Chapter 5
CARBON MANAGEMENT

Abstract

Policies aimed at curbing carbon dioxide (CO_2) emissions will alter the energy mix, increase energy-related costs, and require reductions in demand growth. Effective carbon management will be aided by developing legal and regulatory frameworks to enable carbon capture and sequestration (CCS). As policymakers consider options to reduce CO_2 emissions, they face the challenge of creating a global framework that includes a transparent, predictable, economy-wide cost for carbon emissions.

This chapter considers climate, energy, and emissions concerns by examining the natural carbon cycle in the context of global and U.S. energy sources and uses. Various carbon management options raise new regulatory and policy implications.

An outline of the Carbon Management chapter is as follows:

- Carbon management
- Energy efficiency and demand reduction
- Transportation
- Carbon capture and sequestration.

There is growing concern that the climate is warming and that CO_2 emissions play a role. The most recent report by the Intergovernmental Panel on Climate Change (IPCC) about the physical science basis for climate change states: "Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."[1] ("Very likely" is greater than 90 percent likelihood, according to the IPCC report.)

Moreover, initiatives in increasing number are emerging, within both the public and private sectors, aimed at reducing carbon emissions. Such a trend highlights the potential for carbon constraint to become a significant feature of future energy strategies. In particular, future carbon constraint could alter the way in which the world uses the fossil fuels that currently provide most of our energy. Since changes in fossil-fuel use could affect diverse lifestyles, economic activity, and energy supply, it is becoming increasingly important to plan for ways to accommodate carbon-constraint policies within any overall energy strategy.

To better understand the range of potential energy futures, the Demand Task Group (see Chapter One) studied in detail five publicly available worldwide energy-demand projections provided by the Energy Information Administration (EIA) and the International Energy Agency (IEA). Economic growth is the primary driver in all these projections. The expected economic growth rates were greater

1 The Fourth Assessment Report of the Intergovernmental Panel on Climate Change: *Climate Change 2007: The Physical Science Basis.*

than the current annual rate of 3.1 percent (1980–2000) in all the projections except for the explicitly low-growth EIA Low Economic Growth projection. Four of the projections studied are based on energy-policy assumptions that extend energy policies in effect today. The energy growth rates for these four projections range from 1.5 to 2.5 percent per year, with only the EIA Low Economic Growth projection having an energy growth rate less than the 1980–2000 energy demand growth rate of 1.7 percent per year.

Policy assumptions can play a major role in determining the outcome of energy demand projections. The IEA created the Alternative Policy scenario in an attempt to estimate future energy demand, given the major energy policies now under consideration by governments around the world. Currently, there are more than 1,400 energy-related policies either in place or proposed by various countries. The IEA first removed from the list policies already in place. From the remaining policies, it incorporated those that are likely to be implemented in the future. These additional policies included those that increased biofuels use; increased the use of other renewable energy sources; increased the use of nuclear-power generation; created an environment that promoted energy efficiency; encouraged clean-fuel technologies use; and increased the production of domestic fuel supplies.

Key Information: Greenhouse Gases

The earth maintains an equilibrium temperature by re-radiating the energy it receives from the sun. So-called “greenhouse gases” trap some of the re-radiated energy. Much of the debate in the past was not directed at the link between global temperature and climate change, but more towards the degree of global warming and the role of man-made greenhouse gases versus the role of natural mechanisms.

Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), fluorinated gases (CFCs), sulfur hexafluoride (SF_6), and nitrous oxide (N_2O), to which human activity contributes atmospheric emissions. Of these, carbon dioxide is the most significant in its potential impact on global temperatures. The degree of warming is linked to the total volume of CO_2 in the atmosphere; since the beginning of the industrial revolution, the amount of CO_2 in the atmosphere has risen by about a third, from around 2,100 billion tons to around 2,750 billion tons. These figures are usually expressed as concentrations of CO_2 in parts per million of the total mass of the atmosphere. The pre-industrial levels of CO_2 were about 280 parts per million and current levels are rising through 380 parts per million. In order to stabilize the concentration of CO_2 and other greenhouse gases in the atmosphere, annual global emissions would have to be brought under control and then made to decline year after year.

