ISSUES IN ENERGY AND SUSTAINABLE DEVELOPMENT

Stephen R. Connors
M.I.T. ENERGY LABORATORY
Room E40-465, connorsr@mit.edu
tel: 253-7985, fax: 253-8013

I. INTRODUCTION

Energy has long played a central role in the development and functioning of the world's economy. An essential input to agricultural production, transportation, industry, commerce and the home, reliance on energy will continue to grow as world population increases and standards of living improve. The trend towards increased mobility, urbanization and an integrated global economy will further accelerate our energy use and dependence. History has also shown us that increased energy use and mechanization brings with it its own burdens with respect to the environment, health, safety, lifestyle and community.

Recent analysis of international energy trends shows that under "conventional development strategies," global energy consumption is projected to be half again as large in 2015 as it was in the early 1990s, and may double again between 2015 and 2030.[2] Most of the growth in energy use and its associated environmental impacts will occur in developing countries. While future changes in population, technology, and economic growth are unknown, what is clear is that a balance between energy, economics, and the environment will be needed for sustainable development to occur.

1 NOTE: This white paper is an updated version of an essay written for *The Consensus Building Institute* in April of 1997. Used as a discussion piece for the **Fourth International Programme on the Management of Sustainability** (Netherlands, June 1977), its intended audience is business leaders without a detailed background in energy.

2 Critical Trends: Global Changes and Sustainable Development. New York: United Nations, 1997.

A growing dependence on energy carries significant costs of its own. The extraction, refinement, transportation and storage of fuels carries an immense environmental burden, as does its ultimate consumption, and disposal of waste products. These burdens have local, regional and global manifestations, ranging from impacts on soil, groundwater and land-use, to those on atmosphere and ocean. Foremost among many communities are the local and regional environmental impacts. While these are not new issues, the need to manage our energy use and reduce its negative impacts has grown more immediate as regional economies grow and prosper.

Presently, the most important global issue is the role of energy in climate change. Burning fossil fuels (coal, oil, natural gas) and biomass (wood, crop residues, dung) produces carbon dioxide (CO_2) gas as well as energy. Carbon dioxide is a "greenhouse gas," which traps infrared radiation (heat) from escaping the atmosphere, affecting the earth's thermal balance.[3] International concern about the impacts of "global warming" on rainfall patterns, sea level, frequency of severe storms, ecosystems and agriculture led to the negotiation of an international treaty, the 1992 United Nations Framework Convention on Climate Change (FCCC). The FCCC calls for

> "...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. ...within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."[4]

In December 1997, the Conference of the Parties to the FCCC negotiated a THE KYOTO PROTOCOL, which if ratified, requires participating countries–mostly industrialized nations–to reduce their greenhouse gas (GHG) emissions to eight percent below 1990 levels by 2012. The role of energy in meeting these goals is central, both as a source of CO_2 emissions (the largest anthropogenic greenhouse gas), primarily via the combustion of fossil fuels and as a major driver of economic growth. Because almost all of the world's countries depend on fossil fuels for most of their commercial energy, decisions to reduce emissions will have very direct economic as well as environmental impacts. The carbon-hydrogen bond in fossil fuels (hydrocarbons) *is* the source of energy, and therefore it is very difficult to continue using fossil fuels without producing significant GHG emissions. As such, *substantial and sustained* reductions in GHGs, such as the initial eight percent reduction called for in the Kyoto Protocol, will influence national energy policies and investments as directly as individual governments' economic and environmental goals have in the past.

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[3] Most of the greenhouse gases in the atmosphere such as water vapor come from natural sources, and the greenhouse effect has helped keep the earth warm enough to support life. Recently, however, human activities have rapidly increased the atmospheric concentration of greenhouse gases, creating the risk that global temperatures may rise faster than human societies and natural ecosystems can adapt. Carbon dioxide emissions from energy use and forest clearing are believed to account for most of the human contribution to global warming. The other major greenhouse gases are methane, nitrous oxide and chloroflourocarbons (CFCs). See The Second Assessment Report of the Intergovernmental Panel on Climate Change. United Nations, June 1996.

[4] Framework Convention on Climate Change. United Nations. May 1992.

