Dynalytics Corp.

Vulnerabilities of the United States' Energy Supply
The International Context

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SUMMARY

The economies of several countries with poor but large and increasing populations, including those of China, India, Indonesia and Pakistan, will require vast additional amounts of food, water, steel, petrochemicals, and certainly energy, in the near future. The world's energy production, refining and processing, and transportation systems are, however, now severely constrained. Although many large energy projects are planned, and many are underway, current bottlenecks can not be eliminated within the immediate future.

Production and transportation of oil and gas are being interrupted by accidents and weather-related events throughout the world. Unfortunately, international disputes are ongoing, and terrorist activities outside of the United States are becoming more frequent, more sophisticated and more severe. These terrorist activities, which are likely to become more successful, will strongly exacerbate energy shortages. Given the international geopolitical situation and the current energy infrastructure weaknesses, suddenly arising long-duration disruptions should be expected, together with extremely large increases in fuel and electricity costs. It appears to be extremely risky and imprudent for any company to not prepare to handle this situation.

Environmental factors and the Kyoto Treaty are certainly important considerations that need to be addressed when assessing energy plans. Since, however, the focus of this presentation is on energy disruptions in the very near future, they will not be discussed herein.

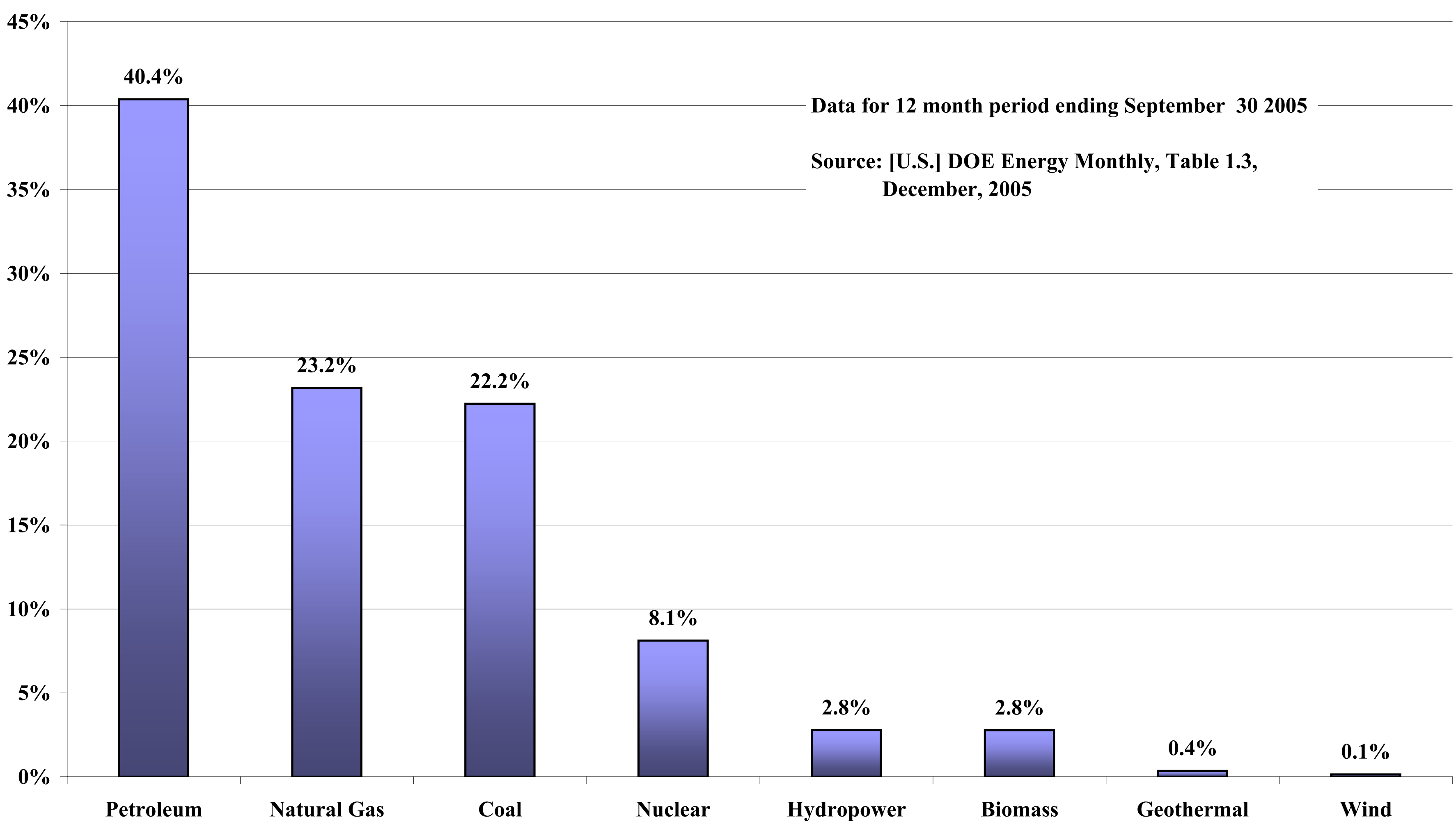
This presentation discusses the current international and United States energy situation with a focus on immediate credible threats, and offers specific suggestions for industrial companies to implement immediately.

CURRENT FUEL USAGE

The world relies on a handful of primary[1] fuels for transportation, lighting, heating and cooling, production and manufacturing, and other purposes that bring comfort and quality to lives. These primary fuels fall into three broad categories: fossil fuels (coal, petroleum and natural gas,) nuclear, and "renewable" (hydropower, biomass, wind, solar and geothermal.) Usage of these in the United States[2] is illustrated on Figure 1 which shows that petroleum is dominant. Other countries, of course, have different use profiles.

[1] Primary Fuels are those used directly or converted to other types of energy such as gasoline or electricity.
[2] [U.S.] Energy Information Administration, Monthly Energy Review, Table 1.3, December, 2005

Figure 1
U.S. Primary Energy Usage by Type



Importantly, many industrially important countries, as shown on Figure 2, generate substantially higher percentages of their electricity from nuclear power plants, lowering the potential impact of disruptions to (or higher prices of) hydrocarbon fuels. China and Russia currently generate relatively small amounts of nuclear-based electricity, but are actively proceeding to increase this.

Much (39 percent) of the primary energy used the United States is converted to electricity for distribution and use. The average mix[3] used for this is shown on Figure 3, on which it can be seen that fossil fuels account for 68.5 percent of the total. The largest consumer of energy in the United States is, as seen on Figure 4, the industrial sector which uses it largely for process heating, machinery drives, and facility HVAC. Lesser industrial uses, on a sector-wide basis, include electrochemical processing, facility lighting, and process cooling and refrigeration. Many individual industrial companies, of course, utilize process cooling and refrigeration substantially more than the average user within this sector.

The distribution of specific energy types that that one sub-sector, manufacturing,[4] uses is shown on Figure 5, on which it is seen that hydrocarbon fuels represent approximately 73 percent of the total.

The production of many materials on which our economy depends is highly energy-intensive, consuming approximately 20 percent of the energy used in the United States' industrial energy sector. Energy-intensive chemical products and intermediates include ethylene, ammonia, methanol and chlorine. Production of major construction materials including steel, aluminum and cement is also energy-intensive.

Within the United States, the second largest use of primary energy is, as shown on Figure 4, for transportation purposes, followed by residential and commercial purposes.

Although the amount of electrically driven transportation, ranging from battery-operated golf carts to electrified railroads, is noticeable, the overwhelming fraction of transportation energy is provided by gasoline and diesel fuel. These account for approximately 14,000,000 barrels[5] per day, or 70 percent of United States crude oil use.

Substituting one fuel for another is most often impractical. Fuel combustion chamber volumes and dimensions are established on a fuel-specific basis, as is the fuel delivery system to the plant and then to the boilers, engines, kilns, etc. The exhaust gas fans, ducts and stacks are, likewise, designed to accommodate a specific fuel. Finally, air pollution control equipment such as wet scrubbers, baghouses and selective catalytic reduction systems are also designed to accommodate a specific fuel. Although it is frequently possible, with some equipment modifications, to use fuel gas in a system

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[3] [U.S.] Energy Information Administration, Monthly Energy Review, December 2006, Table 7.2a, p. 99
[4] North American Industry Classification System (NAISC) Code 325.412
[5] One barrel of oil contains 42 U.S. gallons, or 158.9 liters

Figure 2
Percent of Electricity Generated by Nuclear Power Plants
2005

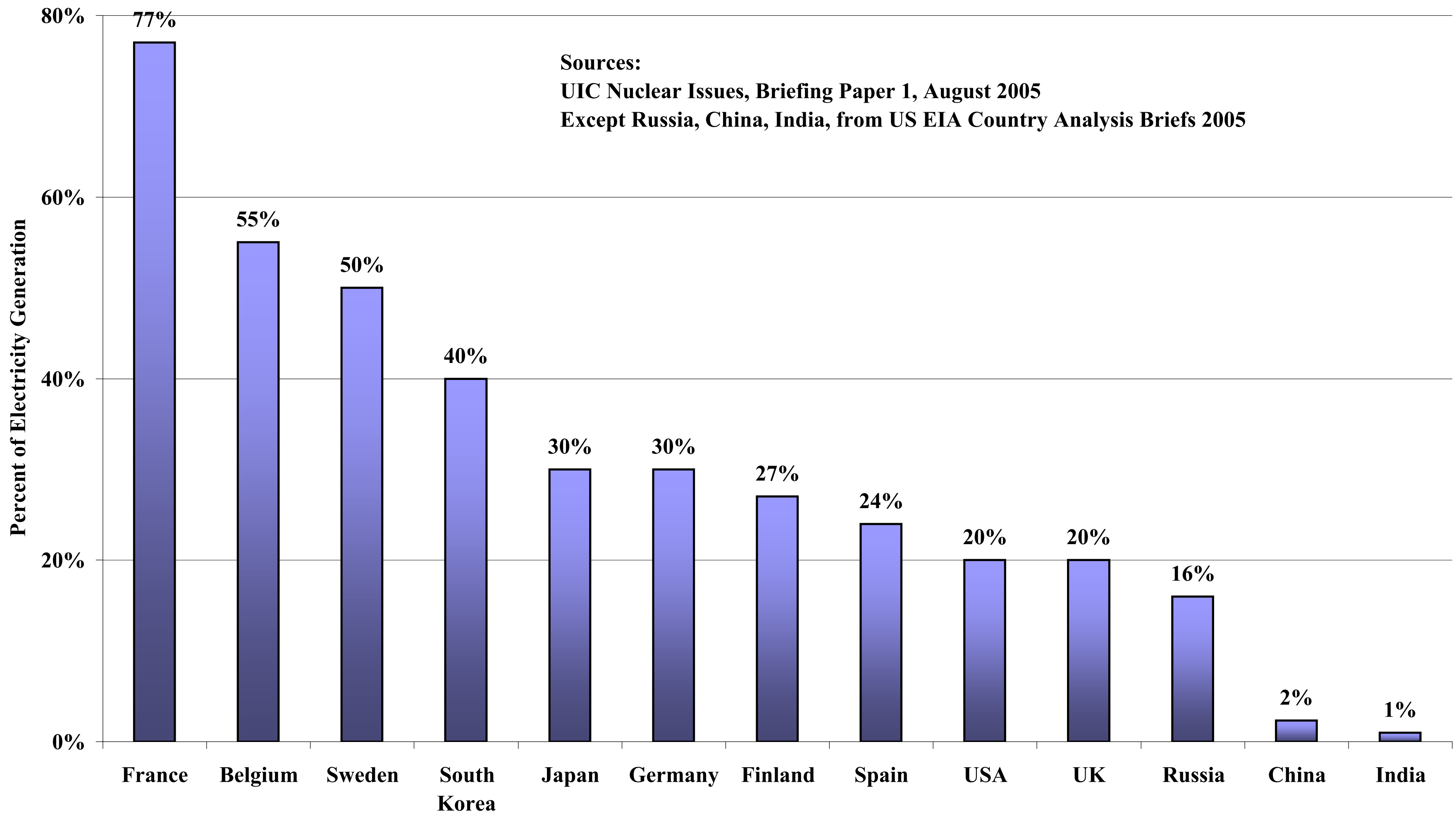
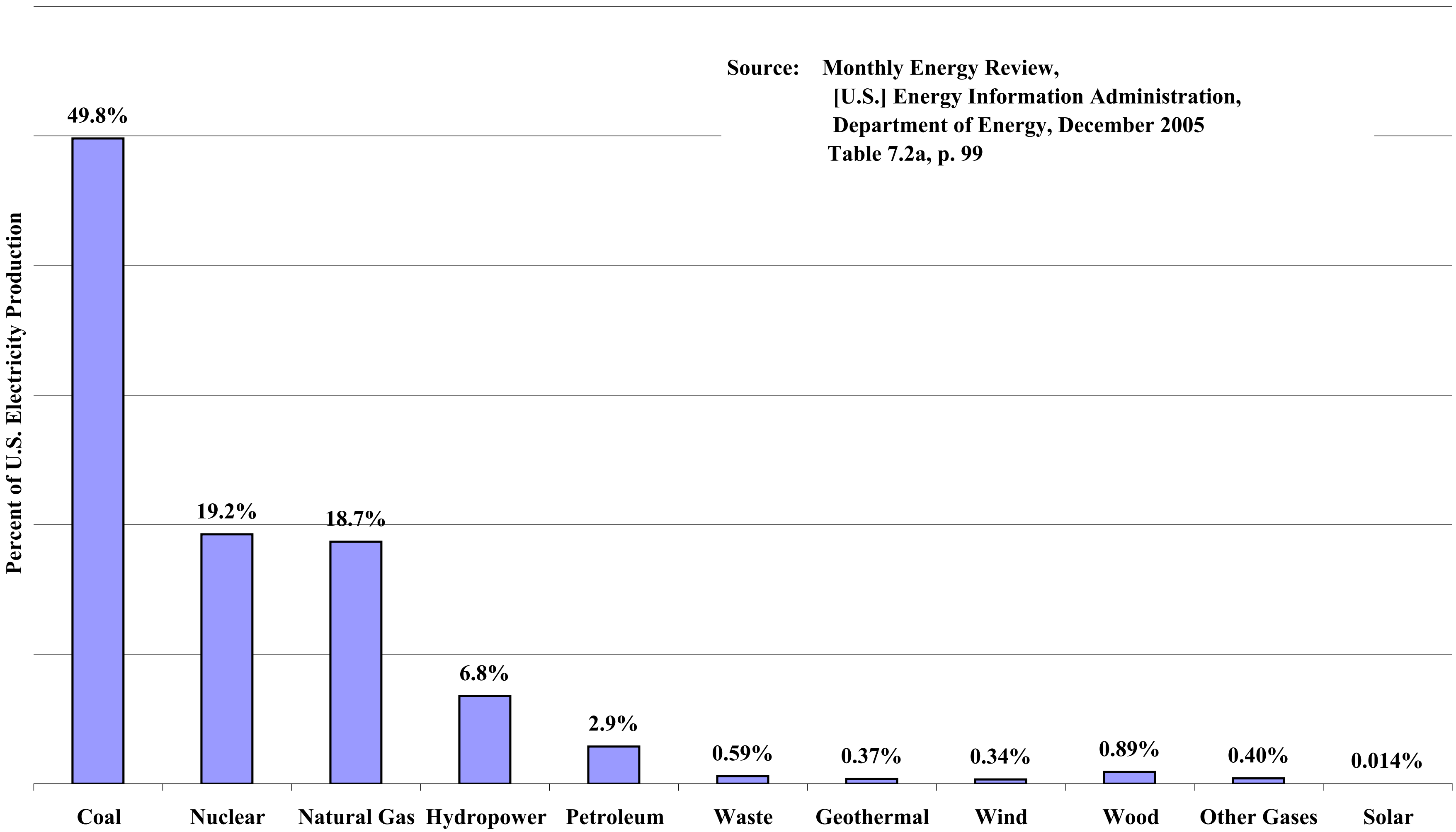


Figure 3
Electricity Production by Fuel Type
(United States - 2005)