Any approach to reducing the growth of the levels of greenhouse gases in the atmosphere must include either reducing the emissions of CO_2 to the atmosphere or enhancing the sinks for CO_2. The former can only be achieved by reducing the amount of fossil fuel burned or by capturing the produced CO_2 and preventing it from reaching the atmosphere. Enhancing carbon sinks can be achieved by increasing the mass of carbon tied up in the biosphere. For example, growing more trees in forests, attempting to induce the growth of algae blooms in oceans, or using more no-till farming methods (increasing carbon uptake in soils) could reduce the levels of CO_2 in the atmosphere.

Other greenhouse gases also can be curtailed. Agricultural practices such as reduced use of fertilizer (reducing nitrous oxide emissions), and collecting and flaring or burning methane from livestock waste, landfills, and coal mines could also play a role in offsetting future greenhouse gas emissions. In addition, reducing leakage of sulfur hexafluoride from utility transmission and distribution equipment, and destroying or avoiding production of fluorinated gases and nitrous oxide could also help control greenhouse gases.

The combined results of the five projections can be summarized as follows:

- Generally the projected world oil share of energy demand is lower in the future, while the natural gas and coal shares are higher.
- The projected nuclear share of world energy demand is lower in all cases except the Alternative Policy Case, where it is about the same as in 2000.
- Global CO_2 emissions were 24 billion metric tons in 2000, growing to a projected range between 34 (Alternative Policy Case) and 51 (High Economic Growth Case) billion metric tons in 2030.
- Projected U.S. energy demand growth rate is higher in the future than in the past in all but the Alternative Policy Case.
- Projected energy shares align in essentially the same way in the United States as in the rest of the world.
- The U.S. rate of growth of CO_2 emissions is projected to increase more slowly in the future than in the past, except in the High Economic Growth Case where emissions may grow more rapidly than in the past.

In light of these projections and the likelihood that some carbon constraint will emerge, and the assumption that the world will want to continue to use fossil fuels for a large fraction of energy requirements in the foreseeable future, it is important that governments and industries plan to accommodate a carbon constraint in their energy strategies. It is unlikely that the continued use of oil, natural gas, and coal, could remain unaffected in a carbon-constrained world.

CARBON MANAGEMENT

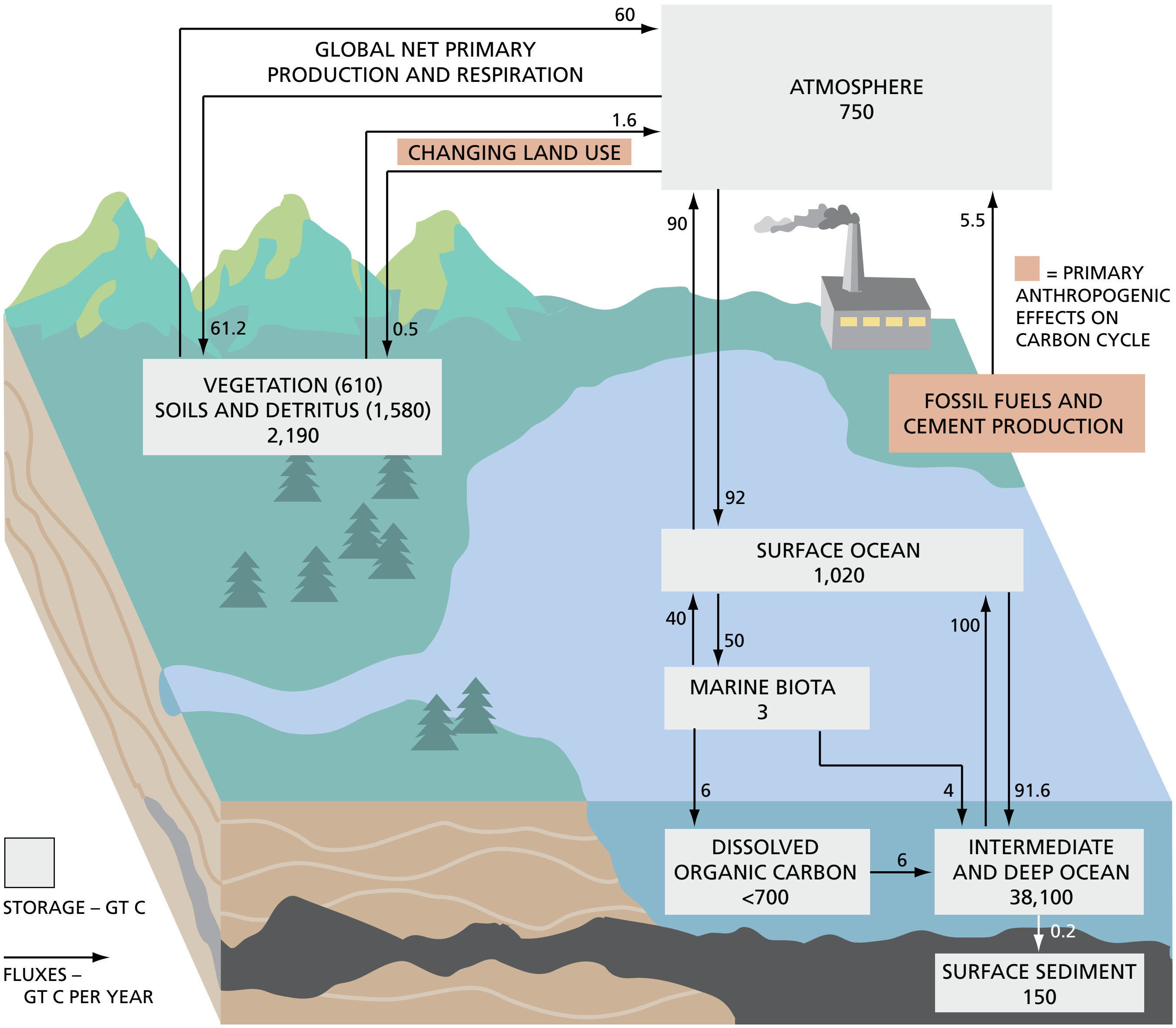
By its nature, climate change is global. The interrelation between energy and other markets requires that an effective response to climate change also, ultimately, be global. Carbon emissions from burning fossil fuels, combined with those from changing land use, augment the large natural flux of carbon between the atmosphere, the land, and the oceans (see Figure 5-1). Rapid mixing in the atmosphere ensures that CO_2 emitted anywhere in the world is quickly distributed about the globe, and since the start of the industrial era, the mass of CO_2 in the world's atmosphere has risen by a third.

