Technology Vision 2020

A report on technology and the future of the U.S. petroleum industry

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ACKNOWLEDGMENT

This technology vision for the United States downstream petroleum industry makes use of an extensive study conducted by the National Petroleum Council (NPC): *Future Issues — A View of US Oil & Natural Gas to 2020.* This vision was prepared as a working document for the API Technology Committee. Sections of *Future Issues* have been incorporated into this document.

EXECUTIVE SUMMARY:

THE U.S. PETROLEUM industry helps meet our nation's energy needs and is a key component of our nation's economy. But its future is filled with uncertainties. Environmental concerns, market forces, and the need for increased efficiency will play a large role in determining the future use of petroleum. One thing is certain: the petroleum industry must be proactive in anticipating and adapting to change.

Our vision is to apply technology to ensure that America has an adequate supply of fuels that are clean, safe, efficient, and competitive. It will take the cooperative efforts of the petroleum industry, universities, technology suppliers, the Department of Energy, and the national laboratories to ensure that technology advances are identified, developed and applied in order to achieve this vision.

This document describes the petroleum industry's role in today's economy and discusses the industry's future research needs. The scope of this vision is for the downstream petroleum industry— that is the refining, distribution, and marketing components of the petroleum business. However where technology needs are identified that also can benefit the upstream segment (exploration and production), these benefits are cited.

Portions of this vision were excerpted from two National Petroleum Council (NPC) reports published in August 1995: *Future Issues—A View of US Oil and Natural Gas to 2020* and *Research Development and Demonstration Needs of the Oil and Gas Industry*. Please refer to both for a more comprehensive view of the U.S. oil and gas industry.

INTRODUCTION:

THE U.S. PETROLEUM industry helps meet the nation's energy needs. It has three components. The exploration and production component finds and produces natural gas and oil that flow through pipelines to refineries or other customers. The refining component makes finished products and chemical feedstocks from crude oil and natural gas. The marketing component distributes and sells finished products to customers. Each of these components continues to undergo dramatic technological changes.

There are important efforts underway at DOE and elsewhere to accomplish similar goals to this initiative for the Upstream Petroleum Industry. DOE has developed a set of *Initiatives for Energy Security,* in response to the recent difficulties caused by low commodity prices, that includes strategies to enhance America's energy security, preserve domestic oil and gas production capacity, lower costs of production, and improve government decision making. Additionally, DOE has initiated other programs as part of its *Comprehensive National Energy Strategy,* adopted last year, which established a number of important goals for the upstream industry, including stabilizing domestic oil production, maintaining the readiness of the Strategic Petroleum Reserve, diversifying import sources to reduce the vulnerability of the U.S. economy to disruptions in oil supply, increasing domestic gas production, and recovering oil with less environmental impact.

There are also two NPC studies ongoing that are coordinated by the DOE's Offices of Policy and Fossil Energy: A Natural Gas study (upstream and downstream), and a Refining study. NPC will start a third study, Critical Infrastructure Protection (upstream and downstream) soon, that will be coordinated by Fossil Energy. Additionally, the administration has established an Interagency Working Group on Energy that will address priority tax, regulatory, and federal land issues for the industry. The interagency group includes, among others, the Departments of Energy, Treasury, Interior, and Commerce, as well as EPA.

Technology Vision 2020

A REPORT ON TECHNOLOGY AND THE FUTURE OF THE U.S. PETROLEUM INDUSTRY

Industry's Role in the Nation's Economy:

THE PETROLEUM industry is an important component of the U.S. economy. It provides fuels for transportation and for heating and industrial uses, as well as raw materials for the chemical industry. The U.S. petroleum industry has developed technologies that have been adopted around the world, such as catalytic processes, advanced materials science, and fuels that deliver better performance and reduce emissions.

In addition to offering thousands of well-paid jobs, the petroleum industry directly contributes significantly to the U.S. gross domestic product. Natural gas and oil provide about 62 percent of the energy consumed in the country and more than 99 percent of the transportation fuels.

