A

Aerobic Cellular Respiration

FIELDS OF STUDY

Biochemistry; Bioenergetics; Thermodynamics

ABSTRACT

Aerobic cellular respiration is one of two processes the cells of living organisms use to break down food and convert it into energy. Aerobic respiration occurs in the presence of oxygen. The four-step process takes the molecular sugars stored in food and transforms them into chemicals that cells use as energy. This energy is what allows cells to perform their basic functions. Due to the presence of oxygen, aerobic cellular respiration produces a larger amount of energy. Anaerobic respiration, another type of respiration, occurs without oxygen. This process also creates energy used to power cells but is less efficient and produces less energy.

KEY CONCEPTS

aerobic: processes that require the presence of oxygen

anaerobic: processes that either do not require or that do not occur in the presence of oxygen

eukaryote: a cell that has a central nucleus structure containing the cell's deoxyribonucleic acid (DNA) and maintains its life through aerobic respiration

mitochondria: organelles within eukaryotic cells, where energy is extracted from the glucose obtained from food

prokaryote: a cell that does not have a central nucleus structure containing the cell's DNA and maintains its life through anaerobic respiration

respiration: the process of extracting energy from glucose by converting it back to the carbon dioxide and water from which it was photosynthesized

WHERE ENERGY COMES FROM

The energy of sunlight is captured by photosynthetic processes that produce one molecule of glucose from six molecules of atmospheric carbon dioxide and six molecules of water taken in from the environment. This process is the foundation of all bioenergy on this planet. Once captured, this energy must be recovered as food by living animal systems in order to obtain the energy that sustains life.

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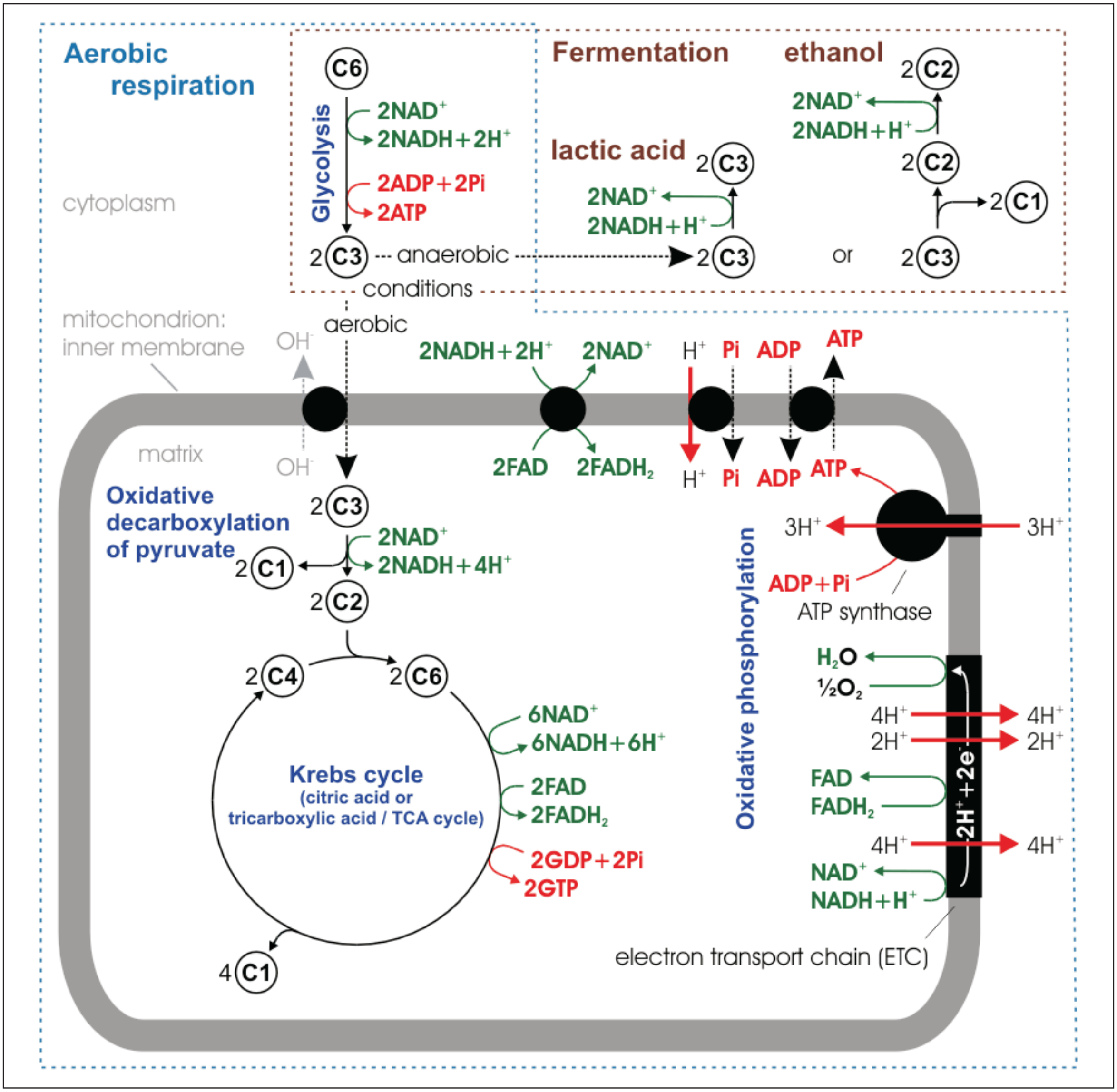
BACKGROUND

