# RATIONALE FOR CONTINUING R&D IN DIRECT COAL CONVERSION TO PRODUCE HIGH QUALITY TRANSPORTATION FUELS

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## ABSTRACT

For the foreseeable future, liquid hydrocarbon fuels will play a significant role in the transportation sector of both the United States and the world. Factors favoring these fuels include convenience, high energy density, and the vast existing infrastructure for their production and use. At present the U.S. consumes about 26% of the world supply of petroleum, but this situation is expected to change because of declining domestic production and increasing competition for imports from countries with developing economies. A scenario and time frame are developed in which declining world resources will generate a shortfall in petroleum supply that can be alleviated in part by utilizing the abundant domestic coal resource base. One option is direct coal conversion to liquid transportation fuels. Continued R&D in coal conversion technology will result in improved technical readiness that can significantly reduce costs so that synfuels can compete economically in a time frame to address the shortfall.

## BACKGROUND

The United States continues to rely heavily on liquid fuels for transportation, and, in spite of the strong interest in using alternative fuels, hydrocarbon liquids will continue to play a significant role in our energy future. This is primarily because of their convenience, high energy density, and the enormous infrastructure in place for their production, distribution, and end-use. Currently, the U.S. consumes about 17.5 million barrels per day (BPD) of oil (about 35 quads/yr - 1 quad/yr equals approximately 500,000 BPD). Of this, 75% is used by the transportation sector.

Current domestic crude production is 6.6 million BPD, having steadily declined from 9 million BPD ten years ago at a decline rate of about 3%/yr. Currently, the U.S. imports over 50% of its petroleum, and the Energy Information Administration (EIA)[1] predicts that this will increase to 68% by the year 2010.
The U.S. currently uses 26% of the world's total petroleum production. Even if this percentage were to remain constant, a signif-

icant shortfall in the petroleum supply in the U.S. is likely to occur because of declining domestic production. Because of competition from rapid economic development worldwide, the U.S. may not be able to import sufficient oil to meet future demand.

Coal resources in the U.S. are enormous. EIA estimates total reserves at 1.7 trillion short tons. Coal represents an inexpensive, domestic resource that can be used as a feedstock to produce clean, high-quality transportation fuels in an environmentally sound manner.

The Department of Energy (DOE) Fossil Fuel Energy's R&D program has been largely responsible for technological improvements in coal liquefaction in the U.S. The goal of the DOE program is to develop and demonstrate coal liquefaction technology that is competitive with crude oil at $25-30/bbl in 1993 dollars. The purpose of this program is to reduce vulnerability to energy supply disruptions, to create new high wage jobs, and to do this while respecting the environment.

THE WORLD ENERGY PICTURE

At the last World Energy Congress meeting in 1992[2], MITRE presented a world energy demand model that was used to estimate total commercial world energy demand to the year 2100. If energy use efficiency does not improve, estimated world demand will reach 2,090 quads by 2100. If energy conversion and end-use efficiencies continue to improve, the world's commercial energy demand will be reduced from 2,090 quads in the no-efficiency-improvement case to about 1,050 quads in 2100. However, even with efficiency improvements, world energy demand will still increase three-fold over the present level of 350 quads per year.

The question is whether this demand can be satisfied with known energy resources. To answer this, the world resources of oil and natural gas must be determined. The United States Geological Survey[3] estimates the world's ultimate resource of conventional oil as 1.7 trillion barrels (about 10,000 quads). Estimates for natural gas are less certain; therefore, a range was assumed: 10,000-20,000 trillion cubic feet[4] (TCF) (10,000-20,000 quads).

Figure 1 shows resource depletion curves. By 2100 oil will be essentially depleted, and natural gas will either be depleted or in rapid decline. Although not shown on the figure, coal availability worldwide is enormous. Estimates range from 45,000 quads[5] for proved reserves to 240,000 quads[6] for the total resource, between 500 and 2000 years supply at current usage rates.

The estimated conventional fossil energy resource and the postulated world energy demand/supply scenario can be combined to produce a world energy demand/supply scenario as shown in Figure 2. In this scenario, it is assumed that oil, gas, and present day nuclear use follow the depletion curves shown, coal use remains constant at the present level, and hydroelectric power supply triples between now and the year 2100. The area designated as "21st Century" represents the energy shortfall. In this constant coal use scenario, the shortfall will have to be supplied by advanced nuclear energy technologies and renewable or sustainable energy technologies.

Figure 2 shows that before the year 2030, and perhaps as early as 2010, the demand on world oil is such that supply cannot keep pace, and the world oil supply starts to decline. This scenario is optimistic, since it assumes that world oil use is essentially constant from the present to 2030. However, world oil use is actually increasing, so that the imbalance of oil supply and demand will occur before 2030. If the world energy demand scenario presented above is credible, then the world may have less than 30 years before a significant shortfall in conventional liquid fuel supplies occurs.

