VOLUME 15, NUMBER 1 August 2007

Science for Democratic Action

AN IEER PUBLICATION Published on the Web as Énergie et Sécurité and Энергетика и Безопасность No. 39

Carbon-Free and Nuclear-Free

A Roadmap for U.S. Energy Policy

BY ARJUN MAKHIJANI, Ph.D.[1]

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[2] 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.

Our report, which this issue of SDA summarizes, examines the technical and economic feasibility of achieving a U.S. economy 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?
- Is a zero-CO_2 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?

SEE CARBON-FREE ON PAGE 2, ENDNOTES PAGE 14

U.S. Navy 750 kW Parking Lot Solar PV Installation near San Diego

Figure 1 *Courtesy PowerLight Corporation*

CENTRAL FINDING

The overarching finding of the study on which this issue of SDA is based is that a zero-CO_2 U.S. 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 25 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.

INSIDE

The Clean Dozen: Twelve Critical Policy Changes...3
Technology Roadmap...8–10
Answers to Last Atomic Puzzler...13
Glossary...14
Summary of Findings...16

CARBON-FREE
FROM PAGE 1

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, are 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 the United States as a country that leads by example rather than one that preaches temperance from a barstool.*

A zero-CO_2 U.S. economy without nuclear power is not only achievable—it is necessary for environmental protection and security.

The tables on pages 8–10 provide a sketch of the roadmap to a zero-CO_2 economy with estimates of dates at which technologies can be deployed as well as research, development, and demonstration recommendations.

A summary of our main findings can be found on the back page.

Editor's note: The Institute for Energy and Environmental Research has boldly gone where none other has gone before. In partnership with the Nuclear Policy Research Institute, IEER will publish in August 2007 a groundbreaking scientific study: A roadmap to how the United States can achieve CO_2 reductions – down to zero – while phasing out nuclear power. This special issue of *Science for Democratic Action* serves as the Executive Summary of that report which will be published as a book in October. Additional resources, including a guide for elected officials to a zero-CO_2, non-nuclear U.S. economy, will be available on IEER's web site, www.ieer.org, in the near future.

Author's note: I would like to thank the Nuclear Policy Research Institute for having sponsored the project that will result in the book on which this issue of *Science for Democratic Action* is based. Helen Caldicott was the star who raised the funds, provided critical comments and suggestions, and had the vision that this study should be done because it is urgently needed. Helen's and S. David Freeman's presentations at NPRI's 2006 energy conference and our private discussions afterwards inspired me to write the book.

Thank you to Julie Enszer for smoothly shepherding this project from beginning to end. I also wish to thank Hisham Zerriffi, Jenice View, and Paul Epstein, who, as members of the Advisory Board of the project (in addition to Helen and Dave and others), contributed valuable insights and criticisms of the draft manuscript and this summary. However, they may or may not agree with the recommendations or conclusions in this summary. The book will contain statements from Board members who wish to comment. Full acknowledgements will appear in the book.

SEE **CARBON-FREE** ON PAGE 3, ENDNOTES PAGE 14

Science for Democratic Action

Science for Democratic Action is published quarterly by the Institute for Energy and Environmental Research:

6935 Laurel Avenue, Suite 201
Takoma Park, MD 20912, USA
Phone: (301) 270-5500
FAX: (301) 270-3029
E-mail: ieer@ieer.org
Web address: www.ieer.org

The Institute for Energy and Environmental Research (IEER) provides the public and policy-makers with thoughtful, clear, and sound scientific and technical studies on a wide range of issues. IEER's aim is to bring scientific excellence to public policy issues to promote the democratization of science and a healthier environment.

Thank You to Our Supporters

We gratefully acknowledge our funders whose generous support makes possible our project to provide technical assistance to grassroots groups working on nuclear-weapons related environmental and security issues, our global outreach work, and our efforts to promote sound energy policy.

Colombe Foundation
Educational Foundation of America
Ford Foundation
Livingry Foundation
Stewart R. Mott Charitable Trust
New-Land Foundation
Ploughshares Fund
Public Welfare Foundation
Town Creek Foundation

Thanks also to the SDA readers who have become donors to IEER. Your support is deeply appreciated.

Credits for this Issue

Thanks to the Nuclear Policy Research Institute (NPRI) for sponsoring the project that will result in the book on which this issue of SDA is based. NPRI and IEER thank the following individuals and foundations for their support of this project:

The Park Foundation
The Lear Family Foundation
The Lintilhac Foundation

And many individual donors who wish to remain anonymous.
Printing: Ecoprint

Editor: Lisa Ledwidge
Science for Democratic Action is free to all readers.

