Preprint
UCRL-JC-145575

Energy Technologies for the Markets of the 21st Century

R.N. Schock

This article was submitted to
18the World Energy Congress, Buenos Aires, Argentina, October 21-25, 2001

October 1, 2001

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

Energy Technologies for the Markets of the 21st Century*

R.N. Schock
Chair, World Energy Council Study Group on Energy Technologies for the 21st Century and
Center for Global Security Research, Lawrence Livermore National Laboratory, Livermore, CA 94550, U.S.A.

1.0 Background

Energy is the fuel of economic development. Yet, this is lost on the over 2 billion people in the world without access to commercial energy, most in rural areas. Meeting their needs, along with the growing needs of the population already with access, provides very large markets for energy and energy services. Studies have repeatedly shown that technology is the single most important historical driver for productivity growth. Technology is also at the heart of the goals spelled out in the World Energy Council s Statement 2000 [1]: accessibility of reliable and affordable modern energy services for all the world s inhabitants; availability of high-quality reliable delivered energy; and acceptability of energy resources produced and used in harmony with the local, regional, and global environment.

With this in mind, the World Energy Council (WEC) at the time of the 17th Congress in Houston decided to identify and examine some of the energy technologies that might sustain the world in the 21st century. This effort would examine steps that might be taken to ensure that these new technologies are available to the marketplace, and what role governments and industry might play to ensure this availability. The WEC launched a major study in 1999, Energy Technologies for the 21st Century, conducted by a study group composed of international energy experts [2].

The first part of the study examined trends in public and private research, development, and demonstration (RD&D) spending over the past 15 years to determine what has been happening with the resource base for future development. Improvements in energy technologies are attained through active RD&D performed now, in advance of their implementation. Energy RD&D also provides insurance against potential impacts such as climate change, oil price shocks, and disruptions in the energy distribution system [3]. This part of the study sought to answer the questions: What is the current situation with respect to energy RD&D and what are the trends? and Are we spending more or less and do these trends vary between countries or regions?

The second part of the study began a process to identify those technologies that might be key in the 21st century and what might be necessary in expenditure, time, and policies to help bring them to market. The emphasis is on what is possible and when from today s vantage, not what will necessarily happen actual developments are unpredictable and it is impossible to foresee the course of actual technology development or economic growth. Nevertheless, using knowledge about current technologies and their projected development, investment costs, and likely time to commercialization, some light might be shed on what could happen over a wide range of possible scenarios.

2.0 Part I — A Comparison of International Energy RD&D Expenditures Since 1985

The study group tried to find out what was actually happening with RD&D spending in light of varying and often conflicting reports. The uncertainty about the facts is worrying given the importance of the subject for global society and in meeting future challenges of availability and quality of services, the satisfaction of basic needs, environmental quality, and the protection of ecosystems.

Energy RD&D is defined as basic and applied research in addition to technology development and demonstration in all aspects of resource extraction and production (from exploration through drilling or mining to refining); power generation (whether from fossil fuels, renewable sources of energy, nuclear fission, and fusion); transmission, distribution, and energy storage; energy efficiency and conservation; end-use technologies; and carbon separation, capture, and sequestration. A wide variety of activities can be classified as RD&D and there is no universally

*This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

accepted definition. Government funding of catalysts and materials science, cellular telephone manufacturer s investments in silicon chips to prolong battery life, defense ministry s investments in portable fuel cells, and a space agency s investments in photovoltaic cells used for communication satellites can all be classified as energy RD&D, at least in part. More often, energy RD&D expenditure is defined as spending within a particular budget category.

Several pitfalls need to be avoided. Comparisons are made more difficult when energy RD&D expenditures are converted to a common currency. Often market exchange rates are applied rather than parities in purchasing power, leading to erroneous conclusions. Most importantly, monetary indicators are input-oriented and can, by definition, give little or no information about the efficiency or success rate of RD&D efforts. Reliable indicators of RD&D output are called for. There is also a lack of inclusiveness about energy RD&D data. In some countries, spending by government laboratories is not included. Private-sector expenditure data are notoriously difficult to obtain and data on venture capital infused into small startup companies are almost impossible to obtain, let alone track.

