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Viewpoint

Assessing the global energy innovation system: some key issues

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Abstract

Energy technology innovation has played central role in the evolution and advancement of the energy sector. The major challenges facing the energy system—ensuring adequacy supply of energy services at low cost while mitigating adverse local and global environmental impacts—will doubtless require further innovation (i.e., research, development, demonstration and deployment) in energy technologies. Yet our understanding of the global energy innovation system is incomplete, with a majority of analyses focusing on energy research and development in industrialized countries, and within that domain, on funding levels. A much more systematic effort is warranted to assess, and fill, the gaps in understanding of the global energy innovation system—only then we will able to develop appropriate policies to guide this system to enable it to meet future challenges.

1. Introduction

Energy services are essential to meeting basic human needs as well as to supporting economic growth, and expenditures on energy represent a significant part of the cost of living and a significant contribution to GNP. The impacts resulting from energy extraction, conversion, and use are major components of many of the most important environmental problems at every scale from the local to the global. And international energy flows are both a significant ingredient in world trade and a potential source of tension and conflict. For all these reasons and more, the character of national and global energy systems is crucial to the human condition and to the prospects for improving it.

Technological advances have driven the long evolution of the energy sector, operating to increase energy's benefits while reducing its costs and risks. Such advances have expanded energy supplies, increased the efficiency of transformation of raw energy resources into desirable end-use forms, improved the availability and quality of energy services while lowering their monetary costs, and reduced the adverse environmental impacts that result from energy extraction, conversion, and use. But recent trends in the organization of the energy sector in many countries, combined with an increasing recognition of the urgency of traditional as well as new challenges facing it, have raised concerns about national and international capabilities to bring forth adequate innovations to meet those challenges in the decades ahead.

Efforts to examine the adequacy of the energy-innovation capabilities have traditionally focused primarily on energy-related research and development (ER&D)—see, e.g., Dooley (1998), Morgan and Tierney (1998), Margolis and Kammen (1999), among other recent studies—which is the foundation of energy innovation but far from the only important ingredient. The processes by which the fruits of ER&D are demonstrated in practical contexts, deployed at increasing scale, and diffused across regional and national boundaries are also critical. Analyses of the trends in, and current status of, ER&D efforts have tended to be based above all on analysis of spending patterns—which of course measure inputs, not outputs—and hobbled by inadequacies in the available data.[1] A narrow focus on ER&D misses other crucial aspects of energy innovation, moreover, notably the process of deployment and diffusion of new technologies. The results is an incomplete understanding of the global

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[1] There seems to be a propensity on the part of energy technology policy analysts to focus largely on R&D budgets. This may be so, in part, because some expenditure data are easily available and quite amenable to "armchair" analysis. In addition, R&D budgets are a clear public policy variable and thus policy analysis and advice naturally tends to concentrate on these numbers.

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energy innovation system[2]—the various institutions and the relationships between them that sustain the development, modification and diffusion of energy technologies—which in turn hinders the development of appropriate policies to guide this system to enable it to meet future challenges. A much more systematic effort is warranted to assess, and fill, the gaps in understanding of the global energy innovation system. This piece highlights a number of issues relevant to such efforts.

2. The energy sector: an evolving context

The confluence of several trends appears to be reshaping both the *willingness* and the *capacity* of the energy sector to innovate. First, energy prices showed a somewhat fluctuating, but ultimately downward trend between the oil-price peak in 1980 and 1998 (BP Amoco, 1999)—for example, in 1998, prices for crude oil were at the lowest since 1976 (although they have risen since then). Low prices for conventional fuels have a direct effect on market interest in technological advances: new alternatives must compete with established technologies that provide cheap energy using conventional fuels. ER&D expenditures are therefore also affected by energy prices: the energy-technology R&D budgets of most IEA countries, after reaching historic highs in the late 1970s and early 1980s in response to the oil shocks, have since declined (and more or less stabilized) at much lower levels (IEA, 1997).