CARBON-FREE
FROM PAGE 2

Main Findings

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

According to the Intergovernmental Panel on Climate Change, global CO_2 emissions would need to be reduced by 50 to 85 percent relative to the year 2000 in order to limit average global temperature increase to 2 to 2.4 degrees Celsius relative to pre-industrial times. A reduction of 80% in total U.S. CO_2 emissions by 2050 would be entirely inadequate to meet this goal. It still leaves U.S. emissions at about 2.8 metric tons per person.

A global norm of emissions at this rate would leave worldwide CO_2 emissions almost as high as in the year 2000.[3] In contrast, if a global norm of approximately equal per person emissions by 2050 is created along with a 50 percent global reduction in emissions, it would require an approximately 88 percent reduction in U.S. emissions. An 85 percent global reduction in CO_2 emissions corresponds to a 96 percent reduction for the United States. An allocation of emissions by the standard of cumulative historical contributions would be even more stringent.

A U.S. goal of zero-CO_2, defined as being a few percent on either side of zero relative to 2000, is both necessary and prudent for the protection of global climate. It is also achievable at reasonable cost.

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[4], 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 on CO_2 emissions is recommended for large users of fossil fuels, defined as an annual use of 100 billion British thermal units (Btu) or more—equal to the delivered energy use of about 1,000 households. At this level, users have the 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 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.

SEE **CARBON-FREE** ON PAGE 4, ENDNOTES PAGE 14

RECOMMENDATIONS
THE CLEAN DOZEN

The 12 most critical policies that need to be enacted as urgently as possible for achieving a zero-CO_2 economy without nuclear power are as follows.

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 – approximately $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 at the federal level high efficiency standards for appliances.
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 and make plug-in hybrids the standard U.S. government vehicle by 2015.
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 (photosynthetic, photoelectrochemical, and other 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 U.S. Environmental Protection Agency's Science Advisory Board.

CARBON-FREE
FROM PAGE 3

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 through most of 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 2.5 times the entire electricity production of the United States. North Dakota, Texas, Kansas, South Dakota, Montana, and Nebraska *each* have wind energy potential greater than the electricity produced by all 103 U.S. nuclear power plants. 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.

Just the parking lots and rooftops in the United States could provide most of the U.S. electricity supply. This also has the advantage of avoiding the need for transmission line expansion, though some strengthening of the distribution infrastructure may be needed. A start has been made. The U.S. Navy has a 750 kW installation in one of its parking lots in San Diego that provides shaded parking spots for over 400 vehicles, with plenty of room to spare for expansion of electricity generation (see cover photo).

One possible future U.S. electricity grid configuration without coal or nuclear power in the year 2050

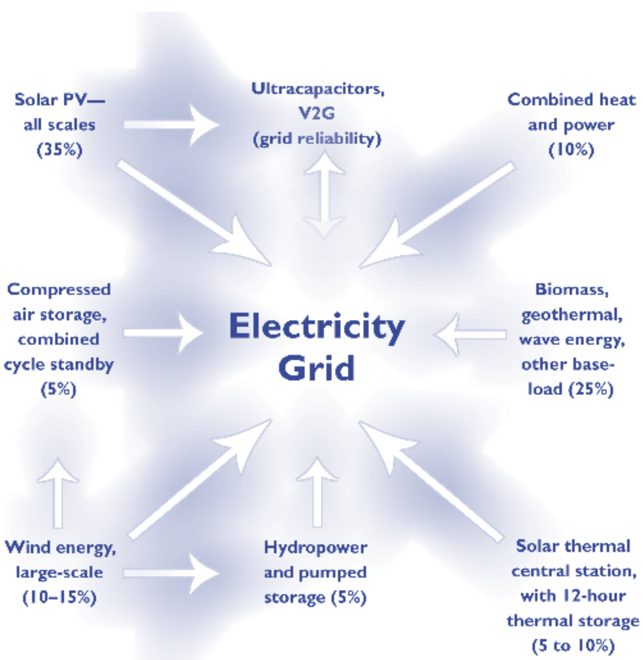


Figure 2 *IEER*

Complete elimination of CO_2 could occur as early as 2040. Elimination of nuclear power could also occur in that time frame.

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 in the cover photo, 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. 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 Altairnano has begun to produce, 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

SEE **CARBON-FREE** ON PAGE 5, ENDNOTES PAGE 14

CARBON-FREE
FROM PAGE 4

according to the state of the requirements of the grid and the charge of the battery in the vehicle. Communications technology to accomplish this via wires or wireless means is already commercial. A small fraction of the total number of road vehicles (several percent) could provide sufficient backup capacity to stabilize a well designed electricity grid based on renewable energy sources (including biomass and geothermal).

Figure 2 on page 4 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.[5]

The tables on pages 8–10 provide the details and estimated technological schedules along with some cost notes for key components of the IEER reference scenario. The IEER reference scenario 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 because constructing new plants at this stage would 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. An early elimination of CO_2 emissions and nuclear power depends on technological breakthroughs, for instance in efficient solar hydrogen production. 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 about 15 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. In that case, a zero-CO_2 economy may be delayed to about 2060.

