

# PRELIMINARY FEASIBILITY STUDY OF THE ESTABLISHMENT OF A CHEMICAL FERTILIZER PLANT IN NEPAL

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# Contents

<b>1</b>	<b>Terms of Reference</b>	<b>5</b>
<b>2</b>	<b>Summary of JICA Feasibility Study -1984</b>	<b>7</b>
2.1	Reasons for Fertilizer Plant Construction	7
2.2	Choice of Fertilizer	7
2.3	Choice of Manufacturing Process	8
2.4	Technical Features of the Chosen Process	9
2.5	Technical Challenges	10
2.6	Implementation and Management	11
2.7	Basic Financial Assumptions/Findings	11
2.8	Other Points of Interest	12
<b>3</b>	<b>Fertilizer Requirement of Nepal</b>	<b>13</b>
<b>4</b>	<b>Review of Existing Urea Plants and Commercial Technologies</b>	<b>15</b>
4.1	Existing Plant Specs	15
4.1.1	HABAC Nitrogenous Fertilizer and Chemicals Company - Bac Giang, Vietnam	15
4.1.2	Nagarjuna Chemicals and Fertilizer Ltd., Kakinada, India	15
4.1.3	Indian Farmers Fertilizer Cooperative Limited - Phulpur Unit I, Allahabad, India	16
4.1.4	Indian Farmers Fertilizer Cooperative Limited - Aonla, India	16
4.1.5	Tata Chemicals, Babrala Urea Plant- Babrala, India	16
4.1.6	Chambal Fertilizers and Chemicals Limited Urea Plant - Gadepan, India	17
4.2	General Energy and Water Usage Figures	17
4.3	Energy Consumption	17
4.4	Summary	18
<b>5</b>	<b>Hydrocarbon and Natural Gas Availability in Nepal</b>	<b>21</b>
5.1	Sufficiency of estimated Kathmandu valley reserves of natural gas for the purposes of the Urea plant	21
5.2	The Indian Natural Gas Pipeline Network	22
5.3	Coal Gasification	23
<b>6</b>	<b>Urea Manufacturing Technologies</b>	<b>27</b>
6.1	Bosch-Meiser Process	27
6.2	Ammonia Manufacturing Technologies	28
6.3	The Haber-Bosch Process	28
6.4	Solid-State Ammonia Synthesis	29
6.4.1	Commercial Status	30
6.5	Hydrogen Manufacturing Technologies	30
6.6	Hydrogen from hydrocarbons	30
6.6.1	Steam-Methane Reformation	30
6.6.2	Coal Gasification	31
6.7	Water Electrolysis	31

## Contents

6.8	Basic Material and Energy Requirements for Electrolysis-Based Urea Plant . . .	33
6.8.1	Hydrogen Requirement . . . . .	33
6.8.2	Water Consumption and Oxygen Production . . . . .	33
6.8.3	Nitrogen Requirement . . . . .	34
6.8.4	Carbon-Dioxide Requirement . . . . .	34
6.8.5	Overall Power Requirement . . . . .	34
6.8.6	Summary Characteristics of Electrolysis Based Plant . . . . .	35
<b>7</b>	<b>Trends in Prices of Natural Gas and Urea</b>	<b>37</b>
7.1	Cost of Natural Gas . . . . .	37
7.2	Trends in Urea Prices . . . . .	37
7.3	Inflation Rate of Urea Prices . . . . .	38
7.4	Capital Required for Construction of Urea Plant . . . . .	39
<b>8</b>	<b>Summary</b>	<b>41</b>
8.1	Financial Calculations . . . . .	41
8.1.1	Base Case . . . . .	41
8.1.2	Sensitivity to capital cost . . . . .	42
8.1.3	Sensitivity to Specific Energy Consumption . . . . .	43
8.1.4	Sensitivity to the Price of Electricity . . . . .	43
8.1.5	Sensitivity to the Selling Price of Urea . . . . .	44
8.1.6	Summary of Sensitivity Analysis . . . . .	44
8.2	Feasibility Analysis of 1000 TPD plant as Function of Electricity Price and Selling Price of Urea . . . . .	45
8.2.1	Best Case Scenario: Capital Cost USD 500 Million . . . . .	46
8.2.2	Intermediate Scenario: Capital cost USD 700 Million . . . . .	47
8.2.3	Worst case scenario: Capital cost USD 1 billion . . . . .	48
8.3	Effect of Oxygen Sales . . . . .	48
8.4	Macroeconomic Effects . . . . .	49
8.5	Conclusions and Recommendations . . . . .	49
8.6	Recommendations . . . . .	51
<b>9</b>	<b>Appendix</b>	<b>53</b>

