Energy Futures for THEW Long-Term

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Controlled thermonuclear fusion, holding the potential for unlimited energy needs, will usher in a New Atomic Age. Based on virtually limitless hydrogen, this key energy sector stands on the threshold of becoming another job and revenue generating mainspring of advanced economies. Hydrogen constitutes 76% of all mass in the universe and 93% of the total number of atoms throughout the universe. Earth's solar system itself consists of 70.68% hydrogen, most of it in the sun and the giant gas planets. There's so much hydrogen around, that meeting Earth's energy requirements really won't have anything to worry about, ever. Learning how to control the hydrogen-helium cycle that fuels Earth's sun, humans soon will master controlled energy extraction from their own "star furnaces." Thermonuclear technologies will dominate the economy after the few remaining obstacles to controlling fusion are overcome.

How Long Will Energy Sources Last?

Thermonuclear energy breakthroughs become urgent around the year 2050-2100, when petroleum resources dwindle and begin scraping the bottom of the barrel. Before 2050, the world will become increasingly reliant upon coal. Around 2250-2500, when reserves of coal also dwindle and reach the limit of cost-effective recovery, the substitution of fossil fuels will be nearly complete. At that point, demand for alternative energy sources will become an imperative. Necessary breakthroughs to practical fusion gain critical mass occur around 2030-2037. Commercial introduction by a succession of advanced hydrogen-helium output, each one providing a huge leap in energy output over the other, will continuously expand energy potentials. Around 2050, deuterium fusion begins to take hold. Next, deuterium-tritium reaction fusion is perfected by 2075, followed by deuterium-helium3 fusion in 2250.

One out of every 6,000-6,500 naturally occurring hydrogen atoms is deuterium. Minuscule amounts of deuterium found in a gallon of water yield the energy equivalent of about 360 gallons of gasoline. One gram of hydrogen converted into helium can produce an amount of energy equivalent to 20 tons of coal. A thimbleful of heavy-hydrogen (deuterium) could generate as much energy as 20 tons of coal.

Hydrogen energy sources here on Earth, if developed, will provide prodigious energy. Supplies could last billions of years. The top ten feet of the ocean contain enough heavy hydrogen to supply projected energy needs on Earth for as much as 50 billion years. Other estimates place the hydrogen content found in all the oceans sufficient to meet Earth's energy demands for another 300 billion years! Fusion is the 500-pound gorilla of energy. Underlying assumptions regarding hydrogen are bullish almost beyond belief.

Science and technology have mastered atomic fission in powerful but rudimentary ways. Nuclear fission, accomplished nearly 60 years ago, led to the abrupt termination of World War II. Since then, fission has been harnessed not only to create vast arsenals capable of potential nuclear annihilation, but numerous peaceful purposes as well. By far, the most important application has been the generation of bountiful electric energy.

Nuclear fission involves splitting large and heavy nuclei into lighter pieces that usually are radioactive.

Supplies of fissile elements are finite. Proven reserves used for conventional fission are expected to last another 50 years.

Nuclear fusion differs markedly from fission. Fusion involves combining or fusing two very light atomic nuclei – basically, hydrogen and helium isotopes – to form a heavier element. Efficient refinement of raw material resources, containing superheated plasma, and "ignition" creating conditions under which plasma would continue to heat itself thus perpetuating the thermonuclear reaction, pose major obstacles yet to overcome. Most difficult of all is attainment of the extraordinarily high temperatures and pressures to break the nucleus of hydrogen – 100 million degrees Celsius for heavy hydrogen (deuterium-tritium) reactions. Temperatures sufficient to ignite nuclear reactions typically occur only in stars and nuclear bomb explosions. The National Ignition Facility is expected to generate temperatures reaching 100 million degrees. This feat involves the focus of 192 laser beams generating 500 trillion watts of power at a mini-pellet of hydrogen gas the size of a small seed.

Plasma, the fourth state of matter, involves phase transitions that occur around 1,000 degrees Celsius. Solid materials found on Earth cannot contain plasma because they vaporize at these extreme temperatures. Containment magnetic traps surmounting this obstacle include tokamaks, stellerators, and magnetic mirrors.

Cold fusion, which could sidestep those enormous temperature requirements, is claimed to have been accomplished by forcing deuterium into minuscule spaces between atoms of a metallic crystal by neutron bombardment and sonic shockwaves, and a variety of other experimental techniques. Replication and verification of these approaches has been difficult to corroborate.

Continuing advances in superconductivity, laser ignition techniques, and magnetohydrodynamics could make thermonuclear fusion from hydrogen isotopes a commercial reality by 2025. At least another 12-25 years will be required for building facilities to generate and supply that energy. Over 40 years of intensive research, so far, have been devoted to developing controlled thermonuclear fusion. Overcoming all obstacles has remained elusive.

Shifting to super-heavy hydrogen (tritium) creates more powerful fusion reactions. Deuterium-tritium reactions yield four times the energy output of deuterium-deuterium fusion. Tritium does not exist naturally on earth. However, it can be manufactured by nuclear bombardment of lithium. Tritium is radioactive and decays into helium-3 within 12.33 years time.

Beyond D-T fusion, helium isotope reactions provide even more powerful energy output than can be achieved with hydrogen isotopes. Deuterium-helium3 reactions provide the highest heat content of any known materials, so far.

Only one known form of material – antimatter – has a higher heat content than D-He3 fusion. Into the distant future, antimatter may very well become the dominant energy source. Historical perspectives involving energy highlight a continuing succession of improved energy sources. Scientific estimates calculate that antihydrogen gas theoretically would yield an energy output 259-fold greater than D-He3 fusion, 1,000-fold greater than nuclear fission, and 7 billion times the energy equivalence of a hydrogen-oxygen rocket propellant. Facts and figures, such as those mentioned here, make it clear that Malthusian-type pessimism has little relevance for sizing up the energy future.

World installed electrical power generating capacity measured in gigawatts rose from 1 in 1960, reached 114 in 1978, hit 219 in 1984, 310 in 1988, and remained stable at 343 between 1996-1998. Capacity is projected to decline to 165-174 gigawatts by 2020. While some countries slack off from nuclear fission, others aggressively pursue adding new capacity.

Electric energy from nuclear sources, highest in Lithuania, reached 77% in 1998. French planning goals sought 85% reliance by 2000, and met 75% of needs in 1998. US users received 22% of electrical needs from nuclear sources during the same year. Many developing nations aggressively pursue fuller development of nuclear fission generating capacity.

