Global Warming: An Energy Technology R&D Challenge

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Two major uncertainties cloud the picture of future energy technology needs: (i) growth of energy demand and (ii) the seriousness and urgency of the greenhouse effect. To allow for these uncertainties, a broad research and development (R&D) effort is needed, one that is balanced with respect to emphasis on improved energy sources and improved efficiency of energy end use and conversion. An Oak Ridge National Laboratory (ORNL) survey of energy technology R&D (*1*) revealed a rich variety of opportunities for improving both end use and supply technologies. It also concluded that the U.S. effort is sufficiently broad, because combined public and private sector investments are supporting work on most of the promising energy technology options at some level.

Although the R&D effort is broad, none of the nonfossil energy sources are ready to be substituted competitively for fossil fuels at the scale necessary to reduce CO_2 emissions. To correct this inadequacy, a three-pronged R&D strategy is required: improve the efficiency of energy conversion and use, improve nonfossil energy sources, and improve technologies tailored to meet the needs of developing nations.

During the past decade and a half, the intensity of energy use (energy per unit of economic output) has declined remarkably in the United States and other industrialized nations. In fact, the Arab oil embargo did much to slow the rate of growth of CO_2 emissions (Fig. 1). Much of this slowing has been the result of technical improvements, and the potential for further cost-effective improvements in the efficiency of energy use is large for all sectors of the economy (*2–7*).

Some of this potential can be achieved with state-of-the-art technology, yet the opportunities for developing even better technologies through R&D are numerous; for example, advanced automobile engines (such as ceramic gas turbines), gas-fired heat pumps (that are 50% more efficient than today's best alternatives), surface wave fluorescent lights, smart sensors and controllers to increase the productivity of industrial processes (*8*) and to make buildings and vehicles more efficient, and much more efficient gas turbines for generating electricity (*9*).

Because of this potential, improving efficiency is the best near- to mid-term (30-year) strategy for moderating the rate of growth of CO_2 emissions. Furthermore, using energy more efficiently in ways that are also economical is an attractive strategy for individuals and nations alike, regardless of concern about the greenhouse effect. It can not only save money but also reduce stress on oil markets and the environment generally, and it can buy time to develop better nonfossil energy sources. Nevertheless, we do not know how far the strategy can take us. It is limited by the dynamics of the market (the negative feedback on prices) and by various market imperfections and institutionalized barriers. Research is needed to learn how to remove these barriers and imperfections most effectively.

However, even if energy is used much more efficiently, a sustainable reduction in CO_2 emissions will require better nonfossil sources. None of the nonfossil energy sources, separately or collectively, are yet ready to be put into use at the level of performance, cost, and social acceptance required to be competitive.

Nuclear power is perhaps the nearest to being ready, but a significantly expanded deployment is constrained by concerns over reactor safety, accidental reactor damage, and diversion of nuclear fuel to weapons; by problems with managing waste; and by escalating capital and operating costs. Biomass and hydropower are resource limited. Solar thermal electric, photovoltaics, and wind are still expensive, and the power they provide is intermittent. Geothermal sources are geographically constrained and often expensive to develop, as are ocean thermal, wave, and tidal power. Fusion is still considered decades away from practical demonstration (*10*). In other words, our technological insurance policy (to provide options to control the changing greenhouse effect at reasonable costs) is not paid up.

The R&D prospects for overcoming some of these inadequacies appear good, albeit not easy to achieve. Recent articles have highlighted some of these prospects, for example, passively safe nuclear reactors (*11*) and cheaper photovoltaics (*12*). Other options include increasing the productivity and reducing the cost of biomass feedstocks and their conversion to transportation liquids; more aerodynamically efficient wind machines; lower cost, more efficient

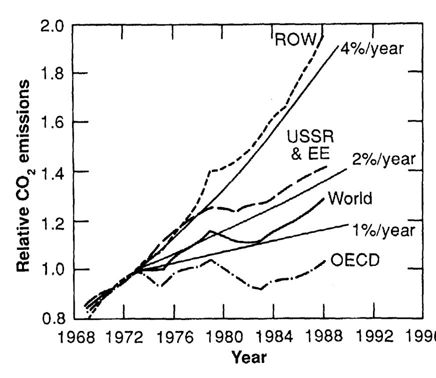

Fig. 1. Relative CO_2 emissions by various nation groups (1973 = 1.0). Shown are the trends for the entire world, OECD, U.S.S.R. and East Europe (EE), and the rest of the world (ROW). The ROW emissions are mainly from developing nations, including China. Thin solid lines show trends of 4, 2, and 1% per year.

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heliostats for solar thermal electric plants; and higher power and higher energy density batteries. All of these developments, including the demonstration of fusion, will require considerable investments and lead time. None of them, except perhaps nuclear and biomass, is likely to make any substantial impact before the beginning of the next century.

We conclude that, for the industrialized nations of the world, reducing the emissions of CO_2 over the next 50 years will be difficult to achieve and can be accomplished only by a combination of much improved efficiency and substantial adoption of nonfossil sources. Efficiency improvements alone might hold emission rates about constant at near today's levels for a few decades (Fig. 2), but sustained reduction much below the current levels will take success with deploying nonfossil sources as well. If this is to be accomplished without spending much more than is currently spent for energy services, R&D to develop more competitive nonfossil sources must be successful.

