APPENDIX A-1. Special Workshop[*] on the Industrial Use of Hydrogen

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[*] Conducted at the University of Michigan, Ann Arbor, April 1, 1975; sponsored by the Institute of Gas Technology, Chicago; and performed for the National Aeronautics and Space Administration, Marshall Space Flight Center, Contract NA 58-30757, IGT Project 8962, W. D. Powers — Contracting Officer's Representative.

SPECIAL WORKSHOP ON THE INDUSTRIAL USE OF HYDROGEN

In connection with exploring aspects of present and future industrial utilization of hydrogen, as addressed in the IGT contract with NASA-MSFC, a cognizant university group was consulted. The objective was to both supplement and augment the information being assimilated by IGT through its direct contacts with the industrial sector.

The University of Michigan was selected by IGT for this consultation primarily because of the reputation of its Chemical Engineering Department's work in the general areas of "clean fuels" and chemicals-oriented industrial applications. Other departments in the University were also known to have applicable backgrounds and current interests in the hydrogen field.

An informal workshop format was chosen, and the workshop took place on April 1 with four participants from the university and four from IGT (listed below). These notes were prepared subsequent to the proceedings with the aid of a tape recording of the session. They are presented here as a series of "key observations" paraphrased from the conversational remarks of the university's faculty participants.

It should be emphasized that these observations are not direct quotes, but are interpretations of the highlights of the workshop conversations. In some instances supplemental information has been added for coherence and clarity, as well as to amplify some of the points.

University of Michigan Participants

Department of Chemical Engineering

Professor Donald L. Katz
Professor Dale E. Briggs

Department of Mechanical Engineering

Professor Edward Lady

Department of Physics

Professor Lawrence W. Jones

Institute of Gas Technology Participants

Mr. Jay C. Gillis	Supervisor, Synthetic Fuels Application (and Study Manager)
Mr. Nicholas P. Biederman	Supervisor, Energy Systems Research
Mr. Timothy D. Donakowski	Assistant Engineer
Mr. William J. D. Escher*	Senior Advisor

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* Mr. Escher prepared these notes on behalf of IGT.

Observations by Professor Donald L. Katz

- Probably any large-scale production of hydrogen above and beyond extrapolated trends for current hydrogen use will be associated with the projected synthetic fuels industry (SNG, Syncrude). The following anecdotes were related as illustrative of the potential magnitude of the syn-fuels industry future demand:

  a. A representative from Dow Chemical Co. visited a major U. S. Steel production facility. Prior to this visit, he felt Dow's energy consumption ranked among the largest in the country; but this use was dwarfed by that of U. S. Steel.

  b. The amount of coal required for gasification to SNG for just the State of Michigan exceeds, by far, the coal requirements of all U. S. Steel facilities.

- It is estimated that hydrogen, if it is more cheaply produced from coal than is SNG (Professor Katz's thesis for the argument), can be mixed with natural gas down to a mixed-gas heating value of about 850 Btu/1000 SCF. This is the value below which significant changes are required in the delivery and utilization system, according to gas industry people he has contacted. This agrument can be implied to bear on the situation of hydrogen produced from other sources as well.

- The chemical industry, particularly the petrochemical manufacturers, is currently dependent on light hydrocarbon feedstock (ethane, propane, butane, etc.) at a level of about 10% of total supplies; but a shift to a coal base for this industry is predicted. This portends a major hydrogen demand to establish the required hydrogen/carbon ratio. This hydrogen will be produced from a portion of that coal, unless a cheaper source is available. This transition, though probably inevitable, is now at the "scratching-the-surface" point.

- The key to justifying large R&D expenditures for hydrogen will be large-scale usage, not the "few-percent-only" applications (such as those represented by reducing atmosphere needs). Use of hydrogen as a major chemical feedstock is likely to be the first such application in view of the users' ability to pay significantly higher prices than can be commanded for hydrogen as a fuel.