THE UNITED STATES ENERGY PERSPECTIVE

Let us now concentrate on the situation in the U.S. The U.S. annually produces about 17 quads of domestic crude oil and natural gas liquids (NGL), and this production is declining. Figure 3 shows a resource depletion scenario from the present to the year 2100 for oil, natural gas, and power from current nuclear plants (nuclear energy from current technologies is assumed to phase out over the time period shown). It is evident from Figure 3 that the declining domestic energy supply, especially liquid fuels, must be made up by expanding petroleum imports or by increasing the use of our domestic coal reserves.

The ability of the U.S. to import oil may be limited. Two import scenarios which may be applied to the U.S. energy situation from now until 2050 are (1) the U.S. will continue to consume 26% of total world petroleum and (2) the U.S. will import a fraction of the world's oil that is proportional to the U.S. GDP compared to the world GDP. In both cases, the supply of oil to the U.S. declines early in the next century.

Two U.S. demand scenarios may be considered. The higher demand scenario is from the EIA, and the essentially constant demand scenario is from the MITRE energy model. Depending on which scenario is selected, a shortfall in petroleum supply (domestic production plus imports) begins somewhere in the 2005-2015 time period and becomes significant by 2010-2030. The probable shortfall is between 1 and 3.5 million BPD in 2030. This is illustrated in Figure 4.

MEETING THE SUPPLY SHORTFALL

One alternative to meet this supply shortfall is to produce liquid fuels from coal. In direct liquefaction, coal reacts with hydrogen in a hydrogen donor solvent vehicle to produce a distillate product that can be refined into liquid transportation fuels. The product from direct coal liquefaction is easy to refine because it is an all-distillate, low sulfur and nitrogen liquid. Transportation fuels that meet the strict environmental regulations expected to be in force in the next century can be made from domestic coals.

If coal conversion is to play a significant role in alleviating the liquid fuel supply problem before the year 2030, then the liquefaction technologies must be in a state of readiness for commercial deployment about 15 years earlier, because lead times for the introduction of new energy technologies are on the order of 10 to 15 years, even after the technologies are technically ready for commercial deployment. Although direct liquefaction technology has undergone very significant improvements over the past decade and achieved a high level of technical readiness, it is still not cost competitive. Therefore, continuing R&D is needed to reduce costs to meet the target of 2015 for the start of commercial deployment. Further R&D can achieve additional process improvements to permit earlier introduction of coal-derived transportation fuels into the marketplace.

Current liquefaction program activities cover all aspects of technology development from basic and exploratory research through bench-scale operations to proof-of-concept (POC) demonstration. The four integrated elements of the direct liquefaction program are. development of the catalytic two-stage direct liquefaction process, coprocessing development, advanced liquefaction concepts development, and POC (3 ton/day) testing of promising technologies.

To help identify the high-cost elements of direct coal liquefaction, DOE contracted with Bechtel[7] to develop a conceptual commercial design of a direct coal liquefaction facility to produce hydrotreated distillate products from either bituminous or subbituminous coal. The Bechtel design, which represents the current state of the art for direct liquefaction, yielded a cost of about $34/bbl of crude oil equivalent (COE). Although higher than the present world oil price (WOP) of about $17/bbl, this cost is significantly lower than earlier estimates of $40-50/bbl because of process improvements from the R&D undertaken over the last decade. Because direct liquefaction technology is still evolving and additional process improvements are expected, costs will decrease further as improvements are incorporated.

THE IMPACT OF CONTINUING R&D ON DIRECT COAL LIQUEFACTION COSTS

Table 1 shows the elements of cost for the baseline direct liquefaction conceptual commercial plant and the estimated reduction in cost that can be achieved by further R&D. Areas of most importance in reducing costs include decreasing capital investment, improving product yields, and reducing catalyst cost.

Several opportunities are available for reducing capital investment, such as increasing space velocity to reduce the number of liquefaction reactor trains and improving $H_2$ production. Replacing the current ebullated bed reactors with slurry reactors decreases the COE cost by about $1-2/bbl. By employing advanced technologies now under development, the capital cost of $H_2$ production can be decreased by an estimated 12% with a resulting decrease in the COE cost of about $1/bbl.

Product quality improvement is equally important. One way to do this is to increase the yield of products boiling below 850°F. An increase of 10% in these products will decrease the COE cost by about $3/bbl. Catalyst costs are a significant contributor to product costs. If 90% of the catalyst can be recovered and reused, the COE cost will be reduced by about $2/bbl.

