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Energy Trends and Their Implications for U.S. Army Installations

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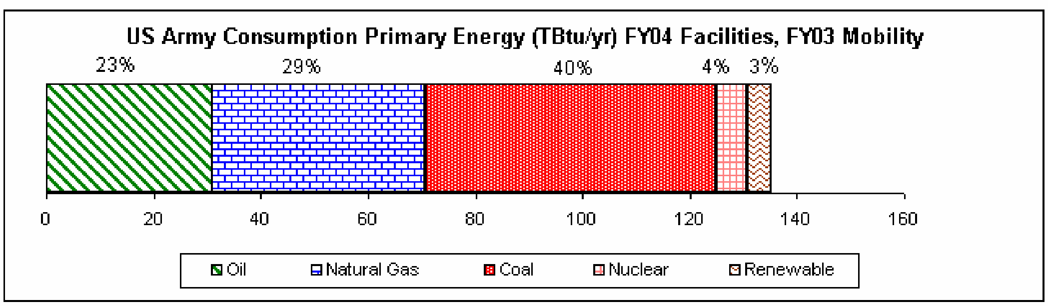
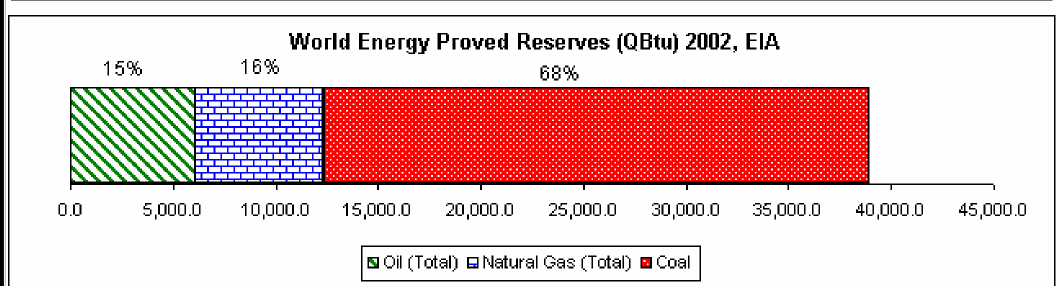
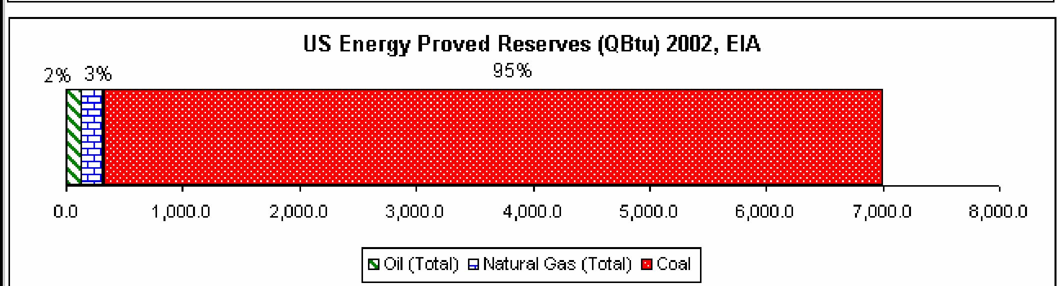
September 2005







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Energy Trends and Their Implications for U.S. Army Installations

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Final Report

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ABSTRACT: The primary issues affecting energy options are those of availability, affordability, sustainability, and security. Since energy resources are unevenly distributed around the world, and the impacts of energy consumption have global reach in both environmental and political terms, any meaningful review of energy-related issues must take a global perspective. This work synopsizes world and national energy issues (including energy source options, resource stocks, and future prognosis) in the context of how Army installations need to respond to changing trends. This report presents implications of actions that may be taken in response to the national and world energy situation, to help the Army to make informed choices on energy utilization that will contribute to sustaining the Army's mission.

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Executive Summary

The Army operates in a domestic and world energy situation that is highly uncertain. To chart an effective and viable path for its energy future, the Army must immediately begin to consider the short- and long-term issues involved in developing enduring energy policies and solutions for its military installations. To sustain its mission and ensure its capability to project and support the forces, the Army must insulate itself from the economic and logistical energy-related problems coming in the near to mid future. This requires a transition to modern, secure, and efficient energy systems, and to building technologies that are safe and environmental friendly. These supply- and demand-side challenges require thoughtful planning and execution using integrated solutions.

Issues

The primary issues affecting energy options are those of availability, affordability, sustainability, and security. Since energy resources are unevenly distributed around the world, the impacts of energy consumption have global reach in both environmental and political terms. Thus, any meaningful review of energy-related issues must take a global perspective. Additionally, world-wide consumption of energy is projected to increase 60 percent by 2030 and may triple by 2050.

- ***Availability.*** Future availability of customary energy sources is problematic. Domestic production of both oil and natural gas are past their peak and world petroleum production is nearing its peak. Growing domestic consumption will continue to increase dependence on foreign and potentially unstable energy sources. Almost half of the existing U.S. natural gas reserves are considered to be either remote or stranded, i.e., they are too far from existing infrastructure, located on restricted Federal lands, or considered too environmentally detrimental to harvest. Construction of an Alaskan natural gas pipe-line and the importation of Liquefied Natural Gas (LNG) are possible solutions to domestic natural gas problems. However, the necessary production and distribution infrastructure will require years to construct. Further, our electrical transmission grid is aging and overtaxed. It was not designed to accommodate the complex high load traffic it must now handle due to deregulation. Its reliability will degrade until appropriate investments are made.

- ***Affordability.*** As demand for natural gas and petroleum exceeds supply on a national or worldwide basis, prices rise. As the Earth's population swells and as standards of living are improved for the developing world, competition for finite resources will increase. The Army's energy demand at CONUS installations will grow as a major Base Realignment and Closure actions restation 70,000 troops from Europe and Asia to the United States and as the Army's transformation of home base support of deployed elements expands computer-processing needs.
- ***Sustainability.*** Worldwide consumption of fossil fuels and it coincident environmental impact continue to grow. The earth's endowment of natural resources are depleting at an alarming rate—exponentially faster than the biosphere's ability to replenish them. It took nature 100 million years to create the energy the world uses in 1 year. Fuel combustion affects the global climate with the production of green house gases and localized production of acid rain, low lying ozone, and smog. Mining and production of fuels destroys ecosystems and biodiversity. The loss of habitat is leading to localized extinction of species. This reduction of biodiversity results in greater vulnerability of the planet to ecological stresses. Wastes from nuclear power generation plants are accumulating and no viable means exists to safely and effectively dispose of them. Current energy policies and consumption practices are not sustainable. They clearly limit and potentially eliminate options for future generations.
- ***Security.*** In an age of terrorism, combustible and explosive fuels along with potential weapons-grade nuclear materials create security risks. The United States currently has 5 percent of the world's population, but uses 25 percent of the world's annual energy production. This disproportionate consumption of energy relative to global consumption causes loss of the world's good will and provides a context for potential military conflicts, at the cost of lives, money, and political capital. A more equitable distribution of resources is in our best interest for a peaceful future.

Energy Trends

Table E1 and Figure E1 summarize the current demand, supply, and proportionate distribution of energy on a global, national, and Army basis. Table E2 lists world reserves. Note that the United States currently imports 26 percent of its total energy supply and 56 percent of its oil supply. The Army and the nation's heavy use of oil and natural gas is not well coordinated with either the nation's or the earth's resources and upcoming availability. The relative fuel shares of energy use versus energy reserves underscore our need to supplement oil and natural gas as our staple fuels. The domestic supply and demand imbalance would lessen if coal and/or nuclear energy could be made more environmentally acceptable or if the renewable share of our energy portfolio were to vastly increase.

Worldwide energy consumption is expected to increase by 2.1 percent/yr and domestic energy consumption by 1.4 percent per year. This will exacerbate global energy competition for existing supplies. Army energy consumption is dominated by facilities consumption. Facilities consumption may decrease in both total quantity and in intensity basis—but not without an aggressive energy program with careful planning, diligent monitoring, and prudent investment. The absorption of overseas troops onto domestic installations will make this outcome especially challenging. The energy consumption associated with Army mobility is expected to remain constant, but may potentially increase depending of future phases of the Global War on Terror and on geopolitical tensions resulting from the world energy situation.

Table E1. Summary of U.S. and world energy consumption.

	Oil	Natural Gas	Coal	Nuclear	Renewable	Electricity	Purchased Steam	Total
Fuel Share of U.S. consumption	40%	23%	23%	8%	6%			100%
U.S. consumption (Q/yr) 2003, EIA	39	23		8	6			98
U.S. Imports (Q/yr)	22	4						26
U.S. imported share	56%	17%						26%
World consumption (Q/yr) 2003, BP renewables, EIA, 2002	147	94	104	24	32			401
U.S. consumed share of world consumption	27%	24%	22%	32%	18%			24%
U.S. Army end use consumption (TBtu/yr), Annual Reports, FY04 facilities, FY03 mobility	29	26	7		1	30	7	100
End use fuel share of Army consumption	29%	26%	8%	0%	1%	30%	7%	100%
U.S. Army consumption primary fuels (TBtu/yr) FY04 facilities, FY03 mobility, EIA 2003 generation mix	31	40	54	6	4			135
Primary fuel share of Army consumption	23%	29%	40%	4%	3%			100%

Table E2. Summary of U.S. and world energy reserves.

	Oil	Natural Gas	Coal	Nuclear	Renewable	Total
U.S. proved reserves (Q) 2002, EIA	132	193	6,678			7,003
Domestic proportion fossil fuel	2%	3%	95%			
World proved reserves (Q) 2002, EIA	6,027	6,317	2,6578			38,921
World proportion fossil fuel	15%	16%	68%			

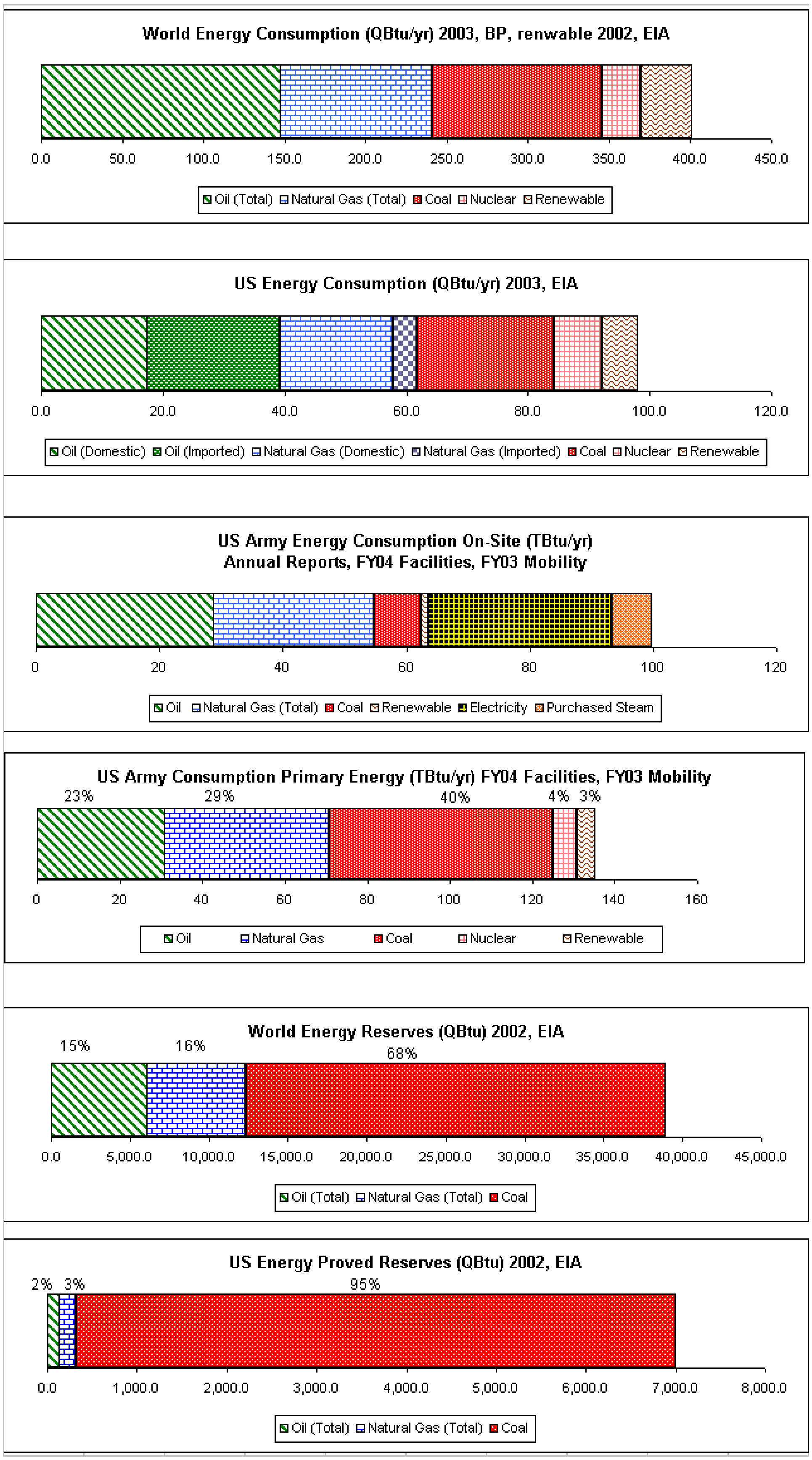

Figure E1. Energy resources and consumption patterns.

Natural Gas Trends

The natural gas market for the near and mid-term is expected to be volatile. Prices will fluctuate significantly based on weather and supply. In the near term, prices will increase continually until the natural gas market is normalized by constructing a gas pipeline from Alaska and northern Canada, expanding exploration and production to areas of the United States now off limits, and greatly increasing imports of liquefied natural gas. The world market for natural gas is currently limited by demand, not supply. However, domestic natural gas production plateaued in 1973 and the United States currently imports 17 percent of the natural gas it consumes. This imported share will increase dramatically in the long term as domestic supplies deplete and the amount of natural gas used to fuel the electric system increases. World natural gas markets will reach equilibrium in about 10 years, but at higher prices that will reflect the higher costs of production and transportation. In the long run, worldwide natural gas production will peak in the 2030-2035 time range and then decline as an available resource.

Petroleum Trends

The oil market will remain fairly stable in the very near term, but with steadily increasing prices as world production approaches its peak. The doubling of oil prices from 2003-2005 is not an anomaly, but a picture of the future. Oil production is approaching its peak; low growth in availability can be expected for the next 5 to 10 years. As worldwide petroleum production peaks, geopolitics and market economics will cause even more significant price increases and security risks. One can only speculate at the outcome from this scenario as world petroleum production declines. The disruption of world oil markets may also affect world natural gas markets since most of the natural gas reserves are collocated with the oil reserves.

Coal Trends

Coal is the nation's largest fossil fuel resource with a two-hundred and fifty-year supply at current consumption rates. Despite of the large production of CO_2 and other air pollutants generated by coal consumption, the utility sector and, possibly, the large industrial sector will continue and increase their use the nation's large supplies of coal. Using current technologies, coal combustion remains problematic, but research shows some promising technological solutions. Deploying poly-generation techniques with carbon sequestration on a large scale may potentially allow the United States to use the nation's coal reserves in an environmentally friendly way to meet both liquid fuel and electricity requirements. Carbon sequestration technologies will begin to play a larger role in the mid-term. However, carbon sequestration techniques must be well thought-out to avoid unintended ecosystem consequences such as unexpected large releases of carbon into the environment.

Nuclear Power Trends

Nuclear power appears headed for a small renaissance. Some nuclear plant upgrades are planned in the short term. In the mid term, a modest construction program is getting under way and some shut-down reactors may be restarted. Light water reactors, for which the United States imports much of its nuclear fuel, are only an interim technology. Developing a breeder reactor program and closing the fuel cycle could offer true energy independence, but at the cost of increased environmental and security risks. It remains to be seen if this is a viable solution from both political and ecological perspectives. Other nations such as France and Japan have closed the fuel cycle and are taking an energy path with a much higher nuclear profile.

Renewable Energy Trends

Renewable energy technologies will certainly be a growing part of the energy mix and will penetrate faster and further than conventional energy advocates think. Early adoption to promote this market and these technologies is inherently in the Army's interest. From an economic perspective, the cost of renewable technologies continues to fall while the cost of conventional energy sources continues to rise.

Electrical System Trends

The electrical system will likely become increasingly problematic over the next 5 to 10 years. Power capacity should suffice. Utilities have overbuilt to meet the peaking market and are planning additions to base capacity. The grid, itself, however is the weak point in the Nation's electrical system. Investments are not keeping up with power flow demands; consequently, bottlenecks exist in certain regions, which lowers the reliability of the grid as a whole. Once ongoing regulation and deregulation activities are settled, appropriate investments can achieve grid expansions and upgrades. The fraudulent electrical pricing and supply manipulations by commodity traders that led to the California energy crisis in 2001 should not recur.

Table E3. Energy options.

