

ATMOSPHERIC STABILIZATION: TECHNOLOGY NEEDS, OPPORTUNITIES, AND TIMING¹

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The issue of global climate change may prove to be the greatest challenge of the 21st century. Its global nature, its intergenerational time scale, and the potential magnitude of the change involved both from the perspective of causes and consequences take it outside the bounds of environmental problems with which humans have traditionally dealt.

Stabilizing Concentrations Not Emissions

The present structure for addressing climate change is the Framework Convention on Climate Change (the Rio Treaty). The Treaty has as its objective the “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.” (Article 2) This is not the same as stabilizing emissions. Because emissions accumulate in the atmosphere, the concentration of carbon dioxide will continue to rise indefinitely even if emissions are held at current levels or even at some reduced level.

Stabilizing the concentration of CO₂ has the very daunting implication that at some point net emissions from all sources (fossil fuels plus cement manufacture plus land-use emissions) must eventually peak and subsequently decline indefinitely thereafter, eventually declining to virtually zero. Limiting the con-

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centration of CO₂, the most important greenhouse gas, to levels ranging from 350 ppmv (parts per million volume) to 750 ppmv, compared with pre-industrial concentration of 280 ppmv, implies a fundamental transformation of the global energy system by the end of the 21st century.

A popular myth is that the world is running out of fossil fuels and will therefore make a natural transition to an energy system based on renewables and conservation during this century, thus leading to a natural limit on cumulative carbon emissions. The reality is that while the most attractive grades of fossil fuel resources may be limited, fossil fuels as a class are abundant. Technology developments could enable fossil fuels to remain the core of the global energy system throughout the century ahead.

Growth in population and incomes can be expected to generate a concurrent growth in the demand for energy services. This growth in demand for energy services coupled with the abundance and usefulness of fossil fuels is anticipated to lead to a continued growth in cumulative global emissions of carbon to the atmosphere throughout the 21st century.

Limiting cumulative global emissions implies that the global energy system, not just the United States energy system, must sooner or later make a fundamental transformation. The suite of energy technologies that could affect this transition from continued emissions growth to peak and indefinite decline includes both non-fossil and, importantly, fossil-fuel energy technologies. Energy conservation, nuclear, solar, sustainable commercial biomass, hydroelectricity, wind and other renewable energy forms can provide energy without directly emitting carbon. But, so too can fossil fuels, if the associated carbon can be captured and disposed of in reservoirs that permanently isolate CO₂ from the atmosphere. It is particularly interesting to note that if the carbon were removed from commercial biomass and permanently stored in isolation from the atmosphere, its energy would be associated with negative emissions. Both carbon capture and disposal and biotechnology hold special promise as avenues for R&D and technology development.

The Link Between Emissions and Concentrations

Unlike other greenhouse gases, carbon dioxide released to the atmosphere is not destroyed but is redistributed among the reservoirs that actively exchange carbon: plants and soils, the oceans, and the atmosphere. A fraction of the fossil

CO₂ emitted into the atmosphere is expected to represent an essentially permanent increase in atmospheric concentrations unless the CO₂ is artificially removed. (Only very small quantities of carbon are permanently removed to geologic formations annually. Though these quantities are not significant over a hundred years, they accumulate to significant totals over thousands to millions of years.)

The cumulative emissions associated with different CO₂ concentrations are large. Table 1 shows cumulative global net emissions from all sources, everywhere, and associated very long-term concentrations.

TABLE 1: LONG-TERM CO₂ CONCENTRATIONS AND ASSOCIATED CUMULATIVE NET GLOBAL CARBON EMISSIONS

Very Long-Term CO ₂ Concentration Objective (ppmv)	Cumulative Net Global Emissions 1750 to 2500 (billions of tonnes of carbon)	WRE Cumulative Net Emissions 1750 to 2100 (billions of tonnes of carbon)	WRE Transient Concentration in 2100 (ppmv)
450	1,600	1,000	450
550	2,300	1,300	540
650	2,900	1,500	605
750	3,400	1,600	640

In 1998 global fossil fuel carbon emissions were approximately 6.6 billion tonnes (metric tons) of carbon per year with an additional approximately 1.5 billion tonnes of carbon per year from land-use change such as deforestation. (The values for land-use change emissions are known with much less accuracy than those of fossil fuel emissions.)

Over the century ahead, cumulative emissions associated with concentrations ranging from 450 ppmv to 750 ppmv are about half of the total budget over all time. This near-term limit reflects the additional constraint that stabilization trajectories never allow transient concentrations to exceed the long-term stabilization value.

