NATIONAL HEALTH, WEALTH, AND ENERGY USE
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SUMMARY
Great disparity exists in the distribution of wealth among nations. National well-being, as measured by such commonly accepted indicators as infant mortality, child malnutrition, life expectancy, and literacy rates correlates well with national wealth, which, in turn, correlates well with energy consumption. Developed industrial nations rank high in national well-being; however, on a per-capita basis, these nations own a disproportionate share of world wealth and consume a disproportionate share of the world's energy. Economic growth correlates well with growth of energy consumption in both rich and poor nations, and, conversely, reductions in energy consumption correlate with economic decline. When energy consumption is expressed as a function of gross national product (GNP) instead of on a per-capita basis, developed nations use energy more efficiently than poorer ones.

Fossil fuels furnish 90% of the world's energy (oil and gas supply 63%), and their use has grown by 14% over the last decade (oil and gas use is up 19%). Long-range concerns about depleting fossil-fuel resources and more immediate concerns about increases in atmospheric CO₂ produced by their combustion and the postulated ill effects of global warming weigh against continued increase in use of fossil fuels and favor alternative energy sources. Examination of alternatives suggests that none of the alternatives, other than possibly nuclear and hydropower (both in environmental and political disfavor), offer hope for supplying more than a fraction of demand. Hence, either the natural limits on use of fossil fuels set political disfavor, or offer hope for supplying more than a fraction of demand. Alternatively, the setting of artificial limits in an effort to control CO₂ emissions (tentatively agreed to in Kyoto and by depleting resources or the setting of artificial limits in an effort to control CO₂ emissions (tentatively agreed to in Kyoto)

INTRODUCTION
For many millennia, the world’s energy was supplied by wood, wind, water, and the muscle power of man and animal or, in today’s lexicon, “renewable” energy. Life, worldwide, was little better than Ashton’s evocative description, “There are...men and women, plague-ridden and hungry, living lives little better, to outward appearance, than those of the cattle that toile with them by day and share their places of sleep by night.”

The earliest sustained use of fossil fuel started in 1233 with coal from Newcastle, England. Chronic shortages and high costs of firewood for cooking and heating drove the use of coal in England upward during the next 500 years, from 33,000 tons in 1564, to 529,000 tons in 1698, and to 6 million tons in 1770 in the early stages of the Industrial Revolution. Rapid growth of coal-fired steam boilers further escalated coal consumption to 84 million tons in 1861 and to a peak of 287 million tons in 1913. Concurrently, Great Britain’s national wealth, or GNP, grew at a rate twice as fast as population from 1801 to 1911, because of the huge increases in productivity that steam power provided.

The Industrial Revolution quickly spread to Continental Europe and North America. Coal was largely displaced by oil in the first half of the 20th Century as huge gains in both economic and physical well-being were experienced in all industrialized nations. Meanwhile, world population grew from approximately 0.75 billion in 1730, to 2 billion by 1930, and to 4 billion by 1975. It is approaching 6 billion as the century ends.

Air pollution from burning of fossil fuels was recognized as a problem centuries ago. “Smog” from coal used for heating and cooking was reported in London as early as 1285, and a resident was actually tried and executed in 1306 for burning soft coal, possibly one of the earliest, and most severe, penalties for pollution.

In the second half of the 20th Century, awareness of “near-ground-level” air pollution from fossil fuels evolved (with the application of technology) into remarkably clean exhaust gases from automobiles and from smokestacks of coal-fired electric-power plants. As the century closes, however, a new concern has emerged: the postulated ill effects of global warming induced by CO₂ emissions. Today, governments are considering limiting the use of fossil fuels.