Cells are the fundamental building blocks that make up all living things. While hundreds of types of cells serve various functions within an organism, they are generally divided into two basic types. Prokaryotes are typically single-celled organisms that lack a central nucleus. The cell's genetic material, or DNA, floats in a gel-like substance called cytoplasm found within the cell. Bacteria are prime examples of prokaryotic cells.

Eukaryotic cells are found in more complex life forms such as humans, animals, plants, and fungi. These cells have a central nucleus that houses the cell's genetic material. They also have various membrane-enclosed structures within the cytoplasm called organelles. Organelles perform different functions within the cell. For example, ribosomes use the cell's genetic instructions to reproduce proteins. Mitochondria are organelles that act as the cell's power plant, taking the nutrients from food and converting it into energy the cell can use.

Aerobic cellular respiration is the primary way that eukaryotic cells produce energy. These cells run on a form of chemical energy provided by a chemical compound known as adenosine triphosphate (ATP). Because ATP molecules are larger, delivering them directly to the body's cells would be a difficult and an inefficient task. The smaller sugar molecule glucose acts as the "fuel tank" that carries the stored energy to the cell. Cellular respiration is the process of converting the glucose into the energy-transferring ATP. In



Stoichiometry of aerobic respiration and most known fermentation types in eucaryotic cell. Numbers in circles indicate counts of carbon atoms in molecules, C6 is glucose $C_6H_{12}O_6$, C1 carbon dioxide CO_2. Mitochondrial outer membrane is omitted. (Darekk2 via Wikimedia Commons) aerobic cellular respiration, oxygen is used as a catalyst to transfer the energy stored in glucose into ATP.

The molecular formula of glucose is written as $C_6H_{12}O_6$, meaning that each molecule is made up of six carbon atoms, twelve hydrogen atoms, and six oxygen atoms. In the first step of cellular respiration, each glucose molecule is broken down into two units of pyruvic acid, a compound with the molecular formula $C_3H_6O_3$, as its pyruvate anion. This process is called glycolysis—a term meaning "sugar splitting"—and takes place in the cell's cytoplasm. To create the energy needed during glycolysis, each glucose molecule also produces two molecules of ATP and two molecules of nicotinamide adenine dinucleotide (NADH). NADH is another energy-transferring molecule and a chemical compound used as a catalyzing agent. The glycolysis process occurs in both aerobic and anaerobic cellular respiration.

For aerobic cellular respiration to proceed, the remaining steps of the process require the presence of oxygen. Through a process called oxidation, oxygen strips away electrons from atoms or molecules by way of a chemical reaction. After glycolysis, the pyruvate is transferred into the cell's mitochondria, specifically, an interior section of the structure known as the mitochondrial matrix. There, the pyruvate reacts with an enzyme called coenzyme A to form a two-carbon molecule called acetyl-CoA. During this part of the process, one carbon atom is stripped away from the pyruvate and combines with oxygen to form carbon dioxide (CO_2), which is released as a waste product to eventually be breathed out. In addition, more NADH molecules are also produced.

The next step of the process is called the citric acid cycle or the Krebs cycle, named after Hans Krebs, the biologist who discovered it in the 1930s. The acetyl-CoA reacts with a molecule called oxaloacetate (OAA), which produces citric acid. The citric acid then goes through a series of reactions to produce energy and carbon dioxide. The end of each cycle produces additional OAA to begin the cycle over again. Because the process to this point has produced two molecules of acetyl-CoA for every glucose molecule, the cycle must repeat itself twice for each glucose molecule. At the end of the cycle, each glucose molecule has been completely broken down. It has produced six carbon dioxide atoms—which are expelled as waste—four ATP molecules, ten NADH, and two molecules of flavin adenine dinucleotide ($FADH_2$), another type of energy-transferring molecule.

