COPING WITH AMMONIA SHORTAGES: PROGRESS IN DEVELOPING COUNTRIES AND IMPACT ON THE U. S.

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Ammonia and other nitrogenous fertilizers are an essential ingredient of the Green Revolution, which ushered in high yielding varieties (HYV) of grain highly responsive to plant nutrient usage.

China and India are the largest nitrogen (N) consumers among the less developed countries, and rank third and fourth in the world. Production of N in India and China is 2 million tons short of demand; both have embarked on ambitious programs to build up domestic synthetic ammonia capacity. While China is expected to reach near self-sufficiency by 1980, India will continue to be in deficit by nearly one million tons of N nutrient.

The imbalance in demand-supply could be alleviated by fuller utilization of existing capacity (which in India has been only 55% employed), improvements in packaging and distribution, balanced agricultural inputs, selection of appropriate nutrient form and NPK ratios, and import of food and fertilizer. Longer term measures include natural and biological means of fixing nitrogen employing symbiotic or asymbiotic relationships with nitrogen-fixing organisms, a shift away from grains toward high-protein legumes (which naturally fix 35 million tons of N worldwide), and population planning.

Coal has lately become the focus of interest as a raw material for ammonia. In a recent comprehensive study on Coal Chemicals by Skeist Laboratories, we find that coal becomes a viable alternative to OPEC oil or decontrolled natural gas under certain conditions. Furthermore, the selection of appropriate coal conversion process or technology is critical as it would lead to difference of 20% or more in operating rate and ammonia production cost. As early as mid-1960s, India launched a program to base a million tons of ammonia on coal.

But synthetic fertilizer capacity is highly capital intensive and could be a huge drain on the foreign exchange resources of a developing country. The current rate of increase in India's population dictates one 1,500 tons/day ammonia plant requiring an investment of $200 MM, coming on stream each year. We expound in this paper an alternative -- the fuller and optimal exploitation of a resource indegenous to India -- the cattle dung. The proposed dung gas system is designed to meet the twin needs of a farmer; it yields manure rich in NPK (3-5% of dung input) and bio-gas (2,000 CF or 1.1 MM Btu/ton dung processed) for cooking and other fuel applications. If 100 million tons of cattle dung were processed in dung plants, such as the ones discussed here, the output in terms of N alone would be equivalent to 3.3 million tons urea (1.5 MM tons N) or $900 million at current prices. The value of fertilizer plus gas approaches $2 billion per year.

Such a plan would bridge the gap between projected demand and supply, not only in fertilizer but also in food, and could potentially support a population growth of 100 million people.

Demand/Supply of Nitrogen

The introduction of HYV in the late 1960s accentuated the need for fertilizers. Of the three plant nutrients, nitrogen, P_2O_5, and K_2O, the nitrogen is by far the most critical, particularly in Asia because of the cropping patterns. Nitrogen, mostly in the form of urea and ammonium nitrate, represents two-thirds of the 15.5

million tons nutrient consumed in Asia in 1975.

Nitrogen production and demand for India, Asia and the world are shown in Table 1. Nutrient consumption in India quadrupled in less than a decade, exceeding 2.8 million tons in 1974-75, of which N made up 2 million tons. Even so, NPK usage amounted to only 15-16 kg/ha compared with 440 in Japan, 82 in the U.S., 40 in China and 41 in the Punjab State of India. Thus, there are wide disparities not only between the developed and the less-developed countries but also among the latter, and even in a country.

Asia's N consumption, currently 24% of the world's total, is expected to go up to 26% in 1980. India and China have combined usage of 6 million tons N -- 60% of Asian market. The Asian market is more or less in balance, thanks to Japan's more than 2 million tons of surplus production. Following massive build-up of N capacity over the next 5 years in China, India and Indonesia as well as the Mideast, Asia's demand/supply should be in balance by 1980 even without Japan's surplus, turning the continent into a net exporter. But India's domestic supply of N will still be a million tons short of demand, making her as the world's largest deficit country. (The merits of domestic production vs. imports in dealing with the deficit are discussed later).