For the report published at this Congress [4], the study group sought to provide country reports in a common format. In all, 47 countries were contacted, 21 responded, and 9 provided detailed reports. These nine represent 70% of the global energy RD&D country expenditures and are thought by the study group to be sufficient to draw some valid conclusions. In addition, the study benefited from statistics from the International Energy Agency (IEA) published in 1997 [5] for 22 member countries and updated electronically to include 1999 data. This results in 23 countries being considered overall, 18 in detail.

The study found that in about half of the 18 countries considered in detail, total government RD&D expenditure declined significantly in real terms between 1985 and 2000. Total government energy RD&D spending in the other half of the countries examined remained stable or increased, and thus there is no basis for reports of a comprehensive decline in government energy RD&D funding over the period. However, U.S. government energy RD&D funding, which is about 40% of the total, fell markedly in this period (**Figure I**), while Japan s government budget expanded by 45% in the same time. In addition, a few countries most notably Japan and France have continued to invest heavily in nuclear RD&D.

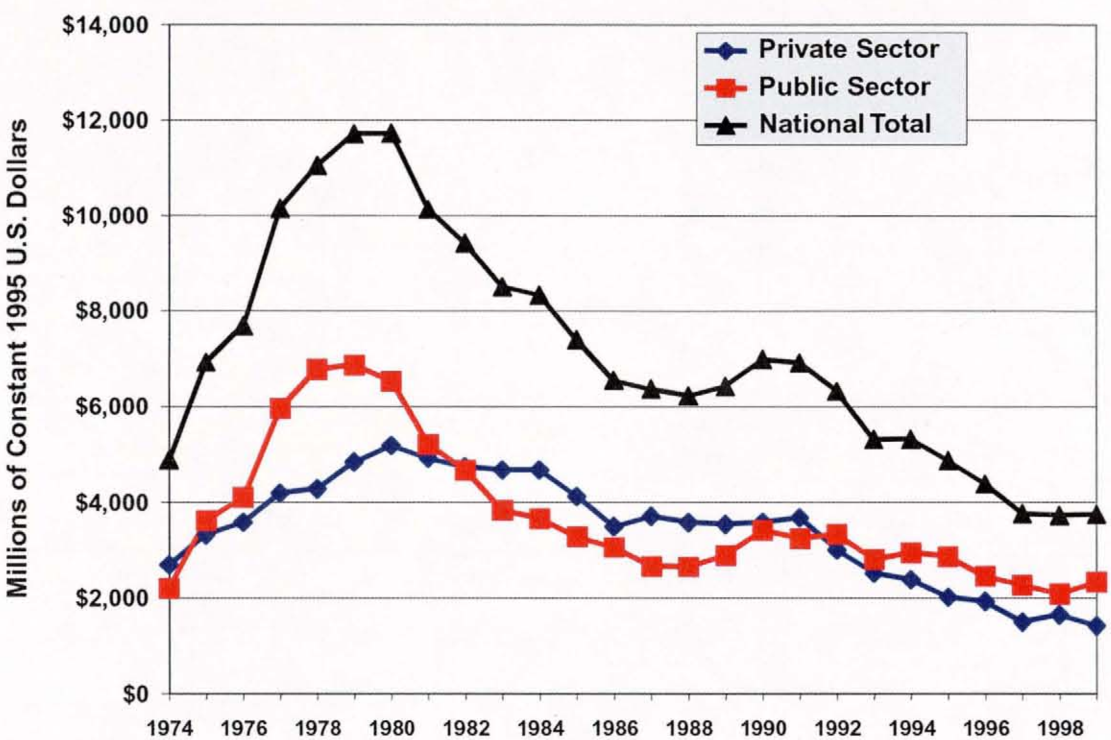

Figure I. U.S. National Investments in Energy RD&D: 1974—1999 [6].

Finally, for the reasons stated above, data on the private sector are problematic. It also appears to be too early to tell whether the efficiency of energy RD&D has increased, something that has been touted as a benefit of the deregulation of energy markets. Nevertheless, U.S. private-sector energy RD&D spending fell dramatically although a similar fall is not shown for such countries as Japan, Republic of Korea, and Sweden. Although inconclusive, the data also indicate that, in the U.S. and U.K., deregulation of electricity markets may have resulted in decreases in the RD&D spending of private industry. In some other countries (e.g., Sweden), deregulation has not yet caused a decrease in private RD&D spending but instead a change to more customer-oriented product development and new services.

