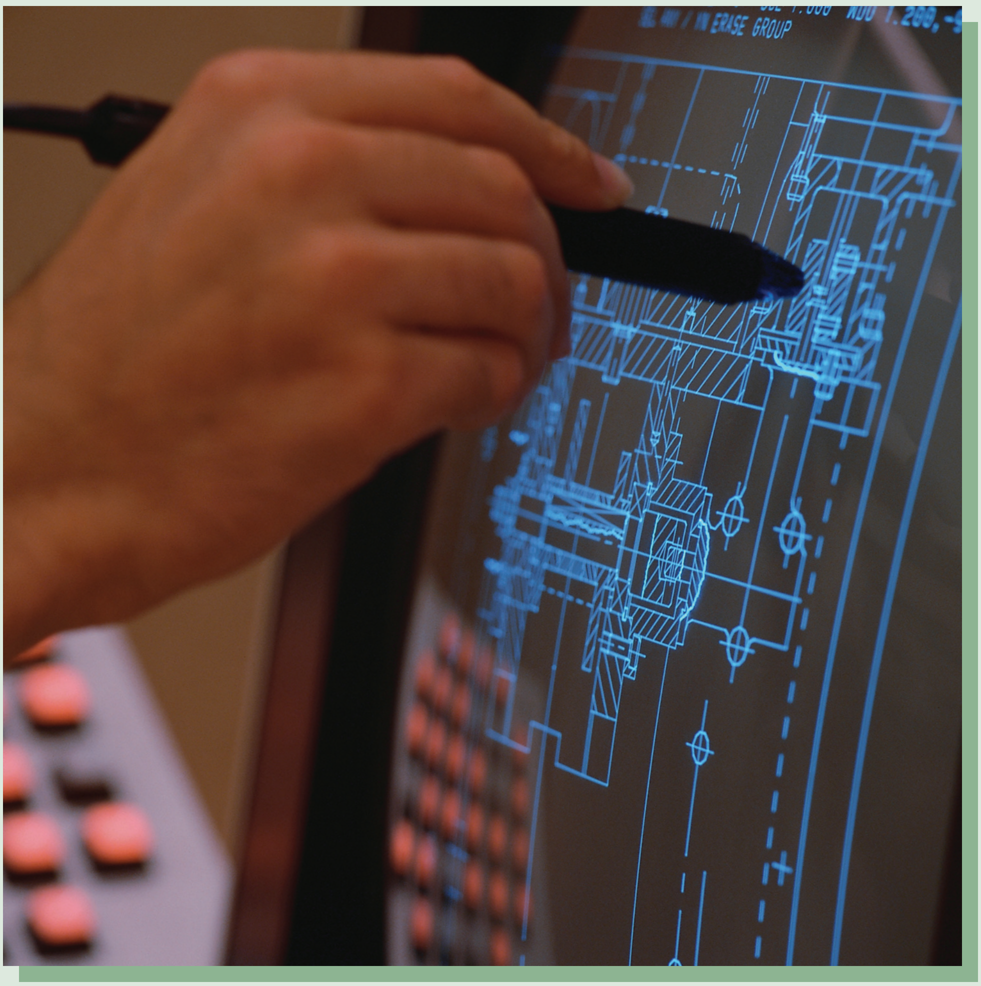
Efficiency—Technical and Economic



CHAPTER

3

First and Second Laws of Thermodynamics

Energy cannot be perfectly converted into useful work. Friction, vibration, and heat loss result in energy leakage. But even a frictionless heat engine perfectly insulated against heat loss would still be unable to transform all its energy input into work.

The First and Second Laws of Thermodynamics[78] explain why this is so. There are some complex mathematics behind each of these laws, but they can be roughly summarized as follows:

The First Law	Energy is conserved—it can neither be created nor destroyed. That is, energy input must equal the total energy output; the input must equal the sum of useful work produced, friction loss, heat loss, etc.
	Energy can be transformed from one form to another (i.e., potential to kinetic or kinetic to potential) any number of times. During each such transformation, some energy may be lost into the environment, but the converted energy plus the energy lost must equal the original amount of energy in the system. The total energy in the system remains the same.
The Second Law	Energy flows "downhill." Objects fall down, not up; heat flows from hot objects to cold; and fluids and gases flow from high pressure to low.

[78]As its name implies, *thermodynamics* is the study of heat in motion.

Machines need *energy differentials* in order to work. Engines must operate between high and low temperature *reservoirs*, high and low pressure zones, or high and low *electric voltages*.

When energy flows downhill, the system's total energy differential is reduced. Energy becomes more evenly distributed and less available to perform useful work. Imagine, for example, a waterfall that pours into the ocean. Suppose that the falling water is used to turn a waterwheel and produce work. When the water reaches the ocean, it still has potential energy because it is above the center of the Earth. Yet, this energy cannot be exploited because there is no lower elevation to which the water can flow.