	Fossil fuels						
	Conventional Oil	Nat Gas Liquids, Deep Water, and Polar Oil	Unconventional Oil - Natural Bitumen (tar sands and extra-heavy crude)	Unconventional Oil - Oil shale	Natural Gas	Liquefied Natural Gas	Coal
Current price	$70/Barrel (WTI-world price)	World oil price	World oil price	Oil shale not economically viable	$6-7/MBtu wholesale at Henry Hub	$4.77/MBtu	$28.62/ton steam coal
Projected price trend	Steady increases expected as world production at or near peak (high was in 1973 @ $75/b in today's dollars).	NA	NA	Unknown	Volatile near term. Stable as LNG imports increase and AK pipeline built. Realistic floor is about $7/mbtu.	Price levels should sustain in the $3-4 dollar range until depletion sets in.	Fairly stable, but will tend to follow other fuels in an upward trend.
World production	25GB/yr	3.6GB/yr	0.25GB/yr	351 metric tons oil/yr	95 TCF	5.9 TCF	104 Quadrillion Btu
Demand expectations	Up 33% worldwide 2004-2020, 2.1%/yr	Part of conventional demand.	Will have to make up increasing portion of oil supply in the future.	If economically and environmentally viable, demand would take all that could be produced.	Up 50% in U.S. 2002-2022 Est. 2.5%/yr growth in U.S.	2 BCF/day, 3% of NG total in U.S., expected to expand rapidly as domestic NG production drops and world market develops, could eventually make up 33-50% of U.S. supplies.	Estimated at 1.5%/yr
Advantages	High energy density, easy to extract, transport and store, highly versatile for technologies, burns at high temp (suitable for IC engines)	High energy density, highly versatile for technologies, burns at high temp (suitable for IC engines)	Can be processed to conventional oil substitute.	Can be processed to conventional oil substitute.	Clean burning with low emissions, supplied by an extensive grid, can be used in a variety of equipment and substitute for petroleum in most cases.	Can be imported to make up for domestic shortage.	High specific energy density, readily available domestic supply, relatively low cost.
Disadvantages	Heavy dependence drives U.S. general economy. Increases reliance on foreign sources. Depletion causes price increases, could lead to disruption and geopolitical instability.	Deep water and polar oil are expensive to develop and limited in extent.	Deposits are mostly located in two countries: tar sands in Canada and extra-heavy crude in Venezuela.	Oil shale and tar sands energy ROI is negative, significant environmental impact	Demand exceeds domestic supply, decline rate about 30%, price volatility,	Infrastructure not ready, 7+yr lead time, high demand in the world market, supply terminals and ships must be expanded to meet demand, 33% energy loss in production.	High emissions. Mining is dangerous, destroys environment and pollutes surface and groundwater. Produces more CO_2 than other fossil fuels.
Domestic availability	Peaked in 1970. U.S. imports 62% of crude oil. Proved reserves are 132Q.	NA	NA	Est. 500Bbl from oil shale in U.S.	Peaked in 1973, plateaued since 1980 due to massive exploration. U.S. has 4% of world reserves. Proved reserves are 193Q.	None, this is an import fuel.	High
Domestic Proved Reserve Life (R/C ratio) if no incr. demand	3.4yrs			500 GB	8.4yrs	LNG is a Product.	140 years hard coal -260 including sub-bituminous coal
Expected world peak production	Est. Peak 2005-2020, non-OPEC first	Natural gas liquids expected to peak in 2027, deep water in 2014, and polar in 2030	Production limited but increasing; heavy dependence; will not peak for decades, production in 2050 expected to be about 5GB/yr	Est. 138,500 billion metric ton of oil	Estimated peak of Production is 2030-2035	Est. Peak 2025	Est. Peak 2050
Current world stock	930-1300 gb	200gb	Est. 170gb from tar sands in Alberta, Canada; est. 27 GB extra-heavy crude in Orinoco, Venezuela	992gb	6204 tcf proved reserves (bp world statistics)	Lng is a product	26,578 qbtu (1,102,587 million tons)
World Proved Reserve Lifetime (No increased demand)	37-52 years	55yrs	999 years	Unknown	65 years	27yrs	255 years
World Proved Reserve Lifetime (projected demand increases)	28-37 years if 2.1% increase	Na	Na	Na	39 years if 2.5%/yr increase		109 years if 1.4%/yr increase
Environmental impact	Production of greenhouse gases, NOx, and CO, drilling and production leads to local pollution.	Production of greenhouse gases, NOx, and CO, drilling and production leads to local pollution.	Production from tar sands results in significant waste, consumes other energy due to the steam required for extraction, and pollutes watersheds.	Large quantities of contaminated water, sulfur, asphalt, and bitumen contaminated sand	Production of ghgs, nox, and CO, drilling and production leads to local pollution. Exploitation of now restricted areas lead to environmental damage.	Same impact as NG when combusted. Terrorist targets. Shipping impacts.	Most environmentally damaging fossil fuel, ghgs, nox, CO, sox, and PM when burned, mining leads to significant local damage.
Applications	97% of transportation industry, to a lesser degree for heating and power generation, chemical feed-	Same as conventional oil.	Same as conventional oil.	Industrial combustion and petrochemical feedstock.	Combustion processes, petrochemical feedstock, could be expanded into a transportation fuel.	Same applications as natural gas, flexible and readily usable fuel.	90% of u.s. coal consumption is in power production.
Technology issues	Except for the Mideast, cheap oil is becoming hard to find. Technology for deep offshore and polar exploration needs to continue to develop.	Expensive to harvest deepwater as depth increases. New technology breakthroughs required. NG liquids a	More energy efficient and environmentally benign extraction technologies required.	Oil shale not currently viable for extraction.	Deep water, polar, in-situ liquefaction all need more research and development.	LNG production facilities have 7yr lead time, LNG ships are potential security threats, LNG terminals need to be constructed.	IGCC technology needed. Polygeneration to liquid crude petroleum currently too costly. R&D thrust.
Investment needs/ limiting factors	Worldwide oil investment required to 2030 is about $3T.	See conventional oil	See conventional Oil	R&D to make process more efficient and environmentally acceptable.	$40B/yr in U.S. for exploration $2.5B/yr in U.S. for transmission pipeline from AK, worldwide investment to 2030 is about $2.7T	Infrastructure needs to be expanded. About $250B in the Middle East is required to built production facilities. See natural gas investment.	R&D in clean combustion and carbon sequestration required. Worldwide investment required to 2030 is approximately $400B.

Table E3. Energy options (cont'd).

Nuclear Power	Renewables								Grid
Nuclear Power	Ethanol	Hydrogen	Biomass	Solar	Wind	Hydroelectricity	Geothermal	Conservation	Electrical System
$33-41/MWh (Uranium costs approx $10/lb U3O8)	About 3 times the price of gasoline.	On a large scale equal to gasoline at the refinery.	$20-40/ton	Electric: 24-48 cents/kWh	3-5 cents/kWh	2.4-7.7 cents/kWh	Cost varies depending on technology.	Cost varies depending on technology.	U.S. average 7.5 cents/kWh
Fairly stable electrical prices. Uranium market has been volatile over the last decade.	Will remain stable unless new technology using cellulosic biomass is perfected, then price will drop.	Highly dependent on technology and transportation issues.	Stable, but somewhat dependent on transportation costs.	Price reduces 20% for every doubling of production.	Price reduces with increased production of turbines and larger turbine sizes.	Very few sites being developed. Price is stable.	NA	Decreasing over time.	Slow growth over time.
32,600 tU in 1999.	3.3 Bgal (U.S. only)	50 million tons	50 EJ/yr (2000) Biomas is not a world commodity,	0.2 Exajoules/yr (2000)	0.2 Exajoules/yr (2000)	10 Exajoules/yr (2000)	57TWh (2002)	NA	13,920 Billion kWh
In the United States, existing plants are being uprated, 2-3 new plants are in the planning stages, demand could grow significantly if carbon dioxide production becomes regulated or taxed.	Demand expected to grow as MBTE is banned in more states and may be banned in U.S. Another 750MGal of capacity under construction. Worldwide it is expected to quadruple over the next 25 yrs.	The demand depends on technology development and the ability to create from sources other than fossil fuels. Increasing demand expected next 10-15 yr.	DOE projects low growth rate, although state renewable portfolio requirements may spur growth	Continues to expand. Production of Solar Electric PV by 2030 expected to be 98 TWh. Solar thermal electric expected to be 21 TWh by 2030.	Fastest growing energy resource. In 2005 it is expected that 2500 MW will be deployed.	High head hydro has peaked in U.S.; all likely sites have been used. New sites controversial in other countries due to environmental impact. Low growth expected.	Production expected to triple by 2030. Will be developed where available, not a world or national market.	Efficiency cost is reducing over time while energy costs are increasing. More demand for conservation expected.	Worldwide expected to double by 2030. U.S. growth expected to grow about 2%/yr.
No air pollution, no GHG emissions, limited import dependence (just source fuel) high reliability, lowest fuel costs, least sensitive to fuel costs	Made from a renewable resource, low emissions, carbon neutral.	Clean burning.	Carbon neutral, renewable resource.	Carbon neutral, renewable resource.	Carbon neutral, renewable resource	Carbon neutral, renewable resource.	Carbon neutral, renewable resource, continuously available 24/7.	Carbon neutral, renewable resource, continuously available 24/7.	Extremely flexible high end commodity.
Plant construction costs $5k/kW (Watts Bar - last one built), extended construction times for new plants, fuel cycle not closed, no spent fuel disposal method at this time, great public fear and resistance to new facilities.	Low return on energy invested to produce, lower specify energy density than gasoline	Derived from fossil fuels, usually NG. Low specific energy density. Leakage problems for pipeline usage.	Should be used near where produces to avoid high shipping costs, low specific energy density compared to fossil fuels.	High cost, still needs considerable R&D and market penetration. Solar access required. Intermittent resource.	Limited sites in areas of high population density. Intermittent resource.	High head applications destroy aquatic systems.	Regional resource, not generally available, mostly in the Western U.S.	None, best path to follow.	Extremely inefficient electric production and distribution paradigm.
104 licensed generating plants = 97.4GW.	Production increasing as demand increases to replace MBTE.	11 Million tons/yr	512 MTon dry of biomass equivalent to 8.09QBtu of primary energy could be available at < $50/dry ton delivered.	NA	10,777 TWh	High head almost fully exploited. Low head potential is about 21,000 MW	Regional resource, not generally available, mostly in the Western U.S.	20-40% of existing and future usage.	System meets demands with isolated problems.
14 yrs	NA	NA	Renewable	Renewable	Renewable	Renewable	Renewable	NA	NA
NA	NA	NA	>250 EJ/yr	>1600 EJ/yr	600 EJ/yr	50 EJ/yr	>250 EJ/yr	NA	NA
0.92 MtU at $15/lbU3O8 (2.96 MtU at $50/lbU3O8).	NA	NA	50 EJ/yr	0.2 EJ/yr	0.2 EJ/yr	10 EJ/yr	2 EJ/yr	NA	NA
10 yrs at low price-33yrs at high price	NA		Renewable	Renewable	Renewable	Renewable	Renewable	NA	NA
10-20 years	NA	NA	Renewable	Renewable	Renewable	Renewable	Renewable	NA	NA
Power plants have large thermal signature. Waste disposal unresolved. Accidents could spread fission products over a large area leading to cancer deaths and unusable land areas.	Ethanol is a by-product of agriculture and has the same agricultural impacts, combustion emissions.	Very benign.	Direct combustion results in CO, NOx, and Particulates. Harvesting and transportation has impacts depending on type and source.	Land consumption. Hazardous waste in production. Some deaths mostly associated with falls from roofs, etc.	Bird kills, noise, visual pollution, and land consumption.	Large dams completely change river hydrology, water temperature, and flood large riparian areas. Low head hydro much more benign and can use run of river.	Some sulfur emissions, significantly less impact that fossil fuels.	None	Electromagnetic radiation, transmission lines, and power plant impacts.
Production of electricity, has potential for production of hydrogen and district heating.	Automobile fuel as a substitute for MBTE or as a motor fuel E85.	Fuel cells	Electric generation and heat source.	Solar thermal and solar electric	Electric Power	Electric Power	Electric Power and thermal loads.	Throughout economy.	Throughout economy.
New, safe reactor designs. Waste disposal unresolved issue. New licensing process underway.	High cost. Low net energy. Cellulose and hemicellulose technology needed to increase feedstock and lower costs.	Carbon fiber storage tanks for compressed H2 could be breakthrough technology.	Continued research on gasification and liquefaction.	Photovoltaics too expensive. Efficiency must be higher and collector costs must be lower.	Turbines continue to increase in size and economies of scale still in effect.	Well developed technology. Fish friendly turbines needed.	Well developed, source constrained.	Somewhat of a market failure, although cost decreasing. Needs more emphasis as national strategy.	Some congestion on grid. Building new infrastructure problematical.
Waste disposal unresolved, closing the fuel cycle unresolved, R&D in breeder reactors and fusion power.	Ethical concern with using food quality starch as feedstock.	R&D on H2 sources, storage, and distribution	R&D on gasification.	R&D in energy storage	Good wind sites are far from population centers.	Most sites for high head used. Environmental factors will prevent further development in OECD countries.	Availability of sites.		$10T worldwide by 2030.

Energy Options

Energy consumption is indispensable to our standard of living and a necessity for the Army to carry out its mission. However, current trends are not sustainable. The impact of excessive, unsustainable energy consumption may undermine the very culture and activities it supports. There is no perfect energy source; all are used at a cost. Table E3 lists energy options and their associated features, including applications, advantages, disadvantages and projected reserve lifetimes.

Energy Implications for Army Installations

The days of inexpensive, convenient, abundant energy sources are quickly drawing to a close. Domestic natural gas production peaked in 1973. The proved domestic reserve lifetime for natural gas at current consumption rates is about 8.4 yrs. The proved world reserve lifetime for natural gas is about 40 years, but will follow a traditional rise to a peak and then a rapid decline. Domestic oil production peaked in 1970 and continues to decline. Proved domestic reserve lifetime for oil is about 3.4 yrs. World oil production is at or near its peak and current world demand exceeds the supply. Saudi Arabia is considered the bellwether nation for oil production and has not increased production since April 2003. After peak production, supply no longer meets demand, prices and competition increase. World proved reserve lifetime for oil is about 41 years, most of this at a declining availability. Our current throw-away nuclear cycle will consume the world reserve of low-cost uranium in about 20 years. Unless we dramatically change our consumption practices, the Earth's finite resources of petroleum and natural gas will become depleted in this century. Coal supplies may last into the next century depending on technology and consumption trends as it starts to replace oil and natural gas.

We must act now to develop the technology and infrastructure necessary to transition to other energy sources. Policy changes, leap ahead technology breakthroughs, cultural changes, and significant investment is requisite for this new energy future. Time is essential to enact these changes. The process should begin now.

Our best options for meeting future energy requirements are energy efficiency and renewable sources. Energy efficiency is the least expensive, most readily available, and environmentally friendly way to stretch our current energy supplies. This ensures that we get the most benefit from every Btu used. It involves optimizing operations and controls to minimize waste and infusing state of the art technology and techniques where appropriate. The potential savings for the Army is about 30 percent of current and future consumption. Energy efficiency measures usually pay for itself over the life cycle of the application, even when only face value costs are considered.

Renewable options make use of Earth's resources that are not depleted by our energy consumption practices: namely solar, wind, geothermal, geoexchange, hydrology, tidal movements, agricultural products, and municipal wastes. Renewable options also make use of the large stretches of land in America, much of which is owned by the government. These options are available, sustainable, and secure. The affordability of renewable technologies is improving steadily and if the market is pulled by large Army application the cost reductions could be dramatic. For efficiency and renewables, the intangible and hard to quantify benefits—such as reduced pollution and increased security—yield indisputable economic value.

Many of the issues in the energy arena are outside the control of the Army. Several actions are in the purview of the national government to foster the ability of all groups, including the Army, to optimize their natural resource management. The Army needs to present its perspective to higher authorities and be prepared to proceed regardless of the national measures that are taken. The following steps by the national government would help the Army with its energy challenges:

- Increase supplies.
  - Recognize and promote energy efficiency as the cheapest, fastest, cleanest source of new energy.
  - Recognize and promote that renewable energy technologies make sense for America on a very large scale.
  - Promote renewable applications and work to change the image of solar roofs and off-shore wind farms.
  - Appropriate the necessary funding to bring Federal facilities to state-of-the-art efficiency.
  - Pull renewable technology markets to produce more cost effective solutions with tax incentives and large Federal applications.
  - Provide incentives for green power production through continued and expanded tax credits.
  - Open up Federal lands for oil and natural gas harvesting where environmentally appropriate.
  - Encourage the development of LNG terminals and infrastructure by streamlining approvals and assisting with local approvals.
- Modernize infrastructure.
  - Support modernizing and expanding the electricity grid.
  - Support the construction of a natural gas pipeline from AK and Canada.
  - Enhance the expansion of LNG terminals and natural gas infrastructure.

- Diversify sources.
  - Invest in research and development (R&D) in clean coal technologies, renewable technologies, carbon sequestration, breeder reactor nuclear power.
  - Invest in R&D in energy efficiency in the built environment.
- Optimize end-use.
  - Significantly increase Corporate Average Fuel Efficiency (CAFE) standards and expand to all classes of motor vehicles.
  - Expand rebate programs for hybrid vehicles.
  - Expand appliance and equipment efficiency standards as many states are doing.
  - Continue and enhance the Federal Energy Management Program.
  - Continue and enhance the Energy Star Program.
- Minimize Environmental Impact.
- Cooperate in global energy markets.

The national and world energy situation mandates strategic planning and action by the Army. The pending challenges of meeting the Army's ongoing energy requirements in a reliable, affordable, sustainable, and secure fashion demand thoughtful and comprehensive approaches. A deliberate careful review of energy source options and resulting tradeoffs is necessary. The informed and disciplined management of consumption is imperative.

The Army has already begun this necessary strategic planning and its *Army Energy Strategy for Installations* defines the overarching mission and goals, and outlines broad approaches for reaching the Army's full potential.* The mission of the Army Energy Program is to provide safe, secure, reliable, environmentally compliant, and cost-effective energy and water services to soldiers, families, civilians and contractors on Army Installations. The five major goals for the program are to:

- eliminate energy waste in existing facilities
- increase energy efficiency in renovation and new construction
- reduce dependence on fossil fuels
- conserve water resources
- improve energy security.

This strategy is timely and on-target with the realities of the energy arena.

* Available through URL: http://hqda-energypolicy.pnl.gov/programs/plan.asp

The Army is developing a Campaign Plan, which details the energy policy, projects and programs necessary to achieve these program's major goals. ERDC-CERL Technical Report (TR)-04-10, *A Candidate Army Energy and Water Management Strategy*, enumerates many ideas for consideration in this next level effort including necessary policy changes and an operational framework with review and adjustment to ensure success. It assesses the current practices and needs of Army energy and water management, aligns present efforts with objectives, identifies gaps in programming, and advises courses for improvement including the centralized management of goals.

In these times of tightening classical energy options, the Army needs to take steps comparable to those in the national agenda mentioned above by modernizing infrastructure, optimizing end-use, minimizing environmental impact, pulling technology markets, cooperating in regional purchases, and leveraging alternate financing. Special attention to the diversification of sources is appropriate. This incorporates a massive expansion in renewable energy purchases, a vast increase in renewable distributed generation including photovoltaic, solar thermal, wind, microturbines and biomass, and the large-scale networking of on-site generation.

The awareness of the energy options, trends, tradeoffs and the implications for Army installations allows for informed decisions, targeting planning and pertinent investment. The Army must continue to improve and optimize its energy and water management to meet mission requirements.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

Système International d'Unités (“International System of Measurement”), commonly known as the “metric system.”

Preface

This study was conducted by the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers, under reimbursable project 3BHKHJ for the Office of the Assistant Chief of Staff for Installation Management (OACSIM) for support of the Army Energy Program. The technical monitor for this effort was Henry Gignilliat, Utilities Privatization and Energy Team, Facility Policy Division.

The work was performed by the Energy Branch (CF-E) of the Facility Division (CF), Construction Engineering Research Laboratory (CERL). Eileen T. Westervelt was the CERL Principal Investigator. Donald F. Fournier, of the University of Illinois Building Research Council, Urbana, IL, made substantial contributions to the work under contract No.W9132T-04-D-0008. The technical editor was William J. Wolfe, Information Technology Laboratory. Dr. Thomas Hartranft is Chief, CEERD_CF_E and L. Michael is Chief, CEERD-CF. The Acting Director of CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

World energy consumption is expected to increase significantly over the next 20 to 30 years. The Energy Information Administration projects an increase of 54 percent from 2001 to 2025 (EIA 2004). The International Energy Agency predicts that, if governments continue with present policies, the world's energy demand will be almost 60 percent higher in 2030 than now (IEA 2004). Fossil fuels will continue to dominate the world's energy mix and are expected to meet most of the increase in demand, but with significant impact on security, economy, and the environment. The share of world energy provided by nuclear power and renewable energy technologies is projected to remain limited. Much of the expected new energy demand will be in the developing nations, especially in Asia, including China and India, the world's two most populous nations, as world population increases and standards of living improve. The United States, the world's third most populous nation, has less than 5 percent of the world's population, but uses a disproportionate 25 percent of the world's energy supply. The U.S. share of the world's energy consumption is expected to fall as world energy consumption grows more rapidly in Asia than in the United States.

Meeting the world's increasing energy demands will require significant investment. IEA puts that estimate at about $16 trillion from 2003 to 2030, or about $568 billion per year for the foreseeable future. The majority of this investment, $10 trillion, is expected to go into the electrical sector in developing nations. Investments in the petroleum sector must be on the order of about $3 trillion to provide infrastructure and offset declines from presently producing oil fields. The natural gas sector will require an investment of about $2.7 trillion for gas-supply infrastructure, especially to enhance exploration and production and for liquefied natural gas infrastructure. The use of coal is expected to greatly increase in China and India. Coal usage will also grow in the United States as the electric power system expands to meet projected growth. Financing these changes will be a major challenge. As international trade in these energy commodities expands, the risk of supply disruptions will grow. The predominance of oil production will be in Persian Gulf nations and Central Asia.

This is a challenging time for the Nation and the world. U.S. energy consumption is expected to increase while the domestic supply of petroleum and natural gas declines. Net imports of energy will continue to grow to meet increasing demand. By 2025, it is expected that the United States will import 38 percent of its energy consumption (up from 27 percent in 2003). This will occur in a setting where overall U.S. consumption is expected to grow at an average annual rate of 1.4 percent, or 30 percent in that time period (EIA 2005).