VARIATIONS IN WEALTH AMONG NATIONS
National wealth is traditionally measured by GNP, the total value of all goods and services produced. [GNP is gross domestic product (GDP) plus net factor income received from or paid to the rest of the world. Factor income consists primarily of dividends and interest received by a nation’s residents; reinvested earnings of foreign affiliates of a nation’s corporations minus payments to foreign residents of interest and dividends; and reinvested earnings of affiliates of foreign corporations. For most countries, the difference between GDP—the total output of goods and services produced by a nation’s labor and property valued at market prices—and GNP is less than 1 or 2%.] Per-capita GNP is a more useful measure for comparison of relative wealth among nations. These data are routinely available in Organization for Economic Co-operation and Development (OECD) and World Bank publications.

Ranking nations by GNP per capita (1996 data with the World Bank Atlas method of converting national currencies between countries at official or market exchange rates), Luxembourg, with a population of only 416,000, has the world’s wealthiest citizens at U.S. $45,360 each. This is 567 times higher than Mozambique, at the bottom, with a population of 18 million and a per-capita wealth...
of only U.S. $80. The wealth among peoples within nations also differs widely. While such major differences, both inter- and intra-nationally, defy the often espoused goals of economic equality, they have always existed and likely always will.

China (Fig. 1) the world’s most populous nation, straddles the mean of national wealth at U.S. $750 per capita. At one standard deviation to either side are South Korea, with U.S. $10,610 per capita, and India, the world’s second most populous nation, at U.S. $380 per capita. The distribution in Fig. 1 is not ideal log-normal but exhibits a steeper slope (i.e., larger standard deviation) among wealthier nations from 10 to 35% of the population and a shallower, though consistent, slope at both less than 10 and more than 35%.

The World Bank also expresses GNP per capita by the “purchasing power parity” (PPP) method, which compares relative wealth according to actual costs of goods and services within each country. Services, in particular, tend to be undervalued in poorer countries. By this method, Luxembourg is still the wealthiest, and Mozambique is still the poorest, now respectively at U.S. $34,480 and U.S. $300 per capita, with a relative-wealth ratio of only 69 instead of 567. This creates the appearance of a “fairest” world by nearly an order of magnitude. Because costs in the U.S. are used as reference, the PPP probability distribution rotates around the U.S. (countries with greater wealth are reduced somewhat, and those with less are increased). Fig. 1 also plots world wealth by the PPP method. China, now at U.S. $13,330 per capita still represents the mean, and South Korea, at U.S. $13,080 per capita, and India, at U.S. $1,580 still lie one standard deviation to either side. Actual wealth of citizens is, of course, unaffected by how GNP is defined. By either of these definitions, two-thirds of the world’s population is between South Korea and India in wealth; one-sixth is wealthier than South Korea, and one-sixth is poorer than India. A side effect of the PPP method is that it increases apparent total world GNP from U.S. $29.5 trillion to $34.5 trillion.

Within nations, the World Bank uses the Gini index, a Lorenz coefficient familiar to petroleum engineers in the context of permeability distributions, to express distribution of wealth. A Gini index of 0.0 denotes perfect equality (all individual citizens have exactly equal wealth), and a Gini index of 1.0 denotes perfect inequality (i.e., all wealth is owned by a single citizen). The actual range of Gini indices is 0.195 in the Slovak Republic to 0.629 for Sierra Leone. The most equal one-sixth of nations (outside of one standard deviation) primarily includes eastern European, the former Soviet Union (FSU), Scandinavian, and a few wealthy western European nations. The least equal one-sixth, ranging from 0.509 to 0.629, is made up almost exclusively of Latin American and sub-Saharan African nations. The median Gini index for all nations is 0.41, and the three nations nearest the median include China, the U.S., and Jamaica, a counterintuitive mix.

The Lorenz coefficient for all nations of the world, ranked against each other by population rather than by internal-wealth distribution, is 0.75 (or 0.53 by the PPP method of GNP). This indicates that distribution of wealth among nations is less equal than within even the least equal nations individually, also a surprising conclusion.