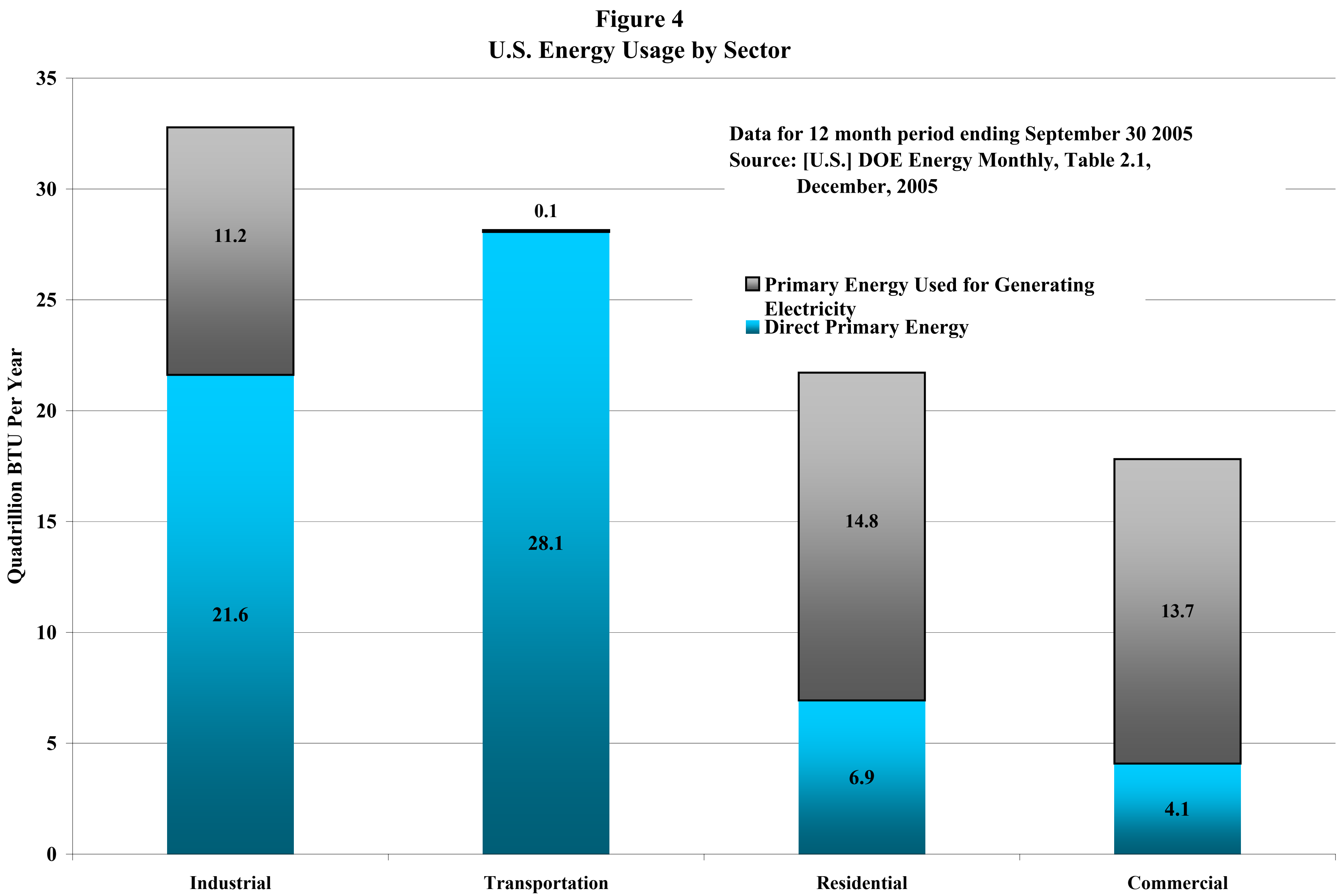
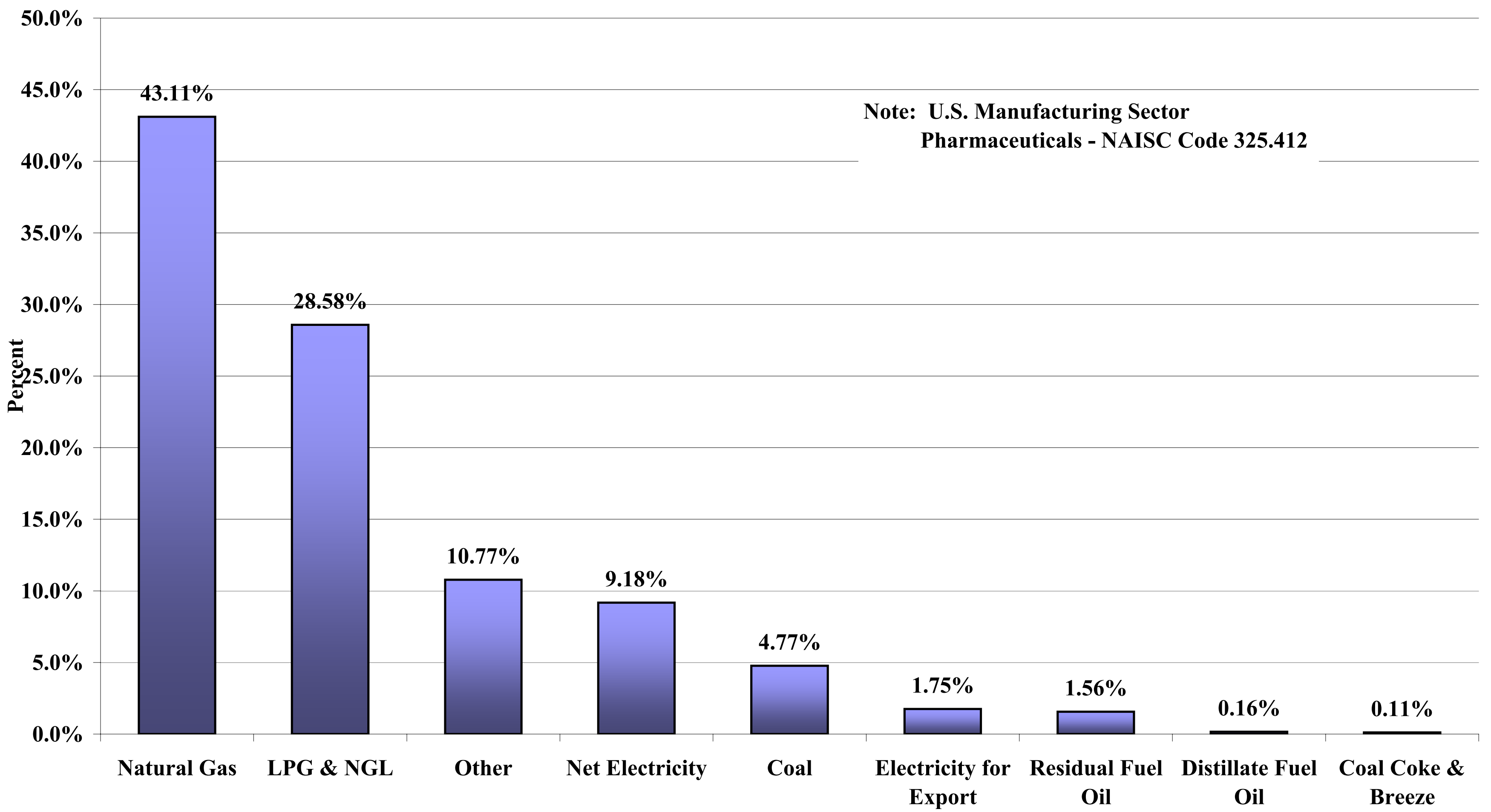


Figure 4
U.S. Energy Usage by Sector
Data for 12 month period ending September 30 2005
Source: [U.S.] DOE Energy Monthly, Table 2.1,
December, 2005
Primary Energy Used for Generating Electricity
Direct Primary Energy
Quadrillion BTU Per Year
35
30
25
20
15
10
5
0
11.2
21.6
0.1
28.1
14.8
6.9
13.7
4.1
Industrial
Transportation
Residential
Commercial

Figure 5
Types of Energy Used
(U.S. Manufacturing Sector)



designed for fuel oil, the reverse is rarely practical. It is virtually impossible to substitute coal for either fuel gas or fuel oil in an existing facility.

While the United States consumes a disproportionately large amount of fuel on a per capita basis, other countries' economies are growing rapidly. The international oil trade and shipping profile is undergoing dramatic changes, with China, whose economy grew at 9 percent in 2005, becoming a major oil and coal importer. In fact, imports by China have accounted for 40 percent of the increase in oil exports since 2000. India, Indonesia and Pakistan are also countries with growing economies (6.9, 5.5 and 8.4 percent per year increases in gross domestic product, respectively), large populations and currently low per capita energy usage that will undoubtedly increase.

FUEL SOURCES ARE INTERNATIONAL

Primary fuels exist in significant quantities in numerous countries. Estimates of reserves provided by various countries and companies are, however, somewhat questionable for several reasons. In addition to deliberate mischaracterizations, there are in fact many uncertainties in estimations. These relate to the physical properties of the basin or mine, the extraction techniques and rates contemplated.

Exports of primary fuels are certainly important revenue sources. For example, the eleven members of the Organization of the Petroleum Exporting Countries (OPEC)[6] derive virtually all their incomes from oil sales. Although not scrupulously adhered to, production quotas are nevertheless important, and these are assigned by OPEC based in large part on estimated reserves. Relatively few countries, however, exhibit any degree of transparency or offer data that would allow independent estimates of reserves.

In the private-industry sector, reserves shown as assets on balance sheets impact the valuation of companies, occasionally leading them to publish highly exaggerated estimates. The Royal Dutch/Shell Group had, as a notable example, overstated its reserves by 5.63 billion barrels in 2005 and had to ultimately reduce its estimate by 41 percent to 13.72 billion barrels. The United States Department of Justice is now conducting a criminal investigation of the situation.

Every country has some reserves of some fossil fuels, and many have uranium-bearing ores. These are indeed used as indigenous fuels in many countries. Relatively few countries, however, have them in sufficient quantity, quality, concentration and accessibility to make it economically practical to produce and export them. The most important countries, from an energy export viewpoint, listed in Table 1, and their customers are part of a multi-billion dollar international trade business.

The United States is vast and has huge amounts of many primary fuels, as shown on Table 2. Its vast economy, however, also consumes enormous amounts of fuel and is, in

[6] Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, Venezuela

fact, a net hydrocarbon (liquid and gas) and uranium importer. Conversely, while some coal is imported, approximately 4 percent of United States coal production is exported.

Table 1
Overall International Energy Market
(Top Producers of Each Primary Energy Source)

Country	Annual Production & Exports (Typical, 2003-2005)						
	Natural Gas 10^9 Cubic Feet		Crude Oil 1000 Barrels/Day		Coal 1000 Tons[7]		Uranium Tons of U[8]
	Produced	Exported	Produced	Exported	Produced	Exported	Produced
Australia	1,300	414	555	-364 Import	**373,400**	303,100	**7,570**
Canada	**6,600**	3,600	3,100	800	73,200	1,000	**10,460**
China	1,210	0	**3,620**	-2,910 Import	**1,630,000**	100	750 (Estimate)
Iran	**2,800**	10	**4,260**	2,722	1,000	-800 Import	0
Kazakhstan	560	10	1,221	1,065	86,500	28,000	**3,300**
Mexico	1,500	-300 Import	3,992	1,756	11,900	-8,500 Import	0
Niger	~0	~0	~0	~0	~0	~0	3,140
Russia	**21,800**	6,500	**9,440**	6,730	**294,,000**	43,300	**3,150** (Estimate)
Saudi Arabia	**2,100**		**9,100**	9,00	0	0	0
South Africa	64	0	18	-270 Import	**242,700**	76,300	758
United States	**18,900**	**-4,300 Import**	**7,500**	**-12,200 Import**	**1,105,000**	**48,000**	**857**

Note: 10^9 is U.S. billion, 10^6 is U.S. million

Renewable Energy

Biomass and ethanol: The major biomass fuels used in the United States include waste wood and waste oil/grease. It is noted that while wood may be considered a primary fuel, the waste oil/grease originates in part from imported hydrocarbons.

Ethanol that is blended with gasoline to produce gasohol may be obtained from corn, and therefore yield additional revenues to farmers in a few States. This has led to politically

[7] [U.S.] Energy Information Administration, Department of Energy, Country Briefs (2005 and 2006)
[8] Uranium Information Centre Ltd, Nuclear Issues Briefing Paper 41, Melbourne, Australia, June 2004. Exports are not reported.

inspired tax credits and mandates to use corn-based ethanol in gasohol leading this to be a rapidly growing fuel. During 2005 there were 3.2 billion gallons of corn-based ethanol produced in the United States.

Table 2
US Primary Fuel Resources[9] - Quadrillion (10^{15}) BTU

Type	Accessible Resources[10]	Available Reserves[11]	% Cost-Effective
Solar	586,687	352	0.06
Coal	38,147	5,266	13.8
Geothermal	22,782	247	1.08
Shale oil	11,704	1	~0
Wind	5,046	5	~0
Petroleum	1,102	156	14.2
Natural Gas	887	231	26.0
Uranium	731	42	5.7
Peat	354	-	~0
Hydroelectric	157	58	36.9
Strategic Petroleum Reserve	See Below	See Below	100

Several countries are strongly encouraging use of renewable fuels. Utility companies in Germany, for example, are legally required to purchase electricity generated from renewable fuels, including biomass, at stated above-market prices for a 20-year period.[12] Within the United States many utility companies are offering "green energy" as a somewhat higher cost option. Some States go farther, requiring utility companies to produce increasing fractions of electricity from renewable fuels.

Biomass (wood + waste + ethanol) accounted for 2.7 percent of the primary energy used in the United States during the first nine months of 2005.[13]

Hydropower: Hydropower is a major source of electricity throughout the world. It, however, leads to many difficult environmental and social problems and therefore, with

[9] [U.S.] Energy Information Administration, Annual Energy Review, Table 1, 2003
[10] Accessible Resources can be accessed with existing technologies regardless of cost.
[11] Available Reserves can be cost-effectively recovered today.
[12] Erneuerbare Energien Gesetz, March 31, 2000, Bundesgesetzblatt I/13, p. 305
[13] [U.S.] Energy Information Administration, Energy Monthly Review, Tables 1.1 and 1.2, December 2005

the exception China, will not have an important role in new electrical generation for many years.

Solar and Wind: These energy sources, unlike other renewables, are environmentally benign. Economic hurdles are being overcome and, in technically suitable sites, these are being increasingly used. They, however, also will not have an important role in new electrical generation for many years.

Imports

Crude Oil: While the United States imports noticeable amounts of gasoline, jet fuel, kerosene, residual and distillate fuel oils, the dominant import, as seen on Figure 6, is crude oil. As a group, the OPEC countries have the world's largest hydrocarbon reserves and are the largest exporters; see Figure 7 for individual OPEC member's crude oil production rates. A consolidated picture is that the OPEC countries have:

Capacity	- 35.40 million barrels per day
Production	- 33.96 million barrels per day (November, 2005) (40.4 percent of world's total supply)
Spare Capacity	- 1.44 million barrels per day (November, 2005) (1.7 percent of world's total demand)

As critical as OPEC is, the United States also obtains crude oil and hydrocarbon products from many non-OPEC countries. Importantly, Canada, Mexico, Norway, Oman and Russia, are not members of OPEC. Current imports are presented on Figure 8, which shows that, in fact, Canada and Mexico provide the largest amounts of imported crude oil from individual countries.

Natural Gas: The United States is also a net importer of natural gas. During the 12-month period ending on October 31st, 2005 it consumed 22,279 billion cubic feet, but only produced 18,144 billion cubic feet. The shortfall was compensated for by withdrawing 126 billion cubic feet from storage and importing the difference, which is growing, of 3,481 billion cubic feet (from Canada), or 9,537 million cubic feet per day.[14]

Liquefied natural gas: Liquefied natural gas (LNG) is the fastest growing energy sector throughout the world, averaging 10 percent per year. Total United States LNG imports were 661.6 billion cubic feet in 2004, which represents approximately 3 percent of the United States natural gas usage. This is widely expected to increase to 25 percent by 2020. While Trinidad is currently by far the largest supplier of LNG to the United States, imports from several other countries, as shown on Figure 9, are also significant.

Five operating LNG terminals with storage and regasification capabilities now serve the United States. These have a combined base-load sendout capacity, as shown on Table 3, of 3.9 billion cubic feet per day which is being increased. Thirteen other proposed terminals have received approvals from the United States Federal Energy Regulatory Commission and the United States Coast Guard, another 15 to 20 are in serious stages of planning, and another 20 to 30 projects are in very preliminary discussion stages.

[14] [U.S.] Energy Information Administration, Natural Gas Monthly, Tables 1 and 2, December 2005