Filling energy needs as this expected energy scenario plays out will become increasingly difficult over the next several decades. The outcome of current domestic and world trends will require considerable investment and many changes in the way we conduct energy business, within the Nation as a whole and on Army installations, in particular. In the near term, unresolved deregulation and market reform issues continue to dominate the electric utility sector, and pit one region against another. The cost-effectiveness and security of new, renewable energy and distributed electrical generation technologies have the potential to change the structure national energy flows significantly, especially at the local or regional level. Coincident with these external changes is a new business environment for military installations that requires privatization of many activities and functions, including utility systems, and the understanding that energy security is extremely important. Over the next several decades, technological and structural transformations will alter energy sources and flows throughout the nation. These transformations, combined with requirements for secure and reliable energy systems, have the potential to bring about major beneficial changes on military installations including sustainable management of energy resources.

Some things are fairly certain about the future. The energy system is large and complex and has a great deal of inertia. Fossil fuels will continue to play an important, even dominant, role for the foreseeable future. Natural gas will be a preferred fuel, although both natural gas and oil will be significantly more expensive in real terms than in the past. Nationally and globally, the demand for energy services for transportation, heating, cooling, and light will continue to grow. Environmental issues will become even more contentious, and the effects of carbon emissions will be an increasingly important concern. Technology will continue to advance ways that will affect all of these circumstances.

There are also some key uncertainties about the future. A main one is the future of oil and natural gas production (its cost and availability) and the impacts of technologies associated with it. The current trend in national motor vehicle fleet fuel efficiency is either static or downward, yet motor vehicle technology and fuel consumption have the potential to change radically for the better (Lovins, Datta et al. 2004). Fuel-efficient technology exists, but not the will to implement it. The carbon emission intensity of the economy is trending down (in tons/GDP) and has the potential to decrease more rapidly than in the past—as energy costs rise, the cost to implement energy efficiency falls. Ensuring reliable sources of petroleum and natural gas will become more problematic as the Nation becomes increasingly more reliant on imports from areas of the world such as the Middle East, Africa, and Central Asia where political stability is not assured. While the Nation is becoming more reliant on imported energy resources, other nations of the world, especially Europe, India, and China, will be in direct competition for them to meet their own increasing demands.

There is an imperative need to examine these certainties and uncertainties of the domestic and world energy situations, and to formulate an effective and viable path for the Army's energy future. The Army must immediately begin to consider the short- and long-term issues involved in developing enduring energy policies and solutions for its military installations. To sustain its mission and ensure its capability to project and support the forces, the Army must insulate itself from the economic and logistical energy-related problems coming in the near to mid future. This requires a transition to modern, secure, and efficient energy systems, and to building technologies that are safe and environmental friendly. These supply- and demand-side challenges require thoughtful planning and execution, and integrated solutions.

Objective

The objective of this work is to: (1) synopsize national and world energy issues (including energy source options, resource stocks, and future prognosis) with a focus on Army installations, and their need to respond to changing trends, and (2) present the implications for actions derived from the world and national energy situation. This summary will allow the Army to make informed choices on energy utilization that will sustain the Army's mission.

Approach

A literature and web search of the world energy situation was done to gather current energy statistics along with past and expected performance over time in the areas of availability, cost, sustainability, and security. World and national energy statistics were reviewed and analyzed. Annual Army data reports were reviewed to generate comparisons of Army consumption with national and world reserves. The collected data were used to create a table of side-by-side energy options and their particular features to show the advantages, disadvantages, and tradeoffs associated with choosing one energy source over another. This information, coupled with the known constraints and values of the Army, led to the formulation of suggested courses of action for national, regional, and installation energy strategies.

Mode of Technology Transfer

Results of this work will be furnished to the Office of the Assistant Chief of Staff for Installation Management (OACSIM), Headquarters, Engineer Research and Development Center (HQERDC), and the Installation Management Agency (IMA). It is anticipated that approved sections will be incorporated into the Army Energy Campaign Plan.

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil

2 Petroleum

Oil is the most important form of energy in the world today. Worldwide oil consumption is about 157 quadrillion Btu per year, or about 39 percent of the world energy supply (IEA 2004). In the United States, oil accounts for about 38 percent of the energy supply, for a total of 39 quads (IEA 2004). In 1970, the United States used about 31 percent of the world's oil supply, down to about 25 percent in 2005. This percentage has been slowly dropping over the last several decades because worldwide demand is increasing faster than U.S. demand—not because U.S. demand has fallen. The U.S. transportation system relies on petroleum products for 97 percent of its energy, while fuel efficiency has essentially remained static for the last decade.

Historically, no other energy source equals oil's intrinsic qualities of extractability, transportability, versatility, and cost. The qualities that enabled oil to take over from coal as the front-line energy source for the industrialized world in the middle of the 20th century are as relevant today as they were then. Oil's many advantages provide 1.3 to 2.45 times more economic value per MBtu than coal (Gever, Kaufman et al. 1991). Currently, there is no viable substitute for petroleum.

The United States now imports about 63 percent of its crude oil supply. That percentage is expected to increase since domestic production is declining and demand is increasing (EIA 2004). The nation is becoming more vulnerable to the potential economic and geopolitical implications of oil market volatilities (Romm and Curtis 1996). Once world demand exceeds supply, the price of oil will begin reflecting monopoly and scarcity rent. In fact, we may have already reached that point where demand exceeds supply. The current price of oil is in the $45-57 per barrel and is expected to stay in that range for several years. OPEC is considering raising its market basket price to the $40-50 range since it has been in that range over a year. Oil prices may go significantly higher and some have predicted prices ranging up to $180/barrel in a few years. World petroleum demand growth is likely to be the key factor for oil markets for the foreseeable future. New oil projects coming on line will only increase world supplies by about 1 percent per year this decade (ODAC 2004). World petroleum demand growth during the 2005 and 2006 period is projected to average about 2.5 percent per year, a rate that exceeds expected growth in non-OPEC supply and global refinery capacity (Figure 1).

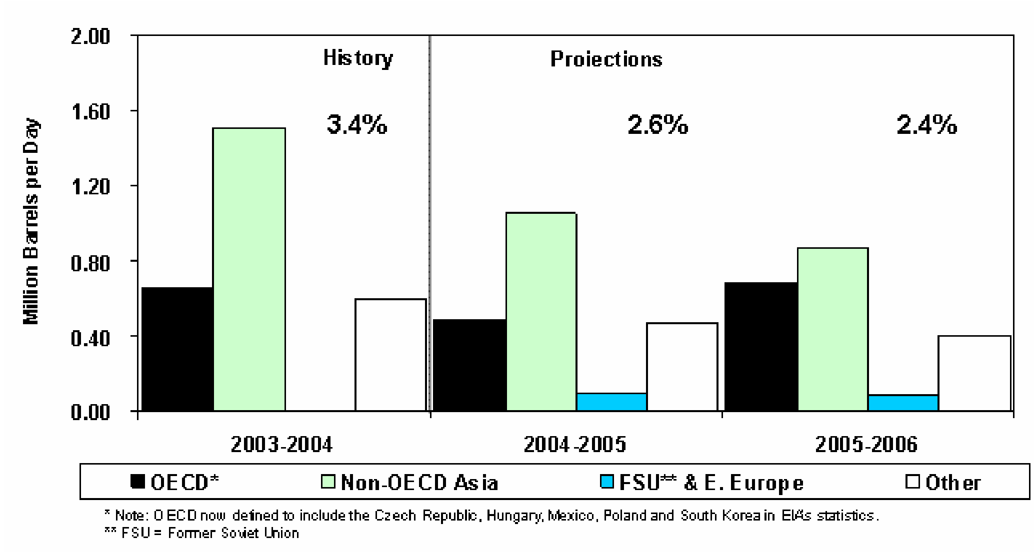

Figure 1. World oil demand, March 05 short-term energy outlook, EIA.

Although this is strong growth, it is down from the 3.4 percent demand growth (2.7 million barrels per day) in 2004. The lower global oil demand growth rate in 2005 and 2006 is attributed to several factors, including the impact of high world oil prices and slower projected Chinese oil demand growth (EIA 2005). These predictions indicate a shortfall in world oil production of 1 to 2 percent during the next decade. This is a sure sign that the oil world supply picture is changing in ways that depart from "business as usual."

Conventional Oil Resources

In general, all nonrenewable resources follow a natural supply curve. Production increases rapidly, slows, reaches a peak, and then declines (at a rapid pace, similar to its initial increase). The major question for petroleum is not whether production will peak, but when. There are many estimates of recoverable petroleum reserves giving rise to many estimates of when peak oil will occur and how high the peak will be. A careful review of all the estimates leads to the conclusion that world oil production may peak within a few short years, after which it will decline (Campbell and Laherrere 1998; Deffeyes 2001; Laherrere 2003). Once peak oil occurs, then the historic patterns of world oil demand and price cycles will cease.

In recent years, the realization of price stability has depended on the effectiveness of nations belonging to the Organization of the Petroleum Exporting Countries (OPEC) to adjust for the production increases and lags of the non-OPEC nations. We have now entered a period where production is lagging behind demand. Presumably, potential excess capacity still resides in OPEC nations, thus allowing them to control the price of oil. The current debate is whether OPEC can in fact increase production to stabilize prices, or if the market will have to adjust demand to meet supply through price mechanisms. Saudi Arabia maintains that it has excess capacity and can increase production to meet demand. Unfortunately, Saudi Arabia has not been able to increase supply above its monthly production peak of April 2003 (EIA 2005). Iraq may also have significant excess capacity if it could be brought into production (EIA 2002). Meanwhile, domestic oil production in both the lower 48 states and Alaska continues to decline. Many non-OPEC oil producers have also passed or are currently reaching their peaks of production.

Petroleum experts Colin Campbell, Jean Laherrere, Brian Fleay, Roger Blanchard, Richard Duncan, Walter Youngquist, and Albert Bartlett (using various methodologies) have all estimated that a peak in conventional oil production will occur around 2005. The corporate executive officers (CEOs) of Agip, ENI SpA (Italian oil companies), and Arco have also published estimates of a peak in 2005. These reliable estimates all project that conventional oil peak production will occur within the next few years (Campbell and Laherrere 1998; Youngquist 1997; Campbell 2004). Reduced demands caused by high prices may delay the peak slightly, but the peak is certainly within sight. Note that the peaking of conventional oil should not be confused with total oil production. Total oil production includes such commodities as natural gas liquids, deep water oil, and polar oil. Inclusion of these will delay the peak to 2008 (Aleklett 2004). Estimates of peak production are not without controversy. The estimates cited above are by those considered “oil pessimists.”

A 2000 U.S. Geological Survey report estimates a much higher availability for the future of petroleum based on three things—reserves growth, higher recoverable fractions, and greater amounts new discoveries (Ahlbrandt, Pierce et al. 2000). The USGS report presents an optimistic picture for the next 20 years or so. Even if there predictions are true, the overwhelming majority of this oil is projected to be in the former Soviet Union, the Middle East, and in North Africa. North American potentials are predominately in the arctic, including National Petroleum Research Alaska (NPRA) and Arctic National Wildlife Refuge (ANWR). Jean Laherrere made an assessment of the USGS report and concludes that:

> The USGS estimate implies a five-fold increase in discovery rate and reserve addition, for which no evidence is presented. Such an improvement in performance is in fact utterly implausible, given the great technological achievements of the industry over the past twenty years, the worldwide search, and the deliberate effort to find the largest remaining prospects.

Laherrere also concludes that reserve growth numbers are not realistic as this only occurs in the United States where the SEC requires a different reporting scheme for petroleum finds than the rest of the world uses (Laherrere 2000). Reserves will not grow as predicted. In fact, some oil companies such as Shell have significantly downgraded their reserve estimates in the recent past (Shell Oil Co. 2005).

In conventional oil fields, usually less than half of the oil in place is recovered. The heavier fractions are left behind because they are too difficult to pump. Secondary and tertiary recovery techniques are used to increase production from a field. The heavier fractions are produced last and are more expensive, yielding less net energy due to the excessive energy required for their production such as pumping costs and steam injection. Eventually diminishing returns is reached and the field is abandoned with considerable oil left in the ground. Somewhat higher rates of recovery are expected due to new technology in finding oil and directional drilling, but these additional recoveries will not add the great percentages projected by the USGS.

Natural Gas Liquids (NGLs)

Natural gas is a hydrocarbon comprised of two parts—a light gas component and a heavier gas liquids component. The light gas consists of methane, while the liquids consist of ethane, propane, butane, isobutene, and natural gas. These liquids are used as petrochemical feedstock, home heating fuels, and refinery blending. Before most natural gas is marketed to a distributor or an end-user, it is processed to remove the natural gas liquids (NGLs). After NGLs are removed from natural gas, they are reprocessed in a unit called a fractionator to break them out for individual sale as propane, butane, and other products. NGLs make up a significant portion of the petroleum supply. There production is tied to the production of natural gas and there is a tradeoff based on the current value of the two products that determines whether the NGLs are sold with the gas content or use as petrochemical feedstock. This causes reserve estimates and production to vary. NGLs make up about 10 percent of the worldwide petroleum production, but this fraction is increasing as natural gas production increases (WEC 2001).

In the United States, NGLs make up about 25 percent of the proven liquid hydrocarbon reserves. In 2003, NGLs made up about 30 percent of the liquid hydrocarbon production (EIA 2004). NGLs play a significantly higher role in the United States than they do worldwide. The NGL fraction in worldwide petroleum production is expected to grow in the future.

Deep Water

Oil located at ocean depths greater than 400-500 meters is considered deep water although the definition varies by region. Estimates of this deep water oil ranges from a low 60 to a high of 180 billion barrels. Around two-thirds of oil and gas discoveries come from deep water now, as exploration successes on shore and in shallow waters become rarer (Westwood 2001). Most resources are located in the Gulf of Mexico and the margins of the South Pacific Ocean e.g., off the coasts of Brazil, Angola, and Nigeria (Campbell 2002).

Despite the vast resources waiting beneath deep waters, exploitation is difficult. New technology may lead to breakthroughs in recovery oil at great underwater depths. Technical troubles and political maneuvering in some countries cause project delays. Host governments in some deepwater provinces, such as West Africa, have put the brakes on some projects to boost the involvement of local companies. This, combined with a focus on short-term returns by some of the oil majors, has slowed deep water developments. Another consideration is that the energy return on energy invested for deepwater oil is less than for conventional oil. It takes a lot of energy to extract it and much less oil will be available to the market than the optimistic number of 180 billion barrels. These wells tend to deplete rapidly with less recovery than shallow or surface wells. A significant amount of oil will be used to build the platforms, drill, and transport the oil. Because of this relative difficulty and high costs in producing deepwater oil, oil companies will likely not be able to extract it rapidly. So while it may slow the rate of decline of the world's oil production, deepwater oil seems unlikely to significantly offset the peak itself.

Polar Oil

The polar region is considered to be mainly a source of natural gas, although there maybe some minor oil discoveries. Oil production on the North Slope of Alaska peaked in 1997 and is already in significant decline. Parts of the NPRA are now being leased for exploration. Production from NPRA is expected to be in the range of 9 billion barrels (Bird and Houseknecht 2002). Whether or not the ANWR is opened to exploration, it will not make a significant impact on world or U.S. oil resources. The expectation for oil production from ANWR ranges from 5 to 16 billion barrels, with a mean of about 10 billion barrels (EIA 2002). This compares with an estimated ultimate recovery from the Prudhoe Bay area of about 13 billion barrels. This production would not start until 2013 and would peak in about 2025 at approximately 900,000 barrels per day (EIA 2003a). All together, Alaskan oil may represent about a two and a half year addition to the nation's oil supplies.

Other Liquids

Other liquid fuels such as ethanol and methanol do not have a much better energy ratios than some of the synthetic oils; a full energy accounting shows that it takes just about the same energy to produce the synthetic fuel as can be derived from the product (Herendeen, 1998 #20). The expanding use of ethanol is not the result of an energy program, but of programs to support farmers and agribusiness. Current calculations show an energy gain of about one third for ethanol, but that calculation assumes the most efficient and effective farming and production, and ignores the environmental impact of modern agriculture. Biofuels will be covered in greater depth under the Chapter 6 “Renewables” (p 29). Liquids from coal are discussed later under Chapter 4 “Coal” (p20).

Unconventional Oil Resources

Studies show that no alternative fuel can currently replace oil. A review of the future prospects of all alternatives concludes “there is no known complete substitute for petroleum in its many and varied uses.” (Youngquist 1999) Some have predicted a growing production of synthetic oil such as from oil shale in the United States, Athabasca tar sands in Alberta, Canada, or extra-heavy crude oil from the Orinoco region of Venezuela (EIA 2004). All of these non-conventional sources of oil have significant problems associated with their production. In many cases it takes as much or more energy to produce synthetic oil as can be derived from the product itself. Also, significant environmental problems are associated with its production. Each of these unconventional resources will be discussed below.

Oil Shale

Oil shale is actually neither oil nor shale. It is organic marlstone containing kerogen, a solid organic material that has not evolved to oil. The United States has an estimated 500 billion barrels of recoverable oil from shale (WEC 2001). Unfortunately, it has not proven to be economically recoverable. It takes two barrels of water to make one barrel of shale oil along with significant amounts of energy, resulting in a poor net energy ratio. Oil shale is found in the states of Colorado, Utah, and Wyoming. These are not areas with high water availability and its production has huge materials handling and disposal problems. The production process creates a larger volume of waste than the material originally removed from the ground and the resulting material contains salt compounds, which can contaminate surface water supplies. Several projects and production methods have been tried over the last several decades, but none were successful. Due to its high energy requirements, the cost of shale oil has historically exceeded conventional oil. To date, the financial and energy economics of oil shale have not been viable; this is unlikely to change.

Tar Sands

The Canadian tar sands are estimated to hold about 170 billion barrels, but the associated production process has similar environmental and net energy problems as oil shale, especially with contaminated waste water. Oil sands production is done by two methods—bitumen mining and in-situ. A majority of non-upgraded crude bitumen production to date has come from three surface mining projects, which averaged a combined 526,510 barrels per day in 2002. A large portion of this production is then upgraded into synthetic crude oil. Mined bitumen production is forecasted to reach 1.56 million barrels per day by 2012. The production process results in two barrels of waste water for every three barrels of oil produced. Roughly two tons of oil sands must be dug up, moved, and processed to produce one barrel of oil. It should be noted that the production in Athabasca is based on the use of natural gas as the energy source. Canadian natural gas is becoming significantly more expensive and is being depleted. In 2002, non-upgraded crude bitumen production from in-situ operations averaged 299,843 barrel per day. Most of in-situ production to date has been marketed in non-upgraded form outside of Alberta and only a small percentage is used in Alberta refineries. In-situ production is forecasted to reach 773,647 bbl/d by 2012 (EIA 2004).

Extra-Heavy Crude

Venezuela contains billions of barrels in extra-heavy crude oil and bitumen deposits, most of which are situated in the Orinoco Belt, located in Central Venezuela. Estimates range from 100 to 270 billion barrels of recoverable reserves (EIA 2004). Venezuela intends to develop these resources using joint ventures with foreign partners. Currently, these joint venture projects convert the extra heavy crude from approximately 9° API crude to lighter, sweeter synthetic crude, known as syncrude, at the Jose refinery complex on Venezuela's northern coast. In 2003, these projects were producing about 500,000 barrels per day of synthetic crude oil and this quantity is expected to increase to 600,000 barrels per day by 2005. Syncrude is considered by the International Energy Agency (IEA) a "non-conventional crude oil." The upgrading process also produces byproducts, such as coke and sulfur. Venezuela's Ministry of Energy and Mines is working on a new licensing round to offer up new blocks for exploration and production in the Orinoco Belt. Production will continue and slowly expand over time to become a more significant portion of the petroleum supply in the long term.

