Impending United States Energy Crisis

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The U.S. oil and gas industry has been dramatically weakened by the recent oil price collapse. Domestic drilling activity reached a new post–World War II low during the summer of 1986. Given a weak, unstable oil price outlook, U.S. capability will continue to deteriorate. In the last year U.S. imports of foreign oil have risen significantly, and if market forces alone dominate, U.S. dependence is expected to rise from 32% in 1983 to the 50 to 70% level in the not-too-distant future. The 1973 oil embargo and the subsequent attempts to improve U.S. energy security vividly demonstrated the huge costs and long periods of time required to change our energy system. These facts, coupled with the nation's generally short-term orientation, suggest a strong likelihood of a new U.S. energy crisis in the early to middle 1990s.

THE UNITED STATES IS LIKELY TO BE HEADED FOR ANOTHER major energy crisis for a number of reasons. These include (i) recent developments in the world oil markets, (ii) the resultant crippling of the U.S. petroleum industry, (iii) the continued existence of the Organization of Petroleum Exporting Countries (OPEC) cartel, (iv) instability in the Middle East, (v) the inherently long times necessary to change the U.S. and world energy systems, and (vi) the short-term orientation of the U.S. public, government, and industry. The background for this unfortunate situation is described below.

Developments in the World Oil Market

In July 1985 Saudi Arabia announced that it could no longer act as OPEC swing producer and that it would increase its oil production from about 2.2 million barrels of oil per day to its previously allotted quota of 4.35. This soon flooded the world oil market and caused the price of West Texas Intermediate crude to collapse from roughly $26 to $28 per barrel in December 1985 to a low of about $10.75 per barrel in July 1986. Concurrently, prices in the Persian Gulf sank to the $7 to $9 per barrel range.

The events that led to this dramatic change were roughly as follows. (i) The Arab oil embargo of 1973 and the Iranian oil crisis of 1979 triggered significant increases in oil prices (*1, 2*) and the expectation of further increases to come (Fig. 1). (ii) These events provided a major incentive for companies and countries to search for and produce more expensive oil, for example, in deep formations, in rugged terrain, in deep waters offshore, and in hostile arctic environments. But finding oil and developing new oil fields are time-consuming operations because of technical complexities and the need for a massive industrial infrastructure. The lag between planning and significant new production is, thus, on the order of 5 to 10 years. (iii) In the middle to late 1970s OPEC controlled the oil markets with a 60 to 70% market share in the noncommunist world. Accordingly, OPEC was able to set world oil prices. (iv) In the late 1970s, new non-OPEC oil began entering the world market, and the effects of conservation and more efficient energy use were beginning to noticeably lower demand patterns. (v) By 1982 market pressures forced OPEC to lower its benchmark oil price from $34 to $29 per barrel and set new production quotas for its members. (vi) Most OPEC members routinely exceeded their quotas and also provided modest price discounts. In the meantime, non-OPEC oil production continued to increase and the pressure on prices intensified. Saudi Arabia pressed its OPEC partners to exert greater production discipline while it voluntarily played the role of swing producer by reducing its own exports.

By the summer of 1985, the Saudi financial situation (*3*) had deteriorated significantly (Fig. 2). The Saudis attempted to pressure other OPEC members to return to their quotas to no avail. Therefore, to avoid a further deterioration of their finances, the Saudis simply increased their oil production to their quota causing the price collapse of 1986 (Fig. 1).

In addition to these events, three other relatively recent marketplace changes are worth noting because of their impacts to date and expected future influence. There are the emergence of a significant worldwide crude oil spot market, some shift from wellhead to destination (netback) pricing, and the development of a futures market in crude. These developments have diffused control of oil prices and built a commodity-like volatility into the oil marketplace. That new volatility has already had a negative impact on petroleum industry planning and financing.

The U.S. Energy Infrastructure

Prior to the 1973 oil crisis, energy supply was relatively low cost, well behaved, and so disaggregated that few people studied and understood it in its entirety. The 1973 oil crisis led to demands for government action, which were often not based on real understanding. In retrospect, many of those actions actually exaggerated the country's problems.

The experiences of the 1970s taught us much about our national energy system and yielded a number of important lessons. A useful summary of this subject was recently developed by the Energy Research Advisory Board (ERAB) of the U.S. Department of Energy and published in a report on future directions for DOE research and development (*4*). Portions of that report particularly relevant in this context are excerpted.

