Letters

Lovins on Energy Costs

Jay James, Jr. (Letters, 28 Apr., p. 381), of the Electric Power Research Institute, claims that capital costs of energy systems quoted by President Carter, presumably from my writings, are miscalculated. But James's first citation (*1*) shows that his objections are both wrong and irrelevant. Specifically:

1) James says I consider only capital costs and equate thermal with electrical energy. In fact (*1, 2*), I add capital to fuel and other operating costs to obtain delivered energy costs. For consistent accounting, I compute capital costs in terms of a standard rate of delivering enthalpy (not free energy), such as 1 barrel of oil per day (bpd), which is ~ 67 kilowatts thermal (kWt). I then allow later for the First Law efficiency of end-use devices in each thermodynamic category of need, such as furnaces and heat pumps for low-grade heat.

2) James suggests I should not compare nuclear with oil investments, because oil is short term. In fact, I mention oil-system capital intensity (*1*) only as an *historic* baseline two orders of magnitude below the capital intensity of marginal electric systems. The energy systems I compare with each other in delivered price (*1, 2*) are all *long-run* marginal sources, all meant to *replace* oil urgently. Other systems are of little strategic interest.

3) James states, without citation, that President Carter's estimate of $20,000/bpd for an Alaskan oil system is "three times too low." In my book (*1*), I state no capital cost specifically for delivered Alaskan oil, though I give a range of ~ $10,000 to $25,000/bpd—derived from the Bechtel data base (*3*)—for 1980's U.S. frontier oil and gas. The exact value for Alaskan oil, which is strongly site- and date-dependent, has been authoritatively estimated to be about $19,900/bpd (*4*). This is remarkably close to the President's estimate, but not to James's ~ $60,000/bpd (which would imply, at my 12 percent per year fixed charge rate, an implausible capital charge of $19.7 per barrel). Even if the long-run alternatives I consider did include oil, the short physical lifetime of oil field investments would not greatly alter the economics as James implies (*5*).

4) James states that the capital costs I assume for a marginal nuclear station and its associated transmission and distribution (T & D) capacity are "very high." In fact, they are Bechtel's data (*3*), converted from 1974 to 1976 dollars and ordering with appropriate indices (*6*) and assuming that the real escalation rate after 1976 is zero (*7, 8*). The 55 percent capacity factor I assume (*1*), considered "extremely low" by James, is broadly consistent with empirical data (*9*)—though I include conservatisms ample to allow for ≳ 80 percent in case the vendors' hopes of greatly improved performance are realized.

5) James implies that my analysis uses a whole-system nuclear capital cost of $5000 per delivered kilowatt electric (kWe), including "an additional 43 percent 'miscellaneous' category." The value I use (*1*) is in fact $3495/kWe delivered, enthalpically equivalent to $235,000/bpd and hence within President Carter's range of $200,000 to $300,000/bpd. The $3495/kWe is calculated (*1, 10*) from section 4 above [assuming marginal T & D losses (*11*) of 10.7 percent] and is conservative. To show this, I also estimate (*1*)—outside the comparative analysis—that a realistic value might be about $5000/kWe delivered (~ $336,000/bpd). The extra ~ $1500/kWe arises not from "miscellaneous" but from estimates for specific terms (*12*) explicitly omitted from the $3495/kWe (*1*).

6) James's "more realistic calculation" yielding $1650/kWe is unstated and undocumented. He cites an estimate by Forbes and Turnage, to whom I have responded elsewhere (*13*), but it states a value of $1975/kWe, is judgmental, cites no sources, and states no grounds for preferring its lower costs and higher capacity factors (65 percent for generation and transmission, 100 percent for distribution) to those of my references. James thus fails to explain why my, or the President's, estimate of nuclear system cost is "three to five times too high"—presumably meaning it should be about $700 to $1500/kWe.

7) James's nuclear cost of $1650/kWe converts, at my 5.8 gigajoules (GJ) per barrel, to $111,000/bpd of delivered enthalpy, not to $56,700 as he states. The origin of his "$66,100/bpd for oil" is equally obscure. His implication that the nuclear system is less capital-intensive than an oil-electric system is absurd (*14*). Accordingly, while it would be foolish to extract oil in order to burn it under a boiler—even in an efficient combined-cycle plant such as James assumes—a recent comparison shows that such a plant would send out 24 percent cheaper marginal electricity than a pressurized water reactor (PWR) (*15*).