We can use machines to reverse the direction in which energy naturally flows. Pumps push water uphill, refrigerators force heat to flow from cold to hot, and compressors drive gases from low to high pressure. However, the system's *overall* energy differential must be reduced even when a machine is used to reverse the natural flow.

A system's *entropy* can be thought of as a measure of the evenness of its energy distribution. The higher a system's entropy, the less available is its energy to do work or to drive machinery. During any energy conversion, the entropy of the entire system must increase. While expending energy can bring order to a subsystem, the disorder of the total system must increase.

Given the Second Law, it is often asked how the Earth has become more ordered (with, for example, the appearance of ever more complex life forms). The answer is that the Earth is not a closed system. While the entropy of the universe (the total system) is always increasing, there is a constant and tremendous flow of energy from the sun to the Earth (a subsystem).

According to Isaac Asimov, "The Earth receives only one-half of one-billionth of the sun's radiant energy. But in just a few days it gets as much heat and light as could be produced by burning all the oil, coal, and wood on the planet."[79]

Because energy can be transformed but not destroyed (the First Law) the Universe will never run out of energy. However, the Second Law dictates that eventually the energy will no longer be usable. That point would come when the Universe is at a completely

[79]Isaac Asimov, *Isaac Asimov's Book of Facts* (New York: Wings Books, 1979), p. 108.

uniform state and there are no longer any energy differentials. With no differentials, no useful work can be done and all life must end.

Ultimately, Thomas Malthus and his gloomy predictions may be correct—we are all doomed. However, the Universe's death by entropy, if it occurs, is many billions of years in the future, so his last laugh will be a long time in coming.

On the other hand, entropy may ultimately be conquered by gravity—the attractive force between matter. If the mass of the Universe is sufficient, gravity will cause it to collapse back to a single point, and another Big Bang could start the whole thing all over again. The Universe may alternately expand and collapse indefinitely and may have already done so countless times.

EFFICIENCY

Most of the energy that goes into producing electricity is lost. Say that a utility company's power plant runs on coal. The coal is burned to boil water and produce steam that, in turn, drives a turbine. The turbine runs a generator, and the generator produces electricity. At each step, energy is lost.

When the coal is burned, some of the heat that is produced escapes up the smokestack along with the hot gases that are formed. At the next stage, less than half of the steam's energy is actually used in driving the turbine. Most is lost to the atmosphere when the spent steam leaves the turbine.

Next, because of heat and friction losses, the generator is unable to convert all of the turbine's kinetic energy into electricity. Then there are power losses in the transmission lines that carry the electricity.

Finally, when the electricity is used, there are still more energy losses because appliances are unable to convert all of their power input into useful work. Throughout this entire process, most of the energy originally stored in the coal is lost. Only a small fraction of it actually goes for productive work.

The *efficiency* of a given machine is defined as the ratio between the usable work that comes out of the machine to the energy that went in. Many things can be done to improve efficiency. For example, insulation can be added to slow heat loss, and lubricants can reduce friction. But, again, no machine can be made to be perfectly efficient. The following chart shows some typical efficiencies of various devices.

From the next table, it can be seen that only about 25 percent of the energy in a gallon of gasoline is actually used to move a car, while the other 75 percent is lost. Or, take the example of the power plant mentioned above. If the boiler has an efficiency of 85 percent, the steam turbine 45 percent, and the generator 95 percent, then the efficiency of the overall system is $0.85 \times 0.45 \times 0.95$ or about 36 percent. If that electricity is used to turn on a light bulb, then the overall efficiency of converting coal into light is approximately 0.36×0.05, or less than 2 percent!

While an electric heater is able to turn all of its power input into heat, a gas furnace is still more efficient if the entire system (from power generation

Energy Conversion Device	Energy Conversion	Efficiency (%)
Electric heater	Electricity/Thermal	100
Electric generator	Mechanical/Electrical	95
Electric motor (large)	Electricity/Mechanical	90
Battery (dry cell)	Chemical/Electrical	90
Steam boiler (power plant)	Chemical/Thermal	85
Home gas furnace	Chemical/Thermal	85
Home oil furnace	Chemical/Thermal	65
Electric motor (small)	Electrical/Mechanical	65
Natural gas combined cycle	Chemical/Mechanical	60
Home coal furnace	Chemical/Thermal	55
Steam turbine	Thermal/Mechanical	45
Diesel engine[80]	Chemical/Mechanical	43
Gas turbine (aircraft)	Chemical/Mechanical	35
Gas turbine (industrial)	Chemical/Mechanical	30
Automobile engine	Chemical/Mechanical	25
Fluorescent lamp	Electrical/Light	20
Human[81]	Chemical/Mechanical	18
Silicon solar cell	Solar/Electrical	15
Steam locomotive	Chemical/Mechanical	10
Horse[82]	Chemical/Mechanical	10
Incandescent light (light bulb)	Electrical/Light	5

Source: Pennsylvania State University's Earth and Mineral Sciences web site: www.ems.psu.edu/~radovic/fundamentals4.html, unless otherwise noted.

to consumption) is considered. Remember that the power plant's efficiency is only about 36 percent. Because the electric heater's efficiency is nearly 100 percent, the efficiency of the overall "power plant/heater" system is 0.36 × 1.00 or 36 percent. That is still much less than a gas furnace's efficiency of 85 percent.