Figure 3 below shows the delivered energy to end uses in the IEER reference scenario (losses in electricity and biofuels production are not included), indicating the approximate pattern of phasing in new fuels and phasing out fossil fuels and nuclear power. It also shows the role of

SEE **CARBON-FREE** ON PAGE 6, ENDNOTES PAGE 14

Delivered Energy, IEER Reference Scenario

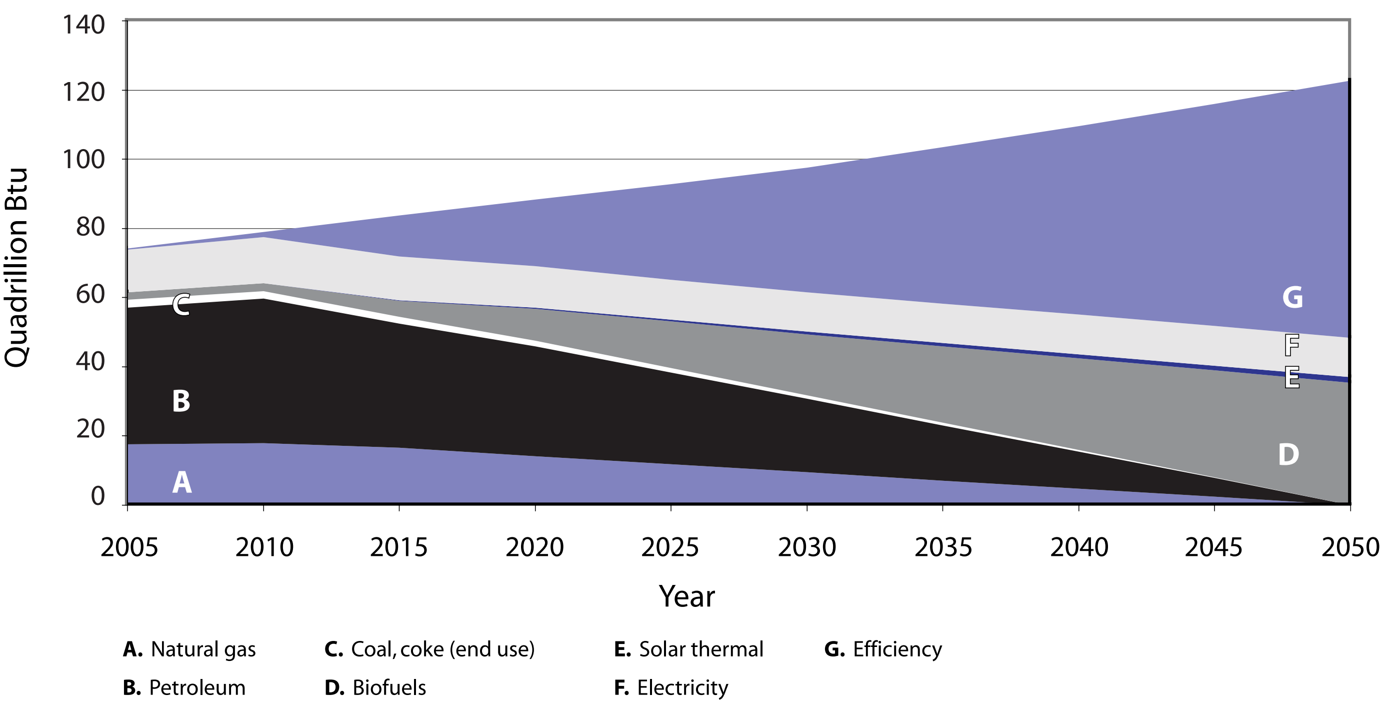


Figure 3 *IEER*

CARBON-FREE
FROM PAGE 5

energy efficiency relative to a business-as-usual approach. The reference scenario envisages a zero-CO_2, non-nuclear economy by 2050.

Figure 4 below shows the corresponding structure of electricity production. The slight decreases followed by increases reflect the faster increase in efficiency envisioned by large-scale introduction of electric cars.

Finding 4: *The use of nuclear power entails risks of nuclear proliferation, terrorism, and serious accidents. It exacerbates the problem of nuclear waste and perpetuates vulnerabilities and insecurities in the energy system that are avoidable.*

Commercial nuclear technology is being promoted as a way to reduce CO_2 emissions, including by the U.S. government. With Russia, the United States has also been promoting a scheme to restrict commercial uranium enrichment and plutonium separation (reprocessing) to the countries that already have it. (These are both processes that can produce nuclear-weapons-usable materials.) This is a transparent attempt to change the Nuclear Non-Proliferation Treaty (NPT) without going through the process of working with the signatories to amend it. The effort will undermine the treaty, which gives non-nuclear parties an "inalienable right" to commercial nuclear technology. In any case, non-nuclear-weapon states are unlikely to go along with the proposed restrictions.

