Kirk-Othmer Encyclopedia of Chemical Technology.

FUEL RESOURCES

The wheel is considered to be the greatest invention and fire the greatest discovery of all time. Together, the invention of the wheel and the discovery of fire as a useful force have led to the application of energy. From the invention of the wheel has come such innovations as steam and combustion turbines, rotors and stators used in electricity generation, diesel and Otto-cycle engines for transportation systems, and windmills, water wheels, and hydroelectric turbines. Similarly, the harnessing of fire has led to the use of various materials as fuels: coal (qv), lignite (see Lignite and brown coal), petroleum (qv), natural gas (see Gas, natural), tar sands (qv), oil shale (qv), peat, wood (qv), and the biofuels (see Fuels from biomass), organic wastes (see Fuels from waste), uranium and nuclear power (see Nuclear reactors), wind, falling water (for hydroelectric power), geothermal steam and hot water (see Geothermal energy), sunlight (see Solar energy), ocean thermal gradients, and the range of conversion products including both electricity and synthesis gas from coal (see Fuels, synthetic) have been used. These fuels are used both to power the wheel-related inventions and to supply energy for process applications: iron- and steelmaking, nonferrous metal smelting and refining, process heat and steam for pulp (qv) and paper (qv) operations, process energy for chemicals manufacture, etc. Harnessed fuels supply the needs of commercial and residential users as well.

Evaluations of fuel resources or total fuel supply focus on critical economic and environmental issues as well as existence. These issues include availability, utilization patterns, environmental consequences, and related economic considerations.

1. Historical Patterns in Fuel Utilization

Preindustrial society relied primarily on wood, other biomass, and falling water for energy. These energy sources provided carbon for steelmaking, heat for domestic and commercial purposes, energy for modest shaft power applications, eg, grinding of grain, and fuel for transportation on riverboats and early railroads. These fuels were readily available and could be gathered up or otherwise harnessed with little capital investment and scant attention to technology. U.S. energy consumption by fuel source from 1870 to 1990 is shown in Table 1.

Industrialization in the United States and northern Europe demanded significant sources of carbon for steelmaking, fuels for pumping water from mines, and energy for manufacturing processes. As the process of industrialization gained momentum manufacturing shifted away from optimal sites along rivers and connected regional economies with transcontinental railroads. Industrialization created a national economy, along with strong regional economies, through the use of energy for manufacturing and transportation systems, and coal was the fuel of choice (Table 1). With the advent of industrialization also came the shift in agriculture toward development of mechanized equipment and chemical fertilizers (qv), and petroleum became the dominant fuel. The emergence of pipelines (qv), has enabled natural gas, followed by complemented oil, to be the desired form of energy. Fuel selection factors, in all cases, include availability, energy density (J/kg or J/m^3), energy transportability, fuel cost, and fuel reliability.

Table 1. U.S. Energy Consumption by Source from 1870–1990, EJ[a, b]

Year	Woodandbiomass	Coal	Petroleum	Natural gas	Hydroelectric	Nuclear[c]	Other[d]	Total
1870	3.1	1.1						4.1
1880	3.1	2.1	0.1					5.2
1890	2.6	4.3	0.2	0.3				7.5
1900	2.1	7.2	0.2	0.3	0.3			10.1
1910	2.0	13.4	1.1	0.5	0.5			17.5
1920	1.7	16.4	2.7	0.8	0.8			22.4
1930	1.6	14.4	5.7	2.1	0.8			24.5
1940	1.5	13.2	7.9	2.9	1.0			26.3
1950	1.3	13.6	14.2	6.5	1.5			37.1
1960	0.3	10.7	21.2	13.4	1.8			47.4
1970	1.1	13.4	28.9	23.2	2.9	0.2	0.01	69.6
1980	2.53	16.27	36.08	21.51	3.29	2.89	0.08	80.13
1985	2.6	18.44	32.62	18.81	3.54	4.38	0.21	78.01
1986		18.21	33.97	17.63	3.58	4.72	0.23	78.33
1987		19.00	34.68	18.72	3.24	5.18	0.26	81.08[e]
1988		19.89	36.10	19.57	2.79	5.97	0.30	84.61
1989		19.98	36.09	20.45	3.04	5.99	0.26	85.81
1990	3.3	20.17	35.40	20.36	3.11	6.50	0.22	85.76

[a] Refs. (1–6).
[b] To convert EJ to Btu, multiply by 9.48×10^{14}.
[c] Nuclear energy is that generated by electric utilities
[d] Other includes net imports of coal coke and electricity produced from wood, waste, wind, photovoltaic, and solar thermal sources connected to electric utility distribution systems. It does not include consumption of wood energy other than that consumed by electric utility industry.
[e] An estimated additional 2.5 EJ of wood energy was consumed for residential heating and light industry.