In other words, it is far more efficient to burn natural gas in a house to produce heat than to burn it at a power plant in order to produce electricity that will later be converted into heat at the house.

Energy Economics

Throughout this chapter, the relative costs of the various methods of converting energy into useful work have been emphasized. Some believe that the most environmentally benign technologies should always be adopted regardless of

[80] Robert Brady, "Diesel Cycle Engines" in John Zumerchik, ed., *Macmillan Encyclopedia of Energy* (New York: Macmillan Reference, 2001), p. 333.

[81] J. R. McNeill, *Something New Under the Sun*, p. 11.

[82] Ibid.

cost. This view fails to recognize that the cost of producing something reflects, to some degree, the effort, resources, and pollution that were spent to make it.

> *"Economics is the study of how individuals transform natural resources into final products and services that people can use."*[83]
>
> **Mark Skousen**

Market prices make it possible to keep score—that is, they enable us to compare the relative value of different resources and decide whether a given action is worthwhile. For example, if the efforts of an oil producer are to be of any use, they must produce more energy in the form of oil than is expended in order to recover and refine that oil. The activity must, in effect, make an energy profit. But how can a producer know whether a net profit is being made?

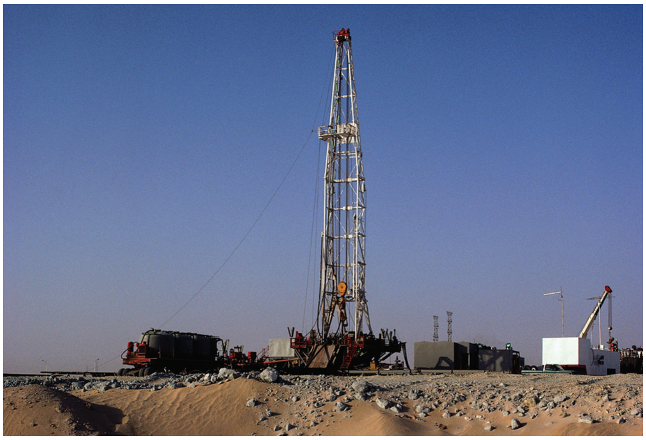
Suppose an oil company discovers a well that it estimates will produce 100 barrels of oil a day. Should the company produce the oil or cap the well? To decide, it could perform an energy balance comparing the number of BTUs contained in the oil against the energy needed to produce and process it. Unfortunately, doing this calculation would be nearly impossible. The company would have to determine the energy required to mine iron ore, transform it into steel, shape the steel into pumps, pipes, valves, and bolts. It would also have to know the energy used to transport this equipment to the well site and install it. Similarly, the energy needed to create, transport, and install all the other materials used would have to be calculated along with that consumed by the laborers and their families while the work is under way.

Even if the company somehow determines that producing the well would result in a net energy gain, what then? Should all 100 barrels a day be produced? The energy balance does not indicate consumer demand. If we only need 50 barrels worth of energy a day, will pumping all 100 barrels leave us twice as well off or just leave us with a storage problem?

An energy balance has another shortcoming. The only reason we could even consider determining profit or loss by comparing energy expended against energy produced is that energy appears on both sides of the equation. It would be reasonable, for example, to invest 50 BTUs in order to recover 100 BTUs worth of oil. But how much energy should be expended to produce a pound of copper?

In a free market, *prices tend, over time, to reflect the costs of producing a commodity*. The oil producer does not need to know how much energy it takes to build a pump; he needs to know only the pump's price. Included in this price are the pump manufacturer's costs for overhead, labor, materials, and energy.

[83] Mark Skousen, *Economics on Trial*, p. 18.



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Knowing the price of the equipment, the cost of its transportation and installation, and the price that consumers are willing to pay for his products, the producer can calculate the monetary profit that he would receive by recovering the oil.

As long as they make a monetary profit, then, producers can be reasonably sure that they are also making a net energy profit.[84]

Market Pricing

In addition to production costs, market prices also reflect demand. If a cold spell in one area of the country increases demand for heating oil, its price will rise, and producers will send more oil there to maximize their profits. As prices drop due to increased supply, oil will be shifted to other markets.