Figure 6
U.S. Petroleum Imports by Type

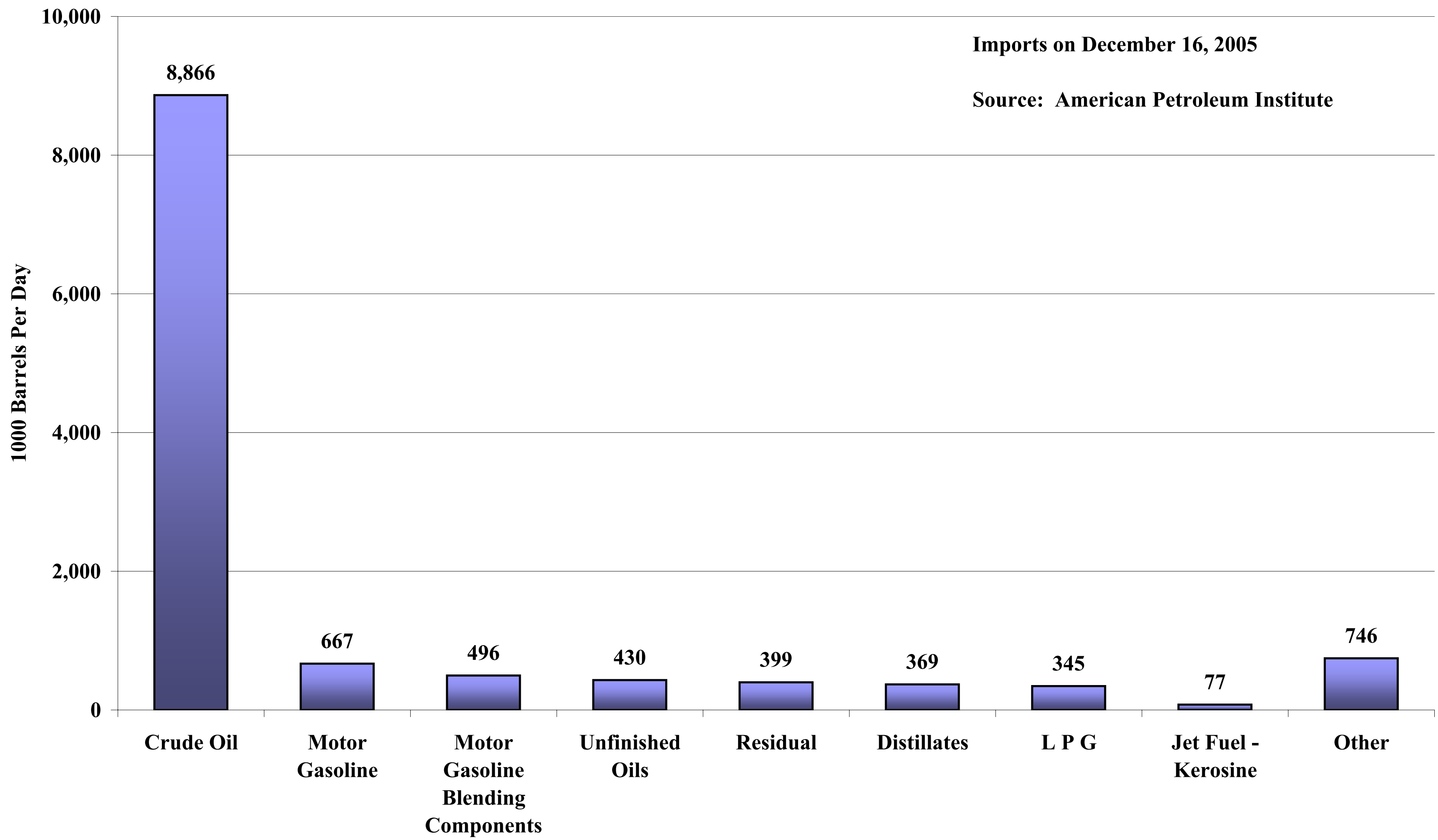


Figure 7
OPEC Crude Oil Production by Country

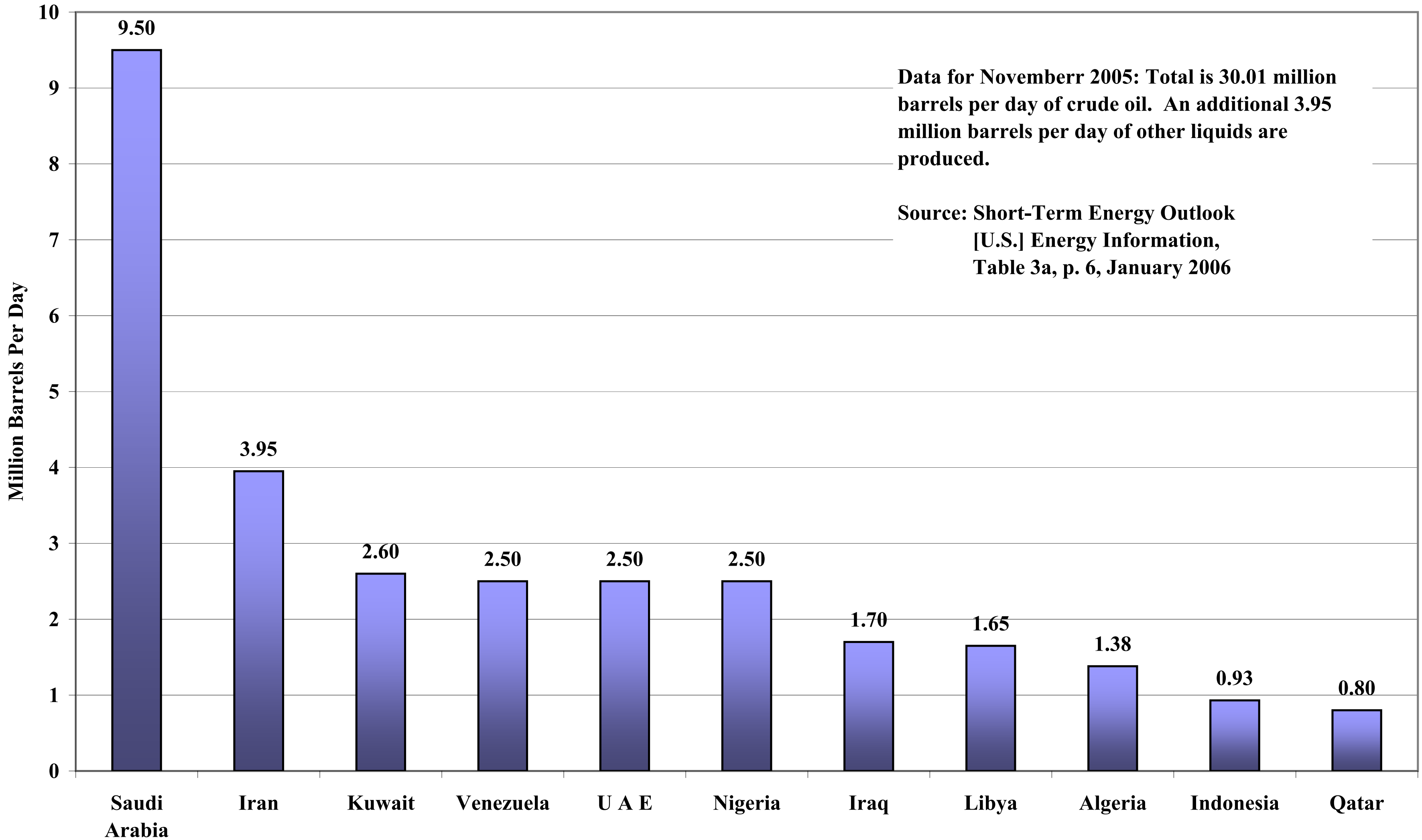


Figure 8
U.S. Petroleum Sources

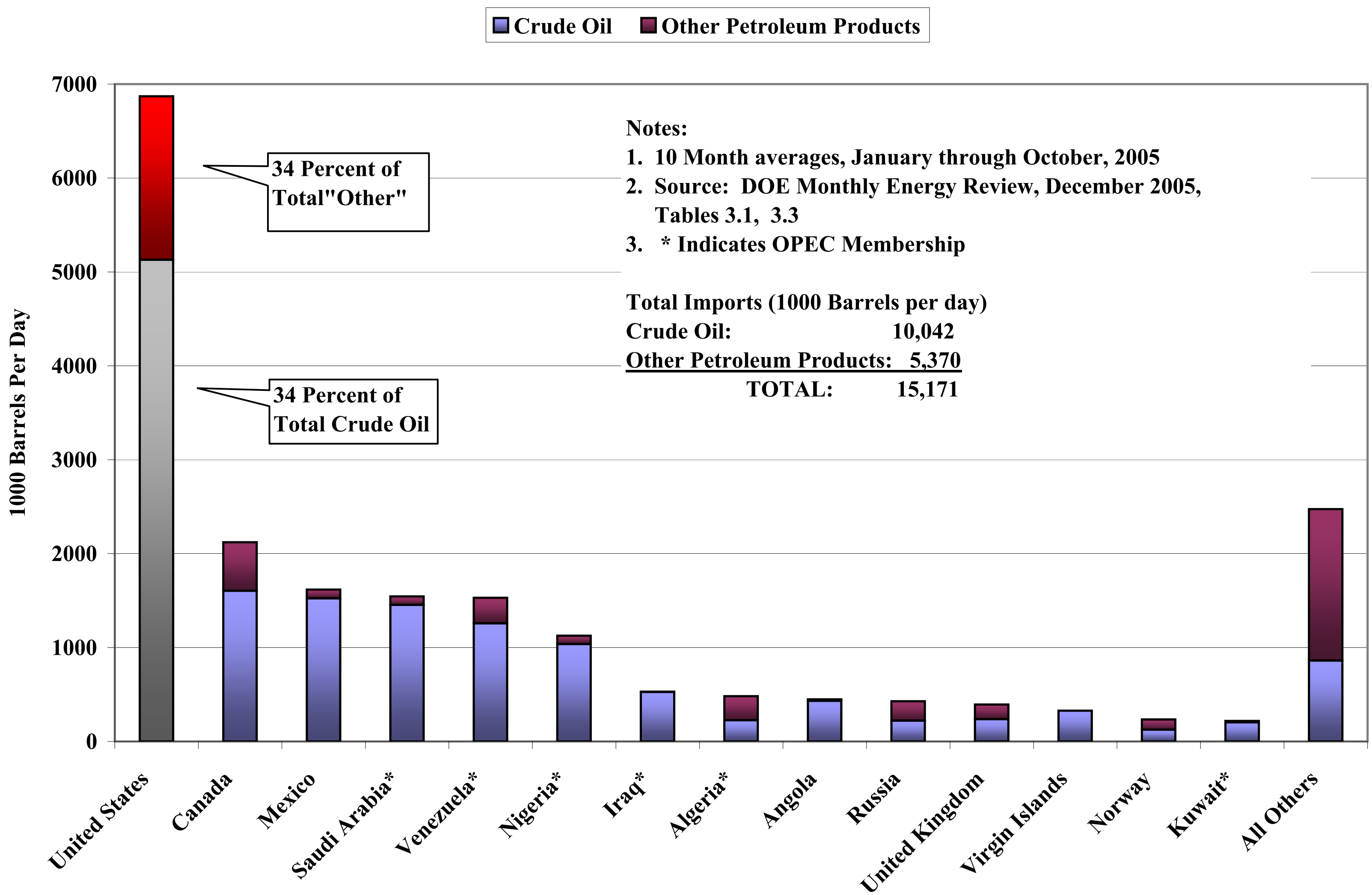
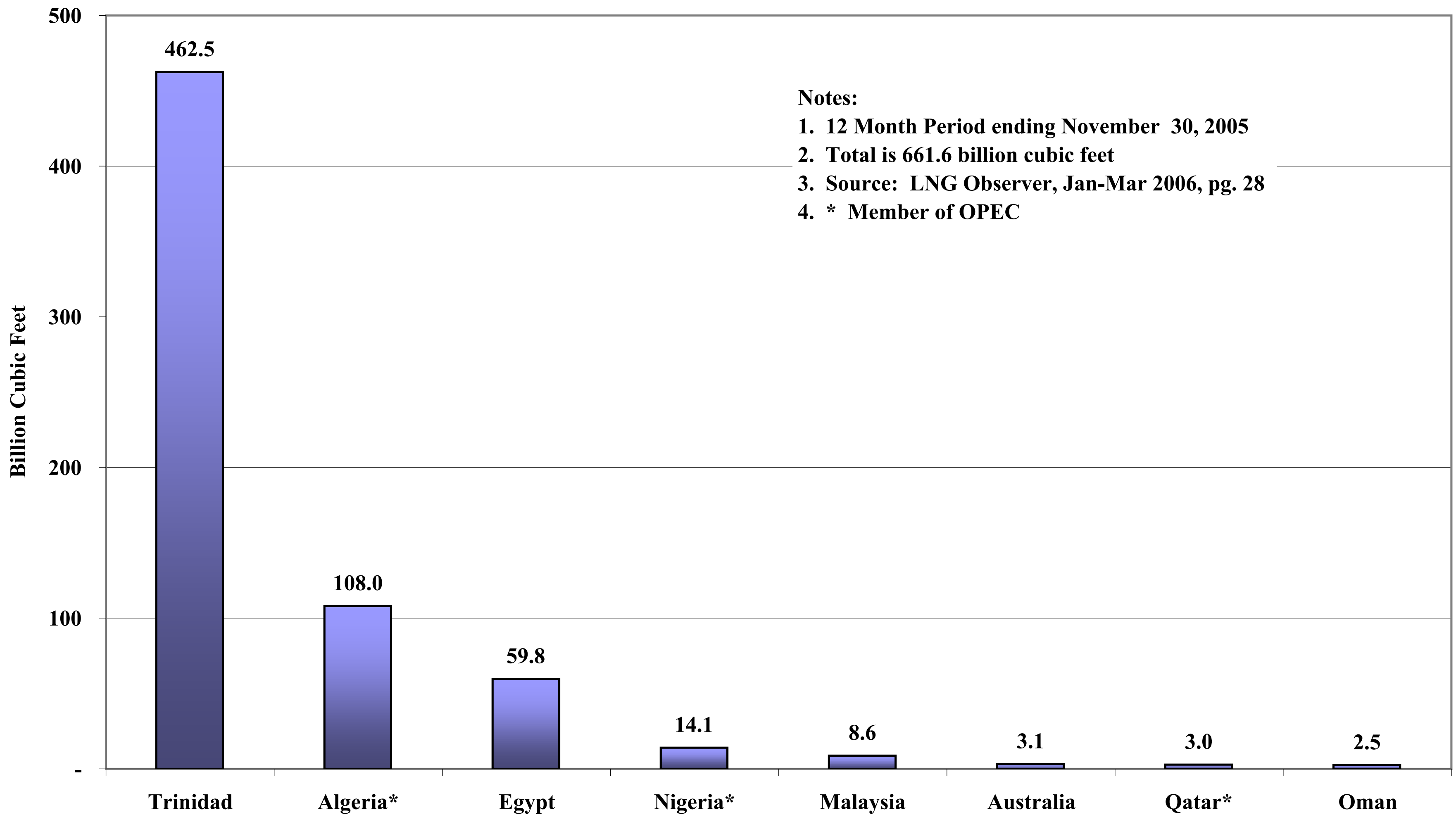


Figure 9
U.S. LNG Imports
Countries of Origin



Unlike natural gas delivered by pipelines, LNG delivered by ships can be readily diverted to another destination for operational or financial reasons; this is not an extremely unusual occurrence.

Table 3
United States LNG Facilities

Facility	Location	Storage Billion Cu. Ft.	Sendout Billion Cu. Ft. / Day
Cove Point	Chesapeake Bay, MD	5.0	1.0
Elba Island	Savanna, GA	4.0	0.68
Everett	Everett, MA	3.5	0.44
Lake Charles	Lake Charles, LA	3.5	1.3
Gulf Gateways	Offshore LA	On-Ship Regasification	0.50

The United States' sources of natural gas are depicted on Figure 10.

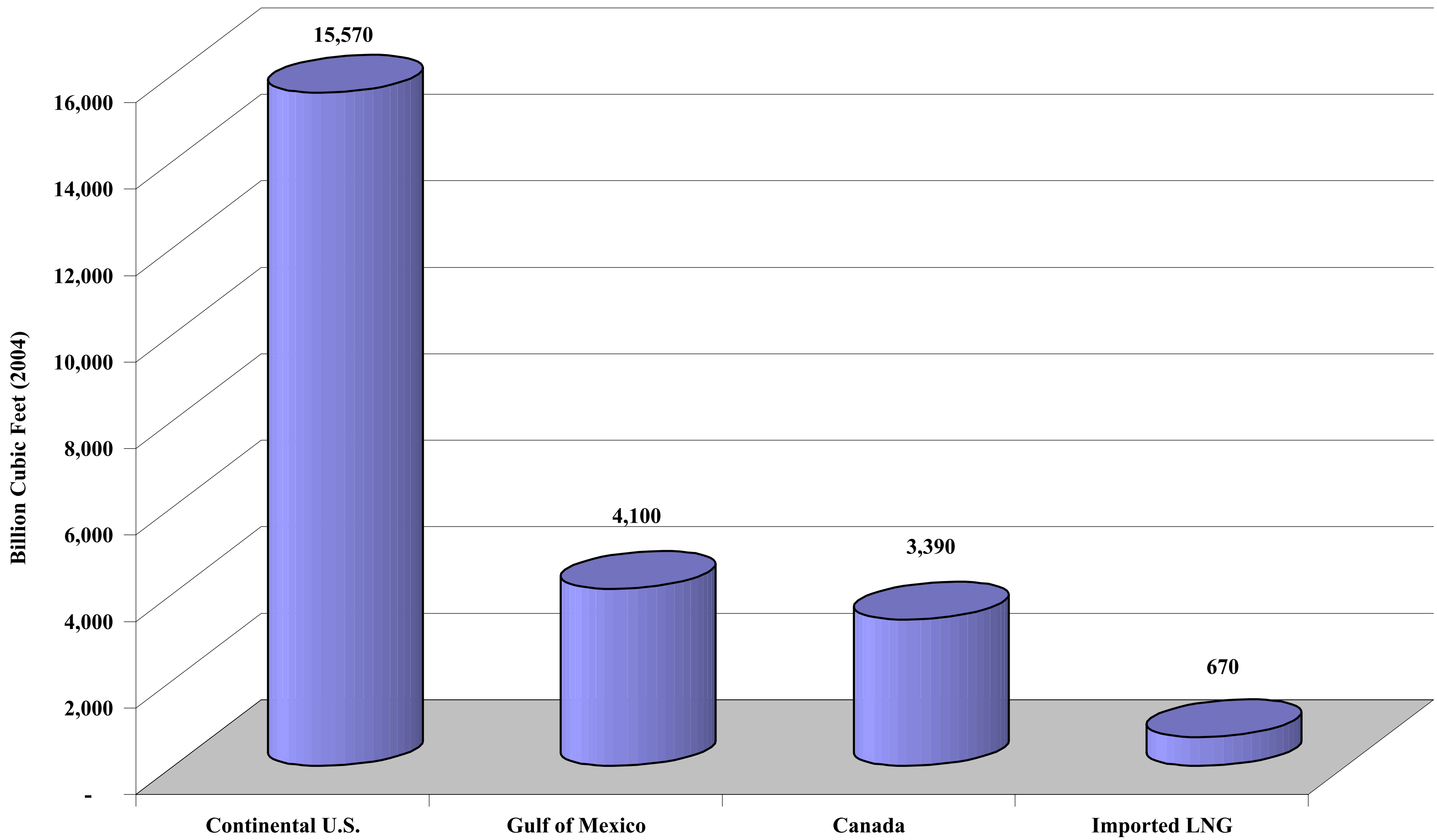
Uranium: Uranium is more common on the earth's crust than mercury or silver; its ores can be found throughout the world. Because of its military uses, there is significantly less transparency about uranium import sources, quantities and costs than there is for hydrocarbons and coals. Clearly, however, at least 78 percent of the uranium used in the 103 operating civilian nuclear electric power plants in the United States in 2004 was imported, with approximately half coming from sources outside of North America.[15]

World-wide uranium mining capacity (42,234 tons of uranium oxide in 2003)[16] is not meeting today's demands by 440 civilian nuclear power plants for 77,000 tons per year of uranium oxide. The balance is supplied from utility company stockpiles or recycled military material. This, however, will become increasingly difficult to maintain since utility stockpiles have been drawn down, China has announced plans to build 27 nuclear power plants by 2020 and India plans to build 17 nuclear power plants by 2017. Russia, moreover, has decided to limit its uranium exports to conserve nuclear resources for the 25 nuclear power plants it plans to build by 2020. Within the United States, eight companies have submitted applications to the Nuclear Regulatory Commission for Combined Construction-Operating Licenses for thirteen nuclear power plants, totaling 17,000 megawatts. If these applications are approved, and if the plants are then built, additional pressure will be placed on the world's nuclear fuel production facilities.

[15] [U.S.] Energy Information Administration, Uranium Marketing Annual Survey, 2003-2004, Form EIA-858

[16] Uranium Information Centre Ltd, World Uranium Mining, Nuclear Issues Briefing Paper 41, June 2004

Figure 10
Natural Gas Sources for the United States
2004



Two countries, Iran and North Korea, have announced that they will proceed with vertically integrated nuclear facilities, including the enrichment activities. These, of course, have major political dimensions that are beyond the scope of this paper. Regardless of the outcome of the enrichment dispute, the additional nuclear power plants will require additional enriched uranium. Additionally, several European countries are reconsidering their decisions to not construct and operate new nuclear power plants.

The United States' sources of uranium are depicted on Figure 11.

Coal: The United States may be self-sufficient with respect to coal supply and demand and, in fact, approximately 4 percent of its coal production is exported. Nevertheless the interplay between environmental restrictions on sulfur emissions, cost and compositions of various coals, and the importance of diversifying coal sources has led to imports from mines in Indonesia and Venezuela. Imports in 2005 were approximately 2 percent of United States coal usage.

PRIMARY FUEL USAGE WILL INCREASE

An examination of the overall economic situation in many countries shows that their populations are large and growing, their populations are poor (as measured by per capita gross domestic products) and they lack modern society's amenities (as measured by per capita electricity generation.) See Table 4 and Figure 12.

It is certain that world energy use will increase as populations increase. Those of China, India, Indonesia and Pakistan, for example, are increasing at 0.6, 1.7, 1.6 and 2.4 percent annually,[17] leading to an additional 34,300,000 people each year in these countries alone who will need energy. Further the per capita energy use in developing countries must increase to provide a higher standard of living. China, for example, has a rapidly growing economy with a manufacturing sector that requires large increases in fuel supplies. It has therefore recently concluded fuel supply agreements with countries as near as Russia (a major supplier to Europe) and as far away as Canada and Venezuela (major suppliers to the United States.) It has actually purchased a share of a Canadian oil sands developer and reached an agreement with Enbridge (Canada's second largest pipeline company) to participate in developing a $2 billion pipeline that will transport oil from Northern Alberta to the West Coast for export to China. Among other effects, potential oil supply to the United States will thereby be reduced and worldwide demand for oil tankers will increase.

The increasing populations of the emerging countries and the need to improve standards of living will lead simultaneously to increased international competition for fossil and nuclear fuels, while many exporting countries will have to use more energy internally, leading to less available for export.