Conclusions about Petroleum

In summary, the outlook for petroleum is not good. This especially applies to conventional oil, which has been the lowest cost resource. Production peaks for non-OPEC conventional oil are at hand; many nations have already past their peak, or are now producing at peak capacity. Polar, deep, and non-conventional will contribute to future resources. Most conventional oil production reserves are in OPEC nations, mainly in Saudi Arabia and Iraq. Oil demands have not been as high as projected during the last decade due to worldwide recessions and this may stretch out the OPEC peak a bit. Currently, non-OPEC nations have been at maximum production and will most likely peak as predicted.

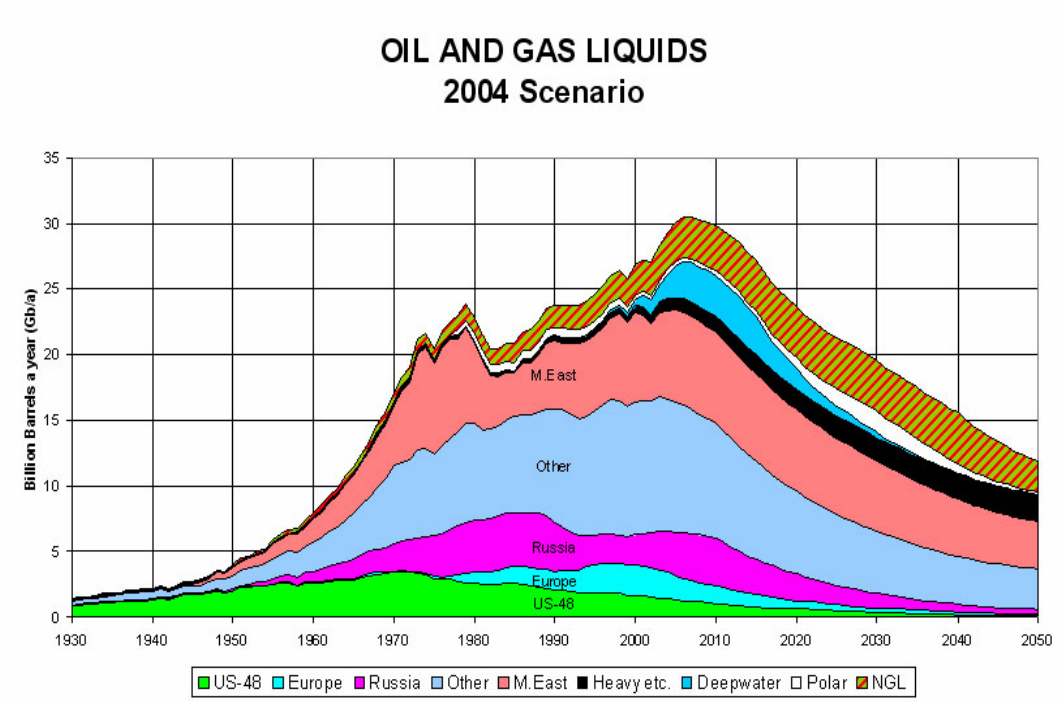

Figure 2. World oil production (ASPO).

Figure 2 shows the projected worldwide oil production (based on analyses from the Association for the Study of Peak Oil and Gas [ASPO]). Note that these are considered pessimistic projections. Others predict far higher production for the future, but discoveries to date have not born out the predictions of the optimists. The optimists premise their estimates for the future entirely on production from the Middle East and Central Asia. They predict OPEC Middle East production to about 52 million barrels/day in 2030, which is more than twice what it is today. Reserves in this region are highly speculative and these nations have not been open about their exploration and reserve estimates. This high a production is an extremely implausible scenario and relies on a worldwide investment of about $3 trillion. Figure 3 shows past oil discoveries and projects future discoveries, comparing them to past and project consumption. Production over the next decade or so will increase at a rate of about 1 percent per year. This will not meet demand and prices will reflect this. After that, worldwide production will begin to fall.

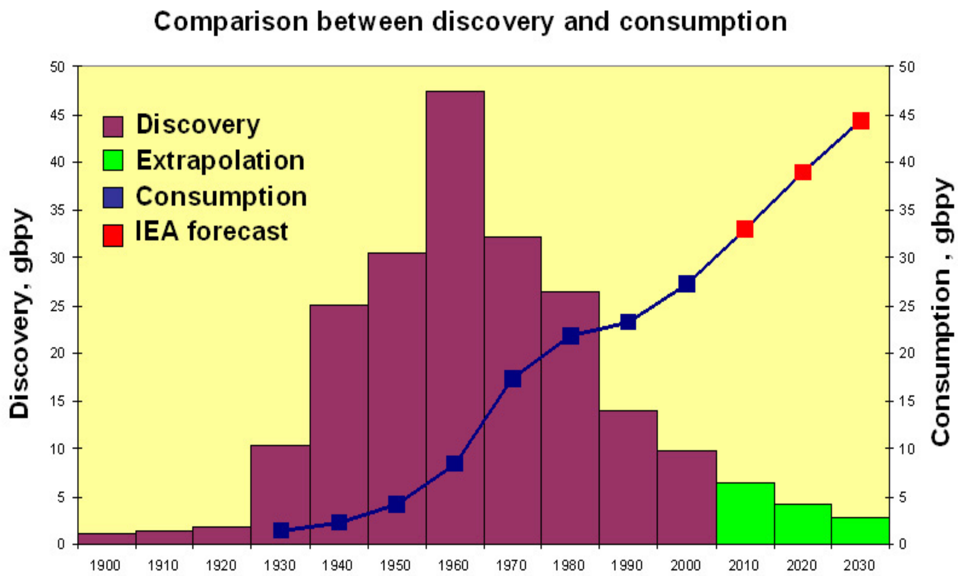

Figure 3. World oil discoveries (ASPO).

3 Natural Gas

Natural Gas Resources

Natural gas is an abundant worldwide resource, but its supply is insufficient to sustain our consumption practices beyond the first half of this century. The United States is headed for a significant crisis in natural gas supply. Domestic natural gas production is dropping and the marginal supply picture makes the system vulnerable to any shock such as an interruption, major storm, or weather extremes of heat or cold. Natural gas prices have consequently been very volatile over the past several years. This trend will continue until major changes are made in the supply situation. A significant upward shift in prices that began in January 2003 caused a drop in consumption as industry responded to higher prices. This price increase may well be permanent with current prices in the range of $7/MBtu at the hub. This upward price trend stems in part from a huge and growing shortfall of about 1 trillion cubic feet (Tcf) in supplies available to the U.S. market. This shortfall would have been experienced even if there were no increase in domestic demand. Unfortunately, at the same time supplies are diminishing, demand is certain to be growing due to the impact of 200,000 MW of natural gas-fired generating capacity that has been added to the grid since 1999. The domestic natural gas demand will become less predictable as the relative share of total demand dedicated to electrical generation increases while the relative share dedicated to the industrial sector declines. Both of these large consuming sectors are in a state of flux due to high natural gas prices. This has led to a decline in demand, due to fuel switching, to industries shutting down, or to production moving overseas. The power industry is responding by increasing its use of coal and by idling gas-fired units as much as possible.

World Natural Gas Supply

The current worldwide demand for natural gas is about 92.5 Tcf. According to British Petroleum world statistics, the proven reserves are about 6,204 Tcf (British Petroleum 2004). This represents a 66-year supply at current consumption rates. Worldwide demand is expected to double in the next 25 years, significantly shortening this supply forecast timeframe to 40 years. Most of the world's reserves are in Russia and the Middle East with North America, Europe, and Asia being increasing importers of natural gas. Maintaining and increasing natural gas supplies will require an investment of about $2.7 trillion over the next 25 years (IEA 2004). Gas supply prices are rising worldwide following the large increases in oil prices.

Domestic Natural Gas Supply

The demand for natural gas is expected to grow by 40-50 percent over the next 20 years in the United States (EIA 2005; Wilkinson, McGill et al. 2005). The demand increase is expected to be led by a growing use of natural gas in the electrical power sector—up from 4.92 quads in 2003 to 10.2 quads in 2020. Despite the fact that the number of drill rigs is growing, the production remains constant or is declining. Discoveries per well drilled have flattened or decreased in recent years. High gas prices have pushed exploration toward marginal wells where gas is known to exist. These wells offer low risk, but have rapid depletion rates and low volume recovered per well. Exploration is also limited by government policy that denies drilling in many public and off-shore areas. The fields where gas producers have been exploiting are old, yielding less natural gas, and the wells have very steep decline rates. Today, the industry must produce 6 Tcf per year of new natural gas just to keep pace with current needs because existing supplies are being depleted by about 29 percent per year. Since the demand for natural gas is growing at 2 percent annually, the nation is facing shortfalls in production.

In 1997, 600 rigs kept production flat. In 2001, more than 1,000 gas rigs were needed to keep production steady and in 2002, 725 rigs are deployed but U.S. natural gas production fell by 6 percent. There are only 1,200 to 1,300 gas rigs in existence making it difficult for U.S. producers to reverse these trends. This has led to increased use of unconventional gas sources. Tight gas sands, coal-bed methane, and gas shales have become a significant portion of our total supply—almost 30 percent of the total. These sources are attractive since they tend to produce for 10, 20, or even 30 years, however, these unconventional resources usually come from low permeability reservoirs that require a relatively high number of modest production wells. It is estimated that about 100 Tcf of coal-bed methane is economically recoverable at today's gas prices.

As traditional sources of production become less productive, the United States needs to do several things: expand unconventional production, push the limits of technology in the deepwater Gulf of Mexico, bring more natural gas into the United States from Canada, provide access to reserves on state and Federal lands, expand liquefied natural gas import capacity, and tap into the supplies of natural gas in Alaska. Bringing Alaskan natural gas south will require the construction of a pipeline estimated to cost $10-20 billion.

The environmental community is emphatic that the United States cannot drill its way to energy independence. It is not persuaded that greater access to the Rocky Mountains, the Atlantic coastline, California's coastline, the Gulf of Mexico and the ANWR is the answer. The void between the expected demand and the resources required is still too big. The environmental harm caused by more drilling would be devastating. Ever since the 1990 Clean Air Act passed, the momentum has shifted to natural gas as the preferred fuel for combustion sources. About 90 percent of all new electric generation capacity will be fueled by natural gas.

At the same time the United States is experiencing supply shortfalls, the demand for gas in this country is rising from about 22 Tcf in 2003 to about 30.7 Tcf in 2020 (EIA 2005), while the supply is only expected to grow from 19 Tcf to 28.5 Tcf, significantly short of the demand. As prices rise and availability has become more problematic projections of future consumption have dropped. Also, U.S. consumption dropped 5 percent in 2003 due to high prices. Previous estimates were that consumption would be 34.9 Tcf by 2025 (EIA 2003). Many consider projecting a domestic supply growth of this magnitude to be an impossibility (Littell 2002). Canada currently produces 6.3 Tcf per year, with about half meeting its own needs and the remainder being exported. This provides about 16 percent of the current U.S. supply. Canada is experiencing the same rapid decline rates on its natural gas wells as in the United States and it is hard pressed to keep up production. The Canadians have opened up ocean drilling off their east coast and are now exporting directly into New England by pipeline. There is also a growing movement in Canada that feels they should preserve what natural gas they have for their domestic market. Thus we see pipeline exports from Canada dropping and they need to be replace by another source of supply.

To meet expected future demand, the industry would need to increase its outlays on drilling activity by 44 percent and to have access to many sites where they can not currently explore for natural gas or oil. Current investment spending is about $28 billion a year but nearly $40 billion annually is needed over the next 15 years. Capital markets have shied away from the exploration industry because it is seen as being one of boom-and-bust. Also, more than 2,000 miles of new gas-transmission pipeline will be required each year until 2010, at a cost of $2.5 billion a year. Unfortunately, pipelines will not get financed or constructed unless the wells are drilled and become productive, which has not yet happened.

Liquefied Natural Gas

The desirability and demand for natural gas will continue to increase, but it is price sensitive and cannot be the panacea for solving the nation's long-term energy needs. There are significant natural gas reserves in the United States, but it is a limited domestic fuel source because in many cases its exploration and production is off limits. This leaves the nation with the choice of importing ever increasing amounts of natural gas through pipelines from Canada or relying on large volumes of imported liquefied natural gas (LNG). It is unlikely that imports from Canada will increase; therefore the choice must be to import LNG. Existing LNG port facilities in the United States have been reopened and expanded and more are planned. Facilities are also being developed in Norway, Nigeria, and Australia to export natural gas. The long-term interest in LNG remains high. During the period 2005-10, the imported re-gasified LNG role in the natural gas market is projected to reach approximately 2 Bcf/d, or 3 percent of the total (Hrehor and Sytsma 2002). Others belief that LNG imports may reach 5 Bcf/d (Fountain 2001). At these levels, LNG would be a more significant part of the supply, but still meet only about 5 percent of the expected demand.

Over the past 20 years, the costs of liquefaction, transportation, and re-gasification have declined significantly. The dramatic cost reduction for LNG liquefaction trains, especially for expansion trains, has made LNG production projects viable even if only part of the capacity is secured with long-term contracts (IEA 2004). This has led to a spot market in LNG. Projections with existing technology are that LNG can be commercially delivered into the United States at a price of approximately \$3.25-\$3.50/Mmbtu, while allowing for a margin to marketers and upstream producers. Moreover, the natural gas market in the United States provides a relatively stable political and economic environment to gas producers who are seeking to produce and deliver LNG supplies. LNG must provide an increasing amount of the nation's imported natural gas, but will probably not be in sufficient amounts to avoid a large mismatch between supply and demand. Ramping up the LNG system has several issues. The sites for many of the proposed terminals are experience significant local resistance to this type of facility. Given the number planned projects that have already received or may soon receive major permits should provide enough capacity to cover likely import requirements as soon as 2007.

These terminals are coming to market during a period that incremental LNG supplies will be uncertain. While numerous new liquefaction projects are being developed over the next few years in countries such as Nigeria, Egypt, and Trinidad, most of it is contracted to buyers in Europe and Asia. Long-term commitments to North America, especially from Qatar, will be significant by 2009. In the interim, the U.S. market will have to continue to rely on spot cargoes. Ultimately new LNG projects help lower prices and smooth volatility in U.S. gas markets, but that is probably 5 years or more away. There may be over 16 Bcf/d of import capacity available by 2009, with around 12 Bcf/d of capacity available under a moderate scenario. Yet North American LNG imports at most will average 6.25 Bcf/d then and could be as low as 3.5 Bcf/d in 2009. Only volumes near the top of the range would be sufficient to significantly lower gas prices. An overbuild scenario, such as has happened with natural gas-fired peaking plants may occur. The Gulf Coast is likely to see new terminals built without firm supply commitments. On a regional basis, terminal capacity should not be a problem. If no terminals are approved in the Northeast, projects in Eastern Canada could fill in the supply gap. The near term issue is not a concern with having too few terminals, but with having too little LNG supply.

Conclusions about Natural Gas

The future of the natural gas market and its viability in the United States depends greatly on decisions that must be made in the political arena about what resources will be exploited and how the natural gas will get to market. It is estimated that there are 272 Tcf of essentially stranded gas in the lower 48 states because access is denied due to environmental considerations or it is on Federal lands (EIA 2004). There is an additional 100 or so Tcf currently stranded in Alaska (Bird and Houseknecht 2002). The American Gas Foundation recently issued a report indicating that the need for public policy makers and industry decision makers to immediately address critical issues that will have a significant impact on the availability and price of natural gas for decades to come (Wilkinson, McGill et al. 2005). They do not expect under any scenario that the natural gas market will return to the conditions that prevailed in most of the 1980s and 1990s—when there was a surplus of supply and relatively low, stable prices. They also conclude that a failure to act swiftly, decisively and positively on issues such as constructing liquefied natural gas receiving terminals and an Alaskan gas pipeline, diversifying our electricity generating mix and increasing access to domestic supplies of natural gas would prolong and exacerbate problems affecting natural gas markets and all consumers of natural gas.

The most immediate question is whether the optimistic projections of the demand for natural gas can hold. U.S. production has dropped by nearly 5 percent while Canadian imports have declined by 23 percent from 2001 to 2004. Meantime, existing wells are producing less gas. Those economic realities coupled with prices that are now about $7 per million BTUs, could likely curb future expected demand and force utilities to build more coal-fired generation since that fuel source is cheaper and more plentiful. From an energy standpoint, this is not bad—but from an environmental standpoint this is problematical.

The near term domestic picture is challenging and the mid and long term pictures are bleak. Worldwide, natural gas is limited by demand, not by supply. Much of the world's natural gas resources are stranded (the gas is not near the market and is difficult and costly to transport). In the near and mid term it is a matter of getting the domestic and world product to market. Proven reserves are about 1,991 trillion cubic feet (British Petroleum 2004). Estimates of the ultimate recoverable range from 12,000 to 15,390 Tcf (Ahlbrandt, Pierce et al. 2000). The lower value is the most realistic.

In the long term, natural gas is like other non-renewable resources; world production will peak later this century and this resource will become scarce. There is an estimated 66 year supply at current rates of consumption while projected growth reduces this to 40 years. World peak production of natural gas is estimated to occur sometime between 2030 and 2050 (Laherrere 2003).

4 Coal

Coal Resources

The United States has over 96 percent of the coal reserves in North America. The United States and the Former Soviet Union combined have 47 percent of the world's coal reserves. China, Australia, India, and Germany round out the top six with another 33 percent or the world's total. U.S. coal reserves of 280 billion tons equal about a 260 year supply at current rates of consumption, assuming the United States would start using more sub-bituminous coals as they represent about half the reserves, but only about 8 percent of the consumption. Thus, based solely on hard coal, our reserves are about 140 years. The United States produces 24 percent of the world's total hard coal (909 million tons of 3,775 million tons) and 9 percent of the world's total brown coal (79 million tons of 901 million tons) annually. China and the United States produce almost 50 percent of the world's total coal (IEA 2000).

Over 90 percent of the coal consumption in the United States goes into producing electrical power. About 6 percent is used by industrial and coke plants with the remaining 4 percent are used by captive markets such as state-owned facilities, or used by the residential and commercial sectors. Over 50 percent of the electricity generated in the nation is from coal. Coal use by all sectors other than electrical generation has been greatly reduced over the last several decades due the air pollution implications of its usage. The high price of pollution abatement systems restricts coals usage to large consumers. Most of the other markets have switched to natural gas or fuel oil.

Environmental Issues

Like other fossil fuels, coal has played an important role in fueling the advancement of civilization, but its use also raises significant environmental issues. Coal mining has a direct impact on the environment, affecting land and causing subsidence, as well as producing mine waste that must be managed and kept from polluting streams and aquifers. Coal combustion produces several types of emissions that adversely affect the environment, particularly ground-level air quality. Concern for the environment has in the past and will in the future contribute to policies that affect the consumption of coal and other fossil fuels. The main emissions from coal combustion are sulfur dioxide (SO_2), nitrogen oxides (NOx), particulates, and carbon dioxide (CO_2). Recent studies on the health effects of mercury (Hg) have also brought to the forefront concerns about emissions of mercury from coal-fired power plants. Interestingly, the radon in coal causes coal-fired plants to have a higher background radiation readings than nuclear plants. Sulfur dioxide emissions have been linked to acid rain. Enforcing limits on sulfur dioxide emissions typically requires electricity producers to switch to lower sulfur fuels or invest in technologies—primarily flue gas desulfurization (FGD) equipment—that reduce the amounts of sulfur dioxide emitted with coal combustion.

As mentioned above, environmental regulation influences inter-fuel competition (how coal competes with other fuels, such as oil and gas), particularly in the power sector, where the competition is greatest. For example, compliance with increasingly stringent restrictions on emissions could be increasingly costly and could lead to reduced demand for coal. On the other hand, improved technologies may provide cost-effective ways to reduce emissions from coal-fired power plants. Integrated gasification combined-cycle (IGCC) technology, which may soon be commercially competitive, can increase generating efficiencies by 20 to 30 percent while reducing emission levels (especially of carbon dioxide and sulfur oxides) more effectively than existing pollution control technologies.