2. Fuel Production and Consumption Since 1970

In the latter twentieth century, technological and political forces have influenced fuel consumption in the United States and throughout the world. Events such as the oil embargo of 1973, political unrest in the Middle East, and the collapse of the Union of the Soviet Socialist Republics, caused disruptions and shifts in petroleum supply systems. The emergence of the North Sea oil field, construction of the Alyeska Pipeline bringing North Slope, Alaska crude to U.S. refineries, and other technical developments also occurred. Most recently, the selection of fuels has been influenced by environmental concerns such as the potential of the fuel to form air pollutants, eg, particulates, NO_x, SO_2, and most recently air toxics (3, 7–10) (see Air pollution; Air pollution control methods; Exhaust control, automotive; Exhaust control, industrial). Moreover, there has been the passage of numerous energy and environmental laws within the United States. Legislation has included the Clean Air Act amendments of 1990 and the National Energy Policy Act of 1992. These laws complement the move toward energy conservation, and the emphasis on materials recycling (qv) for resource management. Further, actions by local and state regulatory agencies in the 1990s, including public utility commissions, have further increased the complexity of fuel supply in the United States.

Trends in commercial fuel, eg, fossil fuel, hydroelectric power, nuclear power, production and consumption in the United States and in the Organization of Economic Cooperation and Development (OECD) countries, are shown in Tables 2 and 3. These trends indicate (6, 13): (*1*) a significant resurgence in the production and use of coal throughout the U.S. economy; (*2*) a continued decline in the domestic U.S. production of crude oil and natural gas leading to increased imports of these hydrocarbons (qv); and (*3*) a continued trend of energy conservation, expressed in terms of energy consumed per dollar of gross domestic product.

Table 2. U.S. Energy Production and Consumption, 1982–1992, EJ[a,b]

Fuel source	1982	1984	1986	1988	1990	1992
			Consumption			
petroleum	31.90	32.76	33.97	36.11	35.40	35.31
dry natural gas	19.52	19.53	17.63	19.57	20.36	21.44
coal	16.17	18.01	18.21	19.88	20.15	19.96
hydroelectric	3.77	4.01	3.64	2.81	3.11	2.94
nuclear	3.30	3.75	4.72	5.97	6.50	7.02
Total	*74.66*	*78.06*	*78.17*	*84.34*	*85.52*	*86.67*
			Production			
crude oil	19.32	19.89	19.39	18.23	16.43	16.02
natural gas liquids	2.31	2.40	2.27	2.38	2.29	2.49
dry natural gas	19.26	18.92	17.38	18.48	19.37	19.27
coal	19.66	20.8	20.58	21.88	23.70	22.75
hydroelectric	3.45	3.57	3.24	2.46	3.09	2.65
nuclear	3.30	3.75	4.72	5.97	6.50	7.02
Total	*67.30*	*69.33*	*67.58*	*69.40*	*71.38*	*70.20*

[a] Refs. 11 and 12.
[b] To convert EJ to Btu, multiply 9.48×10^{14}.

3. U.S. Energy Production, Consumption, and Availability

Production and consumption of commercially available fossil fuel, nuclear power, and hydroelectric power in the United States for the year 1992 is shown in Table 2 (12). Coal production is most significant followed by natural gas and petroleum. Electricity generation and utilization patterns are shown in Table 4. Coal is overwhelmingly the most significant energy source used to generate electricity.

The data presented in Tables 2 and 4 focus on commercially traded sources of energy. During the period 1970–1990, increased emphasis was placed on renewable energy resources (qv), including wood and wood waste; municipal solid waste and refuse-derived fuel; other sources of biomass and waste, eg, agricultural crop wastes, tire-derived fuels, and selected hazardous wastes burned as fuel substitutes in cement kilns; wind and solar energy; geothermal steam and hot water; and other unconventional energy sources. Estimates of the contribution of these energy sources vary. As of this writing biofuel utilization in the United States runs about 3.7 EJ/yr (3.5×10^{15} Btu/yr) in support of process energy needs for industry, cogeneration facilities, and small stand-alone power plants (5), and geothermal energy is about 0.21 EJ/yr (0.2×10^{15} Btu/yr) (6).