[17] Population Reference Bureau, Washington, D.C. [www.prb.org]

Figure 11
U.S. Sources of Uranium

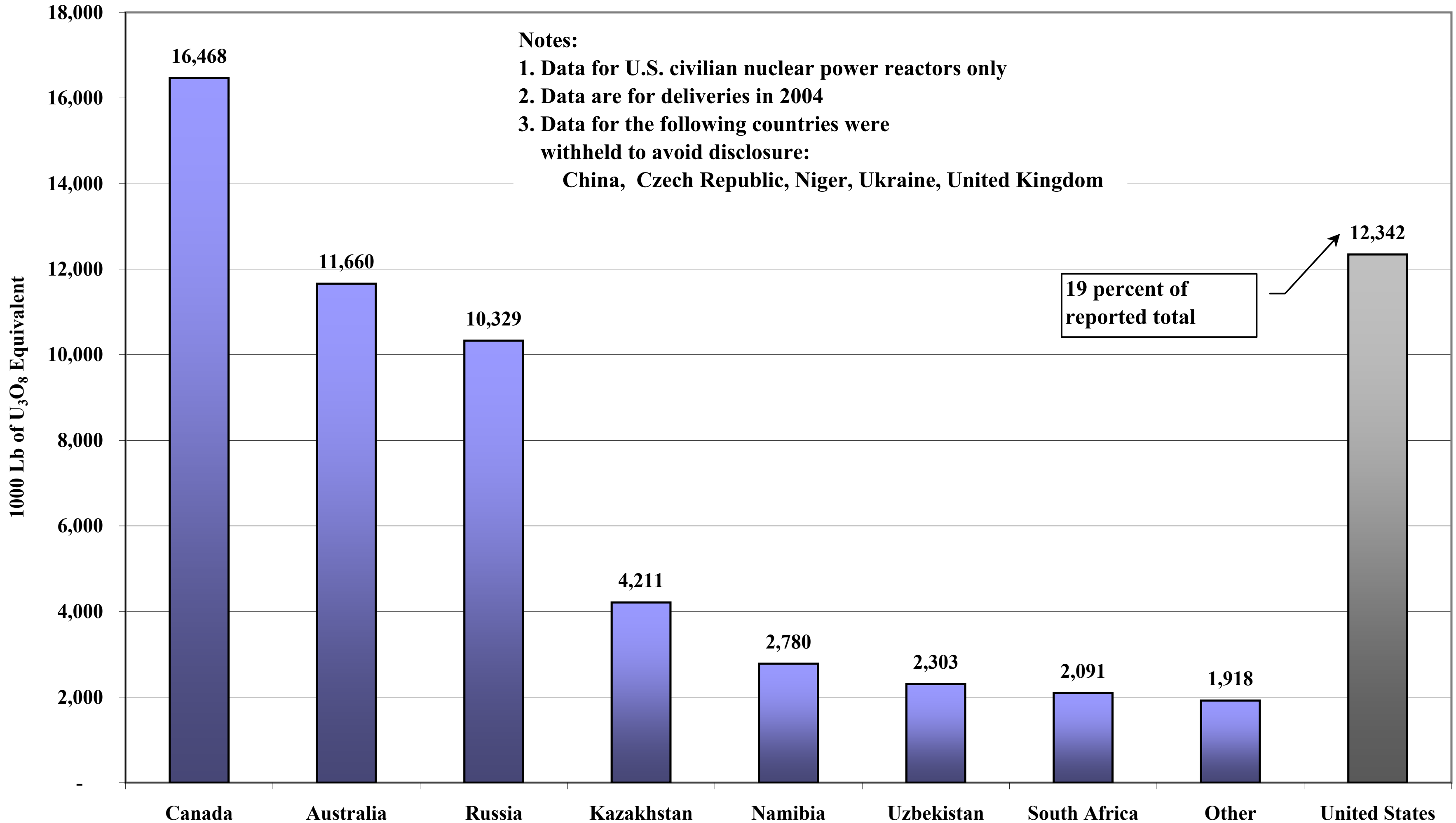


Table 4
Economic Development

Country	Population	Annual Per Capita Electric Generation KWH/ Yr/Person	Annual Per Capita Gross Domestic Product $/Yr/Person
China	1,300,000,000	1,390	1,454
India	1,100,000,000	506	735
Indonesia	242,000,000	453	3,419
Pakistan	162,400,000	473	2,138
Russia	142,400,000	6,426	3,933
Nigeria	137,300,000	145	418
Japan	127,400,000	7,986	36,887
Mexico	106,200,000	1,970	7,156
Canada	32,500,000	16,889	29,508
Venezuela	25,400,000	3,444	5,722
United States	**295,700,000**	**13,367**	**39,901**

HAVE CRUDE OIL AND NATURAL GAS PRODUCTION RATES PEAKED?

While there is general agreement that hydrocarbon production will peak, or has already peaked,[18] there is much controversy about the timing of the peak and the subsequent rate of decline. Certainly, crude oil production from Prudhoe Bay in the United States has fallen by approximately 5.4 percent per year since 1988,[19] from the North Sea by approximately 5.9 percent per year since 1999,[20] from the Oseberg complex on the Norwegian Continental Shelf by 6 percent per year since 1996,[21] from Oman's giant Yibal oilfield by approximately 60 percent since 1997,[22] and from the Samotlor and Romashkino fields in Russia by 83 percent and 90 percent, respectively, since the late 1970s.[23] There are many more examples of declining production.

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[18] Hubbert, M.K.,, Energy from Fossil Fuels, Science, February 4, 1949, pg. 103
[19] Calculated from data presented in Energy Information Administration, Office of Oil and Gas, U.S. Department of Energy, Future Oil Production for the Alaska North Slope, May, 2001
[20] U.S. Department of Energy, Country Analysis Brief - North Sea, August 2004
[21] Calculated from data presented in Energy Information Administration, Country Analysis Briefs – Norway, August 2005, p. 3
Department of Energy, Future Oil Production for the Alaska North Slope, May, 2001
[22] Gerth, J. and S. Labaton, Oman's Oil Yield Long in Decline, Shell Data Show, New York Times, 2004/04/08
[23] Laherrere, J., Estimates of Oil Reserves, International Energy Workshop, Laxenburg, June 19, 2001

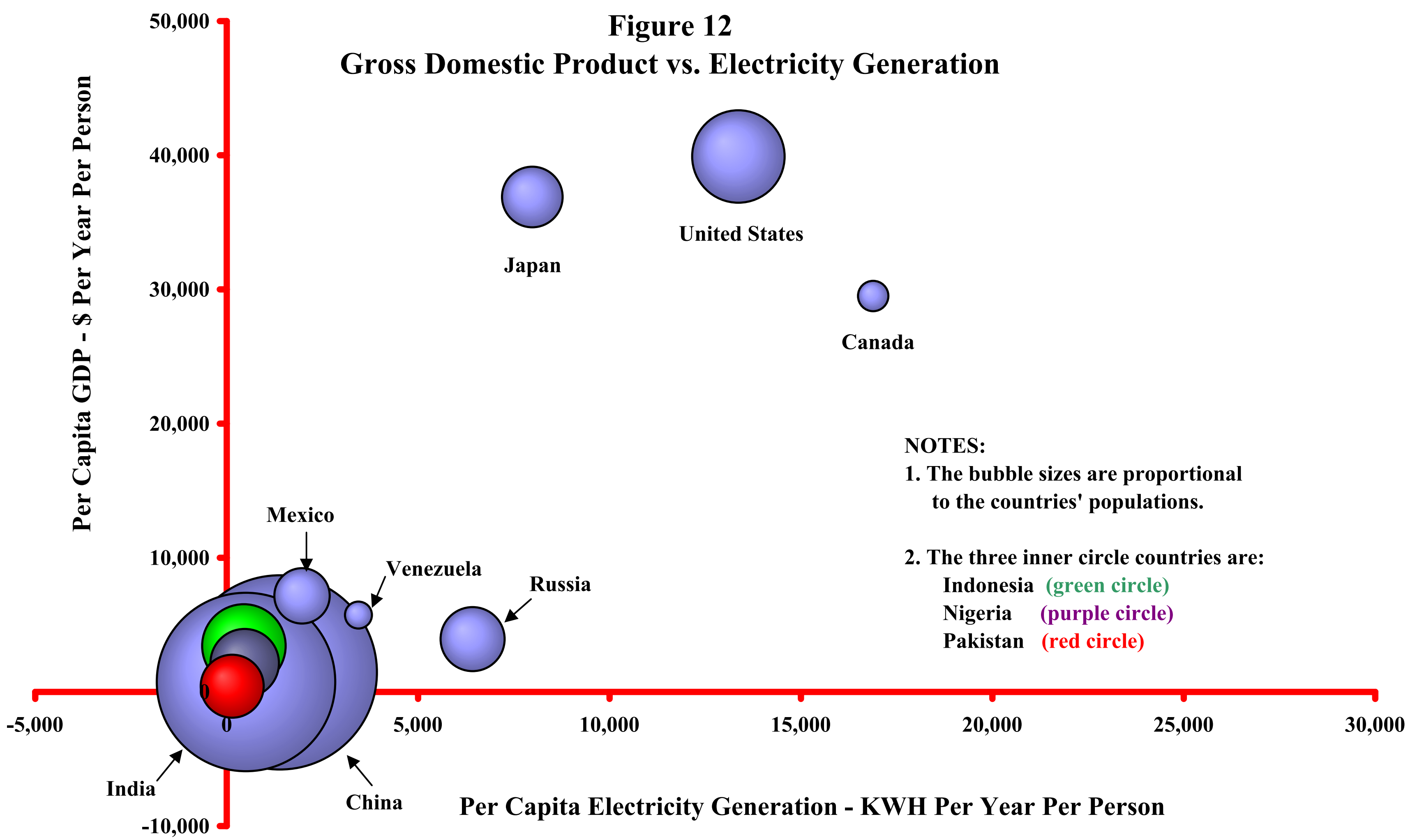
Figure 12
Gross Domestic Product vs. Electricity Generation
Per Capita GDP - $ Per Year Per Person
50,000
40,000
30,000
20,000
10,000
0
-10,000
-5,000
5,000
10,000
15,000
20,000
25,000
30,000
Per Capita Electricity Generation - KWH Per Year Per Person
Japan
United States
Canada
Mexico
Venezuela
Russia
India
China
NOTES:
1. The bubble sizes are proportional to the countries' populations.
2. The three inner circle countries are:
Indonesia (green circle)
Nigeria (purple circle)
Pakistan (red circle)

Upcoming increases in the world's oil and gas supply will, however, partially offset these declines. Major new projects scheduled for completion in 2007 include those in Angola (500,000 barrels per day), Brazil (200,000 barrels per day), Canada (200,000 barrels per day) and the Caspian (400,000 barrels per day.)

In addition to increased supply from new sources, technological advances will increase production from existing fields. Crude oil and natural gas had historically been recovered from subsurface fields through vertically drilled wells. The field's pressure was relied upon to drive the oil or gas through somewhat porous sand or rock and then through perforations in the well's casing pipe to the surface, where it underwent rather simple processing to produce a marketable product. Production rates from all major fields have declined for physical, rather than economic or regulatory, reasons, leading to development of new extraction technologies. These include horizontal drilling (maximum reservoir contact), polymer-free carbon dioxide fracturing, and water or inert gas injection to sweep additional oil out of the basins. Although the newer three-dimensional modeling techniques and improved production technologies have, in many cases, led to increased recovery of a reservoir's oil-in-place, they do not lead to the formation of additional gas or oil.

Production of any nonrenewable material such as crude oil or natural gas comes initially from the sources that are easiest and most economical to develop and then, as these are depleted, from increasingly more difficult and more expensive sources and/or by use of more complex technologies. Oil and gas, for example, are now beginning to be produced from the ultra deepwater zone of the Gulf of Mexico by drilling to depths of 35,000 feet under 3,600 feet of water, costly and risky projects. Similarly, Russia, with foreign partners, is increasing the costly development of the Eastern Barents Shelf that contains the Prirazlomnoye oil field, the Shtokmanovskoye gas field (one of the world's largest), the Timan-Pechora, and the Western-Siberian basins. In addition to new production facilities, pipeline and terminal facilities must also be constructed and operated in regions that have air temperatures below freezing for more than 285 days per year, occasionally falling to -75 degrees Fahrenheit, and ice that allows shipping only during the summer months. As development challenges are overcome, these new sources will increase oil and gas availability very significantly, but only after perhaps five to ten years from today.

In time technological and economic barriers to developing underutilized sources of fuels such as coal bed methane and sub-sea hydrates will be overcome. This will, however, not occur within the immediate future that is the focus of this presentation.

The world will not "run out" of oil or gas in the foreseeable future; prices will simply increase, perhaps dramatically, to compensate for higher extraction, transportation and refining costs.

FUEL PROCESSING PRESENTS A BOTTLENECK

Crude Oil: All crude oils differ to greater or lesser extents with respect to composition. As cumulative production from a given basin increases, the next incremental quantities tend to be heavier, requiring more intensive processing, limiting refinery production rates, and yielding less of the desirable materials. Newly produced crude oils now being marketed also tend, in many cases, to contain high percentages of sulfur and therefore can not be processed in many refineries. Desulfurization capacities in the United States' refineries are definitely constraints.

If high-sulfur crude oils could be processed in a particular refinery, their economics are often marginal since there is virtually no market for byproduct sulfur.[24] Today 90 percent of elemental sulfur is obtained as byproducts of refinery desulfurization operations; the last sulfur mine in the United States closed in August 2000. This has led to sulfur production rates that are now two-million tons per year higher than demand rates. Even worse, annual sulfur production is growing at 3 percent, while demand is growing at only 2 percent. And as an additional "even worse", the supply will further increase because more and more high-sulfur crude oils are being processed and the sulfur content of diesel oil must soon be reduced to ultra-low levels in the United States[25] and the European Union.[26] The refiners and the entire sulfur industry are making monumental efforts to devise additional uses for the excess sulfur. Meanwhile, the price has tumbled to approximately zero (or lower) and stockpiles are increasing.

Other problems with many newly produced crude oils include high amounts of water and salts which can overwhelm crude oil desalters, and high acid contents, leading to unacceptable corrosion rates. These and other problems limit the usefulness of many crude oils. For these reasons, there is usually a price differential of 10 to 20 percent between more desirable light low sulfur crudes and less desirable heavy high sulfur crudes.

Scattered throughout the world, 661 refineries have a total capacity to process 85,127,000 barrels of crude oil per day. These range from seventeen very large facilities with capacities between 400,000 and 940,000 barrels per day, down to numerous facilities that process less than 50,000 barrels per day. See Table 5. In addition to separating crude oil into useful products, each refinery has its own combination of additional processing operations to increase yields of motor fuels and light heating oil and, within limits, to change the proportions of the products it produces.

No new refinery has been built in the United States since 1976; increased capacity and the ability to process somewhat different crude oils have been provided by debottlenecking and equipment upgrading. As a result, refineries in the continental United States currently have a capacity of 17,115,000 barrels of crude oil per day[27] and have been operating at an average of approximately 90 percent of capacity. There is thus little margin for increasing production of jet fuel, kerosene, distillate and residual fuel

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[24] Cooper, H. and L. Ebin, Reviewing Feasibility Studies for Energy-Sector Projects, Hydrocarbon Processing, Houston, TX, Part 1, August 2004, pp 70-75, Part 2, September 2004, pp 121-124

[25] United States EPA, Control of emissions of Air Pollution from nonroad Diesel Engines and Fuel, 49 CFR Parts 69, 80, 89, 1039, 1065, and 1068, Federal Register / Vol 68, No. 100 / Friday, May 23, 2003 / Proposed Rules

[26] Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003

[27] API Refinery Report, December 16, 2005, reported in Oil & Gas Journal, p. 67, Jan 2, 2006

oils by increasing refinery throughput. The international refining capacity is likewise constrained.

Table 5
Oil Refining Capacities[28]

Region	Number of Refineries	Crude Distillation Capacity Million Barrels / Day
Asia	155	22.205
North America	158	20.827
Western Europe	103	14.971
Eastern Europe	93	10.245
South America	66	6.611
Middle East	42	7.034
Africa	45	3.230
World Total	**662**	**85.127**

Natural Gas: Natural gases, like crude oils, differ with respect to composition to greater or lesser extents. Processing, however, is simpler, most often limited to removing hydrogen sulfide and carbon dioxide by solvent absorption processes, adjusting the volumetric heating value by adding compounds, drying and adding odorizers. Many gas plants are integral parts of oil refineries; excess gas plant capacity is not known.

Liquefied Natural Gas (LNG): LNG is an internationally used commodity that is produced in the exporting countries by using large-scale liquefaction plants that operate at very low temperatures. The LNG is then delivered and regasified by heating it at the receiving terminals and introduced into the gas distribution pipeline system. LNG as usually produced, however, has a relatively high concentration of ethane and heavier hydrocarbons, leading to volumetric heating values that exceed those required for the United States market. Regasification plants therefore also contain processes for adjusting the heating value of their product. Although it is possible to deliver LNG to an end-user for local on-site use, in fact however, virtually all imported LNG is regasified at the import terminal. While increasing rapidly, currently the world has a liquefaction capacity of 21.7 billion cubic feet per day, and an import terminal / regasification baseload capacity of 18.9 billion cubic feet per day.

Uranium: Nuclear fuel results from crushing naturally occurring uranium ore, treating it with various acids or solvents, then precipitating and drying the more concentrated product, U_3O_8, commonly known as yellowcake. The uranium in the yellowcake typically contains 0.7 percent of the fissionable form, U-235, and almost 99.3 percent

[28] Oil & Gas Journal, Dec. 19, 2005, p. 64, Table 4

non-fissionable U-238. The uranium in the yellowcake is thus further processed by chemically converting it to uranium hexafluoride and enriching its U-235 concentration in a gaseous diffusion or a gas centrifuge plant to a level of 3 percent to 5 percent for commercial power reactors (or in excess of 90 percent for military uses.) A parallel approach is to downblend (dilute) highly enriched uranium from military surpluses from the former Soviet Union and United States to produce the required lower concentration. Ex-military material now, in fact, provides 45 percent of the utility market's needs.[29] The enriched uranium is then converted into uranium dioxide, UO_2, fabricated into small pellets, and then into larger fuel assemblies for use in reactors. Several countries, not including the United States, send partially depleted fuel assemblies to reprocessing plants where uranium and plutonium are recovered and recycled.

The work required to enrich uranium is commonly expressed as Separative Work Units (SWU);[30] the capacity of a uranium enrichment plant is commonly expressed as SWU per year. The major SWU service providers are facilities in Canada, France, Great Britain, Russia and the United States. Downblending, which represents an important part of the capacity, of course has a major political component. Current world-wide enrichment requirements for civilian power reactors are approximately 39,765,000 SWU.[31] Because of its military significance, the world-wide SWU capacity can not be established from the open published literature. The International Atomic Agency, however, lists the capacity of ten countries, totaling 45,775,000 SWU as of 2005.[32] Assuming no significant changes in the cost of producing and shipping uranium hexafluoride, the concentrations of products leaving the enrichment plants, and that downblending activities continue, then the current enrichment demand can be comfortably met for several more years. Capacities for conversion of yellowcake to UF_6 and for fuel-fabrication are also being met.[33]

Coal: Coals, also like crude oils, differ with respect to composition to greater or lesser extents. They are broadly classified as anthracite, bituminous, and sub-bituminous, with several finer gradations. On a world-wide basis approximately 84 percent is "steam coal," used in utility company boilers for electrical production, and approximately 12 percent is "coking coal", used directly for steel production.[34] Within the United States, the figures are 92 percent and 2 percent, respectively. Small but noticeable amounts of coal are used in industrial combined heat and power plants and as a raw material for chemical production.

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[29] World Nuclear Association, Uranium Markets, October 2004

[30] SWU (more precisely, Kg-SWU or Lb-SWU) is a mathematical function relating work requirement to the quantities of feed, product and waste materials, and their concentrations. Typically, it takes 4.3 SWU to produce 1 kilogram of 3.5 percent U-235. A 1,000 MW reactor requires approximately 100,000 to 120,000 SWU.