The rate of increase of CO_2 emissions by the developing nations was not affected much by the oil embargo; in fact, extrapolating the CO_2 emission behavior of the past decade reveals that the emissions of the developing world may exceed those of the industrialized nations in the Organization for Economic Cooperation and Development (OECD) by about the year 2000. Hence, the energy technology decisions of the developing nations will be a critical factor in determining the future rate of growth of CO_2 emissions. The R&D leading to better technology that would be attractive to key developing nations could yield important results not only for controlling CO_2 emissions but also for reducing future demand for oil, for helping developing nations grow economically, and perhaps for creating substantial new markets for U.S. goods and services.

What might be the cost of technologically preparing ourselves to control CO_2 emissions? Our guess is that an additional combined public and private sector R&D investment of about $1 billion per year is required (*13*). The additional $1 billion is divided as follows:

1) To improve the efficiency and economics of end use and conversion technologies would require an additional $300 million per year. This area of R&D should not be budget limited so long as important options are yet to be explored. For example, many promising R&D options are identified in the Energy Conservation Multi-Year Plan (*3*) but are not included in congressional appropriations. We would suggest that a gradual increase over several years to about twice the current level is warranted (*14*). An important part of the effort would be to evaluate and experiment with policy options that could stimulate the adoption of improved, more efficient technologies.

2) To improve nuclear power, the additional cost might be $3 billion to $4 billion over the next 10 years or about $350 million per year. In the next 10 years, two reactor concepts should be demonstrated: an advanced light water reactor featuring passive safety features and the modular high-temperature gas-cooled reactor (MHTGR) with full passive safety (*15*). Development of the liquid-metal fast breeder reactor with passive safety features could be deferred until the first decade of the next century, but supporting R&D on this and other methods of extending the resources for fissionable material is essential.

3) To develop solar and other renewables, the additional cost is about $200 million per year. The budgets for biomass, hydroelectric, photovoltaics, solar thermal electric, and wind should be increased by a factor of 2 over several years.

4) To accelerate the development of fusion, better coordination of international collaboration is needed. About $1 billion to $2 billion per year is currently expended worldwide on fusion power research. If this effort were well coordinated, it might be sufficient to establish technical and economic potential in 15 to 20 years (*16*).

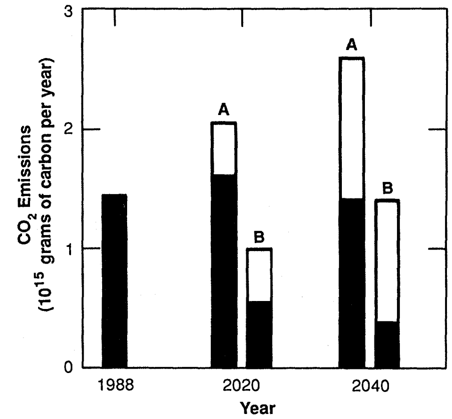

Fig. 2. Estimated potential of efficiency improvements and nonfossil energy sources for reducing U.S. CO_2 emissions. The top, open portions of the bars indicate CO_2 emissions with little expansion of nonfossil sources except hydropower. The lower, black portions of the bars indicate emissions with R&D success and vigorous deployment of nonfossil sources. Case A indicates moderate economic growth and efficiency improvements; case B, larger efficiency improvements, as in (*2*). Details are in (*1*). The 1988 actual emissions are shown for comparison.

5) To develop new technologies or to adapt existing ones to the needs of developing nations, an additional $100 million to $200 million per year will be required. Currently, a small fraction of technical assistance to developing nations is devoted to such R&D. Again, the total effort needs to be shared with the private sector and other industrialized nations.

This additional R&D investment might be derived from both public and private contributions. A tax on fossil fuel use could raise the public sector portion. A tax rate of as little as 0.2% would raise about $600 million per year. The private sector contribution could come from matching funds invested by private firms participating in the R&D. Their profit would be improved technology to sell.

This increased R&D investment, our insurance policy, bears relatively small risk because the potential for success seems large and the resulting improved technologies will be useful, even if the greenhouse effect turns out to be less consequential than many fear.

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13. This value is in the same range as those proposed by various bills introduced in the 101st Congress [S. 324, 101st Cong., 1st Sess. (1989); H.R. 1078, 101st Cong., 1st Sess. (1989)]. The combined DOE, Electric Power Research Institute (EPRI), Gas Research Institute (GRI), and Nuclear Regulatory Commission (NRC) budgets for energy technology R&D amounted to about $2.8 billion in fiscal year 1988 (including supporting work on basic areas of science and technology and on health, safety, and environmental issues). This R&D total is about 0.7% of the total spent for fuels and electricity in 1987.
14. The sum of the levels of funding for efficiency R&D by DOE, GRI, and EPRI for fiscal 1988 was about $250 million.
15. The recent decision by DOE to recommend an MHTGR as one of the new reactors for producing defense materials should help. Cost sharing of reactor development with other nations is also a possibility.
16. A National Research Council report [*Pacing the U.S. Magnetic Fusion Program* (National Academy Press, Washington, DC, 1989)] argues that achieving national goals in magnetic fusion will require 20% more funding of approximately $70 million more per year for the next 5 to 10 years followed by another 25% ($100 million increase per year) thereafter.