# 1 Terms of Reference

[Back to Table of Contents](#)

The following terms of reference for work done during the duration of the Dayitwa fellowship (June 9, 2014 - August 19, 2014) were provided by Mr. Ashish Gajurel of the Investment Board of Nepal:

1. Analysis of the proposed locations: West side of the Hetauda Cement Ltd, Hetauda and Dhalkebar area as recommended by the JICA's feasibility study report.
2. Explore and prepare report of all the existing technologies for the production of Chemical Fertilizer.
3. Study and prepare detailed report of the power and raw materials requirement for the proposed plant.
4. Support in the bidder/consultant selection process for the feasibility study of the chemical fertilizer plant.



## 2 Summary of JICA Feasibility Study -1984

[Back to Table of Contents](#)

Between October 1983 and September 1984, the Japan International Cooperation Agency (JICA), at the request of Nepal's government at the time and in collaboration with Nepalese experts, had conducted a study investigating the feasibility of establishing a chemical plant for Nitrogen fertilizer manufacture in Nepal. The team that conducted the study spent approximately a month in Nepal with the rest of the work being done in Japan. Important findings from this report, which still have relevance in today's context, are summarized below.

### 2.1 Reasons for Fertilizer Plant Construction

The establishment of a large chemical plant is not a trivial undertaking, requiring considerable investment of capital and the availability of raw materials, cheap sources of energy, transportation infrastructure, and a skilled and experienced workforce along with the necessary regulatory supervision and discipline with regards to safety and environmental protection. Given the difficulties regarding the above criteria, it is natural to ask why the government would consider such a project. The JICA report points to the following reasons:

- Fertilizer prices in Nepal are higher than international prices due to transportation difficulties and frequently subsidized by the government.
- At the time of the study, around 93 % of the population of Nepal was reliant on agriculture but the productivity was low.
- Fertilizer consumption in Nepal is low compared to other countries of the world and even other countries around Asia. Among south Asian countries, Nepal had the lowest fertilizer consumption at 7.4 kg/ ha while Sri Lanka had the highest consumption at 41.2 kg/ha. Given the strong dependence of the country's GDP on Agriculture, it would be beneficial to boost fertilizer adoption in farming.
- Estimated chemical fertilizer consumption in 1982/83 was 22,900 metric tons of Nitrogen, 7200 tons of Phosphorus, and 900 tons of potassium. It is thus clear that Nitrogen fertilizer is of the highest demand. The demand for Nitrogen fertilizer was projected to grow to 33,380 tons of Nitrogen by the year 2000 corresponding to 73,000 tons of urea. All of the chemical fertilizer consumed in Nepal was imported.

### 2.2 Choice of Fertilizer

Given the above, the natural choice of chemical fertilizer compound would be a compound that supplies Nitrogen, since it is Nitrogen fertilizer that had the greatest demand. There are several compounds which may be used as Nitrogen source:

- Ammonia based: Ammonia, Ammonium Sulfate, Ammonium Nitrate, Ammonium Chloride, Ammonium Phosphate.
- Nitrate based: Ammonium Nitrate, Sodium Nitrate, Calcium Nitrate

## 2 Summary of JICA Feasibility Study -1984

- Urea
- Cyanamide

Among the above choices, Urea was deemed to be the best choice for the following reasons:

- It was and continues to be the most heavily utilized fertilizer in the world.
- Ammonium nitrate is more easily volatilized into the air compared to urea so urea is the better fertilizer.
- Urea is not absorbed by soil until it decomposes to ammonia and can be washed away by water during this time but this was not found to be a significant issue in Nepal.
- Risk of ammonia volatilization is high in alkaline soils but the soils in Nepal are mostly acidic so this risk is small.
- Ammonium sulfate increases soil acidity so its use is not recommended on the already acidic soil in Nepal.
- Although urea was the more expensive fertilizer, the nitrogen content of urea is twice that of ammonium sulphate so it was a better nitrogen source for the money spent.

### 2.3 Choice of Manufacturing Process

The standard process for urea manufacture at the time that the report was compiled was the Haber process followed by the urea manufacture process. In the Haber process, gaseous hydrogen and nitrogen are reacted at high temperature and pressure to produce ammonia. The ammonia is then reacted with carbon-dioxide in order to produce urea in a second process. In the typical industrial process popular worldwide, natural gas (methane) is subjected to steam reformation to produce both the hydrogen and carbon-dioxide necessary for urea synthesis. The nitrogen is obtained from atmospheric air by liquification and fractional distillation.