[31] International Atomic Energy Agency, Country Nuclear Fuel Cycle Profiles, second Edition, Table 3, p. 6, 2005

[32] International Atomic Energy Agency, Country Nuclear Fuel Profiles, Technical Report Series No. 404, Vienna, 2001

[33] Euratom Supply Agency, Analysis of the Nuclear Fuel Availability at EU Level from a Security of Supply Perspective – Final Report of the task Force, June 2005

[34] The World Coal Institute, Coal Facts, 2005 Edition

Approximately half of the coal is suitable for use as mined. Most run-of-mine coal, however, contains rock, shale and similar impurities, with significant variations from one location to another even within a given coal seam. It is, therefore, often sent to a preparation plant for upgrading. Treatment steps include crushing, screening and, depending on economics, cleaning (beneficiation.) Commercially available preparation processes readily reduce ash content by 75 percent and attain a 15 to 80 percent trace element reduction while recovering 85 percent of the coal's heating value. Customers' needs are frequently most economically met by blending coals of different compositions and properties.

Coal-fired boilers are designed to handle coals with particular carbon, sodium, vanadium and moisture contents as well as ash properties; they cannot tolerate major deviations from these. Thus a boiler designed for anthracite cannot use a bituminous coal without major modifications. Pollution control systems are also boiler- and coal-specific. Boiler design and coal preparation plant capacity definitely constrain flexibility to switch from one coal to another.

The United States coal mining industry is experiencing a moderate labor shortage, which is likely to become more severe as a result of recent highly publicized accidents and deaths. Key mining components such as specialty steels and the very large tires used on mine trucks have become scarce throughout the world, and in some cases unavailable at any cost; this could become a major bottleneck. It is not clear that coal production from United States mines could be increased if necessary. The coal preparation plant capacity and the coal transportation system, discussed below, moreover, limit producers' ability to deliver substantial amounts of additional coal.

FUEL TRANSPORTATION PRESENTS A BOTTLENECK

Crude oil and liquid products are transported from the oil wells to refineries by combinations of pipelines and ocean-going tankers, and to a small extent by trucks, railroads and barges. Each mode has a critical role.

Ocean-going Oil and LNG Tankers: The world's non-military ocean-going tanker fleet is approximately 3,500 tankers, of which 435 are Very Large Crude Carriers.[35] The VLCCs account for approximately one-third of the Ocean transportation by oil tanker. This mode, which is usually an order of magnitude less costly than alternates, has suddenly become very expensive. For example, shipping costs for a two-million barrel crude oil shipment from Kuwait through Suez Canal to Louisiana, taking 30 days, were $6,950,000 in 2004; in 2003 the shipping cost was $2,400,000.[36] Part of the cost increase may be attributed to demand for freighters to handle the substantially increased imports of iron ore by China. Another factor is the requirement[37] of the International Maritime

[35] Very Large Crude Carriers: Capacities of 200,000 to 399,999 tons (~1,250,000 to 2.500,000,000 barrels)
[36] New York Times, June 19, 2004
[37] Annex I of MARPOL Regulation 13(H), revised December 2003

Organization banning carriage of heavy grade oil[38] in single-hull tankers of 5,000 dead weight tons and above after 2005. A large fraction of the fleet will disappear, and thus the world's large oil tankers are now all booked. The third important factor is the "terrorist premium" that insurance and shipping companies are charging.

Approximately 15 billion cubic feet[39] of liquefied natural gas per day are currently transported by specially designed refrigerated LNG tankers. Their number has increased rapidly, from 128 ships in 2002 to 186 in November 2005. The more recently built ships, moreover, are larger (~5.5 MM cubic feet) leading to a 56 percent overall increase in fleet capacity. Charter rates have correspondingly dropped from $150,000 per day in 2001 to less than $30,000 per day in 2005.[40] An additional 125 LNG tankers have been ordered for delivery between 2006 and 2010. Several of these, moreover, will have capacities of 7 MM cubic feet. Although imminent increases of deliveries from Brazil and Venezuela will lead to further demands, it appears that shipping will not be a weak link in the LNG supply chain.

Pipelines: Pipeline transportation is important, and usually the only economically feasible possibility, for moving large amounts of crude oil or gas from interior wells to ports. Examples include the 840,000 barrel per day *Baltic Pipeline System* connecting Western Siberia to the Gulf of Finland, and the *Caspian Pipeline Consortium* that transports approximately 400,000 barrels per day from Kazakhstan's northern Caspian Sea basin across Russia to Novorossiysk on the Black Sea. The crude oil, from both of these pipelines then moved by ocean-going tankers to the international market. Kazakhstan has now started flow through a new pipeline that carries oil to Western China, allowing export that does not cross Russia. The *Baku-Tiblisi-Cehan Pipeline* is also now in service and will soon carry 1,000,000 barrels per day 1,100 miles from Azerbaijan through Georgia to Turkey, avoiding the tanker congestion delays in the Turkish Straits. Approximately 1,200,000 barrels of crude oil per day are also delivered to Eastern Europe by Russia through the *Druzhba (Friendship) Pipeline*.

The main existing crude oil pipelines in the Mid-east are the *Petroline* (East-West) from the Abqaiq oil field westward to the Yanbu port on the Red Sea and the *Sumed Pipeline* from Ain Sukhna on the Gulf of Suez to Sidi Kerir the Mediterranean. The *Trans-Israel Pipeline (Tipline)* is a viable alternate to the Suez Canal, capable of transporting approximately 1,000,000 barrels of crude oil per day from Ashkelon on the Mediterranean Sea to Eilat on the Gulf of Aqaba, where it can be loaded onto Very Large Crude Carriers for transit through the Red Sea and then to either the western or eastern markets.

The *Trans-Panama Pipeline* is a recently reopened alternate to the Panama Canal, capable of transporting approximately 860,000 barrels of crude oil per day from the Port

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[38] Crude oils having a density at 15 C higher than 900 kg/m3 or fuel oils having a density at 15 C higher than 900 kg/m3 or a kinematic viscosity at 50 C higher than 180 mm2/s

[39] LNG Tanker capacities are designated as volumes (cubic feet or cubic meters) of liquid

[40] LNG Observer, Vol 3, No. 1, Jan-March 2006, p. 7

of Charco Azul on the Pacific Ocean to the Port of Chiriqui Grande, Bocas del Toro on the Caribbean.

All of these pipelines, however, are currently delivering liquids and have limited spare capacity; they could handle some, but not all, of the additional demands that would be caused by an interruption in these chokepoints.

There are also several other pipelines in the Mid-east that carry other-than-crude-oil, such as the *Abqaiq-Yanbu Pipeline* that carries natural gas liquids for petrochemical production. Possibly more significant are two currently unused Mid-east pipelines; the *Trans-Arabian Pipeline (Tapline)* to Lebanon, and the *Iraqi Pipeline across Saudi Arabia* to the Port of Mu'ajjiz, near Yanbu. These have been mothballed for technical and political reasons, but might provide additional capacity if essential.

Fuel gas is transported internationally and within most countries through a series of pipelines. Currently, the world's largest gas exporter, Russia, sells 565 billion cubic feet per year to European customers, delivered through Turkey via the 750-mile long *Blue Stream Pipeline*, 246 miles of which is located beneath the Black Sea at a depth of 7,000 feet. Gazprom and its minority partners, BASF and E.ON, have started construction of the *North European Gas Pipeline* that will connect an existing Russian gas pipeline network to the port of Vyborg on the Gulf of Finland, and then under the Gulf and the Black Sea to Greifswald in Northeastern Germany, with an initial capacity of 970 billion cubic feet per year. An important strategic consideration is that this route bypasses Belarus, Poland and Ukraine. Within China, as another example, the 2,500 mile long *West-to-East Pipeline* transports 706 billion cubic feet per year from the Tarim Basin in Xinjiang to the large markets in Shanghai and Beijing. A new 227-mile long pipeline now brings 2,200 billion cubic feet per year of natural gas to Thailand from northern Malaysia.

Europe also receives large amounts of natural gas via pipeline from two other sources. *The Enrico Mattei Pipeline*, (formerly named the Trans-Mediterranean (Transmed) Pipeline) carries 900 billion cubic feet of gas per year from Algeria via Tunisia, 96 miles of which pass under the Mediterranean Sea at a depth of 2,000 feet, to Sicily and mainland Italy. The *Pedro Duran Farell (PDF) Pipeline*, (formerly named the Maghreb-Europe Gas (MEG) Pipeline) carries 300 billion cubic feet of gas per year from Algeria via Morocco, 28 miles of which pass under the Strait of Gibraltar at a depth of 1,312 feet, to Cordoba, Spain. Additionally, the *Trans-Pyrenean Pipeline* carries 120 billion cubic feet per year of gas from Norway through France to Calahorra Spain.

The South American countries are interconnected by several major pipelines. Brazil, for example, receives 310 billion cubic feet of gas per year (half of its gas consumption) by the *Gasbol Pipeline* from Bolivia, and another 36 billion cubic feet of gas per year through the *Parana-Uruguayana Pipeline* from Argentina.

The world's second largest gas exporter, Canada, relies on a 1,875 mile long *Alliance Pipeline* to send 1.3 billion cubic feet per day of gas from Fort St. John in Western

Canada to the Chicago area. A second pipeline, the *Maritimes & Northeast Pipeline*, sends 530 million cubic feet per day from the Sable Island area to Nova Scotia, New Brunswick, and ultimately to the United States gas grid connection in Massachusetts.

Mexico is a net importer of gas from the United States, with approximately 20 interconnections at the Texas and the Californian borders.

The United States contains an extremely extensive network of gas pipelines; Approximately 297,000 miles of pipeline transport 178 billion cubic feet of gas per day.[41] These are, moreover, interconnected with Canadian and Mexican pipelines.

Ocean-going Ships - Coal: Much of the international coal movement is by railroad and by ocean-going ships. During 2004, there were 674 million tons of coal carried in international ocean-going freighters, of which 397 million tons were carried over the Atlantic Ocean and 277 million tons over the Pacific Ocean.[42] This includes all of the coal exported from the major exporters: Australia, Indonesia and South Africa.

Railroads - Coal: The United States is served by seven major railroad companies, of which four carry 90 percent of the countries freight. Approximately 137,000 railroad cars per week are used to carry 21,500,000 tons of coal from mines to users. With 100 cars per train, the railroad system is operating 24 hours per day, seven days per week, at virtually 100 percent of capacity. The important Powder River Basin, which supplies 40 , which supplies 40 cent of the United States' coal, is served by only two railroads (Burlington Northern Santa Fe and Union Pacific) that have had mechanical problems on the Joint Line, leading them curtail use of 15 percent of their scheduled coal loading and deliveries. These railroads, moreover, use locomotives that use Diesel oil to generate electricity for their drives, introducing a vulnerability to an oil shortfall. The major carrier in the Northeast (CSX Railroad) has, in the past, been unable to satisfy the coal delivery demand in the northeast, but now appears to have overcome its problems.

EMERGENCY RESERVES ARE LIMITED

Member countries[43] of the International Energy Agency have agreed to and indeed appear to maintain emergency oil stocks of at least 90 days of consumption. These stocks may be any combination of public and private reserves. While cooperative sharing under emergency conditions is envisioned, this has not yet been tested.

Total oil stocks in the thirty countries that are members of the Organization for Economic Cooperation and Development (OECD) countries as of August 31, 2005 was

[41] [U.S.] Energy Information Administration, Changes in U.S. Natural Gas Transportation Infrastructure in 2004, Table 3

[42] The World Coal Institute, Coal Facts, 2005 Edition

[43] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States

approximately 1,355 million barrels in Europe and 2,788 million barrels elsewhere (including 1,724 in the United States and 645 in Japan.)[44]

The United States Government operates three oil reserve systems; *the Strategic Petroleum Reserve*, the *Northeast Home Heating Oil Reserve*, and the *Naval Petroleum Reserves*. These are as follow:

The Strategic Petroleum Reserve

The United States Department of Energy operates four crude oil storage sites in underground salt domes in Texas and Louisiana, near the Gulf of Mexico. The contents are segregated only by sulfur content; "sweet" containing 0.5 percent sulfur or less, and "sour", containing more than 0.5 percent but less than 2.0 percent sulfur. The maximum storage capacity is 727 million barrels, with a maximum drawdown capability of 4.3 million barrels per day for 90 days, and at decreasing rates thereafter. Release of crude oil from this reserve would be triggered by the President declaring a "severe energy supply interruption."

On January 9, 2006 the inventory was:[45]

Sweet	269.8 million barrels			
Sour	414.5	"	"	
TOTAL	684.3	"	"	(3.9 Quadrillion (10^{15}) BTU)

The Northeast Home Heating Oil Reserve

The United States Department of Energy administers four privately owned oil terminals containing a total of 2,000,000 barrels of heating oil. One is located at Woodbridge, NJ (1,000,000 barrels,) another at New Haven, CT (500,000 barrels,) a second New Haven, CT facility (250,000 barrels) and a fourth at Providence, RI (250,000 barrels.) These can supply the 5.3 million oil-heating households in the Northeast for ten days. Release of home heating oil from this reserve would be triggered by the President declaring a "severe energy supply interruption" as defined by prices exceeding 60 percent greater than its 5-year average.

The Naval Petroleum Reserves

The United States Congress determined in 1996 that the properties that comprised the Naval Petroleum Reserve program no longer served a useful function. Since the divestiture, the Department of Energy has maintained oversight of two minor reserve sites (Teapot Dome in Wyoming and Buena Vista in California) which will be privatized as soon as practical. Additionally, it operates the Rocky Mountain Oilfield Testing Center (the only oil field testing center in the United States.) These, however, produce and now store insignificant amounts of hydrocarbons.

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[44] Oil & Gas Journal, January 2, 2006, p. 69

[45] [U.S.] Department of Energy, Office of Fossil Energy, Strategic Petroleum Reserve – Profile, January 9, 2006

This government-controlled inventory within the Strategic Petroleum Reserve and the Northeast Home Heating Oil Reserve represents approximately 53 days of import protection for the United States.

Industrial Petroleum Reserves

The inventory of crude oil and fuel products in industrial storage varies with season. Recent early winter levels are as shown on Table 6.

Natural Gas Reserves

Usage of natural gas is very seasonal, as shown on Figure 13. Stocks of gas are stored by private industry in approximately 320 depleted fields, 30 salt caverns and 45 aquifers throughout the United States. As of January 13, 2006 there were 2,575 billion cubic feet of working (net available) gas stored, which is 16 percent more than the recent five-year average.[46] A small amount, 12 billion cubic feet, of liquefied natural gas is stored in the four terminals shown on Table 3. The total industrial natural gas reserves, which vary with season, currently represent approximately 50 days of United States consumption.

Table 6
United States Industrial Reserves[47]

ITEM	STOCKS 1000 Barrels	Demand 1000 Bbl / Day	Days of Supply
Crude Oil	324,363	16,820	19
Motor Gasoline	203,646	9,490	22
Distillate	129,855	4,262	28
Jet Fuel	43,553	1,612	25
Residual	38,347	788	53

Coal Reserves

The electric power production sector uses approximately 92 percent of the coal consumed within the United States. It currently holds 113,301,000 tons in reserve, which represent 42 days of use. Industrial reserves of 6,083,000 tons represent 34 days of use.[48]

Uranium-235 Reserves

Reserves of U-235 in nuclear fuels, within the United States, have been reported[49] to have dropped 50 percent since 1985 because mine output could not keep up with demand, and demand will exceed output by 11 percent until 2013. The exact amount of reserves is not known. The U.S has proposed an international nuclear fuel reserve, partly as a way to assure Iran and North Korea that their nuclear power plants will be able to obtain fuel

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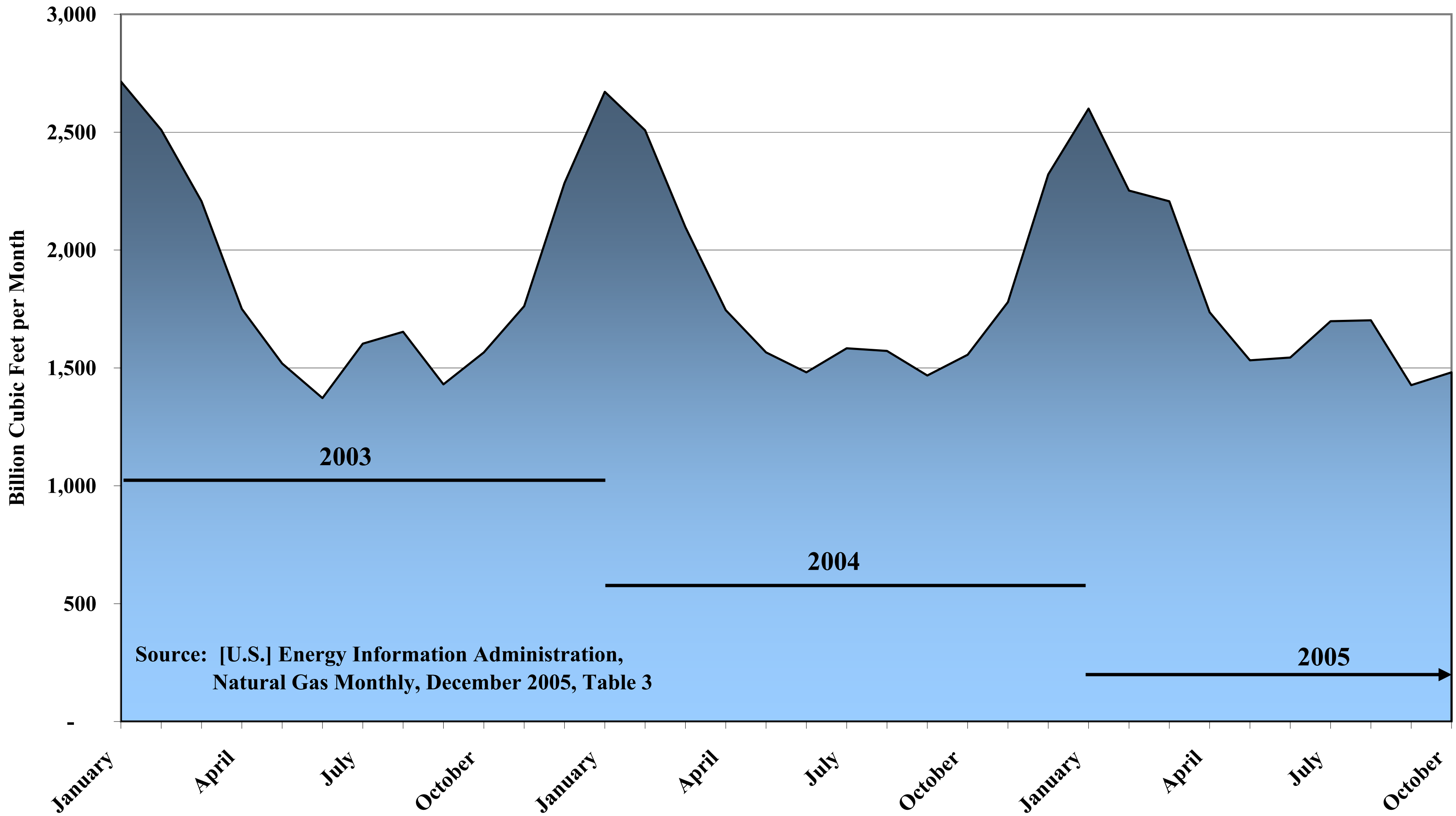
[46] [U.S.] Energy Information Administration, Weekly Gas Storage Report, January 19, 2006
[47] Oil & Gas Journal, Industry Scoreboard, p. 67, January 2, 2006
[48] [U.S.] Energy Information Administration, Monthly Energy Review, Tables 6.2 and 6.3, February 2005
[49] Chambers, M., Uranium prices are set to climb, International Herald Tribune, January 5, 2005

Figure 13
Natural Gas Consumption
In the United States



without developing an indigenous fuel enrichment capability. This reserve, however, has not yet been established.