**NATIONAL MEASURES OF HEALTH AND WELL-BEING, UN GOALS FOR IMPROVEMENT, AND SIZE OF GNP INCREASES NEEDED**

To provide a single quantitative measure of economic and social progress toward general well-being, the UN Development Program (UNDP) introduced its Human Development Index in 1990. The index combines many measures into one, including life expectancy; income, adult literacy, and enrollment in education. Per-capita GNP (PPP method) is used as the income measure, although it is weighted less at more than U.S. $5,990.

Fig. 2 illustrates the strong correlation in rankings between the UNDP Human Development Index and GNP per capita, partially to be expected because GNP per capita is a component of the index. Nevertheless, as an effective single measure, it suggests that GNP per capita is inadequate at less than U.S. $5,990. Accumulating data for all nations below that level (shortfall per capita multiplied by population) shows a need for an additional U.S. $8.3 trillion worldwide (or U.S. $2,100 per capita for 74% of the world’s population (4 billion people total)) so that the average wealth for every nation individually meets or exceeds U.S. $6,000. This would be a total increase of 25% in world wealth (by the PPP method).

The same arithmetic with the World Bank method of determining GNP per capita shows that an increase in world wealth of U.S. $6.5 billion (or a remarkably similar 22% increase) is required, noting that U.S. $6,000 per-capita income by the PPP method corresponds to approximately U.S. $3,000 per capita by the World Bank method because both represent approximately the lower 74% of population by wealth.

With either method, a minimum increase of approximately 25% in world wealth is necessary to achieve a level of income that essentially would wipe out poverty and its ill effects worldwide. Note that this is a minimum because of the implicit assumption that the increase goes only to poorest citizens of the poorest nations. The real world does not work that way, but this establishes a minimum figure for estimating the needed increase in energy consumption.

The UN has articulated and adopted the following specific developmental goals to improve human well-being for the 21st Century:

1. Reduce extreme poverty by half by 2015.
5. Provide universal access to reproductive health services by 2015.

“Development” is used in broad terms to indicate improved living standards or “quality of life.” As the goals suggest, reducing poverty is primary to achieving development, although some of the stated goals seem designed more to impose Western standards of culture (notably gender equality and environmental concerns) on other parts of the world than simply to reduce poverty. A common characteristic of these goals is the extremely short time period, 6 to 16 years, to remedy global conditions that have existed for centuries, if not millennia. Quantifying these goals to a specific level of national income or wealth required for achievement is quite difficult, but the Human Development Index is a rational approach.

NATIONAL WEALTH AND ENERGY CONSUMPTION

Direct comparison of energy use and GNP suggests a near-linear relationship, or an “elasticity” (changes in energy consumption vs. change in GDP) of 1.0. Recent historical data (1975–95) for elasticity, as determined by the U.S. Energy Information Admin. (EIA), have averaged about 0.8 for the world, with a range of 0.4 to 2.0 for different time periods and for different groupings of nations. While the wealthier, developed countries use energy most efficiently, they use much more energy per capita. A few of the poorer countries also seem efficient by the measure of energy use per unit of GNP, in part because a significant portion of their energy consumption is supplied by unmeasured “noncommercial” sources (i.e., wood and other such materials). The large majority of poor countries are economically inefficient users of energy. By far, the least efficient nations are the Russian Federation, members of the FSU, and eastern Europe, followed by those developing countries that are growing fastest (Table 1).

Table 1, which represents specific nations arranged in order from rich (Japan) to poor (India), is striking in two respects. First, in terms of energy use per capita, India is the most efficient, while Japan, western Europe, and the FSU are similar but somewhat less efficient, China is next least efficient, and South Korea remarkably so. However, if energy intensity, bbl oil equivalent (BOE)/U.S $1,000 GNP [1 bbl of oil is assumed to be equivalent to approximately 5.5 million BTUs (1,600 kW-hr, 630 kcal)] is used as the measure of efficiency, Japan is the most efficient, followed closely by western Europe, and then by South Korea. The least efficient by far is the FSU, followed by China and India. There is a remarkable contrast in efficiency, depending on the measure used. Actual level of wealth and rate of development are obvious factors in efficiency of energy use. But population density also is a factor, and deflation, or collapse of economies (such as the FSU, and to a lesser degree, eastern Europe), is a major factor. As a group, the richer nations (as categorized by the World Bank with a GNP of more than U.S $10,000 per capita) represent 16% of the world’s population, generate 81% of the world’s GNP, and consume 56% of the world’s energy. In doing so, the richer nations use nearly seven times as much energy per capita but only one-third as much per unit of GNP. The appropriate definition of efficiency is vital if national behavior is to be judged.

