$689*
Added annual investment for efficiency	$171	$0
Total GDP basis cost (rounded)	**$1,120**	**$1,380**
GDP in 2050	*$40,000*	*$40,000*
GDP fraction: residential and commercial energy services	***2.81%***	***3.45%***

Notes: 1. Business-as-Usual (BAU) fuel and electricity prices: about $12 per million Btu and 9.6 cents per kWh. IEER prices: $20 per million Btu and 14 cents per kWh respectively. BAU electricity price is from January 2006.
2. Added efficiency investments: existing residences: $20,000 per residence; new = $15 per square foot (~$30,000 per house); plus an added $2,000 per house for appliances, replaced every 15 years with prevailing advanced appliances. Investment figures are based on case studies.
3. Commercial efficiency investments: $10 per square foot (greater than examples of platinum level LEED investment)

The total GDP for energy services in all sectors under the IEER reference scenario is estimated to remain under 8 percent. For an individual home owner, the net increased cost of an ultra-efficient new home, including increased mortgage payments, would be on the order of $100 per month, or under 1 percent of average household income in 2050.

Finding 8: The transition to a zero-CO_2 system can be made in a manner compatible with local economic development in areas that now produce fossil fuels.

Fossil fuels are mainly produced today in the Appalachian region, in the Southwest and West and some parts of the Midwest and Rocky Mountain states. These areas are also well-endowed with the main renewable energy resources – solar and wind. Federal, state, and regional policies, designed to help workers and communities transition to new industries, therefore appear to be possible, without more major physical movement or disruption of populations than has occurred in post-World War II United States. It is recognized that much of that movement has been due to dislocation and shutdown of industries, which causes significant hardship to communities and workers. Some of the resources raised by the sale of CO_2 allowances should be devoted to reducing this disruption. For instance, the use of CO_2 capture technologies, notably microalgae CO_2 capture from existing fossil fuel plants, can create new industries and jobs in the very regions where the phaseout of fossil fuels would have the greatest negative economic impact. Public policy and direction of financial resources can help ensure that new energy sector jobs that pay well are created in those communities.

Technology Roadmap Outline to 2025

Table ES-3: Road-Map Supply and Storage Technologies

Technology	**Status**	**Date for large-scale use**	**Next Steps**	**CO_2 price; obstacles; comments**
Solar PV – intermediate scale	Near commercial with time-of-use pricing	2010 to 2015	Orders from industry and government; time-of-use electricity pricing	\$10 to \$30/mt; no storage; lack of large scale PV manufacturing (~1 GW/yr/plant); some manufacturing technology development needed
Solar PV – large-scale	Near commercial	2015 to 2020	Large-scale demonstration with transmission infrastructure– ~5,000 MW by 2015-2020	\$20 to \$50/mt; no storage; transmission infrastructure may be needed in some cases
Concentrating solar thermal power plants	Near commercial; storage demonstration needed	2015 to 2020	~3,000 to 5,000 MW needed to stimulate demand and demonstrate 12 hour storage, by 2020	\$20 to \$30 in the Southwest. Lack of demand main problem.
Microalgae CO_2 capture and liquid fuel production	Technology developed, pilot scale plants being built	2015	Large-scale demonstrations – 1,000 to 2,000 MW by 2012; nighttime CO_2 storage and daytime CO_2 capture pilot plants by 2012. Large-scale implementation thereafter. Demonstration plants for liquid fuel production: 2008-2015	Zero to negative at oil prices above \$30 or so for daytime capture; nighttime capture remains to be characterized. Liquid fuel potential: 5,000 to 10,000 gallons per acre (compared to 650 for palm oil).
Wind power – Large-scale, land-based	Commercial	Already being used	Transmission infrastructure and rules need to be addressed; optimize operation with existing natural gas combined cycle and hydropower plants	Negative to \$46/mt for operation with combined cycle standby. Areas of high wind are not near populations. Transmission development needed

Table ES-3: Road-Map Supply and Storage Technologies (continued)

Technology	**Status**	**Date for large-scale use**	**Next Steps**	**CO_2 price; obstacles; comments**
Solar PV intermediate storage	Advanced batteries and ultracapacitors are still high cost	~2020	Demonstration of vehicle-to-grid using stationary storage (ultracaps and lithium-ion nanotechnology batteries) – several ~1 MW scale parking lot installations	Five fold cost reduction in ultracaps and lithium ion batteries needed. Main problems: lack of large scale manufacturing and some manufacturing technology development needed
Solar PV – intermediate scale -- with Vehicle-to-Grid	Planning stage only. Technology components available. Integration needed.	~2020 to 2025	By 2015, several 5,000 to 10,000 vehicle demonstrations of V2G technology	V2G could reduce the cost of solar PV electricity storage from several cents to possibly ~1 cent per kWh.
Biomass IGCC	Early demonstration stage	~2020	Pilot and intermediate scale plants (few MW to 100 MW) with various kinds of biomass (microalgae, aquatic plants), 2015 to 2020	Baseload power.
High solar energy capture aquatic biomass	Experience largely in the context of wastewater treatment; some laboratory and pilot plant data	~2020	2010 to 2015 pilot plant evaluations for liquid fuel and methane production with and without connection to wastewater treatment	May be comparable to microalgae biofuels production. 50 to 100 metric tons per acre.