Prices also allow the relative values of different goods to be compared at any moment. This is critical information since at any given time resources are limited. Relative prices tell manufacturers what people value most and therefore what they should use their resources to make. Producers that supply the public with the goods they want at prices they are willing to pay will

[84]Viewed in this light, profits perform an essential social service. They provide a signal that indicates whether resources are being efficiently used to provide for consumer needs and desires. Companies that employ the fewest resources to best satisfy customers will make profits. Their success will attract both investors and imitators. Those that provide the least amount of satisfaction at the highest cost will lose money, and either go out of business or change their ways.

make profits. Thus, the market automatically directs more resources to those producers that best meet consumers' needs.

> The phrase, "the market," does not refer to some vast, impersonal, institution that controls individuals and corporations. It refers instead to the continuous exchange of goods, services, and ideas by millions of individuals—some acting on their own behalf and others on the behalf of companies and institutions. These countless actions make up the market. In a *free* market, people communicate, buy, sell, trade, and otherwise interact without third-party coercion (i.e., use or threat of force).

Oil refineries provide a good example of how price drives production. A refinery can turn a barrel of oil into a number of products, including gasoline, diesel, heating oil, lubricants, and feedstock for plastics. By adjusting the refining processes, production can be shifted to make more of one product and less of another. Refiners continually monitor the market prices of the products they make so that they can adjust their output in response to shifts in consumer demand. By so doing, they satisfy their customers and maximize their profits.

A government-run refining monopoly, by contrast, would be driven by politics rather than by consumer demand (as indicated by market price). If, for instance, the farm lobby is particularly powerful, the directors of a government-run facility would hesitate to offend that lobby by shifting production away from the diesel needed by farm equipment and towards another product like gasoline.

THE BIG PICTURE

One of the powers of the free market pricing system is that it incorporates the big picture into local decision making. For example, recycling is typically presented as inherently good—something so obviously beneficial as to be beyond question. But recycling not only saves resources, it also *costs* resources. Recycling plants must be constructed. Used materials must be separated, collected, transported to the plants, and processed. If recycling a ton of paper costs more resources and produces more pollution than it saves, why do it? Without a free-market pricing system, the environmental impact of recycling cannot be determined.

If local energy efficiencies were the only thing that mattered, we would tear down and replace the country's power plants every time more efficient technology became available. While this would ensure that our power plants would always convert energy resources into electricity as efficiently as possible, overall, resources would be wasted.

Economist F. A. Hayek described the price system as "a mechanism for communicating information" whereby dispersed and fragmented bits of information are brought together into a rational whole. "The whole acts as one market, not because any of its members survey the whole field, but because their limited individual fields of vision sufficiently overlap [through relative prices] so that through many intermediaries the relevant information is communicated to all."[85]

A classic example is the creation of the American transcontinental railway in the 1860s. While it was being built, there was continuous debate between the engineers and the financiers. The engineers wanted to use the best construction techniques and the most durable building materials available. The financiers, on the other hand, were deeply in debt and wanted the railroad built as quickly as possible so that it could start generating income. In the end, the financiers won. As a result, much of the railroad's infrastructure had to be rebuilt within a few years of its construction. Railroad ties made from green timber and bridges built of wood rather than stone all had to be replaced.

A tragic waste? Perhaps not. Consider how many resources were saved by the railroad's existence. Goods no longer had to travel by ox cart or by ship around South America. Travel times were cut from months to mere days. Moreover, once the railroad was in place, the construction materials and workers needed to rebuild the railroad could be transported much more quickly and efficiently than before. In all likelihood, completing the railroad sooner rather than later saved far more resources than it wasted.[86]

It may well be, then, that the trade-off between *economic efficiency* and *resource efficiency*, is not a trade-off at all. If a sufficiently encompassing resource balance is made, conserving money should translate into conserving resources. This should not be surprising as money is used to purchase resources either directly (goods) or indirectly (services). While price distortions could sever the relationship between money and resources, such distortions are typically the result of government interference with the marketplace (e.g., currency inflation, or price controls).

William Stanley Jevons founded the study of energy economics with his 1865 book, *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines*. Jevons warned that England's coal boom was coming to an end, and her industry would migrate abroad (to America in particular) where energy supplies were more plentiful. The ensuing "coal panic" caused Parliament to consider retiring the national debt to help the country weather the expected energy crisis.

[85] F. A. Hayek, "The Use of Knowledge in Society," *Individualism and Economic Order* (Chicago: Henry Regnery, 1948), p. 86.

[86] For more on the building of the transcontinental railroad, refer to Stephen Ambrose, *Nothing Like it in the World* (New York: Simon and Schuster, 2000).