Annual U.S. oil and gas production is more than 35 quadrillion British thermal units (Btu) per year, and 24 states have proved reserves of at least 10 million barrels. Oil and gas drilling activities occur in 26 states, and offshore production of oil is on the rise.

Reserves are being found in more remote areas on land and in deeper water offshore, while society has placed many other promising exploration areas off limits. The U.S. share of world oil and gas production has been decreasing and is a decreasing percentage of domestic energy supply, falling below 50 percent in 1995. Coal and nuclear power are making up a significant fraction of energy production.

U.S. refineries are capable of processing more than 15 million barrels of crude oil per day. The country requires about 320 million gallons of gasoline and 147 million gallons of distillate fuel oil per day. In the last 20 years the domestic demand for jet fuel of the kerosene type has almost doubled to 1.5 million barrels per day.

In 1995, the refining industry employed about 95,000 people at 163 refineries in 33 states. These people have jobs that are, on the average safer and more highly paid than other manufacturing jobs. In recent years the number of operating refineries has decreased steadily. The quality of crude oil feedstocks has declined, and laws have mandated changes in composition of fuels with more and higher quality transportation fuels being produced.

There are 182,000 service stations in the United States, mostly run by independent business people employing nearly 2 million people. The number of stations has been steadily declining while the throughput per station is increasing. Nationwide gasoline consumption has been relatively steady, but gasoline usage per capita has been falling. Improvements in car fuel economy have largely offset the increase in miles traveled.

Key Drivers Facing the Industry:

THE DRIVERS identified as having the greatest impact on the petroleum industry in the next 20 years are:

- Environmental Concerns
- Markets and Demand
- Competitive Forces
- Process Improvements
- Energy Efficiency

Environmental Concerns

There will be continuing concerns about the lifecycle effects of petroleum fuels on the environment, such as the impact on air toxics and global climate change. Environmental rules will continue to evolve, hopefully with risk-based or prioritized approaches toward environmental concerns. The type of regulations, the approach used, and the time frame for compliance strongly influences the direction of technological development and progress. There will be focus on minimizing the production of wastes, reducing emissions, and developing more effective technologies for in-situ remediation. There will be increased interest in ensuring that environmentally related expenditures are focused on achieving cost-effective environmental benefits.

At the retail level, environmental improvements will focus on prevention of fuel exposures to the environment through better engineering controls. Reduction of engine exhaust emissions and fuel evaporation emissions will continue via regulations and better engineering and science of both cost effective automotive improvements and fuel specification adjustments.

Markets and Demand

There is general agreement that oil and gas will continue to fuel the United States and world economies well into the next century. Overlaying this driver, however, is the objective to reduce the demand for petroleum fuels by replacing them with cost effective, renewable energy sources.

Petroleum fuels will continue to dominate the transportation market, and these fuels may have to change to meet new regulatory demands. Fuel economy will improve with advances in automotive technologies and lower vehicle weight. This will be somewhat offset by the increase in vehicle miles traveled. Alternative fueled vehicles will find niche situations, but unfavorable economics will inhibit their growth.

Consumers of petroleum products have a key influence on markets and demand. The consumers of the future have expectations of quality, speed and convenience when refueling their vehicles and of safe, low-polluting, and inexpensive high performance petroleum fuels that will continue well into the next century.

Competitive Forces

Increased global competition has led to many joint ventures and mergers combining the assets of two or more companies. This has occurred in exploration and production and in refining and marketing. It has also led to refinery shutdowns as well as the shutdown of inefficient processing units. Although the crude oil refining industry is 25 percent smaller today than it was in the mid-80s, as measured by the number of operat-

US Refining Industry in 1984 and 1997[2]
(capacity and production units in million barrels per calendar day)

	1984	1997
Number of Operating Refineries	214	163
Crude Capacity on Jan. 1	16.1	15.1
Gasoline Production	6.5	7.9
Jet Fuel & Kerosene Production	1.2	1.6
Distillate Production	2.7	3.4
Residual Fuel Oil & Asphalt Production	1.3	1.0

ing refineries (see table), more transportation fuel products are being produced while the crude oil feedstock has become heavier and more difficult to refine. Yet gasoline cost less in 1995 (in inflation-adjusted 1995-dollar terms) than it cost in 1920.[1]

Process Improvements

Refineries will increasingly need capability to accommodate changes in crude slates. Operations will become more sophisticated, and new technology and new approaches will be employed. New catalytic materials will provide the basis for major improvements in existing refinery processes and will lead to new chemistry and new concepts in refining. Improved process and modeling technologies including on-line measurement technologies will allow optimization of facilities.