> The energy substructure of the United States is complex and massive. It includes such diverse suppliers as the oil-gas industry, the public utilities, small cogenerators of heat and electricity, wind-energy farmers, etc. It also includes a multitude of suppliers of energy-related equipment such as turbine-generators, nuclear reactors, air conditioners, water heaters, etc. It

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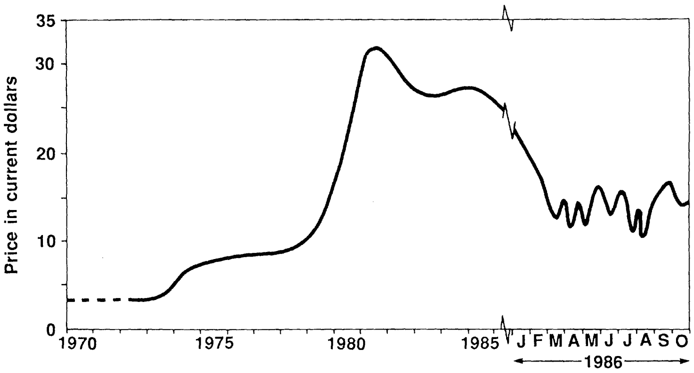
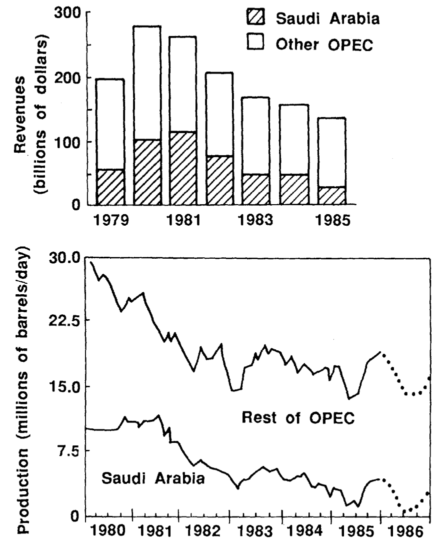


Fig. 1. World oil prices, 1970–1986 (*1–2*).

Fig. 2. Revenue and production trends for Saudi Arabia and OPEC (*3*).



involves a diverse number of demands as well, including transportation, buildings, and industry. There are also regulators at the local, state, and national levels. . . .

In the mid 1970s, when there was a rapid scale-up of federal energy research, many analysts and decision makers in Washington and elsewhere approached the energy problem as if the government had or could have dominant control over all aspects of the country's energy system and could thereby have rapid impact through expanded federal energy research. Experience proved that this was not realistic or desirable. . . .

The process of developing and implementing a new energy technology has been demonstrated to be extremely time-consuming, and therefore, there is a premium on the early development of options needed for the long-term future. A typical new high-technology supply technology may require 20 to 50 years to progress from concept through research and development to an economically and environmentally attractive demonstration. Nuclear power required over 20 years. Solar photovoltaic conversion has been under active development for roughly 20 years and is likely to require another 10 to 20 years before it is an economically competitive source of large scale electric power. Fusion energy, the most difficult technology development of all, has been in active research for about 30 years and is likely to require another 15 to 20 years.

Once a supply technology is commercially viable, three to five decades are required before the installation of the capacity necessary to produce a quad of energy annually.

End-use equipment often comes in smaller sizes than supply technologies, and therefore can often be developed more rapidly. However, many years are still required to install enough new end-use equipment to save a quad of energy annually.

A number of other important lessons have been learned in the last decade of heightened energy awareness and strife. Among the most important are the following:

- The marketplace determines energy technology winners and losers, and the energy marketplace is international.
- Government policies and regulations can skew the energy marketplace.
- Conservation and more efficient end-use technologies can be enormously important.
- Environment, safety, and health considerations can dominate technical and economic factors.
- Development of significant new energy technologies is very risky as well as extremely expensive.
- The U.S. oil production decline is real but it has been and can be mitigated by private industry efforts which are influenced by real market forces and government policies.
- Known oil and gas resources are slowly being depleted worldwide but very large resources of oil and gas remain. A hundred or more years of supply probably exists worldwide.
- Energy use and reserve predictions have been consistently inaccurate.
- Local energy costs impact industrial structure, that is, certain industries can be rendered more or less competitive in the U.S. and world economies depending on their energy costs.
- National energy security is a critical national goal; national energy independence is not essential and is probably not possible in the foreseeable future.
- Economies of scale do not always exist in energy technologies, that is, bigger is not always better.
- Public acceptance of energy technologies is critical to their effective utilization.

With respect to energy supply, the ERAB report made a number of important observations.