Unlike the situation for local and regional environmental issues, the Kyoto Protocol calls for an institutional mechanism to support energy technology transfer to developing countries that could lower the release of greenhouse gases, and their cost of mitigation. Hence, the need to rethink how and why we use energy, and to identify and develop new sustainable energy options. By taking these first steps towards the deployment of a clean and efficient integrated energy infrastructure, it is possible simultaneously reduce emissions related to acid rain, urban smog, toxic exposure and climate change, as well as reduce energy related demand on land and water use.

II. IDENTIFYING SUSTAINABLE ENERGY SYSTEMS

Sustainability and Energy. Sustainability and sustainable development are difficult terms to describe from a technical and quantitative standpoint.[5] No matter how sustainability is defined or measured, a sustainable socio-economic system will require a sustainable energy infrastructure. Energy extraction, production, distribution, use and by-products are central to the interaction between humans and the environment. Although experts debate the sustainability of our global fossil fuel-based energy infrastructure, it seems clear that our generation is extracting energy resources and filling the earth's atmosphere with the combustion products of fossil fuels faster than they can be recycled by natural processes. Unless we make fundamental changes in our energy infrastructure, we are likely to leave future generations with fewer energy resources and a more polluted environment than our generation inherited.

How "unsustainable" is our current system of energy extraction, conversion and use? What will it require to meet future generations' energy needs sustainably? These are daunting questions, for which there is no one "correct" answer. What is clear is that the world's energy infrastructures will need to significantly improve the efficiency at which they produce and use energy. As most people who deal with energy know, it is the services that energy provides–light, heat, motive power, etc.– and not energy itself which is valued. Therefore, when we think about how to reduce our reliance on energy in general–and fossil energy in particular–we must look at how to make both energy production and energy use more efficient. *In the context of sustainable development, society must decouple its demand for energy from its need for continued economic growth.*

When examining today's energy systems we see an extensive network of related activities. For traditional fuels this includes the collection and transport of firewood by household members and small merchants, the production of charcoal in rural

5 The most concise and commonly used qualitative definition comes from the 1987 United Nations report *Our Common Future*, which defined sustainable development as set of activities which meet "the needs of the present without compromising the ability of future generations to meet their own needs." The report suggests a number of ways for moving toward sustainability: advances in science and technology that reduce our dependence on natural resources; changes in government policies and decision-making institutions to integrate environmental and social concerns into economic policy-making; and changes in international institutions and agreements to ensure that international aid agencies and private investors balance economic, environmental and social goals. Our Common Future. World Commission on Environment and Development. Oxford University Press. Oxford. 1987.

areas for transport to cities, or the collection and drying of dung by women and children. When considering commercial fuels there is much more of an infrastructure component, both locally and worldwide. There are resources: oil and gas fields, coal and uranium deposits, forests, rivers, wind and sun. There are technologies for bulk extraction, refinement, transportation and storage. These ultimately reach the end-user as refined products, gasoline, kerosene and electricity for example, ripe for conversion into the final energy service by another tier of technologies, automobiles and trucks, furnaces and air conditioners, machine shops, computers and lamps.

A simple view of a sustainable energy systems might look only at the initial sources of energy and their inherent “sustainability.” For instance, we might decide that only energy derived from renewable resources (e.g. biomass, wind, tides) or inexhaustible resources (e.g. sunlight) can truly be called “sustainable.” If we use this definition, then one possible goal would be to reduce our use of non-renewable energy sources, especially fossil fuels, as quickly as we can. Even if we accept the proposition that in the long run, society must seek to use renewable and inexhaustible resources for its energy supply, we still need to answer the question of how quickly we should make the transition toward these energy sources. However, with the phase out of nuclear generation, this may be an even larger task than anticipated. How to ensure that such technologies are both available and affordable in the relatively near future is an area of primary concern when looking at policies to promote sustainable energy development, particularly since the rate at which such technologies can feasibly be introduced does not appear to be adequately reflected in ongoing international negotiations.

Those who argue for a gradual transition point out that there are many ways to increase energy efficiency and therefore energy sustainability even as we continue to use fossil fuels. Another reason for taking a gradual, evolutionary approach is that we need to balance the environmental advantages of a transition to renewable and inexhaustible resources against the economic and social costs of the transition. Our fossil fuel-based energy infrastructure represents a massive global investment in goods and services. As we make the transition to other sources of supply, we need to make sure that we do not squander our past investment in fossil fuel infrastructures.