A summary of the United States' energy reserves is shown on Figure 14.

SUPPLY CHAIN VULNERABILITIES

Western Europe, North America and South America have substantial inter-country electricity ties. France, for example exports, as an annual average, approximately 8,100 megawatts while Italy imports approximately 5,000 megawatts. Almost all countries experience electricity disruptions either routinely or rarely. These, nevertheless, are almost always intra-country events, and, while occasionally serious, will not be discussed further herein.

Natural disasters

The world's primary energy supply and delivery system may be disrupted be numerous unfortunate and unplanned factors such as hurricanes and earthquakes. These may occur anywhere in the world and, if sufficiently severe, will impact the energy situation in all countries.

While not at all minimizing the tragedies that arose from the 2004 tsunami in Southeast Asia, the entire world would have suffered greatly from an extreme fuel shortage if it occurred further east at the Straits of Malacca, through which 25 percent of the seaborne crude oil flows by tanker. The Straits are also quite important for coal shipments as well as other dry materials such as grains.

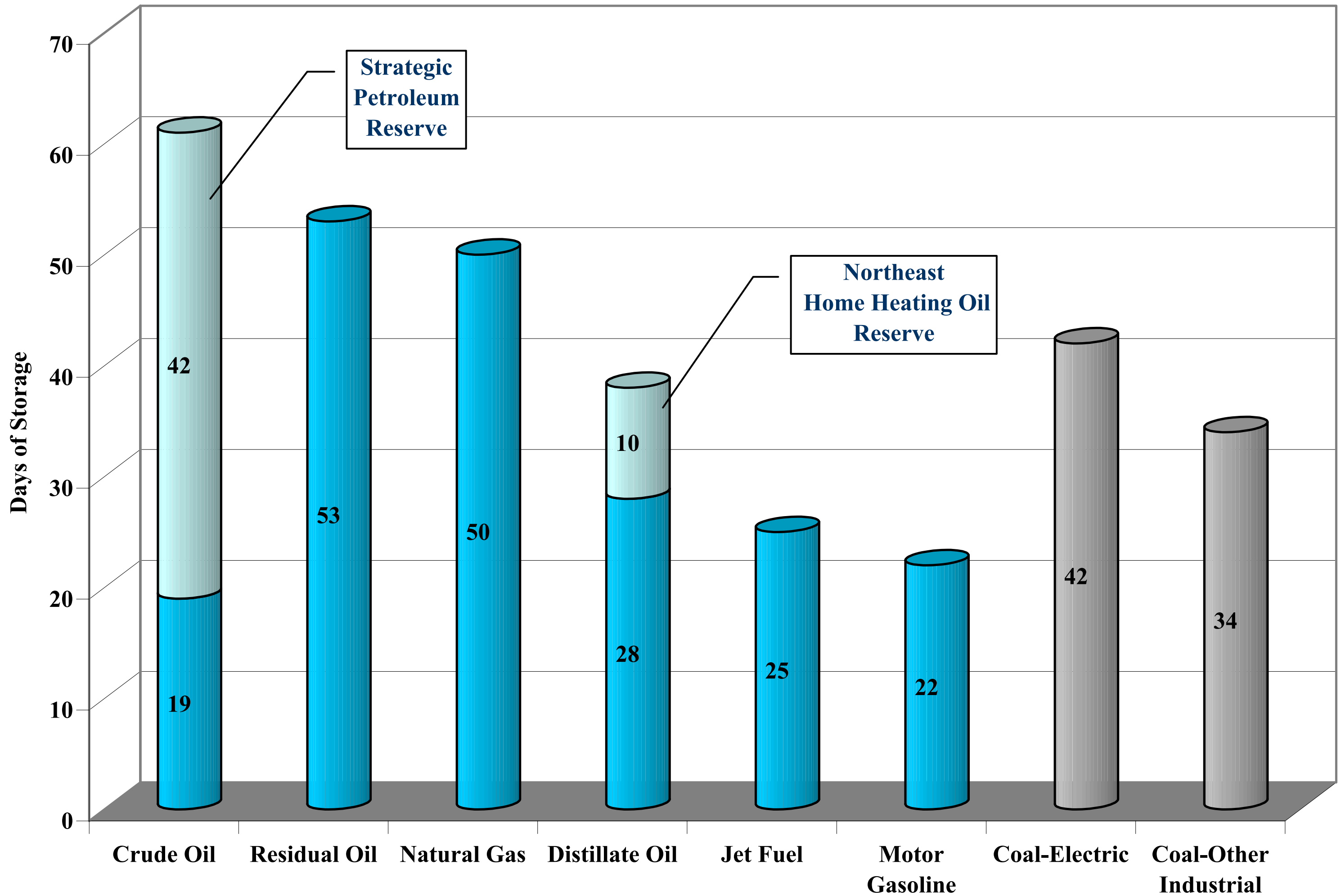
Less awesome and destructive, floods and severe thunderstorms routinely interfere with railroad shipments. A thunderstorm in Topeka, Kansas on October 1, 2005, for example, washed out a railroad bridge and several hundred feet of tracks. For the next five days, Union Pacific had 116 coal trains staged at various points awaiting ways to make deliveries, or to return to coal mines for loading. It took about ten days to return to normal.

Hurricanes fall between storms and tsunamis with respect to the misery and damage they can cause. Hurricane Ivan, for example, led to evacuations and severe damage to production platforms, rigs and pipelines in the Gulf of Mexico. On September 17th, 2004, the day after the storm, (by which time 236 platforms and rigs had been evacuated) 1,233,000 barrels of oil per day (73 percent of daily production) and 5,166,800 million cubic feet of gas per day (42 percent of daily production) were shut-in.[50] Two months later, 6 percent and 1 percent of normal oil and gas production, respectively, were still shut-in.[51]

A year later, on August 29th, 2005 Hurricane Katrina struck the Gulf of Mexico, damaging the shipping channel at Louisiana through which much of the Mideast crude oil

[50] [U.S.] Minerals Management Service, Release #3138, September 17, 2004
[51] [U.S.] Minerals Management Service, Release #3200, November 15, 2004

Figure 14
Crude Oil & Fuel Storage
U.S. - December 2005



flows, as well as much of the nation's oil and gas production and transportation infrastructure. On August 30th, the day after the storm, (by which time 645 platforms and 90 rigs had been evacuated) 1,428,000 barrels of oil per day (95 percent of Gulf of Mexico daily production) and 8,798 million cubic feet of gas per day (88 percent of Gulf of Mexico daily production) were shut-in.[52] Two weeks later 841,000 barrels of oil per day (56 percent of Gulf of Mexico daily production) and 3,383 million cubic feet of gas per day (34 percent of Gulf of Mexico daily production) remained shut-in.[53]

On September 24th, Hurricane Rita then struck Louisiana, leading to the shut-in of additional oil and gas production. As of December 29th, four month after Hurricane Rita struck, 411,000 barrels of oil per day (27 percent of Gulf of Mexico daily production) and 1,954 million cubic feet of gas per day (20 percent of Gulf of Mexico daily production) remained shut-in.[54]

Unusually cold weather can lead to fuel supply disruptions on an international basis. For example, as shown dramatically in mid-January 2005, when temperatures in Russia and Eastern Europe fell to -20 to -30 degrees F, the coldest since 1927, demand for gas naturally rose. Attempting to cope with its own internal needs and weather-related production difficulties, Russia had to reduce its exports to various European countries by 5 to 20 percent.

Strikes, anti-governmental actions and international disputes

Refineries and pipelines have been shut down by strikes and protests due to economic disparities in many countries including Bolivia, Mexico and Venezuela.

They have also been subject to anti-government protests, violent civil wars and separatist movements, inter-ethnic tensions in Algeria, Chechnya, Georgia, Indonesia, Iran, Sudan, Iraq and Nigeria. Killings in Nigeria have, in fact, led Royal Dutch/Shell and Chevron Texaco to withdraw personnel and shut-in approximately 818,000 barrels per day (40 percent) of Nigerian oil production. Similarly, Baluchi nationalists recently attacked the Sui Gas Plant that supplies 22 percent of Pakistan's gas needs; eight people were killed, and the plant was shut down for about a week.

Several unresolved boundary disputes are potentially serious problems. In the Far East, these include those between China and Japan concerning natural gas rights to the Chunxiao gas field in the East China Sea. Japan and Russia each claim sovereignty over several islands, called the "Northern Territories" by Japan and the "Southern Kurils" by Russia. In the Mideast, Iran and the United Arab Emirates each claim ownership of three islands in the Strait of Hormuz, and Iran, Saudi Arabia and Kuwait each claim partial ownership of a huge offshore gas field, called "Arash" by Iran and "Dorra" by the other two countries. One-third of the common border between Georgia and Russia has not been defined. There are numerous other disagreements and undefined borders throughout the world.

[52] [U.S.] Minerals Management Service, Release #3228, August 30, 2005
[53] [U.S.] Minerals Management Service, Release #3350, September 16, 2005
[54] [U.S.] Minerals Management Service, Release #3447, December 29, 2005

Russia now provides 25 percent of Europe's fuel gas and noticeable amounts of crude oil. It thus has enormous, but not necessarily decisive, leverage in its international relationships. This was displayed in January 2006 when Russia reduced gas supplies to Moldova, which quickly agreed to a 100 percent price increase. Simultaneously, Russia attempted to quadruple the gas prices it charged Ukraine. While Ukraine disputed the claim, Russia continued to deliver it gas for further transport to Western countries, but reduced the total by the amount that Ukraine claimed it was due. Ukraine, however, contained to take its full share, leading to a shortfall in Europe's gas supply. After several days, a complex somewhat opaque compromise was reached within which Ukraine agreed to pay almost twice its previous rate for the Russian gas, but also will receive a 47 percent higher transit fee from Russia for gas transportation. Shortly thereafter Ukraine's Parliament fired the President's cabinet, causing much political turmoil. Whether the cause was a simple commercial dispute between the Russian and the Ukrainian gas companies, or a reaction to Ukraine's election of an independent Prime Minister, the fact remains that it and the Moldavian situation happened.

Russia is, moreover, a major supplier to many European countries, as seen on Figure 15. Recent events have made several countries uncomfortable with their levels of dependence, leading them to consider increasing subsidies for renewable fuels and, led by France, to revisit their anti-nuclear power positions.

Terrorist attacks

A relatively new concern is that a terrorist group will deliberately interfere with production and/or international transportation of fuel. Given its importance to the world's economy and indeed civilization itself, it is a tempting target for many groups.

Many international terrorist groups have indicated that they consider all Westerners and their properties to be legitimate targets, and in fact have proclaimed it a duty to attack them. One well known terrorist stated:[55]

> *"Take jihad to stop (the Americans) from getting hold of the oil. Concentrate your operations on the oil, particularly in Iraq and the Gulf."*

Another group indicated:[56]

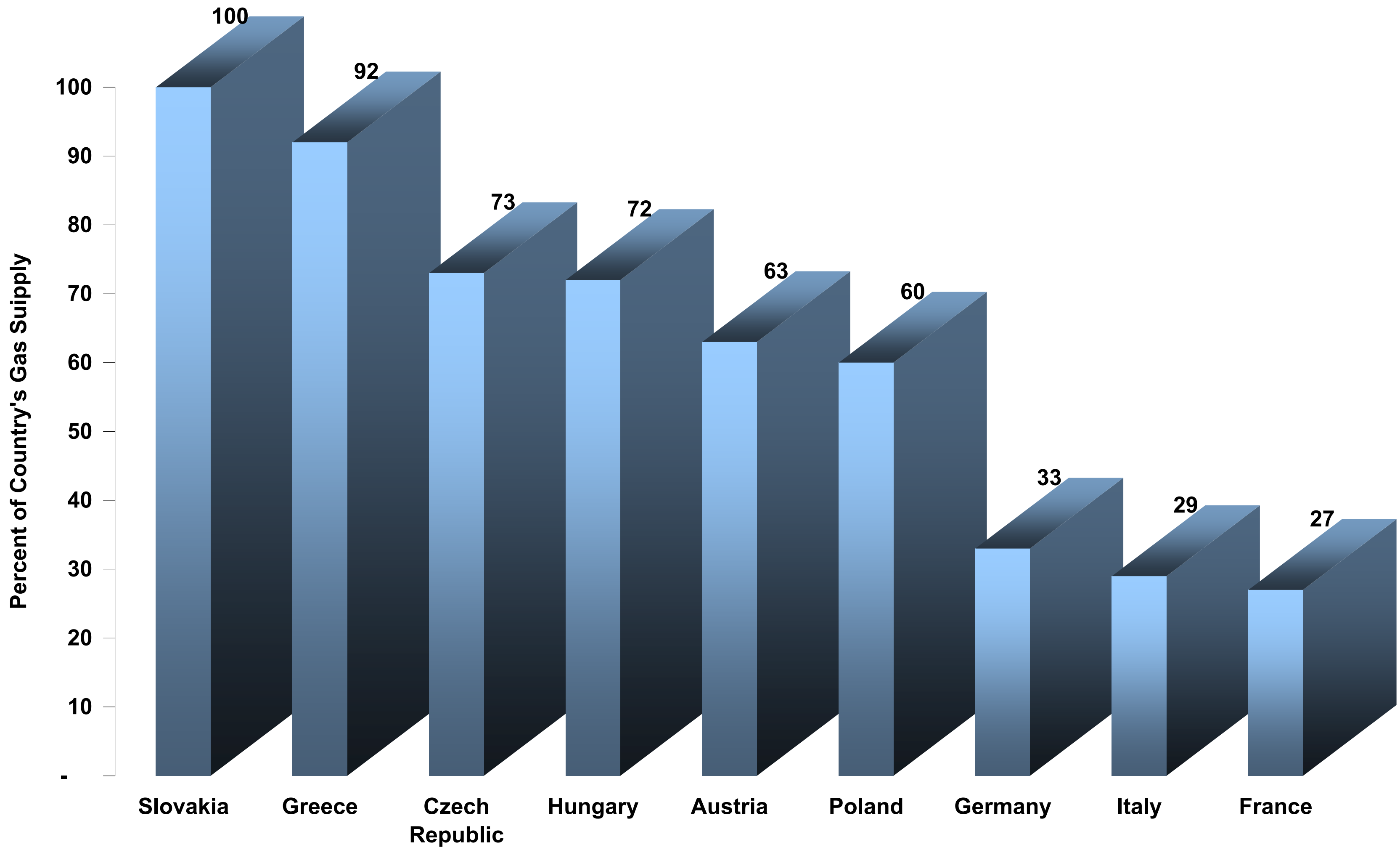
> *"We are capable and determined to destroy the ability of Nigeria to export oil."*

Components of the energy infrastructure have, in fact, been sabotaged by terrorist attacks in many countries.

Oil and gas fields: Crude oil and natural gas fields throughout the world, while guarded and protected to various degrees, are tempting targets for dissident and terrorist groups. Crude oil and natural gas recovery requires availability and operation of computers, pumping and compressor systems, purification processes, and storage and blending

[55] Bin Laden, Osama, Videotape to Saudi Arabia, December 16, 2004
[56] Movement for the Emancipation of the Niger/Delta (MEND), email on January 12, 2005

Figure 15
Countries Dependence on Russian Gas
- 2005 -



systems. As noted above, water or inert gas injection is often used to sweep additional oil out of the basin. Large oil–water separators and water treatment facilities are therefore increasingly important components of crude oil production. Fields, production staff, and production facilities are vulnerable to accidents or attack. Rational well-informed attackers would be unlikely to destroy production capabilities; they are more likely to try to coerce governments by withholding supplies from the international market. Kuwaiti oil fields, nevertheless, were deliberately damaged by Iraqis at the end of the invasion in 1991. Several oil wells in the Bay Hassan oilfield in Iraq were bombed in April 2005. Irrational or unknowledgeable attackers certainly exist throughout the world.

There have been several terrorist attacks in the Saudi Kingdom, including that of May 2004 on the ABB Lummus office in Yanbu during which seven employees were killed and that on the Khobar Towers at which 22 were killed, and several others during the first two weeks of June 2004. Russian facilities and citizens have been, and presumably remain, targets of various separatist groups who have demonstrated a willingness and ability to take violent murderous and destructive actions.

Pipelines and pumping stations: Many attacks have been perpetrated on pipelines, generally leading to local oil or gas shortages. These have been serious within countries such as Pakistan that lack alternate supplies and redundant infrastructure. Insurgents in Columbia, likewise, have frequently bombed pipelines that supply crude oil to refineries. Approximately 40 percent of the feed to the world’s largest refinery, Paraguana in Venezuela, was cut off by sabotage in December 2005. In the same month, terrorists also bombed a crude oil pipeline in Nigeria in December, killing eight people and leading Royal Dutch Shell to shut-in 180,000 barrels per day of crude oil production. This was followed a month later by an attack on the Shell Beneside pumping station that led to 16 people being killed or wounded, and the evacuation of the area. The pipelines supplying natural gas from Russia to Georgia and Armenia were severely damaged by terrorist’s explosions in January 2006. This action was quite serious, interrupting virtually all of Georgia’s supply during an unusually deep cold spell. Initial assessments were that repair efforts might not be completed for four weeks. During the same month, separatist militants attacked three natural gas pipelines in Assam, India. This action affected operations in an oil field, leading to an interruption of crude oil supply to four refineries and an electric power plant.

If attacks on pipelines are sufficiently frequent, they can certainly interfere with a country’s ability to export product. Iraq, for example shut its 600,000 barrels per day crude oil export pipeline after it was subjected to more than fifteen terrorist attacks in early 2005. Within the context of this paper, however, they have not yet had any major effect on the international energy situation. Repairs of land-based pipelines have usually, but not always, been straightforward and generally performed rapidly. Nevertheless, larger scale attacks could be more damaging. The concern is high enough for the United States and Georgia to have created a special military unit to guard the pipelines carrying oil from the Caspian Sea to the Black Sea, with Northrup Grumman Corp. providing aerial surveillance.

Damage to the sub-sea pipelines such as those that bring gas from Algeria and Russia to Europe would be far more difficult and time-consuming to repair. Construction of the deep sub-Black Sea portion of the Blue Stream pipeline, for example, took approximately eight months without fear of attacks. Extensive repairs while being concerned about terrorists could easily take six months.

Although railroad trains, barges and trucks offer diversity of transportation of liquids such as crude oil and refined products, there are currently almost no alternates to pipelines for transporting gases; LNG capacity, while growing rapidly, is still a minor factor. Attacks on the world's gas pipeline system could thus certainly be quite disruptive, particularly throughout Europe and Asia.