But the coal famine did not come. Improvements in mining technology kept costs steady. Oil and, later, natural gas came into the picture, two energy substitutes that Jevons scarcely considered.

To his credit, he understood the *economic challenge* as "the gradual deepening of our coal mines and the increased price of fuel," not that "our coal seams will be found emptied to the bottom, and swept clean like a coal-cellar."[87] Supply would not run out, it would just become more expensive.

Could renewable energies fuel England's industrialization? Jevons was pessimistic. "The wind," he argued, "is wholly inapplicable to a system of machine labour, for during a calm season the whole business of the country would be thrown out of gear."[88] Regarding waterpower, "In very few places do we find water power free from occasional failure by drought."[89] What about burning wood? "We cannot revert to timber fuel," he stated, for "nearly the entire surface of our island would be required to grow timber sufficient for the consumption of the iron manufacture alone."[90] Geothermal? "The internal heat of the earth . . . presents an immense store of force, but, being manifested only in the hot-spring, the volcano, or the warm mine, it is evidently not available."[91]

Nearly a century-and-a-half later, Jevons' concerns remain relevant to the energy sustainability debate. Intermittency, variability, and (un)availability are still obstacles to a significantly increased role for renewable energies in today's economy.

INSTITUTIONS AND ENERGY

Industry requires land, labor, and capital.[92] But these are not enough. Indeed, most third world countries possess all these physical ingredients of thriving industries. What they lack are the institutions that give life to markets. Property rights and the rule of law provide the framework that allows people to turn dead material into the stuff of life. We in the West are so accustomed to these institutions that we no longer see them—they are like the air we breathe. Yet without them our civilization and perhaps even our technology would be impossible.

Property rights are a precondition for trade; one cannot sell that which one does not own. The concept of ownership, then, is fundamental to markets. Nearly as important is the ability to identify a thing's owner. A would-be purchaser of an object must be able to establish that he or she is, in fact, dealing

[87]William Stanley Jevons, *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines*, introduction to the second edition, Macmillan, 1866, reprinted in A. W. Flux, ed., *The Coal Question* (London: Macmillan, 1906), p. xxix.

[88]Ibid., first edition, 1865, p. 122.

[89]Ibid., p. 129.

[90]Ibid., p. 140.

[91]Ibid., p. 120.

[92]Economists define "capital" as physical assets such as natural resources, factories, ships, trucks, or roads.

with the object's owner. Such proof is provided by deeds and bills of sale recognized under the rule of law. Such pieces of paper are abstract or symbolic representations of physical things. Often when a thing, such as a plot of land or a building, is bought and sold, it is only this paper representation that actually changes hands. People in a society recognize that ownership has been transferred through such representational means in accordance with the laws of the land.

Abstract representations of physical objects do far more than just enable them to be bought and sold. They provide a sort of institutional trust that allows buyers and sellers to trade with the confidence that the terms of their agreement will be fulfilled, and, if necessary, enforced. Your home address, for example, is nothing more than a symbolic representation of an actual place, yet it provides a means of locating and identifying your residence. It establishes a point of contact and allows you to receive merchandise, services, and invoices for them at your home. Utility companies can find your house in order to deliver electricity, phone service, water, and gas, and be assured of receiving payment in return.

Documented property can also be used as collateral to borrow money to start a new business or to pay for college tuition. Without legally recognized deeds, capital is idle and its potential wasted.

Such institutions don't just happen, they evolve, as Hernando de Soto explains in his book, *The Mystery of Capital*.[93] Even though one of the founding principles of the United States was respect for each individual's property, many years passed before such rights were codified.

> “*The first and chief design of every system of government is to maintain justice; to prevent the members of a society from incroaching on one anothers property, or seizing what is not their own.*”[94]
>
> ***Adam Smith***

In America's early years, it was not uncommon for a piece of land to be claimed by any number of people—a squatter who built a crude cabin on it and began farming; a trapper who had purchased hunting rights from local natives; a soldier who had been awarded the land by the government he had served; or a railroad that had been given land grants to encourage it to lay

[93]Hernando de Soto, *The Mystery of Capital: Why Capitalism Triumphs in the West and Fails Everywhere Else* (New York: Basic Books, 2000), pp. 105–151.

[94]Adam Smith, *Lectures on Jurisprudence* (Indianapolis, Liberty Press, 1762, 1978), p. 5.

track. Disputes over such lands were fierce and sometimes bloody. Occasionally, troops were called in to run squatters off. They burned cabins, broke fences down, and destroyed crops. But often the people came back and rebuilt their homes as soon as the soldiers had gone.

In the absence of institutional resolutions to conflicting claims, squatters—the people on the ground—developed their own *extra-legal* systems. They wrote up deeds that were recognized by others in the community. Eventually, many such extra-legal property rights were absorbed into law, but the nineteenth century was nearly over before the rule of law caught up with a growing and evolving nation.