Some past studies have demonstrated a historical pattern of decreasing economic efficiency in energy as a nation progresses toward industrial development, followed by much higher efficiency when fully developed and wealthy. Fig. 3 shows primary energy consumption and real GDP data from 1850 to 1985 for five developed industrial nations. Energy use, or intensity, expressed as BOE/U.S $1,000 of real GDP for each nation is plotted vs. time. All show a similar pattern, starting low, peaking, and declining as development reaches a mature stage. Also, those that peak earliest have the highest peaks, but timing and magnitude of peak energy intensity generally correlate with timing of industrialization. Great Britain, where the Industrial Revolution began, peaked in 1880 at 7.5, while Japan did not peak until 1980 at just over 3.

Bookout reported comparable results (Fig. 4). He divided the world into industrialized nations, centrally planned economies...
The federation and nations of the FSU are among the least efficient stages of development and the prior observation that the Russian with both the increased energy intensity expected during earlier decreasing as nations neared full development.

In contradiction, the Russian Federation, and five other FSU countries (Azerbaijan, Belarus, Kazakhstan, Ukraine, and Uzbekistan, selected as examples of decreasing energy growth with large populations) together have a GNP growth rate of 7.2%/yr and an energy use growth rate of 10.2%/yr.

In Table 2, which compares economic growth rate and the rate of change in energy consumption for certain populous countries for 1985–95, provides another measure of the relationship between energy use and economic development. During this period, oil prices and energy costs in general were fairly stable. The highest sustained economic growth rate is China at 8.3%/yr. China also has a high growth rate of energy consumption at 4.4%/yr and of oil use at 5.6%/yr. Four other Southeast Asian countries (South Korea, Indonesia, Malaysia, and Thailand, selected for high growth rates and large populations) together have a GNP growth rate of 7.2%/yr and an energy use growth rate of 10.2%/yr.

In contrast, the Russian Federation, and five other FSU countries (Azerbaijan, Belarus, Kazakhstan, Ukraine, and Uzbekistan, selected as examples of decreasing economic growth with large populations) all had significant decreases in GNP for 1985–95 and significant decreases in energy and oil use. Fully developed countries with only moderate economic growth, including the U.S. and nine western European nations (France, Germany, Italy, Netherlands, Portugal, Spain, Sweden, Switzerland, and the U.K.), exhibit modest growth in use of both energy and oil. Table 2 shows that both increases and decreases in energy use correspond in nearly a linear relationship with economic growth (or an elasticity of about 1.0, slightly higher than the world average of 0.8 as calculated by the EIA).

The U.S. economy during the oil price shocks of 1974, 1979, and 1980 and the minishock of the Gulf War in 1990–91 provides another measure of the relationship between energy use and national economic well-being. The U.S. economy is the world’s largest at 26% of total world GNP (22% by the PPP method), and the U.S. is the world’s largest user of energy at 25% of total world use (in 1966). All recessions in the U.S. (as defined by the Natl. Bureau of Economic Research) in the last quarter century have been associated with sudden oil-price increases. They occurred in 1974, 1980–81, and 1990.