It is not hard to discern that the increasing interest in nuclear power is at least partly a route to acquiring nuclear weapons capability. For instance, 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.[6]

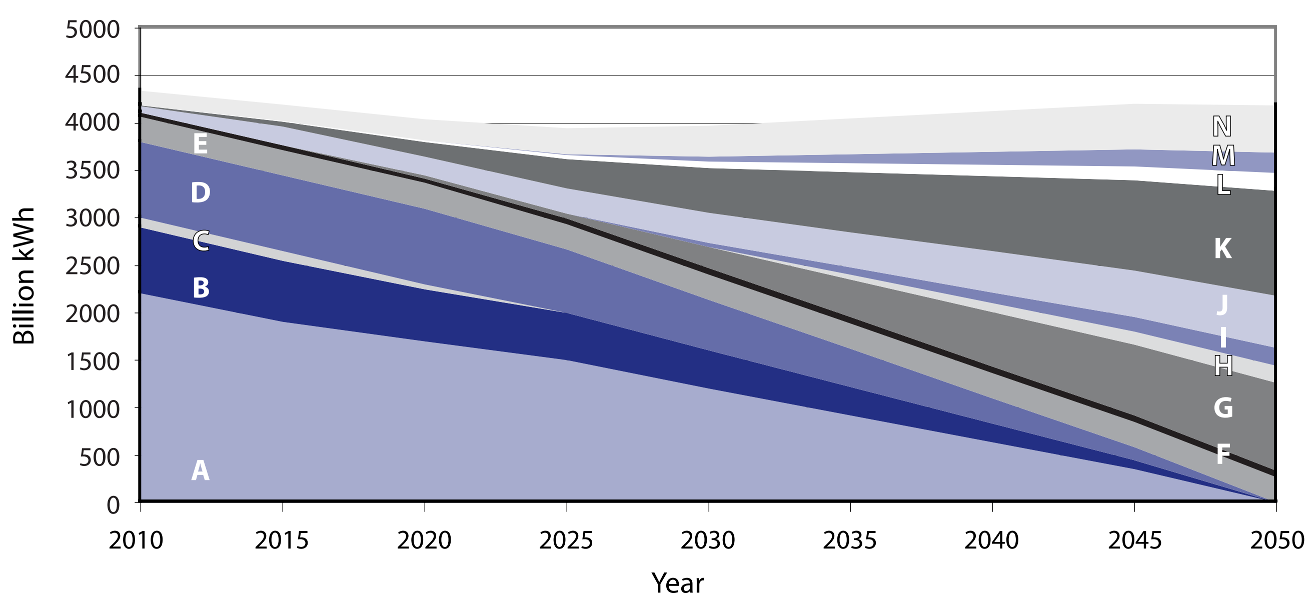
Interest in commercial reprocessing may grow as a result of U.S. government policies. The problems of reprocessing are already daunting. For instance, North Korea used a commercial sector power plant and a reprocessing plant to get the plutonium for its nuclear arsenal.

Besides the nuclear weapon states, about three dozen countries, including Iran, Japan, Brazil, Argentina, Egypt, Taiwan, South Korea, and Turkey, have the technological capacity to make nuclear weapons. It is critical for the United States to lead by example and achieve the necessary reductions in CO_2 emissions without resorting to nuclear power. Greater use of nuclear power would convert the problem of nuclear proliferation from one that is difficult today to one that is practically intractable.

Even the present number of nuclear power plants and infrastructure has created tensions between nonproliferation and the rights countries have under the NPT to acquire nuclear technology. Increasing their number

SEE **CARBON-FREE** ON PAGE 7, ENDNOTES PAGE 14

Electricity Supply, IEER Reference Scenario



A. Coal
B. Natural gas
C. Oil
D. Nuclear
E. Hydropower
F. Geothermal, wood waste, landfill gas, etc.
G. Biomass (solid)
H. Biomass-derived gas standby
I. Geothermal hot rock
J. Wind
K. Solar PV central station & intermediate
L. Solar PV small scale
M. Solar thermal & other
N. Combined heat & power

Figure 4 *IEER*

would require more uranium enrichment plants, 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. In addition, there are terrorism risks, since power plants are announced terrorist targets. It hardly appears advisable to increase the number of targets.