Table 1. Nitrogen Fertilizer Production* and Demand 1970-1980
Million Metric Tons of Nitrogen (N)

	India			Asia		Asia excl. Japan		World
	P	D	Imports/ Deficit	P	D	P	D	
1970	0.71	1.36	0.65	5.1	6.5	3.0	5.6	30
1971	0.84	1.49	0.65	5.6	7.2	3.5	6.3	33
1972	0.95	1.76	0.81	6.5	7.4	4.4	6.7	35
1973	1.1	1.78	0.68	7.7	8.2	5.2	7.4	38
1974	1.1	1.78	0.68	8.1	9.2	5.0	8.4	41
1975	1.7	2.0	0.3	9.8	10.0	6.7	9.2	42
1976	2.2	2.7	0.5	10.4	10.9	7.3	10.0	45
1977	2.7	3.0	0.3	11.9	11.8	8.8	11.0	48
1978	2.7	3.3	0.6	13.3	12.8	10.2	12.0	51
1979	2.8	3.6	0.8	15.7	13.8	12.6	13.0	54
1980	3.0	4.0	1.0	17.0	14.8	14.0	14.0	57

*Nonagricultural capacity ranging 10-25% excluded. Projections for 1975-1980 are based on 70% capacity utilization in Asia, including India, from the third year of a new plant operation.

Forecasts of fertilizer demand in India and other 'non-free market' countries must be qualified. Demand is often constrained by supply. Demand is a function of the cost of fertilizer, purchasing power of farmer and the country, crop prices, timing of application, average land holding, population growth and governmental incentives. A rule of thumb estimate of fertilizer requirement can be made in terms of population growth -- one ton nutrient for 10-15 tons incremental food, sufficient for 30 people per year. Another measure is the optimum rate of fertilizer application. The recommended rate of N for HYV is 100 kg/ha vs. actual use of 42 for rice and 31 for wheat in India. In the case of traditional varieties, the recommended rate is 40-50 kg/ha, in contrast to actual use of 6 for rice and 14 for wheat. Overall nitrogen average in India has been 10 kg/ha, bringing into focus the sizable potential demand and elasticity. The projected demands for India and Asia of 4 and 15 million tons N in 1980 could consequently turn out to be very much on the conservative side.

Measures to Cope with Ammonia Shortages

Short-Term measures include:

- fuller utilization of existing capacity, which has been operating in the 40-70% range in many non-industrial countries, and about 55% in India, owing to power cuts, raw material difficulties and poor maintenance. Newer plants are operating at 70% or higher; at 90-100% India could be self-sufficient in N today. Moreover, the production cost of NH_3 is sensitive to operating rate; increasing it from 70% to, say, 90% would result in 25% lower price.

- improvements in packaging, storage, shipping and handling. These operations account for more than 50% of the cost to the farmer. Freight on urea from Osaka, Japan to Bombay, India, for example, costs only $29/ton in bulk vs. $42 bagged. Further, the choice of high concentration nitrogenous fertilizers like ammonia and urea should lower distribution costs.

- choice of right fertilizers. Urea or ammonium phosphate is more effective for rice fertilization than the nitrate form. Liquid and gaseous fertilizers including aqueous and anhydrous ammonia, nitrogen solutions and NPK solutions are generally more economical than traditional solid forms.

- imports; joint ventures.

Long-term measures include:

- nitrogen fixation, chemical or biological.

- changes in dietary habits, shifting emphasis from cereals to legumes capable of fixing nitrogen from the air. World legume production amounts to 120 million tons, about 10% of cereal grains. Worldwide, the amount of naturally fixed N in high protein legumes like soybeans and peanuts is estimated at 35 million tons in 1975, comparable to the 42 million tons of synthetic N nutrient.

- development of techniques to improve N recovery and utilization from fertilizers, which at present averages only 50% by crops.

- population planning.

Imports vs. Domestic Production

Synthetic ammonia is the source for more than 90% of nitrogenous fertilizers in the world. Natural deposits, organic waste materials and coke-oven by-product make up the remainder.

The most desirable feedstock for ammonia synthesis is natural gas (methane), followed by naphtha, heavy oil and coal. Among the most populous countries of Asia, Indonesia and China have adequate reserves of natural gas and oil to form the basis of a large domestic fertilizer industry. China's natural gas reserves, according to TVA estimates, will support twenty-one 1,000 mtpd (7 million tons/yr) ammonia plants consuming 25% of the reserves. Both Japan and India are heavily dependent on imported high cost naphtha -- the backbone of their fertilizer industry.

