especially when only those students who are selected may be studied.) Substituting the value of $-.54$ for r and assuming an upper bound of .50 for R^2 yields (by Eq. 2) the inequality

$$.3542 \geqslant r_1^2 + r_2^2 + 1.08 r_1 r_2 \qquad (4)$$

This inequality is very restrictive; possible positive values for r_1 and r_2 are illustrated by the area of the ellipse in the first quadrant of Fig. 2 (hatched area). If, for example, r_1 equaled r_2, its largest value would be .34, not altogether atypical of the actual values found.

As pointed out to me by Hoffman (*6*), the values of r will be particularly negative for schools that tend to be applicants' second or third choice. Applicants with both high GPA's and high GRE's are more likely than others to be admitted by their first-choice schools; hence, second-choice schools will have a preponderance of students who are high-low or low-high. Such schools would be especially unlikely to yield studies in which GPA or GRE considered singly predicts a later variable.

If, on the other hand, r is not negative—or in general the correlation between admissions criteria is not negative—then the school from which the sample is obtained must either have mainly students who are high on all variables (and hence have a greatly restricted range), or have a large group of students who are low on all variables (in which case the school is atypical). The point is that a desirable range can be obtained on the variables only at the expense of inducing a negative covariance structure, because a school that considers students who are low on some variable will admit only those who are high on others; this negative covariance structure in turn restricts the zero-order correlation between the variables and any future measure of interest.

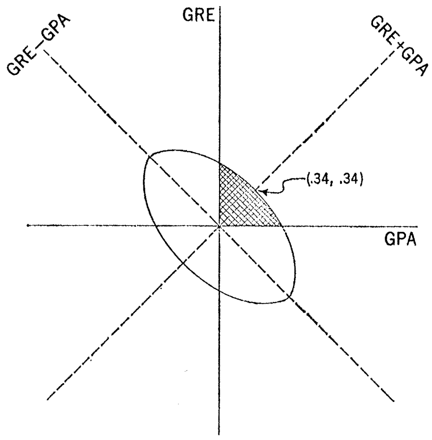

Fig. 2. The ellipse defined by Eq. 3.

There simply is no way in which the single correlations can be high. But note that the multiple correlation may contrast strikingly with the single validities; in the 1974–75 class, for example, it is possible to have a multiple correlation as high as .71 based on two single validities of only .34.

But even such multiple correlations would describe only the group of selected students, whereas the question of interest in the admissions procedure is how well the variables evaluate the applicant population. Without a study in which a sample of the applicants—rather than of the selected students—is evaluated, it is impossible to tell. Yet such a study is completely infeasible. Even if rejected applicants are monitored throughout the rest of their work careers, it is impossible to evaluate how they would have done had they been admitted, because the rejection itself constitutes an important "treatment" difference between them and the selected students. The alternative is to admit a sample of the applicant population without using the standard admission variables to select them—preferably, to select at random. At worst, such a procedure can be considered to be unethical, and at best it does not arouse much enthusiasm at departmental meetings. The result is a dilemma. Studies involving admission variables will yield low correlations of necessity, and hence these low correlations cannot be used to determine whether the admissions variables are any good. They may be. Or on the other hand, they may be unfair or invalid—and their use may merely perpetuate an unfortunate status quo.

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7. Supported in part by NIMH grants MH-21216 and MH-12972, and by NSF grant GS-32505. F. Andrews, W. Chaplin, D. Hintzman, and P. Hoffman contributed very valuable comments to earlier drafts of this article. I would like to express my appreciation to all four of them, while not holding them responsible for the defects that remain. Finally, I thank L. Rogers for her careful compilation of the relevant data.

NEWS AND COMMENT

Oil and Gas Resources: Academy Calls USGS Math "Misleading"

In 1922, before the discovery of a vast pool of oil under eastern Texas, the U.S. Geological Survey solemnly predicted that the nation's cumulative oil production would not exceed 15 billion barrels, a figure that suggested the United States might soon run out of oil. Happily, the Geological Survey was wrong, although its estimate was not unreasonable considering the infant state of petroleum geology.