Nuclear power plants operating worldwide totaled 442 with 38 under construction in 1998. Construction of nuclear power plants, require 12 years to complete in the US. It requires only 5 years time in France, and 6 years in South Korea. Onerous regulatory obstacles and pockets of spirited protestors and detractors – politics, in short – figure prominently in delaying US projects.

Long lead times for construction of nuclear facilities and huge capital requirements, combined with adverse public opinion tend to discourage construction of reliable and low cost nuclear power plants. From a practical standpoint, capital costs have a great deal to do with the pace of America's nuclear energy development. Gas-fired generating plants range between $400-500 per kilowatt, compared to $1,000 or more for nuclear power plants.

Since 1996, nuclear energy has been the second largest supplier of electricity in the US. Nuclear power plants supply more electricity than oil, natural gas, and alternative energy sources combined. Nuclear and coal sources supplied a combined 77% of U.S. electrical energy requirements in 1999 – 20% nuclear, and 57%, coal.

Public attitudes turned cautious following the March 29, 1979 incident at the Three Mile Island reactor site, and the April 26, 1985 accidental meltdown at Chernobyl. Global warming concerns, strange as it may seem, ultimately may rally environmentalists to back non-polluting fusion power over fossil fuel sources.

With nuclear fission plants about to be displaced by fusion, coupled with a host of varied concerns and rationales, some nations have taken a go-slow attitude. Most far-sighted among these nations is Iceland. The Prime Minister of Iceland already has planned switching over to a hydrogen-based energy economy between 2012-2017. Italy has gone so far as to entirely phase out nuclear fission by shutting down its 3 plants. Austria has imposed a complete nuclear moratorium and phase-out, and quasi-moratoria also exist in Switzerland and Sweden. Germany's ruling coalition also has announced goals to phase out all of the nation's 19 nuclear reactors. In the US no new nuclear power plants have been ordered since 1973. Operating plants numbered 104 in 1998, down from 112 operating units in 1990.

The bold faced reality is that nuclear fission is an obsolete technology. Improved technological approaches look promising. However, investing massive sums in ill-fated technologies does not appear to be the best course of action. It takes about 25 years to construct and get a nuclear power plant operational in the US. It's much shorter elsewhere, even in Japan. Considering the atomic devastation of Hiroshima and Nagasaki, that use pattern amazes me. The overarching problem is that during this 25 year timeframe, hydrogen fusion begins to emerge. At that point, nuclear fission likely will atrophy and be all but abandoned. In some European nations, nuclear energy provides 80% of electric power. It's something like >22% in the US – plenty of room for growth, obviously. Time will rapidly obsolete nuclear fission plants.

Growing Energy Demand

Overall, the global need is for more, not less energy. Electricity demand worldwide is projected to quadruple over the next 50 years. The French Academy of Sciences projects as much as a nine-fold boost! Shorter-term forecasts place global energy demand increases in the range of 34-44% by 2010, and 54-98% by 2020. There is little doubt about the trend. Global energy needs show no sign of abating. They are accelerating.

Boosting energy demand is world population growth. Global population will more than double by 2050. This trend, minimally, suggests a proportionate doubling of energy demand. Increased energy needs imposed by energy-intensive economic activities – particularly in lesser-developed nations – could increase energy demands an additional 3 to 5-fold. Growing energy demand is driven by the 2 billion persons currently without access to energy services due to poverty and lack of supporting infrastructures. Overall, it may not be unreasonable to plan toward a 10-15-fold increase in energy needs by 2100. No matter how energy needs are sized up, it is obvious that new and abundant sources of energy are imperative.

Many variables enter into calculating global energy demands. Projections covering a huge range of possibilities can be found. Robert Zubrin forecasts energy consumption (measured in terawatts or 1 million megawatts) that amounted to 14 in 1998 will nearly quadruple to 53 in 2050; then almost quadruple again to 192 by 2100; and soar to 2,500 by 2200.

Zubrin's foregoing projections suggest that between 1998-2100 the terawatt-years of cumulative energy use will total 7,000 terawatt years. Meeting that level of cumulative demand highlights the energy dilemma. Earth's known fossil fuels amount to a mere 3,000 terabit years. Adding estimated unknown fossil fuels – estimated at 7,000 terawatt years – underscores limitations of Earth's predicament. Traditional nuclear fission generation adds an additional 300 terawatt years; and nuclear fission generated by breeder reactors could add another 22,000 terawatt years. But the promise of hydrogen and helium prodigious energy potentials points the way to a new and different energy future.

Extraterrestrial sources could provide bounteous potentials of energy-producing materials so vast that they are hard to comprehend. Extraterrestrial hydrogen and helium can sate thermonuclear energy output far beyond the 9-10 billion year life cycle of this solar system. Considering that only another 4-5 billion years remains until the expanding photospheric death throes of the sun rages and life on Earth is wiped out, it's doubtful that this planet's needs will fail to be sated. Measured in terawatt years of potential energy, extraterrestrial helium isotope He3 includes: lunar, 10,000 years supply; Jupiter, 5.6 billion; Saturn, 3.04 billion; Uranus, 3.16 billion; Neptune, 2.1 billion. Extracting hydrogen/helium from Jupiter is foreclosed due to the planet's size, gravity and equatorial rotational velocity. The giant gas planets have been dubbed the "Persian Gulf of the solar system." All too soon, giant ocean tankers no longer may be transporting petroleum from places like the North Seas, Persian Gulf, or Alaskan North Slope. Instead, inter-planetary tankers will extract and/or transport their bounty gathered from surfaces and gas enshrouding clouds that engulf these planets. Resource recovery concepts, foresee interplanetary mining/transport vessels capable of utilizing atmospheric planetary materials native to each planet to fuel the recovery vessel propulsion systems.

Lunar stores of helium-3, blasted onto the lunar surface by solar winds, are locked up in raw regolith surface materials. Concentrations in lunar regolith are relatively small – about 4 parts per billion. At this concentration, processing 250,000 tons of regolith would be required to extract a single kilogram of helium-3.

