Energy Strategies for a Carbon-Free Future

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In 2050 the earth's population is expected to be at least twice its present size. Energy requirements will be astronomical. Satisfying those requirements while minimizing global carbon dioxide output may well be the most formidable challenge of the 21st century. In this connection, the authors outline strategies for reaching a carbon-free, and thus environmentally neutral energy economy.

At some point during the 21st century our major energy sources will be free of carbon. As Figures 1 and 3 indicate, an evolutionary process toward steadily diminishing use of carbon-based fuels has been underway for at least a century. This process involves a steady transition to higher-quality fuels and continuing decarbonization of energy systems.

Decarbonization reduces the adverse environmental impacts per joule of energy consumed. It results in triple dividends: higher energy quality, lower carbon dioxide emissions, and generally lower environmental damage at both the local and regional levels.

There are a number of reasons for concern regarding the environmental impact of energy generation and use. For one thing, it has been well established that the release of carbon dioxide during the combustion of fossil fuels results in growing atmospheric concentrations that can collectively alter the earth's energy balance and thereby cause changes in climate. Although carbon dioxide is not the only greenhouse gas produced by human activities, it accounts for roughly half of the anthropogenic sources of global warming.

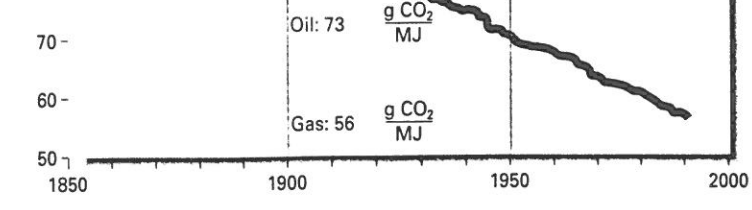
Why all the Fuss?

The problem is that emissions of carbon dioxide are increasing and are likely to continue to do so unless deep cuts in the carbon content of our energy-related emissions are made on a global scale. To put this in perspective, at the beginning of the nineteenth century, before the onset of the Industrial Revolution, atmospheric carbon dioxide concentrations were approximately 280 parts per million. Today, they stand at 357 parts per million. And if current emission levels continue, these concentrations will reach 550 parts per million during the next century – a doubling of preindustrial levels. The Intergovernmental Panel on Climate Change (IPCC) – an international scientific body involved in the assessment of global warming – concludes that by 2050, assuming a doubling of preindustrial atmospheric carbon dioxide concentrations, mean temperatures may increase by 1.5 to 4.5 degrees Celsius.

Just how difficult it will be to avoid such climate changes – and their associated environmental impact – is illustrated by the extent of our dependence on fossil fuels. Today, these fuels are the major source of all energy consumed worldwide. As such, they account for 85 percent of carbon dioxide emissions – constituting the largest mass flow of waste associated with human activities. At present, energy-related carbon dioxide emissions amount to about six billion tons of carbon (or more than 20 billion tons of carbon dioxide) per year. Such gigantic material flows are difficult to avoid or collect, and are impossible to store on a permanent basis. Worse, carbon dioxide tends to accumulate in the atmosphere, with about one half of all releases remaining for many decades. Some of the carbon dioxide emitted from Watt's first steam engine is still in the atmosphere.

Once carbon dioxide is released into the atmosphere, it is difficult to remove. Plants absorb carbon from the atmosphere, but the area needed to absorb an additional 6 billion tons of energy-related carbon emissions is about 15 million square kilometers, an area roughly comparable to all currently cultivated lands combined. The largest carbon sink is the ocean, but the absorption process – which takes place over thousands of years – is far too slow for human purposes.

Fig. 1
Global decarbonization of energy from 1860 to 1990, expressed in tons of carbon per ton of oil equivalent (tC/toe).