The high probability of achieving the improvements discussed above suggests that a $6/bbl decrease in the COE price to about $28/bbl is readily achievable. The R&D strategy is to concentrate efforts over the next few years in the high potential areas listed above. With no further R&D, direct coal liquids will remain at the Bechtel baseline cost of about $34/bbl of COE, and coal liquids would not be competitive with petroleum until 2030. With continued R&D, the cost of direct liquids will be reduced to about $28/bbl ($0.67/gal) and be competitive in 2017, 13 years earlier.

STRATEGY FOR DEVELOPING A COMMERCIAL COAL LIQUEFACTION INDUSTRY

Once cost competitiveness is achieved, the next step is to achieve commercialization. Initial pioneering production of coal-derived transportation fuels will require a capital expenditure of $3.8 to $4.6 billion for each plant to produce about 70,000 BPD of liquid fuels; it may require five to seven years to achieve full production. Because of the costs involved, coal-derived liquid fuels will probably not make a major contribution to the nation's transportation fuel needs until a significant imbalance between crude oil supply and demand occurs, expected sometime between 2015 and 2030.

The liquefaction plants to produce coal-derived fuels will be designed to meet the highest standards for environmental compliance. The transportation fuels produced by coal liquefaction technologies will be environmentally superior to their petroleum-derived counterparts and will be capable of meeting all requirements of the 1990 Clean Air Act Amendments. Coal liquefaction technologies can also be utilized to co-convert wastes, such as plastics, to environmentally acceptable fuels.

The key to commercialization will be integration with the existing petroleum refining/distribution infrastructure. In achieving commercialization, two intermediate technologies are important. The first is coprocessing of petroleum-derived wastes (plastics, tires, waste oil) with coal. Development of this technology is being driven by dwindling landfill availability and increases in tipping fees. These additional incentives may permit early implementation of this technology. The second technology is coprocessing of coal with heavy petroleum resids or oils. This technology is seen as being commercially feasible as a mid-term option and is likely to account for the first production of coal-based transportation fuels in existing petroleum refineries.

## THE CONTRIBUTION OF DIRECT COAL LIQUEFACTION TO THE U.S. ECONOMY

If construction of coal liquefaction plants can be initiated in the year 2012, one million BPD capacity could be in place by 2030. Although direct coal liquefaction would only provide a portion of the energy mix needed to address the U.S. shortfall, production of high quality transportation fuels from U.S. coal will constitute a new and growing domestic industry that will employ engineering and construction personnel, plant operators, coal miners, and related workers. An estimated 333,000 jobs would be created by a one million BPD industry.

Demonstrating the ability to produce coal-derived transportation fuels at $28/bbl by the year 2010 could have the effect of moderating the world oil price at $28/bbl from 2017 onwards with consequent savings to the U.S. economy of up to $200 billion (1993 dollars) between 2015 and 2030. An R&D program that can reduce dependence on oil imports, help in providing national energy security, provide domestic jobs, and save $200 billion in balance of payments is a sound investment in the nation's future.

## CARBON DIOXIDE EMISSIONS

Concern has been expressed that increased coal use will result in excessive emissions of carbon dioxide into the atmosphere; thereby exacerbating the potential for global warming. Figure 5 shows the energy mix that will result in no further increase in annual carbon dioxide emissions in the U.S. over the present. This figure shows that, because of the decrease in oil and gas, coal use can be increased substantially after 2015 with no net increase in annual carbon dioxide emissions. Coal use can be increased by about 7 quads over present consumption by 2030 with no further increase in carbon dioxide emissions. If this amount of coal were used for production of liquid fuels, about two million BPD of coal-derived fuels could be produced.

## CONCLUSION

Because of the long-term nature of the market opportunity and the consequent long wait for return on investment, without government participation, private industry is unlikely to fund these activities. Therefore, continued government support for laboratory, bench, and POC activities is essential to continue the development of transportation fuels from coal.

The analysis presented in this paper clearly shows that the world will need substantial amounts of "new" energy to continue economic progress in the next century. The U.S. has the opportunity to develop coal liquids technology that will help ensure our continued economic prosperity by creating a new industry with highly skilled jobs and providing opportunity for export of U.S. technology on the world market without compromising environmental quality.

**References**


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3. USGS, 14th World Petroleum Congress, Norway, May 1994.
4. Masters, C.D., "Oil and Gas - Where in the World and Why?" 8th V.E. McKelvey Forum on Mineral and Energy Resources, Houston, TX, February 1992.
5. World Resources Institute, "People and the Environment," Oxford University Press, 1994.
6. Institute of Gas Technology, "World Reserves Survey 1987," 1989.
7. Bechtel and Amoco, "Direct Coal Liquefaction Baseline Design and System Analysis," report prepared for DOE under Contract DE-AC22-90PC89857, March 1993.