Petroleum

Oil industry experts project that petroleum reserves will run dry around 2050. OPEC foresees supplies lasting until 2080. Other forecasts calculate a 42-50 year remaining supply of petroleum. American Petroleum Institute estimates of 1.4-2 trillion barrels, including probable new discoveries and technology advances, are projected to provide supplies for another 63-95 years. Various experts foresee production peaking between 2005-2020, and then declining. The obvious conclusion is simply that reliance on finite fossil fuels is waning – rapidly.

Previously, expert forecast have been short of the mark. Pennsylvania's state geologist, during the days of kerosene dominance, ominously warned: "the US (has) enough petroleum to keep its kerosene lamps burning for only four years." Over the years a staccato of dire warnings asserted oil supplies would be depleted during the 1920s, the 1940s, and the Club of Rome's 1972 sensationalized report prophesied that supplies would last only another 20-31 years. Pessimistic speculations are rampant. So are the optimistic ones.

As things turned out, world oil consumption of 436 million tons in 1950; more than doubled to 1,020 million tons in 1960; doubled again to 2,025 in 1969; and reached 3,423 tons in 1998. The stark reality is that fossil fuel supplies are finite and world supplies are steadily being drawn down. As world supplies of petroleum dwindle ARCO's Chairman and CEO recently stated (1999): "We've embarked on the beginning of the last days of the age of oil."

Current consumption (2000) amounts to 72 million barrels of crude oil daily. Experts forecast that production will peak at 85 million barrels per day by 2010. Thereafter, output may drop to about 30 million barrels by 2025-2030, and 15 million around 2035-2050.

Petroleum and natural gas supplies, as they dwindle to precariously low levels around 2050, no longer will be burned as fuel. Use will be largely confined to the value-added end of the spectrum, including production of plastics and fine chemicals. Petrochemical sector products are vast and varied: dyes, plastics, resins, sulfur, crude petroleum: gasoline, diesel, kerosene, lubricants, illuminants, plastics, synthetic fibers, dyes, solvents, paints, paraffin, bitumen, insecticides, fertilizers, synthetic rubber, solvents, explosives, glycerin, polishes, toiletries, pharmaceuticals, food preservatives, adhesives, detergents, chewing gum, and hundreds of other uses too numerous to mention.

Petroleum locked up in much more diffuse and difficult forms – tar sands and oil shales – are huge. Cost of extraction, at current prices, makes exploitation financially impossible. As supplies grow scarce and processing technologies enable greater productivity advances, things may change.

Conservation of supplies and energy efficiency increases suggest additional potentials for stretching out petroleum supplies. One surprising indicator of potential automobile fuel economy is underscored by the 7,591 miles per gallon record set at the Shell Mileage Marathon in 1992.

Increasing world reliance upon OPEC-suppliers steadily enhances cartel opportunities to raise prices. OPEC accounted for 67% of global oil supplies in 1973; dropped to 38-40% in 1987; 35-45% in 1995; and zoomed up to 63% by 2000. Saudi Arabia alone can produce enough oil to supply the world; therefore, the Saudi's virtually control world oil prices. OPEC resurgence and capacity to control petroleum supplies and prices is very likely to be reasserted from here on.

In the span of about a century, the world devoured far more natural resources than were consumed by all the other humans that ever lived on this planet! The US alone, representing about 4% of world population, accounted for 24% of global oil use in 1997. With the end of finite resources more clearly in sight, attitudes are divided into two camps: 1. Those who fear the worst (running out of everything, and bringing society to a screeching halt); and 2. Those whose abiding optimism, instills a certainty that new ways to deconstruct and reconstruct matter, and/or the ability to mine resources elsewhere in the cosmos will satisfy our every need.

Gasoline annual consumption runs about 160 billion gallons in the US. This means that a $1 boost in price takes $160 billion out of consumer pocketbooks, gas tank by gas tank. Gasoline prices are likely to rise at least $2 more per gallon, and possibly higher, as supplies become scarce (and costly). Compared to the US, prices are already that high (above $5.00 gallon range) in many European and Scandinavian nations. Income-price elasticities are certain to wreak havoc on consumption patterns.

Petroleum – Early Development and Uses

Oil supplies have served world needs for at least 5000 years. Oil seepages were gathered and consumed as an illuminant since about 3000BC! By 500 BC, petroleum was being extracted using hollow bamboo tubes to tap near-surface supplies.

Today, when we think of petroleum, attention is riveted on the OPEC countries. Interestingly, OPEC countries actually discovered their "hidden treasure of black gold" in recent years. Oil wasn't discovered in Saudi Arabia and Kuwait until 1938! Not until the 1960s did the immense Middle Eastern reserves outproduce all other areas. OPEC, founded in Baghdad in 1960, acquired effective cartel control over supply and prices in the following years. Precipitous increases in petroleum prices were largely responsible for at least one worldwide economic depression. Since then, oil supplies and prices have acquired a major role in international diplomacy, and a focal point leading to wars. In more recent times, environmental mandates add to higher petroleum prices.

Colonel Drake was not the first to undertake modern oil discovery. First stirrings actually commenced in Ontario in 1857, 2 years before Colonel Edwin Drake's discovery in Pennsylvania. Following Colonel Drake's oil well in 1859, the principal use, mainly kerosene used for lighting, quickly displaced whale oil. Lighter petroleum fractions, including gasoline, simply were discarded! Heading into the 20th century, oil provided a mere 2.4% of energy use. That low level of consumption was soon to change. Following Edison's demonstration of electricity in 1882, demand for petroleum began to surge. US households served by electricity zoomed from 10% to 30% between 1910-1930.

Infrastructure development greatly accelerated demand. The first drive-in gasoline station opened in St. Louis in 1907. The New Jersey turnpike, opened in 1951, ushered in high speed and limited access roadways. The first major chain of highway motels – Holiday Inns – opened in 1952. Fast food drive-in restaurants hit big time with the opening of McDonald's in Des Plaines situated in suburban Chicago. Drive-in theaters became a favorite gathering place during the 1950s. With most major needs conveniently available along major roadways, Americans turned to the open roads in huge numbers. These developments helped set the stage for a dramatic take-off of energy demand that persists and continues to grow to this day.

After Henry Ford built his first car in 1896, popularity of motorized vehicles opened up huge new markets that far surpassed kerosene use. The Wright brothers 1903 demonstration of flight with heavier than air machines opened up another voracious new use for gasoline and kerosene. Battlefield mechanization involving tanks, trucks and aircraft began in earnest during World War I, 1914-1918. In 1940, the Arabian Peninsula nations supplied a mere 5% of global oil, a small fraction of the 63% then provided by the US. US dominance in production and refining of petroleum during World War II provided a decisive advantage. US supplied 90% of oil requirements for allied forces.