3.1. Coal Availability and Utilization

There are vast reserves of coal (qv) and lignite (see Lignite and brown coal) in the United States (Table 5). The total reserve base exceeds 425 billion metric tons equivalent to 11,200 EJ (10.6×10^{18} Btu) and is distributed throughout 32 states. This reserve base has increased by 8.3% since the 1970s despite the high levels of fuel production (6). Total U.S. recoverable reserves exceed 240 billion metric tons or 6100 EJ (5.8×10^{18} Btu) and are distributed among three geographic areas: the Appalachian, Interior, and Western coal producing regions. Of these, the western region contains 53.6% of the recoverable reserves, the interior region 25.8%, and the Appalachian region 20.6%. Reserves can also be evaluated in terms of the sulfur (qv) content of the coal. The sulfur is important owing to environmental considerations. Of the recoverable reserves, 34.3% contains $>0.6\%$ sulfur, 33.9% contains 0.61–1.67% sulfur, and 31.8% contains $<1.68\%$ sulfur.

Coal production and consumption in the 1990s reflects the shift toward the use of western, lower sulfur coal. In 1970, West Virginia, Kentucky, and Pennsylvania ranked 1–3 in coal production, respectively. In 1990, Wyoming, Kentucky, and West Virginia held those ranks, and Texas and Montana

Table 3. Total Final Consumption per Gross Domestic Product OECD Countries, 1973–1989[a,b]

Country	1973	1979	1987	1988	1989
North America	0.45	0.41	0.32	0.32	0.31
Canada	0.55	0.52	0.41	0.41	0.41
United States	0.44	0.40	0.31	0.31	0.31
Pacific	0.30	0.26	0.20	0.20	0.20
Australia	0.36	0.35	0.31	0.31	0.31
Japan	0.30	0.25	0.18	0.19	0.18
New Zealand	0.33	0.35	0.39	0.40	0.41
Europe	0.38	0.35	0.30	0.29	0.28
Austria	0.35	0.34	0.30	0.29	0.28
Belgium	0.58	0.51	0.40	0.39	0.38
Denmark	0.36	0.33	0.23	0.23	0.22
Finland	0.50	0.44	0.38	0.36	0.36
France	0.36	0.31	0.26	0.25	0.24
Germany	0.39	0.36	0.30	0.29	0.28
Greece	0.38	0.38	0.40	0.40	0.41
Iceland	0.48	0.35	0.29	0.31	0.33
Ireland	0.45	0.43	0.38	0.36	0.35
Italy	0.34	0.29	0.25	0.24	0.24
Luxembourg	1.43	1.18	0.78	0.76	0.78
Netherlands	0.49	0.47	0.41	0.38	0.37
Norway	0.39	0.36	0.31	0.30	0.29
Portugal	0.39	0.43	0.46	0.49	0.49
Spain	0.31	0.35	0.29	0.30	0.29
Sweden	0.44	0.41	0.32	0.32	0.30
Switzerland	0.21	0.21	0.20	0.19	0.19
Turkey	0.65	0.62	0.61	0.60	0.61
United Kingdom	0.40	0.36	0.30	0.29	0.28
Total OECD	*0.41*	*0.37*	*0.29*	*0.29*	*0.28*

[a] Ref. 13.
[b] Ratio of total final consumption of energy to gross domestic product (GDP). Measured in metric tons of oil equivalent per $1000 of GDP at 1985 prices and exchange rates; changes in ratios over time reflect the combined effects of efficiency improvements, structural changes, and fuel substitution.

entered the top 10 coal producers. Whereas Appalachia remained the most significant energy production region, the western coal producing states surpassed the interior states in solid fossil fuel production (Table 6). The average coal heating value reflected the shift from Appalachia and the interior to the West, declining from 25.8×10^6 J/kg(11.1×10^3 Btu/lb) in 1973 to 24.8×10^6 J/kg(10.7×10^3 Btu/lb) in 1980 and 24.3×10^6 J/kg(10.4×10^3 Btu/lb) in 1990. The shift in coal production toward western coal deposits also reflects the shift in coal utilization patterns (Table 7). Electric utilities are increasing coal consumption on both absolute and percentage bases, whereas coke plants, other industrial operations, and residential and commercial coal users are decreasing use of this solid fossil fuel.