Timing

Wigley, Richels and Edmonds² (WRE) in 1996 developed global net emissions paths that were consistent with various stable, long-term concentrations of atmospheric CO₂, which Wigley (this volume) has updated. For stable CO₂ concentrations ranging from 350 ppmv to 750 ppmv, global emissions of CO₂ must peak in this century and then begin a long-term decline. The average concentration in 1999 was 368 ppmv and pre-industrial values were in the neighborhood of 280 ppmv. The timing and magnitude of the global carbon emissions peak depends on the desired CO₂ concentration as well as on a variety of factors shaping future U.S. and global technology and economy. It is important to point out that the concentration that will “prevent dangerous anthropogenic interference with the climate system,” the goal of the Rio Treaty, is not yet known.

Values taken from WRE for alternative CO₂ concentrations, peak CO₂ emissions, CO₂ emissions in the year 2100, and associated timing are given in Table 2 below.

TABLE 2: FOSSIL FUEL EMISSIONS ASSOCIATED WITH REVISED WRE TRAJECTORIES STABILIZING CO₂ CONCENTRATIONS AT 350 TO 750 PPMV³

Long-Term CO₂ Concentration (ppmv)	350	450	550	650	750
Maximum Global CO ₂ Emissions (billions of tonnes carbon per year)	7.0	7.8	10.6	12.8	7.0
Year of Maximum Global Emissions along WRE Trajectory	2004	2010	2036	2051	2004
Year 2100 Global CO ₂ Emissions (billions of tonnes carbon per year)	-0.5	3.7	6.8	10.1	-0.5

The time path of emissions will have a profound effect on the cost of achieving atmospheric stabilization. The WRE emissions paths were constructed to lower costs by avoiding the premature retirement of capital stocks, taking advantage of the potential for improvements in technology, and reflecting the time-value of capital resources.

Along the WRE trajectories, energy-technology transitions away from reference-case emissions begin gradually. Near-term reductions in emissions growth rates depend on technology that is already available. It takes decades to go from “energy research” to the practical application of the research within some commercial “energy technology” and then perhaps another three to four decades before that technology is widely deployed throughout the global energy market. Low- and non-emitting technology becomes increasingly important over time in global emissions trajectories that stabilize the concentration of CO₂. Their future availability requires investments in energy R&D substantially in advance of the desired deployment.

Transition rates of global CO₂ emissions away from reference emissions become more stringent as the concentration ceiling is lowered. For example, for a global concentration of 550 ppmv, net global CO₂ emissions begin to depart from present trends (i.e. deviations of more than 100 million tonnes of carbon from present trends) within the next 10 to 20 years (Wigley, this volume). Note that the concentration of 550 ppmv is not necessarily preferred to any other concentration and is used here purely for illustrative purposes. Emissions growth rates decline more rapidly along paths leading to stabilization at concentrations lower than 550 ppmv, such as 350 ppmv or 450 ppmv. Conversely emissions growth rates decline less rapidly along paths leading to stabilization at concentrations higher than 550 ppmv, such as 650 ppmv or 750 ppmv. The lower the long-term concentration ceiling, the greater the dependence on present technology and the less gradual the transition.

A Credible Commitment

A credible commitment to limit cumulative global carbon emissions is an important complement to technology development aimed at stabilizing the concentration of CO₂. Such a commitment could focus energy R&D toward lower- and non-emitting energy technologies and expedite the deployment of new energy technologies and into widespread adoption in the marketplace. Such a commitment is unlikely to be achieved without cost. It is likely to entail the diversion of some resources from uses that would otherwise be attractive. The cost of stabilizing the concentration of greenhouse gases will depend on many factors including the desired concentration, economic and population growth, the choice of policy instrument, and the portfolio of energy technologies that might

be made available. Not surprisingly costs are higher the lower the desired concentration of greenhouse gases. They are also higher for higher rates of economic and population growth. And, they are lower the better and more cost effective the portfolio of energy technologies that can be developed. This last point about the role of technology is very important, but not well appreciated.

Energy Technology in Scenarios with Growing CO₂ Emissions

It is also not well recognized that most long-term future projections of global energy and greenhouse gas emissions and hence, most estimates of the cost of emission reductions, assume dramatic successes in the development and deployment of advanced energy technologies occur for free. For example, the Intergovernmental Panel on Climate Change (IPCC) developed a set of scenarios based on the assumption that no actions were implemented to mitigate greenhouse gas emissions.