Costly Displacement of Petroleum-Based Infrastructure

Shifting away from petroleum and internal combustion engines, entails enormous economic ramifications. Far-flung economic investments, institutions and resources comprising petroleum and related sectors – pumping, shipping, refining, storing and distributing, and end uses – will incur unavoidable dislocations, substitutions, and costs. From discovery, through refining and end uses, giant petroleum companies, automotive and aircraft manufacturers have topped lists of the world's biggest economic undertakings. Direct and indirect entrepreneurial activities, in the aggregate, constitute the world's largest business.

What is to become of the huge investments in oil drilling equipment, pipelines, oil tanker fleets, refining plants, distribution equipment, gasoline stations, and so on? What happens to gasoline engine manufacturing? Not only motor vehicles, but all other gasoline, diesel, propane and natural gas driven equipment will be affected. Watercraft, skimobiles, all terrain vehicles, auxiliary generators, and the entire arsenal of war machines (from aircraft carriers to Humvees) are among the affected interests facing massive changeover. Gas fired boilers, residential heating and cooling systems, and appliances of all kinds also could become obsolete or require major retrofitting. Business architects of destiny need to be figuring what to do and how to make the change over relatively painless and less disruptive.

Financial stakeholders in these outcomes – investors and stockholders in fossil fuel and related businesses – also need to be looking ahead as the industry runs out of its traditional resource base. Investors, now including a majority of all Americans, should not be left holding the bag. Will shrewd insiders "bail out" and minimize their losses due to waning value of capital producing assets those stockholdings support? Will unsophisticated stockholders who are unable or unconcerned about asset management fail to get out on a timely basis? Who will incur and bear the brunt of this massively costly obsolescence?

Transportation Impacts of Petroleum Depletion

Hardest hit by dramatic increase in the price of oil will be transportation, which accounts for some 62% of domestic oil consumption. This domineering share dwarfs the 25% use by industry, and 9% consumption of commercial and residential users.

Personal travel in the US, a whopping 89.7% of it, is on roadways. Worsening traffic congestion, more cars, and more drivers are coming. Registered vehicles in the U.S. rose from 8,000 in 1900, to 144.2 million in 1992. Vehicles and drivers will increase 20-25% by 2010. Mileage driven will nearly double. Vehicles per household will increase: 1.28 in 1969; 1.68 in 1983; 2.0 in 2020.

Worldwide, the number of motor cars and trucks in service is expected to double between 1996-2036, rising from 625 million in 1996; to 1 billion by 2026; and reach 1.25 billion by 2036. A few years ago, car owners in China, the most populous nation in the world, were rare. Only 1 out of every 690 Chinese owned a car. The handwriting is on the wall. Pent up demand and rising affluence already is imposing dramatic change.

Motor vehicles – as major energy users and environmental pollution culprits – will be a constant target for government regulators. However, citizen frustration with bumper-gridlock may actually goad tougher policy changes intended to relieve motor vehicle traffic. Traffic jams consume increasing time and escalate driver aggravation. During 1989, bumper gridlock accounted for a loss of 1.6 billion man-hours. The number of lost hours is expected to climb to 8.1 billion by 2005.

Airline passenger volume also is poised to skyrocket, imposing greater demands on gasoline and kerosene fuels. Boom time in travel and tourism is coming. Airline passengers, 243 million of them in 1978, more than doubled to 599 million by 1998, and are projected to reach 900 million by 2007 (FAA estimates).

For piston powered (internal combustion engine) propeller-driven aircraft, the problems are much the same as motor vehicles. Jet fuels, basically kerosene, burns at 125F. Blends using methane or napthene additives have a flash point of only 110F. Compared to motor vehicles these relatively cool temperatures generate about one-fourth the temperature of internal combustion engines.

Coal can be converted into liquid fuel and used as a substitute for gasoline and aircraft fuel. South Africa currently relies on synthetic gas for motor vehicles, and Germany's WWII motorized war machine relied for up to 57% of fuel needs – including as much as 95% of aviation fuels – from vast synthetic fuel facilities. German chemistry, the finest worldwide in the early-1900s, had developed processes for extracting gasoline from coal. The irony is that chemical company leaders, especially I.G. Farben, sought these developments because of widespread fears that petroleum would soon run out. Friedrich Bergius (inventor of the hydrogenation process) and Carl Bosch (I.G. Farben chairman) shared the 1931 Nobel Prize in chemistry for these feats. Hitler's war machine built up enormous synthetic fuel capacity to run the machines of warfare. Destruction of Germany's synthetic production facilities has been given major credit for defeat of the Axis wear machine. By the first quarter of 1944, synthetic fuels provided 57% of Germany's fuel supply. Until such time as practical hydrogen-based propulsion system for aircraft can be developed, alternative synthetic fuels will have to be relied upon.

Natural Gas

Still another cushion against the drawing down of petroleum and the shock of OPEC oil price increases yet to come, is natural gas. U.S. proved reserves amount to a 12-year supply. Suspected reserves extend domestic availability to a total of 50 years. Should it become technically and financially possible to extract supplies from shale, coal deposits, sandstone, and quantities mixed with salt water under the Gulf of Mexico, supplies could last as long as 200 years.

World consumption of natural gas, measured in terms of million tons of oil equivalent, skyrocketed from 187 in 1950 to 1,022 in 1970, and more than doubled to 2,210 in 1998. Enormous accelerated use has been jolted by the fact that natural gas burns cleaner than most other fuels, cost less, and enjoys a considerable environmental advantages over competing energy sources. Most of the world's known natural gas reserves are situated in the Soviet Union.

Nascent motor vehicle uses of natural gas, methanol, ethanol, butane, propane and other interim cleaner-burning fuels may assist the transition from gasoline to hydrogen powered vehicles. Natural gas pipelines, pumping stations and distribution lines may be able to convert to hydrogen with relatively modest capital costs. Seals and compressors would have to be changed, pipe diameters may have to be increased, and additional pipelines would have to be built. Remote areas could be served by trucks or trains with supplies delivered in liquefied form. Ships for transporting liquefied gasses also could be converted.