Environmental considerations also were reflected in coal production and consumption statistics, including regional production patterns and economic sector utilization characteristics. Average coal sulfur content, as produced, declined from 2.3% in 1973 to 1.6% in 1980 and 1.3% in 1990. Coal ash content declined similarly, from 13.1% in 1973 to 11.1% in 1980 and 9.9% in 1990. These numbers clearly reflect a trend toward utilization of coal that produces less SO_2 and less flyash to capture. Emissions from coal in the 1990s were 14×10^6 t/yr of SO_2 and 450×10^3 t/yr of particulates generated by coal combustion at electric utilities. The total coal combustion emissions from all sources were only slightly higher than the emissions from electric utility coal utilization (6).

Table 4. Electricity Supply and Disposition, 1990[a]

Supply and disposition	Quantity, kW·h × 10^9	Percentof total
Fuel type for electric utilities generation		
coal	1560	55.6
petroleum	117	4.2
natural gas	264	9.4
nuclear power	577	20.5
pumped storage hydroelectric	−2	
renewable sources/other[b]	293	10.4
Total	*2808*	*100*
imports	*2*	
Fuel type for nonutilities[c] generation		
coal	33	15
petroleum	5	2.3
natural gas	100	45.9
renewable sources/other[b,d]	80	36.7
Total	*218*	*100*
sales to utilities	*106*	
generation for own use	*111*	
Electricity sales by sector		
residential	924	34.1
commercial/other	843	31.0
industrial	946	34.9
Total	*2713*	*100*

[a] Ref. 14.
[b] Includes hydroelectric, geothermal, wood, wood waste, municipal solid waste, other biomass,and solar and wind power.
[c] Includes cogenerators, small power producers, and all other sources, except electric utilitieswhich produce electricity for self-use or for delivery to the grid. The generation values fornonutilities represent gross generation rather than net generation (net of station use).
[d] Includes waste heat, blast furnace gas, and coke oven gas.

3.2. Oil and Natural Gas Availability and Utilization

U.S. resources and reserves of petroleum (qv) and natural gas (see Gas, natural), including natural gas liquids (NGL) are limited. As of January 1, 1992, U.S. reserves of petroleum were some 151 EJ (24.7×10^9 bbl) and U.S. reserves of natural gas were 182 EJ (17.3×10^{16} Btu) (11). Since 1976, the United States has experienced a significant decline in oil reserves. In 1976, proven petroleum reserves totaled 205 EJ (33.5×10^9 bbl). Between 1976 and 1993, some 210 EJ (3.4×10^{10} bbl) were added to the reserves, and 263.5 EJ (4.31×10^{10} bbl) were produced, yielding a net reserve loss of 53.8 EJ (8.8×10^9 bbl) (14). Similarly, from 1976 to 1992 there was a net reserve loss of 44.5 EJ (4.22×10^{16} Btu) of dry natural gas (16).

As shown in Table 8, U.S. distribution of oil and natural gas reserves is centered in Alaska, California, Texas, Oklahoma, Louisiana, and the U.S. outer-continental shelf. Alaska reserves include both the Prudhoe Bay deposits and the Cook Inlet fields. California deposits include those in Santa Barbara, the Wilmington Field, the Elk Hills Naval Petroleum Reserve No. 1 at Bakersfield, and other offshore oil deposits. The Yates Field, Austin Chalk formation, and Permian Basin are among the producing sources of petroleum and natural gas in Texas.

The decrease in petroleum and natural gas reserves has encouraged interest in and discovery and development of unconventional sources of these hydrocarbons. Principal alternatives to conventional petroleum

Table 5. U.S. Coal Reserves by State, 1990, EJ[a, b–– b, cd]

State	Reserves	State	Reserves
Alabama	114	Montana	2,848
Alaska	146	New Mexico	106
Arizona	6		
Arkansas	10	North Dakota	229
Colorado	403	Ohio	438
		Oklahoma	38
Illinois	1,857	Pennsylvania	691
Indiana	241	South Dakota	9
Iowa	52	Tennessee	20
Kansas	23	Texas	316
Kentucky	697	Utah	146
Louisiana	12	Virginia	62
Maryland	18	Washington	34
Michigan	3	West Virginia	880
Missouri	143	Wyoming	1,614
Total	*11,155*		

[a] Refs. 6 and 15.
[b] Reserve data are based on demonstrated reserve base. Minable reserves differfrom these figures.
[c] Georgia, Idaho, North Carolina, and Oregon also have some reserves.
[d] To convert EJ to Btu, multiply 9.48×10^{14}.