The last step of aerobic cellular respiration is called the electron transport chain. This occurs in the christae, a folded area in the inner membrane of the mitochondria. During this step, energy from NADH and $FADH_2$ is transferred into ATP. The electron transport chain is a series of proteins that transfers high-energy electrons along the inner membrane of the mitochondria. This process creates hydrogen ions—hydrogen atoms that have lost their electrons. As the hydrogen ions build up, a protein known as ATP synthase channels them through the membrane, capturing their kinetic energy and transforming it into chemical energy found in ATP. At the end of the aerobic cellular respiration process, each glucose molecule can produce from thirty-six to thirty-eight molecules of ATP. The leftover electrons that have passed through the chain combine with the oxygen to form water (H_2O).

Cells can also produce energy without oxygen, but this process is far less efficient. Anaerobic cellular respiration shares the process of glycolysis with its aerobic counterpart. However, without oxygen, the process splits off into fermentation in which the glucose is broken down by microorganisms such as bacteria or yeast. Fermentation is the same process used to make beer, wine, and cheese. In humans, a lack of cellular oxygen can break down glucose into lactic acid. During strenuous exercise, in which the body uses oxygen very quickly, a buildup of lactic acid can cause a burning feeling in the body's muscles.

—Richard Sheposh

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Air Conditioning

FIELDS OF STUDY

Electromechanical Engineering; HVAC Trades; Thermodynamics

ABSTRACT

Air conditioning (AC) is the process of conditioning several air properties simultaneously, including temperature, humidity, velocity, and quality (amount of fresh air), to ensure that the space matches desired conditions. Modern air conditioning is used to control indoor environments, providing thermal comfort to occupants and suitable environmental conditions for process applications. Air conditioners often consume large amounts of available electrical energy.

KEY CONCEPTS

dehumidification: the artificial removal of water vapor from the air inside of a building in order to maintain human comfort level and prevent damage due to condensation and mold growth

energy efficiency ratio: a rating according to the amount of heat energy removed from the air per watt-hour of electricity consumed by the particular system

humidification: the artificial addition of water vapor to the air inside of a building in order to maintain human comfort levels and avoid physical damage due to dehydration

humidity: the amount of water vapor in ambient air, relative to the maximum amount of water vapor possible in air at specific temperatures and pressures (100 percent humidity); for example, 25 percent humidity means the amount of water vapor present in air is 25 percent of the maximum amount possible

water vapor: water that exists in the air of the atmosphere as a gas

USE OF AIR CONDITIONING

Air conditioning (AC) is the process of treating, or conditioning, air. Through air conditioning, several air properties are controlled simultaneously, including temperature, humidity, velocity, and quality (amount of fresh air), to ensure that the space matches desired conditions. Requirements for air conditioning are usually divided into those needed for comfort applications, or the satisfaction of the human and animal occupants of the environment, and those needed for process applications, or the satisfaction of prescriptive conditions necessary to accommodate the technologies involved with a specific process.

A BRIEF HISTORY OF AIR CONDITIONING

From the very first rudimentary techniques of ancient times to the highly complex systems of today, human beings have always been searching for ways to ensure comfort in built environments. In ancient Rome, for example, water was conveyed from aqueducts through the walls of selected houses to achieve a cooling effect. The same effect was produced in medieval

In ancient times, the Egyptians hung wet reeds in windows and thresholds to chill the incoming breeze. (Wikimedia Commons)

Persia with a different technique, using a combination of water cisterns and wind towers; during hot seasons, evaporating water from the cisterns provided a cooling effect to the air stream blown into the buildings by the wind towers. In several Chinese dynasties, the use of specific apparatuses aimed conditioning air has been documented; these ranged from manually powered rotary fans to water-powered fan wheels and water jets from fountains (between the second and thirteenth centuries CE).

The pioneer of modern air-conditioning was the American engineer and inventor Willis Carrier. In 1902, Carrier designed the first large-scale electrical air-conditioning unit in the world, the "apparatus for treating air," to address a manufacturing problem in a lithography company. With Carrier's machine, the temperature and humidity in the plant could be controlled, improving the manufacturing process. Carrier was granted a patent for his invention in 1906. Installation of air-conditioners started in the following years, mainly targeting industrial applications, due to the size and cost of the first machines.

Household electric "box" fan with a propeller-style blade. (Wikimedia Commons)

Over the years, smaller and safer equipment brought the air-conditioning industry into the residential and transport sectors, focusing on thermal comfort. In the 1920s central air-conditioning systems were running in office and recreational buildings, and in the 1930s the first packaged and room air conditioners were installed. The first automotive air conditioner was introduced by Packard in 1939, although its operation was not very user-friendly. Nowadays, with the advent of electronic miniaturization and complex control algorithms, the satisfaction of people and process requirements can be achieved at a very detailed level and, most important, with increased energy efficiency.