In an attempt to reduce dependence on imported naphtha and the foreign exchange component of NH_3, India has turned to coal recourse, even though plant investment for coal is 50-60% higher than for naphtha reforming. Three 900 mtpd NH_3 plants based on Koppers-Totzek coal gasification are under construction, and could furnish nearly one million tons of ammonia per year. In fact, a small 300 mtpd Winkler plant gasifying lignite has been operating since the early 1960s. Experiments are also in progress to use ammoniated coal for fertilizer.

India may also examine the possibility of importing LNG from Mideast. Abu Dhabi, separated from India by no more than 2,000 miles of water, flares 10 billion cubic meters of gas -- sufficient to produce 10 million tons of NH_3. Importing LNG would of course require investment in cryogenic tankers and special storage and handling equipment. India is reported to be actively considering a $300 million joint ammonia venture in Abu Dhabi.

Alternatives

Some of the alternatives for a country deficient in feedstocks and food are presented in Table 2.

Table 2. Relative Economics of Food vs. Fertilizer - Imports and Domestic Production (Developing country importing raw materials)

	Rice	Wheat
Cereal price, \$/kg	0.40	0.17
N cost, \$/kg (\$275/ton urea mid-1975, India)	0.60	0.60
Incremental food production, kg, by application of 1 kg nutrient (Response ratio)	15	10-12
Value of incremental food, \$	6	2
Food/Nutrient cost ratio	10	3-4
Population supported by 1 ton nutrient/year**	30	20-25

New investment in domestic production*	
Plant investment, 1,000 mtpd ammonia from naphtha	\$125 MM
Ammonia production cost	\$175/mt
Raw material cost % of nutrient (N) cost	46%
Ammonia selling price with 20% ROI	\$250/mt
Raw material cost % of nutrient (N) price	32%

* Total plant investment for 1,000 mtpd ammonia based on naphtha reforming is reported to be \$125-130 MM, and production cost \$175/mt at 90% operating rate. ROI at 20% translates to a sales price of \$250/mt ammonia or \$305 mt. N. Imported naphtha is assumed at \$90/mt; 0.88 tons naphtha required per ton NH_3 or 1.073 tons (\$97)/ton N.

**One ton grain supplies 5,000 cal/day for one year - sufficient for 2 people at an average 2,500 cal/day per capita.

Clearly, it is far more desirable to import plant nutrient than food. Typical ratios of food/nutrient costs are 3-4 for wheat and 10 for rice. The economics of raw material imports generally appear to be more favorable than fertilizer imports; however, the advantage is not always decisive. Feedstock makes up nearly one-half N production cost, excluding ROI, at \$90/ton imported naphtha. While it is reasonable for a developing country to want to achieve self-sufficiency in fertilizers, it is questionable whether a no-imports policy, and the investment it entails, represents optimum allocation of resources.

Impact on U.S. Exports

As a result of heavy investment in NH_3 capacity all over the world, most countries that are importers now will either achieve self-sufficiency (e.g. Latin America) or become exporters by 1980 (Indonesia). In the Mideast, Iran and Kuwait are expected to have 1/2 million tons of N for export. Indonesian industry, operating at a remarkable 100% level, should have another 1/2 million tons for export. No significant increase in capacity or demand is foreseen for Japan, and she will continue to look for overseas markets for 2 million tons of surplus product. Heavy construction is also reported in Russia, presumably with the objective of doubling by early 1980s its present capacity of 12 million tons of ammonia. Western Europe will probably have 1 million ton nitrogen surplus.

It appears, therefore, that American N exports will be facing increasingly tough competition. In any event, the opportunities for American engineering companies for sale of technology and equipment are indeed impressive - as exemplified by M. W. Kellogg which reportedly has contracts for eight 1,000 tpd ammonia plants in China alone.

Cattle Dung ("Gobar") Gas Scheme

The cattle dung gas plant, illustrated in Figure 1, is a simple but ingeneous device that integrates and 'optimizes' the production of fertilizer and fuel - the two essential commodities for the farmer.