Without international cooperation in the coming decades, achieving significant reductions in CO_2 emissions would be elusive, and disparity in national responses would create challenges to the international trade regime as different nations sought to address and prioritize what they saw to be their own particular concerns.

Approaches to reducing CO_2 emissions could include the following elements:

- Energy efficiency and demand reduction
  - Better and more efficient use of energy in all sectors, including transportation, buildings, industrial energy use, and power generation
  - Improved efficiency will need to be translated into reduced energy demand rather than solely into increased performance
- Use of lower-carbon fuels
  - Shift from coal to natural gas
- Use of non-carbon based power ("decarbonization")
  - Nuclear power
  - Wind power
  - Solar power
  - Ocean and geothermal power
- Use of "carbon neutral" energy sources
  - Biomass to augment power generation
  - Biofuels to augment hydrocarbons used for transportation
- Carbon capture and sequestration
  - Preventing the release to the atmosphere of CO_2 generated by the combustion of fossil fuels.

Innovation and deployment of new energy technologies in global energy systems could improve the potential for significant reductions in CO_2 emissions while maintaining the desired level of economic activity. This would require substantial private- and public-sector investments in research, development, demonstration, and deployment. The most cost-effective CO_2 policies would involve broad, technology neutral, market-based mechanisms to create incentives for the private sector to undertake these technology changes.



Source: OSTP NanoEnergy Brief, 10 August 2005, available at www.er.doe.gov/bes/presentations/OSTP_NanoEnergyBrief_10AUG05.pdf (based on D. Schimel, D. Alves, I. Enting, M. Heimann, F. Joos, D. Raynaud, and T. Wigley, 1996: "CO_2 and the Carbon Cycle").