General Requirements for Indoor Air Conditioning	
Temperature (Celsius)	20°–25°
Relative humidity (%)	35%–65%
Air Velocity[a] (ms-1)	0.1–0.25 $m.sec^{-1}$
Fresh Air Supply Rate[b] (m3h-1 per pax)	25–35

a. In the occupied zone.
b. Ventilation requirements depend on the space to be conditioned and the level of activity, and they are often regulated by national or federal codes.

AIR-CONDITIONING PROCESSES

Because atmospheric air is a mixture of dry air and water vapor, AC systems must be capable of handling heat- and water-transfer processes. (An air-conditioning process is described by changes in the thermodynamic properties of atmospheric air between the initial and final states of the conditioning process. Heat and moisture supply and removal rates are calculated on the basis of mass and energy balances.) Basic processes include sensible heating, wherein heat is added to atmospheric air, with a corresponding temperature increase; sensible cooling, wherein heat is removed from the air (resulting in a drop in ambient temperature); humidification, the transfer of water vapor to the air, usually by steam injection or evaporation from a water spray; and dehumidification, the removal of water vapor from the air using a cooling coil or a desiccant unit. A combination of these processes is often required to achieve the desired temperature and humidity lev-

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Natural Energy Flows

FIELDS OF STUDY

Environmental Engineering; Environmental Studies; Thermodynamics

ABSTRACT

Natural energy flows are sources of energy that do not need to be processed with additional energy but, rather, naturally flow through the world and need only be harvested or otherwise put to work.

KEY CONCEPTS

anthropogenic emissions: byproduct emissions of materials like carbon dioxide from the burning of fossil fuels caused by human activities

photosynthesis: the process in which chlorophyll-containing cells produce glucose from atmospheric carbon dioxide and water in the presence of sunlight

EARTH'S ABUNDANT ENERGIES

The term *natural energy flows* was popularized in environmentalism by the Hannover Principles, a document drafted by William McDonough and Michael Braungart in 1992, in anticipation of the Expo 2000 at Hannover, Germany. Natural energy flows are those sources of energy that are naturally flowing through the world already and need only be harvested or otherwise put to work; they include the flow of running water, the movement of the seas, the kinetic energy of wind, the solar radiation of sunshine, and the geothermal energies beneath the surface of Earth. They are not coequal with renewable energy sources, which would include biofuel.

CONSTANT MOVEMENT

Massive amounts of energy flow along the surface of Earth constantly. The sun radiates some 28×10^{32} calories of energy every year, about 13×10^{23} calories of which are intercepted by Earth. Of those intercepted calories, approximately one-third are reflected back into space. (This quantity, called the "albedo," varies locally according to weather conditions and type of surface coverage; snow-covered land reflects the most energy, as much as 90 percent, while ocean surfaces reflect less than 10 percent, and cloud cover also influences albedo.) The rest of the solar energy is absorbed by Earth or its atmosphere. Almost half is converted into heat, some of which powers the water (hydrologic) cycle of evaporation and precipitation. A small amount of sunlight, about 0.2 percent, is converted into the energy of wind, water currents, and waves. Even less than that, 0.1 percent, is used by photosynthesis. A tiny amount of the Earth's energy (tiny, that is, relative to this solar energy) comes from other sources, the geothermal heat emanating from Earth's interior and the tidal energy resulting from the gravitational interactions between Earth and the Moon. By contrast, sunlight accounts for tremendous amounts of Earth's energy and leads to most other forms. For example, photosynthesis by plants turns solar energy into chemical energy and stores it as carbohydrates in the plant, which over a geologic timescale when buried under great pressures eventually becomes gas, coal and petroleum deposits. Thus, even when humans are not harnessing natural energy flows, these flows are nevertheless the source of most of our energy.

McDonough was a New York City architect; Braungart, a German chemist. Together they collaborated on a sustainable design they called "cradle to cradle." The Hannover Principles articulated guidelines for the design of objects and buildings. The principles focused on interdependence with the natural world, the consequences of design decisions, waste and life-cycle assessments, the interrelationship between sustainability and human rights, and the responsible use of energy. With regard to natural energy flows, the document says, "Rely on natural energy flows. Human designs should, like the living world, derive their creative forces from perpetual solar income. Incorporate this energy efficiently and safely for responsible use."

McDonough has elaborated on this in later writing—indeed, he and Braungart have spent much of their subsequent careers refining and elaborating on the ideas in the Hannover Principles. In particular, McDonough has downplayed the idea of interpreting the directive to "rely on natural energy flows" in a quantitative way, and he does not appear to support renewable energy quotas or quantified energy efficiency goals. Instead, he and Braungart call for a fundamentally new approach to design, not simply a more efficient version of current designs. He has proposed buildings that sequester carbon, fix nitrogen, and make oxygen and distilled water while powered by solar energy; in general, the Hannover Principles seem primarily focused on solar power among the renewable energy sources.