The equipment consists of a fermentation well or digestor, a gas holder and an inlet tank and an outlet tank connected by pipes. The cylindrical fermentation well is below ground level, lined with brick and mortar. The gas holder is made of mild steel or fiberglass reinforced polyester.

Cattle dung and other organic material mixed with equal volume of water and urine is fed to the inlet tank in a slurry. An equal amount of fermented slurry, minus about one-fourth converted to gas, flows out into the compost pit or outlet tank. Initially the fermentation well is completely filled with slurry; it takes about 10 days for enough gas to be generated to fill the holder. The outlet tank is located below the level of the inlet tank to achieve the necessary pressure balance. The pressure of gas collected in the gas holder is equal to the weight of the holder. A pipe connects the gas holder to kitchen or nearby points where gas would be utilized.

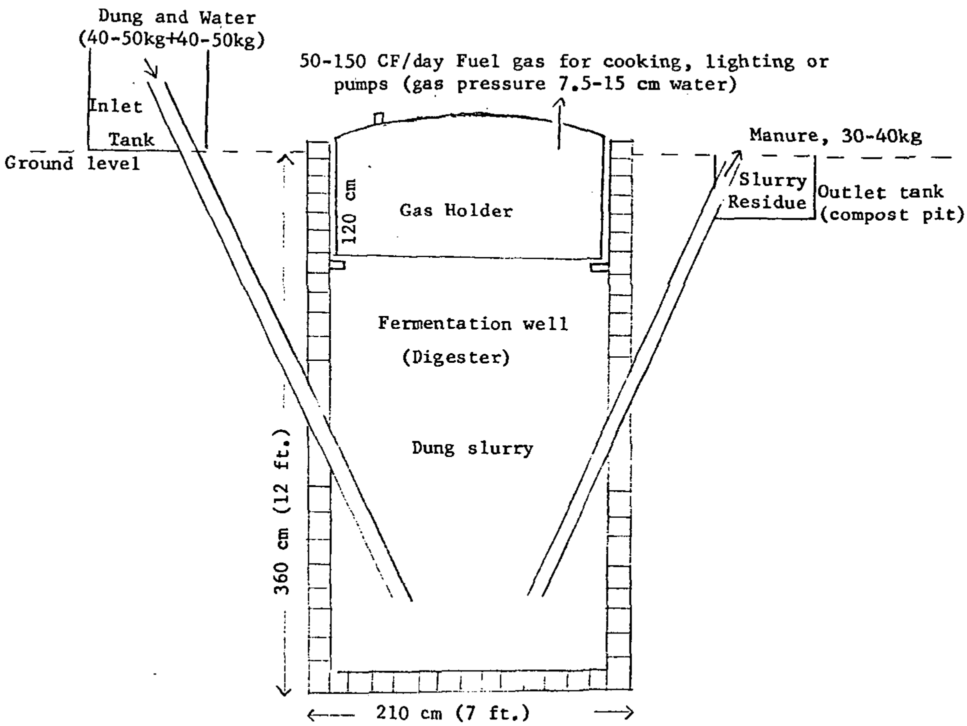

Figure 1. Catle Dung Bio-gas Scheme - 100 CF Gas/day (3 cm/d; not drawn to scale)

Table 3. Inputs and Products of 100 CFD Dung Gas Plant

Inputs:

40-50 kg/day (for 100 CF Gas)
(Cattle durg mixed with equal amounts of water and catle wine).

Every 100 CF gas capacity requires dung of at least 4-5 animals. Dung averages at 10 kg/day per adult cow or bullock and 14 kg per buffalo on site. The availability of dung for conversion may in fact be substantially lower, as the cattle are not always stable bound.

Outputs:

1. Gas: 1-3 CF/kg of fresh dung

Composition	Vol. %
CH_4	50-60
H2	5-10
CO_2	30-45
N_2	1-2
H_2S	Traces

Heating Value: 550 Btu/CF

Typical gas requirements:

Cooking	-	12-15 CF/person/day
Electricity	-	22 CF/KWH
Gas engines	-	15-16 CF/HP-Hr

2. Slurry residue/manure product 75-80% of dung input (remainder turns into gas)

Nutrient		Content on dry basis
Nitrogen	N	1.5-2%
Phosphate	P_2O_5	1 - 2
Potash	K_2O	1

Economics

Capital investment and operating costs of 100 CF/day gas plant and estimated value of products are as follows:

Capital investment

Equipment	-	$120
Construction	-	$140
		$260

Annual operating costs*

Maintenance (paint)	$10
Interest at 10% on 75% of investment (25% gov't. grant)	20
Depreciation (15 yrs)	17
	$47

Value of Products

Gas: (100 CFD) x (360) = 36 MCF - 20 MM Btu/yr @ $1.25/MCF ($2.27/MM Btu)	=	$45
Manure (NPK < 5%) approx. 15 tons @ $5/ton	=	$75
Total value		$120/yr.