At the same time, the face of the energy sector in the US and many other countries is being altered by a number of factors. These include the deregulation and restructuring of energy markets in the industrialized countries, the privatization of the energy sectors in many developing countries with a concomitant increase in market access for and interest by multinational corporations, a dramatic rise in the use of and demand for natural gas, and a global wave of corporate mergers and acquisitions. The results have included numerous mergers and alliances among energy firms,[3] a convergence of the electricity and nonelectric-energy businesses, and increased emphasis on short-term financial returns in the energy/electricity sector (PCAST, 1997, PCAST, 1999; Economist, 1999).

These changes are occurring in parallel with growing recognition of the challenges facing the energy sector in the new century. Among these are the urgent need for increasing the availability of energy in developing countries—an issue that has gained prominence in the last decade as many such countries have liberalized their economies and intensified their efforts to enhance energy supplies to satisfy increasingly restless consumers as well as to remove constraints to industrial growth. At the same time, impacts of air pollution on health and ecosystems in many parts of the developing world have reached alarming levels (Smith, 1993; Mage et al., 1996), throwing a spotlight on the significant local impacts of energy conversion and use. On a global scale, the issue of greenhouse-gas-induced climate change has assumed increased prominence because of the growing persuasiveness of the evidence that such change is already occurring, the enormous scale of its potential impacts, and the recognition that a substantial reorientation of the energy system in industrialized and developing countries that will be required to control GHG emissions to the extent needed to prevent intolerable disruption of the climate system (PCAST, 1997; Hoffert et al., 1998).

3. ER&D budgets: A hazy picture

An evaluation of the scale and character of the current state of national and international ER&D efforts, as well as trends over time, is an essential first step in examining the innovative capacity of the energy sector. But such an assessment is difficult for a number of reasons.

First, the range of R&D activities that can be relevant to the energy sector is very broad. It includes basic research (such as on turbulence, which is ultimately useful in reducing the drag in oil pipelines and in improving fuel injection and combustion in car and aircraft engines); applied research (such as on improved designs and materials for turbines that lead to more fuel-efficient airplanes and powerplants); and development (such as on production methods for aluminum space-frames for lighter cars). What should count as energy-relevant research is often unclear. Building a comprehensive picture of the R&D activities that are relevant to the energy sector is therefore a formidable task.

To complicate the analytical task further, ER&D activities are carried out in a variety of institutions-—universities, government laboratories, firms of various sizes, research consortia (such as the Electric Power Research Institute (EPRI) and the Gas Research

[2] Our concept of the global energy innovation system is a derivative of the idea of 'national innovation systems' (Lundvall, 1992; Nelson, 1993). The global energy innovation system can be thought of as comprising of various national energy innovation systems where the latter for any individual country is the component of its innovation system that is relevant to energy technology research, development and diffusion.

[3] To give a few major recent examples, mergers among oil firms have included those between Exxon and Mobil; BP Amoco and Arco; and Elf Aquitaine and TotalFina. The merger of VEBA and Viag has yielded Germany's largest utility, and the FPL group and Entergy have merged as have Unicom and PECO Energy to form two of the largest US utilities. Among energy technology providers, ABB and Alstom have merged their power generation businesses, while Siemens has acquired Westinghouse Power Generation. Within the automobile industry, Daimler and Chrysler have merged while Renault and Nissan have formed an alliance. Given the continuation and the pace of this consolidation, we can expect further significant changes within these sectors.

Institute (GRI) in the United States), as well as independent think tanks and NGOs. Notably, not all of the players are active in all parts of the ER&D chain.