Instead of the standard process, the chosen process for the urea plant to be potentially constructed in Nepal was to produce hydrogen by electrolysis and carbon dioxide by extraction from cement factory flue gas. The targeted plant capacity was to be 275 tons of urea per day to meet the projected demand in Nepal, even though the general trend was for plants to have capacity between 1000 and 1800 TPD (Tons Per Day) for economies of scale. This was deemed suitable for the following reasons:

- There was no identified source of natural gas within Nepal
- Hydroelectric power was indigenous to Nepal so hydrogen production by electrolysis was the natural choice
- Several hydro projects, including the Sapta Gandaki project, were scheduled to come online in the near future leading to a surplus supply of electric power
- There was no industrial source of CO<sub>2</sub> in Nepal, with the only viable alternative being cement factory flue gas which generates around 20% CO<sub>2</sub> due to both coal burning and calcium carbonate decomposition

## 2.4 Technical Features of the Chosen Process

- Urea production capacity to be 275 tons per day of dry, prilled Urea.
- Plant to be located adjacent to Hetauda Cement Factory
- Process plants required:
  - Hydrogen plant - 28.4 TPD (tons per day)
  - Nitrogen plant - 132 TPD
  - Ammonia plant - 160 TPD
  - Carbon dioxide plant - 207 TPD
  - Urea plant - 275 TPD
- 25% KOH solution to be used as the electrolyte for the hydrogen production process
- Ammonia to be made by compressing H<sub>2</sub> and N<sub>2</sub> at a molar ratio of 3:1 to 310 atm by reciprocating compressor and passed over catalyst at 400°C. Unreacted gas to be fed to waste heat boiler to recover the heat of reaction and produce steam at 26 atm.
- Urea produced by reacting ammonia and carbon dioxide at 200 atm and 200° C
- Material required:
  - Water
  - Electricity
  - Coal
  - Air
  - Flue gas
  - Bags for fertilizer
  - Catalysts and chemicals
- Required utilities:
  - Electric power receiving - 86 MW
  - Water treatment - 183 TPH
  - Water demineralizer - 32 TPH
  - Cooling tower - 6500 TPH
  - Steam generator (using coal) - 27.5TPH
  - Instrument & plant air - 1500 Nm<sup>3</sup> PH
  - Emergency power generator - 0.8 MW
  - Waste water treatment - 55 TPH
- Product storage and loading : 2100 tons in bulk and 7000 tons bagged. Bagging capacity is 40 TPH and 100 TPH capacity for loading to trucks
- Auxiliary facilities
  - Admin building 800 m<sup>2</sup>
  - Canteen 800 m<sup>2</sup>
  - Maintenance office 400 m<sup>2</sup>

## 2 Summary of JICA Feasibility Study -1984

- Maintenance workshop 1320 m<sup>2</sup>
  - Analytical lab 400 m<sup>2</sup>
  - Chemicals and parts warehouse 320 m<sup>2</sup>
  - Guard house 30 m<sup>2</sup>
  - Parking lot 150 m<sup>2</sup>
  - Medical room 200 m<sup>2</sup>
  - Plant analytical 30 m<sup>2</sup>
  - Engineering/supervision = 910 man months
  - Construction labor = 21700 man months
  - Peak labor force = 1800 persons
- Operations staff: 92
  - Needs road 12 m wide and requires moving of 230,000 m<sup>3</sup> of earth
  - All plants, but in particular the Urea and Ammonia plants must be operated continuously because frequent start-up and shut-down is bad for efficiency and catalyst lifetime.
  - Consumption of CO<sub>2</sub> would be 0.75 ton/ ton Urea.
  - Estimated land requirement was 100000 m<sup>2</sup> ( 200 m × 500 m)
  - Water is required for cooling water make-up and electrolysis. Estimated usage was 4,400 tons per day.
  - Estimated electric power requirement for the plant would be 83 MW
  - Waste water will be treated in hydrolysis tank to remove and recover ammonia and treated water to be discharged with other waste water
  - Equipment weight : 8500 net tons / 25400 freight tons
  - Construction estimated to take 36 months

