Opportunities in Ammonia from Coal

Shortage of natural gas, a problem to ammonia producers even before energy situation, can be overcome by use of existing coal gasification technology.

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In addition to providing a possible solution to the U.S. energy requirements, this country's large domestic coal reserves could also be directly used with existing, commercially demonstrated technology for the production of ammonia.

Aside from assured access to a domestically controlled feedstock, the coal field locations as compared with major ammonia markets is another logical reason to build coal-based U.S. ammonia plants. This can be seen in Figure 1, a map showing the location of coal fields and, superimposed, the Corn Belt and northern plains agricultural regions. Data for all regions of the country are in Table 1, which compares 1973 regional U.S. ammonia consumption for fertilizers, ammonia production capacity, and coal reserves.

As shown, the historical geographical distribution of ammonia production capacity has been dictated both by regional market demands and regional availability of natural gas. The location of natural gas supplies led to the building of over 30% of U.S. ammonia production capacity in the Delta states, which consume only 5% of the ammonia used in the U.S. for fertilizers. On the other hand, the Corn Belt

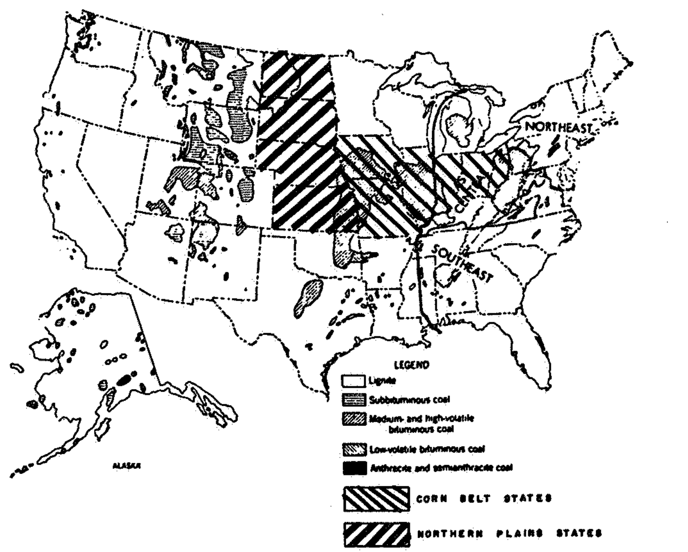

Figure 1. Coal fields of the United States and Corn Belt and northern plains agricultural regions.

Table 1. Comparison of U.S. regional consumption of ammonia for fertilizer, production capacity of ammonia, and coal reserves

Region	Consumption, 1973[1] 1,000 ton/yr.	% U.S.	Capacity, 1973[2] 1,000 ton/yr.	% U.S.	Coal reserves[3] Million ton	% U.S.
Northeast	385	3.8	653	3.8	70,822	4.6
Lake States	825	8.2	34	0.2	—	–
Corn Belt	2,531	25.1	2,329	13.6	246,277	15.8
Northern Plains	1,601	15.8	1,173	6.8	371,397	23.9
Appalachia	642	6.4	1,474	8.6	180,683	11.6
Southeast	911	9.0	742	4.3	13,358	0.8
Delta States	538	5.3	5,425	31.6	2,420	0.2
Southern Plains	1,120	11.1	3,267	19.0	16,225	1.0
Mountain States	565	5.6	346	2.0	516,855	33.3
Pacific States	946	9.4	1,218	7.1	6,183	0.4
Continental U.S.	10,064		16,661		1,424,320	
Alaska	1.3	–	510	3.0	130,089	8.4
Hawaii	34.6	0.3	—	–	—	–
Total U.S.	10,099	100.0	17,171	100.0	1,554,309	100.0

[1] U.S. Department of Agriculture.

[2] TVA.

[3] U.S. Department of Interior. States with less than 500 million tons reserves excluded from totals.

and northern plains states together consume over 40% of ammonia used in the U.S. for fertilizers while having only 20% of domestic production capacity. The data in Table 1 show, for example, that almost 40% of U.S. coal reserves are located in the Corn Belt and northern plains states. This makes these locations, among others, particularly attractive for coal-based ammonia plants.