In addition to sulfur dioxide, increased restrictions on emissions of nitrogen oxides, particulates, and carbon dioxide are likely. Coal-fired generation faces steeper environmental cost penalties than new natural gas-fired generating plants. For nuclear and hydropower, which compete with coal for base-load power generation, the future is unclear. Many nuclear power plants are expected to reach the end of their service lives in the next decade or two and what will replace them is still unknown. The siting of new large hydroelectric dams is also becoming more difficult because of increased environmental scrutiny and most sites have already been developed. With hydroelectric dams it is more of a question of when will they be taken down due to their environmental damage to the aquatic systems they disrupt (EIA 2001).

By far the most significant emerging issue for coal is the potential for a binding international agreement to reduce emissions of carbon dioxide and other greenhouse gases. The Kyoto Protocol to the United Nations Framework Convention on Climate Change, which went into effect on 16 February 2005, is legally binding on its 128 parties (Climate Change Secretariat 2004). The United States has pulled out of the protocol. On a Btu basis, the combustion of coal produces more carbon dioxide than the combustion of natural gas or of most petroleum products (combustion of petroleum coke produces slightly more carbon dioxide per unit of heat input than does combustion of coal). Carbon dioxide emissions per unit of energy obtained from coal are nearly 80 percent higher than those from natural gas and approximately 20 percent higher than those from residual fuel oil, which is the petroleum product most widely used for electricity generation. In 1999, the United States and China were the world's dominant coal consumers and also the two top emitters of carbon dioxide, accounting for 25 percent and 11 percent, respectively, of the world's total emissions.

Clean coal technologies of the future still have to deal with the carbon issue. This may change if the integrated gasification combined-cycle technology also includes ways to sequester carbon dioxide (Gray and Tomlinson 2003). Poly-generation or co-production plants produce more than one useful product—clean liquid transportation fuels and other chemical products in addition to electricity from combined cycle power plants. Poly-generation also allows for the capture of carbon dioxide during the coal conversion process. Seventy such large plants could generate 35 gigaWatts of power and produce 2.4 million barrels per day of zero sulfur liquid fuels. This is enough to displace the imports from the Persian Gulf. They would use about 350 million tons of coal per year, which is about 32 percent of present production. Of course, using this technology will greatly shorten the time to coal depletion.

Conclusions about Coal

Coal is an abundant resource and will continue to play a major role in the world's and nation's energy mix for several hundred years, despite environmental issues with its mining and use. Worldwide coal consumption is projected to increase 90 percent in the next 25 years, but remain about 22 percent of energy over that time period as total energy consumption grows. In the United States, coal's major market will remain the electrical sector, but enhanced technologies such as poly-generation where coal is gasified and used to fuel combined cycle combustion turbines and to make naphtha, Fischer-Tropsch diesel fuel, and ammonia have significant potential to enhance the role of coal.

The price of coal has escalated considerably in the last few years, but since all the other fossil fuels have also escalated in price, it competitive position has remained stable or better. Coal has will play a significant and growing role in U.S. energy supplies in the mid to long term. New, cleaner technologies and the supply problems with petroleum and natural gas will combine to give coal a boost.

5 Nuclear Power

Nuclear power is at a turning point. A few years ago, many predicted that nuclear power was "dead." In fact, several countries in Europe intend to phase out their nuclear power programs, or are prohibiting new plants from being built, although the summer heat waves being experienced has caused some second thoughts on this. In the United States, the last nuclear power plant to come on-line was Watts Barr in 1996. Construction of the second unit on the site was halted at 80 percent completion. Watts Barr cost almost $5,000/kW. After that, no new plants were expected to be built. Today, 104 commercial nuclear generating units are licensed to operate in the United States. (This includes the Brown's Ferry Unit 1, which has been shut down since 1985, but retains a license. Plans are moving ahead to repair and restart it.) The U.S. reactors are of two basic types: 69 units are pressurized water reactors (PWRs) comprising about two thirds of the capacity and 35 units are boiling water reactors (BWR). Figure 4 shows the growth in generation and capacity factors of nuclear power in the United States

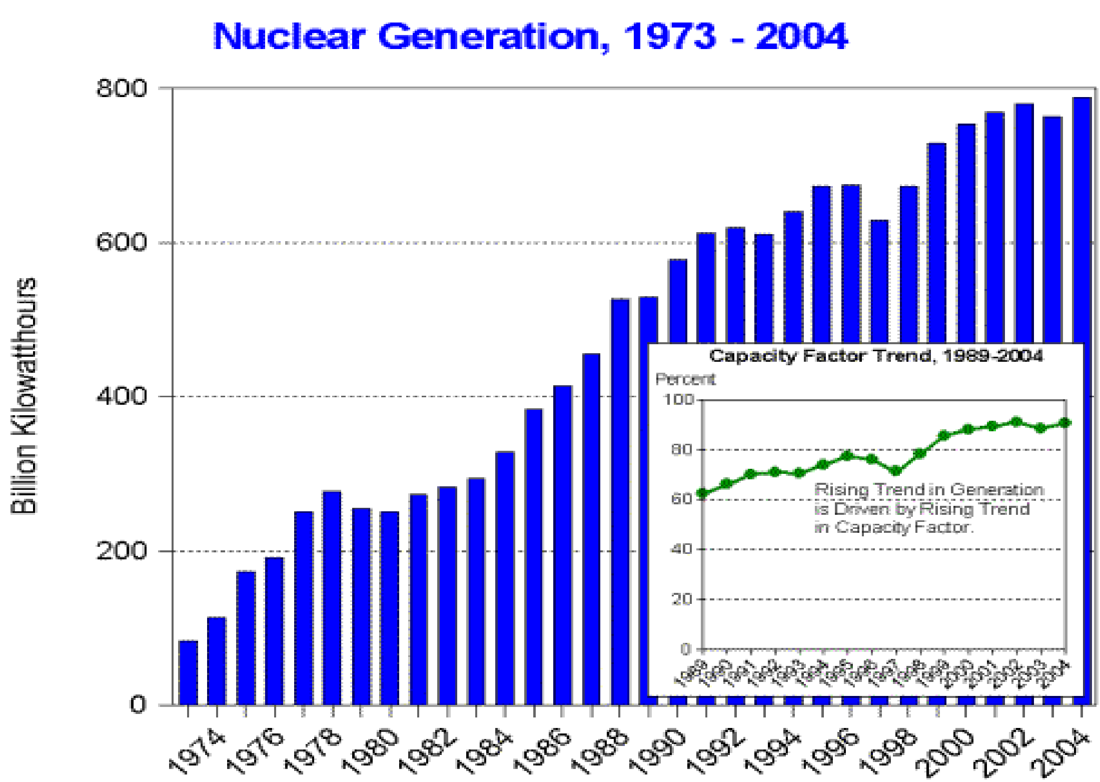

Figure 4. Growth of nuclear power generation (*Monthly Energy Review*, EIA/DOE).

Note that power plant capacity has remained flat with some up-licensing to about 102,162 megawatts. Also note that generation from these reactors has increased significantly over the last decade. This is due to several factors: the technology has matured, plants are achieving higher burn up rates for their fuels at slightly higher enrichment levels, unplanned outages have decreased, and ownership has consolidated leading to better management and engineering practices. This has led to 12 percent of America's plant capacity generation about 20 percent of the electricity.

The North American Electricity Reliability Council and other industry sources estimate that about of 15,000 MW of new capacity needs to be added each year. Most of new capacity that has come on-line in the last decade has been gas-fired combustion turbines. The nation is betting its electricity future on the availability of low-cost natural gas—a high-risk policy. Natural gas prices have risen significantly and will remain very volatile for some time. Relying almost solely on natural gas for future generation has been a serious mistake and a significant number of merchant plants have either been cancelled or moth-balled. One of the primary goals of the proposed National Energy Policy is to add supply from diverse sources. This means balancing imported and domestic oil, gas, coal, hydropower, nuclear, and non-hydro renewable resources. Nuclear energy is seen as a base-load generation source that has the environmental advantage of no air pollution and no greenhouse gas emissions. However, this ignores the issue of waste disposal, which is contentious. Nuclear energy supports our energy security by diversifying energy sources and limiting import reliance, if you ignore the importation of nuclear fuel.

Nuclear power is a proven source of energy with 102,162 MWe currently operating in the United States (EIA data as of May 2002). Nuclear power plants are generating 20 percent of the nation's electricity requirements. Worldwide, about 359,000 MW of capacity generated 2,654 TWh of electricity in 2002. Many European nations such as France, Belgium, and Sweden and Far East Nations such as Korea and Japan are the most reliant on nuclear power (IEA 2004). In the United States, there has been a recovery of the nuclear plant financial and regulatory basis, including restructuring, license renewals, and power uprates. Previously submitted power uprate requests alone represent approximately 1060 MWe of additional generation. Additionally, approximately 5730 MWe of expected nuclear plant output expected to be submitted to the United States Nuclear Regulatory Commission (US NRC) over the next 5 to 7 years.

U.S. nuclear plants are arguably our most reliable source of electricity and have shown 20 years of steady improvements in operating reliability. Compared to other generation sources, nuclear power plants have one of the highest availability rates, currently above 90 percent. They have one of the lowest production costs with the possible exception of only large-scale hydropower. Fuel costs are at all-time lows and make up a small part of the costs of producing nuclear power, the rest is capital costs of the plants, operation and maintenance, and major repairs. The nuclear power industry is the least sensitive to fuel costs.

Uranium Production

In year 2001, U.S. uranium production was 2.6 million pounds of U3O8, a decline of 33 percent from the 2000 production total and the lowest since 1953 (EIA 2003). The number of operating mining facilities in 2001 declined to 3 in-situ leaching plants. Among the energy sectors, foreign direct investment affiliates are most prominent in uranium concentrate production, accounting for 96 percent of the U.S. total for 2000. Production of uranium concentrate in the United States totaled 4 million pounds in 2000, a decline of 14 percent. The two foreign-affiliated companies are Cameco (Canada), which has two producing plants, and BHP Billiton (Australia), which has one producing plant. All three plants are in situ leaching plants as noted above. Cameco's Highland, WY and Crow Butte, NE plants produced a total of 1.7 million pounds in 2000, which was 43 percent of total U.S. production. Cameco continues to be the world's largest producer of uranium. Additionally, Cameco processes uranium and operates four nuclear power plants in Canada. BHP Billiton's Smith Ranch, Wyoming plant was the only other in situ uranium leaching plant operating at the end of 2000. BHP Billiton is an Australian diversified resources company with significant mining operations (both energy and commodities) and petroleum exploration and development operations.

One of the two domestic uranium enrichments plants that were privatized in 1998 was shut down in 2001 due to the large amounts of enriched uranium imports from former Soviet Union countries and other Western European nations at subsidized rates. The United States may soon be in the position of importing 90 percent of its enriched uranium supply. New fuel sources include uranium and plutonium manufactured from scrapped nuclear weapons. Additionally, DOE is seeking approval of the proposed Mixed Oxide Fuel (MOX) Fabrication Plant near Aiken, SC. The facility, to be built under contract by the Department of Energy, will convert surplus weapons grade plutonium to fuel for commercial nuclear reactors. Much of this plutonium will also come from Russia. The current uranium and plutonium market approach is hardly the road to energy independence. Uranium is an abundant resource and the long term outlook for supplies is good. There has been a glut on the market due to weapons conversion, but that may disappear by 2005. Prices will rise and mining and processing in the United States will have to ramp up again. If breeder reactors were to be developed and become viable, uranium resources would be virtually renewable and last for thousands of years.

Nuclear Energy's Future in America

More recent developments include significant advances in design relative to currently operating plants, the most recent of which were built nearly 20 years ago. Plants incorporating these new designs would be safer and more efficient than existing plants. The US NRC has certified three new designs. These designs include the General Electric Advanced Boiling Water Reactor (ABWR), the Combustion Engineering System 80+ (a large pressurized water reactor design now owned by Westinghouse), and the AP-600 (a passive pressurized water reactor from Westinghouse). Westinghouse is currently proceeding with obtaining approval for design certification on the AP-1000 – a larger version of the AP-600. Plants using the GE and CE designs have been built in Japan and Korea, and a GE plant design is under construction in Taiwan (Quinn 2001).

In addition, Exelon (currently the largest nuclear operator in the United States) is investing in the South African Pebble Bed Modular Reactor (PBMR) design. General Atomics (GA) is moving forward with the GA Gas Turbine-Modular Helium Reactor (GT-MHR) and Westinghouse is working on the International Reactor Inherently Safe (IRIS) reactor design. The PBMR and GT-MHR are graphite-moderated, helium-cooled reactors with advantages over PWR and BWR technologies in both efficiency (42–48 percent vs. 25-38 percent) and safety (passive safety designs and meltdown proof fuel designs yielding a small plant footprint and minimal reactor containment requirements). Two nuclear utilities are considering building new plants in the United States. One is proposed for Clinton site in Illinois and the other in at the North Anna site in Virginia. The Clinton site is moving ahead with the early site approval process.

New nuclear power capacity additions are dependent on the successful resolution of several highly political issues. Some positive forces are driving the need for new nuclear generation such as a national desire for fuel diversity, a growing concern to reduce greenhouse gases and the continuing expansion of the U.S. economy and the subsequent growth in power consumption. On the other hand, there are forces holding back the potential for new nuclear capacity; namely the selection and implementation of a long-term high-level waste disposal facility, the total life cycle cost of currently approved nuclear designs remains marginally competitive as compared to alternatives, and the potential expiration of the Price-Anderson Act (liability indemnity limitations). Until these issues are adequately addressed and resolved, prospects for new nuclear capacity will remain uncertain. Despite the uncertainty of these issues, the uprate and restart market segment has been significant over the last several years.

The total uprate market has led to an additional 5,000 MW of nuclear capacity. Also, several studies are underway reviewing the feasibility of restarting previously shutdown nuclear power plants. If restarting existing shutdown nuclear power plants proves feasible, then it may lead to the addition of another 5,000 MW of nuclear capacity by 2010.

If the issues revolving around nuclear power were resolved in favor of adding new capacity, new additions may be in the range of 30,000 to 50,000 MW. This capacity would most likely come online between 2010 and 2020. The estimated range assumes that maintaining the percentage of non-emitting power generation capacity at least current levels (about 30 percent) is a national priority. The estimate also considers the impact of several factors including nuclear retirements, nuclear uprates, potential for non-nuclear non-emitting capacity additions, and efficiency improvements.

The new nuclear power capacity market may form into a base load segment and a peak-load segment. The base-load segment capacity may be met by traditional designs such as the AP-1000. Preliminary industry estimates suggest that 8 to 10 plants costing $2.5 to $3.0 billion per plant would be needed to meet the base-load demand. The peak-load segment capacity may be better met by the smaller, modular designs such as the GT-MHR or the PBMR. Assuming the PBMR design, preliminary internal estimates suggest 12 to 14 sites with 10 PBMRs per site at a cost of $1.2 to $1.4 billion per site would be needed to meet the peak load demand.

Conclusions about Nuclear Power

Nuclear power is a crucial asset in the current electrical generation grid of the United States. The future of nuclear power in the United States is very much an unknown. This stems mostly from the inability to solve the waste issues and the public opposition to new plants. The U.S. Department of Energy (USDOE) intends to proceed with planning new plants and eventually opening the waste repository in Nevada.

Worldwide, nuclear projects are moving ahead slowly. Most projects are in Asia with China anticipating a large development program for nuclear power. Korea and Japan also plan additional plants.

Estimated domestic uranium deposits are 225 million pounds at $30/lb and about 760 million pounds at $50/lb. U.S. consumption is about 54 million pounds per year with large amounts currently imported. Worldwide resources are estimated at 5,000 million pounds at $30/lb and 6,500 million pounds at $50/lb. About 31 percent of the low cost reserves are located in Canada. Annual worldwide requirements range from 121 to 175 million pounds per year (WEC 2001). Assuming an annual usage of about 150 million pounds per year, this equates to about a 33 to 43 year supply at current consumption rates. Here again, since uranium is a non-renewable natural resource, it supply will eventually reach a peak and trend downward. However, there is no shortage of world capacity to supply uranium at this time. Development of new plants is growing very slowly, with much nuclear power generating capacity projected to shutdown over the mid term.

6 Renewables

There is no doubt that renewable energy must be a key element of the energy mix of the future. Renewables tend to be a more local or regional commodity and except for a few instances, not necessarily a global resource that is traded between nations. One of these instances is the purchase of hydroelectric power from Canada. Renewables make up about 6 percent of U.S. energy usage. Figure 5 shows the makeup of renewables in the nation's energy mix (Mayes, Guey-Lee et al. 2004).

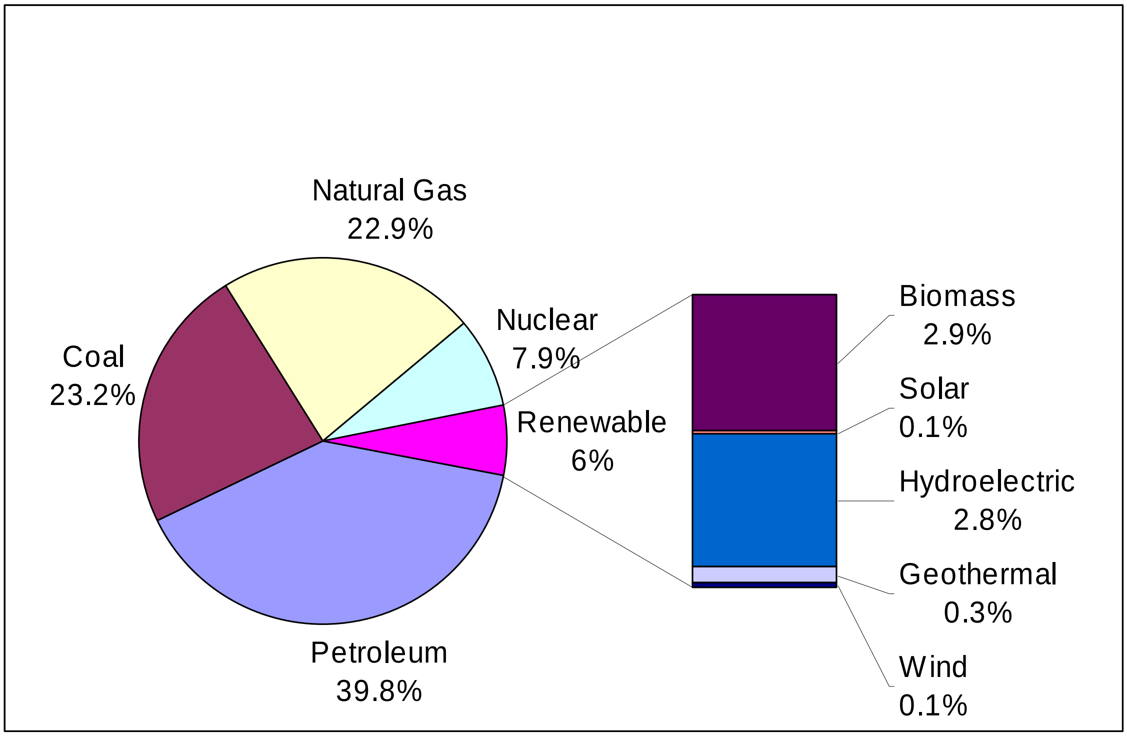

Figure 5. Role of renewables in the U.S. energy supply (EIA/DOE).

Although renewables play only a small role in the U.S. energy mix, renewable energy is regarded increasingly as a profitable and rational investment. This is in light of dramatic and continuing reductions in capital costs, reliability improvements, the volatility of fossil fuel prices, and the environmental compliance costs of generating electricity from fossil and nuclear fuel sources. Below is an update on the current status of various renewable technologies.