Bioscience will be increasingly introduced into refinery operations as the technology advances. This could provide environmental and performance improvements in fuel and chemical processing like desulfurization and demetalation of crude oils and refinery product streams.

New structural materials and nondestructive on-line testing will reduce maintenance costs and will extend the useful life of equipment. Advances in computational methods and process control will continue to make major contributions to solve problems for the design of higher quality, safer and more environmentally compatible processes and products.

Processes for safer storage, handling and delivery of fuels to consumers will evolve in the distribution and retail areas. New automated, convenient dispensing systems capable of a variety of transactions will enable the consumer of the future to save precious time.

Energy Efficiency

New technologies, market incentives, and an increase in the scale of operations will continue to improve the efficiency of energy use. Deregulation of utilities will give refineries greater flexibility to produce and sell electric power and improve their overall efficiency.

Better engine efficiency (improved miles/gallon) for consumers will be driven by mandates and competitive forces. Improvements in both gasoline and diesel engine efficiencies will result from treating the engine-fuel combination as a single entity to be optimized. New sources of energy for consumer use, such as fuel cells for cars, will be refined and optimized.

Petroleum Industry of the 21st Century:

FUTURE DOMESTIC exploration and production (E&P) will take place in more remote locations on land and in deeper water offshore. E&P will continue to be an operation dependent on cutting-edge technology such as computing power and software, materials demands, and design of novel equipment. E&P will have a reduced impact on the environment.

In the future, refineries will become even safer, more reliable, more energy efficient, and have reduced impact on the environment. They will be highly automated with integrated process and energy system controls. Products will continue to meet changing specifications set by regulators and by industry consensus responding to the demands of society. There will be increasing uses of natural bioscience processes such as biotreatment of process water, bioremediation of soil and groundwater, phytoremediation and potentially bioprocessing units. The refinery will be larger and located on the site of a current refinery.

Service stations of the future will be larger, more convenient, have higher throughput and will provide extra services. Impact on the environment will be reduced because of improvements in the fueling process and in the underground storage tank. Stations will be safer, more environmentally friendly places to work, and improvements in station construction, sizing, supply logistics and lighting will reduce the energy consumed per gallon of gasoline sold.

Performance Targets:

PROPOSED PERFORMANCE targets for the petroleum industry are as follows:

- To demonstrate continuous improvement in environmental impact on air and water, and reduce solid waste production driven by flexible metrics that focus on environmental improvement over prescriptive solutions and control tactics. Progress will be monitored through a comprehensive audit and report issued every five years beginning in the year 2000.
- To identify routes to achieve an improvement of 10 percent in manufacturing plant energy efficiency by the year 2020.
- To improve our industry's leadership position versus all U.S. manufacturing industry on appropriate measures of safety and reliability by the year 2010.

To reach these performance targets, technology must improve in a number of areas.

Technology Needs:

A NUMBER of technology areas have been identified as high priority needs for the petroleum industry. It is important to note that certain principles should guide the develop-

[1] *How Much We Pay for Gasoline*, April 1996, American Petroleum Institute.
[2] *Basic Petroleum Data Book* and *DOE/EIA Petroleum Supply Annuals.*

ment of industry-wide collaborative research efforts. These principles are outlined in the Appendix and summarized below:

- Potential users should determine if research is necessary.
- Research should develop new, pre-competitive technology.
- Research should provide a mechanism to lower the cost of compliance with environmental regulations.
- All research should benefit the public and industry as a whole.

The following areas illustrate potential research directions. The research needs have been grouped by broad subject area with environmentally driven projects listed first, followed by process improvement research needs.

There are also some technology areas in which individual petroleum companies have active research. There may also be pre-competitive projects in these technologies that meet the principles for collaborative research and may also benefit society.

