Book Reviews

Energy in a Finite World: A Fifty-Year Global Perspective (Cambridge, Mass.: Ballinger, 1981), 2 vols.

After I read *Energy in a Finite World*, a recent conversation with a U.S. Navy captain came to mind. The captain was involved in long-term studies on the navy of the future. What kind of a navy would the United States need 30 years from now when ships built today will be obsolete?

The captain said that if anyone had asked him in 1930 what kind of a fleet the United States would need in the 1960s, he would have planned on the basis of the following assumptions:

The enemy would probably be Germany and/or Japan.

The British Empire, a principal U.S. ally controlling one-fourth of the world, would continue to have a vast navy to protect its worldwide interests.

To meet a potential German or Japanese challenge at sea, the navy of the 1960s would probably consist of more advanced battleships and cruisers, diesel-powered submarines, and aircraft carriers with propeller aircraft.

None of these basic assumptions would have proved correct. The political and strategic environment has changed drastically, and the navy of the 1960s bore scant resemblance to the one of the 1930s. Radar, sonar, computers, nuclear propulsion, missiles, satellites, titanium submarine hulls, and so on—all integral parts of the modern navy—did not exist in the 1930s, and it would have been difficult to have foreseen the widespread use of these innovations 30 years earlier.

The IIASA team has done an excellent job of examining a number of world energy demand and supply scenarios for the next 50 years. The use of numerous interacting models, and the detailed technical descriptions of constraints on the supply options, suggest that nothing was left out. Every aspect of the energy problem was thoroughly researched by a team of more than 140 scholars.

Even though the authors maintain that new technological developments in the decades ahead would not substantially change their long-term energy

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scenarios, this reviewer, reading chapter after chapter of this convincingly written document, could not help but recall the navy captain's warning.

The authors make clear from the outset that their study is not a "forecast" of what the future will be like, but that the scenarios used are meant only to serve as guidelines for determining what is feasible over the coming five decades. All scenarios, however, inevitably come up with the same conclusion in the end: the growth in aggregate energy demand is astronomical, and given the limitations on hydrocarbon resources, the world cannot develop further in the long run without development of nuclear power on a massive scale.

The study has basically followed an engineering and economic approach. Assumptions about population and economic growth rates, and about income and price elasticities, are clearly spelled out and seem quite reasonable. A number of well-known recent sources were used to show the magnitude of world conventional and nonconventional hydrocarbon resources. All scenarios assumed a degree of international cooperation; no major surprises (technical, political, or other), or sociopolitical constraints were left out of the analysis. Aggressive conservation and resources development policies were also assumed (except in one case concerning the use of nuclear power).

A time frame of 50 years was selected in order to show the severity of the energy problem over time and because it was expected that 50 years would be sufficient time to make possible the transition to a sustainable global energy system. This would also allow adequate time for social systems and individual lifestyles to change and to enable any new energy system to capture an important share of the market.

The report differs from many other recent reports not only in the time frame selected, but also in scope. While most studies cover either the industrial countries, the developing world, or the centrally planned economies, the IIASA study is global in nature. This approach has a great advantage in that it shows not only the enormity of the problem of energy and development in the LDCs, but also clearly indicates that the degree of interdependence in the world will have to grow substantially if there is to be adequate energy for the poor countries to improve their standard of living.

Unfortunately for the average reader, accustomed to thinking in terms of mbd or million tons of oil equivalent, the use of the term "terawatt-year per year" is somewhat confusing. The study would also have benefited from a more structured writeup and a clear set of energy balances in the final chapter. Apart from these relatively minor points, the report is quite clear in the message it presents.

The study arrives at a number of interesting conclusions:

1. The world is endowed with the necessary physical resources to support a population of 8 billion in 2030. Moreover, this appears possible without shifting completely to sustainable energy sources. Such a shift must eventually come, according to the authors, but we can buy perhaps another 50 years of using mainly fossil fuels. By the year 2030, worldwide average per capita energy use would be between 2.8 and

4.5 kWy/year,[1] compared with an average of about 2 kWy/year today. It is interesting that in the IIASA scenarios overall developing countries' per capita energy use in 2030 would still be only a fraction of what it is in the industrial countries today. And even this modest achievement would be possible only under an almost mind-boggling nuclear and hydrocarbon development program.