ENERGY MANAGEMENT

The call for reliance on natural energy flows has been referred to as energy management, analogous to waste or water management. It is concerned with more than just the sustainability of its energy sources, in other words. Using natural energy flows reinforces and explicates humankind's connection to the planet by thriving from its already extant mechanisms, such as wind and water currents. The usual view of advocates is that natural energy flows alone—indeed, even solar power alone—are sufficient to meet humans' energy needs and that not attempting to use them to meet those needs is letting them go to waste.

There has been some suggestion that the use of natural energy flows may have environmental consequences that have not yet been made clear because their use is not yet widespread enough to understand the consequences of their use. John Holdren, one of President Bill Clinton's science advisers and Director of the Office of Science and Technology Policy under President Barack Obama, while publishing extensively on climate change and the need for proactive policies to reduce anthropogenic emissions, has also insisted that there is no known energy technology with negligible environmental impact. Windmills may harm avian life; hydropower frequently disrupts ecosystems; reservoirs and solar collectors need land to occupy; and some collection of geothermal energy is nonrenewable.

—Bill Kte'pi

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NATURAL GAS

FIELDS OF STUDY

Environmental Sciences; Geology; Petroleum Engineering

ABSTRACT

Natural gas is largely composed of methane and is one of the three major fossil fuels used to generate energy. Natural gas may lead to the development of economically viable and efficient alternatives to fossil fuels.

KEY CONCEPTS

biogenic: produced by the decomposition of organic matter under anaerobic conditions

clathrate: a class of compounds in which a small molecule such as methane becomes trapped within the crystal lattice structure of water ice crystals as they form at cold temperatures in a wet environment

odorant: a compound having a strong, easily detectable and unpleasant odor, such as the sulfur-containing mercaptans, an odor characteristic of skunks

reserve-to-production ratio (RP): the amount of gas in a reserve relative to the annual rate at which gas is being removed from the reserve, stated in years

thermogenic: produced by the thermal decomposition of carbonaceous matter

AN IMPORTANT FUEL

Natural gas is one of the three major fossil fuels currently used to generate energy. In 2015, it was the fastest-growing fossil fuel in use, providing approximately 25 percent of the world's total primary energy, according to the International Energy Agency (IEA) supply. However, uses for natural gas vary between less developed and more developed nations; the former using natural gas largely for household heating and cooking and the latter for industry, electricity production, residential uses, and a small percentage of transportation fuels.

Natural gas consists primarily of methane and other hydrocarbon compounds. It is odorless and colorless and is often found associated with other fossil fuels, such as coal or petroleum beds. However, there are nonassociated stores of natural gas in isolated beds. Like other fossil fuels, natural gas is a highly combustible substance that, with recent infrastructure developments, is relatively easy to transport and store. Its combustibility makes it a highly effective resource for generating energy and heat.

THE CREATION PROCESS

It is generally believed that two processes create two types of natural gas. Biogenic gas is created when bacteria decompose organic material at shallow depths below Earth's surface. For example, these gases can be observed when wetlands are disturbed and "swamp gas" is released. Thermogenic gas develops deep underground, resulting from compression and heat. Holes must be drilled to access thermogenic gas deposits. Once accessed, in most cases, the natural gas must then be pumped to the surface. In a few cases, however, the gas will flow freely because of natural pressure. Both thermogenic and biogenic gases are created from biomass that has been buried in anaerobic environments. There is also a third theory that nonassociated gas stores exist far below Earth's surface, which were created during the formation of the earth.

The naturally occurring clathrate solid known as methane hydrate represents an intermediate formation of natural gas. Methane hydrate typically forms in cold, wet environments such as cold ocean floors and in terrestrial permafrost. It has also been observed to form as liquefied natural gas (LNG) is vented from storage tanks on humid days. Methane molecules become encased in the pores of a cage structure formed as water molecules freeze about them. Naturally occurring methane hydrate is believed to exist in large quantities on cold ocean floors, forming there with methane from either or both of biogenic and thermogenic sources. Also known as "ice that burns," the technology for harvesting the material from the oceans has not yet been developed.

One of the earliest known extractions and uses of natural gas by human society occurred during the Han dynasty (200 BCE). Chinese laborers drilled for natural gas with bamboo and used it to boil sea water for salt extraction. In the late 1700s, cities and towns in Britain used natural gas for lighting. In the United States, the first known intentional drilling for natural gas occurred in New York State in the 1820s. However, it was not until the invention of the Bunsen burner in 1885—allowing for more conventional uses such as cooking and heating—that natural gas became a viable option for generating energy around the world.