The nuclear waste problem has resisted solution. Increasing the number of power plants would only compound the problem. In the United States, it would likely create the need for a second repository, and possibly a third, even though the first, at Yucca Mountain in Nevada, is in deep trouble. 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.[7]

Finally, since the early 1980s, Wall Street has been, and remains, skeptical of nuclear power due to its expense and risk. That is why, more than half a century after then-Chairman of the Atomic Energy Commission, Lewis Strauss, proclaimed that nuclear power would be "too cheap to meter," the industry is still turning to the government for loan guarantees and other subsidies. The insurance side is no better. The very limited insurance that does exist is far short of official estimates of damage that would result from the most serious accidents; it is almost all government-provided.

Wall Street has been, and remains, skeptical of nuclear power due to its expense and risk.

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.

Our research indicates that annual use of delivered energy (that is, excluding energy losses in electricity and biofuels production) can be reduced by about one percent 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 increase greenhouse gas emissions. The outcome will depend essentially on policy choices, incentives, and research and development, both public and private.*

Food crop-based biodiesel and ethanol can create and are 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 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 5 and 6 on page 11 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

SEE **CARBON-FREE** ON PAGE 11, ENDNOTES PAGE 14

TABLE 3: TECHNOLOGY ROADMAP TO 2025—SUPPLY & STORAGE TECHNOLOGIES

Technology	Status	Deployable for large-scale use	Next steps	CO_2 abatement cost; 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 per metric ton; 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 per metric ton; 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 per metric ton 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 per metric ton 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 per metric ton for operation with combined cycle standby. Areas of high wind are not near populations. Transmission development needed.
Solar PV—intermediate storage	Advanced batteries and ultracapacitors are still high-cost	~2020	Demonstration of vehicle-to-grid using stationary storage (ultracapacitors and lithium-ion nanotechnology batteries)—several ~1 MW-scale parking lot installations	Five-fold cost reduction in ultracapacitors 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 demonstration 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 3 (continued)

Technology	Status	Deployable for large-scale use	Next steps	CO_2 abatement cost; 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.
Photolytic hydrogen	Laboratory development	Unknown—possibly 2020 or 2025	Significantly increased R&D funding, with goal of 2015 pilot plants	Potential for high solar energy capture. Could be a key to overcoming high land area requirements of most biofuels.
Photoelectro-chemical hydrogen	Concept demonstrated; technology development remains	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	2015	Independent safety certification (2007?); large-scale manufacturing plants	Large-scale manufacturing to reduce costs. Could be the key to low-cost V2G technology.
Carbon sequestration	Technology demonstrated in context other than power plants	Unknown. Possibly 15 to 20 years	Long-term leakage tests. Demonstration project ~2015 to 2020	For use with biomass, plus back-up, if coal is needed.
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/metric ton CO_2. Lower CO_2 price with time-of-use rates.
Nanocapacitors	Laboratory testing of the concepts	Unknown.	Complete laboratory work and demonstrate the approach	Has the potential to reduce costs of stationary electricity storage and take ultracapacitor technology to the next step.
Electrolytic hydrogen production	Technology demonstrated	Depends on efficiency improvements and infrastructure development	Demonstration plant with compressed hydrogen vehicles needed ~2015 to 2020	Could be used in conjunction with off-peak wind power.

TABLE 4: TECHNOLOGY ROADMAP TO 2025—DEMAND SIDE TECHNOLOGIES

Technology	Status	Deployable 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	Efficiency depends on the vehicle. Can be much higher.
Plug-in hybrid vehicles	Technology has been demonstrated	2010	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.
Building design	Commercial, well known	Already being used	Building standards, dissemination of knowledge, elimination of economic 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 per metric ton.
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 per metric ton in many circumstances.
Micro-CHP	Semi-commercial	Already being used	Building performance standards 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	2012 to 2015?	Government and commercial sector orders	Solar concentrators focus light indoors; work in conjunction with CFL. Five-fold cost reduction needed.
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 per metric ton, possibly more in some cases. Great potential 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 ill be modest, with possible reduction in net cost of energy services.

coal-fired power plant in Louisiana shown in Figure 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 CO_2 emissions into biodiesel or ethanol.

Water hyacinths, shown in Figure 6, have been used to clean up wastewater because they grow rapidly and absorb large amounts of nutrients. Their productivity in tropical and subtropical climates is comparable to microalgae – up to 250 metric tons per hectare per year. They can be used as the biomass feedstock for producing liquid and gaseous fuels.

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, solar energy can be used to produce hydrogen; this could be very promising for a transition to hydrogen as a major energy source. Techniques include photoelectrochemical hydrogen production using devices much like solar cells, high-temperature, solar-energy-driven splitting of water into hydrogen and oxygen, and conversion of biomass into carbon monoxide and hydrogen in a gasification plant. Tailored algae within a highly controlled environment and fermentation of biomass can also be used to produce hydrogen. 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 7 on page 12 shows direct hydrogen production from sunlight using algae deprived of sulfur in their diet.