2. The IIASA study projects, in two out of three demand scenarios, substantial to large growth in per capita energy use in the industrial countries. IIASA concludes that long-term conservation connotes hardship. "What has emerged quite starkly from our study is that any way of balancing demand and supply, whether high, medium, or low, would lead to some form of hardship." This view contrasts with a number of recent studies in the United States and Europe (CONAES, Leach, etc.) suggesting the potential for reducing per capita energy demand in industrial countries without loss in income or major changes in lifestyle. IIASA has included a scenario for the industrial countries showing an actual decline in per capita use of energy, but concludes that this scenario requires massive changes in the composition of GNP (to services) and lifestyles.
3. The authors of the IIASA study suggest that in the long run there are limits to growth. Their high economic growth scenario (about 3 percent per year) would result in a more than doubling of per capita energy use in the world. This, the study concludes, would cause massive social and environmental problems that the world would have to learn to live with. Hence, economic growth rates of 5 percent per year, such as the world experienced in the 1950s and 1960s, would appear to be out of the question. The IIASA study's treatment of the interrelationship between energy developments and environmental problems is different from another major systems study of the early 1970s, *The Limits to Growth*, but the conclusions are not dissimilar and are quite disturbing in what they say about developing countries' prospects of substantially improving their living standards. The low-growth scenario is considered more benign from the environmental point of view, but it would suggest only very slow improvement in per capita consumption of goods in most of the developing world throughout the next 50 years. These are very important conclusions for the future stability of the world. If even with an almost perfect flow of resources, goods, and services among the nations of the world (as assumed in the IIASA study), the developing countries have little chance of ever catching up economically with the developed countries, one can only imagine what will happen to their development prospects in our much less than perfect world.
4. Nuclear power is essential for the future of world energy supply if sufficient oil, gas, and coal resources are to be left in the ground for longer-term liquids needs. A nuclear moratorium case was examined,

1. KWy (kW-year) = 5.154 barrels of oil equivalent.

and IASA concluded that if implemented it woud lead to virtual exhaustion of world natural gas resources by 2030. The team was not unaware of the current controversy about nuclear power, but concludes: "All things considered, a nuclear moratorium may seem an interim solution to the highly polarized situation for the next few decades, but from a long-term global perspective it woud have its price." That price would be early exhaustion of hydrocarbons, long before the transition to other energy sources could be completed. The IIASA high nuclear scenario suggests a growth in nuclear power from 160 gigawatts (GWe) in 1980 to 10,000 GWe by 2030. Those who are opposed to nuclear power would consider the expansion projected here too high a price to pay. They maintain that with adequate conservation, coal use, and speeding up of the renewables option, nuclear power would not be required and could be phased out gradually. The IIASA study would argue that in the longer run this would lead to serious deterioration of the environment and substantially reduced economic growth potential, particularly where it is most needed, in the LDCs. The basis for this conclusion is the inability of the industrial countries to free up hydrocarbons for use elsewhere under a nuclear power moratorium. In view of the current political climate concerning nuclear power in most industrial countries, and the unfavorable economics of nuclear power in some of these countries, the near- and medium-term future of nuclear power continues to be highly uncertain. Some countries are talking about gradually phasing out nuclear power, while others are looking at nuclear as a temporary phase before the world can turn almost exclusively to renewable energy sources.

The IIASA team sees a continuing important role for nuclear power even after 2030. Large-scale use of nuclear energy in electricity generation combined with larger penetration of electricity in world energy markets would free hydrocarbons for feedstock and transportation uses. Nuclear power, according to the study, has an important role to play, not only for electricity generation, but also for district heating, liquefaction of coal, the production of hydrogen from water, etc.

It would require a revolutionary change of mind in most Western democracies to achieve the growth in nuclear power projected in the IIASA study.

5. The study concludes that the return to coal as a major energy source is not only necessary but inevitable, both for the coal-rich nations and for the rest of the world. While the team believes that coal will still be used as a primary fuel in electricity generation and industrial uses, they conclude that "coal should not be used as the major source of primary energy for meeting world demand for large amounts of energy over the next 50 years, since this would not only deplete its resource base within 100 years but also create severe environmental and human health hazards." Years ago, the former shah of Iran used to say that oil and gas should not be used as boiler fuel but reserved for nobler uses. The IIASA study suggests that within the next few decades coal is likely to be added to the former shah's list. There is no doubt that if coal demand

were to grow at the rate of oil demand in the 1950s and 1960s, world coal production would peak by the middle of the next century. It is not inconceivable that future generations will look at the wastage of coal in the same way we currently look at the waste of oil and natural gas as boiler fuels.