Table 1. Estimated Cost Impact of Continued R&D on Direct Liquefaction

| Cost Elements, $MM | Baseline 28,776 tpd | Increased Space Velocity | Improvement in Yield | Catalyst Recovery & Recycle | Improvement in Hydrogen Production |
|---|---|---|---|---|---|
| Coal Handling | 222 | 222 | 226 | 226 | 226 |
| Liquefaction | 941 | 762 | 762 | 822 | 822 |
| Gas Cleanup/Byprd Rec. | 297 | 297 | 297 | 297 | 297 |
| Product Hydrotreating | 107 | 107 | 113 | 113 | 113 |
| ROSE Unit | 46 | 46 | 43 | 43 | 43 |
| Gasification | 334 | 334 | 342 | 342 | 302 |
| Air Separation | 244 | 244 | 250 | 250 | 220 |
| ISBL Field Cost | 2192 | 2013 | 2034 | 2094 | 2024 |
| OSBL Field Cost | 978 | 978 | 981 | 978 | 968 |
| Total Field Cost | 3170 | 2991 | 3015 | 3072 | 2992 |
| Total Capital | 3889 | 3669 | 3699 | 3768 | 3670 |
| Refined Product Cost, $/bbl | | | | | |
| Capital* | 23.61 | 22.25 | 20.37 | 20.77 | 20.23 |
| Coal | 7.84 | 7.85 | 7.51 | 7.51 | 7.51 |
| Catalyst | 2.57 | 2.58 | 2.33 | 0.23 | 0.23 |
| Natural Gas | 3.59 | 3.45 | 2.90 | 2.74 | 2.69 |
| Labor | 1.66 | 1.67 | 1.51 | 1.51 | 1.51 |
| Other O&M | 0.33 | 0.33 | 0.29 | 0.29 | 0.30 |
| By-Product Credits | (4.18) | (4.05) | (3.43) | (3.29) | (3.25) |
| RSP | 35.42 | 34.08 | 31.48 | 29.76 | 29.22 |
| Quality Premium | (1.19) | (1.19) | (1.19) | (1.19) | (1.19) |
| COE | 34.23 | 32.89 | 30.29 | 28.57 | 28.03 |
| Plant Output, million bbl/yr | 24.16 | 24.16 | 26.58 | 26.58 | 26.58 |

*Includes maintenance materials, taxes, and insurance.