8) James presumes that if a nuclear power station is not built, a fossil-fueled one must be built instead. But more electricity, from any source, is not a sensible answer to our current energy supply problem: heat (now 58 percent of U.S. delivered enthalpic needs) and portable liquid fuels (34 percent) (*1*). The premium end uses that are electricity-specific—now 8 percent of total end-use energy needs in the United States (*1*), ~ 7 percent in Western Europe (*2*)—are already saturated (*16*). Electricity is too costly and slow to make further saturation worthwhile. While James seems to think the energy problem is how to expand domestic supplies to meet extrapolated homogeneous demands, I think it is how to meet *heterogeneous* end-use needs with a minimum of energy (and other resources) supplied *in the most effective way for each task*. Accordingly, debating which kind of power station to build is like debating which is the best buy in champagne when all one wants is a drink of water. That is surely the point of President Carter's economic comparison (*17*) of nuclear with nonelectric investments—and of mine (*1, 2*) with both soft technologies and the far cheaper improvements in end-use efficiency.

9) The key question for petroleum-dependent countries is, What investment can relieve that dependence fastest per dollar invested (subject to other constraints)? Nuclear power—with its complexity, inherently long lead times, and narrow markets—fails that test, while a soft energy path—relatively simple, fast, accessible, and diverse—passes it (*1, 2*). This rate advantage of the soft path is *independent* of countries' access to transitional fossil fuels. Moreover, while soft technologies can substitute in every end-use category, nuclear power can readily displace only baseload electricity. Hence replacing *every* oil-fired power station (thermal and gas turbine) in the countries of the Organization for Economic Cooperation and Development (OECD) with nuclear power overnight would reduce OECD oil consumption by only 12 percent and reduce the imported fraction of that consumption from about 65 percent to 60 percent (*18*)—at the cost of in-

creased dependence on imported uranium and capital. It is thus all the more irrational to suggest that, without nuclear power, nations must war over oil.

As several thousand pages of critiques and responses on the soft-energy-path thesis show (*13*, *19*), this is not the first time someone has decried "soft numbers" before verifying references. May I renew my earlier plea (Letters, 24 June 1977, p. 1384) that analysts get on with substantive refinement, extension, and application of soft-path concepts?