NONRENEWABLE RESOURCE

Natural gas is considered a nonrenewable resource because recoverable reserves are being exhausted at a rate that is a tiny fraction of the amount of time needed to create them. The Russian Federation, the United States, Iran, and Canada produced about 48 percent of the world's natural gas, as of 2014, and the United States and Russia accounted for more than one-third of the world's total natural gas consumption in 2013, based on data from the IEA and the U.S. Energy Information Administration. If extracted with contemporary technologies and known costs, current reserve-to-production ratio estimates (R/P ratio, measured in years) suggest there are enough conventional reserves to satisfy society's consumption needs for the next several decades. The vast majority of these proven reserves are located in Russia and the Middle East. The largest deposits are in Iran, Russia, and Qatar. The largest conventional gas field is the Urengoy

Field in the Western Siberian Basin, east of the Gulf of Ob, within the Arctic Circle. The Urengoy Gas Field was discovered in the 1960s and held an estimated initial total of 280 trillion cubic feet (8 trillion cubic meters).

Historically, natural gas was considered a low-value byproduct found interspersed with oil and coal deposits. Until the early twentieth century, natural gas was too inefficient for use as a large-scale energy resource. Because of a lack of technological development and insufficient infrastructure, producers could not get natural gas to markets in a feasible manner, and it was often burned off or allowed to vent into the air on site. Natural gas production remained slow during the industrial era, until post-World War II, when improvements in pipeline construction (and hence fuel transport) and safer infrastructure made natural gas technologically possible and economical. In 1937, after an undetected leak caused an explosion at the New London School in Texas, killing at least 300 people, minute amounts of odorants (such as mercaptan) were added to retail natural gas. This allows consumers to detect leaks in order to prevent fires or explosions.

IMPACT OF WORLD WAR II

During World War II, large pipelines were built in the United States from Texas to the northeast states to ensure energy security for the country during wartime. These pipelines were known as "Big Inch" and "Little Big Inch," and were responsible for transporting more than 350 million barrels of crude oil and refined products to the northeast before the war's end in the summer of 1945. After the end of the war, there were debates to determine if the pipelines should continue to transport oil or be converted to transport natural gas. The issue was settled in 1946, when an influential coal miner strike motivated the Senate and War Assets Administration to award the Tennessee Gas and Transmission company a lease to supply natural gas commercially. This transition made natural gas readily available to the northeastern United States, where there was a high-demand home heating market.

A COSTLY ENDEAVOR

Although current techniques (such as seismology) have reduced the costs of finding, extracting, and processing the fuel, natural gas production is an uncertain, complex, and costly endeavor. Natural gas straight out of the well is often accompanied by water and liquid hydrocarbons, including benzene, toluene, ethylbenzene, and xylene (BTEX), hydrogen sulfide (H_2S), and other organic compounds that must be removed. To make "pipeline quality" natural gas, it must be passed through units (called heater treaters) with chemical substances that absorb the byproduct water from the gas. Once the chemical extraction solution is saturated with water, the heaters raise temperatures to boil off the water. When cool, these large volumes of byproduct water are pumped to a "produced water" tank. The chemical separating fluid, which has a higher boiling point than water, cools and is recycled into reuse. Byproduct oily substances that were produced with the gas and water become volatile and recondense in a separate holding tank. This "condensate water" is commonly re-injected underground or hauled offsite to waste evaporation pits. In some cases, temporary pits are constructed, which hold waste materials and drilling mud so they can be reused through the drilling process. In order to reclaim drilling pads and sites, reserve pits must be drained and covered with topsoil or a capping material within a month of drilling completion.

After natural gas is processed and impurities are removed, it is often liquefied and compressed for storage and transport. Storage is an important issue, as most gas is used for heating during winter. A refrigeration process is used to condense the gas into liquified natural gas (LNG) by cooling it to -160°C (-260°F). LNG is then stored in insulated tanks, specially engineered to hold a cold-temperature liquid. LNG storage tanks are typically double-walled, composed of an outer wall of thick concrete and an inner wall made of steel. Between the walls is a thick layer of insulation. Often such storage facilities are underground to increase insulation. LNG will boil off and evaporate as natural gas, no matter how efficient the storage or refrigeration. This gas is then removed from the tank and used as a fuel on site, or refrigerated again to return it to the liquid state and placed back into the storage tank. If no pipeline is available to immediately transport gas, LNG also makes natural gas easier to store and transport. When LNG is transported (by train, truck, or ocean tanker) to its destination, or when it is removed from storage, it must be regasified.

Regasification is accomplished by heating LNG and allowing it to evaporate back into its gas state at typical temperature and pressure conditions. Regasification is usually done at a facility where the gas can be placed into storage or directly into a pipeline for transport.