Figure 1

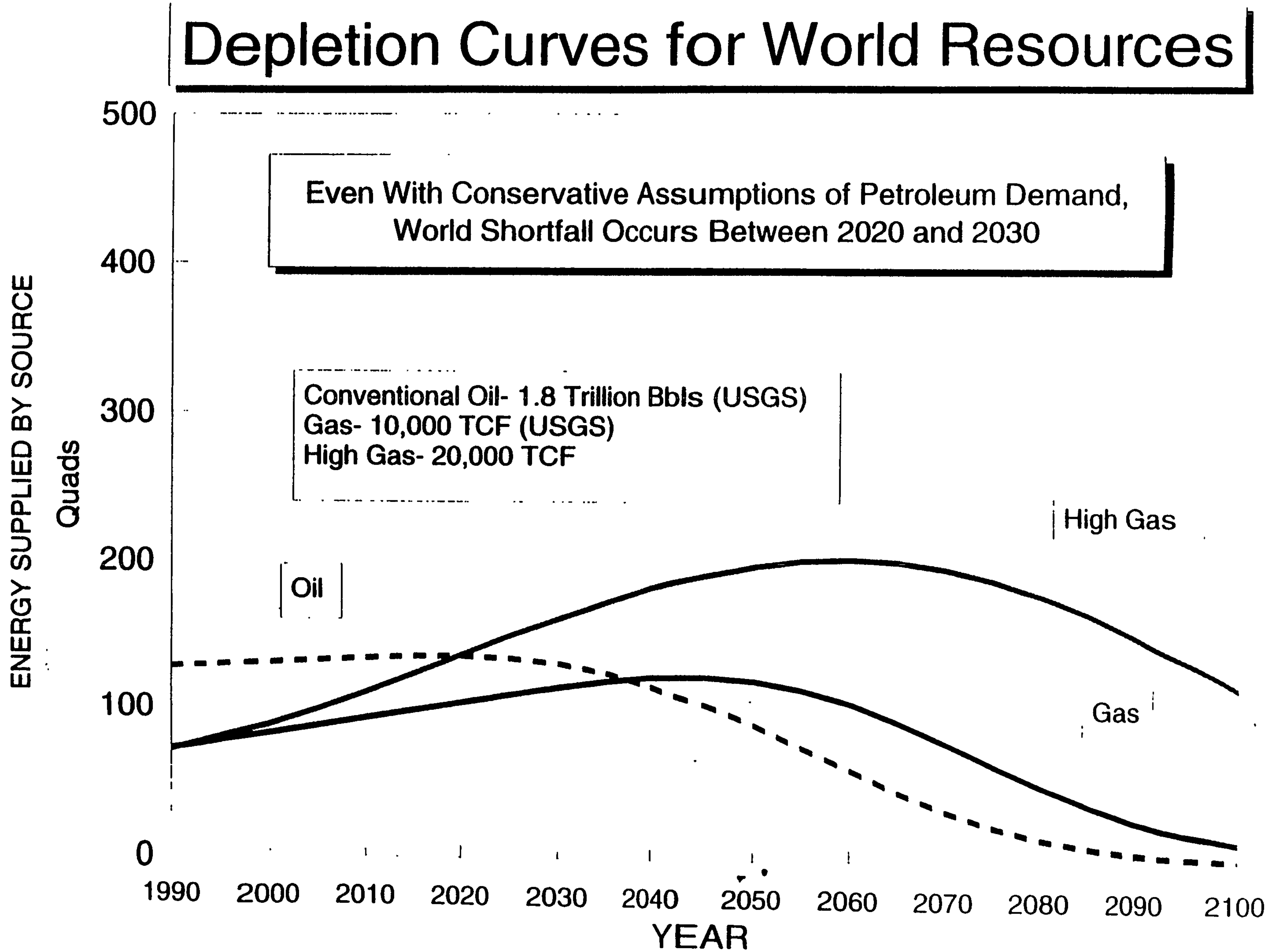

Depletion Curves for World Resources
Even With Conservative Assumptions of Petroleum Demand, World Shortfall Occurs Between 2020 and 2030
Conventional Oil- 1.8 Trillion Bbls (USGS)
Gas- 10,000 TCF (USGS)
High Gas- 20,000 TCF
Oil
High Gas
Gas
ENERGY SUPPLIED BY SOURCE
Quads
500
400
300
200
100
0
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
YEAR