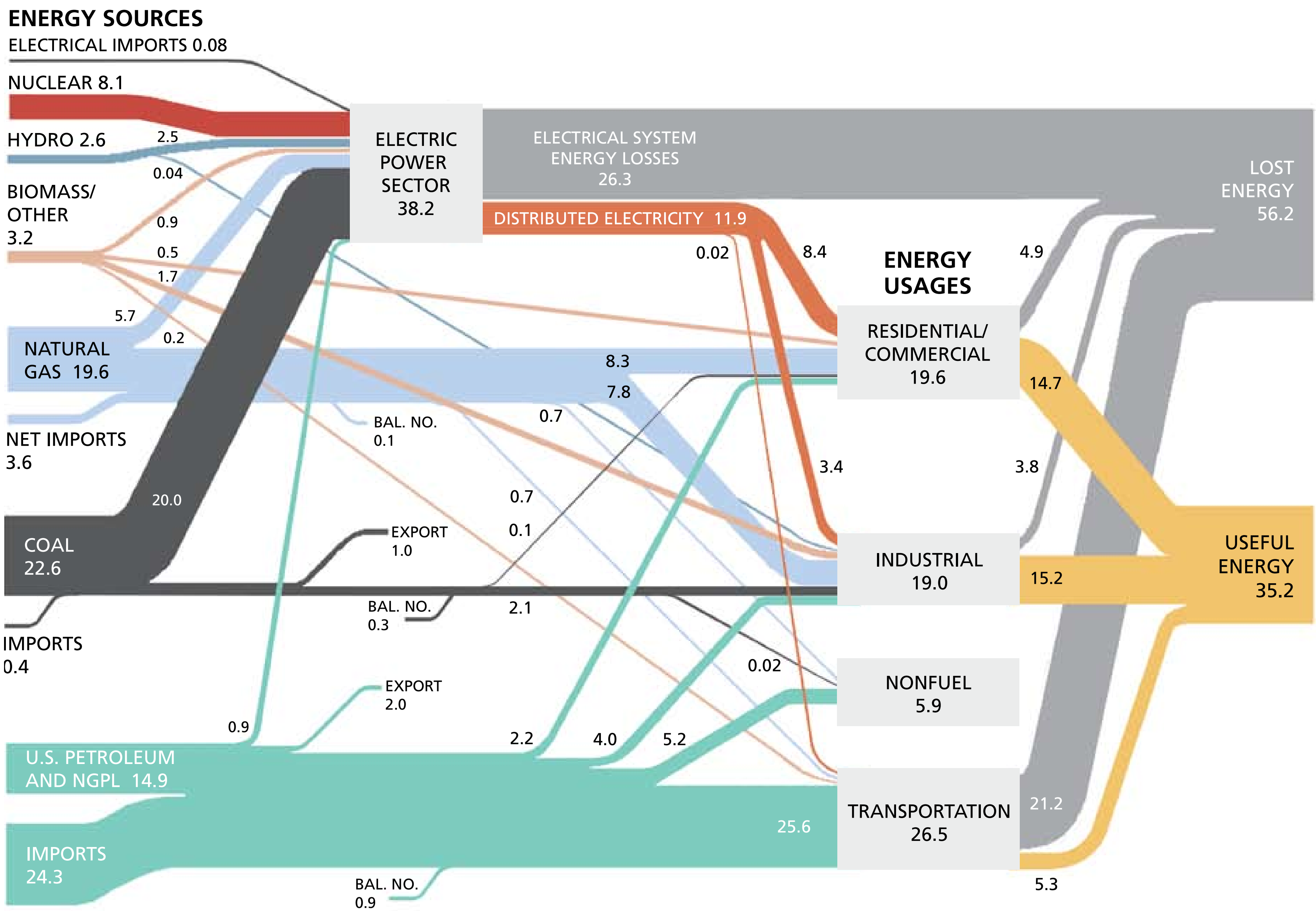
FIGURE 5-1. *The Global Carbon Cycle, with 1990s Carbon Fluxes in Gigatons of Carbon (GT C) per Year*

The Continued Use of Domestic Energy Resources under Carbon Constraint

Currently, fossil fuels (oil, natural gas, and coal) provide more than 80 percent of the world's energy needs. In terms of global CO_2 emissions from fossil fuels, oil accounts for 39 percent of these emissions and natural gas for 20 percent, while coal accounts for the remaining 41 percent.[2] Within the United States, fossil fuels similarly provide more than 80 percent of the nation's energy needs, as shown in Figure 5-2, which details the distribution both of the sources and the uses of the national energy budget in units of 10^{15} Btu (quads) (where 1 quad = 293 billion kilowatt-hours). The figure reveals both the degree of dependence on fossil fuels and the amount of energy lost, which in turn provides some measure of the potential scope for efficiency improvements.

Absent societal and market responses to climate change, oil, natural gas, and coal would continue to

2 International Energy Agency, *World Energy Outlook 2006.*



Source: Lawrence Livermore National Laboratory, 2004.