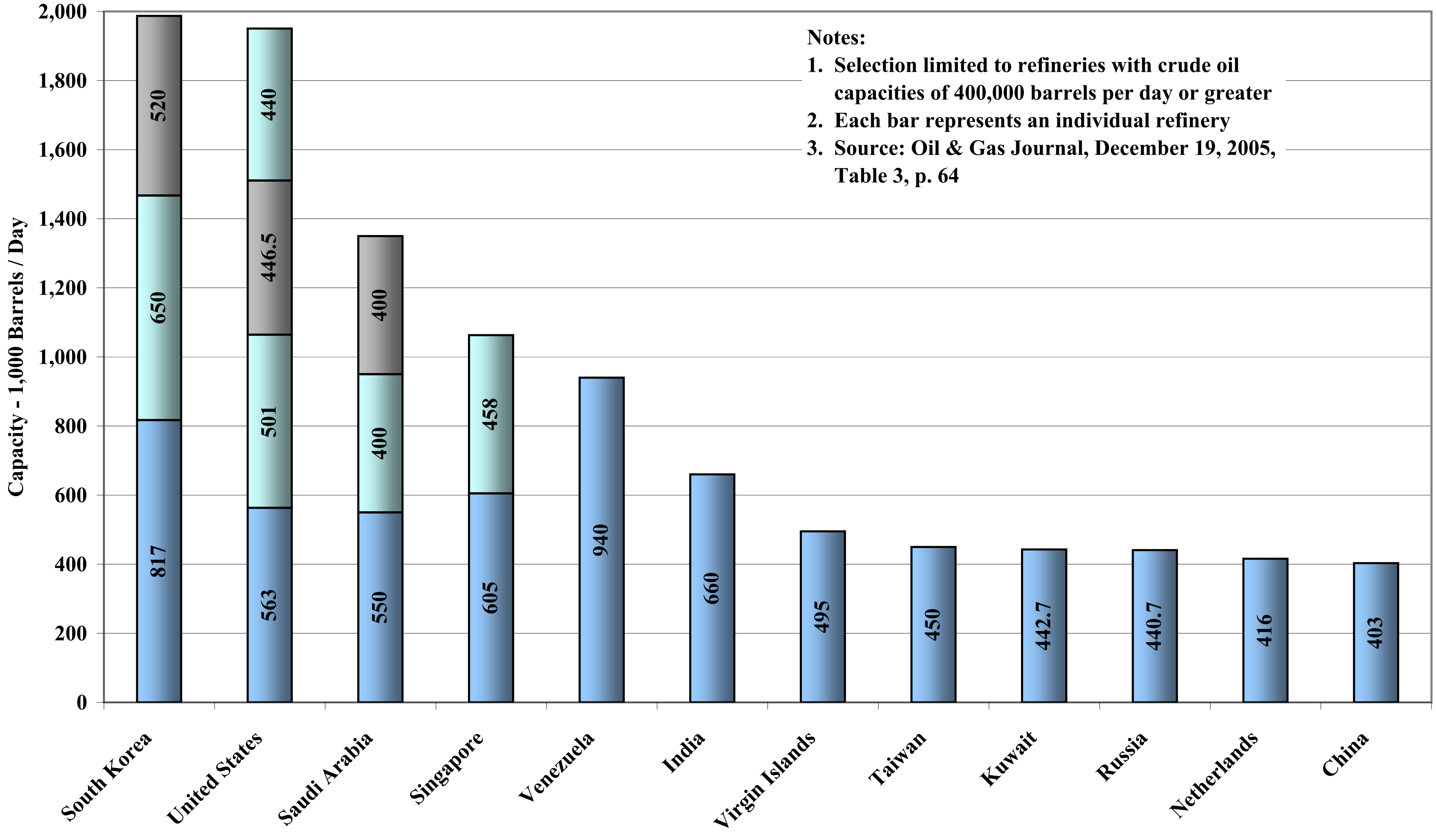
Terminals and storage facilities: Since Saudi Arabia is an exceedingly important crude oil supplier, the operation of its export terminals is critical. The primary export facilities are located on the Persian Gulf at Ras Tanura (6 million barrels per day) and at Ras al-Ju'aymah (3 million barrels per day), and on the Red Sea at Yanbu (5 million barrels per day.) These collectively can thus handle approximately 14 million barrels per day, which comfortably exceeds the Kingdom's production capacity of 10.5 million barrels per day. Loss of any one of these would, however, lead to very serious consequences; loss of two of them would be exceedingly serious.

Russia has become an important crude oil supplier to Asia and Europe, with major terminals at Primorsk (880,000 barrels per day) on the Baltic Sea, Novorossiysk (900,000 barrels per day) and South Ozerereyevka (600,000 barrels per day), both on the Black Sea, Pivdenny (180,000 barrels per day) near Odessa, Poland, and several smaller facilities. Loss of any one of these would have serious adverse impacts on Europe and on the Asian and Russian economies.

Similarly, the Israeli oil ports and terminal facilities at Ashkelon on the Mediterranean Sea (9.4 MM barrels) and Eilat on the Gulf of Aqaba (8.5 MM barrels) have become important. Connected to each other by a high capacity pipeline, they allow crude oil arriving at the Mediterranean Sea from Black Sea ports to bypass the Suez Canal, alleviating its tanker size limitation, or alternately the long route around Africa for delivery to the east. This pipeline, moreover, is rather unique in being able to transport oil in either direction. Both of these Israeli facilities, however, are within range of Palestinian and South Lebanese rockets.

Refineries: Twenty large refineries with capacities of 400,000 barrels per day of crude oil or more are sited in twelve countries, as shown on Figure 16. While terrorist groups may attempt to attack facilities anywhere, seven of the large refineries are located in countries (Kuwait, Saudi Arabia) that are clearly in unstable regions or in which terrorists have already been active (India, Russia, Netherlands.) The loss of production from a major refinery would lead to lowered product exports and a reallocation of crude oil. Since only Saudi Arabia and Russia have meaningful spare crude oil production capacities, a successful attack in these countries would have a noticeable impact on the

Figure 16
The World's Largest Refineries
By Country and Capacity



world-wide energy balance. In addition to availability issues, prices would undoubtedly rise beyond normal supply and demand considerations because of psychological factors.

Only four of the largest refineries are located within the United States (the 563,000 barrel per day ExxonMobil facility in Baytown, Texas, the 501,000 barrel per day ExxonMobil facility in Baton Rouge, Louisiana, and the 446,500 barrel per day BP PLC facility in Texas City, Texas, and the 440,000 barrel per day facility at Lake Charles, Louisiana.) These are the sixth, ninth, thirteenth and sixteenth largest refineries in the world, each processing approximately 3 to 4 percent of the crude oil refined in the United States. Since the United States refineries are currently operating in excess of 90 percent of their capacities, the loss of any one or more of these would cause serious energy problems, not only throughout the Southwest, but also throughout North America.

Shipping: The biggest and most likely immediate threat by far is terrorist attacks on shipping.[57] Much of the crude oil supplied to the highly industrialized countries such as the United States and Japan are transported in Very Large Crude Carriers (VLCCs)[58] or the larger Ultra Large Crude Carriers. During the first nine months of 2005, 141 ships were boarded, 15 fired upon, 11 hijacked, and 256 crewmembers taken hostage. This, however, is actually an 18 percent reduction over the same period in 2005. The waters off of Somalia, conversely, have become exceedingly dangerous, and *"Ships not making scheduled calls at Somali ports are advised to keep at least 200 nautical miles from the Somali cost."*[59] During the first nine months of 2005 there were 61 pirate attacks reported on ships in Indonesia, 10 in the Malacca Straits, and 13 in Nigerian waters.[60] Most of these attacks were small scale ventures of two or three "pirates" who stole an anchored ship's stores such as paint, lines, tools and the like. Many larger ventures resulted in the kidnapping of officers and engineers for ransom. As with automobile accidents, a substantial number of events are not reported because of concerns that insurance premiums will rise or adverse publicity will occur.

More ominous than piracy for financial gain were attacks by as many as twenty persons on three to five well equipped speedboats, armed with machine guns, who steal ship's documents.[61] Possibly an even more ominous situation is the hijacking of tankers by pirates who demanded that crews teach them how to steer, but had no interest in docking operations. Ten armed men, for example, hijacked the chemical tanker Dewi Madrim in March 2003, steered it through the Strait of Malacca, and left with equipment and technical documents. More recently, on March 12, 2005, a group of 35 pirates, displaying machine guns and rocket-propelled grenade launchers, seized the 1,289-tonne tanker MT Tri Samudra. This vessel was carrying methanol through the Strait of Malacca from Borneo Island to Belawan, Sumatra, but was ordered by the pirates to sail to another port (Dumai, Sumatra), and the ship's captain and chief engineer were kidnapped. The

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[57] Luft, G. and A. Korin, Terrorism Goes to Sea, Foreign Affairs, 83(6), p. 61, November/December 2004
[58] Very Large Crude Carriers: Capacities of 200,000 to 399,999 tons (~1,250,000 to 2.500,000,000 barrels)
[59] ICC Commercial Crime Service, Weekly Piracy Report, Alert,10-16 January 2005
[60] IRIN News, November 17, 2004
[61] [U.S.] Office of Naval Intelligence, Civil Maritime Analysis Department, Worldwide Threat to Shipping, Mariner Warning Information, Published weekly

ship's owners believe the pirates were, in fact, terrorists from the Free Aceh Movement that is fighting for independence. At least one authority,[62] however, is skeptical of terrorist involvement, noting that *"…hijacking would be a very inefficient way to get training, which would be good only for an identical ship in identical conditions. And in any case, the sobering reality is that no specialized training is needed to drive a ship into a bridge, a port facility, or another ship."* While accepting these points, future cooperation between pirates and terrorists is certainly plausible.

As another example of not-for-profit attacks, on January 7th 2005 a Sri Lankan naval attack craft was destroyed and twelve sailors killed by a fishing vessel rigged with explosives.[63] This attack was ascribed to the Tamil Tiger rebel group. Ransom and sale of stolen material was certainly not the purpose.

Various international and United States agencies have identified many locations as critical to the world-wide flow of oil, coal and many other items; Table 7 presents six of them. These have narrow inlets/outlets that could be blocked by accidents or terrorist attacks. If they were closed the economic result would be staggering. Costs of shipping, security and insurance would undoubtedly greatly increase, driving up costs substantially.

While the focus of this paper is on energy, many other materials pass through these points such as grains, metals, ores, industrial equipment and consumer products. An interruption would, curtail delivery of these and, moreover, impact shipping traffic in each direction. It would, moreover, lead to a demand for more tankers to compensate for the use of non-optimum routes, thus increasing delivery times and shipping costs. Premiums for shipping insurance, if available, would also dramatically increase. The duration of a blockage would obviously depend on its nature. A blockage of the Suez Canal provides one benchmark. During the 1956 war between Egypt and Israel, the Egyptians blocked the Suez Canal with shipwrecks and with mines. After the war, it took more than one year of multinational effort to clear it sufficiently for traffic to resume. While ship-mounted cranes and mine-sweeping abilities have improved since then, the ability to cause damage has also increased. A one-year effort to restore traffic appears to be plausible.

As bad as an attack on any of these would be, it must be remembered that terrorist groups frequently attack several points simultaneously. Recent examples include the September 11th 2001 attack by four teams (three successful) on the United States, the May 16th, 2003 simultaneous attacks on five sites in Casablanca, Morocco, the November 15th, 2003 bombing of two synagogues in Istanbul, Turkey and the March 11th 2004 attacks on three train stations in Madrid, Spain.

[62] Dragonette, C.N., Letter to the Editor, Foreign Affairs, p. 174, March/April 2005
[63] Office of Naval Intelligence, Mariner Warning Information, January 11, 2005

Table 7
Crude Oil Shipping Chokepoints[64]

Chokepoint	Location	From / To	To / From	MM[65] Barrels Per Day
Strait of Hormuz	Oman / Iran	Persian Gulf	Gulf of Oman (Arabian Sea)	16.5 – 17.0
Strait of Malacca	Malaysia / Singapore	Indian Ocean	South China Sea (Pacific Ocean)	11.7
Bab el-Mandab	Djibouti / Eritrea/Yemen	Red Sea	Gulf of Aden (Arabian Sea)	3.0
Bosporus/Turkish Straits	Turkey	Black Sea	Mediterranean Sea	3.1
Suez Canal	Egypt	Red Sea	Mediterranean Sea	1.7
Panama Canal	Panama	Pacific Ocean	Caribbean Sea (Atlantic Ocean)	0.5

Loss of any of the first three of these chokepoint routes could not be accommodated by simply diverting tankers to the Bosporus, Suez or Panama Canals; the largest tankers they can handle are the Suezmax[66] class or the Panamax[67] class vessels. Transit time and cost would, of course, increase if smaller tankers and non-optimum routes had to be used. Although the loss any of these routes may be somewhat mitigated by using trucks, smaller tankers, barges and increasing flows through pipelines, the adverse impact would, nevertheless, be substantial.

Antiterrorist Measures

Although the oil producing countries and companies spend tens of million dollars on security, piracy and terrorist attacks continue. International initiatives have not led to impressive results.

The United Nations *"Convention of the Law of the Sea"* defines the conditions under which hot pursuit of a foreign ship, arrest of persons, seizure and disposal of property, and imposing penalties is permissible.

It is, unfortunately, relatively easy to repaint and slightly alter the outward appearance of a hijacked ship and reregister it in Liberia, Malta or Panama for operation under a "Flag of Convenience." The United Nation's International Maritime Organization has adopted

[64] World Oil Transit Checkpoints, Country Analysis Briefs, [U.S.] Energy Analysis Briefs, November 2005
[65] MM: million (1,000,000)
[66] Suezmax Class Crude Carriers: Capacities of 126,000 to 199,999 tons (~790,000 to 1,250,000 barrels)
[67] Panamax Class Crude Carriers: Capacities of 50,000 to 79,999 tons (~314,000 to 503,000 barrels)

'*Measures to Prevent the Registration of "Phantom" ships.*'[68] This, however, "*invites governments to…*" and "*urges governments to…*" It is a very weak document.

Law enforcement within territorial waters is, of course, the responsibility of each nation. Several South Asian countries, however, do not have the naval and military resources to perform satisfactorily; informal cooperation has helped on an ad hoc basis. In 2004, however, Indonesia, Malaysia and Singapore began coordinated patrols of the Malacca Strait, with Japan participating in drills. A more intense structured *"Regional Maritime Security Initiative"* (RMSI) has been discussed within which the United States would provide military assistance upon request. Although it has been resisted by various countries as an intrusion into their national sovereignty, discussions continue.

After numerous discussions, four countries (Indonesia, Malaysia, Singapore, and Thailand) agreed that they would jointly implement an *"Eye in the Sky"* program to enhance the security of the Malacca Strait. The countries provide sufficient resources so that one or two aircraft now patrol the Straits every day, providing timely information to naval vessels.[69]

Japan hosted a Ministerial Conference on International Transportation Security in Tokyo in January 2006. With fourteen countries and four international organizations participating, its concluding joint communiqué states that:

> *"We recognize that acts of terrorism pose a serious threat to international transport and that acts of piracy and armed robbery against ships recur with alarming consequences ... We therefore believe that it is essential to reduce the vulnerability of international maritime transport to such unlawful acts."*

The Ministers present agreed to adopt various Conventions and Protocols that, if truly implemented, should enhance maritime security.

Several groups collect information about successful and attempted piracy incidents and disseminate details to the maritime community. These include weekly reports from the United States Office of Naval Intelligence, monthly reports from the International Maritime Organization (Division of the United Nations) and daily status bulletins and weekly reports from the Piracy Reporting Centre (a group within the International Maritime Bureau, which in turn is part of the International Chamber of Commerce.)

Two Specific Disruption Scenarios

There is enormous uncertainty in predicting the depth and duration of energy interruptions, and no end to the calamities that can be imagined. Nevertheless, a realistic planning basis must be established. The following scenarios appear to be plausible.

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[68] Resolution 923(22), 22nd Assembly, November 2001

[69] The Jakarta Statement on Enhancement of Safety, Security and Environmental Protection in the Straits of Malacca and Singapore, Meeting on September 7, 2002

Scenario 1

Extremists gain control of the governments of Iran, the United Arab Emirates, Qatar and Iraq (or their oil fields) in the Mid-East. They attempt to damage Western countries' economies by withholding 90 percent (8.2 million barrels per day) of the production they control. The Saudi Arabian government is not overthrown but, worried about internal Muslim extremists, decides not to increase production to compensate for the shortfall, even if it could.

Other countries including Canada, Mexico, Norway, Russia and Venezuela (an OPEC member) are concerned about damaging their oil fields by increasing production rates, but decide to do so by 5 percent. This provides an additional 1.0 million barrels per day.

The United States government decides to release crude oil from the Strategic Petroleum Reserve at a rate that would deplete it over a twelve-month period. Assuming 90 percent could be withdrawn, this provides 1.7 million barrels per day.

The OECD countries and Japan decide to release their reserves at a rate that would deplete them over a twelve-month period. Assuming 90 percent could be withdrawn, this provides 5.8 million barrels per day.

The net effect on the world's oil supply over a twelve-month period caused by extremists controlling the output of the four Mid-East countries named above could thus be approximately offset by coordinated cooperative actions of other countries. It would, however, take several weeks for decisions to be implemented and the transportation/distribution lags to pass. The impact of a shortage would initially lead to increased oil prices, and quickly cascade to affecting the prices of direct products such as fuels and petrochemicals.

Within this scenario, the world's crude oil availability has been reduced by 10 percent for many months. Values of price elasticity[70] may be estimated from past market reaction to shortages. The following values have been derived from the following data presented by Peters.[71] The OAPEC[72] oil embargo of 1973 reduced supplies by 9 percent, leading to price increases of 227 percent. Elasticity was therefore (-0.09/2.27), or -0.040. During 1980, when Iraq declared war on Iran, oil supplies were reduced by 4 - 5 percent, leading to price increases of 261 percent. Elasticity was therefore (-0.045/2.61), or -0.017. An average value of -0.028 is therefore appropriate for relating cost to supply.

[70] Elasticity is defined as: $E = (dQ/Q) / (dP/P)$, where E is elasticity, Q is quantity, P is price

[71] Peters, S., Courting future resource conflict: the shortcomings of Western response strategies to new energy vulnerabilities, Political Science Department, Giessen University

[72] Organization of Arab Petroleum Exporting Countries: Algeria, Bahrain, Egypt, Iraq, Kuwait, Libya, Qatar, Saudi Arabia, , Syria, United Arab Emirates

In response to a 10 percent shortfall in crude oil supplies, and recognizing that there are many uncertainties, the cost of crude oil could reasonably be expected to more than triple its current value of $45 per barrel, rising to $160 per barrel (i.e., -0.028 = (-0.1/[dP/P]. Therefore dP/P = 3.6). It might then fall back to the $45 per barrel range as supply increased. Conversely, the psychological shock of this scenario might lead to substantially higher prices for crude oil and hydrocarbon products that persist for long times.

Since energy supplies are vital to the wellbeing of many industrialized nations, another reaction might be for one or more of them to undertake military actions. Other than to note that a coalition might be difficult to assemble, and the risks of escalation and irreversible damage to supplies would be high, and the political and military outcome uncertain, this possibility will not be discussed further in this paper.