Figure 2

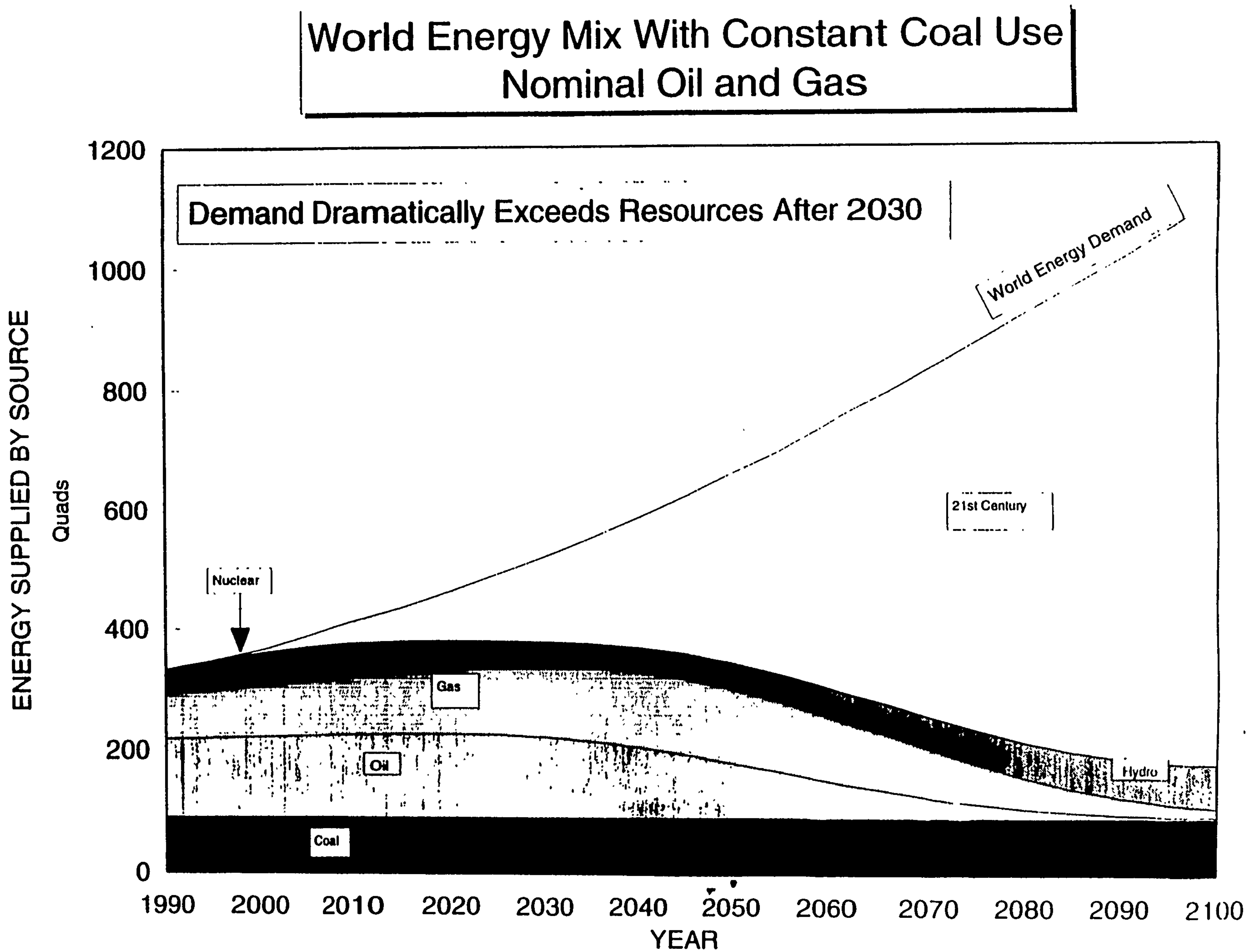
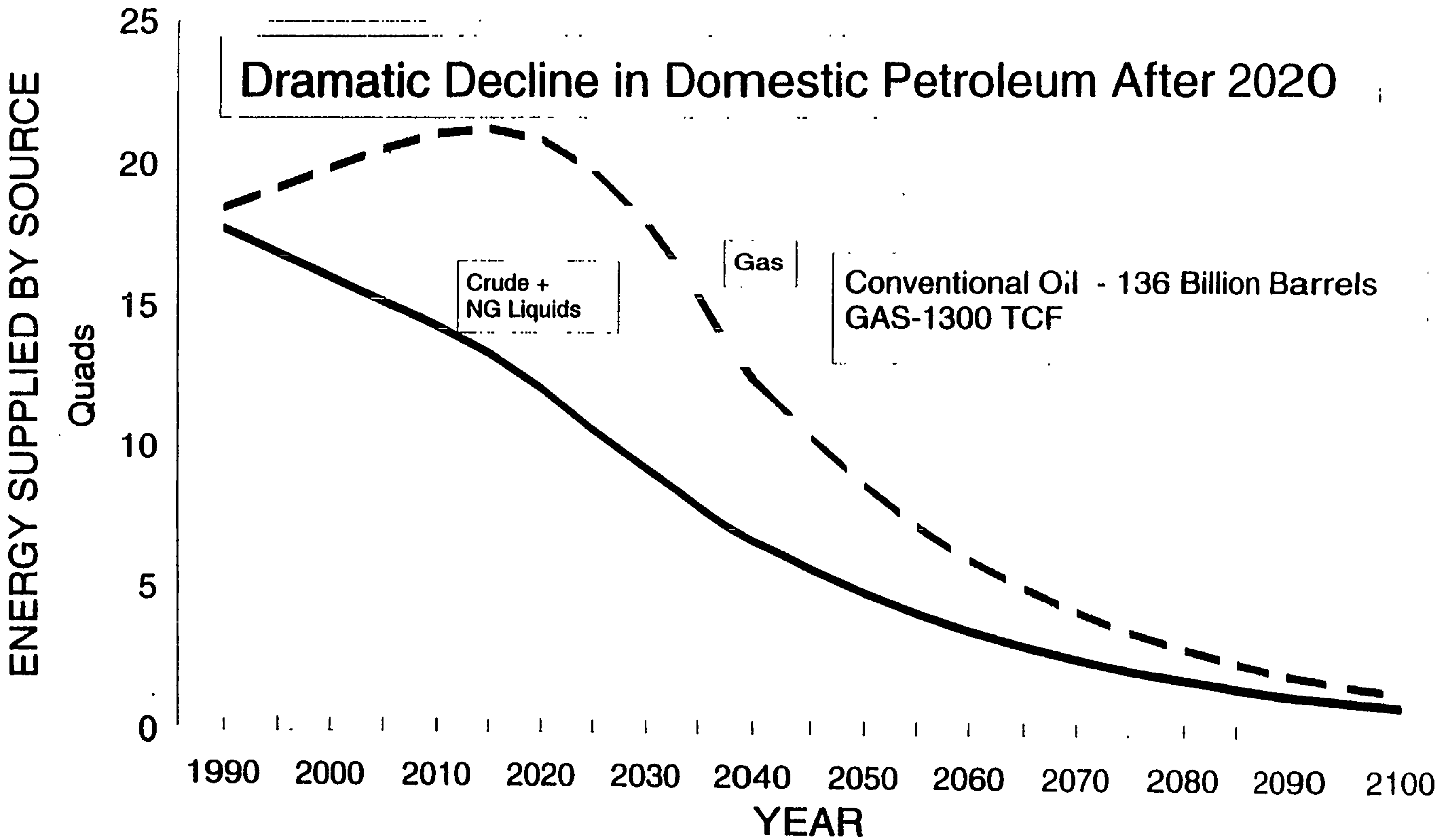