The United States was fortunate that property rights were fairly well established (at least in principle if not always in fact) by the time Edwin Drake drilled his oil well in 1859.

Petroleum production presented new property rights issues because oil (and natural gas), unlike other minerals, can migrate from one part of a reservoir to another. Eventually a system evolved in which surface and subsurface rights were held to be distinct (that is, the surface rights to a piece of land can be bought and sold independently of the subsurface, or mineral rights).

In addition, U.S. Courts established the *rule of capture* that held that oil was owned by whoever pumped it out of the ground.[95] This rule created an incentive for different producers owning or leasing land lying atop the same reservoir to sink wells and pump out the oil as fast as possible. Such rapid production wasted resources and resulted in reservoir damage, reducing the amount of oil that could ultimately be recovered from the field.[96]

The problems caused by the rule of capture were eventually solved when companies *unitized* their fields, i.e., let one company handle production while all shared the costs and profits according to a negotiated formula. Regulatory roadblocks and fear of anti-trust suits, however, delayed this solution for years.[97]

Despite problems with American property rights laws as they applied to oil and gas reservoirs, the laws provided the necessary framework by which these resources could be found, produced, and sold.

[95] In the 1880s, the Pennsylvania Supreme Court established the "rule of capture" granting property rights to "migrant" minerals such as petroleum to the act of physical possession (as versus the ownership-in-place law for hard minerals).

[96] For more on the problems associated with U.S property rights as established for petroleum reserves, see Robert Bradley, Jr., *Oil, Gas & Government: The U.S. Experience* (Lanham: Rowman & Littlefield, 1996), pp. 64–69.

[97] Ibid., pp. 109–31.

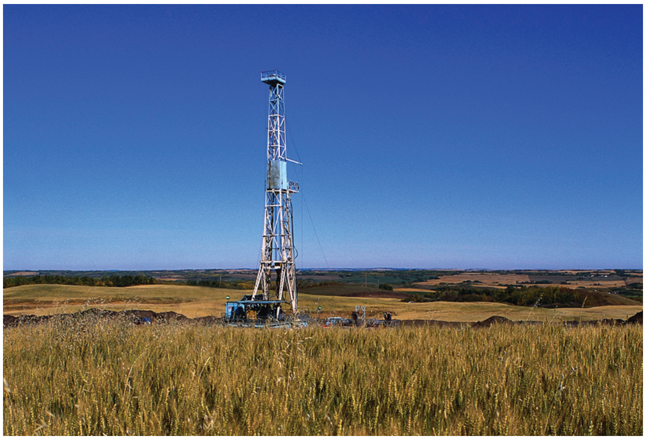
Within such a framework, oil production benefited the entire population of the country. Farmers and ranchers, under whose land the oil was found, were compensated for the use of their land by oil explorers, drillers, and producers. The owners, employees, and shareholders of oil companies, and of oil well service and supply companies, benefited. Refiners and retailers profited as well. Most of the benefits, however, accrued to the millions of people who were supplied with increasingly affordable energy to power their cars, homes, places of business, towns, and cities.

People living in countries without strong private property laws benefit far less from the land's oil and mineral wealth. In the first place, companies hesitate to invest in countries that do not recognize property rights. Oil production and mining are *hardware* businesses that require a lot of machinery, concrete, and steel. How can you build a facility if you cannot establish clear title to land on which to build it? Why build a plant or factory if the local government can lay claim and take it from you? As Lee Raymond, the chairman of ExxonMobil, the world's largest oil company, stated, "We are prepared to take the commercial risks that accompany the fluctuations of the world energy market. But we do not want to take unnecessary legal risks, especially those that arise from deficiencies in the legal structure of a country."[98]

Outside North America and Europe, government ownership of subsurface rights is the rule rather than the exception. In fact, governments control most of the world's oil and gas reserves—from the Middle East, to countries of the former Soviet Union, to Central and South America. Often governments offer *concession agreements* to outside companies in exchange for developing their resources. Such agreements establish unambiguous legal title and clearly spell out responsibilities. The parties (i.e., the government and the production companies) agree upon a framework for legally binding dispute resolution and guarantee restitution in case of damages. These agreements offer companies an element of security to offset the risk of investing in a country in which laws follow the whims of the rulers.

Even under such arrangements the citizens of developing countries do not always benefit from the production of oil and minerals to the same degree as do citizens of western nations. All too often, "public ownership" translates into ownership by the rulers. Money paid to a government by oil producing companies may go toward building the nation's infrastructure, or it may just disappear into the rulers' personal offshore bank accounts.

[98]Lee Raymond, "The Rule of Law in International Oil & Gas Development," *World Energy*, Vol. 5, No. 1 (2002), p. 111.