Table 6. Largest Coal-Producing States in 1990, EJ[a, b]

State	1990production	Rank
Wyoming	4.37	1
Kentucky	4.11	2
West Virginia	4.02	3
Pennsylvania	1.67	4
Illinois	1.43	5
Texas	1.32	6
Virginia	1.11	7
Montana	0.89	8
Indiana	0.85	9
Ohio	0.84	10
Total	*20.63*	

[a] Ref. 6.
[b] To convert EJ to Btu, multiply by 9.48×10^{14}.

Table 7. U.S. Coal Consumption by Sector, 1970–1990, EJ[a, b]

Year	Electricutilities	Industrial		Residential andcommercial	Totalconsumption
		Coke plants	Other		
1970	7.60	2.29	2.15	0.38	12.42
1975	9.64	1.98	1.51	0.22	13.35
1980	13.51	1.58	1.43	0.15	16.67
1985	16.47	0.98	1.79	0.19	19.43
1990	18.36	0.94	1.81	0.16	21.27

[a] Ref. 6.
[b] To convert EJ to Btu, multiply by 948×10^{14}.

Table 8. Crude Oil and Natural Gas Proved Reserves, EJ[a--bc]

State	Oil proved reserves	Gas proved reserve[d]
Alaska	37.22	10.22
California	25.80	3.19
Louisiana	4.15	11.79
Oklahoma	4.28	15.83
Texas	41.59	39.87
Wyoming	4.63	11.02
federal offshore	16.03	31.02
Total	*133.72*	*122.94*

[a] Ref. 16.
[b] To convert EJ to Btu, multiply by 9.48×10^{14}.
[c] As of Dec. 31, 1991.
[d] Gas reserves equal dry natural gas plus natural gas liquids.

Table 9. Fuel for Electric Utility Generation of Electricity 1970–1990, $kW{\cdot}h \times 10^9$[a]

Year	Type of facility			Total
	Petroleum	Gas-fired	Internal combustion andgas turbine	
1970	174	361	22	557
1975	273	288	28	589
1980	238	326	28	592
1985	97	279	16	392
1990	113	246	22	381

[a] Ref. 6.

reserves include oil shale (qv) and tar sands (qv). Oil shale reserves in the United States are estimated at 20,000 EJ (19.4×10^{18} Btu) and estimates of tar sands and oil sands reserves are on the order of 11 EJ (10×10^{15} Btu) (see Tar sands; Shale oil). Of particular interest are the McKittrick, Fellows, and Taft quadrangles of California, the Asphalt Ridge area of Utah, the Asphalt, Kentucky area, and related geographic regions.

The unconventional reserves of natural gas occur principally in the form of recoverable methane from coal beds. As of 1991, reserves of coal bed methane totaled 8.6 EJ (8.2×10^{15} Btu), principally in the states of Alabama, Colorado, and New Mexico (16).

Domestic petroleum, natural gas, and natural gas liquids production has declined at a rate commensurate with the decrease in reserves (see Table 2). Consequently, the reserves/production ratio, expressed in years, remained relatively constant from about 1970 through 1992, at 9–11 years (16). Much of the production in the early 1990s is the result of enhanced oil recovery techniques: water flooding, steam flooding, CO_2 injection, and natural gas reinjection.

Whereas the use of petroleum and natural gas is significant in the electricity generating sector, this usage declined from 1970 to 1990, in part owing to the 1977 Fuel Use Act (Table 9). The legislation of the 1990s and the growth of independent power producers (IPP) generating electricity for utilities in combined cycle combustion turbine (CCCT) facilities, may mean a reversal in the trend for oil and natural gas utilization for power generation (qv). In any event, total U.S. oil and gas consumption (Table 1) remains high, and these are the fuels of choice for residential, commercial, industrial, and transportation applications.

3.3. Other Fuel Availability and Utilization

As shown in Table 2, nuclear, hydroelectric, and geothermal resources now contribute some 9.8 EJ (9.3×10^{15} Btu) annually to the U.S. economy. Of these energy sources, nuclear power is the dominant force

Table 10. Municipal Waste to Energy Projects[a]

Location	Capacity, t/d
Mass burn	
Hillsborough County, Fla.	1100
Pinnelas County, Fla.	2700
Tampa, Fla.	910
Baltimore, Md.	2000
North Andover, Mass.	1350
Saugus, Mass.	1350
Peekskill, N.Y.	2000
Tulsa, Okla.	1000
Marion County, Oreg.	500
Nashville, Tenn.	1000
Refuse-derived fuel	
Akron, Ohio	1000
Duluth, Minn.	360
Niagara Falls, N.Y.	1800
Dade County, Fla.	2700
Columbus, Ohio	1800
Hartford, Conn.	1800

[a] Ref. 18 and 19.

having over 70% of the total. U.S. nuclear power production continued to increase through 1990, but nuclear electricity generation may have peaked at 6.5 EJ for political and social reasons. Hydroelectric power generation remains relatively stable. There are annual variations in supply which depend on local weather, eg, rainfall, snowpack, and regional economic conditions. Geothermal energy (qv) has been developed to only a modest extent.