FIGURE 5-2. *U.S. Energy Sources and Uses in 2002 (Quadrillion Btu per Year)* play a major role in energy supply over the next three decades and beyond. In particular, because of its high energy density, and the convenience of using a liquid fuel, petroleum would continue to dominate transportation. Conventional oil, heavy oils, and, to a lesser extent, biofuels and liquid fuels derived from natural gas and coal would ensure continuity of supply for transportation at relatively low cost. At the same time, heat and power would be dominated by coal and natural gas from domestic resources.

The question arises: What happens to this projection if there is significant constraint on CO_2 emissions? Given that most energy-related CO_2 emissions come from fossil fuels, the use of these resources cannot remain unaffected in a carbon-constrained world. A combination of improved efficiency, demand reduction, decarbonization, and CCS would be needed to reduce emissions. CCS would strongly determine the extent to which we could continue to use a variety of fossil fuels, and in particular it would enable the continued use of the large domestic U.S. coal reserves while still reducing CO_2 emissions. Similarly, incorporating CCS, China and India could reduce their CO_2 emissions while continuing to use their own substantial coal reserves.

ENERGY EFFICIENCY AND DEMAND REDUCTION

Improving the efficiency of energy use within the industrial, commercial, domestic, and transportation sectors has the potential to reduce energy use without reducing economic activity, and to reduce the associated CO_2 emissions. However, to achieve this, incentives would be needed to encourage investments in higher-efficiency capital and to encourage using newly gained efficiency to actually reduce demand. Key to stimulating long-term investment by the private sector in more energy-efficient capital would be a steady, predictable, long-term increase in the cost of CO_2 emissions. This would be enhanced by government incentives to economically retire older, high-CO_2 emitting plants as well as to invest in newer, low-emissions capital. Incentives in the building sector, both commercial and domestic, would be needed to encourage the use of higher-efficiency construction techniques and efficient cooling and heating systems, which often come at a higher initial cost with a long "pay-back" period.

TRANSPORTATION

While CCS can address CO_2 emissions from coal and the extra emissions associated with producing unconventional oil, it cannot address the tail-pipe emissions produced when using hydrocarbon fuels for transportation. If we wished, in a carbon-constrained world, to continue significant use of gasoline and diesel as transportation fuels, and at the same time to reduce CO_2 emissions, then other approaches would be needed. The appropriate measures to achieve such reductions would focus largely on a combination of improved engine efficiency and on regulatory mechanisms to reduce demand.

There is potential to almost double the efficiency of existing gasoline- and diesel-powered vehicles. And there are technologies to augment internal-combustion engines in cars using electric hybrids and plug-in electric hybrids, which are already available. So long as the centralized electricity generating plants control CO_2 emissions, then the electrification of cars helps reduce overall CO_2 emissions as well as reduce the requirements for oil imports. Examples of such solutions include integrated coal-fired power with CCS or alternative low-carbon electricity sources such as nuclear, wind, or other renewables.

However, technical efficiency improvements may not, by themselves, lead to a reduction in the demand for hydrocarbon fuels. Over the past two decades, light-duty vehicle efficiency improvements in the United States have been countered by increased miles driven and heavier, higher-performance vehicles. Active policies to reduce demand for transportation fuel would be an important element in any portfolio of strategies to reduce CO_2 emission in a carbon-constrained world. Demand reduction could be achieved by combining approaches that reflect the following considerations:

- Reducing carbon emissions from transportation would have key importance in a carbon-constrained world.
- Public education, particularly of the next generation of consumers, would play an important role in long-term strategies to reduce demand.
- Improved engine efficiency enables demand reduction, especially if accompanied by other mechanisms to reduce demand.

- Increasing fuel price is unlikely to be sufficient by itself. A combination of increased price and regulation would probably be necessary to reduce demand effectively.
- Government incentives to increase the use of public transport would help reduce demand for transportation fuel.
- Congestion charges and high-occupancy vehicle (HOV) systems would further help reduce fuel demand.
- Government incentives to retire older, less-efficient vehicles would help reduce fuel demand, and programs to audit the energy efficiency of the existing fleet would be an effective complement to such incentives.