Natural gas powered vehicles have been in use for decades, especially in European nations. Some taxis in NYC and Hartford use natural gas. Motor buses in cities such as Vancouver and Chicago also are powered with natural gas. Use has spread to many cities. Across the US, 1,312 natural gas refueling stations have cropped up. Servicing mainly fleet vehicles, buses and trucks, very few of these filling stations are open to the public.

Compressed natural gas tanks are bulky, heavy, costly, and limited in capacity. Advanced materials, including high-density polyurethane and carbon fiber sandwiched construction improve many of these shortcomings.

BMW joint efforts with MVE-INC (Burnsville, Minnesota) have developed a liquefied natural gas system featuring a heat exchanger to vaporize minute amounts of the fuel that is stored in a insulated tank about as heavy as a regular gas or diesel fuel tank. These cryogenic tanks store LNG at -260 degree Fahrenheit.

Motor Vehicle Fuels - Hydrogen

Ultimately, hydrogen, not natural gas, will become the primary energy source for motorized transport. Changeover from gasoline engines to gas and hydrogen-fueled vehicles requires transitioning to ease financial burdens of obsolete equipment. Scientists are working on a wine-bottle-sized unit – called a plasmatron – which can transform gasoline into hydrogen rich gas. Electric arcs create conditions and temperatures to convert fuel-air mixtures into a plasma. Much larger versions of such equipment already are used for industrial purposes that are driven by hydrocarbon fuels converted into hydrogen-rich gas mixtures.

There are some important jurisdictions to follow – and learn from: Iceland and Germany which have already embarked on hydrogen conversion efforts. Hydrogen fueling stations for motor vehicle are cropping up. The first public hydrogen filling station, opened in 1999 at the Munich airport. Both liquefied and gaseous hydrogen fuels are available. Liquefied hydrogen requires cryogenic storage at -423 degrees Fahrenheit. Gaseous hydrogen, stored in high-pressure tanks, is utilized by motor buses. In the US, the first hydrogen fueling station opened in Dearborn, Michigan.

Storing hydrogen is not easy:

1. Compressed hydrogen gas stored in high-pressure tanks provides a denser fuel source. Heavily clad tanks are required to safely contain potentially explosive contents. Memories of the ill-fated explosion of hydrogen gas contained in the Hindenburg zeppelin at Lakehurst, New Jersey create uneasiness.
2. Liquefied hydrogen stored under pressure at cryogenic temperatures (-250 degrees Celsius or -423 degrees Fahrenheit) provides another approach. Catastrophic explosion of the liquefied hydrogen carried by the Challenger space shuttle also creates consumer wariness.
3. Metal hydride storage in liquid and powdered form is the safest approach. Compounds including titanium-iron

and magnesium-nickel, posses a strong affinity for hydrogen. One shortcoming is weight – tanks weigh 800 pounds and provide a mere 4-gallon equivalent of gasoline. Carbon nanotubes measuring a few dozen atoms wide combined with lithium and potassium store large quantities of hydrogen at normal pressure. These storage cells can be recharged and discharged many times without appreciable decreases in absorptive power. Carbon nanofiber mass of merely one gram can deliver 10 liters of hydrogen – an energy density of 16,000 watt-hours per kilogram. This capacity provides a massive advantage over watt-hours of electrochemical energy stored in: lead acid rechargeable batteries, 30; nickel cadmium, 40; nickel-metal hydride; and lithium-ion, 130.

Another approach for generating hydrogen supplies calls for erecting vast arrays of photovoltaic cells in desert areas that uses the electricity generated to electrolytically separate hydrogen from oxygen that constitute water. This arrangement would provide raw hydrogen to fuel thermonuclear plants for generating massive amounts of electric power and heat. Other promising new developments, including one that utilizes sunlight striking water spiked with catalysts to generate hydrogen, also show promise. These so-called "water splitters" may provide an inexpensive source of hydrogen to power fuel cells or for raw material pursuant to fusion energy.

Fuel Cells

DaimlerChrysler's 4-passenger model (Necar4), introduced in 1999, runs on liquid hydrogen with a cruising range of 280 miles. Also under development is a fuel cell using methanol that is broken down into hydrogen that is used, in turn, to run fuel cells. Fuel cells involve no moving parts, require less maintenance (compared to gasoline engines), are energy efficient (50% more so than traditional gasoline engines), and generate few undesirable emissions. Fuel cells operating on methanol have considerable advantages over nickel-cadmium batteries. The power generated is 20-fold greater, weigh considerably less, cost less, and recharge quickly and simply (by adding more fuel).

Fuel cell sales totaled $305 million in 1998. Sales volume was expected to reach $1.1 billion in 2003, and as much as $10 billion by 2010. Studies forecast that 10,000 motor vehicles will be operating on fuel cells by 2003. Ballard Power Systems (Vancouver, Canada), in partnership with DaimlerChrysler since 1989, foresees commercial viability of fuel-cell powered vehicles by 2010.

Mass produced fuel cells designed for motor vehicles recently cost around $30,000 – about 10-fold the cost of gas-powered motors, according to DaimlerChrysler estimates. Demonstration buses using these technologies – already operating in Chicago, Washington, and Vancouver – sell for $1.2 million. Diesel buses, in stark contrast, sell for around $250,000. Cost, space and weight of fuel cell systems pose both design and mileage-efficiency obstacles. Other problems involve limited operating range and scant availability of recharging facilities. Some fuel cell vehicles are capable of matching the 280 mile driving range of conventionally fueled vehicles before refueling. Recharging facilities, on the other hand, are rare.

No matter now well-intentioned product offerings may be, and no matter how idealistically perfect the concept, if economic considerations aren't part and parcel of the evaluation, commercial success is unlikely. Without public subsidies and research funding, advance of these technologies would lag.

Fuel Cells – Home Energy Appliances of the Future

In addition to motorized vehicle applications, residential fuel cell energy systems may help boost hydrogen use. History has a way of repeating itself. In the days before central electric generating plants, the Edison Electric

Illuminating Company installed complete electric generation systems on site at individual locations. Development of hydrogen-based fuel cells seems to be headed in the same direction. Servicing of these units would be conducted along lines similar to those used for servicing central air conditioning and heating.