One IPCC reference case that is frequently cited is IS92a. It assumes “technological change as usual.” This central reference scenario assumes that by the year 2100 three-quarters of all electric power would be generated by non-carbon emitting energy technologies such as nuclear, solar, wind, and hydro, and that the growth of crops for energy (commercial biomass) would account for more energy than the entire world’s oil and gas production in 1985. Yet even with all these assumptions of technological success, the need to provide for the growth in population and living standards around the world drives fossil fuel emissions well beyond 1997 levels of 6.6 billion tonnes of carbon per year to approximately 20 billion tonnes of carbon per year by 2100. Subsequent analysis by the IPCC as well as independent researchers serves to buttress the conclusion that, even with optimistic assumptions about the development of technologies, the concentration of CO₂ in the atmosphere may well continue to rise throughout the century. (See Wigley, this volume.)

Stabilizing the concentration of CO₂ requires either greater deployment of technologies, which are already assumed to constitute a major share of the global energy system, or the development and deployment of additional technology options. For example, technologies such as carbon capture and disposal, terrestrial carbon sequestration, fuel cells, hydrogen systems, and biotechnology could play significant roles in future global energy systems, if cost-effective technology

options are available that can simultaneously meet other societal requirements including health, safety, reliability, other environmental concerns, performance, amenity, and cost.

There's No "Silver Bullet"

No single technology controls the cost of stabilizing CO₂ concentrations under all circumstances. The portfolio of energy technologies that is employed varies across the world's regions and over time. Regional differences in such factors as resource endowments, institutions, demographics and economics inevitably lead to different technology mixes in different nations, while changes in technology options inevitably lead to different technology mixes across time.

Technologies that are potentially important in stabilizing the concentration of CO₂ include energy efficiency and renewable energy forms, non-carbon energy sources such as nuclear power and fusion, improved applications of fossil fuels, and technologies such as terrestrial carbon capture by plants and soils, carbon capture and geologic disposal, fuel cells and advanced energy storage systems, and commercial biomass and biotechnology. The latter holds the promise of revolutionary change for a wide range of energy technologies.

Many of these technologies play only a minor role in their present state of development. Research and development by both the public and private sectors could provide the scientific foundations needed to achieve improved economic and technical performance, establish reliable mechanisms for monitoring and verifying the disposition of carbon, and to develop and market competitive carbon management technologies. For example, advances in the biological sciences and biotechnology hold the promise of dramatically improving the competitiveness of commercial biomass as an energy form and potentially opening up new pathways for revolutionary breakthroughs in other technologies such as carbon capture and disposal.

Investments in Energy R&D

Energy R&D occurs in a variety of places around the world and is undertaken by both the public and private sectors, sometimes independently, sometimes in partnership. Developing a suite of technology options whose performance is

equal to that assumed in reference emissions scenarios developed by the IPCC and researchers whose work is reported in the open literature, is a challenge in its own right. Developing and deploying a further suite of technologies for a world in which emissions peak and decline indefinitely thereafter is even more daunting.

New energy technologies are the product of energy R&D investments ranging from investments in basic science, biotechnology, individual technology components, and energy systems development. The mix between public and private sector participation varies across cultures. In market economies the private sector is particularly adept at energy R&D that is relevant to the development and deployment of new technologies. In contrast the public sector performs better in energy R&D that develops the underlying scientific foundations for technology development, e.g. biotechnology, computational sciences, materials science, and technology to monitor and verify emissions mitigation, as well as in technologies which are either high risk and/or too long-term for private sector development. Risks associated with the inability of present decision makers in the public and private sectors to foresee the course of future development, either in terms of policies and institutions or R&D outcomes, can be managed through investments in a portfolio of energy-technology options.

Recent Energy R&D Trends

Recent trends in public and private spending on energy research and development in the world and in the United States suggest that the role of technology in addressing climate change may not be fully understood nor appreciated. Figure 1 shows that although public investment in energy R&D has increased very slightly in Japan, it has declined significantly in the United States and even more dramatically in Europe, where reductions of 70 percent or more since the 1980s are the norm.

Moreover, less than 3 percent of this investment is directed at technologies that, although not currently available commercially at an appreciable level, have the potential to lower the costs of stabilization significantly.