REGASIFICATION TERMINALS

The two types of regasification terminals are called liquefaction terminals and regasification terminals. Liquefaction terminals, which turn natural gas into LNG, are on the export end of transactions. Regasification terminals, which turn LNG back into natural gas, are on the import side of operations. Currently, most natural gas is transported domestically within enormous infrastructure-intensive pipeline networks. Natural gas pipelines are often constructed of carbon steel to withstand the extremely high pressure of transporting compressed gas over large distances. Gas pipelines typically have small gathering systems that are composed of small diameter pipelines (5—20 centimeter, or 2—8 inches). These “gathering lines” tap into gas fields and gather to larger “trunk lines,” which typically have an 20-120 centimeter, or 8- 48 inch, diameter and are large transnational or international transmission pipelines. Natural gas as a final product is delivered through another set of local pipelines directly to consumers. For example, the United States has natural gas gathering lines over a length of 32,000 kilometers (20,000-plus miles), and additionally, more than 432,000 kilometers (270,000 miles) of natural gas transmission lines.

The Federal Energy Regulatory Commission (FERC) regulates natural gas in the United States. Their primary responsibilities are to regulate transmission and sale, approve facility siting, render penalties for FERC energy market violations, oversee environmental matters, and administer reports. Safety rules fall under the purview of the Department of Transportation’s Pipeline and Hazardous Materials Safety Administration (PHMSA). In early 2016, PHMSA required older pipelines to be pressured tested and previously unregulated gathering lines to be marked and undergo repairs and preventative maintenance in response to several accidents in the 2010s and concerns about leaks along pipeline routes contributing to greenhouse gas emissions.

DEREGULATION

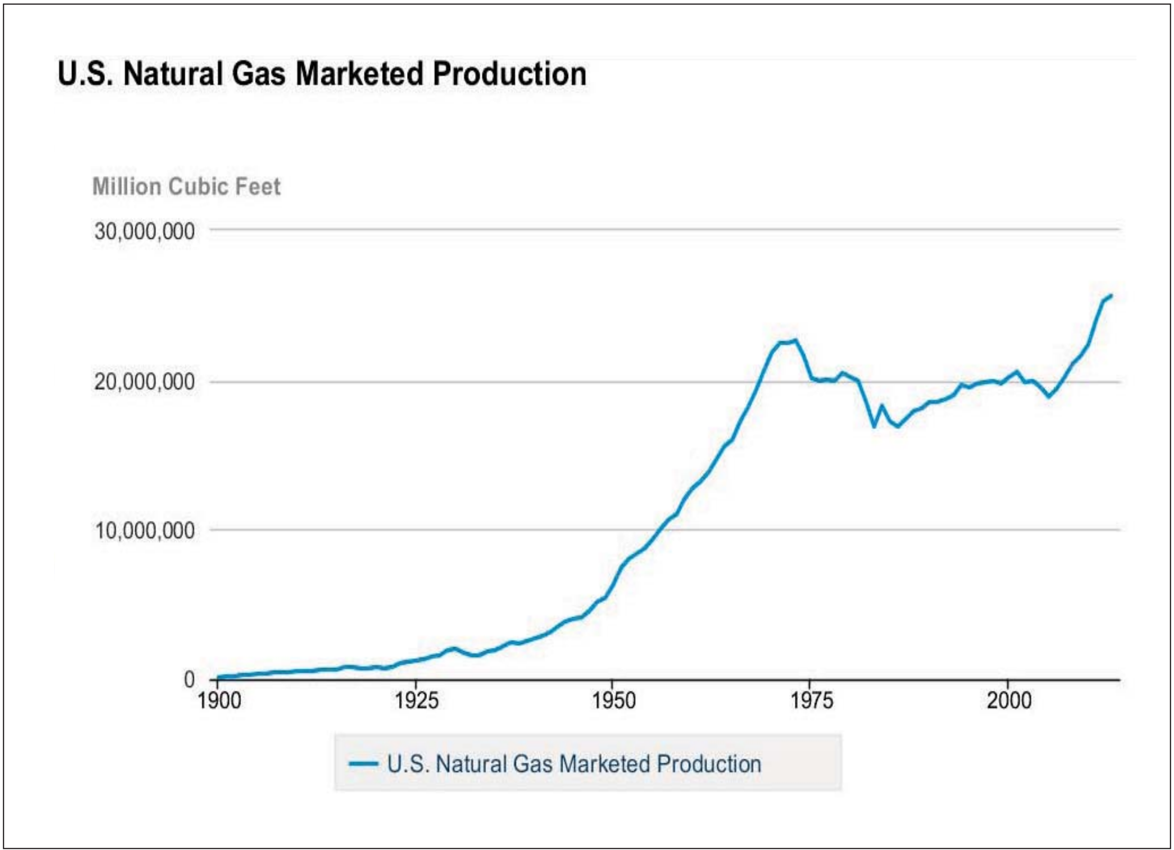
Since the mid-1980s, the demand for, and production of, natural gas has risen significantly. This is largely due to deregulation, geopolitical dynamics, rising energy demands, and new technologies. In this context, natural gas is often characterized as an energy source that can potentially bridge society’s current fossil fuel dependence to the development of economically viable alternatives to fossil fuels. Natural gas burns much cleaner than other fossil fuels and the development of infrastructure and technology has made it much easier to extract and transport. In the early part of the twenty-first century, T. Boone Pickens (an oil tycoon and prominent alternative energy promoter) advocated the development of natural gas-powered automobiles in the United States. Pickens claimed that by