Coal gasification technology, using air, oxygen, steam and/or hydrogen, has been practiced commercially since the 1920's and 1930's. Several German processes, such as Lurgi, Koppers-Totzek, and Winkler, have been used for many years in producing synthesis gas for steam raising and heating as well as feedstock for ammonia, methanol, and synthetic liquid fuels. None, however, have been used in the U.S. for any products.

Several coal gasification plants recently announced and approved by the Federal Power Commission will use Lurgi gasifiers for synthesis gas production. This gas will be upgraded to high Btu synthetic natural gas (SNG) by shift conversion, CO_2 removal, and methanation. The effluent gas from a Lurgi gasifier contains approximately 10% CH_4. While this is satisfactory for SNG production, it would require air or 0_2 injection secondary reforming (and attendant additional costs) to be suitable for ammonia production.

The Koppers-Totzek process is an entrained fuel gasification process, conducted at atmospheric pressure and very high temperatures (approximately 2,700°F). At these high reaction temperatures, the gasifier effluent contains no hydrocarbons higher in molecular weight than methane. In fact, the CH_4 content itself is less than 0.2%. The carbon monoxide-hydrogen content is about 85%, making it an ideal gas mixture for ammonia synthesis. The process was introduced in 1938, and of the 52 gasifier units operating or designed since then, 49 are used to produce synthesis gas for ammonia production. The process can handle any type of coal from anthracite to lignite, provided the moisture content is reduced to 2%-10% and the coal crushed to 75% less than 200-mesh.

Economic analysis based on Koppers-Totzek

Our analysis of ammonia production via coal gasification is based on the Koppers-Totzek process. However, it should be kept in mind that these economics are general and illustrate commercially available coal gasification processes. Our analysis of the Winkler process shows it would give similar economics on some types of coals. The Lurgi process, modified for ammonia production as referenced above, would also yield similar economics on certain types of coals.

Figure 2 shows a simplified block diagram for ammonia production using the Koppers-Totzek process. Dried pulverized coal is fed into the gasifier using screw conveyors equipped with a mixing head for oxygen injection. Steam is fed around the burners to shield the reaction zone and protect the reactor walls from excessive heat. Less than a stoichiometric quantity of oxygen is fed to produce a partial oxidation reaction. By good distribution and intimate contact in the reaction zone, thermal equilibrium is reached at a gas temperature of approximately 2,700°F. Usually about 95% of the coal is combusted. Between 50 and 60% of the ash is entrained overhead with the product gases, while the remaining 40 to 50% falls to the bottom of the gasifier into the ash disposal system and is tapped off as slag.

Following gasification, the temperature of the raw product gas is quenched in a waste heat boiler system where high pressure steam is generated. The water gas shift reaction:

$$CO + H_2O \rightleftharpoons H_2 + CO_2 \quad (1)$$

reaches equilibrium at a temperature 100-200°F below the gasifier outlet temperature, and this sets the ultimate gas composition. Product gas is scrubbed with water to effect further cooling and additional removal of ash and unconverted carbon entrained in the gas stream. Electrostatic precipitators are used for final particulate removal prior to gas compression. The gas is compressed to 450 lb./sq.in. gauge and fed to an H_2S absorption system for complete H_2S removal. The H_2S rich acid gas is sent to a Claus plant for conversion into elemental sulfur. A typical gas composition at this point is as follows (in vol.-%): H_2, 37.8; CO, 60.2; CO_2, 0.6; N_2 + A, 1.1; and CH_4, 0.3.

The gas must now be converted into high-purity hydrogen. This is accomplished in a two- or three-stage shift system. Following this, carbon dioxide is removed by a suitable absorption process (hot potassium carbonate or equivalent) and methanation is used to convert residual CO and CO_2 to CH_4. A liquid N_2 wash could alternatively be used to remove residual CO. This would simultaneously add the required N_2 quantity for ammonia synthesis. The synthesis gas feed is then compressed to ammonia synthesis loop pressure, ~ 2,500 lb./sq.in. gauge, mixed with an unconverted recycle stream and fed to the ammonia synthesis reactor. Conventional ammonia synthesis technology is utilized in this section of the plant.