### Table 2—Changes in Wealth and Energy Use: Selected Countries, 1985–95

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (millions)</th>
<th>GNP</th>
<th>Energy</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>1,200</td>
<td>8.3</td>
<td>4.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Southeast Asia*</td>
<td>322</td>
<td>7.0</td>
<td>2.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Japan</td>
<td>125</td>
<td>2.9</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>U.S.A</td>
<td>263</td>
<td>1.3</td>
<td>2.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Western Europe*</td>
<td>336</td>
<td>1.1</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Russia</td>
<td>148</td>
<td>-5.1</td>
<td>-3.1</td>
<td>-6.8</td>
</tr>
<tr>
<td>Other FSU*</td>
<td>109</td>
<td>-8.2</td>
<td>-4.0</td>
<td>-9.0</td>
</tr>
<tr>
<td>World</td>
<td>5,754</td>
<td>3.2</td>
<td>1.6</td>
<td>1.4</td>
</tr>
</tbody>
</table>

*See text for countries included.

Source: World Bank, BP

### Fig. 5—Misery index and high oil prices in the U.S.

### Fig. 6—Misery index vs. U.S. oil price for 1950 to 1996 (in constant 1996 U.S. dollars).
Oil-price increases in 1974, 1979, and 1980 were caused by artificial constraints on oil supply. A side effect was to drive up prices in the U.S. for oils principal competitors, natural gas and coal. The oil price spike induced by the Gulf War was associated with the last and mildest of the four recessions in the U.S. since 1970, and gas and coal suffered no concurrent price increases.

Fig. 5 shows three common measures of economic misery— inflation, unemployment, and interest rates—that all have a consistent relationship with oil price. Adding these three together (with each expressed as a percentage) defines a composite “misery index.” This index stayed below the range of 10 to 15 from 1950 through the 1970’s, further implying no shortage at this time.12,13

In 1974, this misery index doubled to a peak of 25 as oil prices soared from less than U.S. $10 to nearly $33/bbl. It abated to 20 or less before 1979 as the U.S. economy assimilated the first oil-price shock, but leaped again to more than 31 in 1980–81 as oil prices jumped from U.S. $34 to $55/bbl. By 1986, when oil prices dropped below U.S. $21/bbl, the misery index dropped to 15 and has remained generally low except for a brief excursion over 18 in 1990 coincident with a U.S. $5/bbl increase in oil prices (on an annual average basis) brought on by the Gulf War.

Table 6 plots misery index vs. oil price. Not only is there a good linear relationship, but the misery index increases by approximately one percentage point for each U.S. $3/bbl increase in the price of oil, providing useful guidance concerning the impact of major tax increases on fossil fuels. The inescapable message is that higher energy prices cause economic misery and recession. While the specific price increases cited were caused by OPEC, the Iran-Iraq war, price speculation, and the Gulf War, future price increases in the near term are likely to result from increased taxes enacted to reduce burning of fossil fuels and, ultimately, from a genuine physical shortage of oil. Meanwhile, continued instability in the Middle East may also impose short-term price increases. Whatever the cause, oil-price hikes inevitably have an adverse impact on the world’s economic well-being.

Fossil Fuel Use and Future Supplies

Impending shortages of fossil fuels, particularly oil, have been predicted repeatedly, and incorrectly, many times. Among the current spate of such predictions concerning when and at what level peak world oil production will occur are Campbell and Laherrere’s of 71 million BOPD in 2003, Bookout’s of 75 million BOPD in 2010, and Int'l Energy Agency’s of 82 million BOPD in 2014. Nominally, these forecasts are all similar in both time and magnitude.

In contrast, EIA projects 106 million BOPD in 2020, with production rate still increasing.11 Similarly, the recent history of growth of production rates and of proved reserves (in relation to each other) suggests no basis for concern. Table 3, which summarizes these data for fossil fuels for 1985–97, shows that reserves have grown at a faster pace than production for all three.6 Notably, oil reserves increased by 86% while oil-production rate increased by only 26%. Extrapolation of these growth rates supports the seemingly unlikely conclusion that an infinite supply of oil exists. Alternatively, the data certainly provide no basis for believing a near-term physical shortage exists. Recent oil prices, near modern-day lows, tend to confirm this; and the cost of finding oil and gas reserves has dropped to less than U.S. $5/bbl from more than U.S. $15/bbl in the late 1970’s, further implying no shortage at this time.12,13