Now, with the passage of more than half a century, it looks as if the Geological Survey may have erred again, this time on the high side. According to a new survey* put out by the National Academy of Sciences concerning fuels and basic material resources, the amount of oil and gas left to be discovered and produced with current technology in the United States is "considerably smaller" than the 200 to 400 billion barrels of oil and the 1000 to 2000 trillion cubic feet of natural gas estimated as of last March by the Geological Survey.

A more realistic estimate, in the opinion of the Academy's Committee on Mineral Resources and the Environment, is that 113 billion barrels of oil and 530 trillion cubic feet of gas remain to be found and produced onshore and offshore, mostly in Alaska. The

* *Mineral Resources and the Environment* (National Academy of Sciences, Washington, D.C., February 1975), 348 pp.

main implication of the Academy committee's lower estimates (which are in addition to proved reserves) is that a large increase in annual production of oil and gas in the United States is "very unlikely."

Two years in the making, the Academy report broadly reviews national supply-and-demand prospects for fossil fuels and essential metals. Among the report's main conclusions is the thought that industrialized nations face the possibility of a "series of shocks of varying severity" in the not-so-distant future as shortages occur in one critical material after another—not as a consequence of international cartels, but of the physical limits of the earth's resources. The committee foresees declining national self-sufficiency in copper, and it recommends nonmilitary stockpiling for some "threatened materials" such as tin, helium, mercury, and the platinum metals, supplies of which may be limited by political action or waning resources, and for which there are no ready substitutes.

Beyond stockpiling, emphasized Brian Skinner, a Yale geologist and chairman of the committee, in a news conference on 11 February, the report urges the adoption of a conservation ethic "as a kind of national religion," both for fuels and scarce industrial materials.

Skinner and the resource committee also make a point of trying to disabuse policymakers of the notion that technology will come quickly to the rescue whenever shortages develop.

"The theses that technology is infinitely improvable and that substitution is infinitely possible, we feel, are highly suspect," the report observes. It adds that, in any case, the United States "has allowed itself to become woefully weak in basic materials technology."

Probably the report's most controversial aspect is its judgment in the matter of oil and gas resources. For more than a decade, the Geological Survey's estimates—a major basis for federal petroleum policy and the conventional wisdom that supply would increase uniformly with price—have stood conspicuously above estimates developed by major oil companies. For just as long, one of the Survey's more prominent researchers, M. King Hubbert, has been saying that the Survey's numbers were wrong. To Hubbert, now 71 and a past president of the Geological Society of America, the Academy's judgment is sweet vindication.