Biomass and waste fuels contributed some 3.7 EJ to the economy (see Fuels from biomass; Fuels from waste). These fuels include wood and wood waste; spent pulping liquor at pulp and paper mills; agricultural materials such as rice hulls, bagasse, cotton gin trash, coffee grounds, and a variety of manures. When wood waste and numerous other forms of biomass are added to *municipal solid waste (MSW)*, *refuse-derived fuel (RDF)*, methane recovered from landfills and sewage treatment plants, and special industrial and municipal wastes such as tire-derived fuel, these together contribute about 5 EJ (4.7×10^{15} Btu) to the U.S. economy (17). Of these fuels, wood and the biofuels are typically employed in industrial settings either to generate process steam (qv) or to cogenerate electricity and process steam. Some condensing power plants have been built by such utilities as Washington Water Power, Burlington Electric, and several IPP firms. There are some 1500 MW of electricity generating capacity based on wood and the biofuels in existence as of 1993.

MSW incinerators (qv) are typically designed to reduce the volume of solid waste and to generate electricity in condensing power stations. Incineration of unprocessed municipal waste alone recovers energy from about 34,500 t/d or 109 million metric tons of MSW annually in some 74 incinerators throughout the United States. This represents 1.1 EJ (1.05×10^{15} Btu) of energy recovered annually (18). Additionally there are some 20 RDF facilities processing from 200 to 2000 t/d of MSW into a more refined fuel (19). Representative projects are shown in Table 10.

Other sources of energy worth noting are the extensive wind farms, solar projects, and related emerging unconventional technologies. These renewable resources provide only small quantities of energy to the U.S. economy as of this writing.

3.4. Trends in Energy Technology and Future Fuel Consumption

Increased economic activity usually means an increase in energy consumption particularly for generation of electricity, manufacturing of products, transportation, and residential and commercial applications. Regulatory and political requirements associated with energy supply and utilization require increasing attention to environmental concerns in order to ensure reliable energy availability without undue environmental degradation. Thus attention is being paid to increasing the efficiency of fuel utilization as well as to reducing the formation of airborne emissions ranging from particulates NO_x and SO_2 to the management of air toxics such as HCl and trace metals.

3.4.1. Coal

Technologies traditionally deployed for coal utilization include using pulverized coal (PC), cyclone, and stoker-fired boilers. For PC boilers, technologies being deployed or developed include the use of micrometer-sized coal, staged fuel–staged air low NO_x burners, limestone injection multistage burners (LIMB), reburning for NO_x control, and advanced techniques for overfire air management. Cyclone-fired boilers also are capitalizing on reburning technologies and air management techniques. Further, both PC and cyclone-fired boilers are utilizing cofiring techniques, blending nitrogen and sulfur-free biomass fuels, and low sulfur tire-derived fuels with the coal for both cost control and emissions reduction (17, 20).

Advanced coal utilization technologies include the development of bubbling, circulating, and pressurized fluidized-bed combustion for electricity generation and process energy production (see Coal conversion processes; Fluidization). Since the early 1980s, over 250 fluidized beds have been installed that have capacities ranging from 25 GJ/h to 1 TJ/h. Whereas fluidized beds are fired using every solid fuel available, these beds are predominantly used for coal combustion. Projects include the Shawnee No. 10 boiler of TVA, the Black Dog project of Northern States Power, and the Colorado-Ute circulating fluidized-bed project. Advanced coal utilization technologies also include integrated gasification combined cycle (IGCC) systems where coal is gasified and the low or medium heat-value gas is then utilized in a combustion turbine and the exhaust is ducted to a heat recovery steam generator (HRSG). The initial demonstration of this technology was initiated in 1979 at the Cool Water project near Barstow, California. More recent projects are under development in Polk and Martin counties in Florida, and at the Tracy Station of Sierra Pacific Power Co. in Nevada. Post-combustion technologies including alternative acid gas scrubbing technologies, urea or ammonia injection for NO_x control, and combinations of air pollution control systems are also emerging to support coal utilization.