Several recommendations derive from this part of the study. It would be helpful for future analyses if governments engaged in energy RD&D could produce expenditure data in both current and constant prices, the latter at something like five-year intervals. Governments should also encourage greater international cooperation and effectiveness in energy RD&D efforts to disperse advanced energy and energy services to the potentially large markets of the developing world. In general, market mechanisms to stimulate private investment in RD&D stressing quality and efficiency, such as energy set-asides, should be examined by all countries.

3.0 Part II — Robust Technologies for the 21st Century

In identifying technologies likely to impact the marketplace in the 21st century, the emphasis is on what is possible, not what will happen. A comprehensive set of scenarios and technologies is available from the work done by the WEC in conjunction with the International Institute for Applied Systems Analysis (IIASA) [1,7] and from the Intergovernmental Panel on Climate Change (IPCC) [8]. The preliminary work from this part of the study will be released at this Congress [9].

The study has already indicated a number of important trends in energy systems. This work used a model that examines a range of alternative developments of future energy technologies to assess the spread and distribution of costs. Rather than attempt to predict any one direction, the robustness of certain energy technologies (the number of times they appear) across a wide range of scenarios is significant. This should be helpful to energy executives in planning future technologies, either as new ventures or as competition for existing technologies. It is worth keeping in mind that technology can change either incrementally or in a sudden jump and has historically done both. A sudden development in energy technologies might, for example, be a scientific breakthrough that makes energy from nuclear fusion a reality. Yet, most technological change takes place gradually and small changes accumulate over time to produce large effects in the end. Performance is increased, costs are reduced, and environmental impacts are mitigated as a result of technical change. It is important to recognize that RD&D portfolios with a range of technologies are the only real hedges against uncertainties inherent in the range of scenarios representing the future. In the following, technology trends in synthetic liquids, electricity production, and transportation fuels will be summarized.

3.1 Synthetic Liquids

In examining synthetic liquids, the production of synthetic liquids by 2020 is found to be shared almost equally by methanol from coal and natural gas and by ethanol from biomass (**Figure II**). The bars span the ranges of the scenario estimates and the median values are shown. The wide range of energy estimates results from differing assumptions among scenarios about economic growth, technical advancement, environmental constraints and actions, social and regulatory conditions, etc.

If coal is still a large source of energy in 2050, it would be the dominant source for liquids (**Figure III**). However, in less coal-intensive (i.e., carbon-constrained) scenarios, biomass liquids predominate, as might be expected. Not surprisingly, hydrogen produced from natural gas is important early in the century, although by 2050, hydrogen from natural gas increases by five-fold in the highest scenarios and two and one-half times for the median of all scenarios. Hydrogen from nuclear- and solar-produced electricity, while increasing its market share, does not become dominant until after this time frame.