- Oil, natural gas, and coal dominate current energy supply (nearly 90% of primary energy supply in 1984) and are expected to continue to dominate supply beyond the year 2000. The energy supply and distribution system is huge and complex, and it cannot change quickly.
- The assured supply and distribution of liquid transportation fuels, electricity, and natural gas will continue to dominate supply issues for the foreseeable future.
- Oil is the major primary energy resource in which the U.S. is deficient in relationship to its usage. The major use for oil is transportation, which represents one-fourth of total U.S. energy use. Oil disruption remains the major concern in our energy supply.

It should thus be clear that our energy system has many components and dimensions. One sensitive sector is oil and gas production which is the focus in the rest of this article.

Oil and Gas Resources

Oil and gas exist underground at varying depths in microporous rocks, which are sealed above and on their sides to form a trap. The origin of these hydrocarbons is generally believed to be plant and animal life that was buried from millions to hundreds of millions of years ago and slowly transformed by pressure and temperature into oils of various qualities and gases such as methane, butane, propane, and carbon dioxide.

The term "reserves" is a measure of the amount of oil or gas that has been found and is available for economical production with the use of existing technology. This seemingly simple concept is, in fact, quite complicated. For example, when a new reservoir is discovered with the first well, very little information about the usually very complex areal character of the reservoir is known. It is only after relatively extensive drilling over time that the extent of the reserves can be estimated with any significant accuracy.

Production rates from known reservoirs are dependent on a number of factors such as reservoir pressure, rock type, and permeability, oil viscosity, extent of fracturing, number of wells, and well spacing. Operators can increase production over that which would naturally occur by such methods as fracturing the reservoir to open new channels for flow, pressuring up the reservoir by injecting water, and lowering oil viscosity with heat. These and other supplementary techniques are costly so the extent to which they are used depends on such factors as the economic condition of the owners, the outlook for the sale of the product, and perceptions of future prices.

The tremendous geological variability of different reservoirs means that production profiles can differ from field to field (5). For illustration purposes, representative production profiles for typical oil and gas reservoirs are shown in Fig. 3. Oil reservoirs can be developed to significant levels of production and maintained for quite a period of time, while gas reservoirs decline much more rapidly. On this basis, an oil reservoir with the seemingly large reserve level of a million barrels might produce only 200 to 400 barrels per day during its best years. Against a U.S. daily consumption of roughly 16 million barrels of oil per day, that is indeed only a modest contribution.

An important measure of the longevity of a particular reservoir is the ratio of remaining reserves to production (R/P). This number can be high early in the life of a new field or when production is well below maximum capabilities. Oil reservoirs usually maintain high R/P ratios for many years. Gas reservoirs have lower ratios, which is one reason why a cutback in drilling will hurt gas deliverability sooner than oil.

Against this background, it is useful to consider estimated worldwide oil reserves and national R/P ratios (6). From the data in Table 1, it is easy to understand why OPEC is in such a commanding position with respect to oil supply.

Upstream Operations

The U.S. oil and gas industry can be divided into an upstream sector, which is concerned with exploring for and producing oil and gas, and a downstream sector, which deals with transportation, refining, distribution, and marketing. The upstream sector has been hardest hit by the recent oil price collapse.

The 1985 U.S. upstream sector was a huge economic enterprise employing more than 600,000 people (7) with sales of well over $500 billion (8). Participants include a dozen major oil companies with 1985 net income of more than $15 billion (9), well over a thousand independent oil and gas explorers and producers, a multitude of oil field service companies, which provide seismic surveys, drilling, logging, fracturing, and so on, and a large array of suppliers of steel pipe, compressors, computers (including supercomputers), and oil field chemicals.

Table 1. World oil reserves and reserves to production ratio (6).

Country	Reserves (billions of barrels)	Ratio of reserves to production (barrels per barrels per year)
Saudi Arabia*	166.0	102
Kuwait*	63.9	189
Soviet Union	63.0	15
Iran*	51.0	64
Mexico	48.0	48
Iraq*	43.0	98
Abu Dhabi	30.4	
United States	27.7	9
Venezuela*	24.9	38
Libya*	21.3	54
China	19.1	23
Nigeria*	16.6	33
United Kingdom	13.2	14
Algeria*	9.2	39
Indonesia*	9.1	17
Norway	7.7	30
Canada	6.7	13
India	3.5	20
Egypt	3.5	12
Qatar*	3.3	

*OPEC members.