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Decarbonizing Our Energy Diet

As the global population doubles over the next 55 years, carbon dioxide emissions are also projected to double. But recent research indicates that, even without any particular effort, counter-balancing effects are taking place that tend to offset some of the potential increase in CO_2 emissions. As Figure 1 indicates, over the past 150 years the world has been steadily decarbonizing its energy diet. For each joule of energy we consume, for each dollar's worth of goods and services we produce, we are emitting less carbon into the atmosphere. This is explained by society's continuing transition toward fuels with lower carbon content.

Traditional uses of fire wood and agricultural waste have very high carbon dioxide emissions per joule of energy if they are used in an unsustainable manner. With the introduction of coal as the main source of energy, specific emissions declined, and this trend has continued with the emergence of oil, natural gas, and, more recently, zero-carbon sources such as renewables and nuclear energy. Thus, the shift from coal to oil and gas has resulted in energy decarbonization and lower carbon dioxide emissions.

Second, the energy intensity of human activities is also decreasing due to efficiency improvements and shifts from more to less energy-intensive activities; from smokestack industries to services (Fig. 2). These trends are clearly evident over time. During the last two centuries, for instance, carbon intensity has dropped at a rate of 0.3 percent per year and energy intensity has dropped at a rate of 1.0 percent per year, amounting in all to a 1.3 percent improvement.

Encouraging though they may be, these improvements have been overshadowed by growth in economic output of roughly 3 percent per year. The difference, 1.7 percent per year, parallels the annual increases in carbon dioxide emissions. The question is whether it is possible to accelerate decarbonization of energy to such an extent as to offset increases in future energy needs thereby ensuring adequate energy for economic development while reducing environmental damage. Although the answer is still not entirely clear, it is important to recognize that we are on the right path – a path to the decarbonization of global energy use.

Numerous suggestions have been made to mitigate carbon dioxide emissions. Assuming that most of the components of energy systems, including power plants and infrastructures, will be replaced at least once by 2050, the timely introduction of mitigation options could lead to their widespread diffusion by then. Timely introduction of these options is all the more important in view of the length of time it takes for carbon dioxide to be removed from the atmosphere. Some of today's emissions will still be airborne in 2050. Thus, even if it were possible to radically reduce emissions immediately, concentrations would remain high at least until the middle of the next century.

But much of the potential for mitigating the build-up of greenhouse gases in the atmosphere may never be realized. Limitations include capital requirements, lack of public acceptance, inconsistency of consumers' responses to price and regulatory signals, and, perhaps most important, uncertainty as to whether new technologies will deliver the desired results. These drawbacks aside, it is crucial for us to stress that many problems could be overcome with continued research and development and timely diffusion of mitigation technologies.

Reviewing Our Carbon Mitigation Options

What kinds of mitigation options might we see in the next century? Researchers at the International Institute for Applied Systems Analysis (IIASA) and elsewhere have examined hundreds of options ranging in cost from a few dollars to a few thousand dollars for each ton of carbon release avoided. Among the cheapest and most environmentally benign answers are efficiency improvements and conservation – efficient light bulbs, more efficient cars, better insulation for residential and commercial buildings.

Other strategies involve the energy system itself, particularly switching to more efficient and lower carbon content fuels such as natural gas. This is also consistent with continuing decarbonization of energy. Some mitigation measures on the supply-side could pay for themselves by reducing fuel costs; lower carbon emissions would be a bonus.