6. Related to the recommendation to gradually reserve coal for liquids production is the finding that within the overall energy problem there is a major liquid fuels problem. The study concludes that demand for liquids, which is now about 45 percent of total world energy demand, will still be around 40 percent by 2030. One of the principal reasons is the rapid growth in demand for liquids in the LDCs. At the early stages of industrialization, according to the study, the need for liquid fuels is very high. Only toward the second part of the next century is hydrogen expected to become a viable commercial substitute for oil and coal liquids.

   One could add to the IIASA findings the observation that a growing number of developing countries in Africa and Asia are faced with serious deforestation. Governments in a number of these countries are already subsidizing kerosene use in order to prevent further deforestation.
7. In contrast to earlier perceived notions of dramatic growth potential of the electricity sector, the IIASA team was surprised to find that the share of the demand met by electricity would grow much more slowly than initially perceived: from 14 percent of total energy use today to 20 percent by 2030.
8. Commercial renewable energy sources could grow rapidly to about 15 TWyr/yr in 2030, which is equal to twice the total global primary energy used today.[2] However, there are problems with local availability and competition with existing land and water use, and according to the IIASA study, the transition to renewable energy sources cannot be completed in a period of 50 years.
9. The Middle East and North Africa will remain crucial throughout the next 50 years. World oil production outside the Middle East (including synthetic oil) is expected to continue to grow even after 2000. Yet, according to the IIASA study, "the relative elasticity of demand for liquid fuels allows the Middle East and North Africa to make the crucial difference between an oil glut and oil shortage. . . . Even by reducing the use of liquid hydrocarbons to their most essential uses by taking into account the contributions of a young coal liquefaction industry, we still see a dominant role for the Middle East and North Africa in the oil export market."

   Much of the U.S. popular press in recent months has voiced the opinion (based on what has taken place in the world oil market in 1980–1981) that demand for OPEC oil would be reduced to a fraction of the current level within 10 to 15 years. This reviewer shares the view of the IIASA team that the major Middle East oil producers will continue

2. 1 TWyr/yr = 30 quads = 15 mbd.

to be a most important source of liquids supply to the world, a source for which there are no substitutes.

10. To provide the world with adequate liquids, the Middle East and North Africa will have to produce an average of 33.6 mbd through 2030, and North America and the USSR will have to embark on a vast synfuels program, exporting significant volumes of liquids, primarily from coal, to other parts of the world. Without this conventional output from the Middle East and North Africa and the nonconventional liquids from North America and the USSR, the world could not even sustain the low world economic growth rates of 2.4 percent per annum.
11. In contrast to those who argue that after a transition period of about a decade the industrial world will have solved its energy problems, the IIASA study shows that on a global basis there is likely to be a continuing energy crisis throughout the entire 50 years of the forecast. The global crisis, and in particular the liquid fuel problems, will continue to have a major impact on the industrial countries as well.

These principal findings of the IIASA study suggest that from the purely technical and economic point of view, the world can sustain not much more than 2.5 percent of economic growth over the period of the next 50 years, unless we are willing to pay the price of serious worldwide deterioration of the global environment. Economic growth rates in the industrial countries would be below 2 percent, and average LDC growth would be no more than 3 percent per year.

The report assumes no major restrictions on trade in oil, gas, coal, or uranium; no major upheavals interfering with energy resources trade; and no significant domestic opposition to a wide variety of energy developments. However, no energy study of this scope can be complete without considering those sociopolitical issues in order to test the feasibility of the scenarios.

It would be interesting to know the underlying price assumption of the high and low energy demand scenarios. If, for example, as indicated in the study, the supply of liquid fuels will continue to be tight throughout most of the period of the demand estimates, would not price rises further reduce the energy-GDP coefficient for the period from 2000 to 2030 in the industrial countries? It would appear that the energy-GDP coefficient in the low energy scenario assumes relatively small oil and energy price increases, especially between 2000 and 2030.

In addition to further integration of the world economy, possibly leading to an actual reduction in per capita energy consumption in the industrial countries (the 16-TW case), this reviewer wonders whether the authors of the IIASA study have fully examined the conservation potential in the residential/commercial, transportation, and industrial sectors of the industrial countries' economies. The energy-GDP coefficient used for both the 1975–2000 and the 2000-2030 periods (high and low scenarios) suggests that they may not have.