In practice, this gradual, efficiency-oriented approach directs us to look for ways to reduce environmental impacts and improve efficiency along the entire energy “supply-chain.” Energy, and its economic value, is lost at every conversion step, with every kilometer of transport, often with every day or week of storage. Each loss or inefficiency, requires that the “upstream” infrastructure be larger or serve fewer people. When assessing the relative efficiency of components and systems, energy professionals can use “life cycle assessment” tools. These consider not only the energy consumption and losses of a device or process, but include the “imbedded energy” and environmental aspects of the technologies’ manufacture, transport, use and disposal. The design of systems which minimize energy losses and material requirements alike is commonly referred to as “eco-efficiency.”

Energy and Eco-efficiency. For individual consumer items (soaps, plastics, packaging, etc.) the introduction of such eco-efficient products can proceed rapidly. However for energy this is a greater challenge. As noted above, energy provision and supply is a very extensive and complex set of tasks. Since it is more system than product oriented, development and deployment of a sustainable energy system takes much more time. Its components, such as refineries, pipelines, dams, and transmission lines subsequently stay in place for decades. The same can be said for buildings. Therefore the design and implementation of a sustainable or eco-efficient energy infrastructure needs to look not only at the mix of energy resources and technological components, but how to develop new components and introduce them over time. While individual components might undergo rapid, revolutionary development, those responsible for overseeing large portions of the energy supply-chain must work on a more slower, more evolutionary time-scale.

A recent case study of the electric industry in the New England region of the United States shows the advantages of identifying several options for reducing environmental impacts over time. It also shows the advantages of analyzing several possible combinations of fuel-switching, improvements in generation efficiency and end-use efficiency. The study looked at different ways for electric utilities to reduce nitrogen oxide (NO_x) emissions from electric generating plants, in order to meet the emissions standards of the revised Clean Air Act. The study showed that by promoting more efficient uses of electricity and renewable electricity generation, utilities could postpone or even entirely avoid the need to install new NO_x reduction technologies at existing power plants. The study also found that efficiency improvements would reduce not only NO_x emissions, but other emissions such as SO_2, CO_2 and particulates as well. The study cautioned that efforts to increase end-use efficiency and renewables need to be coordinated with improvements in fossil-fueled generating equipment. Failure to improve generation efficiency could lead to an over-reliance on old, high emissions fossil generating plants in later years, resulting in a net *increase* in some emissions.[6]

The Technological and Social Basis for a Sustainable Energy System. So what might an integrated energy infrastructure look like in a more general sense? The above discussion gives some very useful hints. Improvements at the end of the supply-chain, in the way energy is ultimately consumed, have effects which cascade all the way back up the supply-chain. End-use efficiency improvements reduce the need for new fuel and energy supplies, extending the lifetime of current energy resources and their associated infrastructure. Improving the efficiency of electricity use, for example, may have significant benefits as well, especially in capital constrained developing nations which face high capital costs for new generation units, transmission and distribution systems, as well as fuel supply facilities.

On the supply-side, the more local and direct the provision of energy supplies, the fewer the losses from transportation and conversion. This is one reason why

[6] "No Good Deed Goes Unpunished: The End of IRP and the Role of Market-Based Environmental Regulation in a Restructured Electric Industry," S.R. Connors and E.T. O'Neill. Proceedings of the United States Association for Energy Economics 17th Annual North American Conference. October 1996. pp. 125-134.

renewable energy sources tend to look so attractive, at least technologically. Solar radiation and wind can be converted directly into electricity to supply local needs. For these particular energy sources a fuel delivery system is not needed. For developing countries the lower infrastructure requirement is important since energy services can be provided without waiting for the construction of a costly and extensive fuel supply infrastructures. There are also additional non-energy benefits to many renewable energy sources. Hydropower can provide water supplies to people and crops as well as energy. Growth of biofuel crops can increase local employment and provide electricity as well as solid and liquid fuels.

Efficiency improvements do not necessarily require new fuels, generating systems or end-use technologies. Improvements are also possible if organizations and individuals change the way they use existing technologies. Changing technologies and the way we use them is not, however, just a technical problem. Political and economic factors (e.g. regulations on energy-related pollution, the price of energy) have a great effect on the rate at which new technologies and new practices are adopted by organizations and individuals. Social perceptions regarding energy use, and other cultural factors, such as tolerance of the conspicuous consumption of energy because it symbolizes affluence, also play a role.