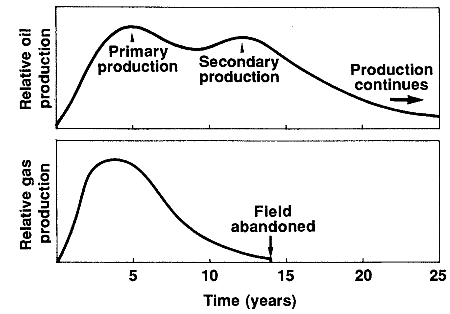


Fig. 3. Production profiles of typical oil and gas reservoirs whose production is not limited by market constraint or government regulation (5). Oil flows generated by natural geological pressures are called primary production. Secondary production results from supplementary actions, such as water injection into the reservoir.

The search for oil and gas is risky and costly. For instance, a "prospect" of a million barrels of reserves, which is considered to be relatively small "stakes," might cost several million dollars for people, land, geological and geophysical surveying, drilling, and testing. The likelihood of success, the so-called "chance factor," of such relatively modest endeavors might range typically from 10 to 40% depending on the geographic proximity of other production.

Higher stakes chance factors can range from 5 to 20%. The most famous, most expensive recent high stakes exploration failure was the 1984 Mukluk prospect in the Alaskan Beaufort Sea. At a cost of roughly $1.5 billion, no commercial oil or gas was found.

Although pre-drilling geological and geophysical techniques for finding oil and gas have become increasingly more sophisticated in recent years, they fall far short of providing a clear picture of the subsurface, including the existence of oil and gas resources. There is thus no substitute for drilling a well to confirm geological models and to establish the presence of hydrocarbons. On this basis, the number of drilling rigs in operation at any particular time, the so-called "rig-count," is an important measure of U.S. upstream activity.

There are different kinds of wells drilled in upstream operations. A development well is drilled to enable increased production from a known reservoir; it usually does not increase reserves unless a new reservoir is hit by accident. An extension exploration well is aimed at finding a new reservoir near an area of known production. Extension drilling can have a relatively high chance of success (30 to 60%). This is because of its proximity to known production, which usually results in a good understanding of the local geology, which is already established to be hydrocarbon-prone.

Finally, there is wildcat exploration drilling. It is done in areas where there is little or no subsurface information from previous wells. Wildcat exploration is the most risky. During the period 1960 through 1979, only 1 to 2% of U.S. wildcat wells yielded new fields of greater than 1 million barrels of oil or 6×10^9 cubic feet of gas. Ten to 16% of such wells yielded enough oil or gas to be brought into commercial operation, however (10). Thus, while rig count is a significant measure of industry activity, it is important to understand the types of holes being drilled. If most wells being drilled are development, then the national reserve base will soon be more rapidly decreased as the flow from these wells depletes reserves faster. When there is a significant amount of exploration drilling, the national reserve base will be supplemented.

Finding Costs

In exploration, one of the most important measures of a company's success is its so-called "finding cost." This is a difficult number to calculate because it must include costs integrated over a number

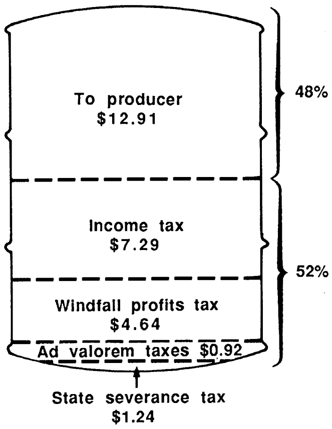


Fig. 4. Components of the wellhead price of Texas crude oil at $27 per barrel (*11*). These taxes are in addition to royalty payments to the landowner or the federal government.

of years for staff, land, seismic surveys, drilling, logging, research, previous exploration failures, and so on. These costs are then divided by the reserves discovered, which are usually not well known for three or more years after discovery, when the reservoir is defined by development drilling.

Before the recent price collapse, acceptable finding costs were on the order of $6 to $7 per barrel of reserves. This is because field development costs range from $5 to $10 per barrel, and oil prices were above about $25 per barrel. Although this might indicate the potential for large profits, it must be recognized that royalty payments of 12.5 to 25% must be paid "off the top," along with significant taxes (*11*), which leaves a much more modest net to the producer (Fig. 4). The 1986 tax reform law will not only add an estimated additional $10 billion burden to the domestic industry (*12*), it will reduce incentives for investment in the upstream by individual investors (*13*). With oil prices at $10 to $15 per barrel, it is easy to understand why domestic exploration was so drastically curtailed.