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Governments in poor countries do both too much and too little. South American economist Hernando de Soto and his team of researchers worked for 289 days to get all the certifications needed to open a small garment workshop on the outskirts of Lima, Peru. "The cost of legal registration was $1,231—thirty-nine times the monthly minimum wage."[99] Some 26 months of effort were needed for a taxi driver to get approval for a route. Obtaining permission to build a house on state-owned land took nearly seven years and 207 administrative steps by 52 government offices. De Soto's team found similar levels of red tape in Egypt and Haiti.[100]

At the same time that these governments have erected monumental roadblocks to individual initiative and productivity, they have failed to create the legal structure essential to any modern society. What developing nations need most are legal systems that document and uphold property rights, enabling people to easily transfer, trade, and borrow against their property.[101]

THE ENERGY INDUSTRY

The petroleum industry is actually made up of five sub-industries or *sectors*. Each sector represents a different stage in the petroleum processing chain. In industry jargon, the exploration and production sector is called the *upstream* part of the business, transportation the *mid-stream*, and refining, wholesaling, and retailing the *downstream*.

[99] Hernando de Soto, *The Mystery of Capital*, pp. 19–20.

[100] Ibid., pp. 20–21.

[101] Ibid., pp. 210–11. Also see the box discussion on page 189 below.

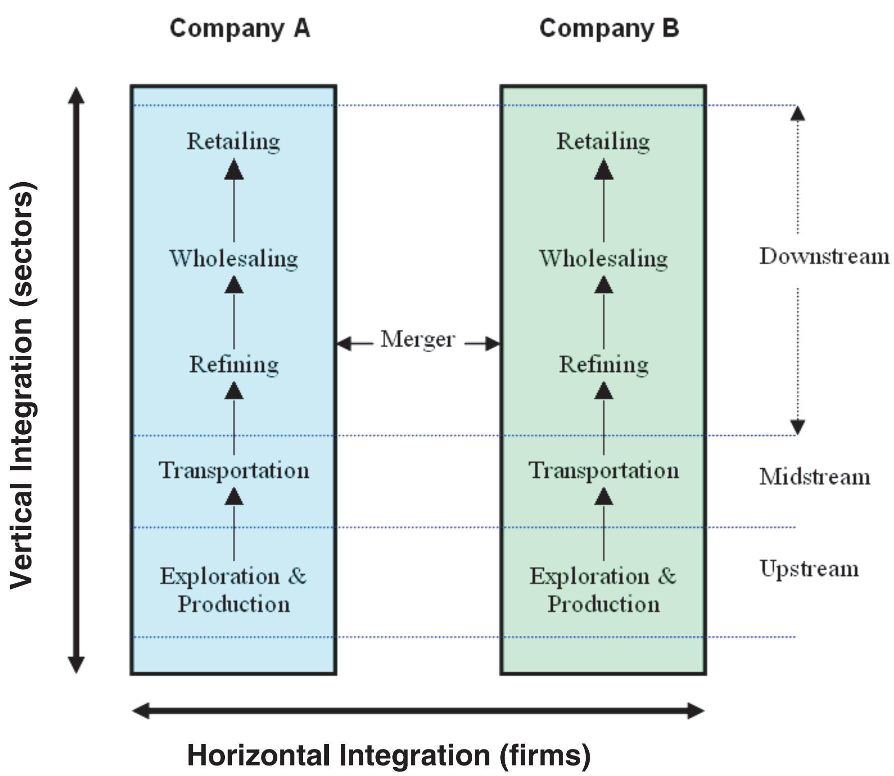
The largest firms in the energy industry are *integrated* across these industry sectors. Oil *majors* such as ExxonMobil and Royal Dutch Shell produce, refine, transport, and market crude oil and oil products.

Oil becomes increasingly valuable as it moves downstream. Yet the supply of, and consumer demand for, the final product determine the value of the entire chain of activities, not the other way around. Crude oil's value is governed by the prices consumers pay for gasoline, fuel oil, and other end products, rather than what crude oil costs to find, produce, and refine.

Over time, however, costs and prices tend to approach each other. In order to stay in business, a company must charge enough for its product to cover its costs. On the other hand, if a firm charges substantially more than its costs, competitors will move in and win customers by offering lower prices.

Oil Industry Segmentation

The petroleum industry is divided into five general sectors from the production of crude oil to the final sale of petroleum products. Each of these divisions has associated service industries such as drilling contractors for exploration and production and pipeline construction companies for transporters.



Shown in the illustration are two forms of corporate integration. H*orizontal integration* is expansion by a company within its own sector, perhaps by purchasing or merging with a rival. For example, the "seven sisters" of the 1960s oil industry, Exxon, Gulf, Texaco, Shell, Chevron, Mobil, and British Petroleum, are now four: ExxonMobil, Shell, BP, and ChevronTexaco (Chevron combined with Gulf before its merger with Texaco).