The Challenge of Implementing Sustainable Energy Systems. The previous section showed that there are a number of clear technological and social options for improving the sustainability of our energy infrastructure. As societies pursue these options, diversifying their energy sources, their generation and distribution infrastructure, and their end-use technologies and practices, they will also face a more subtle challenge: integrating energy sources and systems. For example, most renewable resources are intermittent, and cannot be relied upon to generate power or provide fuels exactly when society requires them. The sun doesn't shine all day, nor does the wind continuously blow. Rainfall for hydropower may have sharp seasonal variations, or be subject to droughts. Droughts also effect the growth of biomass fuels, and many energy crops cannot be harvested year-round. The more an energy system relies on intermittent renewable resources, the more energy system managers will need to find new storage technologies and develop new systems for scheduling the delivery of power from different sources.

More broadly, making the transition to a more diversified (and hopefully more sustainable) energy system will require continuous improvements in both technologies and management systems. Such programs need not be cost prohibitive however, since without such initiatives many developing countries would need to import greater amounts of fuel, and develop a larger, less efficient energy infrastructure. Different energy technologies and management systems will be required by country and region, depending upon available local resources, skills, and initial economic, environmental and social conditions. Both developed and developing countries will need to make steady progress in the development and introduction of cleaner fossil fuel resources and generation technologies; renewable energy resources and generation technologies; and more efficient end-use technologies. Steady improvements in fossil, renewable and end-use technologies, and their efficiency, can lead us in the direction of a more sustainable global energy system. The next question we must answer is how to develop the management systems, policies and financial incentives to take us in this direction.

III. PROMOTING THE DEVELOPMENT OF SUSTAINABLE ENERGY SYSTEMS

How can government and industry policy-makers help promote the development *and* deployment of more sustainable energy systems? At the most basic level, the transition demands skilled people, appropriate policies and positive economic incentives in the energy sectors of every country. To ensure that all three are in place requires deliberate–sometimes enlightened–action by government officials, industry leaders and international agencies. Below are just some of the initiatives that they must pursue if the transition is to be successful.

Technology and Resource Initiatives. The development and deployment of new energy sources and efficient technologies is clearly a key element in the transition to a sustainable energy infrastructure. If there is no market demand for these new sources and technologies, talented individuals are unlikely to spend their careers trying to develop them. At present, market demand is limited by the relatively low cost of fossil fuels and the relatively high cost of most alternative energy sources in most regions. In addition to R&D on alternative and efficient technologies, there is still an unmet need for R&D on energy systems, going beyond the component and small system levels to include large portions of the supply-chain, including a better understanding of multiple intermittent resources.

Ideally, government policy-makers and corporate investors should pursue a full spectrum of R&D, including fossil and renewable energy sources, supply- and demand-side efficiency, and systems integration. Improvements in the links between basic research, applied research and commercial product development are also needed, to ensure that the best new technologies make it to market. As the example of research on New England's utility industry showed, policy-makers and investors could also benefit from system-level research on the environmental impacts of different mixes of energy sources and generation technologies. Additionally, governments, energy producers and energy users could benefit from more research on the economic and environmental impacts of different energy policies and regulations. This policy research should aim to develop and test policy instruments that promote energy efficiency and minimize environmental damage at least cost to industry and consumers.

Governments and industry have numerous ways to promote research, development and demonstration. For basic research topics (e.g. basic chemistry, physics, environmental research and monitoring related to energy production and use), government facilitated R&D appears to be best. Often the results of this research are not profitable to private firms because they do not lead immediately to marketable products, but they may be very useful to society as a whole. "Pre-competitive" research is an area where government and industry should collaborate. For example, applied research to develop and test the feasibility of new technologies and research on energy systems integration may offer the potential for commercial profits, but may be too risky for any one corporation to undertake alone. Finally, when R&D is likely to result in a patentable product or process, the private sector does not rely on government support.

Getting Prices Right. Earlier, we pointed out that prices for fossil fuel sources of energy are usually lower than prices for alternative fuel sources. Low prices for conventional energy sources reduce incentives for energy producers to develop alternative energy sources, and for consumers to use energy more efficiently. Furthermore, diversifying our current energy infrastructure requires large capital expenditures at the beginning of the diversification process. In exchange, diversified energy systems may offer lower long-term recurring costs for fuel, waste management and waste disposal.