Even before the price collapse, a significant change was taking place in the U.S. oil and gas industry (*14*). This was the result of the fact that finding costs in the United States have been steadily rising in recent years, which is a consequence of the fact that the United States is the most heavily explored area in the world and most of the "easily discovered" resources have already been found. In 1985 the number of new oil and gas discoveries decreased more than 65% in comparison with 1984 (*15*).

Exploration results in the 1980 to 1985 period were generally discouraging for many companies, because finding costs were high and increasing. For this reason, a number of major oil companies were shifting toward greater emphasis on international exploration

Table 2. Recent petroleum company mergers of more than $1 billion (*16*).

Companies: Buyer	Companies: Seller	Year of sale	Purchase price (billions of dollars)
Chevron	Gulf	1984	13.2
Texaco	Getty	1985	10.1
DuPont	Conoco	1981	7.4
U.S. Steel	Marathon	1982	6.2
Mobil	Superior	1984	5.7
Royal Dutch Shell	U.S. Shell	1985	5.7
U.S. Steel	Texas Oil & Gas	1986	5.4
Occidental	Cities Service	1982	4.0
Coastal	American Natural Resources	1985	2.45
Diamond	Natomas	1983	1.4
Phillips	Aminoil	1984	1.3
Phillips	General American	1983	1.14
Total			63.99

and production. In addition, many independents were also not achieving satisfactory financial results and were simply reducing their exploration programs or going out of business. All this was quietly occurring before the recent price collapse.

Recent Changes in the U.S. Petroleum Industry

Prior to the 1986 oil price collapse, oil price deterioration had resulted in poorer earnings for many companies, which in part led to lower stock market prices for those companies. To some this meant that it was "cheaper to explore for oil on Wall Street" (*16*), with the result that a number of small companies were acquired by larger ones (Table 2). In all such recent transactions, roughly $70 billion changed hands, but none of those expenditures led to the addition of any new reserves for the country.

Next, there was the spate of corporate "raids" wherein outside investors attempted to take control of some of the major oil companies through leveraged buy outs. To defend themselves from takeover, the target companies took steps that dramatically increased their debt. This added financial burden dramatically weakened the companies involved, and one result was a greatly reduced ability to explore for new oil and gas.

The oil price collapse of 1986 caused successive waves of casualties in upstream activities, reductions in employees, and increased bankruptcies and foreclosures. The Petroleum Equipment Suppliers Association reported in May that its members' work force was less than half the 1982 level and dropping each week (*17*).

At first, many industry executives did not believe that the collapse would be long-lived. They, therefore tended to continue operations at previous levels. As the depth and probable length of the collapse became clearer, more dramatic cuts in budgets and people were required to maintain reasonable balance sheets for the year or simply to avoid bankruptcy.

Oil Price Outlook

Today industry leaders generally expect a long period of relatively low oil prices and significant price instability. The OPEC production agreements of August and December 1986 temporarily caused oil prices to firm but were considered very frail. First, they required voluntary constraints on production by OPEC members and many non-OPEC producers. In the past, cheating was rampant, so that quota adherence was far from a certainty. Violations and charges of violations of the August agreement were almost immediately cited against Venezuela, Gabon, Ecuador, and the United Arab Emirates (*18*). Second, the Iran-Iraq war has resulted in reduced production from these two countries. If that 6-year-long war were to end soon, it is possible that the world oil market could again be flooded as those counties or the victor strive for income to rebuild war-related losses. Third, OPEC discussions on extension of the August agreement indicated great discord and strong differences of opinion (*19*), which continued to fuel the uncertainty.

Against this background, projections of future oil prices are difficult to make but are needed for planning purposes. General expectations are for oil prices in the $15 to $20 per barrel (1986 dollars) for 3 to 5 years followed by gradual increases to $25 per barrel in the mid-1990s and maybe $30 per barrel by the year 2000 (*20*). In addition, the possibility of one or more future collapses in prices is a real threat. Any new price drops could ruin many companies and banks, which were greatly weakened by the events of 1986.

On this basis, industry upstream activities have been dramatically curtailed. As of July 1986, the major companies had reduced their capital budgets by almost 40% and a survey of 115 independents indicated a nearly 50% cutback (*21*). Further reductions are expected. Seismic exploration activity, a precursor to drilling, has sunk to the lowest levels since the mid-1930s (*22*). United States rig count (*23*) dropped dramatically (Fig. 5). This simple statistic masks the fact that much of the recent drilling is for field development and not for exploration.

Because of low prices and large uncertainties, low levels of drilling are expected to continue for years. At this rate, U.S. oil and gas reserves will decline further and domestic production will deteriorate significantly with time. Because the status and outlook for most U.S. reservoirs are poorly defined and not centrally reported, no one knows for sure exactly how fast the decline will occur.