### Potential Impact of Global-Warming Concerns and the Kyoto Protocol on Fossil-Fuel Use

Driven by concerns that a continuing increase in CO₂ concentration in the Earth’s atmosphere (from 295 ppm in 1900 to 360 ppm today) would result in global warming with adverse effects, the Intergovernmental Panel on Climate Change (IPCC) was formed to study the matter. In 1995, in a carefully crafted statement, the IPCC said, “the balance of evidence suggests that there is a discernible human influence on global climate.” This was heralded by environmentalists and politicians alike as a potential disaster deserving immediate action. The IPCC also concluded that buildup of CO₂ in the atmosphere might result in a temperature increase of 2 to 5°F by the year 2100.

Two seemingly more critical questions were not addressed by the IPCC, or anyone else, in an effective manner.

1. Aside from any potential effects of human activity, what is the general outlook for world temperature changes caused by Mother Nature?
2. What is better for life on Earth, a warmer or a cooler climate?

In the absence of answers to these questions, any action to reduce possible additive effects of human activity must be considered irrelevant, meaningless, and potentially counterproductive.

Nevertheless, 174 nations ratified the UN Framework Convention on Climate Change, which is aimed at stabilizing the level of greenhouse gases in the atmosphere. In December 1997, these nations agreed to the Kyoto Protocol, which sets out the first steps toward achieving a reduction in fossil-fuel emissions. So-called Annex I countries (essentially all industrialized nations) are to reduce aggregate “net” emissions from use of fossil fuels to 5% below their 1990 levels by 2008–12. The U.S. agreed to a 7% reduction.

In a simple world, the Kyoto Protocol seems to translate into a straightforward 5% (7% for the U.S.) reduction below 1990 levels in use of fossil fuels, a draconian cut from anticipated levels. However, nothing is simple, and the protocol provides for a system of “tradeoffs” that are largely undefined and that provide opportunities for both relief for individual nations and evasion of intent. The final economic impact on both nations and energy companies cannot be assessed effectively.

For the U.S., the EIA has prepared an estimate of impacts for a number of scenarios. In their reference case (no change), the EIA estimates that U.S. CO₂ emissions would exceed 1990 levels by 33% in 2020. In their most drastic case (no trade-offs), a carbon tax would be levied to cut CO₂ emissions to 7% below 1990 levels, as agreed to by President Clinton. The level of tax required...
to accomplish this was estimated to range upward to U.S. $360/metric ton of carbon (in 1996 U.S. dollars) beginning in 2004 and peaking in 2008. Converting this to numbers that are more meaningful to the general public, the carbon tax would be U.S. $0.86/gal for gasoline, U.S. $5.33/Mcf for natural gas, and U.S. $219/short ton for coal. Compared with 1996 prices, this is a 70% increase in the price of gasoline, a 225% increase for natural gas, and 69% for coal.

ENERGY ALTERNATIVES TO FOSSIL FUELS

It seems credible to believe that the actual physical shortages and price increases experienced during the oil crises of 1973 and 1979–80 would have provided fertile ground for large-scale replacement of fossil fuels by alternative sources of energy. In fact, this did not happen. Beginning in 1986, oil prices dropped and stabilized at only twice, in real terms, their pre-1973 level and seemingly unlimited availability was restored. More important, perhaps, was absence of any viable substitute that was cost-effective and available in quantity.

The largest nonfossil-fuel components of world energy supply today are nuclear at 7% and hydropower at less than 3%. Both existed before the 1970s energy crisis. Nuclear power has subsequently grown significantly worldwide, but hydropower has not. For the future, use of nuclear power is projected to decrease slightly, and the only large new hydropower project under construction is the Three Gorges dam in China.

Since the end of the oil crisis in 1985, nonfossil-fuel use in the U.S. increased from 11.3% of total energy supply to 15.0%, but this is essentially all nuclear and hydropower, neither of which is expected to increase in the future. In fact, nuclear power is expected to drop dramatically early in the next century as existing licenses to operate expire.