- If national policy on the issue of sulfur as a pollutant is predicated to be "put it in a pile (as elemental sulfur) and not into the air," there will be a continuing buildup of demand for hydrogen for desulfurization purposes. This is a unique role for which hydrogen has no real "competition."

- With regard to coal-produced hydrogen, it may be instructive to examine historically the transition of companies such as Union Carbide Corp. from coal-based production of hydrogen to natural gas (ca. 1942 in Charleston, W. Va., in the case of UCC).

- Relatively vast quantities of metallurgical-grade coal are currently being held for steel production purposes. In view of the cost ramifications of stringent stack-gas clean-up restrictions and the rapidly mounting prices for all fuels, including coal, one can at least imagine that the steel producers might make a transition to hydrogen and release this metallurgical coal to the fuels market in the distant future.

- Oxygen (as produced in water-splitting hydrogen production) will likely be in demand by coal-gasification facilities ("an infinite sink"). Oxygen can be used, for instance, to produce a nitrogen-free intermediate-Btu gas directly while air cannot.

- Historically, the growth in oxygen utilization has been paced by steel-industry usage.

- Sulfur removal from high-sulfur-content (4% to 5% heavy oils, e.g., vacuum still bottoms) fuels in order to comply with air-pollution restrictions, will increasingly be a consumer of hydrogen. This class of fuel might constitute, in effect, 2 out of 9 or so million barrels/day of U.S. refinery production and hence represents a step-up for hydrodesulfurization.

- In-the-field hydrogen upgrading of tar sands and oil shale is an area with significant potential. "In situ hydrogenation" would be an interesting (and technically challenging) approach to examine. Note as possibly relevant that hydrogen uniquely reflects reverse solubility trends at temperatures below ambient — i. e. , the lower the temperature, the smaller the amount of hydrogen that will dissolve in the liquid.

- Hydrogen production, in lieu of electricity production, via controlled nuclear fusion, is a most appealing prospect. If used in synfuels production, this would, in effect, double the utility of our coal. In fact, any nonfossil source of hydrogen that becomes technically and economically feasible will have a most favorable impact.

- Techniques better than current coal-to-hydrogen production methods (e. g. , Koppers-Totzek) that will be capable of producing truly low-cost hydrogen are much needed. Use of state-of-the-art processes appear to limit the market to the chemical industry instead of to fuels-oriented usage, either directly or in synfuels production.

- To develop a "scenario-insight" into possible trends in usage of hydrogen, were it to become comparatively cheap and abundant, one should strike an analogy with the historical facts of the U. S. shift to natural gas in the 1950 to 1970 time period. At the beginning of this period natural gas was abundantly available. Subsequently, FPC pricing constraints provided for a sustained artificial incentive for expanded use. Because natural gas can be viewed as a good "analog" to hydrogen — i. e. , a clean, convenient, gaseous fuel and feedstock — observed trends in industry usage during these decades should be instructive to the prospective hydrogen case.

- In relation to the above point, natural gas having evolved into the principal feedstock for hydrogen production because it is cheap and convenient, the industrial trends in this production and the related uses of hydrogen can be "tracked down" through contacts with manufacturers of steam-reforming equipment.

Observations by Professor Dale E. Briggs

- Present and projected utility use of fossil fuels is vastly larger than the chemical industry's consumption. Fuel and raw material selections depend substantially on the present and projected economics; it is therefore important to keep up with the current projected costs.

- On the other hand, the chemical industry can afford to pay considerably more for these feedstock fuels than the energy utilities can. In Turkey, for example, ammonia is produced from coal and air, even though the capital cost is high, because the raw materials are available.

- In competitive development of a nuclear-electric and a nuclear-hydrogen economy, the relative apportionment or balance between electricity and hydrogen will almost certainly be controlled by economics.

- In a conversion to hydrogen (or in any major energy-system switchover), industries will more easily be able to meet the necessary capital requirements than, say, the residential sector, provided industry can gradually and effectively "roll-in" these costs.

- In the industry's potential conversion to hydrogen, evolutionary processes are necessary to provide an "adaptive stretch-out" and to reduce the "trauma of change."