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.*

Operating demonstration algae bioreactor at a coal-fired power plant in Louisiana

Figure 5 *Courtesy Greenfuel Technologies Corporation*

Water hyacinths can yield up to 250 metric tons per hectare in warm climates

Figure 6 *Courtesy Center for Aquatic and Invasive Plants, Institute of Food and Agricultural Sciences, University of Florida*

Table 1 on page 12 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 kilowatt-hour (kWh) electricity, averaged over all sectors) the costs would be lower.

Further, the impact of increases in costs of CO_2 abatement on the total cost of energy services is low enough that the overall share of GDP devoted to such services would remain at about the present level of about 8 percent or perhaps decline. It has varied mainly between 8 and 14 percent since 1970, hitting a peak in 1980. It dropped briefly to about 6 percent in the late 1990s when oil prices tumbled steeply, hitting a low of about $12 per barrel in 1998.

Table 2 on page 12 shows the total estimated annual energy and investment costs for the residential and commercial sectors in terms of GDP impact. The lower energy use per house and per square foot, higher needed investment, and somewhat higher anticipated costs of electricity and fuels under the IEER reference scenario are taken into account. The net estimated GDP impact of reducing residential and commercial sector energy use by efficiency improvements and converting entirely to renewable energy sources is small and well within the range of the uncertainties in the calculations.

The total GDP for energy services in all sectors under the IEER reference scenario is estimated to remain at about 8 percent or less. For an individual new home owner, the net increased cost, including increased mortgage payments, would be between about $20 and $100 per month; the latter is less than 0.7 percent of projected median household income in 2050.

SEE **CARBON-FREE** ON PAGE 13, ENDNOTES PAGE 14

TABLE 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	Combined cycle plant idled to provide standby. Highest cost at lowest gas price: $4 per million Btu.
Pulverized coal	Nuclear power	Medium- to long-term	$20 to $50	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. Long-term natural gas price: $6.50 per million Btu or more.

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 per kWh; pulverized coal = 4 cents per kWh; nuclear = 6 to 9 cents per kWh.
3. Petroleum costs $30 per barrel or more.
4. CO_2 costs associated with wind energy related items can be reduced by optimized deployment of solar and wind together.

TABLE 2: ANNUAL RESIDENTIAL (R) AND COMMERCIAL (C) ENERGY AND INVESTMENT COSTS IN 2050, IN BILLIONS OF 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	$205	$0
Total GDP-basis amount (rounded)	**$681**	**$689**
GDP in 2050	*$40,000*	*$40,000*
GDP fraction: residential and commercial energy services	**1.70%**	**1.72%**

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 each time, assumed to occur in one of every three sales of existing buildings between 2010 and 2050; new = $10 per square foot (about $20,000 per house, approximate LEED-certified house added cost); plus cost of replacing appliances every 15 years with then-prevailing advanced appliances. Investments for solar thermal heating, combined heat and power, and geothermal heat pumps added to these figures for the proportion of residential area using them. LEED stands for Leadership in Energy and Environmental Design; it is a building certification program.
3. Commercial efficiency investments: $10 per square foot; this is more than examples of platinum level LEED investment. Investments for solar thermal heating, combined heat and power, and geothermal heat pumps have been added to these figures.
4. GDP = consumption expenditures + investment + government spending (on goods and services) + exports – imports.

Direct Solar Production of Hydrogen Using Algae

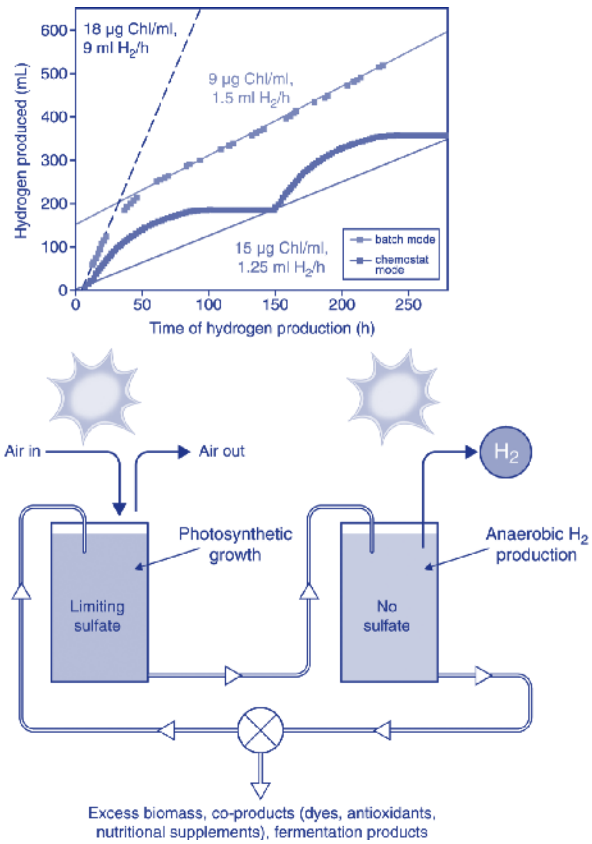


Figure 7 This diagram/graph was developed by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Note: In the "batch mode" the production is stopped periodically to replenish the nutrients. In the "chemostat mode" nutrients are supplied continuously to maintain production. "Chl" stands for chlorophyll.