Table ES-3: Road-Map Supply and Storage Technologies (continued)

Technology	**Status**	**Date for large-scale use**	**Next Steps**	**CO_2 price; obstacles; comments**
Hot rock geothermal energy	Concept demonstrated; technology development remains	2025?	Build pilot and demonstration plants: 2015-2020 period	Baseload power
Wave energy	Concepts demonstrated	2020 or 2025?	Pilot and demonstration plants needed	Possible baseload power
Photosynthetic hydrogen	Laboratory development	Unknown – possibly 2020 or 2025	Significantly increased R&D funding, with goal of 2015 pilot plants	High solar energy capture. Could be a key to overcoming high land area requirements of most biofuels
Photothermochemical hydrogen		Unknown – possibly 2020 or 2025	Significantly increased R&D funding, with goal of 2015 pilot plants	High solar energy capture. Could be a key to overcoming problems posed by agricultural biofuels (including crop residues)
Advanced batteries	Nanotechnology lithium ion batteries; early commercial stage with subsidies (or high end automobile market)	2015	Independent safety certification (2007?); large scale manufacturing plants	Large-scale manufacturing to reduce costs. Could be the key to low cost solar energy-V2G technology.
Carbon sequestration	Technology demonstrated in context other than power plants	??	Long-term leakage tests. Demonstration project ~2015-2020	For use with biomass, plus back up, if coal is needed.

Table ES-3: Road-Map Supply and Storage Technologies (continued)

Technology	**Status**	**Date for large-scale use**	**Next Steps**	**CO_2 price; obstacles; comments**
Ultracapacitors	Commercial in certain applications but not for large-scale energy storage	2015 to 2020?	Demonstration test with intermediate scale solar PV. Demonstrate with plug-in hybrid as a complement to battery operation for stop-and-start power.	Complements and tests V2G technology. About a five-fold cost reduction needed for cost to be ~\$50/mt CO_2. Lower CO_2 price with time-of-use rates
Nanocapacitors	Laboratory testing of the concepts	Unknown. Concept not proven	Complete laboratory work and demonstrate the approach	Has the potential to reduce costs of stationary electricity storage and carry the ultracapacitor technology the next step
Electrolytic hydrogen production	Technology demonstrated	Depends on efficiency improvements and infrastructure development	Demonstration plant with compressed H vehicles needed ~2015-2020	Could be used in conjunction with off-peak wind power

Table ES-4: Road-Map Demand Side Technologies: 2008-2020

Technology	Status	Date for large-scale use	Next Steps	CO_2 price; obstacles; comments
Efficient gasoline and diesel passenger vehicles	Commercial to ~40 miles per gallon or more	Being used	Efficiency standards needed	Depends on the vehicle.
Plug-in hybrid vehicles	Technology has been demonstrated	2012 to 2015	Efficiency standards, government and corporate orders for vehicles	Large scale battery manufacturing needed to reduce lithium ion battery cost by about a factor of five.
Electric cars	Technology with ~200 mile range has been demonstrated; low volume commercial production in 2007 (sports car and pickup truck)	2015 to 2020	Safety testing, recycling infrastructure for battery materials, large scale orders, solar PV-V2G demonstration	One of the keys to reducing the need for biofuels and increasing solar and wind power components.
Internal combustion hydrogen vehicles	Technology demonstrated	Depends on infrastructure development	10,000 psi cylinder development and testing of vehicles. Demonstration project.	
Biofuels for aircraft	Various fuels being tested	2020?	Fuel development, safety testing, emissions testing	
Hydrogen-fuel aircraft	Technology has been demonstrated	2030?	Aircraft design, safety testing, infrastructure demonstration	In combination with solar hydrogen production, could reduce need for liquid biofuels

Table ES-4: Road-Map Demand Side Technologies: 2008-2020 (continued)

Technology	**Status**	**Date for large-scale use**	**Next Steps**	**CO_2 price; obstacles; comments**
Building design	Commercial, well known	Already being used	Building standards, dissemination of knowledge, elimination of disconnect between building developers and users	Residential and commercial building energy use per square foot can be reduced 60 to 80 percent with existing technology and known approaches. CO_2 price, negative to $50/mt.
Geothermal heat pumps	Commercial	Already being used	Building standards that specify performance will increase its use	Suitable in many areas; mainly for new construction.
Combined heat and power (CHP), commercial buildings and industry	Commercial	Already being used	Building performance standards and CO_2 cap will increase use	CO_2 price negative to <$30/mt in many circumstances.
Micro-CHP	Semi-commercial	Already being used	Building performance standards and CO_2 cap will increase use	
Compact fluorescent lighting (CFL)	Commercial	Being used currently	Appliance and building regulations needed	Negative CO_2 price. Mercury impact of disposal needs to be addressed.
Hybrid solar light-pipe and CFL	Technology demonstrated; beta-testing being done in commercial establishments	2012to2015?	Government and commercial sector orders	Solar concentrators focus light indoors; work in conjunction with CFL. Five fold cost reduction needed.

Table ES-4: Road-Map Demand Side Technologies: 2008-2020 (continued**)**

Technology	**Status**	**Date for large-scale use**	**Next Steps**	**CO_2 price; obstacles; comments**
Industrial sector: examples of technologies and management approaches: alternatives to distillation, steam system management, CHP, new materials, improved proportion of first pass production	Constant development of processes	Various	Hard cap for CO_2 with annual assured decreases and no free allowances will lead to increase in efficiency	Variable. Negative to possibly \$50/mt, possibly more in some cases. Much scope for economical increases in efficiency exists at present costs, since energy costs have gone up suddenly. Successful reductions of energy use indicate that overall cost will be modest, with possible reduction in net cost of energy services.