CARBON CAPTURE AND SEQUESTRATION

In a carbon-constrained world, CCS would allow us to sustain many of the benefits of using hydrocarbons. Even where the CO_2 generated by burning hydrocarbons cannot be captured easily, as with using oil for transportation, sequestering CO_2 from other sources (such as coal-fired power stations) can help create—to some degree—the margin needed to allow for the volumes of CO_2 that escape capture. Fossil fuels are likely to remain an important part of the energy mix, because of the continuing competitive (direct) cost of hydrocarbons, and the huge investment already made in infrastructure to deliver them. Therefore, the combination of fossil fuel use with CCS is likely to be emphasized as a strong complement to strategies involving alternative, non-hydrocarbon, energy-supply sources, and to measures designed to encourage more efficient energy use. Here we compile key questions about the potential for CCS technology.

What is the Contribution of CCS to Maintaining Energy Supply from Fossil Fuels?

In a carbon-constrained world, CCS would play a key role in allowing the continued use of coal and the growing use of unconventional oil. By providing a means for dealing with a significant fraction of the CO_2 emissions from fossil fuels, CCS would allow us to retain fuel diversity for many decades. CCS would be implemented largely in association with burning coal, which, worldwide, now accounts for 41 percent of all CO_2 emissions from fossil fuels. At the same time, chemical plants and centralized power generation using natural gas or oil could also incorporate CCS.

The growing need to provide transportation will increase the pressure to move towards other fossil sources for liquid fuels, such as unconventional oil (heavy oil, shale oil, tar sands) and coal-to-liquids (CTL) technologies. Since exploiting these resources comes with a significantly heavier CO_2 burden than with conventional oil and natural gas, then in a carbon-constrained world, CCS would become increasingly important. CCS can be directly applied to the extraction of unconventional oil and to the CTL process, and has the potential to mitigate the extra CO_2 burden beyond that from using these fuels for transportation. This facilitates their use under carbon constraint.

CCS also has application to disposal of petroleum coke (petcoke), which is the "bottom of the barrel" residue produced by the world's refineries. Petcoke is similar to coal as a fuel, but petcoke's generally higher sulfur level can be a significant challenge to its use for power generation. However, gasification, along with CCS, makes it possible to burn polluting fuels like petcoke because removing pollutants from a high-pressure gas stream is much cheaper than from a stack. Petcoke-fueled power, combined with CCS, has the potential to transform a costly problem into a profitable technology.

What is the Level of Readiness for Large Scale CCS?

The technologies for capturing CO_2 from pre- and post-combustion gas streams are available. However, their costs are somewhat uncertain and constraints remain on the levels of oxygen, particulates, and sulfur oxides for effective extraction using conventional amine solvents. Current capture technologies also prefer steady-state conditions that do not always prevail in the power-generation industry. Similar concerns apply to the more sophisticated pre-combustion capture. However, broadly speaking, the capture technologies exist and are not critically dependent on new technological breakthroughs. The same is true for CO_2 sequestration technologies; the oil industry has extensive experience with pumping liquids into subsurface formations and evaluating the security of these formations for storage. Currently, several pilot projects have successfully demonstrated sequestration of CO_2 in volumes amounting to millions of tons.

Still missing is the demonstration of fully integrated CCS at commercial scale, along with an established legal and regulatory environment that will enable and encourage CCS. There is, we believe, a strongly growing need within the United States to implement full-scale integration of power generation and CCS. Elsewhere, there are efforts to create just such integration. China, in particular, with funding from the European Union, plans a full-scale plant with CCS within the next five years. The United States should not delay such implementation while awaiting further research. We recommend that the United States achieve the necessary refinements in the largely existing technologies by accelerating full-scale implementation. Further, the United States should share its experience with other nations.

Does the Capacity for Underground Storage Exist?

It is very likely that there is ample storage space in subsurface formations to store enough CO_2 to substantially alleviate atmospheric emissions. What is less well known is the distribution and availability of these storage resources. While exhausted oil and natural gas reservoirs will provide room for considerable amounts of CO_2, it will probably be necessary to also use deep saline formations, depending, for example, on the siting requirements for power stations with CCS. Subsurface storage space will become a resource, with its own supply curve, and we recommend that the United States extend activities by the Carbon Sequestration Regional Partnerships and conduct, at a federal level, a full survey of the nation's potential sequestration sites. A preliminary map of potential U.S. storage sites is shown in Figure 5-3. Other nations should be encouraged to do the same.

What is the Cost of CCS Compared to Other Approaches to Carbon Mitigation?