* Excluding the cost of labor of owner-operator.

Return on Investment

$$ROI = \frac{\text{Average yearly profit}}{\text{Original fixed investment + working capital}} = \frac{73}{(260x0.75) + 0} = 37\%$$

The 37% ROI or 3 year payoff period is attractive. But even the small investment could strain the resources of an Indian farmer; the government therefore provides 25% grant as an inducement and the balance on loan.

The size of dung unit is determined by the number of cattle and fuel and fertilizer needs. A range of 100-300 CFD is common but there is no reason why, say 5,000 CFD plants cannot be built near cattle farms. The economics of scale are appealing -- 300 CFD entails an added investment of less than one-half that for 100 CFD. Even the small 100 CFD unit, within the reach of an 'average' farmer, yields enough gas to support a family of 5-6. Furthermore the 15 tons of manure furnishes 225 kg of nitrogen assuming 1.5% N content.

If we assume an average holding of 3 hectares per family (actually 75% of some 500 million holdings are said to be 2 hectares or less), the nitrogen content of the manure represents a seven-fold increase in the present rate of usage of 10 kg/ha. In a narrow sense, the 100 CFD plant is thus capable of making the farmer self-sufficient in these areas.

Efficiency

The idea of processing animal dung to make manure plus fuels is hardly new. Simple as well as complicated devices for producing methane from organic waste have been reported both in the U.S. and in South America. The distinguishing feature of the dung gas technique is its 'ideal' distribution of fuel and fertilizer involving a simple and low cost device.

One might question as to why dung should not be used directly as manure and N source, and secondly the wisdom of disrupting the age-old practice of using dung cakes for cooking and other fuel. (In India 70 million tons of dry dung are used annually for fuel). The rationale lies in improved efficiency and selectivity. For instance, 60% thermal efficiency was reported for gas as opposed to only 11% for dung cakes. Consequently, 20% more useful heat is produced with only 20-25% of dung converted to gas than when the entire dung is burned for fuel. Similarly, it has been claimed that 43% more manure is produced than in manure pit, presumably due to selective decomposition by bacteria in fermentation well.

The availability of fertilizer near the point of application will tend to minimize the considerable costs and losses associated with the distribution of synthetic nutrients. The dung manure is of course not a substitute for ammonia and urea, but will augment them. Even by itself the manure acts as a good soil conditioner, enhancing fertility.

A Plan

We can envision a plan for India for the construction of the capacity to process 100 million tons of dung annually, one-eighth the total production of dung.

The potential values of products of the dung gas system are presented in the following Table. The estimated yield of N nutrient alone amounts to 3.3 million tons - more than sufficient to bridge the gap between India's projected demand and supply through at least 1980. NPK output totals 4 million tons or $1.5 billion. (If imported, these would have claimed more than on-half of India's foreign exchange earnings from exports). The co-product bio-gas (200 billion CF; 550 Btu/CF) is valuable not only for its $250 contribution, but in that it will deter diversion of dung to solid fuel usage.

Table 4. Products and Value of 100 Million Tons/yr. Cattle Dung Processed in Dung Gas Units

Product	Quantity/yr.	Equivalent to	@	Value
Fertilizer				
Nitrogen N	1.5 MM tons	3.3 MM tons urea	\$275/mt	\$900 MM
Phosphate P_2O_5	1.5 MM tons		\$300/mt	\$450 MM
Potash K_2O	1 MM tons		\$150/mt	\$150 MM
Fuel				
Dung gas or Bio-gas	200 billion CF or 11,000 billion Btu	107 billion CF natural gas, 1,030 Btu/CF	\$2.27/MM Btu	\$250 MM
			Total	\$1,750 Million

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