High Temperature Solar & Photovoltaics

Analysts predict the opening of specialized niche markets in this country for the solar power industry over the next 5 to 10 years. The photovoltaic (PV) market is estimated to grow at 20 percent per year. About 20 U.S. companies produce PV panels today, twice as many as in the late 1970s. The United States produces roughly one-third (the largest percentage of any country) of all PV systems. The cost of PV systems has fallen by more than a factor of four since 1982 and continues to decrease as technology and production methods improve. There are two basic categories of solar technologies—PV and concentrating collectors. Each of these will be discussed in more detail below.

Photovoltaics

Photovoltaic cells are devices that use silicon-based semiconductor materials—similar to those used in computer chips—to convert sunlight directly into electricity. The electric current can either be used immediately, or it may be stored, as in a battery, for later use.

The most common type of PV array is a flat plate collector. These can either be fixed in one position or designed to track the movement of the sun. Photovoltaic cells are approximately 4 in. square and produce about 1 watt of energy. About 40 cells make up a module. Modules are grouped together to form arrays that can extend several feet in each direction.

One of the barriers to widespread use of PV is the high capital costs for PV systems. Capital costs range from $5 to $12 per watt. The 20-year life-cycle cost ranged from 20 cents to 50 cents per kilowatt-hour. One advantage of PV systems is that they have virtually no operating costs. In some rural areas where grid-source utilities are not available, PV is more cost effective than connecting to the grid. Government subsidy programs are available in some areas to help reduce the capital cost to the consumer. The rising cost of grid-source power and new technological developments are making PV more affordable every year.

Thin Film PV

Thin film Photovoltaics are one of the most promising technologies for renewable energy generation in the future. Thin-film PV development began in the early 1980s and has made significant advancements since. The USDOE has a goal to advance this technology to the point that it is possible to develop thin-film PV at a cost of $.33/W with a 15 percent efficiency and manufacturing costs of only $50/m2 (NREL 2001).

A number of thin-film technologies are currently being developed. Three of the most common technologies are amorphous silicon (a-Si), copper indium diselenide, and cadmium telluride (CdTe) .

1. ***Amorphous Silicon***—A-Si technology has been around the longest. Commercial production of amorphous silicon systems is currently at about 10 MW of capacity (Zweibel 1999). A-Si has relatively low efficiencies (about 11 percent) in comparison to some of the other technologies. Its multi-junction cell structure requires a vacuum-based process and production is comparatively slow. There is still a significant amount of research in this area, although the advancement seems to have been at a plateau for the past few years. A new "hot wire" technique looks promising for speeding up the fabrication process and reducing the efficiency degradation that has been a problem with this technology in the past.
2. ***CopperIndium Diselenide***—CIS has reached very high efficiencies (about 18.8 percent) in laboratory development. NREL has made the most significant advances in this technology. The largest manufacturer of commercial systems based on this technology, First Solar, produces less than 1 MW of CIS annually.
3. ***Cadmium Telluride***—Commercial production of CdTe is not yet available, but plans have been announced to build manufacturing facilities capable of producing 20 MW annually in the coming years. Efficiencies for this technology have reached upwards of 16 percent, however, the first plants to be opened with this technology will probably start at much lower efficiencies—around 6 to 8 percent. One of the difficulties faced by most PV technologies is in making the jump from small-scale systems to utility-scale systems.

Very recently, Lawrence Berkley National Laboratories and some of its research partners made a breakthrough discovery involving indium gallium nitride (In1-xGaxN) that may open the door for a new solar technology that could drastically increase the efficiency of photovoltaics. This alloy is capable of absorbing light from the full solar spectrum. This mean that solar cells made of this alloy could be able to absorb solar radiation from the entire visible light spectrum—near infrared to far ultraviolet—and convert it to electrical current. Existing technologies are only capable of receiving a small range of the visible light spectrum. Some technologies feature multi-junction cells, or cells with two layers, each capable of absorbing a different portion of the light spectrum to increase their efficiency. However, these multi-junction cells are complicated and expensive to produce (LBNL). Gallium nitride is used widely for industrial purposes, indicating that it may be produced inexpensively enough for mass applications. This technology is very new and undeveloped at this point and no solar cells have been made from this alloy yet. Scientists at the National Renewable Energy Laboratory's National Center for Photovoltaics are skeptical at such an early stage that this technology will revolutionize the PV industry; still the technology looks promising and is being explored.

Cost of Thin-Film PV

Currently, the cost of manufacturing thin-film PV is generally comparable for all technologies. Table 1 lists current estimated manufacturing costs for PV using CdTe as a baseline.

Table 1. Summary of the first solar CdTe manufacturing model at 20 MW/year (Zweibel).

Component	Direct Manufacturing Cost ($/m2)	Comments
Materials (all)	$48	Semiconductors only about $5; mostly encapsulation, substrate, and modularization
Capital (all)	$10	Semiconductors only about $5
Heat, Electricity, Water	$3	Energy payback < 3 months for energy added during manufacturing
Labor	$12	Plant labor and operations management
Maintenance of Equipment	$3	4% of Initial Capital Cost
R&D	$4	Must maintain technical lead
Warranty	$5	3% of sales (very high for early high prices)
Rent and factory overhead	$5	Factory overhead at 1.5% sales
Total direct manufacturing	$90/m2	Projected from existing technology, not yet optimized

A number of factors contribute to the high cost of manufacturing PV systems. These include the complexity of the chemical structure, cost of capital for the process, waste of expensive feedstock, environmental controls, maintenance and down time, and the different finishing processes. Zweibel does state, however, that these numbers will tend to decrease as the process becomes optimized for higher volumes. Table 2 lists the associated costs and factors that should reduce costs in the future as the technology develops.

Table 2. Reasonable, long-term goals for thin film manufacturing (Zweibel).

Component	Direct Manufacturing Cost ($/m2)	Comments
Materials (all)	$28	Volume purchases reduce all costs, especially substrates; lower-cost encapsulation
Capital (all)	$5	All process can be optimized, rates increased, layers thinner
Heat, Electricity, Water	$2	Larger volumes, thinner layers
Labor	$6	Full automation
Maintenance of Equipment	$2	4% of lower capital cost
R&D	$1	Rising sales, lower prices
Warranty	$1	Lower prices, greater product reliability
Rent and factory overhead	$5	Larger volumes
Total Direct Manufacturing	$50	Optimization, R&D, and higher volumes

The data in Table 2 also show that the goal of the USDOE to reduce manufacturing costs to $50/m2 is achievable in the future.

Concentrating Solar Power

There are three kinds of concentrating solar power systems—troughs, dishes, and power towers.

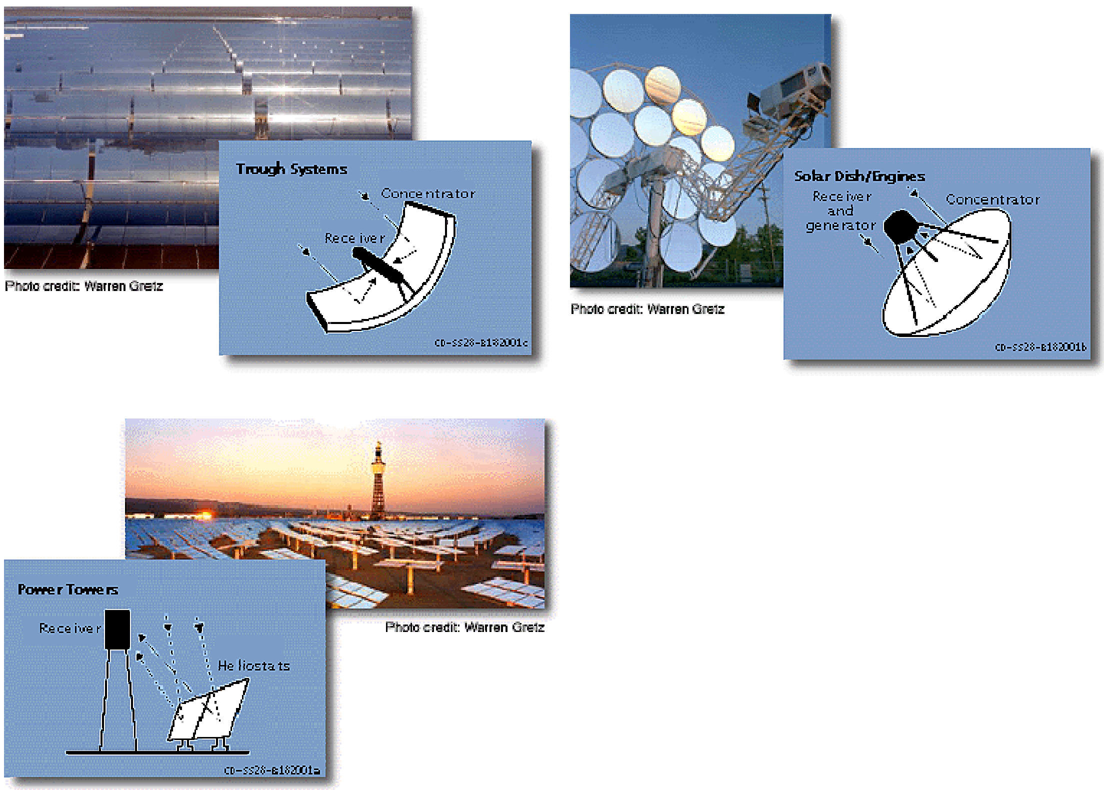

Figure 6. Three kinds of concentrating solar power systems (photos from http://www.eren.doe.gov/state_energy/technology_overview.cfm?techid=4).

Trough Systems are the most efficient technology available now. Currently, all parabolic trough plants are "hybrids," meaning they use fossil fuel to supplement the solar output during periods of low solar radiation. Typically a natural gas-fired heat or a gas steam boiler/reheater is used. In place trough systems currently generate about 80 megawatts (MW) of electricity each year.

Dish Systems should be capable of producing about 25 megawatts of power generation per individual system. However, these systems are not commercially available yet.

Power Towers use mirrors called heliostats to focus the sun's energy onto a receiver located on top of a tower. This energy heats molten salt from 500 °F to about

1000 °F. The salt's heat energy is then used to generate electricity in a conventional steam generator. The molten salt retains heat efficiently, so it can be stored for hours or even days before being used to generate electricity. Solar Two, a demonstration power tower located in the Mojave Desert in California, can generate about 10 MW of electricity annually.

One of the main advantages of concentrating solar power technologies is that it utilizes the same technologies and equipment used by conventional central station power plants. This makes concentrating solar power technologies the most cost-effective solar option for the production of large-scale electricity generation. These systems are more easily integrated into existing utility infrastructure than other solar technologies. Since they utilize existing technology and equipment, they generally are better received than "revolutionary" systems, which are seen as unknown quantities and invite skepticism. The USDOE estimates that by 2005 there will be as much as 500 MW of concentrating solar power capacity installed worldwide.

Concentrating solar power technologies currently offer the lowest-cost solar electricity for large-scale power generation (10 MW-electric and above). Current technologies cost $2,000-$3,000 per kilowatt, which competes with nuclear and environmentally compliant coal plants. This results in a cost of solar power of 9¢-12¢ per kilowatt-hour (kWh). New innovative hybrid systems that combine large concentrating solar power plants with conventional natural gas combined cycle or coal plants can reduce costs to $1,500 per kilowatt and drive the cost of solar power to below 8¢ per kWh.

The southwestern United States has the highest potential to benefit from concentrating solar power. California, Nevada, Arizona, and New Mexico are each developing policies that will nurture the development of their solar-based industries. India, Egypt, Morocco, and Mexico are also developing solar-based industry programs. Greece (Crete) and Spain currently have independent power producers working to develop trough powered projects as well.

Wind

Wind energy was the fastest-growing energy technology worldwide, growing at a rate of about 20 percent per year. The total installed worldwide capacity is over 47,000 megawatts (MW) with about 8,000 MW installed in 2004 (GWEC 2005). Similarly, wind energy capacity in the United States increased by 60 percent from 2,554 MW in 2000 to 6,740 MW in 2004. Growth in the United States is continually hindered by the sporadic nature on tax incentives. Worldwide, the wind energy market is $1.5 billion industry.

The average wind speed has the largest effect wind power generation. Since the power in the wind is proportional to the cube of the wind speed, a 16-mile per hour (mph) site could produce 137 percent more power than a 12-mph site. Using taller wind towers helps increase power output also since wind speed increases with height above the ground. The wind speed probability distribution (how much of the time the wind blows at various speeds) is also extremely important.

California, with 2,096 MW capacity, and Texas, with 1,293 MW capacity, are the two states with the most installed wind power capacity. Wind energy is rapidly gaining ground in Iowa, Minnesota, Wisconsin, and Wyoming (AWEA 2005). The Great Plains region also has vast wind resource potential. Table 3 lists the top 20 potential locations for wind power in the United States.

The Top Twenty States for Wind Energy Potential

As measured by annual energy potential in the billions of kWhs, factoring in environmental and land use exclusions for wind class of 3 and higher. Source: An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States, Pacific Northwest Laboratory, 1991.

Table 3. Wind energy potential by state (PNNL).

Rank	State	Capacity (billions of kWhs)
1	North Dakota	1,210
2	Texas	1,190
3	Kansas	1,070
4	South Dakota	1,030
5	Montana	1,020
6	Nebraska	868
7	Wyoming	747
8	Oklahoma	725
9	Minnesota	657
10	Iowa	551
11	Colorado	481
12	New Mexico	435
13	Idaho	73
14	Michigan	65
15	New York	62
16	Illinois	61
17	California	59
18	Wisconsin	58
19	Maine	56
20	Missouri	52

Role of Tax Credits and Subsidies

A 1.5-cent per kilowatt-hour production tax credit (PTC) for wind energy was included in the Energy Policy Act of 1992. Passage of the PTC reflected recognition of the important role that wind energy can and should play in our nation's energy mix. It also was intended to partially correct the existing tilt of the Federal energy tax code, which has historically favored conventional energy technologies such as oil and coal. Generally, the credit is a business credit that applies to electricity generated from wind plants for sale at wholesale (i.e., to a utility or other electricity supplier). It applies to electricity produced during the first 10 years of a wind plant's operation.

The wind PTC expired on 31 December 2003, but was extended again in October of 2004 for 2 years, until the end of 2005. A permanent extension would significantly increase the stability in the wind development sector by providing a stable financial environment. The PTC is a 1.5 cents/kWh tax credit that is adjusted annually for inflation and is currently about 1.9 cents/kWh.

All energy technologies are subsidized by the U.S. taxpayer. Subsidies come in various forms, including payment for production, tax deductions, guarantees, and leasing of public lands at below-market prices. Subsidies can also be provided indirectly, for example through Federal research and development programs, and provisions in Federal legislation and regulations. For example, loopholes in the Clean Air Act currently exempt older power plants from compliance with Federal pollution standards and become, in effect, a subsidy that lowers the price of electricity from coal-fired power plants.

Barriers to Wind Power

Power transmission is a key factor for the future of wind power. For wind power to be utilized to its full capacity would require a huge investment in upgrading the existing utility lines to high voltage transmission lines.

Another factor inhibiting wind power is the existing system where line operators charge generators a penalty fee if they fail to deliver electricity when they are scheduled to do so. The purpose of this fee is to discourage the generator company from supplying or withholding electricity at strategic times of either high or low demand to gain a competitive advantage. This is detrimental to wind power companies since the power generation depends on how much and when the wind is blowing. The intermittent nature of wind power does not exempt it from these penalties under the existing system. Wind energy development in the United States also slowed during the late 1990s as a result of uncertainties about deregulation and competition in the electric power industry, but it seems to have rebounded since.

Wind Energy Costs

Wind energy is one of the most cost-competitive renewable energy technologies. The cost of electricity from wind has dropped from $0.35 per kilowatt-hour (kWh) in 1980 to less than $0.036 per kWh today at a large wind farm on a good site (AWEA 2002). The DOE's hopes to further reduce costs to $0.025 per kWh at good wind sites through improved technology and favorable financing arrangements. Capital costs of large wind farms are currently about $1000 per kilowatt of capacity. This means that the 6,740 MW of wind power capacity in the United States represents roughly a $7 billion investment.

According to Ryan Wiser and Edward Kahn of Lawrence Berkeley Laboratory's Energy and Environment Division, one key factor that could drive down the cost of wind power deals with the financing and ownership of the venture. Wiser and Kahn estimate that a typical 50-MW wind plant could generate power for 3.5 cents/kWh if an investor-owned utility (IOU) owned and financed the facility instead of a wind developer (Wiser and Kahn 1996). Private wind developers are eligible for a Production Tax Credit (PTC), which allows them to operate at a slightly lower cost. Public utility ownership is not eligible for the PTC but they do receive some assistance in the form of the Renewable Energy Production Incentive (REPI). REPI is not a tax deduction, so money to fund it must be approved each year by Congress. Since the source of funding for this initiative is somewhat variable, the financial community views it as risky. If the number of investor-owned and financed wind plants increased, it could significantly drive down the cost of wind power generation as well as make wind more power available to more people.

Another initiative that could boost wind power in the United States is the Renewables Portfolio Standard (RPS). The RPS would require each company that generates electricity in the United States, or in a given state, to obtain part of the electricity it supplies from renewable energy sources such as wind. To meet this requirement, the company could either generate electricity from renewables itself or buy credits or electricity from a renewable generator such as a wind farm. This "credit trading" system has been used effectively by the Federal Clean Air Act to require utilities to reduce pollutant emissions.

Conclusions about Wind Energy

Wind energy is a viable energy source for expanded development in the nation. Off shore capacity is just now starting to be investigated. The potential is significant as shown in Table and with more and more states adopting renewable energy portfolios and with the renewal of the production tax credit, wind is poised for another large increase in capacity. Wind could readily provide up to 6 percent of the nation's electricity by 2020.

Wind also has the potential for significant application in developing countries. The United States is only third in the world with wind energy capacity. Germany has almost three times as much capacity as the United States and is a significantly smaller nation. Spain is next in capacity with about 30 percent more capacity than the United States (GWEC 2005).

Biofuels

Biofuels are liquid transportation fuels made from plant matter instead of petroleum. There are two primary biofuels: ethanol and biodiesel. There are number of different technologies being explored for each of these two general categories. These biofuels have less harmful emissions than fossil fuels, help reduce greenhouse gas buildup, reduce dependence of foreign oil, and support agriculture and rural economies. A few of the more common technologies will be discussed below.

Ethanol

Ethanol, also known as ethyl alcohol or grain alcohol, can be used either as an alternative fuel (usually with 15 percent gasoline—E85—requires slight engine modification) or as an octane-boosting, pollution-reducing additive to gasoline (usually 8-10 percent, 5 percent in California). One out of every 8 gallons of gasoline sold in the United States now contains about 10 percent ethanol. Because ethanol contains about one-third less energy per gallon than gasoline, E85 vehicles will get fewer miles per gallon.

Ethanol from Grain (chiefly the starch in kernels of field corn) is the primary means of current ethanol production in the United States. Currently 7 percent of the corn grown in the United States is used to make ethanol. This accounts for 1.6 billion gallons annually, which is 400,000 gallons short of the production capacity of 2 billion gallons annually. Some experts forecast that by 2004, the production capacity could be as high as 3.5 billion gallons.

Advanced Bioethanol Technology allows fuel ethanol to also be made from cellulosic (plant fiber) biomass, such as agricultural forestry residues, industrial waste, material in municipal solid waste, and trees and grasses. Although the price of bioethanol made from plant fiber has dropped from $4.50 per gallon in the 1970s to around

$2.30 per gallon today with the use of genetically engineered fermenting organisms, the price still needs to come down more to be competitive with fossil fuels.