Residential fuel cell units about the size of a regular furnace generating 3 kilowatts have been developed by the Electric Power Research Institute and Analytic Power (Boston). Household electric use ranges between 2-10 kilowatts, averaging 1.5 kilowatts of power. Fuel cell units eventually are expected to cost about $3,000. Operating costs of about 8 cents per kilowatt hour, compare favorably with average current household energy costs that range between 4-12 cents per kilowatt hour. Developers foresee a potential US market for 25 million units.

Many other businesses are developing appliance-sized home power plants. Micro Gen – a joint venture involving Plug Power and General Electric – strive to equip 1 million fuel cell on-site installations by 2001. So far, 50 demonstration units were installed in 1999, and another 500 installations were planned for 2000.

Advent of on-site power systems, some contend, involves a potential longer-termed shift away from central energy producer/sellers. They foresee decentralized home-based producers able to sell excess energy into local energy grids. Other energy producing components – mini-gas turbines and photovoltaic among them – add credibility to these possibilities.

Larger free-standing units provide a wide and growing range of other special energy needs. The largest hydrogen-based fuel cell system weighs 8 tons and generates 300 kilowatts. This bank of polymer-electrolyte membrane cells (PEM fuel cells) relies upon chemical reactions between hydrogen and atmospheric oxygen creating water as a byproduct. Two units have been ordered to power submarines commissioned in 2003 for Germany's navy. Italy's navy also ordered two similarly equipped submarines. High-volume industrial and commercial applications – including office buildings, hotels and apartments – for these new power units are obvious.

Needs for on-site back-up power sources to avoid disruption of sensitive operations may bolster on-site power system sales. Power brownouts, blackouts and outages of all types are a bane to energy-sensitive operations – including computer applications and semiconductor manufacturing. These shortcomings impose an estimated $28 billion in lost production on US business (DOE estimate).

Fuel Cells – Miniaturized Applications

Yet another facet of hydrogen-based energy system development, involves small-scale applications for energy-hungry portable equipment. Miniaturized versions of fuel cells are under development for use in portable electronic devices that are cropping up everywhere one looks.

Methanol-based fuel cells consuming only one liter of fuel could provide as much as 5,000 watt hours of energy. This would be enough to run a computer laptop for a week or longer – about ten-fold the output of today's energy-dense champ, lithium-ion batteries.

Costs weigh heavily in favor of fuel cell technologies – 30 hour output at a cost of $2-5. This affordable price is markedly lower that than nickel-cadmium batteries. NiCad batteries with a 20 watt output for one hour, weigh about one pound, and cost roughly $20. Comparable lithium-ion batteries run for three hours, and cost even more – about $80. Liquid hydrogen can deliver 800 times the power output of a nickel-cadmium battery. However, cryogenic storage necessity (-420 degrees Fahrenheit) makes diminutive applications unlikely, if not impossible.

Coal Supply and Use

Coal production levels indicate 230 year supply availability, and up to 400-500 years with enhanced efficiencies. UNESCO estimates (c.1997) are more pessimistic, projecting that coal reserves will last for another 200 years.

THE US is the "Saudi Arabia of coal," possessing reserves with an energy equivalent greater than proved OPEC reserves. US recoverable coal supplies, as of 1998, amounted to 274 billion tons. Compared to other energy sources, 95% of known US coal supplies remain untapped and available. Remaining coal reserves dwarf other energy-producing materials – 2% for oil and 3% for natural gas – yet to be extracted within the US territory.

Worldwide, coal reserves constitute something less than 90% of all known fossil fuel stores. Three nations – US, China, and the Soviet Union – account for over 80% of world coal reserves.

World consumption of coal, measured in terms of million tons of oil equivalent, doubled between 1950 and 1998, rising from 1,043 to 2,236 million tons (oil equivalent). World production of coal is expected to soar, rising from 2.8 billion tons in 1981 to 6-7 billion tons by the year 2000. Currently, approximately 62% of total world energy use comes from fossil fuels – a whopping 38% of it from coal.

US electric energy generation from coal amounted to 56% of total output in 1998. Coal use, in the U.S., is expected to become and remain the dominant energy source for many years. DOE energy growth projections for coal are bullish:

2015-2020 = 45%
2010-2015 = 38%
2005-2010 = 30%
2000-2005 = 21%
1998-2000 = 11%

The long and the short of impending energy demands is that "king coal" stands to bridge the gap. Traditional petroleum and natural gas supplies are fading. Before hydrogen and helium for thermonuclear energy generation become commercially viable, cost effective and widespread, coal will become the energy mainstay.

Further environmental regulations surely will be imposed to minimize polluting effects, particularly of lower-grade and high-sulfur content coal. About 40% of new generating plant costs already involve pollution control investments. Advanced combustion technologies and processes under development promise cleaner burning coal fired facilities – even for lower grade fuels that will be burned when higher grade reserves are drawn down. Utilities may be able to afford more emission control efforts. But, will it be worth it? What, exactly, are the costs and benefits of such action? Cost-effective pollution control equipment will make coal use increasingly attractive.

Social-Political Impacts on Energy

Critical variables materially affecting energy involve population growth, modernization, industrialization, and urbanization – especially in lesser developed nations. Population growth and increased affluence drastically boost world energy demands. UN projections that population growth will level off and stabilize are, at best, hopeful. My assumptions are much, much higher over the long term. Domestic use of energy will hinge, to a considerable extent, upon effects of global supply and demand. World energy use increases (measured in quadrillion Btu/year) vary. My assumption is that demand/use will soar at least 3-4X current levels. As dollars chase short supplies, prices will soar. Economic, political and social pressures – at that point – will escalate dramatically for technological fixes. Recall that every dollar increase in US gasoline consumption entails $160 billion in immediate consumer outlays. That kind and scale of economic pressure could make subsidies and full-throttle technological encouragement to find viable alternative energy sources more popular with taxpayers.