Private investors, who use market interest rates and focus on financial costs and benefits that can be realized within two to ten years, will generally find investments in diversification less attractive than continued investment in conventional energy infrastructure. In contrast, a society that cares about the long-term welfare of the present generation, the welfare of future generations, and the non-monetary impacts of alternative investments (e.g. on environmental quality and social equity) should employ a longer time-horizon–economically speaking, and a broader set of criteria for evaluating investments than a private investor. The challenge for governments, business leaders and concerned citizens is therefore to make private and public investments in the energy sector flow in directions that support society's longer-term perspective and non-financial interests.

How private firms can approach these topics is discussed in the book FINANCING CHANGE.[7] Many sections describe how to communicate the multiple benefits of "eco-efficienct" practices to accountants, lenders, etc. in the private sector. Firms can reduce their regulatory and insurance costs by adopting cleaner, more environmentally responsible practices. In addition, government regulators can make sure that information about firms' environmental performance is available to investors and the public. Governments can also end subsidies for inefficient uses of energy and other natural resources, make firms and consumers pay the full cost of their polluting activities, and ensure that tax policies favor long-term investments.

Competition and Market Mechanisms for Sustainable Energy Use. When it comes to getting more sustainable energy technologies and practices into the marketplace, finding ways to promote "best practice" behavior in the energy industry becomes important. Some energy sector analysts believe that increasing global competition, along with deregulation of the energy markets in many countries, are driving private investors to focus on short-term profitability at the expense of long-term investment. They also fear that competition and deregulation are making it harder for governments to regulate environmental and social impacts in the energy sector. Valid concerns, both.

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7 Financing Change: The Financial Community, Eco-Efficiency, and Sustainable Development. Stephan Schmidheiny and Federico Zorraquín with the World Business Council for Sustainable Development. M.I.T. Press. Cambridge MA. 1996

Using the electric sector as an example, is it possible for governments to promote long-term investment in a more-sustainable energy infrastructure in a price competitive energy market? In some cases, the answer appears to be yes. While increased competition does tend to demand shorter economic paybacks, it can also promote innovation and accelerate the introduction of more efficient, cleaner technologies. To make sure that competition meets social as well as financial goals, governments need to make clear and fair rules that penalize energy production and service companies for negative impacts and reward them for good environmental performance. Simply stated, a well structured competitive market makes and sells products that do the job they are claimed to perform, and protects the environment and the people making and using the products from harm. These goals may be achieved either by imposing regulations, or pollution fees and other market instruments.

"Performance standards," which tell industries the environmental goals they need to meet, may be a more efficient way for governments to stimulate innovation than "technology standards," which tell industries exactly what technologies or practices they must use to protect the environment. In addition, governments may be able to reduce industry's cost of meeting performance standards by using "economic instruments" in addition to legal obligations.

Several countries are experimenting with such performance standards and economic instruments; the U.S. government has been one of the most active experimenters in the energy sector, primarily with the use of "tradable emissions permits" in the electric industry. In 1990 the U.S. federal government decided to limit the total amount of sulfur that the U.S. electric industry could emit. By doing so the government effectively mandates the level of environmental improvement that industry must achieve, but allows industry considerable flexibility in meeting it. Over the last several years, many electric utilities have found innovative and cost-effective ways to reduce their sulfur emissions. The U.S. Environmental Protection Agency is now implementing similar performance standard / tradable permit systems for NO_X and other emissions.

Internationally, a similar "cap and trade" system for international greenhouse gas emissions is under consideration. This system would set a limit on the greenhouse gas emissions various countries can emit, and allocate permits based on some combination of their current emissions and their expected future industrialization needs. In theory, a cap and trade system could expedite technology transfer to developing countries and achieve cost-effective emissions reductions, as the location of GHG emissions are less important than their level. Many questions remain however about how to decide the target level of greenhouse gas emissions, how to allocate permits, and how to monitor compliance with the permit system.

As the sulfur example above illustrates, performance standards that require firms to limit emissions of individual pollutants can stimulate significant technological innovations. When firms have to meet several performance standards at the same time, they have an even greater incentive to look beyond "end-of-pipe" technological solutions, and consider alternative energy generation technologies and fuel sources. When facing the need to control three or four emissions simultaneously, companies will begin to look at technologies that avoid such emissions entirely. For some energy producers and consumers, simultaneous reductions in sulfur dioxide, nitrogen oxides, carbon dioxides, air toxics and solid wastes may actually be cheaper to achieve through efficiency improvements and the use of alternative energy sources than through installing many different pollution control technologies.