Toxic Combustion By-Products

Toxic combustion by-products, or air toxics, are regulated under the Clean Air Act Amendments of 1990. One source of air toxics at oil refineries is emissions from petrochemical process heaters. A CRADA on this subject has recently been conducted by Sandia National Laboratories and other participants, and further research would be useful.

Testing for polychlorinated dibenzodioxins, dibenzofurans and biphenyls is one possibility. A project focused on dioxins is being proposed in this area.

Better Data for Decisions

Often regulations include extra levels of conservatism because of lack of data. In some cases, it may be more cost-effective to generate better data, thereby reducing the need for costly, conservative assumptions. This will help assure that the effectiveness of environmental expenditures is increased.

Examples include: the effect of surface roughness on air dispersion calculations, the effect of infiltration on the transport of contaminants through the vadose zone, the effect of bioremediation and volatilization on contaminants in the vadose zone, and determining the concentrations below which free phase liquid flow does not occur in soil.

Air Quality Modeling

Simulation models are commonly used to assess the impacts of emissions on air quality. These models range from fairly simple dispersion models used to represent releases of inert materials from a single source, to extremely complex 3-dimensional, photochemical models used to simulate atmospheric processes over a wide region.

For global climate change issues, even larger models are used. Increasingly, these models are being relied upon to estimate the effectiveness of control measures and to demonstrate compliance with air quality standards.

Yet, there are many limitations and uncertainties in their formulation and operation. Following are several particularly challenging issues:

- New national ambient air quality standards (NAAQS) have been established for fine particulate matter (PM2.5). However, PM modeling and secondary organic aerosol (SOA) formation are still in their infancy.
- New air quality standards based on long averaging times (such as annual average PM standards) require modeling over longer time periods than standards based on shorter averaging times.
- Increasing interest in pollutant transport and regional air quality concerns (such as OTAG issues) requires modeling of much larger geographic domains.
- Important atmospheric processes of different pollutants are often interrelated (especially for ozone and PM). Hence, comprehensive modeling approaches must be developed and implemented to evaluate optimum control strategies for all pollutants.
- As air quality standards become more stringent, the contributions of background pollutant levels become relatively more important. Additional work is required to determine the level and origin of background ozone and PM, and in light of this, to understand the effectiveness of control measures in attaining federal air quality standards.

Reliable air quality modeling also depends on availability of accurate emissions inventory data. Inventory development work is an on-going project with many opportunities for improvement.

PM 2.5 Standard

EPA has proposed a new air quality standard for particulate matter sized under 2.5 microns. Work is required to scientifically determine emissions and composition of such particulates from industry facilities as well as mobile sources. New sampling or analytical methods may need to be developed. Where such particles present an unacceptable risk, cost-effective control technologies or process changes will be required.

Phytoremediation

Phytoremediation looks very promising, but there is much to be learned. There is a need to determine the optimum approach for phytoremediation of polynuclear aromatic hydrocarbons, oxygenates and heavy metal contaminated soil. In addition, work is required to develop understanding of the effect of root density distributions on phytoremediations effectiveness.

Sensor Technology

DOE's National Laboratories have shown substantial expertise and research capability in sensor technology. Chemical sensors that can detect small concentrations of hydrocarbons in gas streams and physical sensors that measure temperature and pressure could be studied to determine their possible use in a processing environment.

Vehicle Emissions

Measurement of emissions from automobiles has been an excellent area for cooperative research. Under the auspices of the Coordinating Research Council, the automotive and petroleum industries are carrying out research of mutual interest. As emission standards and advanced technology vehicles are introduced, additional tests will be required. Pressure will continue for changes to be made in both gasoline and diesel fuel composition.

With the continued reduction in automobile exhaust emissions, the relative impact of fugitive gasoline emissions such as diurnal, running loss, refueling and other vapor/liquid losses becomes more of a concern. Hence there is an opportunity to develop a completely sealed fuel handling and storage system to reduce and perhaps eliminate some of these emissions.