Scenario 2

Extremists, in a well coordinated campaign to damage Western countries' economies, successfully interrupt the westerly flowing oil chain by attacking, burning and sinking tankers in the Suez Canal and the Bosporus, and simultaneously destroying the Pedro Duran Farell (PDF) Pipeline that carries gas from Algeria via Morocco to Spain and the Enrico Mattei Pipeline, that carries gas from Algeria via Tunisia to Italy. They, additionally, seek to punish the West's trading partners, Japan and South Korea, by interrupting tanker traffic in the Strait of Malacca.

Simultaneous attacks on three congested ocean lanes and two undersea pipelines are not inconceivable. If successful, these attacks would affect the flow of 15.3 million barrels of crude oil per day and 3.4 billion cubic feet of gas per day to Western Europe. Since oil and gas transportation has been seriously interrupted, increasing production will not compensate for the loss. Blockages of the Suez Canal and the Bosporus, deliberately planned to maximize damage and disruption, might, as previously discussed, take twelve months to clear.

Reasonably expected responses to these attacks might be as follows.

Producers that relied on these channels will find other ways, such as railroads, trucks, pipelines or more lengthy shipping routes, to deliver as much of their crude oil as possible. This might reduce the shortfall by perhaps 2 million barrels per day.[73]

The United States government will release crude oil from the Strategic Petroleum Reserve at a rate that would deplete it over a twelve-month period. Assuming 90 percent could be withdrawn, this provides 1.7 million barrels per day.

[73] Author's estimate

The OECD countries and Japan will release their reserves at a rate that would deplete them over a twelve-month period. Assuming 90 percent could be withdrawn, this provides 5.8 million barrels per day.

The net effect on the world's oil supply caused by extremist attacks described above would thus be equivalent to removing 5.8 million barrels per day of crude oil from the world-wide market, representing 7.2 percent of the current world-wide use. Using the elasticity value of -0.028 developed above, the cost of crude oil could reasonably be expected to increase its current value of $45 per barrel by 260 percent, rising to $120 per barrel. Other factors noted in Scenario 1 such as psychological factors and impacts on insurance premiums apply equally to this scenario with respect to the world's crude oil situation.

Other impacts will also be very serious. The Strait of Malacca and the Bosporus each handle vast amounts of products other than oil. These include grains, ores, steels, chemicals, machinery and many manufactured products. The world's economy would suffer greatly if these became unavailable, quite possibly leading to a world-wide recession.

While a loss of oil can be partially offset by using reserves or alternate means of transportation, these possibilities do not exist for gas shortages. The only alternate method is increasing LNG deliveries. There are, unfortunately, no spare liquefaction plant capacities, LNG tankers, or regasification terminals. The loss of 3.4 billion cubic feet per day of gas represents 4.9 percent of Western Europe's supply.

There are, as noted above, relatively few situations within which oil or coal can be substituted for gas. There are also no non-pipeline ways to quickly react to a gas shortage. Thus price elasticity of gas is expected to be substantially lower than for oil. A reasonable approach is to use the smaller (absolute value) value derived above, i.e., -0.017. Acknowledging that there are many uncertainties, a 4.9 percent reduction in gas availability in Western Europe could therefore reasonably be expected to triple gas prices. They might then fall back to near its current value as the demand-supply situation reaches a new equilibrium point, and as mechanical and operational changes are made to the gas supply-distribution system. As noted above, the psychological shock of this scenario might lead to a substantially higher long-term price.

Based on the energy situation described above, Dynalytics believes that the following represents realistic planning boundaries.

- ❑ **A moderately serious interruption: a 10 percent reduction in all types of energy, plus occasional sporadic rolling two-hour blackouts, lasting for a one-month period. Fuel prices will triple.**

- ☐ **An extremely serious interruption: a 20 percent reduction in all types of energy, plus many sporadic rolling two-hour blackouts, lasting for a twelve-month period. Fuel prices will triple.**

PLANNING FOR DISRUPTIONS

Supranational Planning

The major international system for responding to an energy emergency is embodied in the International Energy Agency's International Energy Program (IEP) and Coordinated Emergency Response Measures (CERM.)[74] These present numerous requirements related to emergency energy self-sufficiency through national oil storage, demand restraint, and oil allocation to each country. The measures would be triggered when an international disruption produces a 7 percent loss of supply. Although much of the IEP is clearly defined and self-executing, many of the credible threats to the international oil supply such as strikes or major accidents are specifically excluded from the activation triggers. Importantly, much of the CERM requires unanimous agreement of member nations, each of which has different political, fuel demand and supply situations. These programs have not yet been tested.[75]

The European Union has developed a parallel emergency response system[76] that provides guidance when stocks exceed IEA minima. No central coordinating authority, however, yet exists within the European Union, although new initiatives continue to be considered.

As noted above, the U.S has proposed an international nuclear fuel reserve, partly as a way to assure Iran, North Korea and other countries that their nuclear power plants will be able to obtain fuel without developing an indigenous uranium-enrichment or plutonium reprocessing capability. Many basic issues will need to be resolved before this reserve becomes a reality. For example: Who would own the fuel? How and by whom would the reserve be administered? How would the receiving country's spent fuel be handled? Who is responsible for transportation? Until these and other matters are resolved, this internationally oriented reserve will not be established. Based on the history of other international efforts, it appears unlikely that it will be realized within the next five years.

Decisions about international cooperation, of course, always have major political components. The largest crude oil and natural gas suppliers to Asia are, as noted above, Saudi Arabia and Russia, both of which have been subjected to terrorist attacks by fundamentalist and separatist groups. They are the only two countries with any noticeable spare production capacity, but they have large Muslim populations they might fear offending by openly cooperating with the Western countries when important. Moreover, they might decide that while the West now provides the largest market for

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[74] OECD/IEA, 2003

[75] See Willenborg, R., C. Tonjes and W. Perlot, Europe's Oil Defences, Clingendael International Energy Programme, CIEP 01/2004, The Hague

[76] Council Directives 68/414/EEC, 73/238/EEC, 77/706/EEC, 98/93/EC

their crude oil and gas exports, their future might be better served by favoring the rapidly growing Asian economies when allocating their suddenly limited production.

While reactions to disruptive events can not be precisely predicted, there are clues to be assessed. Russia, for example, has recently announced that a major new, although environmentally controversial, 2,500-mile trans-Siberian pipeline (the *Eastern Pipeline*) will originate from Taishet near Lake Baikal and go eastward in two phases. During the first phase 600,000 barrels per day will travel 1,800 miles to a point near the Chinese border, and 400,000 barrels per day will then be diverted to a direct pipeline to China, The remaining 200,000 barrels per day will be sent by railroad to the Pacific Ocean for delivery to Japan. In the second phase, the capacity will be increased to 1.6 million barrels per day, and a line extended 1,200 miles to the Pacific coast from which the Japanese market can be readily served. This approach appears to demonstrate Russia's confidence in the Asian future and mitigates the risks of having only one country as a customer for this oil.

Governmental Planning

Each government will, of course, respond to a fuel emergency in its own way. The United States government, for example, requires[77] that:

> *Federal agencies shall prepare emergency conservation plans for 10 percent, 15 percent, and 20 percent reduction compared to the previous fiscal year in gasoline, other oil-based fuels, natural gas, or electricity for periods of up to twelve months.*

Many state governments have developed and enacted detailed plans enumerating specific measures to be taken when an energy emergency is declared. New Jersey's Energy Emergency Plan, for example, provides authority[78] to declare that, among many other actions:

- *Temperatures maintained by heating shall not exceed 65 degrees Fahrenheit during business hours or 55 degrees Fahrenheit during non-business hours.*
- *Nighttime professional sports, entertainment and recreational activities shall be curtailed, suspended or rescheduled.*
- *Retail establishments shall be closed from 7:00 P.M. to 9:00 A.M. and all day on Sunday.*
- *All outdoor flood and advertising lighting shall be eliminated.*
- *Gas deliveries may be reduced or suspended to defined classes of users, prioritized by daily rate of use.*
- *Electric loads may be interrupted on a rotating basis every two hours.*
- *Prime suppliers of regulated products [i.e., Utility Companies] shall maintain a store (a "set aside") of 5 percent of that product it sold in New Jersey during the same month of the previous year. The Board of*

[77] 10 CFR Ch 11 §436.105, Emergency Conservation Plan
[78] N.J.A.C. 14:29, Subchapter 2, End Use Reduction

Public Utilities may redirect some or all of the "set aside" to a specified end-user.

The rules recognize that many groups such as communication companies, utility companies, hospitals, and emergency vehicles face special situations. It therefore contains numerous exemptions, and the Board may also issue exemptions for "extraordinary hardship" and "public welfare."

All states have Emergency Energy Plans with greater or lesser specificity of details. In the event that any of them must be implemented, intense and probably acrimonious fighting for priority and exemptions will undoubtedly occur. Since requested exemptions will not all be granted, it is prudent for all industrial and commercial companies to prepare for modifying their operations.

Individual Company Planning

Each company's situation is, of course, unique with respect to the totality of its operations, including its production facilities and available space, staff, supply and distribution chains, product and customer requirements, and financial strength. The two "big picture" questions that management must answer are:

- ❑ *Will the demand for our products probably remain unchanged or even increase (e.g., pharmaceuticals) or probably decrease, possibly close to zero, (e.g., SUVs) immediately after an energy emergency?*

- ❑ *The cost of making and distributing our products will increase noticeably. Considering contractual, public relations and political issues, how much of the increase will we be able to pass on to our customers, and how much must we absorb?*

If demand is likely to remain unchanged or even increase, planning for energy shortages and interruptions longer than heretofore encountered is important. The pharmaceutical sector is an example of one for which demand for many of its products will not change; patients simply need them to maintain their lives. Although demand may be constant or even increase during an energy emergency, the ability to meet it may be reduced by constraints in the availability of energy, raw materials, production staff and the distribution chain.

If, conversely, demand is likely to decrease, planning for orderly shutdowns, storage and maintenance is important. An example is the widespread mothballing of planes in the airline industry.

Possible changes in processes and/or equipment have traditionally been examined as a conceptually simple balance of invested capital versus the resulting savings in operating costs. A new paradigm must, however, now be used for evaluating possible energy-storage and energy-reduction projects. The new framework is:

- *"Past performance with respect to blackouts and fuel shortages is no guarantee of future results." We have had a new set of challenges thrust upon us.*

- *If our company has a limited amount of fuel and electricity available, how should we best use them? Evaluations of alternate courses of action must now consider the possibility that energy resource limitations might cause significant production curtailments or plant shutdowns. Self-generation of electricity, fuel storage and energy efficiency may now be significantly more cost-effective than in safer times.*

While all energy efficiency improvements will be helpful, it is unlikely that major energy reductions will arise from measures that are even now frequently implemented such as adding oxygen trim controllers to existing boilers, operating them at lower pressures, or replacing fixed or two-speed drives with variable speed drives, or changing to premium efficiency motors, or replacing light bulbs with more efficient ones. More drastic steps will frequently be appropriate.

Large energy conservation results are more likely to arise from process changes and/or major revisions to lighting and HVAC systems. These, of course, are process- and building-specific. Importantly, even though the impetus for process revisions or for installing additional energy conservation equipment is to better contend with curtailments, the efficiency benefits will continue to be realized during non-emergency periods.

In addition to process considerations, a basic industry-wide issue that companies must address is keeping computers functioning in a major energy crisis where electricity might be curtailed or rationed for longer periods than previously encountered. Access to many of a company's vital records, process control and process safety systems depends on functioning computers. Loss of these will cause massive production and business disruptions. Emergency and standby generating systems have been installed widely to accommodate electrical outages lasting from milliseconds to a few hours; they, however, have not generally been designed to allow operations for days or weeks. They, moreover, rarely have sufficiently large fuel storage tanks.

While recognizing that each company's situation is unique, there are a number of steps that should be taken immediately by all production companies. Several of these will require environmental permits and/or other governmental approvals. Obtaining permits is frequently time-consuming and may be contentious. The process should be started as soon as possible.

Assess the steps that governmental agencies and your energy supplier will take

As noted above, the United States government, state governments and many municipalities have developed energy emergency plans. In order to assess the realistic

probability of obtaining priority status with respect to energy allocations, it is necessary to understand the criteria and process. Seek information from the staff of all agencies that will be involved with energy use and allocation matters. Application forms, if available, should be filled out to the extent practical, and stored, thus saving critical time when they might need to be filed.
Utility and fuel supply companies have certainly developed contingency plans for managing various levels of supply and delivery interruptions. Discuss their contingency plans with them to ascertain their views of how, to what extent, and under what conditions your company will be impacted by their problems. It is important to understand the conditions under which, regardless of Agreements or Contracts, Force Majeure clauses will be invoked and service suspended.

Examine your business fundamentals
Develop business scenarios for reacting to severe energy emergencies. Evaluate the options of maintaining or changing the current product slate. Reducing or suspending production of certain products to reallocate scarce energy resources may be appropriate.

Understand your current technical situation
It is necessary to set goals and priorities; therefore tabulate every energy-consuming activity, together with information about type, rate and quantity of energy used. The rates and quantities should be reconciled with utility company and fuel supplier invoices. Process energy uses will usually be evident. Discrepancies, however, may arise from overlooking common items such as cooling tower fans and pumps. Simultaneously gather data about the temperatures and flow rates of all streams in order to assess potential heat recovery possibilities.

Examine your spare parts inventory practices
Evaluate the condition and reliability of critical equipment and control systems because forced unscheduled outages damage equipment. Since, particularly in an emergency situation, obtaining replacements will be slow and expensive, upgrade equipment where necessary. The types of spare parts kept and their inventory levels should also be reexamined. The cost impact of increasing spare part inventory levels may be lessened by establishing cooperative approaches with equipment suppliers and/or local production companies.

Examine your current processes
Companies in many industrial sectors have found it very cost-effective to reduce off-specification product rejection rates that unnecessarily consume raw material, energy and plant capacity. These wastes may be reduced to very low levels by employing more stringent quality control and inspection measures than normally used for raw materials and intermediate products.

Providing for increased storage of raw materials, intermediate and final products will help if intermittent production becomes necessary. Shelf-life and storage temperature requirements must, of course, be considered. Additional storage capability will also provide flexibility in dealing with railroad, trucking and related transportation issues that may arise.

Perform high electric-demand operations at off-peak periods. This is commonly recommended to reduce peak demands and obtain lower cost rates. It will not change the amount of electrical energy used, but may help if rationing or allocations are instituted.
In the event of an energy emergency, fuel-flexibility will be important. Investigate the possibilities of using alternate fuels, and implement them where practical.

Revisit heat recovery operations
Reactor design and operation, and separation processes are usually key proprietary technologies that have taken considerable time and resources to develop. They are the last things to consider changing. There are, nevertheless, steps that might reduce energy consumption, to the lower levels justified by maintaining operations, without impacting the process streams.

Where heat recovery is currently practiced, investigate increasing it by taking low-cost steps that are frequently marginally economical when reviewed within conventional energy accounting scenarios. Condensate return from steam traps represents a simple example. Storage of heated or cooled streams (i.e., thermal storage) for later use is another.

Somewhat more costly steps include installing additional or larger heat exchangers to increase the amount of energy recovered from compressor intercoolers, refrigerant condensers, distillation system condensers or other process streams. A process review might show that some pump and piping systems might also have to be changed, and that corrosion from condensation from flue gas streams might establish the technical limits to additional heat recovery.

Cogeneration, (concurrent production of electricity and steam or chilled water) has probably been examined by every production company in the world by now, and most often rejected based on a narrow balance of capital costs versus energy cost savings. A fresh look based on effectively using the limited amount of energy that would available to continue operations might indicate that it is, in fact, justified under this new scenario,

Realistic possibilities should be implemented where practical since the new driving force is maintaining an ability to continue operation.

Consider moderate incremental process changes
There are incremental steps that might reduce energy usage by modifying the process streams' compositions and/or time-temperature profiles.

Investigate using recycled products as raw materials. Since the composition of these partially match those required in the finished products, a substantial energy savings is often possible. Several industries such as pulp and paper, iron and steel, and hot-mix asphalt production routinely use recycled materials. These, of course, are not trivial changes. They might require laboratory and pilot plant testing, and interaction with such agencies as the Food and Drug Administration.

Install a truly adequate backup electrical generator system

It is very important to have an oil-fired emergency backup electrical generator of sufficient capacity installed and available within seconds to supply power to all critical equipment and operations. When an energy emergency had arisen in the past, such as the United States East-coast blackout of August 2003, there was a sudden demand for emergency electricity generators, which quickly became unavailable. The situation will again be severe with respect to the generators sought used by industrial companies since they employ higher capacity units, more complex startup and control systems, more durable construction, and varied fuel supply systems. These are usually custom-designed and use many components that are not normally kept in generator suppliers inventories.

Battery-operated starting systems are among the key components of emergency electricity systems, and have been found to be surprisingly unreliable. Dynalytics notes that nickel-cadmium batteries, although somewhat more costly, offer many advantages over the low-cost common lead-acid batteries, and should always be chosen.

Given the nature of the emergency under consideration, the amount of fuel oil stored on-site must also be adequate. Each company must assess the frequency and quantity of fuel oil that it might obtain during an emergency. Any substantial increase in oil storage will probably need review and approval of the local building, fire and health departments, and possibly of the company's insurance company.

Environmental permits must be secured for installing and operating diesel engine-driven electricity generators, possibly, as noted above, an arduous process. Although the anticipated use of these units is for emergency backup generation, permit restrictions that are commonly agreed to may not be appropriate, given the long operating times that may be required. It is important to establish whether the desired operating scenarios are limited to emergency generation only, or also include non-emergency periods.

Examine your employee situation

Assess the minimum operating staff level, by function, that is absolutely necessary for continued operation. Then establish ways this need will be met.

Employees will react to an energy emergency in a variety of ways, depending on its nature, expected duration, and their personal and family situations. Meet with employees and, if there is a union, its representatives for an honest discussion of employee and company needs. They may want a flex-time policy, car pools, a temporary child care operation, expanded meal preparation and service, much relaxed rules for personal telephone calls, expanded telecommuting, or undoubtedly other unforeseen items. Decide which requests can be reasonably met and prepare a plan in sufficient detail so that lead times are minimized and it can be quickly implemented. Sick leave, absence and lateness provisions of normal Personnel Policies should be reviewed and altered if necessary. Present the plan to the staff, consider their further input, and revise it as necessary. Keep them informed; their cooperation will be critical.

Prepare to communicate

If your company produces critical items such as pharmaceuticals and finds itself faced with substantially higher costs and reduced production, irresponsible charges of price gouging and conspiring to withhold product or manipulate the market place will inevitably be leveled. Develop a fact-based presentation, including handouts and contact information, that explains the situation, how and why you are reacting as you are, and what steps are being taken to improve the situation. The audience will be public officials and the affected users.

Develop a professional relationship, through tours, briefings or lunches, with reporters of the print and broadcast media to establish the mutual trust necessary for discussing situations frankly and candidly. Public support will be particularly important if, as is the case with the recent flu vaccine shortage, any segment of the public believes its health is at risk.

THE AUTHOR

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