- Meeting process-heat requirements may be a beginning point for fuel uses of hydrogen or mixtures of hydrogen and carbon monoxide, particularly when a "clean fuel" is required. Exemplifying this potential is GM's recent serious pursuit of K-T coal gasification units as natural gas curtailments critically affected such production operations as paint drying.

- The existing competitive situation discourages any such shift (as mentioned above) because it would bring near-term higher costs in manufacturing for the companies that made the change. Across-the-board legislation would probably be necessary to effect such a shift if it were not otherwise economically advantageous.

- In desulfurization of heavy oils, sulfur is removed from the oil by combining it with hydrogen. It is desirable to hydrogenate chemical bonds left free after the sulfur removal because this provides a reduction in molecular weight instead of polymerization into asphalts and asphaltenes.

- Solid wastes can be treated with hydrogen and carbon monoxide to reduce the amount of waste solids and to produce fuels. Feedlot wastes in cattle production and wastes from grass-seed production are two potential candidates for such treatment. Carbon monoxide could be produced by using the oxygen liberated during hydrogen production to partially oxidize the solids.

- Sewage treatment and waterway cleanup processes may be the leading markets for new uses of oxygen.

- The concept of direct hydrogen in situ hydrogenation of coal and oil shale is intriguing, but poses major problems in containment and method of heat input.

- In hydrogen production from hydrocarbons, including coal, the carbon is being used as a reducing agent for water splitting. In the long run, it will be better to conserve the carbon for other uses and to develop alternative water-splitting and hydrogen-recovery methods.

- Present coal gasification processes for hydrogen production are capital intensive and, in most cases (e.g., Koppers-Totzek), require oxygen, which is expensive to produce. Thermal efficiencies of the systems in use today are not very high.

- Again, the capability of the industrial sector to efficiently roll-in large new investments, as required for rather drastic changes in technology such as in the case of an overall hydrogen system, places industrial applications in a potential "leadership position," but government regulatory forces (and presumably economic incentives) would have to be applied to effect the shift.

Observations by Professor Edward Lady

- Ammonia is and has been used as a hydrogen carrier. An example is ammonia cracking to produce annealing gas, a nitrogen-hydrogen mixture. Were pure hydrogen available, nitrogen for such mixtures could be derived from air separation.

- One advanced concept for hydrogen application would be to use it to enhance oil production from depleted fields in an "in situ hydrocracking" mode. Heat could be generated locally with oxygen-hydrogen combustion using excess hydrogen for combination with the remaining crude.

Observations by Professor Lawrence W. Jones

- Direct reduction of iron and other metal ores with hydrogen seems to offer much potential.

- It is instructive to consider the very-long-range situation as we consider hydrogen's role. Eventually, the world situation must be based on stable, self-sustaining use of all resources, with major recycling. Hopefully, we will keep this scenario in mind and minimize the fragmented "blind-alley" excursions in the evolution of the energy systems.

- A very real concern mitigating against full-scale exploitation of world coal is the long-term ramifications of the atmospheric carbon dioxide buildup that will result. Derivation of hydrogen from nonfossil sources avoids this potentially catastrophic route.

- The primary early use of hydrogen by industry will be as a feedstock and, eventually, to free hydrocarbons (otherwise destined for fuel use) for feedstock use.

- Though posing considerable logistical and on-board-storage technical challenges, hydrogen can be used directly as a transportation fuel. It can also be used in the synthesis of methanol or synthetic hydrocarbons, the other major contenders for future vehicular fuel supplies; thus in any case, hydrogen is necessary for the transportation sector.

- Use of hydrogen as a reducing atmosphere in solid-state-device production, currently a very small use, might grow markedly if mass-produced, solar-cell efforts were expanded.

- Urban solid-waste disposal via incineration is a major source of air pollution. Employing hydrogen and oxygen to convert such wastes would not only provide useful by-products (e.g., fuel and synthesis gas), but would also clean up urban air.