For example, references to 35-mpg cars and 40-percent improvement in home heating requirements by 2030 seem very conservative now. Even mileage driven per car—usually kept constant or growing with real income—may decline in the era of the communications revolution. Daily commuting 50 weeks per year may have gone the route of the horse and buggy by 2030, thereby saving millions of barrels of oil per day. Several recent studies, such as the CONAES report of the National Academy of Sciences, suggest the possibility of a growing industrial economy in the United States with per capita energy use actually falling. This reviewer wonders, indeed, if a substantial reduction in per capita energy use cannot be achieved in the developed countries without the major material sacrifices suggested in the IIASA report.

On the other hand, the authors of the IIASA study are quite correct that the early industrialization process in the LDCs will by definition require an energy-GDP coefficient of close to or higher than 1. The vast amount of commercial energy required to make this possible far outweighs potential savings in the developed countries. It has become fashionable in certain circles to focus only on renewable energy sources for rural use in developing countries, but renewable energy sources cannot be used for the development of heavy industries, a modern transportation sector, etc. It is not up to us in the industrial countries to decide what route the developing world should take. Most developing countries have opted for major diversified urban industrialization, and that means very rapid growth in energy demand.

The IIASA study clearly indicates that economic growth and energy demand are limited in the long run by available supply. Again, only physical and economic criteria were used to determine output. This reviewer believes that the supply scenarios presented are overly optimistic, based on physical availability and production constraints. The latter are largely self-imposed.

IIASA assumes that world oil production—now at about 60 mbd—will peak at between 71 and 96 mbd in 2030, with the Middle East and North Africa (1980 output of about 24 mbd) producing 33.6 mbd of oil and liquids through 2030. This reviewer's view—shared by many in the industry—is that world oil production may already have peaked in 1979–1980—if not, it is likely to peak at between 60 and 65 mbd in the next few years. Both U.S. and Soviet oil output have probably peaked and will decline soon; North Sea production will probably increase by less than 1 mbd; and the output of non-OPEC LDCs will grow by 4 to 5 mbd. OPEC production is not likely to go much above 30 mbd, and certainly not to the roughly 40 mbd suggested in the IIASA study. By the end of the century, almost all major oil-producing regions will be in decline. Hence, the estimated world output of 71 to 96 mbd of conventional oil by 2030 seems out of the question and probably needs to be cut in half.

Nonconventional liquids from coal, shale, tar sands, and heavy oil are expected to supplement conventional oil production on an ever-increasing scale. Most of these liquids are expected to come from the United States, the Soviet Union, and to a lesser extent from Canada, Venezuela, Australia, and a number of other smaller producers.

The study suggests an output of between 15 and 30 mbdoe of synfuels in the United States by 2030. This means that between 150 and 300 huge synfuel plants producing 100,000 barrels per day (b/d) each will have to be constructed, mainly in the western part of the United States. After 2030 these numbers would progressively increase, with the projected decline in world conventional oil and gas production.

Based on this reviewer's substantially lower assessment of long-term world conventional oil and natural gas supplies, synfuel production by 2030 would have to be doubled again to meet the overall liquids demand in the IIASA scenarios. If only about one-third of those additional synfuels would have to be produced in the United States to enable the overall goal to be met, an additional 15 to 30 mbd of synfuels (or 150 to 300 additional plants) would have to be built. Even the "limited" output of 30 mbd now seems unlikely in view of numerous environmental problems and public opposition to such gigantic projects. The current economic and political climate in the United States suggests a production of only a few hundred thousand b/d of synfuels in 1990. It just does not seem realistic to expect a hundredfold production increase in the following 40 years.

For synfuels and stationary uses (primarily electricity), the United States would have to produce between one-third and one-half of the 7 to 13 billion tons of coal per year needed to meet world demand in the IIASA study, even under IIASA's very high oil and gas supply scenarios. Coal output growth of 4.5 to 8 times current production seems very high, but technically possible. Again, the biggest uncertainty will be public acceptance, because the socioeconomic consequences of such rapid growth would certainly be immense.

The IIASA team is not unaware of the potentially adverse impact of such massive coal and synfuel developments. But the report remains neutral on the sociopolitical issues and assumes that the liquids required to meet world demand will somehow be produced. Somewhere in the study, it is suggested that the United States in 2030 will be in the position Saudi Arabia is in today: ". . . the liquid fuel demand seems irreducible, and the coal resource is available. The world needs the coal-based liquid fuel supply that North America could export. . . . Ultimately, the pressure on North America and the U.S. is for exports of its vast energy resources to a growing world."