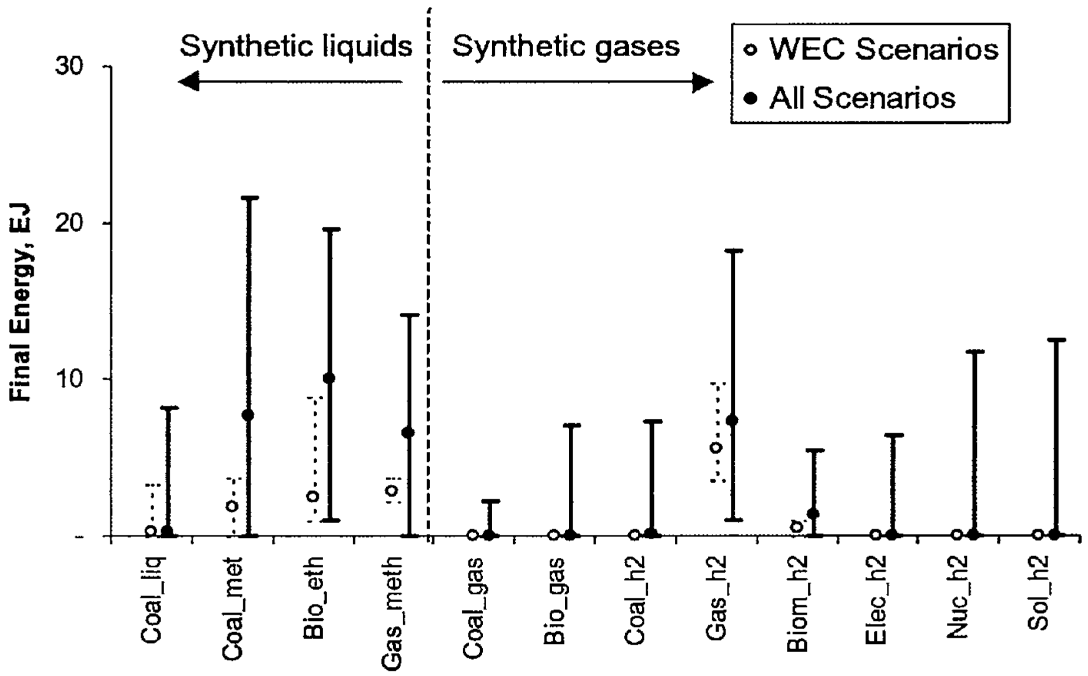

Figure II. Ranges of synthetic liquids and gases production across scenarios for 2020 [9]. Solid lines represent the range of all scenarios from the IPCC, dashed lines the range of the IIASA—WEC scenarios.

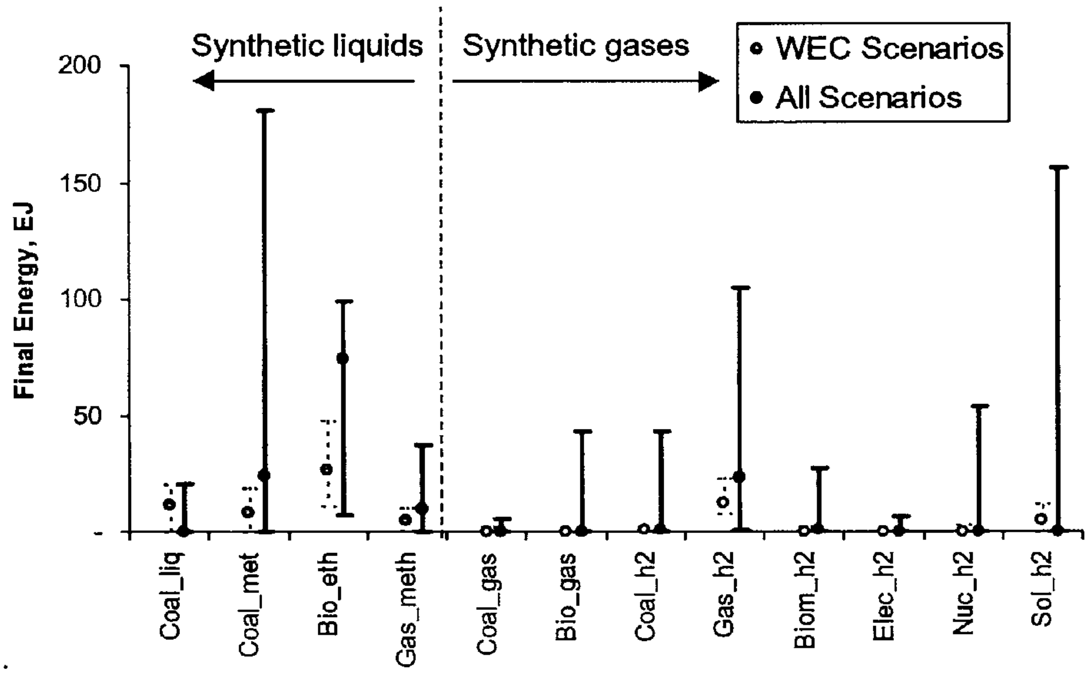

Figure III. Ranges of synthetic liquids and gases production across scenarios for 2050 [9]. Solid lines represent the range of all scenarios from the IPCC, dashed lines the range of IIASA—WEC scenarios.