The lower price of oil has caused a significant increase in U.S. oil consumption. This is in part due to greater use by traditional oil users and in part due to switching by gas consumers to oil in equipment with dual fuel capability. From late September 1985 to the same period in 1986, U.S. oil usage is up roughly 6% (*24*) after years of relatively flat consumption while U.S. oil imports were up 43% versus a year earlier (*25*). As of mid-1986, U.S. oil production had dropped about 3%. The integrated effect is a 40% U.S. dependence on imported oil in June (*24*) as opposed to about 32% in 1982 and 1983 and 35% in 1973 (*26*).

Good statistics on cutbacks, bankruptcies and other losses in U.S. oil and gas production capabilities are not easy to come by, but the reductions are extensive (*27*). The American Association of Petroleum Geologists reported a 25% jobless rate among its members in October, the worst since the depression of the early 1930s (*28*). All the major oil companies have cut their upstream research personnel, and many have refocused to short-term research and technical services. Universities offering degrees in oil field professions report major drops in enrollment, which in 1985 were already down to 50% of their 1982 peaks (*29*). Almost all companies reported drastic drops in profits or increasing losses in their upstream activities in each quarter of 1986.

The U.S. oil and gas reserves have and will continue to drop as long as low prices and market instability continue. This will mean that domestic production will decline, resulting in an ever-increasing dependence on foreign oil. In addition, the decrease in U.S. upstream capabilities and related professionals will mean that a revival of U.S. exploration, be it because of a more healthy marketplace or government action, will require years to restart and years more to yield significant results. The long period required to crank up industry activity after the 1973 crisis vividly demonstrates this fact (Fig. 5). A doubling of the 1973 drilling level required more than 6 years, in spite of large financial incentives and large pressures from the government and the public.

Remaining U.S. Oil and Gas Resources

It is certainly reasonable to ask whether the U.S. oil and gas production decline can be abated or production increased, or both, given proper incentives. The answer that oil people will give is very much in the affirmative, but price levels and price stability will dramatically affect what is possible.

Opportunities exist in the following: (i) remaining oil and gas in undiscovered structural traps, reservoirs that are generally formed by deformations in the subsurface, (ii) resources in areas heretofore withheld by federal and state governments, (iii) oil and gas in stratigraphic traps, reservoirs that are subtle in character and more difficult to find than structural traps; (iv) heavy oil; (v) enhanced oil recovery from known reservoirs that have been through primary and secondary production; and (vi) gas in tight sands, in deep formations, and remote locations.

Table 3. Estimated remaining recoverable U.S. oil and gas resources (*30–34*). Estimates involve sometimes differing assumptions on oil and gas prices. Higher prices lead to higher reserve estimates.

Resource	Oil (billions of barrels)	Gas (trillion cubic feet)
Undiscovered in structural traps (*30*)	26	156
Undiscovered in stratigraphic traps (*30*)	40	360
Undiscovered in land now unavailable (*31*)	29	195
Heavy oil (*32*)	10	
Enhanced oil recovery (*33*)	7–110	
Tight gas (*34*)		192–574
Totals	100–200	900–1300

There are a number of estimates of the extent of these resources. Many suffer from our incomplete understanding of the details of U.S. geology. Many are very sensitive to price. Some assume existing technology. Still others require new technology, and most would greatly benefit from improved technology.

Various estimates of potential U.S. reserves from these sources (*30–34*) are indicated in Table 3. Depending on when they are developed, production from these sources could reach many millions of barrels per day and could provide all U.S. gas needs for many decades. This would dramatically benefit U.S. energy security and would allow for an orderly transition to alternate energy technologies in the early to middle 21st century.

The National Dilemma

The oil price collapse is clearly good news for some and bad for others. Consumers of energy have benefited by lower costs and gained from having more disposable income for nonenergy uses. The U.S. balance of payments has benefited from lower oil import costs. Some people in Washington initially hailed lower energy prices as a national windfall that would stimulate the economy. This turned out to be difficult to track in part because oil industry upstream operations are so extensive that the ripple effects of the depression in the oil industry went further and deeper than expected.