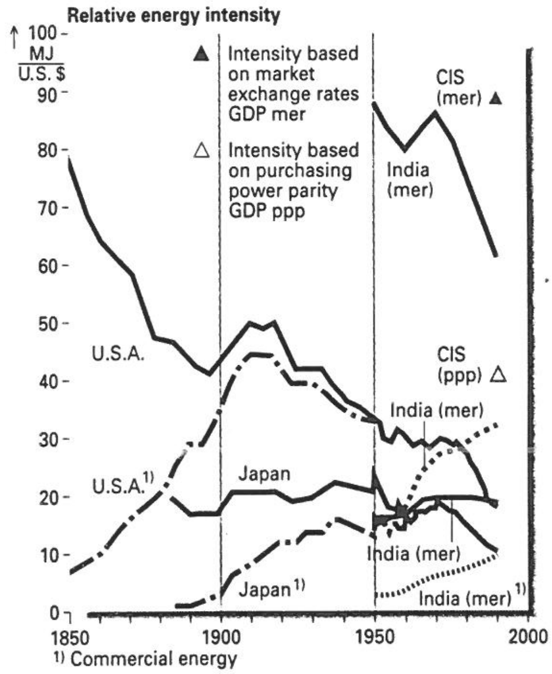

Fig. 2
Primary energy intensity, including biomass, of value added from 1850 to 1990, expressed in kilogram oil equivalent per GDP constant in 1990 U.S. dollars measured at market exchange rates, (mer), and at purchasing power parity, (ppp).

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A reasonable alternative is to avoid fossil fuel emissions altogether. Biomass has been used as a fuel since antiquity. New technologies allow efficient conversion of dedicated crops and fast-growing trees into heat, fuels, and electricity. Such a system could be sustainable, with new crops reabsorbing the carbon dioxide emitted from conversion of the previous harvest.

Other renewables, such as wind, solar, and hydro, do not emit any carbon. Electricity from wind and solar power systems is still relatively expensive, but costs are steadily decreasing. The expectations are that they will decline further as these systems mature, making them increasingly competitive.

Nuclear power is another carbon-free source of energy; but it faces difficulties. Construction costs are high in developed countries due to complex licensing and regulatory procedures, and public acceptance is low. There are also serious concerns about safety and proliferation.

Finally, in some regions, reforestation is the cheapest and most attractive option for carbon reabsorption from the atmosphere, but there are potential conflicts with other uses of land. On balance, using biomass as a fuel rather than as a storage medium for carbon, is a more attractive option.

All of these options could contribute to accelerating the current pace of decarbonization, but as far as the short- to medium-term is concerned, it is clear that humanity will continue to rely on fossil fuels not only due to habit and convenience, but also due to their abundance.

Methane: A Realistic Transitional Fuel

In this regard, natural gas poses the least threat. Consisting mostly of methane, it is a very potent greenhouse gas when released into the atmosphere; but following combustion, it releases much less carbon dioxide per joule of energy in comparison than other fossil energy sources. If we compare it with coal, for example, natural gas emits about 50% less CO_2 for the same amount of energy. Therefore, shifting to a methane economy in the next decades would be a realistic mitigation strategy. Moreover, natural gas could lead the way to more environmentally compatible energy systems which would rely on hydrogen and electricity – the advantage being that both are carbon-free. Methane can therefore be viewed as a type of transitional hydrocarbon until hydrogen and electricity can be produced without fossil fuels. In other words, it could serve as a bridge between the current energy system and a nonfossil, carbon-free energy future.

As nonfossil energy sources are introduced into the primary energy mix, new energy conversion systems will be required to satisfy increasing electricity demands. In this regard, hydrogen would be an ideal candidate. A methane economy would increase the role of energy gases, eventually opening the door to the use of hydrogen combined with electricity. This could result in virtually pollution-free energy carriers. The advantage of this strategy is that it is evolutionary in character. Increasing use of natural gas, renewables, and nuclear energy would be consistent with historical dynamics. Furthermore, the timing might be right. Gaseous energy would provide a bridge to the middle of the next century. The transition would last about 50 years or as long as the replacement of traditional energy sources by coal and the replacement of coal by oil (Fig. 3). To the extent that both hydrogen and electricity can be produced from methane, the separated carbon could be contained and subsequently stored, for example, in depleted oil and gas fields. As the methane contribution to global energy subsequently declines, carbon-free sources of energy would take over and eliminate the need for carbon handling and storage. This would also conclude the process of global decarbonization. •

Fig. 3
World primary energy shares 1850-1990 in percent.
Source: Nakicenovic, (1984); updated by British Petroleum (1995).