- Controlled thermonuclear fusion, as pursued by KMS Fusion Inc. (in Ann Arbor) and others, has a unique potential for direct water-splitting processes. Unlike fission processes, fusion principally produces fast neutrons, not heavy fragments. These are quite effective direct water-splitting agents. In fact, KMS is pursuing this method of hydrogen production for eventual methane production in an effort supported by the natural gas industry and sponsored by Texas Gas Transmission Corp.

- In a practical sense, a detailed survey of the small, present-day uses of hydrogen, e.g., synthetic gem manufacturing, would not appear to be fruitful. The trend toward hydrogen usage will quite likely be controlled by large-quantity industrial users.

- In summary, any progression into hydrogen usage will be evolutionary in nature and will be driven by the forces of economics.

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APPENDIX A-2. Standard Industrial Classifications (SIC) for Hydrogen Applications

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STANDARD INDUSTRIAL CLASSIFICATIONS (SIC) FOR HYDROGEN APPLICATIONS*

SIC 2900 — Petroleum

Petroleum-Refineries Processes

Every petroleum refinery has processes that both consume and generate hydrogen. Listed below are a few major hydrogen-consuming processes:

- Hydrotreating — Hydrogen is consumed in the process of removing sulfur from petroleum fractions.
- Catalytic Reforming — A process in which light hydrocarbon components are converted into middle-range gasoline fractions. Hydrogen is generated by steam reformers. Occasionally, "spot" hydrogen is required during catalytic reformer start-up.
- Hydrocracking — Hydrogen is consumed in the hydrocracking process. Large molecules are broken down to the middle-range hydrocarbons used in gasoline.

Most petroleum refineries are self-sufficient in generating hydrogen. However, many plants do require a spot backup supply of hydrogen to ensure continuous operation during scheduled or emergency reformer shutdowns, start-ups, and turnarounds.

SIC 2093, 2094 — Food

Hydrogenation of Edible Organic Oils

The edible organic oils in soybeans, fish, cotton seed, corn, peanuts, and coconuts are hydrogenated. This process retards the tendency of the oil to oxidize and turn rancid, improves consistency (producing a solid fat such as margarine or shortening instead of a liquid oil), and reduces the reactivity of the oils. Major edible-oil producers have onsite hydrogen-generating facilities. The opportunity to replace self-generating hydrogen plants increases as onsite production costs and purity requirements increase.

Hydrogenation of Inedible Tallow and Grease

Inedible tallow and grease are treated with hydrogen to produce soap and animal feed.

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* Courtesy of Air Products and Chemicals, Inc.

SIC 3310, 3320 – Metalworking, Ferrous

Reducing Atmosphere

Ferrous metals are heat treated in controlled-atmosphere furnaces to change certain physical properties of the metals. Some specific reasons for heat treatment are to –

- Develop ductility
- Improve machining quality
- Relieve stress
- Change the grain size
- Harden
- Increase tensile strength
- Change the chemical composition of the metal surface, as in case hardening
- Alter magnetic properties
- Modify electrical properties
- Recrystallize and soften cold-worked metal.

Stringent product specifications can be met by use of a controlled-atmosphere furnace. The atmosphere composition and the temperature of the metal are two key variables that must be controlled in the furnace.

A hydrogen-nitrogen (HN) atmosphere (reducing atmosphere) is often used to prevent metal oxidation.

Annealed steel is produced in an HN-atmosphere furnace. Annealing is a term frequently used in heat treating. Generally speaking, annealing refines the grain and softens the metal. An annealing operation may be performed to –

- Allow for cold-working of the steel
- Make steel machinable
- Reduce stresses and stains produced while the metal is being shaped or welded.

Bright annealing produces a lustrous surface, as required for all grades including stainless steel and tubing.

For most uses, the ratio of hydrogen to nitrogen varies in an HN atmosphere from 3:97 to 3:7. Dissociated ammonia gas and partially burned fuel gas may be used instead of an HN atmosphere; however, HN systems offer greater purity, flexibility, and safety, as well as higher quality and reproducibility. They can be used without the capital investment that is required for generators.