The economics of a 2,000-ton/day ammonia plant using the Koppers-Totzek process have been estimated, and Table 2 summarizes the results. (Throughout this article, the term ton refers to short ton, 2,000 lb.)

Capital cost is before recent rapid inflation effects

The battery limits capital cost of $64 million is on a third quarter, 1973 basis. Note that this is just prior to the recently experienced rapid escalation of process plant costs. We have not attempted to try to pin down changes in in-

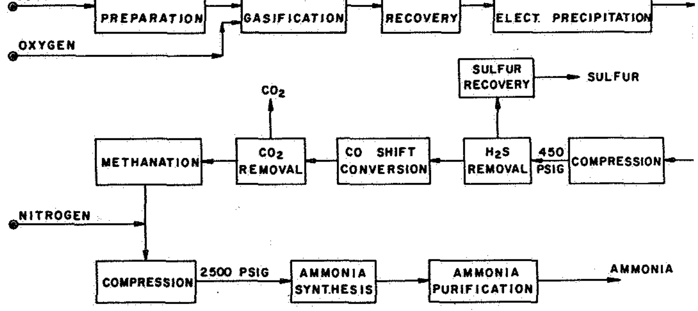

Figure 2. Block flow diagram, ammonia via coal gasification.

Table 2. Ammonia production via coal gasification 2,000 ton/day (Koppers-Totzek process)

Investment costs, 3rd quarter, 1973:	$ millions
Battery limits cost	64
Off-sites cost	26
Working capital	3
Total fixed and working capital	93
Production costs:	**$/ton**
Coal, @ $8.00/ton	10.00
Oxygen, @ $9.60/ton	9.60
Utilities	5.50
Labor, supervision, and related costs	1.60
Capital charges*	19.80
Total production cost	46.50
Return on investment @ 20% before taxes	27.00
Ammonia cost	$73.50

*Capital charges:
Maintenance .... 4.0% battery limits cost (BLC)
General plant overhead .. 2.6% BLC
Taxes and insurance .... 1.5% BLC and off-sites cost
Depreciation .... 10.0% BLC plus 5% off-sites
Interest .... 10.0% on working capital.

vestment during this period of rapid change for fear of confusing the analysis.

The capital investment requirements have been estimated by Chem Systems based on economic information received from Koppers and our own internal studies. Coal is priced at $8.00/ton ($0.36/million Btu), typical of high-sulfur Illinois coal. Oxygen is assumed to be purchased "over the fence" from an oxygen supplier under a long-term, take-or-pay contract. In this manner, the oxygen seller can make oxygen available quite cheaply with highly leveraged financing. Companies like Air Products, Big Three, and Air Liquide have done this in the past and are still encouraging this concept.

To estimate selling price (or transfer price) we have included a 20% before tax return on total fixed investment. While this is recognized as a simplistic approach to estimate ammonia prices, it nevertheless yields fairly realistic figures which lend themselves to the analysis presented here.

On this basis, ammonia cost is estimated at $73.50/ton. At the capacity level chosen, four parallel four-headed Koppers-Totzek gasifiers are employed. This is Kopper's latest design. Previous units have two burner heads, spaced 180° apart.