FIGURE 1: ENERGY R&D FUNDING IS DECLINING

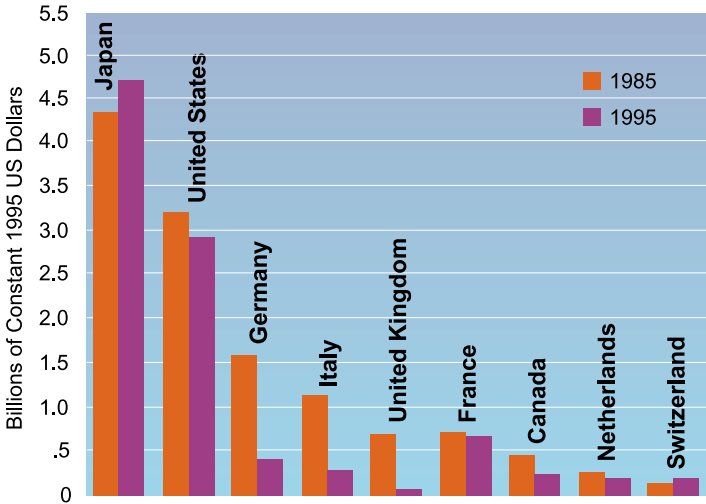
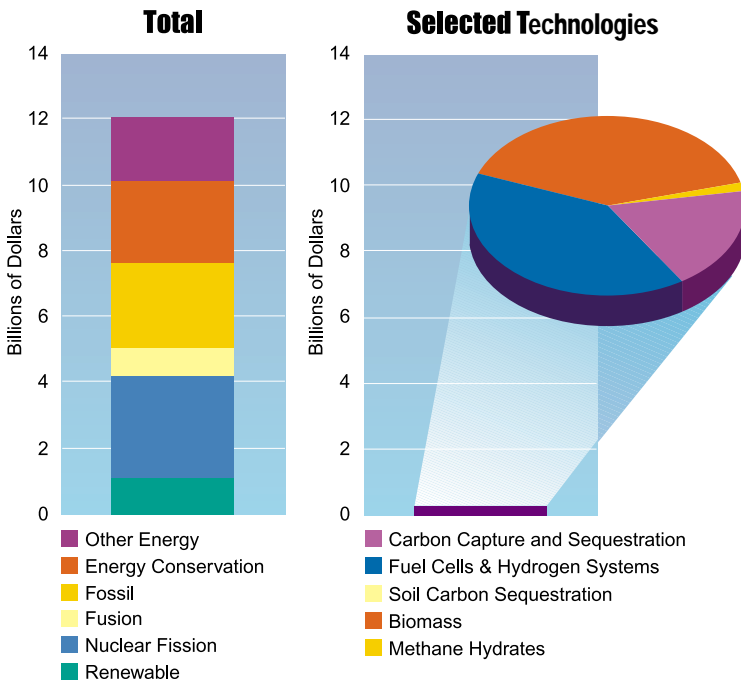


FIGURE 2: GLOBAL ENERGY R&D INVESTMENTS IN 1995



Beyond Energy Technology to a Larger Comprehensive Climate Strategy

While technology is pivotal when it comes to controlling the cost of stabilizing the concentration of greenhouse gases, it is only one of four major elements that are needed in a comprehensive program to address climate change including:

1. Adaptation to climate change,
2. A credible, global commitment that greenhouse gas concentrations will be limited,
3. Reduction of scientific uncertainties, and
4. Energy technology R&D.

In summary, stabilizing the concentration of greenhouse gases at levels ranging up to 750 ppmv represents a daunting challenge to the global community. Along CO₂ emissions trajectories leading to the stabilization of CO₂ concentrations, global CO₂ emissions peak and begin a permanent decline during this century. The development and deployment of a portfolio of low- and non-emitting energy technologies could help minimize the cost of achieving that end, including technologies that are not presently a significant part of the global energy system. While important, energy technology development alone is more effective if complemented by a commitment to resolve scientific uncertainties, facilitate adaptation to climate change that cannot be avoided, and a credible, global commitment that greenhouse gas concentrations will be limited.

Endnotes

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Institute for Applied Systems Analysis (Austria), Japan Science and Technology Corporation, National Renewable Energy Laboratory, Potsdam Institute for Climate Impact Research (Germany), Stanford China Project, Stanford Energy Modeling Forum, and Tata Energy Research Institute (India).

2. Wigley, T.M.L., R. Richels & J. A. Edmonds. 1996. "Economic and Environmental Choices in the Stabilization of Atmospheric CO₂ Concentrations," *Nature*. 379 (6562):240-243.

3. See Wigley, this volume.