SIC 3330, 3340 – Metalworking, Nonferrous

Reducing Atmosphere

The refining process for recovery of tungsten, molybdenum, and magnesium requires hydrogen gas to reduce oxides and prevent oxidation of the metal. An HN reducing atmosphere is also used for annealing or heat treating nonferrous metals. Free or reactive carbon or carbon compounds do not form in a reducing atmosphere. The ratio of hydrogen to nitrogen in the gas blend varies from one operation to another. The blend ranges given above for ferrous metals also apply to nonferrous metals.

A reducing atmosphere of relatively pure hydrogen is used in tungsten processing when oxide compacts are sintered (heated to become a coherent nonporous mass).

Molybdenum is produced from concentrated molybdite. The molybdite is heated to form molybdenum trioxide. The molybdenum trioxide is reduced with hydrogen at 1000° C to produce metal powder and is extruded and formed into rods under pressure. The rods are sintered with direct current in a hydrogen reducing atmosphere. The sintered rods can be readily forged, rolled, or drawn.

Magnesium can be obtained by two different methods. Magnesium chloride can be electrolyzed, or magnesium oxide can be thermally reduced. Hydrogen is consumed in the electrolysis of magnesium chloride. The electrolysis is performed in a heat-resistant crucible made of a ferrous metal. A flow of coal gas or hydrogen carries off oxygen and chlorine that would otherwise become attached to the molten magnesium.

Hydrogen is also used in powder metallurgy to make small metal parts. The powdered metal is placed in a mold, and then heat and pressure are applied in a hydrogen atmosphere.

SIC 3400 – Fabricated Metal Products

Plasma Arc Welding

A plasma is a stream of ionized particles. The plasma torch provides an electric arc between a tungsten electrode and a water-cooled copper nozzle. Gases such as hydrogen, helium, and argon are heated and ionized as they are forced through the arc and nozzle. The advantages of this system include directional control of the flame, a gas shield at the metal surface, and a higher temperature electric arc. Intense-heat plasma torches are employed for cutting, welding, and smelting operations.

Fuel

Oxy-hydrogen torches replace oxy-acetylene torches in underwater cutting when pressurized acetylene exceeds the limit of safety. Oxy-hydrogen is used largely in brazing operations; in welding aluminum, magnesium, and lead; and sometimes for cutting lead. This type of welding provides a 4000°F flame temperature that is well suited for low-temperature brazing and welding. Hydrogen is employed in the "bell-jar brazing" of small parts in which a controlled atmosphere is required.

"Forming Gas"

"Forming gas" is a mixture of 70% hydrogen and 30% nitrogen and is commonly used in small-scale field work.

SIC 3670 – Electronics

Reducing Atmosphere

Brazing is a bonding process in which the materials being joined are heated, but not melted. (The brazing filler metal melts and flows at temperatures above 800°F.) This process is also employed for ceramic-to-metal bonding applications.

Brazing in the manufacture of vacuum tubes, light bulbs, and other electronic equipment is a high-temperature operation accomplished in controlled-atmosphere furnaces. As a result of the high temperature, the metals involved are reactive and easily oxidized; therefore, hydrogen is used to prevent oxidation. Alternatives to the use of hydrogen include use of other nonreactive atmospheres (e.g., argon and nitrogen) and partial combustion of oil or gas. (Crystal-growing also requires hydrogen gas.)

Fuel

Oxy-hydrogen torches are used for glass-tube sealing and fabrication. The oxy-hydrogen torch has a carbon-free flame that cannot be attained with a hydrocarbon fuel.

SIC 3620 — Electrical

Coolant for Electrical Generating Equipment

Public electric utilities require hydrogen as a coolant for large generators, motors, and frequency changers. Hydrogen's greater thermal conductivity provides more efficient cooling than standard air. Hydrogen is circulated through heat exchangers in the shell of the generator to cool the rotor, and is also circulated through the stator windings. Though this is a closed recirculating system, consumption due to losses is usually estimated at 1 SCF of hydrogen per day per megawatt of capacity.