Figure 3 provides a breakdown of the ammonia cost into major components. Capital related charges, including return on investment, account for 64% of the ammonia cost. Coal and oxygen each contribute only 13%. The capital-intensive costs suggest that larger plants would lead to significant economies of scale. A 5,000-ton/day plant could save $10/ton in ammonia costs. This large a plant, however, may pose marketing problems for any single company consider-

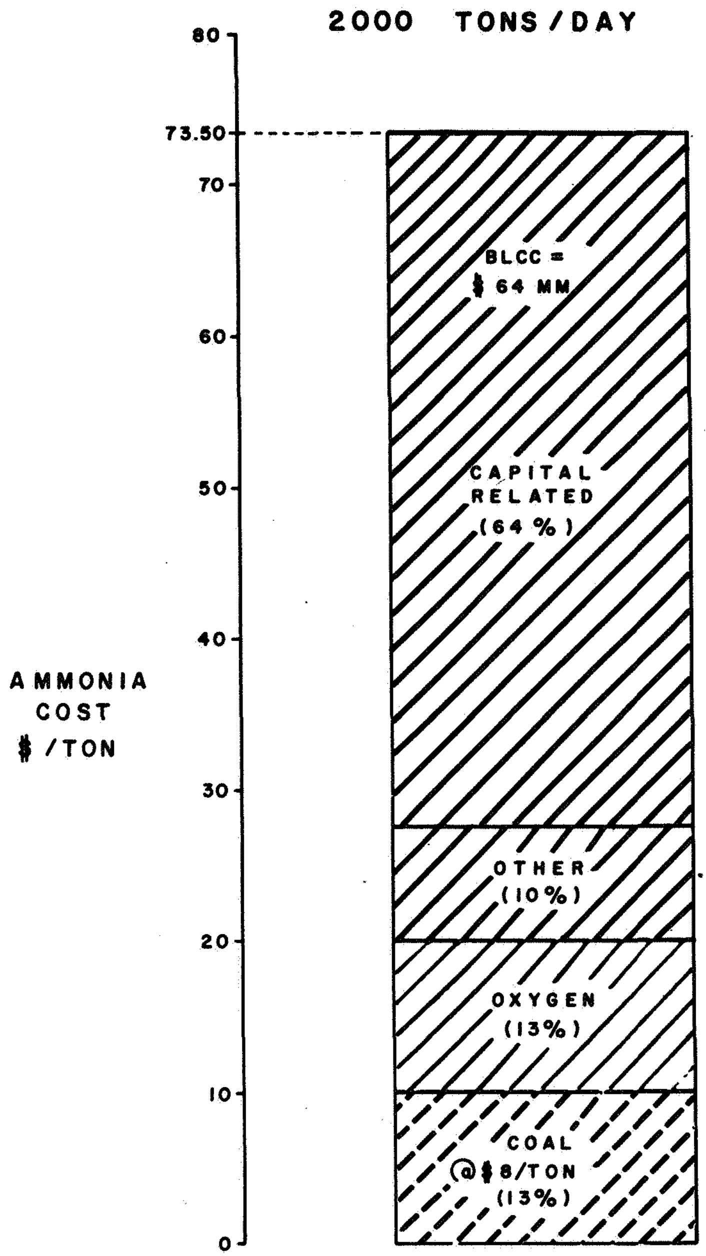

Figure 3. Breakdown of ammonia cost via coal gasification.

ing this type of venture.

To adequately assess the potential of ammonia production via coal gasification, one must review the other alternatives. Presently all ammonia production in the U.S. is based on steam reforming of natural gas. As is well known, the availability of natural gas is rapidly dwindling, and prices for intrastate gas are not controlled by the Federal Power Commission. Natural gas then must still be considered as an alternative for future ammonia plants. Table 3 shows the economics of ammonia production from a 2,000-ton/day steam-methane reforming plant, again on a third quarter, 1973 U.S. Gulf Coast investment cost basis.

With natural gas priced at $1.00/million Btu, ammonia cost with a 20% return on investment is $61/ton. This would be the cost, assuming natural gas available in the same location as the coal gasification plant and the ammonia markets. However, for a Gulf Coast location, which is more likely for a natural gas based plant, transportation costs have to be added to transport the ammonia product to the Corn Belt region. Ammonia pipeline costs are ap-