Industrial R&D plays a central role in the energy sector—R&D spending by firms in energy-related sectors considerably outweighs the corresponding government expenditures on a global basis[4]—but assessing the state of industrial ER&D is particularly problematic. Many of the major players in the energy-technology business are heavily diversified industrials (such as General Electric, Toshiba, Hitachi, and Siemens). Evaluating the portion of their R&D spending that is relevant to energy is difficult, especially since firms rarely release disaggregated R&D data. Industrial R&D spending is often heavily weighted towards development, so that funding levels alone provide a somewhat skewed perspective. Even deciding which firms are engaged in energy-relevant research is not easy. For example, firms that develop advanced materials (such as ceramics and plastics), lubricants, or glasses and coatings may be overlooked in compilations of firms performing ER&D, although advances in each of these areas can have a large impact on energy use. Start-up firms may also play a role in the technical transformation of the deregulated energy sector—a recognition of this possibility has led to the recent growth in venture and later-stage investment funds focusing on the power business (Holman, 1999).

The role of other institutions important to ER&D is not well-researched. For example, ER&D at universities may be particularly critical, especially for new technologies, because of the clear linkages between basic research and invention (Narin et al., 1997; NSB, 1998a). And NGOs, although the total magnitude of their ER&D investments is modest, often focus their efforts on development of simple technologies that focus on the needs of marginalized groups that are overlooked by the market.

Data on ER&D expenditures are collected by a number of agencies. Within the United States, the Energy Information Administration collects R&D expenditures of major energy producers (EIA, 1999) and the National Science Foundation collects some data on industrial energy R&D spending (NSF, 1999). Other ad hoc surveys (such as a GAO (1996) study on the R&D expenditures of major US utilities) or direct elicitation (such as on funding within consortia such as EPRI and GRI) further illuminate domestic ER&D spending. But these efforts leave large gaps in the overall national ER&D picture (PCAST, 1997). The task of carrying out a similar exercise at an international level is even more daunting, not just for similar paucity of data, but also because of variations across countries in categories and definitions for R&D funding in the public and private sector (PCAST, 1999). The only example of an international data set known to the authors is the IEA survey of government energy-technology R&D expenditures for major countries (IEA, 1997).

Notwithstanding the deficiencies in the data, it is quite clear that the magnitude and character of ER&D efforts have been changing quite rapidly in recent years. From the mid-1980s to the mid-1990s, there have been substantial cutbacks in ER&D spending by most industrialized-country governments and also apparently by the oil companies and the electric utilities (IEA, 1997; Dooley, 1998; GAO, 1997). A new corporate R&D paradigm seems to have emerged in which firms (including those in the energy sector) tend to favor research within individual business units rather than in the traditional corporation-wide laboratories, while also relying more heavily on external sources of technology (NSB, 1998b; Larson, 1997). These and other factors—including especially increasing pressures on the short-term "bottom line"—have led to a shorter-term focus in industrial ER&D efforts (IEA, 1997; PCAST, 1997). The rearrangement of the energy sector through domestic and transnational mergers and acquisitions could eventually have substantial further impacts on industrial ER&D, although forecasts of the long-term implications of such shifts are necessarily based largely on conjecture given the absence of any comprehensive assessment of the ER&D system and the factors that influence it.

Unfortunately, much of the literature on the state of the ER&D system ignores the lacunae in the relevant information, and arguments are often advanced as applicable to the whole system while being based on data and analysis relating to only a part of it. This not only leads to conclusions that may not be entirely appropriate, but, perhaps even more important, unintentionally suppresses discussion of the incompleteness of the current data and comprehension about the state of ER&D activities. Efforts to explicitly define what constitutes ER&D, and then to systematically collect the relevant data, would be appropriate first steps towards overcoming this shortcoming.