SIC 2810 — Chemical-Industrial

Chemical Processes That Consume Hydrogen

Although all of the processes below require onsite hydrogen generators, supplemental bulk purchases may be necessary to avoid periodic process shutdowns for generator maintenance or cleaning.

- Methanol is produced by reacting hydrogen and carbon monoxide in the presence of certain metallic oxides. An onsite hydrogen-producing facility is usually required for large-quantity methanol production. Laboratories may require cylinder or small bulk hydrogen supply.
- Aldehydes and ketones are formed from carbon monoxide and hydrogen.
- The manufacture of high-density polyethylene and polypropylene resins requires hydrogen.
- Considerable quantities of hydrogen are required to selectively hydrogenate feedstocks to a uniform degree and to regulate molecular weight.

- Alcohols are formed by reducing aldehydes and ketones through reaction with hydrogen and a catalyst.
- Hydrogen chloride gas is formed by reacting hydrogen and chlorine gas under pressure.
- The hydrogenation of coal and coke produces gasoline, fuel oils, toluene, xylene, and benzene.
- Naphthalene and synthetic natural gas (SNG) production requires supplemental hydrogen.

Pharmaceutical

Hydrogen is used extensively by pharmaceutical companies in manufacturing certain drugs.

SIC 3210 – Glass

Glass Cutting

Hydrogen is consumed in the oxy-hydrogen cutting of glass and in the cutting and high-temperature melting of quartz. Hydrogen is also used in working leaded glass. The hydrogen content must be carefully controlled to avoid burning the lead out of the glass.

SIC 4910 – Nuclear Energy

Hydrogen is the liquid medium in bubble chambers used in the study of high-energy physics. Hydrogen is also used in processing nuclear fuels.

SIC 1925 – Aerospace

Manned Space Program

Liquid hydrogen is used as a propellant in Apollo rockets. Hydrogen is reacted chemically with oxygen, yielding a very high heat of reaction for propulsion. Hydrogen, the lightest known element, was selected as the rocket fuel because it produces the maximum thrust per pound of fuel.

Other Missiles and Rockets

Hydrogen is used as a propellant when the weight-to-energy ratio is sufficiently critical to justify the expense of hydrogen. Alternative propellants are solid chemicals and other liquid fuels such as kerosene.

High-Energy Physics

Experiments on subatomic particles of matter are conducted in liquid-hydrogen bubble chambers. Liquid hydrogen is a target for the high-energy particles (a cold trap) and detects the movement of the high-energy particles. Photographs are taken of the bubbles produced by particles passing through the liquid-hydrogen bath.

Fuel Cells

Hydrogen is required in the use of fuel cells.

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APPENDIX A-3. U.S. Ammonia Plants and Their Production

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U.S. AMMONIA PLANTS AND THEIR PRODUCTION

Table A-3-1, Part 1. AMMONIA PLANT PRODUCTION

Plant	Location	Capacity, 1000 tons/year
Agrico Chemical Co.	Donaldsonville, La.	340
	Blytheville, Ark.	340
	Tulsa, Okla.	425
Air Products and Chemicals, Inc.	New Orleans, La.	210
	Pace Jct., Fla.	100
Allied Chemical Corp.	Geismar, La.	340
	Hopewell, Va.	340
	La Platte, Nebr.	202
	South Point, Ohio	80
American Cyanamid Co.	Fortier, La.	340
Amoco Oil Co.	Texas City, Tex.	720
Apache Powder Co.	Benson, Ariz.	15
Apple River Chemical Co.	E. Dubuque, Ill.	230
ARCO Chemical Co.	Ft. Madison, Iowa	340
Arkla Chemical Corp.	Helena, Ark.	210
Atlas Chemical Industries	Joplin, Mo.	136
Borden Chemical Co.	Geismer, La.	306
CF Industries	Fremont, Nebr.	48
	Donaldsonville, La.	680
	Terre Haute, Ind.	135
Cherokee Nitrogen, Inc.	Pryor, Okla.	55
Chevron Chemical Co.	Richmond, Calif.	130
	Ft. Madison, Iowa	105
	Pascagoula, Miss.	510
Cities Service Co.	Tampa, Fla.	120
Collier Carbon and Chemical Corp.	Kenai, Alaska	510
	Brea, Calif.	260
Columbia Nipro	Augusta, Ga.	122
Commercial Solvents Corp.	Sterlington, La.	340