Table 3. Ammonia production via steam-methane reforming, 2,000 ton/day

Investment costs, 3rd quarter, 1973:	$ millions
Battery limits cost	35
Off-sites cost	26
Working capital	3
Total fixed and working capital	52
Production costs:	**$/ton**
Natural gas, @ $1.00/million Btu	34.10
Catalyst, chemicals and utilities	1.60
Labor, supervision and related	1.00
Capital charges*	10.70
Total production cost	47.40
Return on investment @ 20% before taxes	14.00
Gulf Coast ammonia cost	61.40
Transportation cost, Gulf Coast to Corn Belt	8.00
Corn Belt ammonia cost	$69.40

*See note for Table 2.

proximately $8/ton for the 900 miles between central U.S. and the Gulf Coast. This brings the ammonia cost to $69/ton vs. $73.50/ton from coal gasification. If the natural gas cost $1.15/million Btu, the delivered ammonia cost via both processes would be identical.

Two other options can be considered for ammonia production. The first is via partial oxidation of a heavy residual oil. A 2,000-ton/day plant in the Corn Belt is considered. To obtain ammonia at $73.50/ton as in coal gasification, the high-sulfur residual oil feedstock would have to be priced at $5.95/bbl. With imported crude oil at $12/bbl, a more likely price for the residual oil is $8/bbl. This would yield ammonia at $84/ton.

The second option is by importing ammonia produced in a foreign location, using steam methane reforming, where natural gas is plentiful and relatively inexpensive. To estimate ammonia production in a remote foreign location the following assumptions have been made:

1. Caribbean location; 2,000 miles, one-way trip from Gulf Coast.
2. Plant capacity is 3,000 ton/day.
3. Transportation costs to U.S. Gulf Coast based on 30,000 to 40,000-ton ships.
4. No import duties in the U.S.

To land ammonia at the Gulf Coast at $65.50/ton equivalent to $73.50/ton Corn Belt ammonia, the natural gas at the Caribbean plant site would have to be priced in at $0.85/million Btu. If the off-shore ammonia plant were located in the Persian Gulf, 12,000 miles distance, the natural gas would have to be priced in at less than $0.40/million Btu to yield equivalent Corn Belt ammonia prices.

Summary and conclusions

Figure 4 compares the various options discussed above for Corn Belt ammonia production. Alternatives are shown as a function of feedstock cost. A horizontal line at any

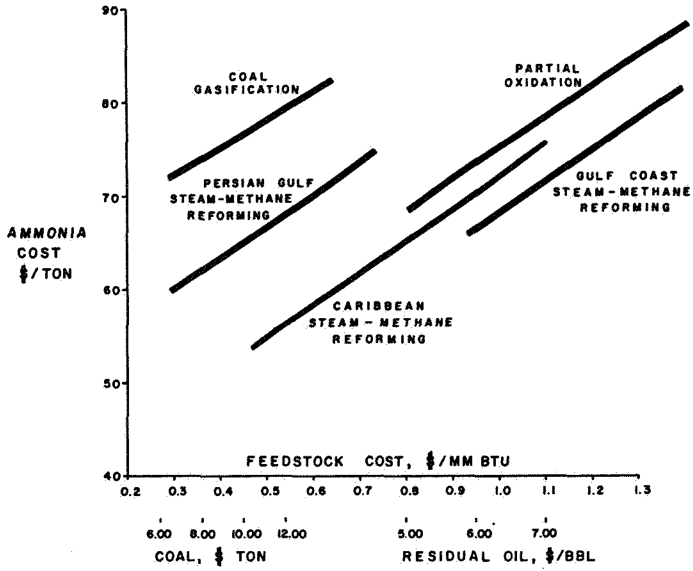

Figure 4. Comparative Corn Belt ammonia costs.

given ammonia price establishes breakeven raw material prices for the several options. For example, to obtain an ammonia cost of $80/ton in the Corn Belt, the following feedstock prices are obtained (at $/million Btu): coal, 0.57 ($12.70/ton); high-sulfur residual oil, 1.15 ($7.20/bbl); Gulf Coast natural gas, 1.33; Caribbean natural gas, 1.00; and Persian Gulf natural gas, 0.65.