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References and Notes

1. A. B. Lovins, *Soft Energy Paths: Toward a Durable Peace* (Friends of the Earth and Ballinger, Cambridge, Mass., 1977), especially chaps. 3, 6, and 8.
2. ———, "Re-examining the nature of the ECE energy problem" [ECE(XXXIII)/2/I.G., U.N. Economic Commission for Europe, Geneva, 1978]; "Soft Energy Technologies," *Annu. Rev. Energy* 3, 477 (1978).
3. M. Carasso *et al.*, *The Energy Supply Planning Model* (Report to the National Science Foundation, Bechtel Corp., San Francisco, 1975), two volumes, acquisition Nos. PB-245 382 and PB-245 383 available from the National Technical Information Service, Springfield, Va.; facility data sheets and updates from M. Carasso and J. M. Gallagher, personal communications, 1976.
4. D. Sternlight (Chief Economist, Atlantic Richfield Corp., Los Angeles), personal communication (1978) of a detailed Arco estimate that the total present-valued investment (exploration, field cost, pipeline, Valdez terminal, and new tankers delivering to existing West Coast terminals), including interest, is about $17,500/bpd (1978 dollars) for the Sadlerochit field (lifetime ~30 years). I have deflated this estimate at 7 percent per year to 1976 dollars and added $4621/bpd for storage, refining, and distribution, all treated as marginal costs [Bechtel data (*1*, *3*) converted to 1976 dollars with the Marshall and Stevens index (*6*)].
5. For illustration, if 30 percent of system investment were at the wellhead and 70 percent downstream, with respective lifetimes of 13 and 30 years, the present value of the stream of original plus replacement investments over 40 years, at a 5 percent per year real discount rate, would be only 30 percent above the total investment if all lifetimes were 40 years.
6. For a 1.1-GWe PWR, $585 per net installed kWe (1974 dollars) is converted to $929/kWe (1976 dollars) using the 1.26 per year index from a 35-plant multiple regression ($r^2 = 0.71$) by I. C. Bupp and R. Treitel, "The economics of nuclear power: De omnibus dubitandum" (Harvard Business School, Cambridge, Mass., 1976). For T & D—respectively $69 and $420 (1974 dollars) per net kWe of installed marginal generating capacity, taking into account supply diversity—the conversion to 1976 dollars is made with the 1.25 Marshall and Stevens Equipment Cost Index.
7. This is highly conservative. For example, a regression ($r^2 = 0.76$) on the 39 U.S. light water reactors (LWR's) completed through May 1977 reveals that, with each successive year of construction permit issuance (1967–1971), controlling for all other significant variables, real plant cost rose $141/kWe. If this kept up, a 1.1-GWe PWR ordered in 1976 (25th unit built by the architect-engineer, outside the northeast region, with a cooling tower) would cost ~$1474/kWe. Both these figures have been converted to 1976 construction dollars with the Handy-Whitman steam-plant construction cost deflator, and would be higher if they were in 1976 GNP dollars [W. E. Mooz, "Cost analysis of light water reactor power plants" (Report R-2304-DOE, Rand Corp., Santa Monica, Calif., 1978)].
8. The assumed LWR cost is also probably too low. For example, the California Energy Commission's draft report to the state legislature on Assembly Bill 1852 [R. Knecht *et al.*, *Comparative Generation Costs* (California Energy Commission, January 1978), appendix 19] estimates $1027/kWe for the Sundesert plant, ordered in January 1976 (neglecting dedicated transmission and deflating to 1976 dollars at 6.5 percent per year). The August 1978 final draft (in press) estimates $1185/kWe.
9. The empirical average for all U.S. LWR's through 1977 was 60 percent (58 percent if weighted by unit size), 53 percent for units over 0.8 GWe. Exhaustive regressions on the entire U.S. data base lead to a predicted average, levelized over the first 10 years of operation of a new 1.1-GWe PWR, of 60 percent, taking account of a new vintage correlation that emerged during 1977 (55 percent without it). See C. Komanoff, *Nuclear Plant Performance Update 2* (Komanoff Energy Associates, New York, 1978). Komanoff and V. Taylor have also prepared an improved analysis of the Mooz data (*7*).
10. Also assumed are Bechtel's (*3*) $61/kWe for marginal fuel-cycle facilities—probably ~ 3 to 5 times too low—updated to 1976 dollars and ordering with the Marshall and Stevens index (*6*), and $100/kWe, calculated (*1*) in 1976 dollars, for the initial core.
11. Bechtel (*3*) assumes 16.4 percent at the margin.
12. The omitted terms are: real escalation after 1976 ordering; marginal investment in reserve margin, land, future services such as waste management and decommissioning, and past or present services such as federal R & D, regulation, and security services; and the ~ 6½ to 8 percent of electric output currently needed to run the fuel cycle. Terms omitted from both the $3495/kWe and the ~$5000/kWe totals include costs of end-use devices, externalities, dynamic net-energy considerations, and any "miscellaneous" items.
13. U.S. House of Representatives, Committee on Government Operations, Subcommittee on Environment, Energy and Natural Resources, *Nuclear Power Costs* (Government Printing Office, Washington, D.C., 1978), part 2, pp. 1103–1115.
14. For example, if one uses Bechtel data (*3*), a 0.8-GWe coal-electric system with a scrubber but no fuel cycle would cost $2200/kWe delivered (1976 dollars) at 0.62 capacity factor (*1*, *9*). If James's oil-fired plant cost the same, an oil-system cost of $30,000/bpd (capital charge at 0.12 per year = $9.9/b, too much to clear the market), divided by 0.46 First Law plant efficiency, would imply a system cost of $3172/kWe—generously assigning the whole oil-system cost to the residual rather than the light fractions (*15*).
15. J. Harding, in (*13*), part 2, pp. 1778–1802. The rationale for considering such a combined-cycle plant at the margin is that California is to have an embarrassing glut of residual oil from refining Alaskan crude oil extracted for its light fractions. Saving residual oil (nearly all of the 15 percent of California oil now burned in power stations) would probably not save crude oil; the residual oil is a by-product, not a motive. California is also considering gasifying residual oil.
16. The ratio of present electricity supply to electricity-specific needs approaches 2 in the United States today, and may exceed 3 after long-run end-use efficiency improvements.
17. J. Carter, remarks to Opening Conference, International Nuclear Fuel Cycle Evaluation, Washington, D.C., 19 October 1977.
18. V. Taylor (Pan Heuristics, Los Angeles), personal communication, May 1978. The proportional import reduction would be greatest in the United States, not in Europe or Japan.
19. U.S. Senate, Select Committee on Small Business and Committee on Interior and Insular Affairs, *Alternative Long-Range Energy Strategies* (Government Printing Office, Washington, D.C., 1977), two volumes [this contains all published critiques and responses except the exchange with Forbes in (*13*)].

Light on the Shroud?

Sindonologists may find the following paragraphs (*1*) of interest.

To make a reinforced plastic that will last for thousands of years, soak a strip of linen in oil of lavender that contains Syrian asphalt and let the fabric dry in the sun. Light will cause chemical bonds to form between adjacent molecules of the tar, converting the sticky