In the longer term the United States as a whole will be hurt by the collapse because the national dependence on foreign oil will escalate significantly. The 43% increase in imported oil between September 1985 and September 1986 is certainly notable. Various projections

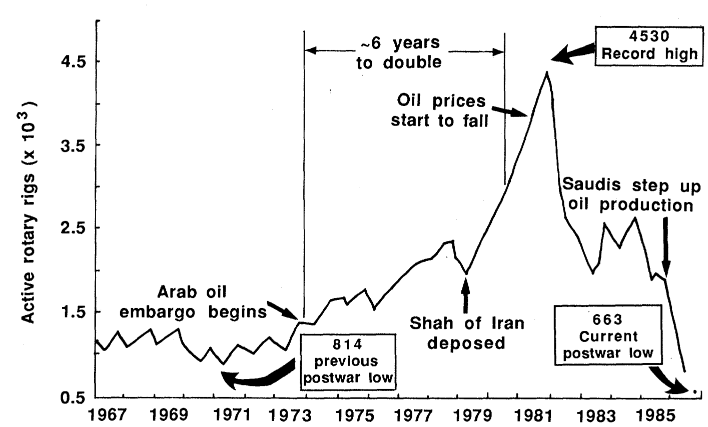


Fig. 5. U.S. rig count since 1967 (*23*).

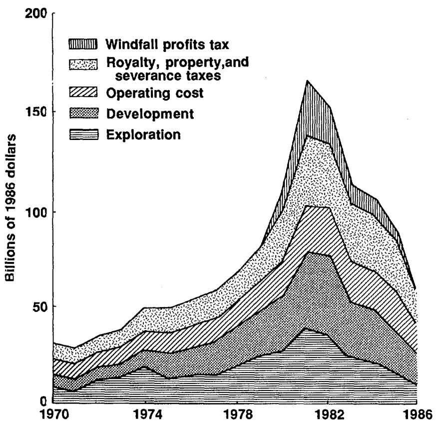


Fig. 6. U.S. exploration, development, and production expenditures from 1970 to the present (*39*).

indicate 50% dependence within a few years, and some project 60 to 70% dependence by the year 2000 (*35*).

As worldwide oil production comes into closer balance with demand, OPEC will regain market control and be able to force up prices, which will significantly affect the U.S. balance of payments for a long period of time. Also, lurking in the background will be the threat of a major disruption in oil supply, which would be even more damaging than the 1973 crisis because of the higher national dependence on foreign oil. Finally, high dependence on OPEC oil would significantly affect U.S. foreign policy flexibility (*36*) and increase the likelihood of war in the Middle East, a possibility that has already led to establishment of a billion-dollar U.S. logistical network in that region (*37*).

What is needed is an adequate level of national energy security. According to DOE (*38*, p. 2), "Energy security means that adequate supplies of energy at reasonable cost are physically available to U.S. consumers from both domestic and foreign sources. It means that the nation is less vulnerable to disruptions in energy supply and that it is better prepared to handle them if they should occur." This definition does not lend itself to quantification so that there is no defined level of imports above which the United States is insecure. National energy security is thus somewhat like military security: there never seems to be a good way to define the line between strength and weakness until a showdown materializes.

The United States could minimize the longer term negative impacts of the oil price collapse through a variety of options. All seem to involve action by the federal government, which has in the past not performed well in such matters and which is under significant pressure from energy consumers to not do anything that would raise their energy costs. Nevertheless, without the proper financial incentives, the U.S. petroleum industry cannot muster the $50 to $100 billion per year (*39*) needed to maintain current U.S. production, let alone increase it (Fig. 6). This is because these companies are owned by their stockholders who demand a reasonable level of financial performance, which prohibits companies from taking undue risks or very heavily investing in the future. There are several options for effective national action.

An oil import fee would raise domestic oil prices above world levels. This could help stabilize the U.S. petroleum industry and spark some renewed exploration. However, as noted earlier, at $25 to $27 per barrel, U.S. exploration interest was waning before the recent price collapse. On that basis, still higher U.S. prices would likely be needed to decrease significantly our dependence on foreign oil from its current levels. On the one hand, a tariff that raised prices into the $30 per barrel range would be unpopular, but on the other hand, it could help to reduce significantly federal deficits: $10 per barrel fee at current import levels could add about $30 billion per year to the federal coffers.

An import fee could be levied by Congress or the president under executive order. In preliminary discussions in Congress, the pressures for exceptions to an import fee have already proven to be significant, even before serious legislative consideration. The result of usual compromises could be a law with so many complications and exceptions that it could not only spawn huge costs to implement, but it could render a fee ultimately ineffective. An exemption-free tax might conceivably be possible through an executive order of the president as an alternative.

An oil import quota controlled by a government board could act to increase domestic energy prices without the legislative hassle of deciding on a per-barrel fee and exemptions. From 1959 to 1972, the United States had an import quota system in place and before 1972, the Texas Railroad Commission limited oil and gas production in Texas through quota allocations. The other benefits and debits of higher oil prices would also accrue under an import quota.