While off-shore production of ammonia appears highly attractive, based on the above natural gas prices, it seems unlikely that the government and industry will allow a major U.S. industry to be "shipped out" to foreign interests. It is more likely that import tariffs would be imposed to equalize domestic ammonia prices. These in turn will be set by the domestic gas price available to new producers. Most probably, this will be natural gas at decontrolled prices or instrastate natural gas at unregulated prices. Assuming that this type of gas will be in the range of $1.00 to $1.50/million Btu, coal gasification as an alternative for ammonia production is entirely reasonable and competitive.

We have shown that ammonia can be produced from existing coal gasification technology at less than $75/ton, with coal priced in at $8/ton. There is presently in this country a considerable effort being expended in developing new coal gasification processes. Most of this work is sponsored wholly or partially by the U.S. government through the Bureau of Mines and the Office of Coal Research. The major emphasis is on production of SNG. However, we can speculate on how the developing technology would affect ammonia production if any of the coal gasification processes were modified for maximizing hydrogen (synthesis gas) rather than methane yield. The obvious choice would be for pressure gasification (300-1,000 lb./sq.in. gauge) with the gasifier effluent containing minimum methane. This would greatly reduce the investment cost of the coal gasification and purification section. In our internal studies, we have estimated that this type of development could reduce the cost of ammonia by 10 to 15%; or $7.50-$10.00/ton.

It is our opinion that during the remainder of this decade, this type of development will be studied more extensively and piloted on a large scale. The same type of gasifier would be ideally suited for methanol production, also receiving considerable attention as an alternate energy source. This will make ammonia production via coal gasification even more attractive, compared to the other alternatives.

With abundant coal reserves in this country compared to the dwindling supplies of natural gas, coal gasification for ammonia production may arrive sooner than we all realize.

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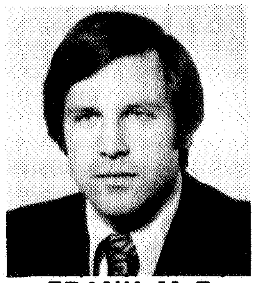

FRANK, M. E.

DISCUSSION

Q. I believe you gave about $5.50 as your utilities cost. What proportion of this was water? What I'm specifically interested in—did you assume that you had an unlimited availability of water or at least an easy availability of water, and what was its cost?

ROTHMAN: Are you asking about cooling water?

Q. Well, cooling and also the reaction that you use in the actual reaction on the steam with the coal for the gasification step?

ROTHMAN: We were assuming a cooling tower and a relative availability of water. About 60% of the utilities cost is for cooling water and steam.

Q. When you're figuring the cost of coal for that big plant out in the Middle West, are you figuring captive coal or coal mined right near the plant, or—your costs sound more like mining costs than you'd buy from a coal company.

ROTHMAN: Well, I'll tell you the problem one has with considering coal. It's always where and when and how. We have, for the purposes of evaluating economics for this study, considered coal cost varying over a range. We've taken numbers like eight to ten to fifteen dollars a ton. Now depending upon the specific user and the specific location, this could be either coal effectively at the mine mouth or coal delivered to some site at a reasonable distance from the mine mouth.

So I'm afraid it will depend, but obviously the price that we are talking about for economics is coal delivered to this plant. The location of the plant and the cost of coal depends very much on the specific circumstances.

Q. You say coal gasification is well proven around the world. In what size is it comparable? Is it proven in sizes to make 2,000 tons a day of ammonia?

ROTHMAN: Well, it's definitely proven in sizes to make 1,000 ton a day ammonia plants. As far as a size unit is concerned, effectively we've assumed a multiple number of gasifiers of sizes which are commercially demonstrated. This means that as far as the coal gasification section and the purification section are concerned, there is no extension of existing technology. The major impact in economics with size is associated with the front end, that is the handling and drying and crushing of the coal, and also the back end purification equipment. This equipment is more extensive for a coal base facility and therefore is more subject to economics of scale.

But as far as the gasifiers are concerned, we have assumed in these economics multiple gasifiers of sizes which have been commercially demonstrated.