CARBON-FREE
FROM PAGE 11

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.

ANSWERS TO ATOMIC PUZZLER, SDA VOL. 14, NO. 4

Calculating CO_2 Emissions from a Natural Gas Fired Plant

1. 36,410 Btu per cubic meter x 1055 joules per Btu = 38,410,000 joules per cubic meter = 3.841×10^7 joules per cubic meter

2. 1 kilowatt-hour = 1,000 joules per second per kilowatt x 3600 seconds per hour = 3,600,000 joules per kilowatt-hour = 3.6×10^6 joules per kilowatt-hour

3. 3.841×10^7 joules per cubic meter / 3.6×10^6 joules per kilowatt-hour = 10.67 kilowatt-hours (thermal) per cubic meter

4. 800 grams = 800/1000 kilograms = 0.8 kilograms → 10.67 kilowatt-hours per cubic meter / 0.8 kilograms per cubic meter = 13.34 kilowatt-hours (thermal) per kilogram

5. System efficiency from thermal to electrical energy = 50% = 0.50

Thermal output per kilogram of natural gas = 13.34 kilowatt-hours (thermal)

Electrical output per kilogram of natural gas = 13.34 kilowatt-hours (thermal) x 0.50 = 6.67 kilowatt-hours (electrical) per kilogram of natural gas

Kilograms of natural gas per kilowatt-hour of electricity = 1/6.67 = 0.150 kilograms per kilowatt-hour of electricity

6. 0.1500 kilograms of natural gas per kilowatt-hour of electricity x 0.734 kilograms carbon per kilogram of natural gas = 0.110 kilograms of carbon per kilowatt-hour of electricity

7. 0.110 kilograms of carbon per kilowatt-hour of electricity x 3.67 kilograms of CO_2 per kilogram of carbon = 0.404 kilograms of CO_2 per kilowatt-hour of electricity

GLOSSARY

Baseload generation: A large-scale power plant designed to generate electricity on a continuous basis.

Biofuel: Fuel derived from biomass.

Biomass: Organic material produced by photosynthesis.

Carbon capture: Capture of carbon dioxide when fuels containing carbon are burned for their energy.

Carbon sequestration: Deep geologic storage of carbon for long periods (thousands of years) to prevent it from entering the atmosphere.

CFL: Compact fluorescent lamp, which is a high-efficiency light bulb.

CHP: Combined heat and power. In this arrangement, some of the energy derived from burning a fuel is used as heat (as for instance in heating buildings or for industrial processes), and some is used for generating electricity.

Combined cycle power plant: Power plant in which the hot gases from the burning of a fuel (usually natural gas) are used to run a gas turbine for generating electricity. The exhaust gas from the turbine is still hot and is used to make steam, which is used to drive a steam turbine, which in turn generates more electricity.

Electrolytic hydrogen production: The use of electricity to separate the hydrogen and oxygen in water.

Geothermal heat pump: A heat pump that uses the relatively constant temperature a few feet below the earth's surface in order to increase the efficiency of the heat pump.

IGCC: Integrated Gasification Combined Cycle plant. This plant gasifies coal or biomass and then uses the gases in a combined cycle power plant.

LEED: Leadership in Energy and Environmental Design – a rating system used for building efficiency. The platinum level is the highest rating.

Microalgae: Tiny algae that grow in a variety of environments, including salty water.

Nanocapacitor: A capacitor that has the surface area of its electrodes increased greatly by the use of nanotechnology.

Photolytic hydrogen: Hydrogen produced by plants, for instance, algae, in the presence of sunlight.

Photoelectrochemical hydrogen: Hydrogen produced directly using devices similar to some solar photovoltaic cells that generate electricity. In this arrangement, hydrogen is produced instead of electricity.

Pumped storage: Using electricity at off-peak times to pump water into a reservoir and then using a hydroelectric power plant to generate electricity with the stored water during peak times (or, when used with wind energy, when the wind is not blowing).

Solar light pipe: A fiber optic cable that conveys light from the sun along its length without leaking it out of the sides, much like a wire carries electricity. It can be used to light the interiors of buildings during the daytime.

Solar PV: Solar photovoltaic cells – devices that turn incident sunlight into electricity.

Solar thermal power plant: A power plant that uses reflectors to concentrate solar energy and heat liquids that are then used to produce steam and generate electricity.