He, in fact, seems to have started the dispute in 1956 with a widely dis-

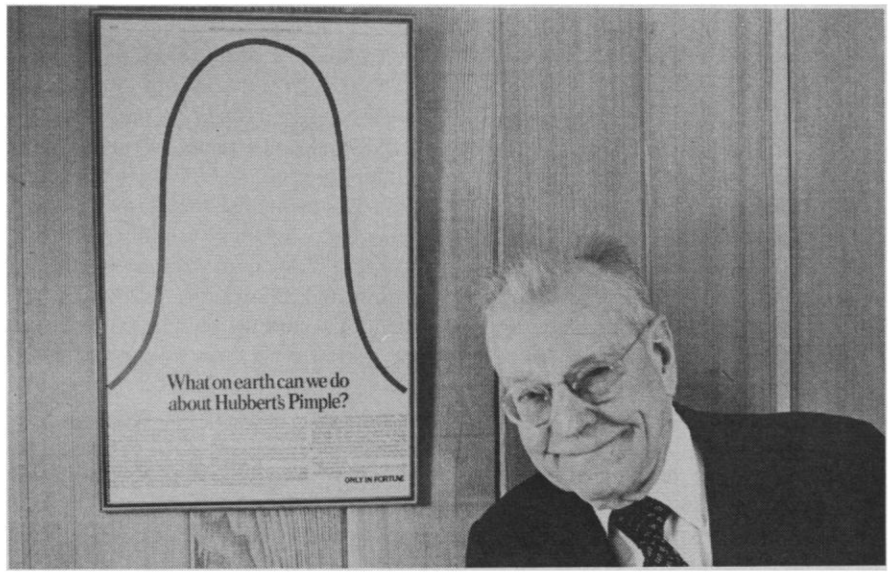


Photo by Eric Poggenpohl

M. King Hubbert believes the petroleum era will be a brief blip in human history.

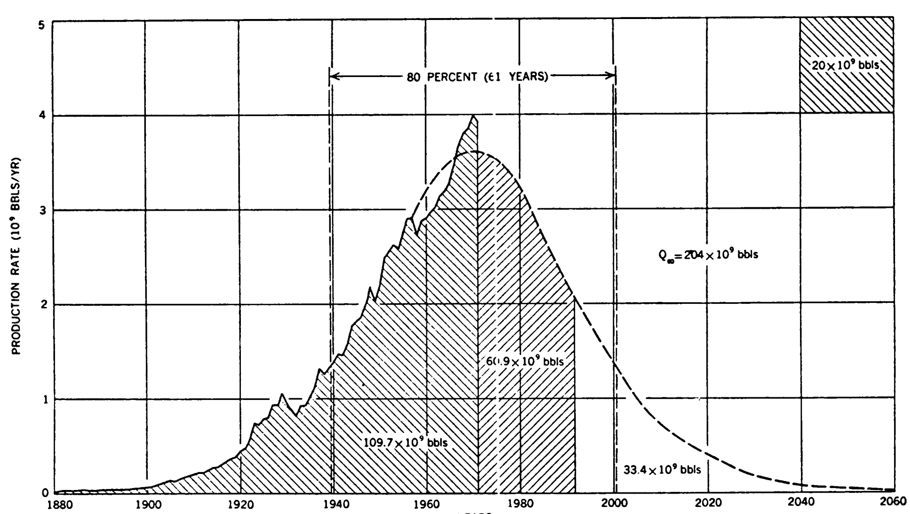
cussed prediction that U.S. oil and gas resources would turn out to be smaller than generally presumed, and that oil production would reach a peak and begin to decline in 10 to 15 years. (Oil production in the United States has been declining since late 1970 and gas production appears to have reached a peak in 1974.)

Hubbert was then one of the Shell Oil Company's leading exploration geophysicists, but his gloomy predictions branded him as a maverick out of step with the cornucopian philosophy of the oil industry. "My grandchildren may have to worry about oil shortages, but I won't have to," was an industry cliché of the time, Hubbert recalls with savored irony. Shell, when it published his 1956 speech, deleted the prediction.

The industry's first reaction was one of dismay and incredulity, Hubbert says in a recent discussion of resource estimates.† The industry's second reaction was to try to prove Hubbert wrong. Within a year, other industry estimators were leapfrogging each other with higher and higher estimates. The Geological Survey trumped them all in 1961 with an estimate that U.S. oil production would eventually exceed 500 billion barrels, or more than five times the amount produced in the industry's first century.

Most of the industry's estimators kept their methods to themselves, and thus beyond scrutiny. Hubbert derived his from a straightforward statistical analysis of past records of discovery and production; his underlying assump-

† *U.S. Energy Resources: A Review as of 1972*, M. K. Hubbert (Senate Committee on Interior and Insular Affairs, Serial No. 93-40 (92-75), Washington, D.C., June 1974), 267 pp.



Hubbert's 1972 projection of petroleum-liquids production onshore and offshore in the conterminous United States.

Handler Reelected NAS President

Philip Handler has been elected to a second 6-year term as president of the National Academy of Sciences (NAS). He was reelected in mail balloting by NAS members, having run unopposed.

Handler, 57, took office on 1 July 1969. A biochemist, he was chairman of the biochemistry department of the Duke medical school at the time of his election to the top Academy post. The constitution of the Academy limits its presidents to two terms and allows the governing council to negotiate the length of presidential terms up to a maximum of 6 years. Handler and the council have agreed on a full, 6-year term.

Handler took office at a time when the Academy was under criticism for frequently providing technical advice which ignored the environmental, economic, and social implications of problems studied. During Handler's first term, a major reorganization of the National Research Council (NRC), the Academy's operating arm, was carried out. The traditional disciplinary divisions were replaced by assemblies and commissions structured, respectively, to permit more effective intradisciplinary and interdisciplinary approaches to national problems. Also important were the establishment of an Institute of Medicine within the Academy framework in 1970 and the apparent reconciliation of major differences between the Academy and the National Academy of Engineering, created in 1964 under the NAS charter.—J.W.

tion was that, given the finiteness of conventional oil resources, what goes up must come down. Oil production would do so, he said, roughly along a bell-shaped curve whose span would be an almost insignificant blip in the span of human history.