Taxes and Subsidies. Tradable permits are of course not the only economic instrument available to promote sustainability in the energy sector. As noted above, governments can also tax energy sources and their emissions to raise the price of energy, internalizing environmental costs which will reduce energy use through process and product innovation. Taxation also allows governments to influence the behavior of many more consumers, utilizing energy products in many different industries and for many different means, than a "cap and trade" system commonly reaches. With better knowledge of the environmental impacts of energy use and their social costs, such taxes can be set near to the socially optimal level, at which the amount of the tax is roughly equal to the social cost of the damaging activity. Governments can use tax revenues to enhance the safety of energy production, fund clean-up activities, mitigate the more diffuse environmental impacts of energy use, or simply replace other forms of taxation.

Coordinating Long-Term Sustainable Energy Development. Governments can use performance standards and economic instruments to direct private investment and behavior in the energy sector, even when competition, privatization and deregulation are limiting governments' ability to use more traditional policy tools. Most governments will also want to maintain some oversight of long-range energy planning, even when most energy sector activities have become fully privatized. In many countries, state-owned and regulated utilities typically issue long-term forecasts for electricity demand, and follow government-mandated plans to meet this demand. These public forecasts and plans inform investors and firms about the likely demand for new technologies over the succeeding ten to twenty years. It is not clear whether privatized utilities will continue to provide public forecasts, or seek public input on their plans for meeting energy demand.

Government policies can have a very direct impact on privatized utilities' planning process and decision criteria. As in other aspects of energy policy, governments need to ensure that private sector decision makers consider long-term social and environmental goals when making major energy infrastructure investments. Energy producers and distributors need government guidance on how to estimate long-term energy supply and demand trends, on whom to involve in their planning process, and on what environmental and social criteria to use as they plan new energy production and transportation facilities. Government will also need to play a coordinating role as utilities continue to sell-off parts of their operations. As the energy supply chain becomes fractionated into energy technology firms, power producers, distributors, service companies and consumers, the need for joint public-private planning and coordination in system design and operation will increase.

IV. CONCLUSIONS

Energy is an essential component of economic development, and energy sector decisions and practices will play a central role in determining the sustainability of development in every country, region and sector. At the same time, decisions and practices in other sectors have a very direct effect on energy supply and demand options. Energy sector policies and investments must be coordinated with those in the key energy end-use sectors: transportation, housing, construction and manufacturing. In each of these sectors, there are major opportunities for improving the efficiency of energy use and developing new technologies and energy supplies.

The challenge of coordinating and integrating economic and environmental decision-making to move us in the direction of greater sustainability is daunting. The environmental, economic and social problems the world face are complex. The money, time, people, talent, and natural resources we have available are finite. Their ultimate solutions will be diverse, requiring collaboration among many people and institutions over time. Development and implementation of sustainable energy systems will require not only cleaner and more efficient energy supply and use technologies, but also decentralized, coordinated systems for policy and management that link energy sector decisions to the broader goal of meeting human needs.

A sustainable energy infrastructure will ultimately utilize an extensive range of energy resources, distribution systems and end-use technologies. Research and development efforts to create these new technological and operational options are only the first step. Governments, corporations and consumers must develop policies and practices that meet both financial goals and broader economic, environmental and social performance goals. Such transitions in both technologies and policies will require long, sustained efforts. Fortunately, incremental improvements in energy use are less disruptive to the economy and society-at-large, and offer many side benefits. Progress towards a sustainable society is not a sprint, but a marathon. The development of a sustainable energy infrastructure will happen as a result of continuous improvement by individuals and organizations who have the knowledge and the incentives to take a long-term view.

A. APPENDIX: THOUGHTS ON MAPPING: SCOPES AND LEVELS OF KNOWLEDGE

When considering the requisite scope of energy-related research needed to 1) find suitable paths to a sustainable energy future and 2) convince decision-makers that various elements of these paths should be explored in greater detail and perhaps implemented, it is useful to think about our "state of knowledge" regarding energy, its prospective uses, and its respective social and environmental burdens–our "knowledge infrastructure" so to speak. As many sustainability related issues are comprised of a) complex problems, b) dispersed, supply-chain solutions and c) finite resources (time, money, people, etc.,), the level of knowledge required to actually craft and implement a *true* solution is rather high.