Tax incentives for domestic exploration and production could stimulate the domestic energy industry. The public would not feel the added costs directly in higher energy prices, but it would feel them indirectly in the form of the negatives associated with higher federal outlays and deficits.

Switching off of oil and gas dependency is an appealing concept and was a major national thrust in the middle to late 1970s. While eventually the U.S. must "phase over," a rapid switch has enormous complications as detailed in the ERAB report cited earlier (*4*). Solar energy has proven to be inherently very expensive in most instances and cannot readily supply the liquid and gaseous fuels needed for much existing equipment. Synthetic fuels were given a major research and development push and were also found to be extremely expensive. Nuclear power development is essentially dead in the United States because of overregulation and public fears. Coal remains a viable option for many applications, though it carries significant but manageable environmental costs. Fusion power is still far from ready for practical application. Finally, most of the easy conservation has been implemented, and although more is both possible and desirable, it is likely to be expensive and time-consuming to implement. Note, however, that because of lower prices, energy usage is already climbing; the government has relaxed automobile makers fleet average mileage requirements, and upward revision of the 55-mile-per-hour national speed limit is under serious consideration. In fact, the country seems to have lost a part of its conservation ethic.

It is clear that there are a number of options that could stop the current slide into extreme national dependence on foreign oil. However, because none are simple, because people are generally happy with lower energy prices, and because the country tends to be short-term oriented, there appears to be a low probability of action before the problem becomes severe. It is for these reasons that a future national energy crisis seems likely, probably sometime in the early to mid-1990s, when U.S. oil dependence is above 50% and OPEC has regained control of world oil markets.

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Chemical Reactions on Clays

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Layer aluminosilicates catalyze reactions in numerous ways. They stabilize high-energy intermediates. They can store energy in their lattice structures and can release it in the form of chemical energy. They can catalyze redox reactions and can serve as photocatalytic devices. They often exhibit high surface acidity. Organic reactions that are catalyzed by the agency of clays are reviewed. The role of clays in prebiotic chemistry is also examined.

The synthetic chemist rarely borrows accessories for the laboratory from the vast stockroom of nature. We resist scooping some dust into a reaction flask. Yet elegant chemistry can be performed if clays are used as supports or catalysts. The design of intercalated clay catalysts has been reviewed recently (*1*). Clays, long used as catalysts for cracking hydrocarbons, are also crucial to soil chemistry (*2*). Clay-related chemistry has burgeoned in recent years. This article will document some of the applications of acidic clays to carbocationic reactions and condensations, of clay surfaces to cycloadditions and rearrangements and to redox reactions; and it will consider the possible involvement of clays in biogenesis.

The Structure of Clays

Examination with a microscope shows that clay particles are organized, often into parallel plates stacked one upon another: kaolinite, for example, displays hexagonal flakes. Dehydrated clays, such as potter's clay, can reabsorb water. The class of clay minerals known as smectites share this property. Water molecules insert between the stacked plates. These planar arrays gain lateral mobility in hydrated clays, accounting for the plasticity of these materials.

The distance between these layers, or the basal distance, is revealed by x-ray diffraction. For smectites, this basal distance varies from about 10 Å in totally dehydrated clays, collapsed to such an extent that adjacent layers come into van der Waals contact, to as much as 20 to 50 Å, depending upon the number of intercalated water layers within the gap (known as the interstitial or the interlamellar space).

The primary structure of a smectite is lamellar, with parallel layers of tetrahedral silicate and of octahedral aluminate sheets. The secondary structure, that is, the constitution of the clay, stems from the valence deficiencies that occur in a not altogether random manner (if one considers the whole family of clay minerals). For example, Al(III) or Fe(II) can replace Si(IV) in the tetrahedral layer. The tertiary structure is a consequence of the secondary structure. This is a result of the effect of interstitial cations (such as Na^+, K^+, and Ca^{2+}, . . .) that are trapped as freely moving ions between the negatively charged planes.

Clays are aluminosilicates. The aluminum(III) cations are bonded to an octahedral arrangement of oxygen anions. Repetition of these AlO_6 units in two dimensions forms an octahedral layer. Likewise, a tetrahedral layer is formed from SiO_4 silicate units.

Clays are classified (*3*) according to the relative number of tetrahedral and octahedral layers. Montmorillonite clays, which have been used in organic chemical applications, have an octahedral layer sandwiched between two tetrahedral layers. The basal distance is

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