Biodiesel

Biodiesel made from animal fat or vegetable oil, is a renewable pollution-reducing alternative to petroleum diesel. In the United States, the second largest producer and user of biodiesel, the fuel is usually made from soybean oil or recycled restaurant grease. Biodiesel can be directly substituted for diesel either as neat fuel (B100) or as an oxygenate additive (typically 20 percent—B20). Biodiesel contains slightly less energy than petroleum diesel and it is denser, so fuel economy tends to fall 7 percent for every 10 percent biodiesel in the fuel blend. Because it gels at higher temperatures than petroleum diesel, pure biodiesel requires special management in cold climates. Biodiesel costs about $2.50 per gallon now, but should drop to $1.50 per gallon with large-scale commercial production. Low soybean and recycled cooking oil prices have helped to reduced costs to near $1.50 per gallon even at current production rates. While biodiesel is more expensive than petroleum diesel, B20 generally only costs 8 to 20 cents per gallon more than regular diesel.

Biofuel Costs

Corn ethanol costs roughly $1.20 to $1.50 per gallon. Gasoline containing 10 percent ethanol receives a Federal excise tax exemption of 5.3 cents per gallon (with 10 percent ethanol additive), effectively providing a 53-cent-per-gallon (of 100 percent ethanol) subsidy. This makes the cost of ethanol comparable to that of gasoline and petroleum-derived gasoline additives. In addition to the Federal excise tax exemption, which has been in place since 1979, 16 states (AK, CT, HI, ID, IL, IA, KS, MN, MO, MT, NE, ND, OK, SD, WI, WY) now also provide excise tax exemptions or producer credits for ethanol. These tax incentives are to entice more producers to enter the market, thus driving down the cost of ethanol.

Energy Balances for Biofuels

Energy balances for biofuels have been the source of controversy for quite some time. Energy balances are expressed in terms of the net energy value (NEV). This is the ratio of the amount of energy produced compared to the amount of energy consumed in the production process. Many have argued that the energy balance for biofuels is negative, or in other words, once all of the inputs have been accounted for, more energy was expended than produced. At least two recent studies have shown this is no longer the case. Improvements in crop yields and also in biofuel production technology have helped to achieve a positive energy balance for biofuels.

In the first study from the U.S. Department of Agriculture, a number of earlier studies on the topic of the NEV of corn ethanol dating back to the late 1970s are reviewed. The following is part of the concluding remarks from their report:

> We conclude that the NEV of corn-ethanol is positive when fertilizers are produced by modern processing plants, corn is converted in modern ethanol facilities, and farmers achieve average corn yields. Our NEV estimate of over 21,000 Btu per gallon could be considered conservative, since it was derived using the replacement method for valuing co-products, and it does not include energy credits for plants that sell carbon dioxide. Corn ethanol is energy efficient, as indicated by an energy ratio of 1.34; that is, for every Btu dedicated to producing ethanol there is a 34-percent energy gain. Furthermore, producing ethanol from domestic corn stocks achieves a net gain in a more desirable form of energy, which helps the United States to reduce its dependence on imported oil. Ethanol production utilizes abundant domestic energy feedstocks, such as coal and natural gas, to convert corn into a premium liquid fuel. Only about 17 percent of the energy used to produce ethanol comes from liquid fuels, such as gasoline and diesel fuel. For every 1 Btu of liquid fuel used to produce ethanol, there is a 6.34 Btu gain (Shapouri, Duffield et al. 2002).

One of the key factors in achieving positive net energy values for ethanol has been the 39 percent increase in corn yields since the late 1970s (Shapouri, Duffield et al. 2002). Advances in ethanol production technology and also for fertilizer and farm inputs have also contributed to making the process more energy efficient.

A second study by David Andress & Associates, Inc., reviews three recent studies related to energy balances for corn ethanol. In this report, the net energy gain for corn ethanol was found to be between 21-34 percent. It also states that the energy requirements for ethanol are 33 to 44 percent less than those of gasoline and between 44 to 50 percent less than MTBE (Andress 2002).

Andress also discusses cellulosic ethanol, a process where ethanol is produced from agricultural residues. This process has two main benefits. First, cellulosic ethanol uses virtually no fossil fuels. Electricity and heat necessary to produce ethanol are generated from the lignin in the feedstock in a power plant that is integrated with the ethanol plant. The second benefit is that since no fossil fuels are used in this process, the net greenhouse gases associated with ethanol production are virtually eliminated.

Biomass

Biomass energy is energy produced from organic residues. Organic byproducts of food, fiber, and forest production such as sawdust, rice husks, and bagasse (the residue remaining after juice has been extracted from sugar cane) are the most economical biomass fuels for generating electricity. The U.S. biomass power industry is primarily located in the Northeast, Southeast, and West Coast regions where they have access to large supplies of agricultural and forest product residues. The biomass industry represents a $15 billion investment and supports 66,000 jobs. Currently biomass accounts for 1 percent of total electricity production in the United States.

Biomass Technologies

There are two main biomass technologies. Biomass gasifiers turn solid biomass into a flammable gas. Biogas can be cleaned and filtered to remove impurities before it is burned, allowing use of a wider range of biomass fuels. Also, the gas can be used in more efficient combined cycle power generation systems. The efficiency of these combined-cycles can exceed 40 percent. Co-firing involves substituting biomass for a portion of coal in an existing power plant boiler. It is the most economic option for the near future in terms of biomass fuels. Much of the existing power plant equipment can be used without major modifications making co-firing much less expensive than building a new biopower facility.

Biomass Cost

Existing coal-fueled power plants can produce power for about 2.3¢/kilowatt-hour (kWh). Co-firing with inexpensive biomass fuels can reduce this cost to 2.1¢/kWh, assuming that the cost of biomass fuels is less than the cost of coal. In today's direct-fired biomass power plants, generation costs are about 9¢/kWh. In the future, advanced technologies such as gasification-based systems could generate power for as little as 5¢/kWh. For comparison, a new combined-cycle power plant using natural gas can generate electricity for about 4¢-5¢/kWh at fall 2000 gas prices.

For biomass to be economical as a fuel for electricity, the source of biomass must be located near to where it is used for power generation. This reduces transportation costs—the preferred system has transportation distances less than 100 miles. The most economical conditions exist when the energy use is located at the site where biomass residues are generated (i.e., at a paper mill, sawmill, or sugar mill).

Hydropower

Today's hydropower plants range in size from small, local projects producing several hundred kilowatts to huge dams and reservoirs that generate 10,000 MW or more and supply energy to millions of people. By the early 1900s, hydroelectric power accounted for more than 40 percent of the nation's supply of electricity. In the 1940s, hydropower provided about 75 percent of all the electricity consumed in the West and the Pacific Northwest and about one third of the total United States' electrical energy. The absence of additional viable hydropower sites in the United States led to the increase in development of other forms of electric power generation. Hydropower's percentage has slowly declined and today provides about one tenth of the nation's electricity when viewed from a source energy basis. Looking at the net energy basis and understanding that hydropower has little conversion losses, hydro provides about one third of the nations net electricity.

Hydropower is the nation's leading renewable electrical energy source. It accounts for 81 percent of the nation's total renewable electricity generation. Hydropower is also the least expensive source of electricity in the United States, with typical efficiencies of 85 to 92 percent during production. For every kilowatt-hour (kWh) of electricity produced by hydropower, only 0.6 cents is needed to pay for operating and maintaining the plant. Comparable costs are 2.2 cents/kWh at nuclear plants and 2.1 cents/kWh at coal plants. Of course, not counted is the capital cost of the dams and structures and the environmental damage done to the ecosystems they displace.

The potential for high-head hydropower has been fairly well used in the nation. High-head hydropower is clean, but not green due to the environmental disruption the dams cause. A recent study focusing on low-head/low-power sites shows significant potential for additional renewable hydropower in the nation (Carroll, Reeves et al. 2004). The study produced an engineering estimate of the magnitude of United States water energy resources on a comprehensive scale. The assessment estimated that the total annual mean power potential of the United States is approximately 300,000 MW. Of this amount, about 90,000 MW is excluded from development. With about 40,000 MW of annual mean power already developed (corresponding to a total hydropower capacity of approximately 80,000 MW), the total available power potential is estimated to be about 170,000 MW or about 60 percent of the total power potential. The density of available power potential is approximately 50 kW/sq mi. Low head/low power potential makes up about 21,000 MW of the total available potential. Division of the available low head/low power potential among low head/low power technology classes showed that 34 percent fell within the operating envelope of conventional turbines, 16 percent fell within the operating envelope of unconventional systems, and 50 percent fell within the operating envelope of microhydro technologies. In addition to the low head/low power potential, it is estimated that there is a total of 26,000 MW of high head (30 ft or greater)/low power potential available in the 50 states. Conventional turbine sites and unconventional system sites are numerous except in the central part of the country, arid areas of the West, and where there are high concentrations of high power or high head/low power potential. Microhydro sites are abundant and exist everywhere in the country except in the plains from North Dakota to the Texas panhandle and in Hawaii, where virtually all the resources are in the high power (equal or greater than 1 MW) or high head/low power classes. High head/low power sites are abundant and are generally located in the mountainous areas of the country.

Much of the potential remains undeveloped due to the economic viability and remoteness of the sites. The economics may change as conventional source of electricity become more expensive and environmental unacceptable.

Geothermal

Geothermal energy is contained in underground reservoirs of steam, hot water, and hot dry rocks. In the generation of electricity, hot water or steam extracted from geothermal reservoirs in the Earth's crust and used in steam turbines to drive generators producing electricity. Moderate-to-low temperature geothermal resources are used for direct-use applications such as district and space heating. Lower temperature, shallow ground, geothermal resources are used by geothermal heat pumps to heat and cool buildings.

Geothermal Resources and Use

Worldwide, geothermal used to produce electricity was about 56TWh in 2002 (IEA 2004). This is expected to triple in the next 25 years. Much of this growth will be in North America. Seventeen nations use geothermal power with the United States being the largest user.

Geothermal resources are finite and the known geothermal resource areas in the United States having resource conditions sufficient to generate electricity are rare, occurring domestically only in the western states and Hawaii. There is an estimated electricity generating capacity of 27,400 megawatts, which is believed to be sustainable for 40 years. Of the currently identified resource base in the United States, around 3,000 megawatts of capacity was installed by 1995. Of this, about 2,700 MW is operational today using a dry steam process.

The major concern about geothermal resources has been the declining production at The Geysers, located along the San Andreas Fault in Sonoma County, CA. The Geysers area produces more electricity than any other geothermal field in the world but has reached its peak production. Part of the depletion problem is the type of process used. New plants are using the flash steam process and re-injecting the condensate.

Coso Hot Springs is another major electrical producing geothermal area and is located in the middle of the Mohave Desert of California, closer to Death Valley than to any metropolitan area. It lies within the boundaries of the China Lake Naval Air Weapons Station (NAWS). There are five plants that use a flash steam process located with a total capacity of about 250 MW. The development and operation of the field were contracted out, with the electricity being sold to the utility servicing the area, Southern California Edison. The Navy contracted with CalEnergy Company, Inc. (CECI) to support the development of the field.

Binary cycle geothermal power generation plants differ from dry steam and flash steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units. In this type of system, the water from the geothermal reservoir is used to heat another working fluid, which is vaporized and used to turn the turbine/generator units (Renner 2005). The advantage of the binary cycle plant is that they can operate with lower temperature waters (225° F - 360° F), by using working fluids that have an even lower boiling point than water. They also produce no air emissions and are more environmentally friendly than dry steam technology. An example of an area using a Binary Cycle power generation system is the Mammoth Pacific binary geothermal power plants at the Casa Diablo geothermal field.

Geothermal district heating systems pump geothermal water through a heat exchanger, where it transfers its heat to a secondary loop that is piped to buildings in the district. A second heat exchanger if often used to transfer the heat to the building's heating system. The geothermal water is injected down a well back into the reservoir to be heated and used again. The first modern district heating system was developed in Boise, ID. In the western United States, there are 271 communities with geothermal resources available for this use. Modern district heating systems also serve homes in Russia, China, France, Sweden, Hungary, Romania, and Japan. The world's largest district heating system is in Reykjavik, Iceland. Since it started using geothermal energy as its main source of heat Reykjavik, once very polluted, has become one of the cleanest cities in the world (Nemzer 2001).

Geothermal heat is being used in some creative ways; its use is limited only by our ingenuity. For example, in Klamath Falls, OR, which has one of the largest district heating systems in the United States, geothermal water is also piped under roads and sidewalks to keep them from icing over in freezing weather. The cost of using any other method to keep hot water running continuously through cold pipes would be prohibitive. And in New Mexico and other places rows of pipes carrying geothermal water have been installed under soil, where flowers or vegetables are growing. This ensures that the ground does not freeze, providing a longer growing season and overall faster growth of agricultural products that are not protected by the shelter and warmth of a greenhouse.

Environmental Issues with Geothermal Energy

Geothermal is an effective renewable energy resource where it is available. Domestically, this is mostly in the western states and Hawaii. There are several environmental impacts from geothermal that should be considered. These are land use, air emissions, and water emissions (Reed and Renner 1995).

The actual land used in geothermal operations is fairly small, and other applications such as crop growing or grazing can exist in proximity to the roads, wells, pipelines, and power plants of a geothermal field. The average geothermal plant occupies about 400 m^2 for the production of a gigawatt hour over 30 years. If the entire life cycle of other energy sources are examined, the energy sources based on mining (such as coal and nuclear) require enormous areas for the extraction and processing in addition to the area of the power plant.

In most geothermal systems, non-condensable gases make up less than 5 percent by weight of the steam phase. Thus, for the same output of electricity, carbon dioxide emissions from geothermal flashed-steam power plants are only a small fraction of emissions from power plants that burn hydrocarbons. Binary geothermal power plants do not allow a steam phase to separate, so carbon dioxide and the other gases remain in solution and are re-injected into the reservoir, resulting in no atmospheric emissions. For comparison, each megawatt-hour of electricity produced in 1991, the average emission of carbon dioxide by plant type in the United States was: 990 kg from coal, 839 kg from petroleum, 540 kg from natural gas, and 0.48 kg from geothermal flashed-steam.

Hydrogen sulfide can reach moderate concentrations in the steam produced from some geothermal fields, and some systems contain up to 2 percent by weight of H_2S in the separated steam phase. This gas presents a pollution problem because it is easily detected by humans at concentrations of less than 1 ppm in air. Development of technology to remove H_2S is well advanced and now used in dry-steam and flashed-steam geothermal power plants to keep H_2S emissions below 1 ppb. These processes remove over 99.9 percent H_2S from the air emissions.

Ammonia occurs in small quantities in many geothermal systems. In flash steam geothermal power plants, the ammonia is oxidized to nitrogen and water as it passes into the atmosphere. Since the high pressures of combustion are avoided, geothermal power plants have none of the nitrogen oxides emissions that are common from fossil fuel plants. To compare with conventional technology, each megawatt-hour of electricity produced in 1991, the average emission of nitrogen oxides by plant type in the United States was: 3.66 kg from coal, 1.75 kg from petroleum, 1.93 kg from natural gas, and zero from geothermal.

In the United States, only the lower-temperature geothermal waters that are of drinking-water quality are allowed to flow into streams or lakes. All other geothermal applications require that the cooled water be injected back into the reservoir. To protect potable ground waters in shallow aquifers, both the production and injection wells are lined with steel casing pipe and cemented to the surrounding rock. This type of well completion prevents the loss of geothermal water to any freshwater aquifers and confines the injection to the geothermal reservoir.

The production and injection system for geothermal water also prevents any contamination of surface waters. Water injection in the hotter geothermal systems does not require any pump pressure at the surface, since the cold injection water drops under the influence of gravity into the less dense, hot water of the reservoir. Cooler geothermal systems or those with rocks of lower permeability will require some pump pressure to inject the water into the reservoir. Geothermal power plants in the United States use cooling towers to condense the turbine exhaust fluid (either steam or organic fluid), and no waste heat is dumped into rivers or the sea. In comparison, waste heat disposal from fossil and nuclear power plants can cause disruption of the biota in local water bodies.

Conclusions about Renewables

Renewables have significant potential in the United State to contribute energy in a more environmental friendly format, close to where it is needed. The economics of renewables will change over time as they begin to receive some of the subsidies that have been the largess of the more traditional power sectors. Also, their costs will continue to drop as deployment increases and economies of production scale and standardization can take effect. Most are significantly more environmentally friendly than the fossil fuel or nuclear alternatives. Clean energy technologies will impact faster and to a greater amount than current projections. In the next 10 years, projected investment in clean, renewable energy technologies is in the range of $100 billion (Makower, Pernick et al. 2005). This will be spurred by a growing number of states requiring renewable energy portfolios and the high cost and instability in the oil and natural gas markets. Biofuels, despite their dubious energy effectiveness, will grow considerably due to tax credits and government programs. Wind energy is expected to experience growth as long as the production tax credit is renewed.

7 The National Electrical System

Generating Capacity

According to the North American Electricity Reliability Council's (NERC's) 2004-2013 assessment, the immediate future for generating capacity is adequate provided new generating facilities are built as planned. There could still be localized supply problems. The longer term picture is uncertain (NERC 2004). The demand for power in the United States and Canada is predicted to grow by about 69,000 megawatts over the next 5 years, about a 2 percent per year growth rate. The average peak demand has been growing by about 2.2 percent per year. Projected new plants are expected to generate between 67,300 MW, which is adequate to meet the demand, but since the plants are not evenly distributed across various regions, pockets of under-capacity exist.

The adequacy of the supply of electrical resources in the long term (between 2009 and 2013) is increasingly uncertain for the United States and Canada. Long-term adequacy depends on merchant plant, or unregulated, developers' response to market signals to not only to construct facilities but to also get regulatory approval and financing. Factors that influence long-term capacity are: timely completion of planned capacity additions, the ability to construct the required associated transmission facilities, ability to obtain siting and environmental permits, ability to obtain financial backing, price and supply of fuel, and political and regulatory actions. This is not a trivial concern since for the first time in several years, beginning in the fall of 2001, projects that were delayed or cancelled exceeded ones being announced. Often, financing was the problem and the situation is not getting any better. Many utility holding companies are on the verge of bankruptcy and are shedding assets to become more solvent.

Transmission Systems

North American transmission systems are expected to perform reliably in the near term. Transmission networks are now being subjected to new loading patterns resulting from increased electricity usage and are spending more time at their reliability limits. More than 5,600 new circuit miles of transmission facilities are planned for construction throughout the United States and Canada through 2008 according to NERC. A total of about 10,275 miles need to be added over the 2004-2013 timeframe. That amount represents a 5 percent increase in total installed extra high voltage circuit miles, with most of the additions intended either to address local transmission concerns or to connect to proposed new generation units to the transmission grid.

In the long term, reliable transmission will depend on the close coordination of generation and transmission planning and construction. This coordination activity must now be accomplished through different means than in the past and involves coordination among many different market participants. A combination of market signals and regulatory decisions will dictate the location and timing of generating capacity additions, and also will influence the siting and construction of new transmission facilities. This has been a result of deregulation.

With an estimated 159,000 to 286,000 MW of new generation to be added by 2011, the transmission system does not appear to be adequate. That is because the planned generation represents a 30 percent increase over currently installed levels. This must be compared to the 5 percent jump in transmission capability.

The mismatch is attributed to several factors. First, transmission owners will only build when regulators and policy makers see an obvious need for more capacity. Speculative transmission projects are not doable because of the high cost of construction and the difficulty in getting lines and plants sited. Second, transmission lines benefit several stakeholders, including merchant plants, but the costs are largely borne by the larger utilities, which are reluctant to build the needed transmission facilities for others where their return on investment is uncertain.

The location of new generators has an affect on reliability. New facilities that are near demand centers will burden transmission systems less, but are far more difficult—if not impossible—to get permitted. Conversely, remote locations with large tracts of land have become desirable plant sites, but need transmission capacity. Also, new natural gas-fired plants can be built faster than the transmission system can be upgraded to accommodate them. This can lead to transmission system overloads and systemic problems on the grid.