3.4.2. Petroleum and Natural Gas

The dominant technologies under development for oil and gas include advances in combustion turbine design. These include applying aircraft engine technology to power generation (qv), and placing emphasis on higher temperatures and increased efficiencies in the combustion turbine. Other technologies of significance include dry low NO_x combustion systems employing principles of staged fuel–staged air, and various catalytic and noncatalytic ammonia injection systems in the post-combustion environment.

3.4.3. Other Fuels

The emerging technologies for unconventional and renewable fuels somewhat mirror those associated with coal: cofiring of biofuels and coal in PC and cyclone boilers, fluidized-bed combustion systems fed with biofuel or a blend of various solid fuels, combustion air management, and gasification–combustion systems. Additionally, technologies associated with post-combustion pollution control for the alternative solid fuels are similar to those developed for coal utilization. At the same time, significant advances have been made in such alternative technologies as fuel cells (qv), photovoltaic cells (qv), wind energy, and the broad range of renewable resources. All of these technologies, combined with those for the dominant fossil fuels, are designed to promote fuel supply and utilization within the framework of an environmentally conscious society.

Table 11. World Fossil Fuel Reserves, EJ[a, b]

Region	Coal reserves 1991[c]		Petroleum reserves 1992[d]		Natural gas reserves 1992[d]	
North America	6,570	(6,565)	499	(500)	346	(344)
Central and South America	254	(254)	419	(447)	172	(193)
Western Europe	2,964	(2,578)	90	(136)	187	(222)
Eastern Europe and former USSR	7,818	(8,252)	358	(378)	1,818	(1,929)
Middle East	5	(5)	4,048	(3,651)	1,360	(1,387)
Africa	1,623	(1,623)	370	(462)	320	(344)
Far East and Oceania	7,950	(7,942)	270	(345)	309	(401)
Total	*27,185*	*(27,221)*	*6,054*	*(5,918)*	*4,512*	*(4,820)*

[a] Refs. 11 and 12.
[b] To convert EJ to Btu, multiply by 9.48×10^{14}.
[c] Data from the World Energy Council. Values in parentheses are from British Petroleum.
[d] Data from *Oil and Gas Journal*. Data in parentheses are from *World Oil*.

Table 12. World Energy Production 1991, EJ[a, b]

Region	Crude oil	Natural gas liquids	Dry natural gas	Coal	Hydroelectric	Nuclear	Total
North America	26.22	3.75	24.64	24.73	6.64	7.94	102.28
Central and South America	10.56	0.31	2.56	0.82	3.73	0.11	14.90
Western Europe	9.52	0.46	8.21	9.60	5.06	8.10	68.64
Eastern Europe and former USSR	22.86	0.89	29.52	20.97	2.67	2.93	74.12
Middle East	36.83	1.64	4.59	0.03	0.14	0	12.53
Africa	15.04	0.43	2.81	4.64	0.48	0.10	10.49
Far East and Oceania	14.85	0.33	6.29	36.38	4.81	3.21	82.97
Total	*135.88*	*7.81*	*78.61*	*97.18*	*23.51*	*22.40*	*365.40*

[a] Ref. 11.
[b] To convert EJ to Btu, multiply by 9.48×10^{14}

4. World Fuel Reserves, Production, and Consumption

Energy reserves, production, and consumption in the world economy are given in Tables 11, 12, and 13, respectively. As these tables indicate, the overwhelming sources of petroleum reserves and supply are in the Middle East. Other significant sources of reserves include Russia, the North Sea, North American countries, and parts of southeast Asia. There are also significant concentrations of coal reserves in Russia and China. The dominant coal-producing countries include China and the United States, plus Poland, South Africa, Australia, India, Germany, and the United Kingdom. China is the single largest coal producer and consumer, utilizing over 22 EJ/yr (21×10^{15} Btu/yr) of this solid fossil fuel.

In addition to the significant consumption of coal and lignite, petroleum, and natural gas, several countries utilize modest quantities of alternative fossil fuels. Canada obtains some of its energy from the Athabasca tar sands development (the Great Canadian Oil Sands Project). Oil shale is burned at two 1600 MW power plants in Estonia for electricity generation. World reserves of tar sands total some 6400 EJ (6.1×10^{18} Btu), and world reserves of oil shale total some 20,400 EJ (19.3×10^{18} Btu).