4. Looking beyond ER&D budgets

While an examination of ER&D expenditures is necessary for the evaluation of energy innovation systems, it is important to note that just as tracking

[4]For example, the world's ten largest automotive companies together spent over 29 billion dollars in 1995 on R&D, much if not all of it classifiable, in a broad sense, as energy R&D (DTI, 1996). The total energy R&D expenditures of IEA governments in the same year were approximately 10 billion dollars (IEA, 1997).

and assessing R&D requires more than tabulating expenditures, assessing innovation capability requires much more than appraising R&D efforts. Innovation involves not just the development of new technologies, but also their demonstration in real-world contexts and their deployment at significant scale (see Allen (1967) for example).[5] More specifically, an undue focus on the sizes of R&D budgets under-emphasizes:

- the character of the ER&D portfolio in terms of payoff horizons, risk levels, and fuel sources (*i.e., allocation of the input*);
- the effectiveness of ER&D efforts in terms of technological advances for a given expenditure (*i.e., input–output relationships*);
- and the effectiveness of implementation and diffusion of new technologies (*i.e., utilization of the output*).

Shedding more light on all these issues is a challenge to policy research.

Another aspect of the global energy innovation system that merits more attention is the extent to which the direction of energy-technology innovation has been guided by (industrial and individual) consumer needs and desires communicated mainly through the market by consumer demands. Relying too heavily on the market for the steering of the innovation system is dangerous because of the well-known deficiencies of the markets in relation to externalities, public goods, and meeting the needs of those lacking the purchasing power to send market signals (PCAST, 1997; PCAST, 1999). All three areas of market deficiencies—externalities (e.g., air pollution, global climate change), public goods (e.g., macroeconomic and national-security benefits of reliable and affordable domestic energy supplies), and meeting the basic needs of the very poor—happen to be of particularly great importance in the energy sector.

Far more attention is needed, in particular, to the needs of the poorest two billion people on the planet, who consume very little energy at present and therefore do not constitute a large market, but whose lives could be significantly bettered by improved access to energy services (Reddy et al., 1997). The energy-related needs and concerns of this group are rarely integrated into energy innovation efforts, and, in fact, are under-studied and poorly understood. Activities under global environmental regimes also seem to be bypassing these groups—for example, approaches such as the Clean Development Mechanism under the UN Climate Convention are likely to focus almost exclusively on those who currently are users of commercial energy (and thus GHG emitters) in the South, ignoring the poor who are not (Sagar, 1999; Sagar and Banuri, 1999). An increased emphasis on research to better understand the needs of these marginalized groups and to explore ways to stimulate energy innovations tailored to those needs could have substantial paybacks in human-welfare terms.

5. Focusing on the energy innovation system

There has been an increasing recognition within the science and technology policy community that technological change and development is best understood as the outcome of 'national innovation systems' (Lundvall, 1992; Nelson, 1993; OECD, 1997). These systems can be loosely defined as a network of institutions—public and private—whose activities and interactions are central to the development, modification and diffusion of new technologies (Freeman, 1987; Nelson, 1993). Such a systems-based analysis of innovation requires a focus on the various national and transnational institutions involved in the production, diffusion and use of knowledge relevant to technological development, the linkages and interactions between these institutions, and the resulting flows of knowledge, technology, financing and other resources. A similar approach—with an explicit systemic focus—to examining the process of energy technology innovation in different countries should be quite fruitful. Hence, a mapping of the relevant institutions, their energy-innovation activities, and the relationships between them should be an important research focus. Both domestic and international linkages between institutions are particularly relevant for global energy innovation—key partnerships include those between different agencies within governments; between the public, private and non-profit sectors; between developing- and industrialized-country institutions; and between domestic and transnational institutions (PCAST, 1999).

6. Conclusion

A broad research effort to better understand various aspects of the energy innovation process, map the relevant institutions and their activities, and assess the magnitude and character of current efforts would be valuable for many reasons. Above all, an accurate assessment of the global energy-innovation system is prerequisite for judging the system's adequacy in relation to the challenges facing the energy sector and for suggesting policies to improve the innovation system's performance. Gaps in the energy-innovation system are not likely to be filled until the gaps in our understanding of this system are filled.

[5] PCAST (1999) has referred to the whole innovation process as Energy Research, Development, Demonstration and Deployment (ERD^3).

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