Table A-3-1, Part 2. AMMONIA PLANT PRODUCTION

Plant	Location	Capacity, 1000 tons/year
Cooperative Farm Chemical Assn.	Lawrence, Kans.	340
Diamond Shamrock Corp.	Dumas, Tex.	160
Dow Chemical Co.	Freeport, Tex.	115
E. I. du Pont de Nemours & Co.	Beaumont, Tex.	340
	Belle, W. Va.	340
	Victoria, Tex.	100
El Paso Products Co.	Odessa, Tex.	115
Euval Corp. (Penzoil Chemical, Inc.)	Hanford, Calif.	21
Farmers Chemical Co.	Tunis, N. C.	210
	Tyner, Tenn.	170
Farmland Industries, Inc.	Dodge City, Kans.	210
	Ft. Dodge, Iowa	210
	Hastings, Nebr.	140
	Enid, Okla.	425
Felmont Oil Corp.	Olean, N. Y.	85
FMC Corp.	S. Charleston, W. Va.	24
Goodpasture, Inc.	Dimmitt, Tex.	30
W. R. Grace and Co.	Woodstock, Tenn.	340
	Big Springs, Tex.	100
Green Valley Chemical Co.	Creston, Iowa	35
Hawkeye Chemical Co.	Clinton, Iowa	138
Hercules, Inc.	Hercules, Calif.	70
	Louisiana, Mo.	70
Hill Chemical Co.	Borger, Tex.	340
Hooker Chemical Co.	Tacoma, Wash.	23
Kaiser Agricultural Chemical Co.	Savannah, Ga.	150

Table A-3-1, Part 3. AMMONIA PLANT PRODUCTION

Plant	Location	Capacity, 1000 tons/year
Mississippi Chemical Corp.	Pascagoula, Miss.	175
	Yazoo City, Miss.	340
Mobil Chemical Co.	Beaumont, Tex.	260
Monsanto Co.	Luling, La.	450
New Jersey Zinc Co.	Palmerton, Pa.	35
Nypak, Inc.	Pryor, Okla.	105
	Kerens, Tex.	125
Occidental Agricultural Chemical Co.	Lathrop, Calif.	96
	Plainview, Tex.	52
Olin Corp.	Lake Charles, La.	490
Pennsalt Chemicals Co.	Portland, Oreg.	8
Phillips Pacific Chemical Co.	Kennewick, Wash.	155
Phillips Petroleum Co.	Beatrice, Nebr.	210
	Etter, Tex.	210
	Pasadena, Tex.	230
PPG Industries, Inc.	Natrium, W. Va.	50
Reichhold Chemicals, Inc.	St. Helens, Oreg.	90
J. R. Simplot Co.	Pocatello, Idaho	102
Sun Oil Co.	Marcus Hook, Pa.	133
Tenneco Chemical Company	Houston, Tex.	210
Tennessee Valley Authority	Muscle Shoals, Ala.	74
Terra Chemicals International, Inc.	Port Neal, Iowa	210
Triad Chemical Co.	Donaldsonville, La.	340
U.S. Agri-Chemicals, Inc.	Cherokee, Ala.	177
	Chairlen, Pa.	400
	Geneva, Utah	70
Valley Nitrogen Producers, Inc.	El Centro, Calif.	162
	Helm, Calif.	165

Table A-3-1, Part 4. AMMONIA PLANT PRODUCTION

Plant	Location	Capacity, 1000 tons/year
Visitron Corp.	Lima, Ohio	510
Vulcan Materials Co.	Wichita, Kans.	23
Wycon Chemical Co.	Cheyenne, Wyo.	167