One can imagine economists and political scientists, at the University of Tripoli in 2010, busily debating in academic exercises whether the United States will be a short- or long-term profit maximizer, and what the next move of the coal lords of Wyoming and Colorado will be in exploiting a world in dire need of their products. Coal mine owners in the United States and Russia may be engaged in purchasing the plush resorts in parts of North Africa constructed there in the foregone days of the oil boom, and military planners in Europe may be dreaming of plans to occupy coal mines in the United States in case the latter were to contemplate a coal embargo. *L'histoire se répète!*

The IIASA scenario of hydrocarbon supplies still assumes a massive nuclear power program in the world during the next 50 years. It is assumed that 60 percent of all electricity will be generated from nuclear power. In the high nuclear case, the report considers an increase in nuclear power capacity from about 160 GWe in 1980 to 10,000 GWe in 2030, but this figure is later rejected because it would not be technically possible to build that many plants during the next 50 years.

Again, the authors of the IIASA study are not unaware of current opposition to nuclear power, but they argue that to forgo the nuclear option would be a sad mistake, leading to early exhaustion of fossil fuels.

In spite of the massive nuclear and renewable energy program, and an increase in projected natural gas use from about 42 trillion cubic feet (tcf) in 1975 to 168 tcf in 2030, the study concludes: ". . . one of the striking features of the supply scenarios of Chapter 8 is that they are still very much fossil in nature. Instead of reducing our use of oil, we realized that we will have to expand it. . . ." By 2030, liquids demand would only have been reduced from 45 percent of global demand today to 40 percent. Hence, in spite of the slogan "OPEC is dead, long live OCEC (Organization of Coal Exporting Countries)," the oil producers seem to have an excellent long-term future after all.

If, as this reviewer fears, the conventional oil, natural gas, nuclear power, and synfuel scenarios turn out to be unrealistically high in view of physical (oil and gas), environmental, socioeconomic, and political constraints, what then will happen to energy demand and economic development in LDCs?

The IIASA study serves as an eye-opener. The authors obviously were not trying to "forecast" energy demand and supply, but to show certain demand trends under specific assumptions of economic growth. Having arrived at a high and low demand scenario, they then considered the long-term supply options. This reviewer would argue that the demand scenarios for the developed countries may be too high, but the developing countries' demand estimates appear very reasonable. Even with somewhat further reduced demand in the industrial countries, and taking into account what this reviewer would consider a more realistic conventional oil supply scenario, the supply problem remains immense. The future painted here of nuclear, coal for direct burning, and synfuels will certainly not appeal to large segments of the population in the industrial countries. The IIASA study serves an important purpose. If we don't like the scenarios presented here, or believe that the methodology is basically unsound, the study can serve as the focus of a debate, not only on future demand and supply options in the developed countries (a subject already covered by numerous studies), but on how the developing world can industrialize at the modest rate suggested in the IIASA study and what supply options are open to it, given not only physical limits on resources, but unequal distribution of those resources and global environmental concerns related to the vast expansion of synfuels, coal, and nuclear power.

As with the navy captain in 1930, the sheer magnitude of long-term energy scenarios presented by the IIASA team seems to this reviewer like thinking about the unthinkable. One can certainly believe that many people in the western United States may have difficulty agreeing to live with a synfuel production almost equal to OPEC's current level of oil production. But then, again, 50 years is a long time away and perceptions are bound to change. If our great-grandparents in nineteenth-century Europe or America could come back to take a look at the brave new world we live in today, they might not like what they see either.

Herman T. Franssen
International Energy Agency, Paris

James W. Howe and James J. Tarrant, "An Alternative Road to the Post-Petroleum Era: North-South Cooperation" (Overseas Development Council, 1980).

The energy problems of developing countries are attracting increasing attention. At first this topic seemed of interest mainly to the development community, and analysis was limited to the probable effect of rising oil prices on economic development. But more recently the realization has grown that the developing countries are already a major factor in the international oil market, and that their oil purchases may rise to 30 percent or more of total availabilities by the year 2000. Consequently, energy prospects for developing countries have become an important topic not only to the development community but to energy researchers, the foreign policy community, bankers, oil companies, and all those concerned with international economic and political developments.