Natural Gas and Electricity Interdependency Issues

The increase in gas-fired power generation capacity has created a new link between the natural gas and electricity markets. The use of substantial natural gas by the power sector brings a new dimension of price elasticity to the natural gas demand—both short term and long term—based on the alternatives to natural gas for power generation offered by the electricity system in its totality. As the natural gas and the electricity systems become more closely interlinked, the reliability of the two systems has to be assessed in combination. This raises the issue of reliability of electricity supply in case of a gas supply disruption, and the question of possible back-up fuels for natural gas in power plants.

In addition, the increased use of natural gas for power generation has strong implications for both the long-term external security of supply and the short-term reliability of the power and gas systems, because when natural gas enters the electricity sector, it is the marginal fuel, just before oil products in peaking plants. The impact on future natural gas prices and their volatility should be a national concern.

The impact of a gas supply disruption on electricity security will depend on the flexibility developed in both systems. Although a large percentage of power capacity based on natural gas is multi-fired, the alternative fuel is oil distillate. Operators do not always have enough economic incentives to store the alternative back-up fuel (even for short periods). In addition, environmental legislation may restrict the use of any alternative fuel and seriously limit fuel-switching possibilities.

The increased use of gas in power generation has created security of supply problems in New England when high electrical demand coincided with high natural gas demand during an extreme cold spell. If present trends continue as the USDOE predicts, the growing use of natural gas in power generation must be based on increased natural gas imports. This may present a security of supply problem that needs to be addressed on a national level to ensure there is a reasonable portfolio of fuel source to the electric grid.

8 Hydrogen Economy

To overcome the energy-related environmental, security, health, and sustainability issues facing our nation, the USDOE is working to build an energy economy based on hydrogen. This hydrogen electric economy is expected to use renewable energy resources like the sun, wind, hydropower, and biomass to produce clean, sustainable electricity and hydrogen for our nation (Hock, Elam et al. 2004).

The concept of an economy based on hydrogen and associated technologies is only in its infancy. The issue of where the hydrogen would come from to fuel the national economy has not really been addressed. Hydrogen does not occur freely in nature; it is an energy carrier produced industrially like electricity. Initial markets are reforming hydrogen from natural gas and other fossil fuels. This is of no benefit from an energy standpoint since the process still relies on fossil fuels. For instance, if the source of hydrogen were from coal gasification in a clean process, it would accelerate coal depletion. The nation's coal reserves would be reduced from 250 years to 75 years.

A viable hydrogen economy must make hydrogen from renewable energy resources like wind and tidal power, utilize some biological process, or rely on the dissociation of water from electricity produced by nuclear power plants. To make up for the petroleum input to the transportation sector, would require about 150 million tons of hydrogen (Turner 2004). To dissociate enough water to support the process would require the amount of electricity generated in the nation to double, and would use about 100 billion gallons of water per year. There are also energy inefficiencies in the production of hydrogen and in its usage. It greatest benefit is that it can be stored, transported in pipelines, make electricity cleanly in fuel cells or combusted in microturbines, or used for transportation. Hydrogen can also act as storage medium for intermittent renewable technologies such as photovoltaics and wind power that do not have consistent generation capabilities. Although making hydrogen from electricity and then making electricity from hydrogen makes little sense from an energy perspective.

The major developing market for hydrogen is the transportation sector, which is 97 percent petroleum fueled. Effective use of hydrogen in pure-hydrogen vehicles has significant storage and transportation problems. Hydrogen is a bulky gas and it is not nearly as easy to work with as gasoline. Compressing the gas requires energy, and compressed hydrogen contains far less energy than the same volume of gasoline. It takes roughly four times the volume of hydrogen compared to gasoline to get the same energy potential. It is lighter, but more bulky. This also makes it a problem in fueling aircraft.

Solutions to the hydrogen storage problem are in development. Hydrogen can be stored in a solid form in hydrides such as sodium borohydride. This technology has appeared in the news recently because Chrysler is testing it. As sodium borohydride releases its hydrogen, it turns back into borax, which can be recycled back into new borohydride.

Once the storage problem is solved and standardized, a network of hydrogen stations and the transportation infrastructure will have to be developed. The main barrier to this is settling on a standard technology. Fueling stations networks will not develop until there is a storage technology that clearly dominates the marketplace and a clear demand for them. If all hydrogen-powered cars from all manufacturers used sodium borohydride, then a station network could develop quickly.

The hydrogen economy is getting more research and visibility. The environmental problems of the fossil fuel economy are combining with breakthroughs in fuel-cell technology, allowing some initial steps and demonstration technologies.

Beyond the transportation sector, moving to a pure hydrogen economy will be harder. The power-generating plants will have to switch over to renewable sources of energy, and the marketplace will have to agree on ways to store and transport hydrogen. These hurdles will likely cause the transition to the hydrogen economy to be a rather long process.

In summary, there are tremendous technical hurdles to overcome; once we have solved the production, transmission, and resource issues and then the switch to hydrogen may occur. This is a long-term issue and the hydrogen economy is decades away. The tools to make it work, such as safe nuclear reactors, windmills, and fuel cells are still in the development or early adoption phases. Realizing the potential benefits of a hydrogen economy—sustainability, increased energy security, a diverse energy supply and reduced air pollution and greenhouse gas emissions—hydrogen must be produced cleanly, efficiently, and affordably from regionally available, renewable resources.

9 General Conclusions and Implications

Throughout the 20th Century, the United States has been a profligate energy consumer. The rapid and expansive growth of the economy was based on cheap and abundant energy. Little thought and planning have been given to how to transition to the realities of the 21st Century when petroleum and natural gas resources will become depleted. The U.S. economy uses 50 percent more energy per unit of GDP than the other developed nations of the world (EIA 2004). The fossil fuel-based, automobile-centered, throw-away economy is not a viable model for the United States or the rest of the world over the long term. It is not sustainable.

The natural gas market for the near and mid-term is expected to be very volatile with significant price swings based on weather and supply availability. In the very near term, expect higher prices fairly consistently until the natural gas market is normalized. This will come about by developing a gas pipeline down from Alaska and northern Canada, expanding exploration and production to areas of the United States now off limits, and greatly increasing imports of liquefied natural gas. In the mid-term the world market for natural gas is limited by demand, not by supply. The natural gas markets will reach an equilibrium in 10 years or so, but at higher prices due to higher costs of production and transportation. In the long run, natural gas will reach a peak of worldwide production and decline as a resource starting in the 2030-2035 time range.

The oil market will remain fairly stable, but with steadily increasing prices as world production peaks. Demand now exceeds production and we are seeing that effect on prices. After the peak is reached, geopolitics and market economics will result in significant price increases above what we have seen to date. Security risks will also rise. To guess where this is all going to take us is would be too speculative. Oil wars are certainly not out of the question. Any disruption of world oil markets may also affect world natural gas markets.

Despite environmental issues such as carbon dioxide emissions, coal consumption will grow in the utility sector and, possibly, the large industrial sector. The nation has large supplies of coal in the West and it will most likely be utilized. Poly-generation techniques have the potential to utilize our nation's coal reserves in an environmentally friendly way that helps us meet both our liquid fuel requirements and our electricity requirements. Carbon sequestration technologies will start to play a larger role in the mid-term. Caution is advised here as these technologies must be well thought-out to avoid unintended consequences such as large unexpected releases of stored carbon dioxide.

Nuclear power appears headed for a small renaissance with plant upgrades in the short term and a modest construction program getting under way in the mid term. Also, some shutdown reactors may be restarted. Hasty commercialization in the U.S., safety concerns, and unresolved long term storage of its wastes, has caused the nuclear era to be a failure. This is not a firm foundation for further expansion of the industry. Light water reactors are only an interim technology and true energy independence would come from a breeder reactor program and closing the fuel cycle. It remains to be seen if this is a viable solution from both political and environmental perspectives. Other nations such as France and Japan have taken this path.

In spite of being heavily promoted and supported by public and private funding, contributions of non-fossil energy sources ranging from geothermal and central solar to corn-derived ethanol and biogas remain minuscule on the global scale. Wind turbines have been improved enough to be seriously considered for large-scale commercial generation especially under renewable portfolio situations. Photovoltaics have proved their great usefulness in niche markets such as space and specialized terrestrial applications but not yet in large-scale generation. Their future will lie in distributed generation applications and building integrated systems and not in central plant concepts. Renewable energy technologies are certainly going to be a growing part of the energy mix and will penetrate faster and further than conventional energy advocates think. Early adoption to promote this market is inherently in the government's interest.

The electrical system will likely become increasingly problematic over the next 5 to 10 years. Power capacity should suffice as we have overbuilt the peaking market and additions to base capacity are in the planning stages. The grid, itself, however is the Achilles heel of the Nation's electrical system. Investments are not keeping up with power flow demands and bottlenecks exist in certain regions lowering the reliability of the grid as a whole. Once the ongoing regulation and deregulation activities are settled, grid expansions and upgrades can be achieved through appropriate investments. The fraudulent electrical pricing and supply manipulations by commodity traders that led to the California energy crisis in 2001 should not reoccur.

In conclusion, we are clearly entering a very different period for global energy markets and relations. We shall continue to face geopolitical risks and uncertainties and concerns around energy security will continue to rise. Petroleum will remain the most strategic and political energy commodity with natural gas running a close second. There will be increasing focus on sustainability and potential constraints of our current energy paths—especially in light of climate change, investment requirements, and resource depletion. The situation is particularly acute in the case of petroleum. These are complex issues and they have to play out in relation to one another. The roles of leading actors in the global energy system will also change as the center of gravity for oil production shifts back towards the Middle East and Central Asia. Asia, especially China and India, will assume a much larger role in energy consumption and will actively vie with Europe and North America for global energy resources such as petroleum and natural gas.

When considering the future, we should also consider the many lessons of the twentieth century. Slow substitutions of both primary energies and prime movers should temper any bold visions of new sources and new techniques taking over in the course of a few decades (Smil 2000). The first half of the 20th Century was dominated by coal, the dominant fuel of the previous century. Three nineteenth-century inventions—the internal combustion engine, the steam turbine, and the electric motor—were critical in defining and molding the entire fossil fuel era we are still in. Despite the issues of peak petroleum, the dominant energy systems during the first decades of this century will not be radically different from those of today. We have a large and robust energy system with tremendous inertia, both from a policy perspective and a great resistance to change.

One thing is certain: it is going to be challenging and comprehensive approaches to energy issues are required. Uncertainty cannot be an excuse for inaction. Integrated resource planning is required and issues must be addressed from both the supply and demand viewpoint. The U.S. cannot drill its way to energy independence nor can we do it all with renewables and efficiency. A secure, reliable, and cost effective energy system must be robust, diverse, and aggressively incorporate renewables, energy efficiency, and intelligent use of fossil fuels.

10 Recommendations for the Army and Military Installations

Recommendations

Energy issues in the near term call for a strategy that addresses new technologies, enhances reliability and efficiency, and protects the Army from the volatility expected in energy pricing and availability over the near and mid-term. This will take strategic planning and a concentrated effort of upgrading the built environment for maximum efficiency an imperative. Also required is the construction of an efficient, reliable, and secure energy web on each major installation.

Effective action requires the integration of the traditional elements of supply and demand, transmission, and distribution with new technologies such as efficient equipment, energy storage, load management, and distributed generation. By moving the installation energy system into the information age—applying micro-grids, tri-generation plants, integrated renewable technologies, and centralized controls—we can optimize the system, minimize the need for new infrastructure, lower costs, and make the system more secure. A diversified fuel mix is a pre-requisite for energy security, stability of prices, and reliability of supply. This should be taken into consideration when developing Army-wide energy plans or long-term installation strategies. It is particularly required against the background of the growing short term focus and instability of the worldwide energy markets.

A centralized management approach and funding is required to develop the strategic plans and achieve critical mass as an initiative that attracts third party cooperation and financing. The installation of 2020 needs energy security, sustainability, and flexibility to function as "homes" to the force and joint power projection platforms. Energy must be viewed as a primary mission enabler (Riggs 2003). Significant energy and monetary savings can be attained from greater efficiency in the built environment while energy security may come at a higher price than current approaches. The coming years will see significant increases in energy costs across the spectrum. Not only are energy costs an issue, but also reliability, availability, and security. It is time to think strategically about energy and how the Army should respond to the global and national energy picture. A path of enlightened self-interest is encouraged. The 21st Century is not the 20th Century—issues will play out differently and geopolitics will impact the energy posture of the nation and our military installations. Technology will change more rapidly and flexibility will be a crucial part of installation operations. This must also extend to the energy infrastructure and its operational concepts.

Energy Implications for Army Installations

The days of inexpensive, convenient, abundant energy sources are quickly drawing to a close. Domestic natural gas production peaked in 1973. The proved domestic reserve lifetime for natural gas at current consumption rates is about 8.4 yrs. The proved world reserve lifetime for natural gas is about 40 years, but will follow a traditional rise to a peak at about 2035 and then a rapid decline. Domestic oil production peaked in 1970 and continues to decline. Proved domestic reserve lifetime for oil is about 3.4 yrs. World oil production is at or near its peak and current world demand exceeds the supply. Saudi Arabia is considered the bell-whether nation for oil production and has not increased production since April 2003. After peak production, supply no longer meets demand, prices and competition increase. World proved reserve lifetime for oil is about 41 years, most of this at a declining availability. Our current throw-away nuclear cycle uses up the world reserve of low-cost uranium in about 20 years. We will see significant depletion of Earth's finite fossil resources in this century.

We must act now to develop the technology and infrastructure necessary to transition to other energy sources. Policy changes, leap ahead technology breakthroughs, cultural changes, and significant investment is requisite for this new energy future. Time is essential to enact these changes. The process should begin now.

Our best options for meeting future energy requirements are energy efficiency and renewable sources. Energy efficiency is the least expensive, most readily available, and environmentally friendly way to stretch our current energy supplies. This ensures that we get the most benefit from every Btu used. It involves optimizing operations and controls to minimize waste and infusing state of the art technology and techniques where appropriate. The potential savings for the Army is about 30 percent of current and future consumption. Energy efficiency measures usually pay for themselves over the life cycle of the application, even when only face value costs are considered.

Renewable options make use of Earth's resources that are not depleted by our energy consumption practices: namely solar, wind, geothermal, geoexchange, hydropower, tidal power, bio-products, and municipal wastes. Renewable options also make use of the large stretches of land in America, much of which is owned by the government. These options are available, sustainable, and secure. The affordability of renewable technologies is improving steadily and if the market is pulled by large Army applications the cost reductions could be dramatic. For efficiency and renewables, the intangible and hard to quantify benefits—such as reduced pollution and increased security—yield indisputable economic value.

Many of the issues in the energy arena are outside the control of the Army. Several actions are in the purview of the national government to foster the ability of all groups, including the Army, to optimize their natural resource management. The Army needs to present its perspective to higher authorities and be prepared to proceed regardless of the national measures taken or not taken.

The following steps by the national government are recommended to help the Army meet its energy challenges:

- Increase National Supplies and Release Capacity
  - Recognize and promote energy efficiency as the cheapest, fastest, cleanest source of new energy.
  - Recognize and promote that renewable energy technologies make sense for America on a very large scale.
  - Promote renewable applications and work to change image of solar roofs and off-shore wind farms.
  - Pull renewable technology markets to produce more cost effective solutions with tax incentives and large Federal applications.
  - Appropriate the necessary funding to bring Federal facilities to state of the art efficiency.
  - Open up Federal lands for oil and natural gas harvesting where environmentally appropriate.
  - Encourage the development of LNG terminals and infrastructure by streamlining approvals and assisting with local approvals.
  - Provide incentives for green power production through continued and expanded tax credits.
- Modernize National Infrastructure
  - Support modernizing and expanding the electricity grid.
  - Support the construction of a natural gas pipeline from AK and Canada.
  - Enhance the expansion of LNG terminals and natural gas infrastructure.
- Diversify and Enhance Domestic Sources
  - Invest in R&D in clean coal technologies, renewable technologies, carbon sequestration, breeder reactors, and closing the nuclear fuel cycle.
  - Invest in R&D in energy efficiency in the built environment.
- Optimize End-use
  - Significantly increase Corporate Average Fuel Efficiency (CAFE) standards and expand to all classes of motor vehicles.

    - Expand appliance and equipment efficiency standards as many states are doing.
    - Continue and enhance the Federal Energy Management Program.
    - Continue and enhance the Energy Star program
- Minimize Environmental Impact
- Cooperate in global energy markets

The national and world energy situation mandates strategic planning and action by the Army. The pending challenges of meeting the Army's ongoing energy requirements in a reliable, affordable, sustainable, and secure fashion demand thoughtful and comprehensive approaches. A deliberate careful review of energy source options and resulting tradeoffs is necessary. The informed and disciplined management of consumption is imperative.

The Army has begun this necessary strategic planning and its *Army Energy Strategy for Installations* (http://hqda-energypolicy.pnl.gov/programs/plan.asp) defines the overarching mission and goals, and outlines broad approaches for reaching the Army's full potential. The mission of the Army Energy Program is to provide safe, secure, reliable, environmentally compliant, and cost-effective energy and water services to soldiers, families, civilians and contractors on Army Installations. The five major goals for the program are:

- eliminate energy waste in existing facilities
- increase energy efficiency in renovation and new construction
- reduce dependence on fossil fuels
- conserve water resources
- improve energy security.

This strategy is timely and on-target with the realities of the energy arena.

ERDC/CERL's Technical Report TR-04-10, *A Candidate Army Energy and Water Management Strategy* (Fournier and Westervelt 2004), enumerates many ideas for consideration in this next level effort including necessary policy changes and an operational framework with review and adjustment to ensure success. It assesses the current practices and needs of Army energy and water management, aligns present efforts with objectives, identifies gaps in programming and advises courses for improvement including the centralized management of goals. This report recommends a tiered approach including the national, regional, and installation level planning and action. The concept for action is imbedded in a framework of coordination, execution, and delivering outcomes. The execution section provides for modern, secure, and efficient facilities and systems. Large increases in renewable energy use, combined with higher levels of energy efficiency, and the deployment of combined heating, cooling, and electrical plants using carbon sequestration technologies, can go a long way towards a sustainable and secure energy path for Army installations.

To reduce risk and accelerate results, the use of alternative financing options is recommended. Installations should develop comprehensive energy plans using a process consisting multiple phases as follows: information gathering, energy and facility audits, management interviews, cost-benefit analyses and modeling, and strategy development. Energy projects defined in the plan should be tailored to fit the wide range missions, facilities, and operations on military installations. Implementation plans are then required for each installation. This would be a combination of OMA, MCA, and third party initiatives. The plan should be tailored to each installation based on mission, availability of renewable energy resources, and the availability of third party partnerships. The planning stage should evaluate the regional resources such as renewables and partnerships with utilities as part of the information gathering stage.

In these times of tightening classical energy options, the Army needs to take comparable steps to the national agenda mentioned above by modernizing infrastructure, optimizing end-use, minimizing environmental impact, pulling technology markets, cooperating in regional purchases, and leveraging alternate financing. Special attention to the diversification of sources and greatly enhanced energy conservation is appropriate. This incorporates a massive expansion in renewable energy purchases, a vast increase in renewable distributed generation including photovoltaic, solar thermal, microturbines and biomass, the large-scale networking of on-site generation, extremely efficient new buildings, and much greater emphasis on improving the efficiency of the existing building stock.

The awareness of the energy options, trends, tradeoffs and the implications for Army installations allows for informed decisions, targeting planning and pertinent investment. The Army must continue to improve and optimize its energy and water management to meet mission requirements.

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The primary issues affecting energy options are those of availability, affordability, sustainability, and security. Since energy resources are unevenly distributed around the world, and the impacts of energy consumption have global reach in both environmental and political terms, any meaningful review of energy-related issues must take a global perspective. This work synopsizes world and national energy issues (including energy source options, resource stocks, and future prognosis) in the context of how Army installations need to respond to changing trends. This report presents implications of actions that may be taken in response to the national and world energy situation, to help the Army to make informed choices on energy utilization that will contribute to sustaining the Army's mission.

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