CCS represents a competitive way to address a substantial fraction of the potential need for carbon mitigation; the IPCC Special Report on Carbon Dioxide Capture and Storage points out that including CCS in a mitigation portfolio could achieve suitable stabilization of CO_2 concentrations in the atmosphere at a lower cost than otherwise.[3] The IPCC report observes: "Models indicate that CCS systems will be competitive with other large-scale mitigation options such as nuclear power and renewable energy technologies. These studies show that including CCS in a mitigation portfolio could reduce the cost of stabilizing CO_2 concentrations by 30 percent or more. One aspect of the cost competitiveness of CCS technologies is that they are compatible with most current energy infrastructures."

Current estimates for the cost of CCS implementation on coal and natural gas fired power plants are about \$40/ton of CO_2. This includes the cost to capture the CO_2, compress it to supercritical (liquid) form, and inject it in the subsurface for sequestration. To put this cost in perspective, \$40/ton of CO_2 equates to between 2 and 4 cents per kilowatt-hour depending on the fuel source, with gas at the lower end of the range and coal at the upper end.

Efforts to reduce CCS costs would focus on capture technology, which today accounts for about half the cost. There is considerable scope for improving the current capture technologies, and for implementing new ones. Nonetheless, research in these areas should parallel implementing current technologies, and should not serve as a reason to delay a rapid start on full-scale CCS.

What is the Role of CO_2-Based Enhanced Oil Recovery (CO_2-EOR) in CCS?

Large volumes of naturally occurring CO_2 obtained from underground deposits are currently used by the oil industry to enhance the recovery of oil from mature reservoirs.[4,5] This CO_2-EOR is currently conducted without regard to storing the CO_2 "downhole." However, with relative ease present technology could

3 Intergovernmental Panel on Climate Change, *IPCC Special Report on Carbon Dioxide Capture and Storage*, 2005, Interlachen, http://www.ipcc.ch/.

4 Melzer LS (ed.), "CO2 Sourcing for Enhanced Oil Recovery," The University of Texas of the Permian Basin's Center for Energy and Economic Diversification Short Course #13 on Carbon Dioxide Flooding, Presented at the Annual CO2 Flooding Conference, Midland, Texas, December 6, 2004.

5 Bliss K, "Final Report for DOE Award No. DE-FC26-03NT41994, Admendment No. A000," report submitted by the Interstate Oil and Gas Compact Commission, Oklahoma City, OK (January 24, 2005): 31, available at http://www.iogcc.state.ok.us/PDFS/CarbonCaptureandStorageReportandSummary.pdf.