Spinning reserve: The capacity of electric power plants that are kept switched on ("spinning") but idle in order to be able to meet sudden increases in electricity demand.

Standby capacity: Power plants that are kept on standby to meet increases in electric demand.

Ultracapacitor: A capacitor that can store much more electricity per unit volume than normal capacitors.

V2G: Vehicle to grid system. Parked cars are connected to the grid. When the charge on the batteries is low, the grid recharges them. When the charge is sufficient and the grid requires electricity, a signal from the grid enables the battery to supply electricity to the grid.

Endnotes

1. This issue of SDA is a summary of a report of the same title that will be web-published in August 2007 and published as a book in October 2007 by RDR Books. References can be found in the report at www.ieer.org/carbonfree. The study is a joint project of the Nuclear Policy Research Institute and the Institute for Energy and Environmental Research. For their support of this project, NPRI and IEER wish to thank The Park Foundation, The Lear Family Foundation, The Lintilhac Foundation, and many individual donors who wish to remain anonymous.
2. On the Internet at www.supremecourtus.gov/opinions/06pdf/05-1120.pdf.
3. Based on a global population of 9.1 billion and a U.S. population of 420 million in 2050.
4. 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.
5. 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 involve greater CO_2 emissions.
6. Saudi-US Relations Information Service, "27th GCC Supreme Council Summit Wrapup," December 13, 2006, online at www.saudi-us-relations.org/articles/2006/ioi/061213-gcc-summit.html. Viewed June 20, 2007.
7. See for instance the report of the National Academy of Sciences, published in 2006, at http://books.nap.edu/openbook.php?isbn=030909156X.

Thank you.

IEER is grateful to our superscribers (donors of at least $100), hyperscribers (at least $250), and Dr. Egghead's Financial Angels ($1,000 or more).

***Superscribers* since January 2007:**

Ralph C. Bailey
Marion Fulk
Jean Graustein
Louis Ricciuti
Scott Saleska
Ben Schiff
John Tauxe
Joe Whetstone

***Hyperscribers* since January 2007:**

Christensen Family Foundation
Josephine Lowe
David and Kitty Rush

***Dr. Egghead's Financial Angels* since January 2007:**

Kay and Leo Drey

Your generous support helps SDA continue to be an important, useful and free resource for activists, educators, students, policy-makers, journalists and others.

Thanks also to our foundation funders, listed on page 2.

Support IEER's Work Today—*For a Brighter Tomorrow*

IEER IS THE FIRST TO PUBLISH a credible, well-researched how-to guide for a U.S. economy without CO_2 emissions or nuclear power. This Roadmap is an essential ingredient to developing sound U.S. energy policy and defeating arguments for a nuclear power "renaissance."

Help IEER make federal and state policy-makers aware of the Roadmap. Your financial support will bolster our efforts to get major elements of the Roadmap adopted into state and federal policy. IEER will thank you. So will your kids and grandkids.

Yes! I'd like to support the Institute for Energy and Environmental Research.
(Donations are tax deductible. IEER is a 501(c)3 nonprofit organization.)

- ☐ Contributor, $50
- ☐ Superscriber, $100+
- ☐ Hyperscriber, $250
- ☐ Dr. Egghead's Financial Angel, $1,000+
- ☐ Other amount: $____

☐ Check here if you'd rather not be acknowledged by name in *Science for Democratic Action.*

E-mail address (to receive IEER updates, less than one a month): ______________________________

Checks payable to IEER. Send to IEER, 6935 Laurel Ave., Suite 201, Takoma Park, MD 20912 USA

Or donate online: **www.ieer.org/donate/**

Questions? Please call us at (301) 270-5500

Thank you very much for your support.

SUMMARY OF MAIN FINDINGS

1. A goal of a zero-CO_2 economy is necessary to minimize harm related to climate change.
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, 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.
3. A reliable U.S. electricity sector with zero-CO_2 emissions can be achieved without the use of nuclear power or fossil fuels.
4. The use of nuclear power entails risks of nuclear proliferation, terrorism, and serious accidents. It exacerbates the problem of nuclear waste and perpetuates vulnerabilities and insecurities in the energy system that are avoidable.
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.
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 increase greenhouse gas emissions. The outcome will depend essentially on policy choices, incentives, and research and development, both public and private.
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.
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.

From *Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy,* www.ieer.org/carbonfree/

The Institute for Energy and Environmental Research
6935 Laurel Avenue, Suite 201
Takoma Park, MD 20912 USA

Address service requested.

Printed with vegetable oil based ink on recycled paper containing 30 percent postconsumer waste. Produced carbon neutral by Ecoprint.

Nonprofit Org
U.S. Postage
P A I D
Permit #1400
Silver Spring, MD