The Geological Survey in the late 1950's took—and staunchly defended—a simpler approach. It estimated the volume of sedimentary rock likely to contain oil, determined that about one-fifth of this sediment had been adequately explored by drilling, and that, therefore, four-fifths of the nation's recoverable oil remained to be found. Hubbert argued that this reasoning assumed oil would continue to be found at a constant rate per foot of exploratory drilling, whereas in reality finding rates had fallen precipitously since the 1930's and were still falling. The Survey clung to its reasoning, and Hubbert clung to its arithmetical Achilles' heel with the tenacity of a terrier.

Over the years the disagreement evolved into a professional feud between Hubbert and defenders of the Survey's estimates, chief among them the present director of the USGS, Vincent E. McKelvey. In an interesting contrast with the usual practices of government agencies, the Survey hired Hubbert in 1964. During the next decade he kept up his criticism from within, largely without effect.

The debate over oil and gas resources was generally regarded as theological until the Arab oil embargo struck in 1973 and the White House began making noises about achieving self-sufficiency at least partly through dramatic increases in domestic oil and gas production. (The Project Independence report released last November, for example, accepts the National Petroleum Council's contention that holding the price of oil at $11 a barrel could more than double the present production rate of 9 million barrels a day by 1985. The Academy report, in effect, says this is probably impossible.)

Last June, with the disagreement no longer academic, and with revised industry estimates in hand that were close to Hubbert's numbers, the resources committee agreed to arbitrate (*Science*, 12 July 1974).

The crux of the disagreement was the finding factor used by the Survey—the average ratio of oil in thoroughly explored sediments to the oil expected in a volume of unexplored rock. A ratio of one—that is, equal concentrations in explored and unexplored rock—leads to a prediction of 400 billion barrels of undiscovered, recoverable oil. A finding ratio of one-half, everything else being constant, reduces the Survey's estimate to 200 billion barrels.

In discussions with the committee's resource estimation panel, Survey officials indicated that these ratios were guesses. Hubbert, not one to guess, applied a little freshman calculus to drilling statistics and came up with a finding factor of one-tenth for the thoroughly drilled lower 48 states. Plugging this into the Survey's arithmetic gives an oil resource estimate of 120 billion barrels.

How the Academy committee arrived at its own estimate was not entirely clear, however. Besides consulting with the Survey and Hubbert, the committee spoke at length with researchers from several oil companies whose estimates were well below the Survey's. None is identified, although one certainly was Mobil Oil, whose former vice-president for research and production, John Moody, was a member of the resource estimation panel. After all these deliberations, Skinner said, the panel decided that an estimate of 105 billion to 120 billion (the median of which is 113 billion) "appears realistic."

With present technology, future discoveries plus past production and known reserves add up to a cumulative 247 billion barrels, in the committee's view, and an additional 100 billion barrels might someday be recoverable with new technology. Hubbert's comparable estimate, published last year, is 253 billion barrels.

In the end, Skinner said, it appeared to the committee that the Survey had used "misleading arithmetic," although not with any intent to deceive. "You can either guess at the [finding] factor," he said, "or you can derive it."

World Resources

What does this imply for estimates of world petroleum resources? And for the Survey's predictions of mineral resources?

Not much, apparently. Methods differ from one substance to another, and petroleum, being one of the least accessible, is one of the hardest to measure. No standard method exists for estimating this resource, but the committee accepts industry estimates that the world's undiscovered recoverable oil amounts to about 1130 billion barrels and its natural gas to 4900 trillion cubic feet. (Proved, if unmarketable, reserves of shale oil in the United States alone are said to eclipse these figures at an estimated 4 trillion barrels.)

The Geological Survey, in any event, is not conceding defeat or error. Different methods are based on different premises and are therefore hard to compare, says chief geologist Richard Sheldon. Most estimates include economic factors in one way or another, for example, but the Survey, Sheldon notes, has aimed for relatively "price-free" figures that include a larger measure of speculative resources than most. All in all, he told *Science*, "the [Academy] report did an excellent job of establishing a floor on resources, but it didn't pay much attention to the ceiling, which is much harder to estimate."