Most of this white paper has focused on the primary technological and institutional dimensions of identifying and implementing a sustainable energy infrastructure. Due to length considerations meeting the challenges of substantial and sustained greenhouse gas reductions has served a proxy for broader sustainability issues. Similarly, the "scope" of the energy sector has similarly been the focus from the "knowledge" side, focusing on the range of energy supplies and end uses, the need to balance supply and end-use initiatives from a supply-chain or life cycle perspective, and the need to look at long-term turnover and management of energy infrastructures (both supply and demand) rather than just technological snapshots.

"Mapping" of our sustainable energy research portfolio also requires that we look at our "level" or state of knowledge (as both researchers and as a society) when large policy decisions are made. Over the past several years I have developed a "learning curve" analogy for this "knowledge infrastructure" which is illustrated on the next page. Along the "knowledge" axis are data, information, knowledge and wisdom.[†] For our purposes, the series of overlapping lines along the learning curve parse out the various stages required to move up the "knowledge infrastructure;" problem existence (PE) , problem definition (PD), solution specification (SS) and solution implementation (SI). Using climate change again as an example, atmospheric and meteorological monitoring yield PE results, global circulation models address PD issues.[‡] The solution specification step yields several sub-steps as shown below, moving from bottoms-up identification of technological options (TO) and then strategies (TS) and then on to policy instruments (and institutions) necessary for deployment or implementation (PI). With this taxonomy, the M.I.T.'s Joint Program on the Science and Policy of Global Change integrates the PD and SS/PI stages, with a stakeholder education element. The Energy Lab's Energy Choices Program complements this effort by focusing primarily on the TO an TS areas.

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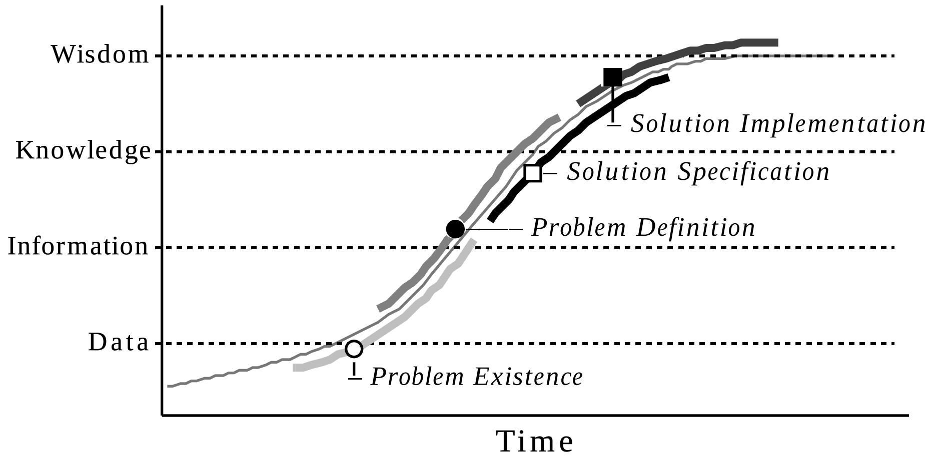
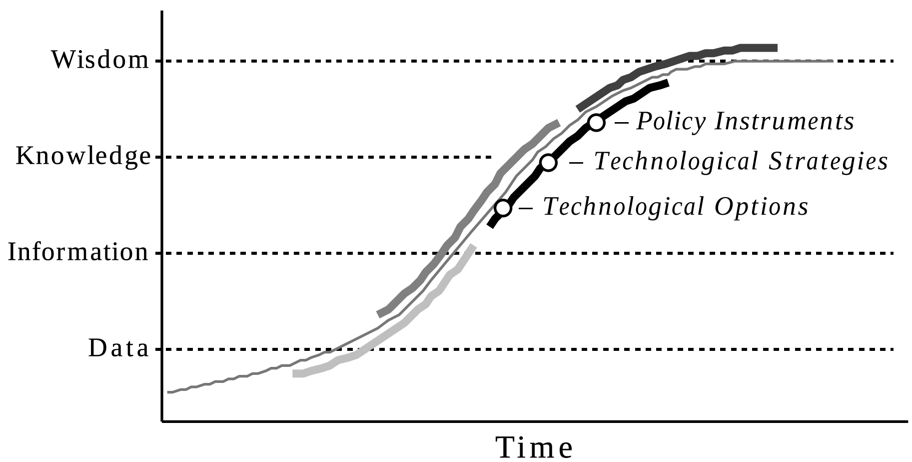
† Loosely interpreted, data can be considered as numbers or perhaps indicators. (e.g. atmospheric concentrations of CO_2 are increasing.) Information is then recognizing trends, or the fundamentals in those numbers. (Fossil fuel combustion is behind those increases, and temperatures, sea level, etc. may rise.) Knowledge is understanding what those trends may mean. (Northern latitude temperatures may rise x°C, sea level by y meters by 2xxx, etc.), with Wisdom indicating what we know they *don't* mean – or "we know what we don't know." (Normally being able to deal with the uncertainty in our analysis or level of knowledge.)