3.2 Electricity Generation

Because electricity-generation technologies are responsible for such a large part of energy consumption and have tended to grow worldwide in step with economic growth, the portended changes are of great interest. Here, again not surprisingly, the relative roles of traditional electricity-generation technologies, such as conventional coal, decrease consistently across all scenarios, while the role of advanced technologies (such as fuel cells, gas and coal combined cycles with carbon removal, and solar- and nuclear-power generation) become more important over time. However, these changes do not appear to take place in a meaningful way until after 2020 due to the rigidities in the system, in particular the embedded infrastructure. Twenty years from now, standard coal, integrated coal-gasification combined-cycle, natural gas and natural-gas combined-cycle, and conventional nuclear and hydropower are major contributors to electrical generation. Nevertheless, in this time frame, natural gas combined-cycle with carbon separation and sequestration, advanced nuclear, solar (photovoltaic conversion), wind and fuel cells continue to develop so that, by 2050, these technologies replace much of the global systems. **Figure IV** shows the deployment of fossil-fuel electricity-generation technologies during the 21st century across a range of scenarios.

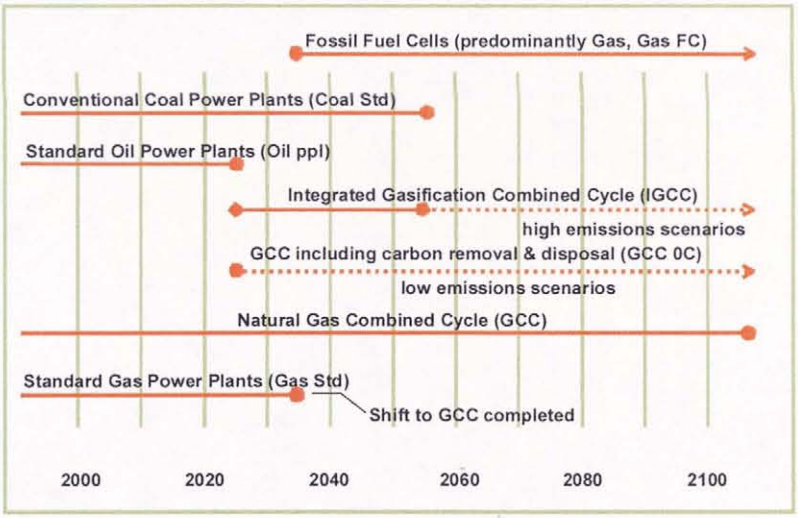

Figure IV. Deployment of fossil electricity-generating technologies during the 21st century [9].

It is interesting to note that investment costs in electricity-generation technologies are predicted to decrease most rapidly for photovoltaic power, from clearly the most expensive today to being competitive by 2050. Natural gas combined-cycle, however, still maintains the position of lowest investment cost to beyond 2050.

3.3 Transportation Fuels

Nearly all of the global transportation needs are met today by oil and its derivatives and this will not change anytime soon. In all scenarios, the role of oil decreases while the synthetic fuels, alcohol and hydrogen, become more important. While oil is still the most important fuel in 2050 and has increased its volume share as the market increases, its market share for transportation fuels will decrease. Natural gas, ethanol, methanol, electricity, and hydrogen are all important contributors by now (**Figure V**).