Geothermal energy supplied 0.31% of U.S. energy in 1985; that has dropped by approximately half to 0.17% today. All other sources used to generate commercial electric power (wood, waste, wind, photovoltaic, and solar) almost doubled, from a minuscule 0.023% to a still insignificant 0.039% in 1997. (Although not reported on a consistent basis in 1985, some additional renewable sources of energy are now accounted for in EIA’s monthly reports.) In 1997, these amounted to 3.165 quads or 4.4% of total energy use and consisted of wind, biofuels, solar, and some additional hydroelectric and geothermal energy.

Essentially, only three alternatives to continued heavy dependence on fossil fuels exist for the future: solar (including wind, water, and biomass), nuclear, and conservation. It might be argued that geothermal and tidal energy can, and are, also being harvested, but the actual level of use and the potential for future exploitation appears to be inconsequential. Both solar and nuclear power (in the form of plutonium-based breeder reactors) actually have the potential to supply almost unlimited power. However, increased nuclear power, particularly plutonium, has essentially been ruled out by all nations because of both environmental and terrorist or rogue-nation concerns. To date, solar power, including wind, other than hydroelectric power (whose growth is limited by both environmental concerns and limited future sites), has succeeded in penetrating only a few small niche markets, such as wind-generated electricity and solar cells for small power loads at remote sites. Biomass and geothermal energy seem similarly limited for large-scale application.

Barring a significant technology breakthrough in either renewable-energy availability or cost, fossil fuels appear to be the only real choice well into the next century. Indeed, the EIA forecast for 1995 to 2015 shows use of fossil fuels growing at 2.3% annually, with use of all other fuels (including nuclear and renewables) growing roughly half as fast at 1.3%.

CONCLUSIONS

1. The Industrial Revolution and the huge increase in productivity associated with massive use of fossil fuels increased the total wealth in those nations that experienced them and resulted in an even greater disparity in wealth among nations than within them.
2. Increasing wealth correlates directly with improved living standards in nearly every dimension, from infant, child, and maternal mortality to life expectancy, as well as with increased access to all levels of education and to greatly improved health care.
3. National wealth correlates well with rate of energy consumption, as does rate of growth or decline in a national economy with rate of growth or decline in energy use.

4. Fossil fuels have dominated the energy needs of the Industrial Revolution since its earliest days (coal only at first; today, oil and gas use is twice that of coal).
5. Contrary to many current predictions of the imminent end of cheap oil, oil reserves (and gas and coal reserves) continue to increase at a faster rate than production. In addition, real oil prices are near a modern-day low, and exploration and development costs are less than U.S. $5/bbl, down by two-thirds in the last 20 years.

6. Technology, where applied, has largely eliminated pollution from automobile exhausts and power-plant smokestacks, but concern over growth of CO₂ content in the atmosphere has resulted in the Kyoto Protocol to cut fossil-fuel emissions by wealthy industrialized nations 5% (7% for the U.S.) below 1990 levels by about 2010 rather than an expected growth of 30% or more.

7. Basis for the Kyoto Protocol is an IPCC report estimating a potential increase in global temperature attributable to human activities of less than 2°F to more than 5°F during the next century. Two more fundamental questions have not been addressed: the combined net effect of human and natural temperature changes over the next century and whether a cooler or a warmer climate is better for life on Earth.

8. The industrialized nations produce seven times as much CO₂ per capita than do the poorer nations. This is the egalitarian basis for limiting future CO₂ emissions of the industrialized nations but not the underdeveloped ones.

9. By contrast, the poorer countries generate three times as much CO₂ per unit of GNP, meaning that the Kyoto Protocol pits overall worldwide economic growth with its benefits to all mankind against CO₂ production in a counterproductive manner.

10. In the absence of significant technological or economic breakthroughs, the only alternatives to fossil fuels as significant sources of energy early in the next century are nuclear and hydropower, both in political and environmental disfavor by much of the world.