Natural gas drilling rig in Texas. (David R. Tribble via Wikimedia Commons) transitioning the transportation fleet to natural gas, U.S. society could fight the rising costs of oil with a smaller environmental impact, particularly in terms of reducing air polluting auto emissions.

Deregulation is a particularly important aspect of natural gas use. Natural gas has been regulated since the mid-1800s. The U.S. Congress passed national-scale regulations in the form of Natural Gas Act (1938) in order to manage interstate natural gas transmission and control monopolies. By the 1970s, however, many consumer states in the Midwest were experiencing shortages, despite adequate levels of supply in producer states. To remedy this, congress passed the Natural Gas Policy Act (1978), which created a single natural gas market and equalized supply and demand. This market-based approach was further embraced by FERC Orders (436 and 636), which unbundled transport, storage, and marketing, resulting in more consumer choice. As a result, prices decreased for large commercial and industrial customers but declined only slightly for residential consumers.

TRADED COMMODITIES

In the United States, a large percentage of natural gas is traded on the New York Mercantile Exchange (NYMEX) located in New York City. NYMEX is the exchange for energy products, metals, and other commodities, and transactions reflect the prices of traded commodities. Thus, U.S. gas prices are closely correlated with trading on NYMEX. Currently, the price of natural gas in the United States is signifi-



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Glossary

absolute zero: the temperature at which there is absolutely no energy present; the temperature at which the volume of an ideal gas, decreasing as temperature decreases, becomes nonexistent

AC and DC: acronyms for alternating current and direct current, respectively

acetogens: bacteria that acts to break down cellulosic material, producing acetate (or acetic acid) as a product of the digestion process

acetone: 2-propanone, also known as dimethyl ketone

acid mine drainage: water runoff from mines in which sulfur from certain minerals has reacted with the water to produce sulfuric acids that leach toxic heavy metals from other minerals present

actinide: elements belonging to the actinide series in the periodic table, having atomic weights greater than that of actinium

activation energy: the amount of energy required to perturb a system sufficiently to render it unstable

actuator: a device that when activated performs a motion that causes a function such as extending a robotic arm or extending an aircraft's landing gear to be carried out

aerobic: processes that require the presence of oxygen

agricultural revolution: the period in which nomadic hunter-gatherer societies established agriculture in place, leading to the establishment of permanent settlements where the products of agriculture would be readily available

albedo: the amount of light and other energy reflected from a planet relative to the amount that it receives; an albedo of 0.3 indicates that the planet reflects and emits 30 percent of its incoming insolation back into space

alkaline: mineral material capable of acting as a base, as opposed to an acid

alkanes: organic molecules composed solely of carbon and hydrogen; in normal alkanes the carbon atoms are joined together linearly, in branched alkanes the carbon atoms are joined together as groups attached to a simple linear structure

alternating current: electrical current produced by magnetic oscillation, which reverses direction periodically rather than flowing continuously in one direction; for example, normal household current in North America oscillates at a frequency of 60 Hertz (60 cycles per second) and therefore reverses direction 120 times per second

alternative: indicates some feature or process that is intended to displace and be used instead of the historical standard feature or process

alternative energy sources: refers to energy sources that do not rely on unsustainable fossil fuels (petroleum, coal, natural gas) but are entirely renewable (wind power, solar photovoltaics, small-scale hydropower, etc.)

American system: a production manufacturing system that relied on specialized or single-purpose machines rather than general or multipurpose machines

ampere: the standard unit of electrical current, defined as the movement of 1 coulomb of electric charge through a potential difference of 1 volt in 1 second

anaerobic: processes that either do not require or that do not occur in the presence of oxygen

analytical engine: a programmable mechanical calculating device proposed by Joseph Babbage but never actually constructed, as a refined and advanced version of his difference engine

animal electricity: the notion that the electrical energy causing muscle response when muscle tissue was

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Subject Index