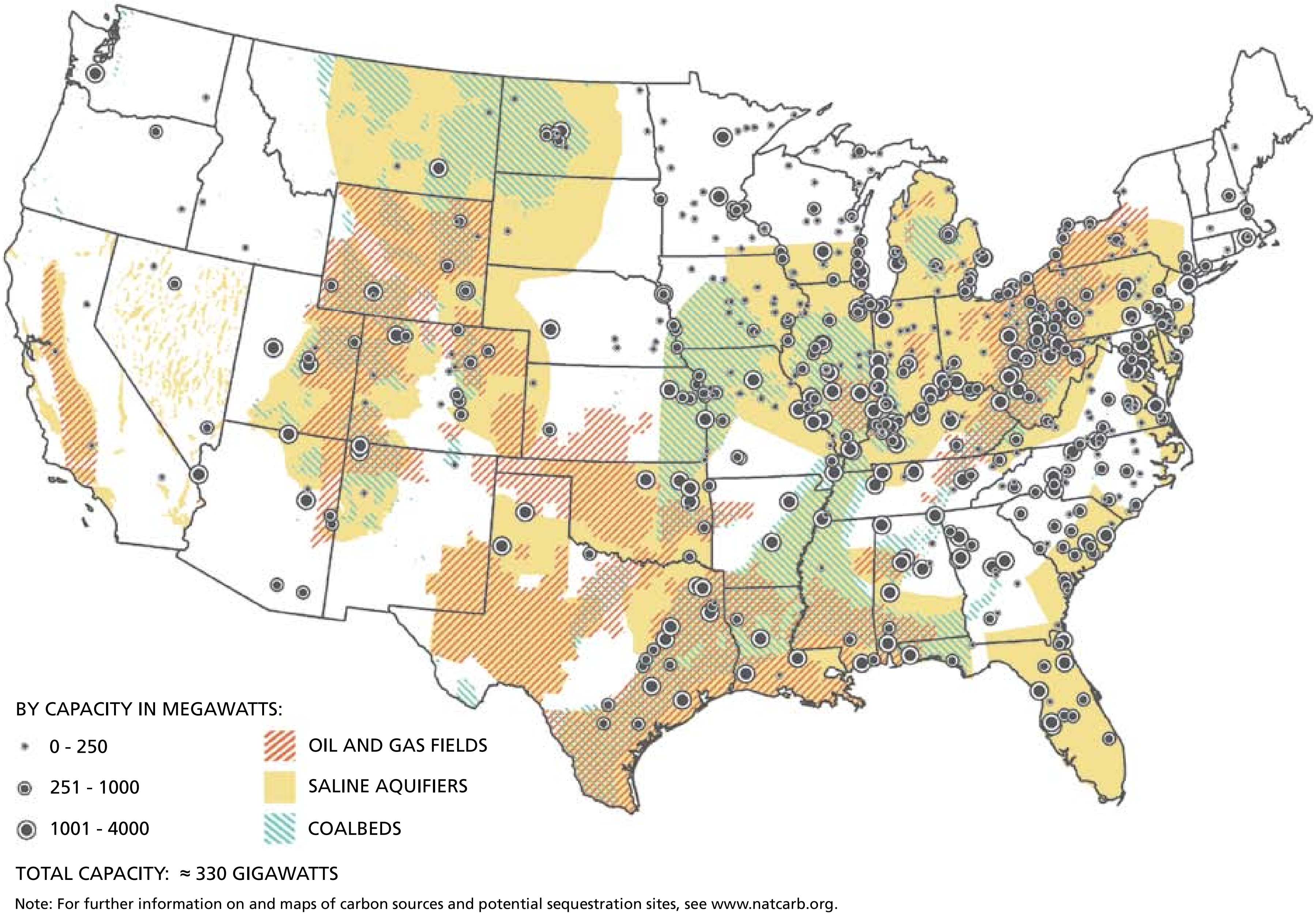


***FIGURE 5-3.** U.S. Coal-Fired Power Plants (2000) and Potential Sequestration Sites*

be modified to emphasize such storage. In a carbon-constrained world, we could also expect rising pressure to use anthropogenic CO_2 to drive this recovery enhancement, which would lead to a net reduction in atmospheric CO_2. While the likely extent of CO_2-EOR provides a relatively small fraction of the capacity needed for CO_2 sequestration, it does offer a strong technology bridge to carbon-sequestration technologies and should be encouraged as an important element of a CCS strategy. Government incentives for CO_2 storage in association with CO_2-EOR, and new arrangements for developing suitable infrastructure for commercial use of anthropogenic CO_2 for EOR with storage, could help CO_2-EOR for storage succeed, particularly as CO_2 becomes increasingly available (and increasingly cheap) under a wide-scale adoption of CCS.

Regulation

The technological hurdles to effectively implementing CCS are surmountable. However, the regulatory framework within which CCS is deployed will play an important role in determining CCS's future. The legislative framework within which CCS is conducted will have a major impact on how rapidly the technology is implemented. And legislation will ultimately determine whether CCS can effectively mitigate carbon emissions and facilitate using future hydrocarbon supplies.

During a 2006 G8 forum on carbon sequestration,[6] more than 120 participants from 15 nations identified 5 critical areas of regulation that need to be resolved in order to facilitate the near-term deployment of CCS:

- Ownership and liability of CO_2 at every step along the "value chain"
- Regulatory treatment of CO_2 and other gases in the CO_2 stream
- Monitoring, verification, and remediation
- Property rights and intellectual property
- Jurisdictional and trans-boundary issues.

Moreover, the roles of federal and state governments, regarding which authority is responsible for which regulation or permitting process, need clarification. Such clarification will help attract commercial players into the carbon capture and storage market. Participants of the G8 forum felt that "progress cannot be made on near term opportunities if this issue is not resolved."

CCS Conclusion

In summary, CCS would greatly facilitate the sustained use of oil, natural gas, and coal to meet U.S. energy demands in a carbon-constrained world. Moreover, it would reduce the pace at which we would otherwise need to develop and employ alternative energy sources. CCS is viable and its introduction is not limited by any need for significant technological breakthroughs.

6 G8 International Energy Agency (IEA) & Carbon Sequestration Leadership Forum (CSLF) First Workshop on Near Term Opportunities, held 22–23 August 2006, San Francisco.