This monograph provides an invaluable introduction for this wide community. It is brief—about 45 pages of main text—but within this space it provides a wealth of information, and very adequate analysis of the role played by energy—both traditional and commercial—in developing countries. The point is made that developing countries have not one, but two, energy crises. Or, as the authors put it, the developing countries are faced with a double energy transition: a transition from oil to the sources of energy that will replace oil (this they share with industrial countries), and "the transition from the traditional energy resources on which most of their people rely to higher quality more abundant and longer lasting sources." The authors relate this diagnosis to the special energy characteristics of the developing countries—the low level of consumption, the rapid increase in use (far outpacing that of the industrial countries both before and after 1973), the wide disparities in amounts and types of energy used in urban and rural areas, and the inefficiency with which both traditional and commercial energy is used.

Faced with these problems, energy strategy in developing countries will involve a mix of improved energy efficiency and the development of both renewable and conventional energy resources. As a background to such strategies, two useful reference tables are provided. The first estimates for most of the developing countries the amount of their conventional energy resources compared with current consumption of commercial fuels. It shows, in many countries, resources very high in relation to current consumption, but, as the authors point out, these resources may not always match local needs, and there are, furthermore, many obstacles (financial and institutional) to the development of these resources. Nonetheless, the table does show that few countries are entirely destitute of conventional energy resources. The second table gives an assessment of the potential use of renewable resources and the new technologies in Third World countries, providing a useful guide to the practical feasibility of these new supply sources.

The main theme of the book is the strong mutuality of interest in energy among the oil-importing countries of both the developing and industrial world. This implies that actions to promote energy development by the industrial countries can be viewed as an investment in international energy security as well as development assistance. Among the actions that industrial countries could take, according to the authors, are increased investment in finding and producing more oil, coal, and gas in developing countries, the provision of technical assistance, and the encouragement of systematic on-site testing of small-scale technologies such as mini-hydro generators and solar pumps. The authors also recommend that a greater proportion of the research and development budgets of industrial countries should be devoted to the energy problems of developing countries.

The purpose of this monograph is to recommend, to policymakers in industrial countries, ways to help in the energy transition in developing countries. It is therefore, strictly speaking, outside the scope of the monograph to outline actions to be taken by Third World governments, which after all must bear the major responsibility for energy and development policy. In practice, however, it is difficult to define the role of outside assistance without a clearer idea of what actions might be taken by Third World governments. This apart, the monograph is a lively, clearly expressed and stimulating analysis of an important problem.

Joy Dunkerley
Resources for the Future, Inc.

J. E. Spearman, *The United States Metallurgical Coal Industry: Reserves, Efficiency, Outlook* (Morgantown: West Virginia University Press, 1980).

This is a relatively brief analysis. The bulk of the study is taken up by supporting documentation. Its application to energy is limited and may be briefly stated.

Approximately 60 percent of metallurgical (met) coals are substitutes for steam coals, and should neither be excluded from such consideration nor considered solely as metallurgical coal. Furthermore, there is a conceptual problem in the separation of metallurgical and steam coals.

In consumption, high and medium volatile met coals can be and are used for steam coal. Many models do not take this into consideration or fail to do so properly. For example, in the PIES model, a met coal is defined as one that has a sulfur content of less than 1.3 percent, an ash content of less than 8.0 percent, and a heat value of more than 26 million Btu's per ton. However, met coal quality is affected by the number and kind of inerts and reactance (as measured by vitrinoid reflectance), by its composition-balance index, by its rank (strength) index, and by its volatility. A low volatile coal is difficult to ignite and burn in a utility context.

While there is no clear separation between met and steam coals, the former usually commands a premium price. However, met coal may be sold as steam coal when there is a lack of met coal demand, when the met coal is owned by a utility, or when it is used for blending with lower-quality steam coals to help meet environmental regulations. For metallurgical purposes, given the relative shortage of high-quality met coals, low-quality (steam) coal often is blended with high-quality coking coals. Additionally, the deep cleaning of a low-quality coal may (at a cost in processing and coal lost) raise steam coal to a met coal standard.

In production, steam and met coals may be joint products from the same seam. The distinction is "more-or-less" rather than "either-or."

The above indicates virtually all of this volume's contribution to the field of energy. The author does provide an analysis of coal cleaning costs (p. 54), but he does not apply it to the question of steam coal/met coal substitutability. Similarly, a coal pricing analysis is developed (p. 88 ff.), but again, no effort is made to connect the two markets, or to shed any light on when, at what price, and at what qualities, met coal will be used for steam coal, and vice versa.