The Survey and the Academy committee would probably agree on at least one point: that the art of resource estimation is, in Sheldon's words, "in a very unsatisfactory state of affairs right now."—ROBERT GILLETTE

New Alchemy Institute: Search for an Alternative Agriculture

Falmouth, Massachusetts. The new alchemists are a small group of people who consider that modern American agriculture is a mighty edifice built on sand. They expect it to collapse, maybe within the next 10 to 20 years, either from intolerable price increases in the fuel and fertilizer needed to sustain it, or because of the accumulating weight of biological damage caused by agricultural chemicals.

While others may dispute the analysis, the new alchemists are acting on it by trying to develop an alternative, and radically different, mode of food production. They want their style of agriculture to depend on renewable sources of power, such as sun and wind, instead of on fossil fuels; on natural biological cycles, not on biocides and chemical fertilizers; to be based on a diversity of crops and varieties, not on genetically vulnerable monocultures; to select plants for their taste and nutrition, not for trucking and packaging qualities; to require little capital investment and encourage people to come back to the land instead of driving them off it.

Such an idyll may not be possible outside the Garden of Eden, but the new alchemists' endeavor to attain it will be important even if it fails. In fact the group has already made quite substantial progress, considering the scantiness of its resources. Greenhouse complexes, solar heating devices, and windmills with brightly painted allegorical suns on their tails are evidence of an unusual experiment in progress at the New Alchemy Institute's 12-acre farm near Falmouth on Cape Cod. The institute is supported by more than a thousand associate members, each subscribing at least $25 a year, as well as by grants from the Rockefeller Brothers Fund and other foundations. It is likely soon to be awarded a contract worth several hundred thousand dollars from the Canadian government to set up an "ark"—a new alchemical food producing system—on Prince Edward's Island.

The New Alchemy Institute was founded in 1969 by two marine biologists, John H. Todd and William O. McLarney. The choice of name implied not a rejection of modern science but a harking back to a time when science, art, and philosophy did not have to be practiced as separate, mutually exclusive realms of knowledge. Todd has a broader training than most scientists—a B.Sc. in agriculture, an M.S. in parasitology and tropical medicine, and a Ph.D. in comparative psychology and ethology—yet he and his associates found, he says, that "with all our scientific training, we could not make any little piece of the world work."

A focus of the group's concern was the damage being done to nature by modern agriculture, and the fact that no one seemed to be tackling the problem at its roots. People in universities seemed to be concerned only with patch-up operations, trying to make the existing system less harmful instead of replacing it altogether.

The group pooled their savings to administer the institute and work on a small ranch in Southern California, where Todd and McLarney held teaching posts at San Diego State University. The goal of developing ecologically derived, low cost, low energy food production continued at Cape Cod when Todd and McLarney transferred to the Woods Hole Oceanographic Institution in 1970. Since early last year they have been working full time at the New Alchemy Institute.

One of the early design goals was to see if it would be possible to raise enough food to support a small group of people on a very limited area. For sufficiently rapid growth, it was necessary to consider tropical systems, which led the new alchemists to experiment with the hot environments created by geodesic domes and greenhouses.

Although these structures trap heat during the day, they lose it at night. Water, however, is an effective storer of heat, which suggested the idea of raising fish.

We brag of being a nation where food is relatively cheap and agriculture efficient, yet ignore the fact that most measures of food prices and farm efficiency fail to take into account the endangerment to such valuable resources as soil fertility, water, wildlife, public health and a viable rural economy. When we stop to consider the full impact of the agricultural tools that have replaced the people who crowded into the cities, it is clear that "modern" agriculture is causing more problems than it is solving. . . . In recent years, conventional science has come under increasing attack for the moral implications of its basic inquiries and the long term significance of its applied tools. There has been relatively little criticism of the agricultural sciences along these lines since the external costs of farming are just beginning to surface with a broad impact. —*Richard Merrill, in* The Journal of the New Alchemy Institute, *No. 2, 1975.*

Commercial aquaculturists nurture their fish with fishmeal, grains, and other foods that, as with feedlot cattle, could be fed directly to humans. To avoid such "agricultural imperialism," the new alchemists have tried to devise less wasteful means of production. Their contribution is not so much of no biocides, no high-energy requirements, and no technical solution where a biological one can be devised instead. Their contribution is not so much in terms of uniquely new ideas, though