World Energy Mix With Constant Coal Use
Nominal Oil and Gas
Demand Dramatically Exceeds Resources After 2030
World Energy Demand
21st Century
Nuclear
Gas
Oil
Hydro
Coal
ENERGY SUPPLIED BY SOURCE
Quads
1200
1000
800
600
400
200
0
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
YEAR

Figure 3

# Projected U.S. Energy Production




EIA Projections to 2010 Followed By MITRE Projection Of Resource Depletion

Figure 4

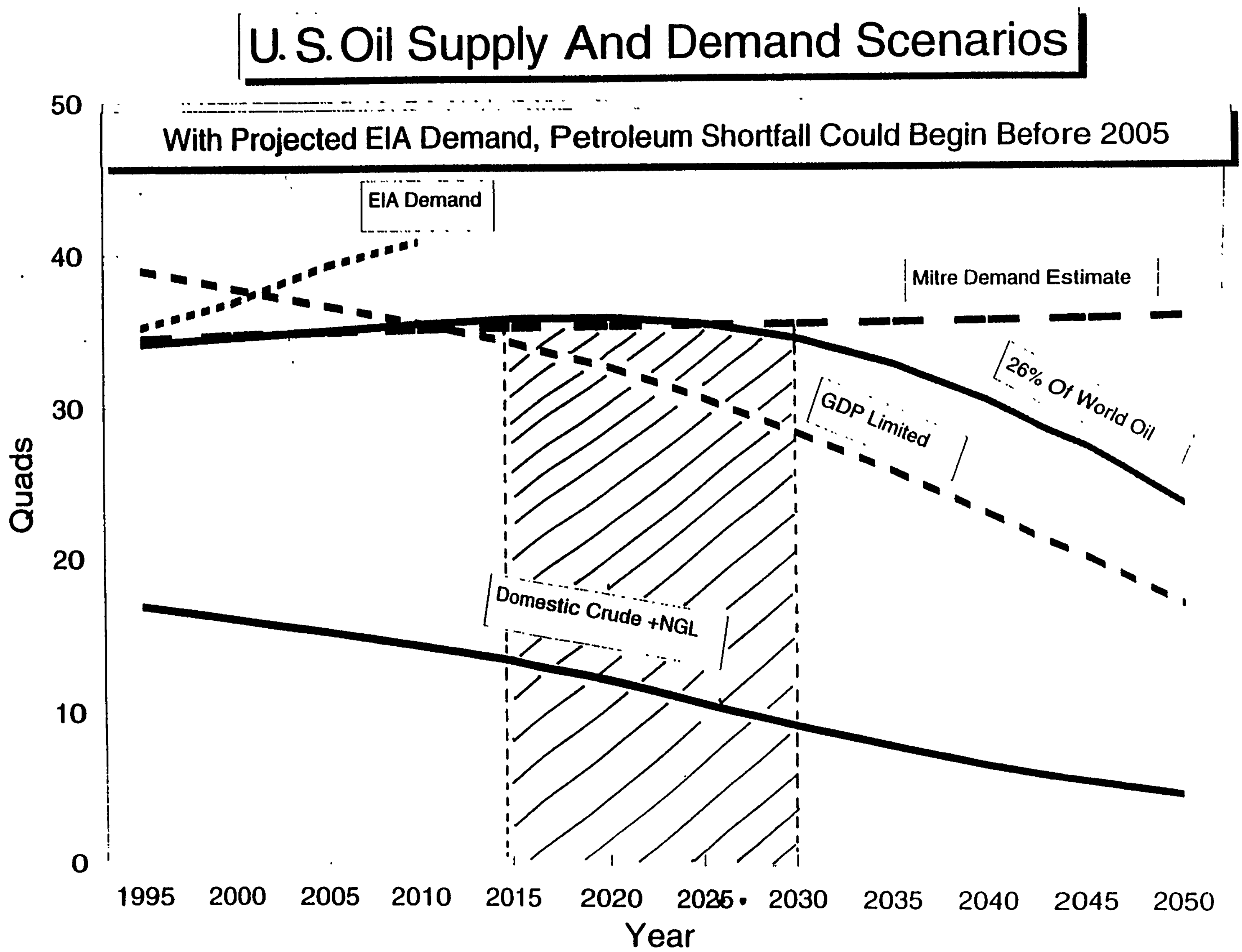
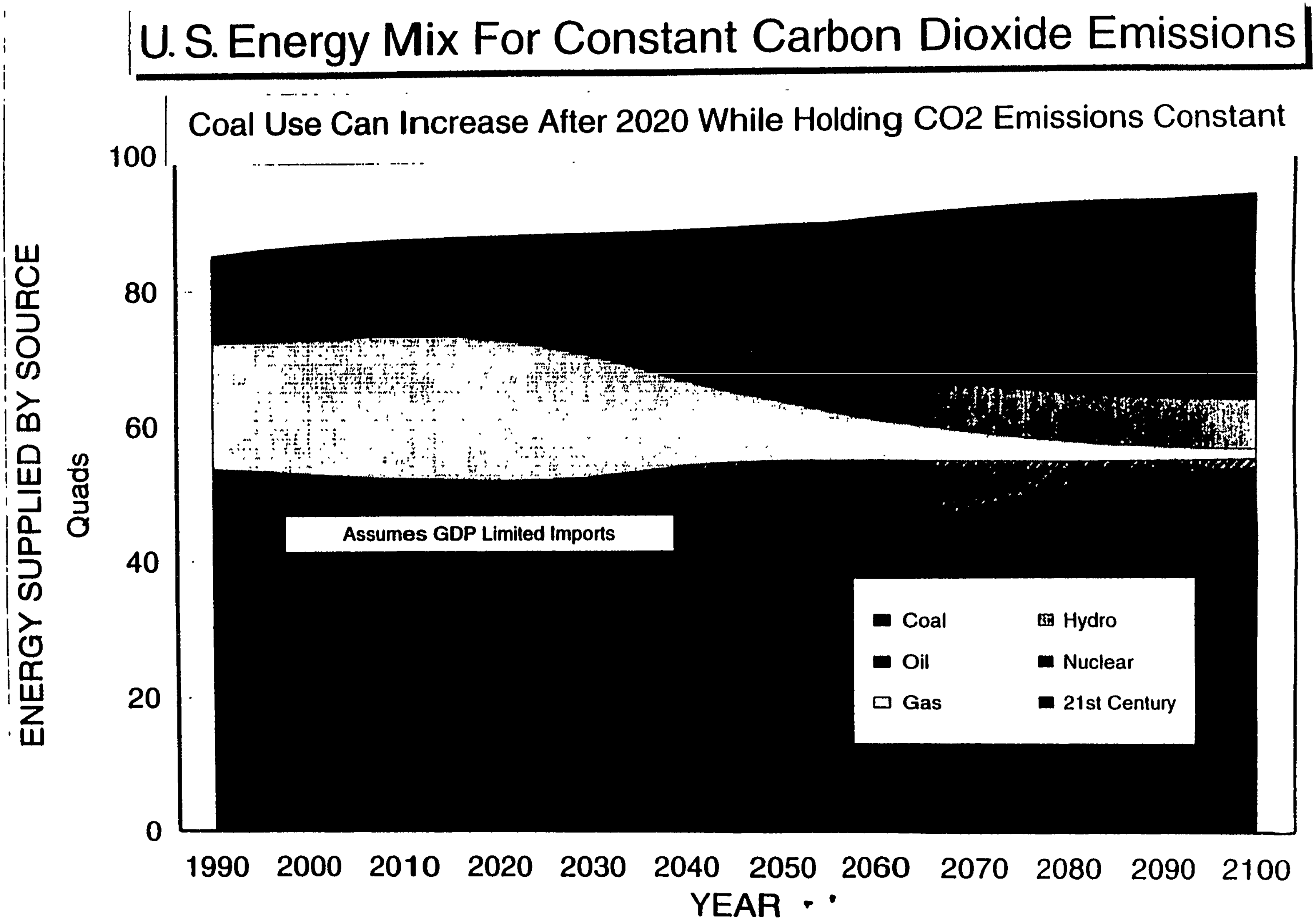

U.S. Oil Supply And Demand Scenarios
With Projected EIA Demand, Petroleum Shortfall Could Begin Before 2005
EIA Demand
Mitre Demand Estimate
26% Of World Oil
GDP Limited
Domestic Crude +NGL
Quads
0
10
20
30
40
50
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Year

Figure 5


U.S. Energy Mix For Constant Carbon Dioxide Emissions
Coal Use Can Increase After 2020 While Holding CO2 Emissions Constant
ENERGY SUPPLIED BY SOURCE
Quads
100
80
60
40
20
0
Assumes GDP Limited Imports
Coal
Oil
Gas
Hydro
Nuclear
21st Century
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
YEAR