APPENDIX A-4. Basic Energy Efficiency and Cost Relationships for Conventional and "Outside-Hydrogen" Ammonia Synthesis

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BASIC ENERGY EFFICIENCY AND COST RELATIONSHIPS FOR CONVENTIONAL AND "OUTSIDE-HYDROGEN" AMMONIA SYNTHESIS

(Based on 1000 ton/day Ammonia-Synthesis Plants)

Case 1. Conventional Steam Reforming of Natural Gas — Medium Pressure Ammonia

(See References 1 and 4 cited in Section 12 of this report.)

Synthesis Process

Inputs

- Reformer

Steam-reforming feed	20×10^6 SCF of natural gas	= 20.0×10^9 Btu
Fuel	13×10^6 SCF of natural gas	= 13.0×10^9 Btu
Electricity	70,000 kWhr	= 0.2×10^9 Btu

- Synthesis Loop

Ammonia synthesis fuel	2×10^6 SCF of natural gas	= 2.0×10^9 Btu
Electricity	30,000 kWhr	= 0.1×10^9 Btu
		35.3×10^9 Btu

Product

Ammonia 1000 tons X 2000 lb/ton X 9700 Btu/lb (HHV) = 19×10^9 Btu

$$\text{Energy Efficiency} = \frac{\text{Product}}{\text{Inputs}} = \frac{19 \times 10^9}{35.3 \times 10^9} \times 100 = 54\%$$

Plant Cost*

Synthesis-gas section	$25,000,000
Ammonia-conversion section	$20,000,000
	$45,000,000

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* Battery limit costs, not including nonprocess buildings, start-up costs, and working capital.

Sample Calculation

The product cost is calculated assuming —

- A 90% plant factor
- A 25% annual fixed-charge rate
- A power cost of \$0.025/kWhr
- A natural gas cost of \$1.00/1000 SCF
- A factor of 1.4 for obtaining the total capital investment from the plant cost.

$$\text{Product Cost, \$/ton} = \frac{\dfrac{(1.4)(45 \times 10^6)(0.25)}{(365)(0.9)} + (35 \times 10^3)(1.00) + (1.0 \times 10^5)(0.025)}{1000}$$

$$= \$85.45/\text{ton}$$

Case 2. Energy Requirements for an Ammonia Plant Using Outside Hydrogen

Input Energy

Raw material	6.96×10^7 SCF of hydrogen/day	$= 22.6 \times 10^9$ Btu
Electricity for air separation	120,000 kWhr/day	$= 0.4 \times 10^9$ Btu
Ammonia-synthesis electricity	505,000 kWhr/day	$= 1.9 \times 10^9$ Btu
		24.9×10^9 Btu

Energy Output

Ammonia	1000 tons/day	$= 19.4 \times 10^9$ Btu

$$\text{Energy Efficiency} = \frac{19.4 \times 10^9}{24.9 \times 10^9} \times 100 = 100 = 77.9\%$$

If the hydrogen is assumed to be produced by a thermochemical plant that is 50% efficient, the overall efficiency of the nuclear heat-to-ammonia process is then —

$$\text{Energy Efficiency} = \frac{19.4 \times 10^9}{47.5 \times 10^9} \times 100 = 40.8\%$$

Plant Cost

Air-separation section	\$ 5,000,000
Ammonia-conversion section	\$20,000,000

Sample Calculation

The product cost is calculated assuming —

- A 90% plant factor
- A 25% annual fixed-charge rate
- A power cost of \$0.025/kWhr
- A factor of 1.4 for obtaining the total capital investment from the plant cost.

$$\text{Product Cost, \$/ton} = \frac{\dfrac{(1.4)(25 \times 10^6)(0.25)}{(365)(0.9)} + (2.26 \times 10^4)(CH) + (6.25 \times 10^5)(0.025)}{1000}$$

where CH is the cost of hydrogen in $\$/10^6$ Btu. The results for various prices of hydrogen have been plotted in Figure 12-5.

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