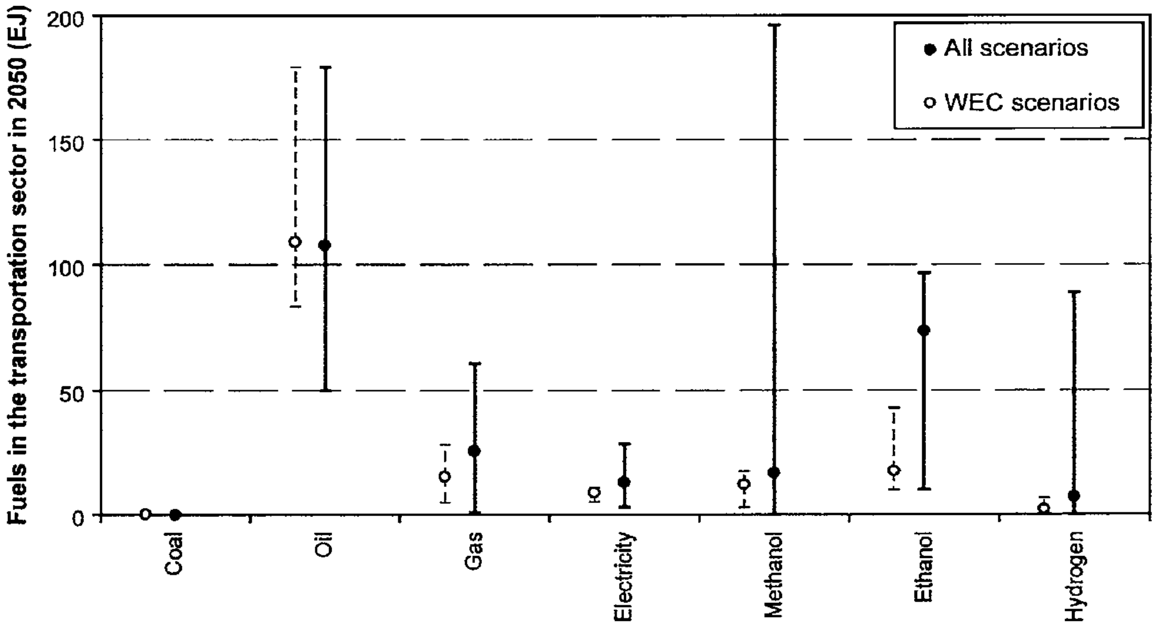

Figure V. Ranges of fuel requirements for transportation across scenarios for 2050 [9].

4.0 Next Steps Completion of the Study

The completion of this study will build on the work done to date in several areas. Technologies not studied during the first phase because of the lack of time (for example, specific end-use technologies and the timing and possible costs of necessary RD&D) will be examined. The strategies of private industry to better identify what is called RD&D and what is considered to be part of the normal operations will be examined (for example, the improvement of cars on an on-going basis by the automobile industry). Finally, an attempt will be made to better understand the role that governments play in terms of funding and regulation (standards, administrative processes, litigation, etc.). Where institutional weaknesses, inappropriate incentives or disincentives, or absence of needed legal or regulatory frameworks are seen to be barriers, the study will point them out.

5.0 Acknowledgments

The study group gratefully acknowledges the outstanding efforts of the authors of the comprehensive country RD&D expenditure reports Denmark, Finland, Japan, Republic of Korea, Sweden, and the United States and thanks its Study Director, Michael Jefferson, for his generous time and quality of effort in synthesizing and documenting the results.

6.0 References

1. *Energy for Tomorrow s World Acting Now!* , World Energy Council, London (2000).

2. R.N. Schock, U.S.A. (Chair), M. Jefferson (U.K), S. Abdel Hamid (Egypt), T. Alvesalo (Finland), W. Emsperger (Germany), J.-R. Frisch (France), S.S. Garcia (Spain), S. Gehl (U.S.A.), H. Haegermark (Sweden), H. Larsen (Denmark), N. Nakicenovic (IIASA), H.-H. Rogner (IAEA), and Y. Tachibana, (Japan).

3. R.N. Schock, W. Fulkerson, M.L. Brown, R.L. San Martin, D.L. Greene, and J. Edmonds: How Much is Energy Research & Development Worth as Insurance? *Annual Reviews of Energy and the Environment*, Vol. 24, 1999, pp. 487—512.

4. M. Jefferson, Energy Research, Development and Demonstration Expenditure 1985-2000: An International Comparison, Paper prepared for the *18th World Energy Congress*, Buenos Aires, October 2001.

5. *IEA Energy Technology R&D Statistics, 1974-1995*, OECD, Paris, 1997; and electronically updated subsequently.

6. J.J. Dooley, *U.S. National Investment in Energy R&D: 1974-1999*, Battelle Memorial Institute, Washington, D.C., Report PNWD-3108 (2001).

7. N. Nakicenovic, A. Grubler, and A. McDonald, *Global Energy Perspectives,* Cambridge University Press, United Kingdom (1998).

8. *Special Report on Emissions Scenarios*, N. Nakicenovic et al., and *Climate Change 2001, Mitigation*, B. Metz et al., both from Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, United Kingdom (2000).

9. N. Nakicenovic and K. Riahi, An Assessment of Technological Change Across Selected Energy Scenarios, Paper prepared for the *18th World Energy Congress*, Buenos Aires, October 2001.