Over the past 30 years, or so, I've maintained that environmental problems attributed mainly to manufacturing will, to a large extent, resolve their own problems. What I mean by this is America (and other post industrial nations) have been easing out of manufacturing as the central and all-pervading economic activity around which society and the domestic economy are based. In other words, as less resources are committed to manufacturing, that sector will continue declining as the culprit or main source of pollutants. Agriculture once engaged over 90% of all US workers. Now, the sector engages about 2% of the workforce on farms. Even that low percent could be drastically reduced to supply domestic needs. As things stand, up to 50-70% of key crops are exported, not consumed domestically. In addition, over 60% of all Americans are obese/overweight which suggests that domestic food consumption could be cut by at least another 20%. Similar trends are underway in US manufacturing. Following the pattern in agriculture, US industry ceased to employ a 50% majority of the workforce in industrial manufacturing during the late-1920s. It's been downhill ever since. Today this sector employs perhaps 10-13% of all American workers. Just as with agriculture, large percentages of manufactured goods are exported. In addition, factor in the ability to do more with less resources. Clocks that once filled an entire temple, now involve paper-thin led display strips. Computers that once filled an entire room, are fitted into computational devices that drive a throw-away greeting card unit that tinkles, says, and sings "happy birthday." Nanotech gets at doing things now considered important to civilization, with quantities measured in quadrillionths of a meter – thousands of time thinner than the thickness of a human hair. Conclusion: less manufacturing activity, using less resources relentlessly continues to reduce and ameliorate environmental sullying.

Energy Environmental Impacts

Global warming worries and environmental insults created by fossil fuels will dim into the distant past in the New Atomic Age. Thermonuclear fusion of hydrogen into helium is environmentally benign, yielding neither radioactivity nor radioactive end products.

Not to delve into wild card assumptions, but I have to take issue with global warming. The 10 degree rise UN worrying and cajoling is a consensus, not a solid scientific projection. I could get into this factor (surely, a major "push" behind finding significant "alternative" energy sources), but withhold that for another place and time. Anthropocentric gasses (mainly CO2, a byproduct of fossil fuel pyrolization) are blamed. EPA has every good reason to respond – assuming that conclusion is right. And, it's well that they should. I've pulled together 10-15 well established cyclical variations – ranging from precession, solar flares, Earth's elliptical solar orbit, ocean currents patterns, and on and on – that actually (really and truly) do cause periods of global cooling and warming. I'm not fully committed to the idea that human contributions is the "straw that breaks the camel's back." Nor am I convinced that suppressing them is cost effective. President Bush's refusal to embrace and go along with the Kyoto protocols reflects just these kinds of reservations. Since that supposed (or real) problem is the causo debendi of EPA's great concern about energy use and controls, it's worth further truly impartial and less emotional discussion.

Global temperature realities are far different. Statistics don't lie, but statisticians sometimes do. Consider, for example, that global warming advocates use a questionable base year from which to calculate warming increases. Overlooked are medieval periods in time when fluctuations in global warming occurred. Global warming projections, loosely correlated with advent of the industrial revolution tend to make galloping assumptions plausible. Lost sight of are the macro variables which truly do – and always have – influenced climate on this third rock from the sun.

Causes and effects are many and varied. They will be debated for many years. For example, what happens to agricultural and forestry crops that benefit from higher CO2 levels? What role does affluence and increasing animal husbandry and livestock production play? Is New Zealand's answer to controlling greenhouse gasses – the infamous Farmers Against Ruminant Tax (FART tax) – off the mark?

Political and social, philosophical and ideological considerations play an important role in encouraging alternative energy sources. My calculations give lesser weight to such considerations.

High percentage increases in newly developing alternative energy sources often are cited with great excitement. Advocates of wind turbines, in particular, seem to get carried away in a euphoria as they cite immense percentage increases in usage. Such numbers do make quite a splash. One percent of one quadrillion is a huge amount; 1000% of a mere million of something looks impressive. The reality is that such comparisons pales to miniscule dimensions in the total overarching context into which it is fitted.

Even with bigger wind turbine blades, and more efficient photovoltaic cells, the relative cost advantage of other energy sources makes it problematical whether they can stand on their own. Output cost disparities between some alternative sources and cheaper sources ranged 15X, or more a few years ago. Solar energy survives amidst hype and hope. The first photovoltaic cell was developed over a half century ago (1954). Productivity is limited by latitude, weather, clouds, rain, accumulation of dust and debris (including avian wastes), length of the solar day, high maintenance costs, and so on. Many of the highest efficiency photovoltaic laboratory curiosities I've read about over the past 20 years appear to be far too fragile to exist outside the laboratory; nonetheless, the hope hypes prospects. Maybe that's good. Maybe it will work out. I, for one, remain dubious and reserve final judgment.

Without massive subsidies and huge tax breaks, the prospects for most alternative energy sources (including hydrogen fusion) would falter and fail. I've read reports indicating that Btu input to produce ethanol from corn is greater that Btu output. Without subsidies, that wouldn't last. A wild card is how long government will continue to heap support on interesting, politically-sensitive alternative energy sources. In the grand scale of overall energy generation, their contribution is (and will remain) miniscule. Traditional clusters of alternative energy (sans nuclear and batteries) are unlikely to attain 10% market share, ever. Some might say 20% which is probably overly optimistic.

Human Energy Sources and Requirements

From time immemorial, humans have drawn down whatever resources could be easily acquired to augment energy needs. Energy demands to sustain primitive humans ranged between 2000-3500 calories per day – a minimum of 1500 to sustain bodily functions, and up to double that amount, depending on physical energy exerted daily. Taming fire and domesticating crops and animals, boosted daily caloric requirements per capita to around 12,000 calories. As the Industrial Revolution took hold, another jump in energy demand was required – estimates of 70,000 calories per person per day have been suggested. Vast increases in the retinue of energy required to sustain modern Americans is estimated at 300,000 calories per day per person.

Shifts in the types of energy relied upon, provides another interesting perspective on energy use that involves each of the four states of matter. To augment reliance on human and animal muscle power, energy needs of increased measure were met by solids (wood, coal); then liquid forms (petroleum products); followed by gases (natural gas and others); and finally the fourth state of matter, plasma (thermonuclear fission and fusion). This article recounts past, present and probable future energy developments, concluding that Earth's supply of energy is – in the cosmic scale of this planet's existence – capable of meeting human requirements through all time.