11. Coal produces about twice as much CO₂ per BTU as gas; oil is approximately midway between. Gas, then oil, is the preferred fossil fuel to meet Kyoto Protocol limits.

12. Superficially, the Kyoto Protocol and likely successor international agreements designed to limit the growth of CO₂ in the atmosphere seem to spell the end of fossil fuels. On balance, they are likely to prove beneficial to the oil and gas industry, particularly organizations with a strong, sophisticated international presence; the ability to understand and manage tradeoffs (and their definitions); and the talent to find and produce oil and gas inexpensively.

13. The immense benefits of economic development for the well-being of mankind, the essentiality of energy to development, plentiful oil and gas supplies, their superiority over coal for CO₂ emission mitigation, and the current absence of any really viable alternatives ensures a strong demand for low-cost oil and gas.
TUBULAR UPDATE

and 2,500 psi snubbing pressure, and (4) 27/8-in. OD for 5,000 psi working pressure and 2,500 psi snubbing pressure.

Previous testing indicated promising results for workover applications, but extensive simulated application testing has been required to determine the true operating envelope, to understand material behavior in complicated combined- and cyclic-loading situations, and to determine safe working life in normal operating conditions.

GENERAL DEVELOPMENTS

Chemical Compatibility. Design flexibility is provided by the large number of liner materials available for advanced-composite CT. The liner material selected for the initial full-scale tests was chosen for its wide range of tolerance to chemicals normally used in the well-servicing industry. Temperature capacity and chemical compatibility are significant design factors. Liner cost varies depending on application needs. Low-cost liners can be used for low-temperature applications. More expensive liners have a broader chemical resistance and temperature application range.

Matrix and fiber material is being tested for compatibility to confirm the chemical resistance of the tubing. Available literature indicates that the constituent materials (carbon, glass, and aramid fibers and epoxy resin) of advanced-composite CT are highly resistant to chemicals. However, system reaction is still being tested for compatibility with brines (NaCl, CaCl₂, CaBr₂), methanol, diesel, H₂S, CO₂, crude oil, gas condensate, corrosion inhibitors, xylene, HCl, and other acids and combinations of acids.

Connectors. A novel connector for the composites was developed by use of design technology from existing steel-CT service-tool connectors. This connector design has exceeded the rating of the CT body itself in combined axial-tension and burst-pressure tests. The service connector has worked reliably and is very simple to install and remove in a field environment. The connector is constructed of corrosion-resistant materials, and the design is well suited to both well-servicing and completion strings. The connector also has been adopted as the standard test connector (Fig. 2) for all product proof testing and as the real core-end-connector termination.

CONCLUSIONS

The first commercial strings of advanced-composite CT for well servicing and completions are in the final stages of qualification. Standard product designs have been established, as well as standard qualification procedures. In some applications, advanced-composite spoolable pipe will cost more than conventional steel tubulars; but in applications where excellent corrosion resistance is required, the benefits of a seamless, corrosion-resistant composite pipe may warrant the additional pipe cost. In well-completion applications, improved flow performance and reduced installation cost because of the speed and ease of installing a continuous pipe string instead of jointed tubulars can make the economics favorable compared with corrosive-resistant material, such as 1%chrome-type tubulars. In well-servicing operations in harsh environments, the savings from using corrosion-resistant composite CT can exceed the additional cost of the pipe.

Please read the full-length paper for additional detail, illustrations, and references. The paper from which the synopsis has been taken has not been peer reviewed. Copyright 1998 Offshore Technology Conference.

MANAGEMENT
(From Page 54)

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REFERENCES


SI METRIC CONVERSION FACTORS

bbl × 1.589 873 E −01 = m³
ft³ × 2.831 685 E −03 = m³
°F (°F − 32)/1.8 = °C
gal × 3.785 412 E −03 = m³
ton × 0.070 316 E +00 = Mg

*Conversion factor is exact.

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