Michael Rieber
University of Arizona

Letters to the Editor

Comment on "An Analysis of the Supply of Oil"

To the Editor:

In his article "An Analysis of the Price of Oil" (Vol. 2, No. 1, April 1981, pp. 77-94), Ali M. Reza argues that even with backward-bending supply curves, lower demand lowers the equilibrium price. So far so good, but he considers this a refutation of my thesis that: "lower imports will not bring about [lower] prices; indeed, they may bring about [higher] prices" (page 84). But in the opening paragraph of my paper, I argued that the price of oil was well below equilibrium. His paper assumes equilibrium, and hence is irrelevant to that problem.

Since 1977, the demand for OPEC exports has dropped from 29 to 22 million barrels daily (first quarter of 1981), yet prices have been raised by a factor of three. (Because there is a lag, and probably a long one, between the price stimulus and the demand response, we can be sure that not much of the drop in imports was due to the post-1977 price hikes.) A lower amount demanded, *and* a 200-percent rise in price, is worth trying to understand. My thesis of nonequilibrium may be wrong, or so badly stated that Mr. Reza misunderstood it, but he does not address it.

I believe the market is still below equilibrium, and even the equilibrium is unstable, but that is another story, or two.

M. A. Adelman
Massachusetts Institute of Technology

Comment on "A Critique of IIASA Energy Models"

To the Editor:

I believe that Dennis Meadows has done a superb job, in his criticism of my *Energy Journal* article (Vol. 2, No. 3, July 1981, pp. 17–28), of characterizing the nature of the models and capturing the character and mood of IIASA's

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energy work. His highly readable paper is, I think, a much more important and basic document than its rather narrowly directed title would hint.

There are a few specifics that I would like, in some cases, to support and, in other cases, to challenge and counter.

In the first three pages, Dr. Meadows's discussions of the Häfele–Lovins dichotomy, while accurate, may be a bit stretched when referring to the models. While it is true that the model structure and the scenario descriptions, to a large extent, are geared more to the Häfele mode of thought than to the Lovins mode, it does not necessarily follow that the scenarios are biased to prove Häfele true. Rather, they tend to do two things in this regard: (1) to show the high (perhaps impossibly high) costs of following a hard or somewhat hard path and (2) to show the extremes to which one's assumptions must go in order to begin to approach a soft path or low energy path.

Dr. Häfele's rebuttal of Lovins (this issue, pp. 35–42), which I have been privileged to see, is a clear and precise statement of the apparent hard–soft or Häfele–Lovins controversy as it relates to the IIASA energy work. The scenarios, in short, incorporate "realistic" economic and technical judgments with *very* optimistic assumptions on conservation and renewables.

Regarding Meadows's discussion of the models themselves, I would like to take issue with two small points. First, the MEDEE model *was* used for analyses of developing country regions; the work was done by an excellent Pakastani analyst with substantial inputs from an Indian and an Argentine. I believe this work is an improvement over other analyses of energy demand in Third World nations.

Second, I believe that Meadows's statements about the inputs required for MESSAGE are a bit misleading. Indeed, there are a great many variables and constraints, but most of the input matrices are nearly empty. In fact, the inputs to MESSAGE in practice are relatively easy to provide, once one has done one's basic homework on constraints regarding market penetration, capital costs, and other physical constraints that limit rapid deployment of energy technologies.

I have to say I was a bit dismayed by the Meadows analogy regarding the models and overlapping lenses; frankly I think it is more wrong than helpful. *Each model looks at a different part of the energy system*; they do not all look at the same landscape. One model looks at energy demand, another at energy supply and conversion, and a third at the capital costs of the system. Looking at entirely different subsectors of the energy sector and modeling those different subsectors with different methodologies is perfectly reasonable and appropriate. If blackness is the outcome, it is not because the models overlap to block the light, but because the analyst who assesses the models does poorly at linking the inputs and results.

Meadows is quite right that the system places great demands on the analyst for good judgment and a sense of reality, but I do not think that this is all bad. In a way, all models require this—even if it is the modeler's judgment regarding which methodology he chooses, and how he represents that mathematically in the model. It is not clear to me that the IIASA models place greater demands on the analyst than do other models. The demands are simply of a different type. This is bad because it is not reproducible, is difficult to explain, and is hard for an outsider to evaluate. It is good because it avoids simple-minded reliance on a mechanical tool.