The entrance of a company into a new sector of the production chain—for example, a producer integrating forward into refining or a refiner integrating backward into production—is termed *vertical integration*. Vertically integrated companies can control risk and quality throughout the processing chain, a strategy that made John D. Rockefeller's Standard Oil so successful.

Many smaller *independents* are able to compete with the large integrated firms, especially in niche markets. Shifting consumer demand determines the market shares held by integrated, partially integrated, and non-integrated (independent) energy firms. The presence or absence of *economies of scale* (falling costs from larger output) and *economies of scope* (falling costs from performing more than one function) determine the size and structure of firms in a free market.

Globally, petroleum companies include both privately-owned *capitalistic* firms and government-owned *socialistic* firms. Capitalism is the dominant economic system in the United States energy market with some exceptions.[102] In Mexico, on the other hand, one giant government-owned company, Petroleos Mexicanos (PEMEX), has a legal monopoly over all oil- and gas-related functions. Other state-owned monopolies include Petroleos de Venezuela, S.A. and

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[102]U.S. municipalities own over a hundred entities that distribute natural gas or electricity in their jurisdictions. The U.S. Department of Energy, a federal agency, operates hydroelectric facilities that were built by the government decades ago.

Repsol in Spain. In such countries, as explained in the last section, the government not only owns the means of production but the oil reservoirs themselves.

In the United States, the natural gas and electricity industries each have three segments—production, transmission, and distribution. Regulation has played a large role in determining the structure of both of these industries. In the past, electric utilities were completely vertically integrated, from production, to transmission, to marketing, while the natural gas industry was totally non-integrated. Relaxed regulation is likely to make the structure of these energy industries more like that of petroleum—a blend of integrated and non-integrated firms. This trend has already begun as some electric utilities have sold their generation facilities to independent power producers.

To the untrained eye, the energy industry may seem like a collection of physical resources: petroleum reservoirs and mineral deposits, oil wells and mines, refineries and power plants, pipelines and power lines. But *intellectual capital* drives these physical assets. The *entrepreneurial* component of the energy business, in which new technologies and strategies are employed to do entirely new things or perform old tasks in new ways, is the engine of progress described in this book. Economist Joseph Schumpeter described capitalist progress as *creative destruction*, a process in which new techniques and technologies render existing modes of operation obsolete.[103]

Economics and Power Consumption

The amount of electricity used in any community varies throughout the day. Consumption is typically much greater during daylight hours than at night when most people are asleep. Usage also varies by season. Much more is needed in summer to run air conditioners and in winter to power heaters than in either spring or fall. But regardless of the time of day or the season, when consumers turn on a switch, they expect the power to be there.

In order to meet this uneven demand, power companies must build their plants large enough to handle peak loads. As more people and industry move into an area, however, the companies may find that their facilities can no longer handle the new demands being placed on them. When this happens, should the old plants be expanded, or should new plants be built?

An alternative to either of these options is to use the existing plant's excess capacity during off-hours to generate power into storage. Then, during times of high demand, this storage can be tapped to supplement the main generators.

[103]Joseph Schumpeter, *Capitalism, Socialism and Democracy* (New York: Harper & Row, 1942, 1962), p. 83.

One way to store excess energy is to pump water up into a reservoir. When additional electricity is needed, the pumps are turned off, and water is released through the dam to turn hydroelectric turbines. A future method might be to use off-peak electricity to break water molecules into oxygen and hydrogen atoms. Hydrogen is an exceptionally efficient and clean burning fuel and can be used to produce electricity.

The problem with such schemes is that, while they may reduce the resources needed to build a new or bigger power plant,[104] they result in higher overall fuel costs. Fuel must be burned to produce the electricity needed to pump the water up into the reservoir. As explained in the discussion of efficiency, significant amounts of energy will be wasted in the process of converting electrical power into potential energy (the increase in the water's energy by virtue of its being placed at a higher elevation). Then only some of the potential energy will be regained when the water falls back down through the turbines. Because of the costs involved, such storage techniques are the exception.

Perhaps the best way to reduce the need for new capacity is to increase the price of power used during peak hours. These higher prices would encourage customers to shift consumption from critical times to periods when demand is lower. People might, for example, choose to run their clothes washers and dryers at night when rates are lower. New metering technology is making this possible.

Nothing is free, and there are no perfect solutions. There are always trade-offs; one thing is lost in order to gain another. Market incentives lead people to balance these trade-offs to make the best use of available resources.

[104]Assuming, of course, that the cost of building the facilities necessary to store and reuse the old plant's excess power is less than that of expanding the old plant or building a new one.