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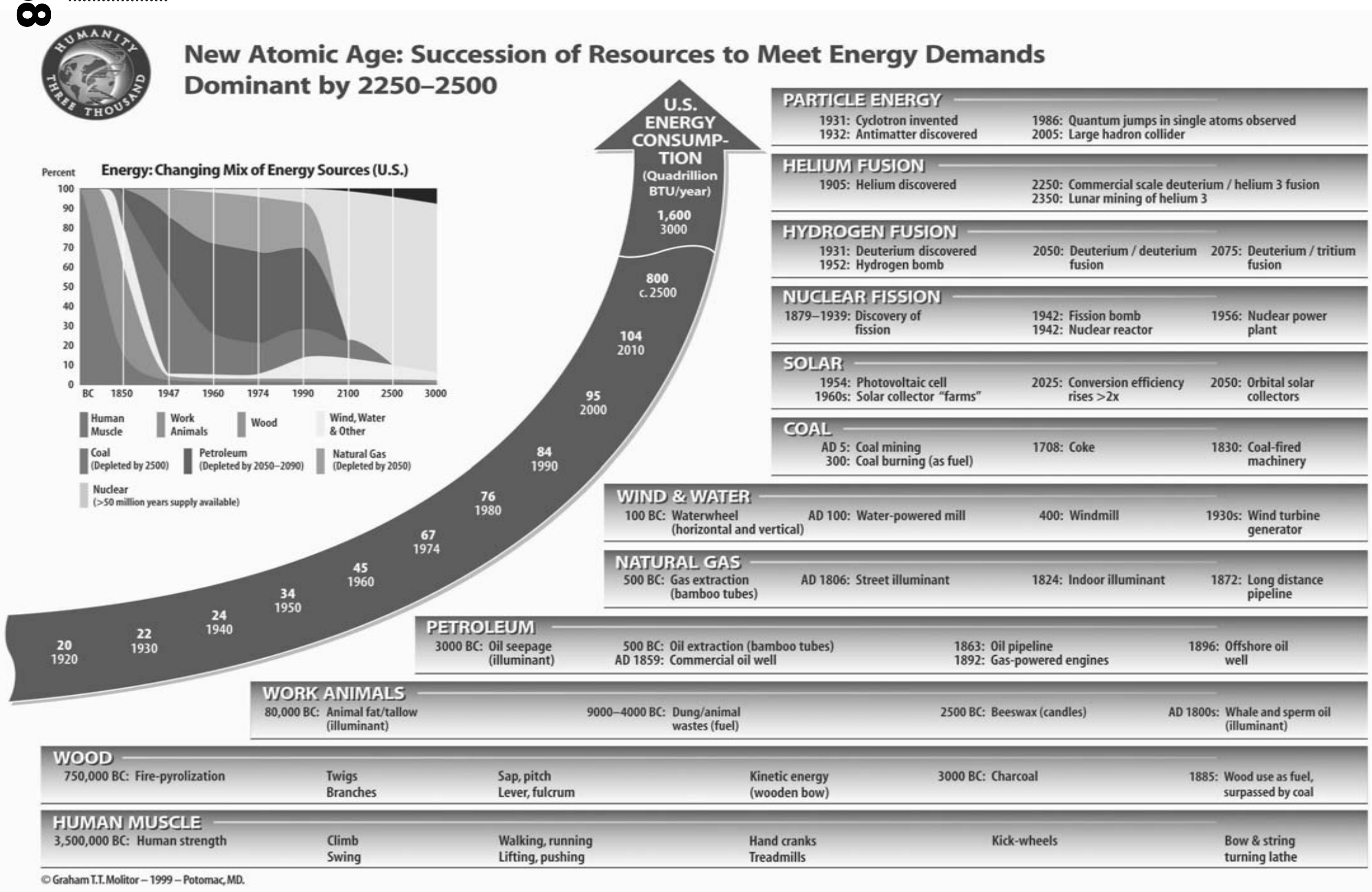
New Atomic Age: Succession of Resources to Meet Energy Demands Dominant by 2250–2500
HUMANITY THREE THOUSAND
Energy: Changing Mix of Energy Sources (U.S.)
Percent
100 90 80 70 60 50 40 30 20 10 0
BC 1850 1947 1960 1974 1990 2100 2500 3000
Human Muscle
Work Animals
Wood
Wind, Water & Other
Coal (Depleted by 2500)
Petroleum (Depleted by 2050–2090)
Natural Gas (Depleted by 2050)
Nuclear (>50 million years supply available)
U.S. ENERGY CONSUMP-TION (Quadrillion BTU/year)
1,600 3000
800 c. 2500
104 2010
95 2000
84 1990
76 1980
67 1974
45 1960
34 1950
24 1940
22 1930
20 1920
PARTICLE ENERGY
1931: Cyclotron invented
1932: Antimatter discovered
1986: Quantum jumps in single atoms observed
2005: Large hadron collider
HELIUM FUSION
1905: Helium discovered
2250: Commercial scale deuterium / helium 3 fusion
2350: Lunar mining of helium 3
HYDROGEN FUSION
1931: Deuterium discovered
1952: Hydrogen bomb
2050: Deuterium / deuterium fusion
2075: Deuterium / tritium fusion
NUCLEAR FISSION
1879–1939: Discovery of fission
1942: Fission bomb
1942: Nuclear reactor
1956: Nuclear power plant
SOLAR
1954: Photovoltaic cell
1960s: Solar collector "farms"
2025: Conversion efficiency rises >2x
2050: Orbital solar collectors
COAL
AD 5: Coal mining
300: Coal burning (as fuel)
1708: Coke
1830: Coal-fired machinery
WIND & WATER
100 BC: Waterwheel (horizontal and vertical)
AD 100: Water-powered mill
400: Windmill
1930s: Wind turbine generator
NATURAL GAS
500 BC: Gas extraction (bamboo tubes)
AD 1806: Street illuminant
1824: Indoor illuminant
1872: Long distance pipeline
PETROLEUM
3000 BC: Oil seepage (illuminant)
500 BC: Oil extraction (bamboo tubes)
AD 1859: Commercial oil well
1863: Oil pipeline
1892: Gas-powered engines
1896: Offshore oil well
WORK ANIMALS
80,000 BC: Animal fat/tallow (illuminant)
9000–4000 BC: Dung/animal wastes (fuel)
2500 BC: Beeswax (candles)
AD 1800s: Whale and sperm oil (illuminant)
WOOD
750,000 BC: Fire-pyrolization
Twigs
Branches
Sap, pitch
Lever, fulcrum
Kinetic energy (wooden bow)
3000 BC: Charcoal
1885: Wood use as fuel, surpassed by coal
HUMAN MUSCLE
3,500,000 BC: Human strength
Climb
Swing
Walking, running
Lifting, pushing
Hand cranks
Treadmills
Kick-wheels
Bow & string turning lathe
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