In short, I am not unduly troubled by the demands made on the analyst in the MMI system; I *am* troubled by the excruciating slowness and complexity of the analyst's job in this sense. The MMI system needs to be much more deftly integrated to make the analyst's job of looking at the inputs and outputs a more straightforward, documentable, and reproducible one.

A further point on this. Meadows says, "MMI is more an accounting system than a forecasting device." I could not agree more. Isn't it delightful to find a modeling set that uses this advantage of computers, and still allows the analyst to have the judgment and integrate capacity that other models place in the invisible hands of some new methodology? Isn't it plausible that a good analyst's judgment is at least as good as some overarching methodology?

Meadows states that "it is possible for an analyst to specify as exogenous inputs to MMI many important features of a hypothetical future without learning from the MMI outputs that the assumptions are inconsistent or infeasible." I agree. I also contend that this is just as true of every other model I know as it is of MMI. The real evaluation of inconsistency or infeasibility comes in the analyst's own judgment about the outputs.

Regarding infeasibility, may I point out that in spite of the optimistic assumptions (on both the conservation and supply sides) made for the scenarios, one credible conclusion could be that *the scenarios do not work*! Note some of the input assumptions: 20 percent of all urban automobile travel in all of OECD is to be electric cars by 2030 in both the scenarios; 50 percent of all new single-family homes and low-rise apartments and service-sector buildings have solar space and water heating systems in all of OECD; 60 percent of the cooking and heating market in developing countries is to be met by commercial renewable sources by 2030. Growth in transportation activity is much lower in the IIASA projections than in any period in the past; efficiencies are much higher. And so on. The point is that the assumptions made were thought to be aggressive in their support of conservation and renewable technologies. The results following these assumptions seemed to indicate that hard technologies would still be needed to such large extents that some analysts could conclude that these sets of reasonable, hopeful assumptions are simply wrong, i.e., that the scenarios do not work. The world cannot mine all that coal; it cannot produce all those synfuels; it cannot raise all that capital. Something must give way; what will it be? Will economic growth be much lower? Will conservation be much higher (an extraordinary possibility if you look at the aggregate coefficients in Chapter 14 of the full IIASA Energy report)? Will developing regions simply not develop?

Not everyone at IIASA sees the scenario results this way, of course. Maybe the scenarios *can* happen, and their results are simply a clarion call to start raising the capital and building the machinery. The assumptions are clear and the results follow pretty straightforwardly from the assumptions. One can choose to discard the results, but that means one must discard the assumptions: make different assumptions and let us see what happens.

I have a final point regarding the plausibility of the scenario results.

IIASA global analyses demand that assumptions be made so that aggregate, cumulative effects are seen. It forces, therefore, soft-path advocates, conservation advocates, hard-path advocates, nuclear advocates, etc., to stipulate not what new technology is emerging in some corner of the earth, or what one research lab or one company is doing, but what the *aggregates* are likely to be. It asks not whether General Motors has a new electric car, but how many people in New York City in 2030 are going to be driving electric cars. It asks not whether you can build a zero-energy house, but how many will be built in Switzerland, or Spain, or Argentina, in the next 50 years. How many of Mexico City's 20 million people in the next 50 years are going to put in solar power heat pumps, drive brand new Honda Civics, or abandon energy-intensive consumer products? One cannot refute the IIASA energy scenarios with proof by isolated example. Anecdotal evidence does not translate directly into a global energy picture. The tremendous inertia of aggregates cannot be ignored.

Meadows made no mention of the scenarios other than the High and the Low, and I think it would be fair to do so. We at IIASA evaluated a very high nuclear case in which we could not achieve the targets that were discussed in the nuclear chapter in the energy report, and we did a high solar case and also found it difficult to get all the solar postulated in the solar chapter in the book. We also did a scenario for very low energy demand, one suggested by Umberto Colombo, a scenario of 16 TW by 2030. The essence of the 16-TW scenario is simply this: transportation activity growth has to come essentially to a halt in developed regions, and the service sector must grow to a very large proportion of the total GNP. Maybe this is perfectly realistic; I don't know. Maybe it is even more plausible than either of the High or Low scenarios. But note that 16 TW is twice what we use today in a world where the readily available oil and gas is rapidly dwindling. It still means tremendous increases in extracted resources. Even Amory Lovins would not grant a supply of 16 TW from renewables by 2030.

I commend *The Energy Journal* for its careful review of the IIASA energy work, and trust that the exchange of views revealed thereby will serve to sharpen the relatively few differences of perception, and enable readers and thinkers to assess the underlying implications for our energy future.

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