Table 13. World Energy Consumption, 1991, EJ[a,b]

Region	Petroleum	Naturalgas	Coal	Hydroelectric	Nuclear	Total
North America	41.95	24.58	21.17	6.64	7.94	102.28
Central and South America	7.88	2.46	0.72	3.73	0.11	14.90
Western Europe	29.67	12.29	13.70	4.98	8.00	68.64
Eastern Europe and former USSR	20.44	27.63	20.27	2.75	3.03	74.12
Middle East	7.78	4.45	0.16	0.14	0.00	12.53
Africa	4.76	1.62	3.53	0.48	0.10	10.49
Far East and Oceania	31.19	6.42	37.34	4.81	3.21	82.97
Total	*143.67*	*79.44*	*96.91*	*23.51*	*22.40*	*365.93*

[a] Ref. 11.
[b] To convert EJ to Btu, multiply 9.48×10^{14}.

Table 14. World Net Electricity Consumption, 1982–1991, $kW{\cdot}h \times 10^9$[a]

Region	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
North America[b]	390.1	406.3	435.9	458.1	477	499.1	524.2	541.6	543.2	552.5
United States	2,086.4	2,151.0	2,285.8	2,324.0	2,368.8	2,457.3	2,578.1	2,646.8	2,712.6	2,759.3
Central and South America	309.9	333.4	355.6	371.1	391.1	403.7	421.7	427.8	437.0	446.9
Western Europe	1,725.1	1,783.4	1,873.2	1,962.6	2,001.7	2,064.9	2,069.4	2,150.8	2,188.9	2,217.1
Eastern Europe and former USSR	1,555.4	1,610.8	1,694.8	1,748.9	1,727.0	1,787.5	1,825.7	1,853.9	1,838.8	1,751.0
Middle East	111.4	121.7	131.3	143.5	149.4	158.3	169.7	180.2	195.6	185.6
Africa	182.9	202.0	206.5	217.7	248.6	254.7	270.5	280.1	282.0	281.0
Far East and Oceania	1,300.3	1,387.0	1,477.8	1,568.9	1,654.4	1,783.0	1,904.8	2,047.9	2,199.1	2,288.5
World total	*7,661.6*	*7,995.6*	*8,461.0*	*8,794.9*	*9,018.1*	*9,408.5*	*9,764.1*	*10,128.4*	*10,397.2*	*10,481.9*

[a] Ref. 11.
[b] Excluding the United States.

Table 15. Projections of World and U.S. Energy Consumption, 1995–2005, EJ[a,b]

Energy source	1995			2000			2005		
	Base	Low	High	Base	Low	High	Base	Low	High
				World projection[c]					
oil	152	141	157	159	147	170	171	152	190
gas	82	80	83	92	89	94	107	100	112
coal	106	102	108	112	107	116	129	118	136
nuclear	24	23	24	26	25	26	31	27	32
other	31	31	32	35	34	36	42	39	46
Total	*395*	*377*	*404*	*424*	*402*	*442*	*480*	*436*	*516*
				U.S. projection					
oil	38	37	38	40	39	41	42	40	44
gas	23	23	23	25	24	25	26	25	27
coal	21	21	21	21	21	22	22	22	23
nuclear	7	7	7	7	7	7	7	7	8
other	8	8	8	9	9	10	10	10	10
Total	*97*	*96*	*97*	*102*	*100*	*105*	*107*	*104*	*112*

[a] Ref. 14.
[b] To convert EJ to Btu, multiply by 9.48×10^{14}.
[c] World consumption totals also include the United States.

Renewable and unconventional energy sources are used more extensively in other parts of the world than in the United States. Tables 12 and 13 document the significance of hydroelectric power throughout industrialized and developing economies. Biofuels are also a significant contributor to certain economies, with proportional contributions as follows: Kenya, 75%; India, 50%; China, 33%; Brazil, 25%; and Scandanavia, 10% (5, 21). Peat is a significant source of energy for Russia, Finland, and Ireland.

World electricity generation and consumption, shown in Table 14 increased from 1982 to 1991, and is expected to continue to do so. Further, the industrialized economies are focusing on issues of energy conservation, materials conservation through recycling, and environmental protection. Given the world trends in fuels availability and consumption, projections of energy production and consumption have been made, as shown in Table 15. These projections, to the year 2005, reflect the emphases on fuel availability, energy economics, and environmental awareness of a world community. Further, they reflect the trend toward increased technology development, leading to economically and environmentally sound energy utilization.

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