‡ Global circulation modelers can tell you whether the "state" of their models resides on PE or SS end of the problem definition step (i.e. how well can they 'replicate the data' or offer specific guidance to 'solution specifiers.')

TAXONOMY OF A "KNOWLEDGE INFRASTRUCTURE"



ELEMENTS OF THE "SOLUTION SPECIFICATION" STEP

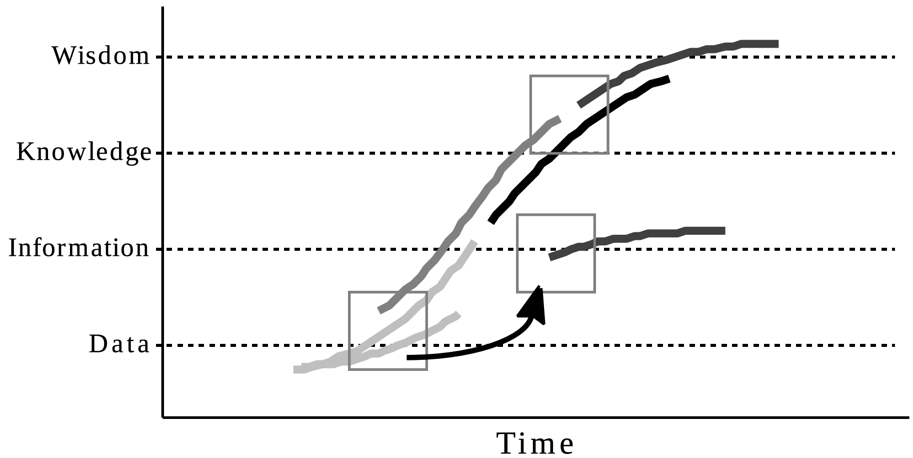


Outreach and stakeholder education are very important elements. Those returning from the COP meeting in Kyoto lamented the virtual lack of scientific discourse within the negotiations. Not surprisingly, the "state of knowledge" when policy decisions are made is crucial to the cost and effectiveness of the resulting policy.

For the Montreal Protocol, the "science" was rather straightforward, as was the solution response. CFCs and other ozone depleters could be banned, as their tertiary functions could be substituted for by alternative chemicals and/or technologies rather easily. For more complicated environmental issues, a much more thorough understanding of the problems *and* solutions are required. The VOC vs. NO_x debate is one such example. Climate change is certainly another one.

Implementing a solution before either the problem, or an effective solution has been identified–what I call "Jumping to conclusions/Jumping to solutions"–has been observed all too often. (See illustration below.) Groucho Marx summed up the political dynamic all too accurately when he quipped “Politics is the art of looking for trouble, finding it everywhere, diagnosing it incorrectly and applying the wrong remedies.” Two environmental examples come to mind. First was the EPA’s sulfur regulations from the late 1970s, which specified lower concentrations at the site, resulting in taller smokestacks and acid rain. (A conservation of mass issue.) A more recent example may be the proposed rules on ultra-fine particulates, where a “volumetric” approach may prove less successful than a “reactivity” approach.

“JUMPING TO CONCLUSIONS / JUMPING TO SOLUTIONS”



In any event, these are some of the interpretive constructs that may be useful for the AGS Mapping Project. Understanding the science, looking for robust solutions, and informing policy-makers of both these aspects are also aspects of a balanced research portfolio. The scope of our energy-related research is certainly important (transportation, agriculture, residential, commercial, industrial / / fossil, nuclear, renewable, end-use efficiency, operational efficiency), as will be the our ability to move ourselves, and our audiences up, the knowledge infrastructure.