Reprocessing of Petroleum Waste

Continual improvement is needed to reprocess efficiently and safely petroleum waste streams such as heat exchanger cleaning residue. Current synthetic drill fluids adhere to offshore discharge cuttings, necessitating expensive disposal approaches. Research could lead to reduced levels of synthetics on cuttings, which would reduce the environmental impact of offshore drilling.

Equipment Integrity

It is important to develop a better understanding of material damage mechanisms, damage growth rates, and material properties of aging refinery equipment. The industry needs to improve technology for on-stream inspection of pressure vessels and piping systems for corrosion and cracks, and develop improved inspection techniques for heat transfer equipment. The industry should continue joint industry efforts to improve non-destructive evaluation of external corrosion of piping under insulation.

Alloy Selection System for Elevated Temperatures

It is necessary to increase data collection concerning corrosion of metals and alloys by high temperature gases. Research should lead to the development of a computer program to predict the corrosion rate for different materials based on a fundamental understanding of atomic and molecular structures.

Analytical Technologies

Research on new analytical technologies could lead to improved process control, yields, and waste minimization. It could also develop new approaches for sampling in odor problem investigations, determine emissions at low concentrations, and measure volatile and semivolatile emissions from water/waste treatment.

Desulfurization

Research on novel methods of sulfur removal from crude oil, possibly in-situ, and petroleum-based transportation fuels could provide a more cost-effective method of desulfurization than conventional hydrotreating. Among these novel methods are biodesulfurization and extraction of sulfur bearing compounds.

Bioscience

A good area for collaborative research might include potential uses of bioscience in refining, ranging from methods for desulfurization, denitrogenation, and demetallation, without high-pressure hydrogen. The extension of current bioremediation techniques used by refiners could be useful in the process areas.

Processing Hydrocarbon Containing Residual Materials

Research should develop an understanding of the issues related to using non-standard feedstocks in refineries. It should also address concerns such as fouling, corrosion, product quality, etc. Feedstocks to be considered include: used lubricating oils, spent solvents, oil water emulsions, and etc.

Energy Efficiency

Methods to improve energy efficiency are always needed. Future environmental concerns on global climate change may foster regulations that limit CO_2 emissions, making some new technologies economically feasible. The petroleum industry needs to find ways to reduce fouling in heat exchange networks.

The impact of fouling during the run is to increase the fuel required in the process furnace over the length of the run. It is important to develop tools and methodologies to monitor and reduce fouling and coking in the crude preheat train. Heat transfer, chemistry, fluid flow, kinetics and feed compatibility are complex issues.

The industry should investigate whether pulsed convection in furnaces could decrease its energy consumption. Currently steam traps last about five years, so a cost effective steam trap with a longer life would save energy.

Novel Methods to Reduce Greenhouse Gases

The effect of greenhouse gases on global warming is a subject of worldwide debate. Nevertheless, there could be corollaries such as improved energy efficiency from discovering novel methods to reduce greenhouse gases such as carbon dioxide (CO2).

Methods for reducing, recovering, and/or re-using these gases should be explored to reduce their impact on the environment.

Additional Research Areas

Additional Industries of the Future research areas listed in Appendix II will be considered only if the project in the area represents a novel approach that is not being investigated or commercially applied by petroleum companies or their suppliers.

Key Challenge

The key issue facing the petroleum industry is to satisfy the demands for safe, abundant and affordable petroleum products within the evolving regulatory environment. The type of regulations, and approach and time frames for compliance will substantially influence the direction of technological development and progress.

Identifying areas of concern in the U.S. petroleum industry and developing a road map to address these concerns are two responsibilities of the API Technology Committee. Research will be proposed to focus on core technologies and critical near term needs.

Consortia will be formed to minimize the cost of long-term research; and collaboration will be developed within the industry, academia, technology suppliers and government laboratories to develop necessary precompetitive technology. Nothing should preclude a company from pursuing its own proprietary cooperative initiatives as it has done in the past with applied and basic research.

APPPENDIX I

PRINCIPLES RELATIVE TO LEVERAGED EXTERNAL RESEARCH IN THE PETROLEUM REFINING INDUSTRY

What is leveraged external research?

The cost of leveraged external research is shared so that the effort of each individual sponsor is leveraged through the efforts of others. Research is generated by a group external to an individual company; the group may include competitors, governmental agencies or laboratories, universities, companies from other industries, or trace organizations. Likewise, the results are shared by the group. The research is not confidential to an individual company and lacks individual ownership of the resulting intellectual property.

Comparison of leveraged external research and internal proprietary research:

The following table illustrates the desired characteristics of leveraged external research projects and compares them with typical internal research projects:

LEVERAGED EXTERNAL RESEARCH	INTERNAL PROPRIETARY RESEARCH
• Collaboration of multiple sponsors	• Single sponsor
• Sponsors agree on utilization and dissemination of results • when and to whom to communicate results • who owns intellectual property	• Results are confidential • trade secrets • patents
• Sponsors may have different reasons for supporting research but have compatible objectives for • the research • its commercial use	• Objective is financial return to individual company through • better product • lower cost raw material • lower production costs • technology sales
• General interest and applicability to all participants and sponsors • willing to share information and results for mutual benefits	• Specific to individual company's • processing • raw material • products
• Based on publicly available information and private contributions that sponsors agree to make • utilizes complementary resources and capabilities of sponsors • expands resources beyond those of a single company	• Utilizes individual company's • trade secrets • patent position • technology strengths • resources
• Longer range applicability	• Shorter time range applicability
• Basic research	• Immediacy
• All participants receive a benefit, but nature of benefits may differ	• Applied research
• Company specific context and benefit	

Principles of leveraged external research in the petroleum refining industry:

1. Leveraged external research is more effective and has a higher chance of being applied if it is needed by the potential users
   - user-pull not technology-push research
   - "industry asks for" projects rather than a research selling an idea
   - need a champion from industry
   - meets normal research project criteria and requirements
   - well defined project with adequate resources
   - identified application and implementation plan if successful; offramps if unsuccessful

2. Leveraged external research develops new, enabling, pre-competitive technology
   - reduces the risks of a new technology
     - · economics must be the impediment to utilization of new technology or unconventional raw materials; not environmental regulations
   - pre-competitive research develops a needed technological resource or extends technological competency by basic research
     - · advanced analytical or computational procedures
     - · sensor and control technology
     - · materials technology and fundamental science of catalysis
     - · not competitive with research private companies are doing on their own
   - leveraged external research is generally not in highly proprietary activities
     - · companies expect catalyst research to give them a competitive advantage
   - using advanced technology effectively and aggressively is considered a core competency of operating companies; hence not an area for collaborative research

3. Leveraged external research can lead to lower cost of environmental regulation by
   - developing new emission reduction technology
   - evaluating new technology to reduce the environmental impact of refineries
     - · joint project including equipment suppliers, refiners and government
   - establishing relationships for the fuel-vehicle system between a) product quality or composition, b) vehicle design, c) vehicle performance and d) vehicle emissions
     - · joint project including fuel and vehicle manufacturers and government
   - analyzing the costs and implications of technology to meet new regulations
   - increasing credibility through government or university participation

4. Leveraged external research on refinery processing and operation advances and protects the public interest through projects that have a greater payout to public as a whole than to individual companies
   - improved training methods and material
   - improved safety practices, risk evaluation and process plant reliability
   - improved energy efficiency of processes and equipment
   - standardization of labeling, documentation, specifications, and handling requirements.

Conclusion:
API company participation in leveraged external research projects with the DOE can lead to more rapid industry acceptance and use of technology and lower overall costs to the nation. The industry can provide meaningful input and plans for suitable leveraged external research projects which could be developed by DOE-refining industry collaboration.

APPENDIX II

The following list of technologies includes areas where individual petroleum companies may already have active research and development projects on-going in their R&D portfolios. Cooperative research opportunities should not duplicate these private research efforts, but should instead undertake projects that meet the criteria for pre-competitive research as described in the Appendix I:

- Novel Catalyst and Process Developments
- MTBE Remediation
- Improving Computational Technologies
- Reducing Solids Formation
- Cogeneration
- Ionic Equilibria
- Desulfurization of crude oil and petroleum products

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