### 2.5 Technical Challenges

- Stability of electricity supply is a key factor for hydrogen production by water electrolysis. However, most of the power generated in Nepal was due to run-of-the river type plants and therefore there were strong seasonal fluctuations. In addition, the load profile is such that there are strong hourly fluctuations during the day. To ensure the stability of supply the following measures would need to be implemented:
  - Power generator at the fertilizer plant to supplement the electricity supply
  - Hydrogen storage facility would allow the electrolysis plant, which is the biggest consumer of electricity, to be operated intermittently, allowing the ammonia and urea plants to be operated continuously
  - Scheduled maintenance should be done during the dry season
  - The plant should be designed to be capable of operating below nameplate capacity
  - Carbon dioxide storage must be provided to act as buffer during the times when the cement factory is shut down

- Urea plants that produce hydrogen from natural gas have access to highly purified carbon dioxide. In the electrolysis scheme, cement factory flue gas must be used as CO<sub>2</sub> source. Flue gas only contains 20% CO<sub>2</sub> and many impurities
- There were no reported instances of cement factory flue gas recovery for urea production anywhere in the world.
- Only Hetauda cement factory with its target capacity would be capable of providing enough high quality CO<sub>2</sub> for the urea plant. It was not constructed yet.
- The technology to recover and purify the flue gas to CO<sub>2</sub> was not well established.
- Road and bridge weight limits would be important technical challenges for transportation of heavy equipment

## 2.6 Implementation and Management

- Recommended formation of a new entity consisting of Nepalese and foreign professionals with the necessary skills and experience for both construction and operation.

## 2.7 Basic Financial Assumptions/Findings

Many of the financial assumptions made during the JICA study in 1983/84 may now be outdated due to changes in technology, urea prices, alternative fertilizers, etc. But the basic assumptions are listed below for reference.

- Production scale targeted to 275 tons per day
- Economic lifetime of project estimated to be 15 years
- Total financing requirement estimated to be \$145 million
- Physical contingency (discrepancies arising due to erroneous estimate, unknown changes in construction requirements) of 5%
- Price contingency (fluctuation and increase in the price of capital equipment over time) of 4% per year. General inflation of 6 % per year
- Financing plan to be:
  - 30% equity, 70% loan
  - Loan terms assumed to be 5% per year interest rate and grace period during construction for foreign loans. 15% interest rate for local loan.
- Prevailing electricity price of 3.56 cents per kWh
- Annual maintenance cost estimated to be 3% of plant cost
- Depreciation rates:
  - 20 years for buildings
  - 10 years for machinery
  - 5 years for vehicles and furniture
  - 10 years for other fixed assets
  - 10 years for pre-investment and pre-operation expenses

## 2 Summary of JICA Feasibility Study -1984

- Administrative expense is 70% of annual personnel expenses.
- Project will use the most efficient electrolysis process available
- Economic value of the the produced urea is taken as equal to the selling price of the urea
- ERR (Economic internal rate of return) was calculated to be 8.2%, NPV calculated to be \$1.02 million at 8% discount factor.

### 2.8 Other Points of Interest

- Transportation of final product to the consumption sites is an important factor to consider when determining the location of the plant.
- Regardless of finances, the selling price of fertilizer might have to match the prices in India because if fertilizer is cheaper in Nepal than India, it will be smuggled across the border.

### 3 Fertilizer Requirement of Nepal

[Back to Table of Contents](#)

According to data from the [world bank](#) [1], the consumption of chemical fertilizer per hectare of arable land in Nepal between the years 2009 and 2013 was 23.2 kg. In comparison, the consumption in Bangladesh was 184.4 kg while that in India was 178.5 kg. The heaviest chemical fertilizer user in the world, Qatar, had a usage of approximately 6000 kg. This fertilizer consumption includes not only nitrogen fertilizer but any kind of chemical fertilizer.

Based on data provided by Mr. Bhagwan Khatiwada from the Ministry of Agriculture [8], the demand for chemical fertilizer according to the District Agriculture Development Offices (DADOs) of Nepal is as follows:

Fiscal Year	Urea(MT)	DAP(MT)	MOP(MT)	Total(MT)
2009/10	289229	213838	19571	522638
2010/11	394986	256957	24953	676896
2011/12	458184	298070	28946	785200

Based on informal discussion with Mr. Khatiwada, he surmises that the demands presented in the above table are overestimates. The actual quantities imported by the AICL (Agriculture Inputs Corporation), the entity responsible for importing and distributing subsidized Urea, are far lower and he estimates that quantities smuggled across the Nepal-India border are not substantial enough to make a significant difference. This observation is corroborated by the quantity reported in a review published in the Nepal Agriculture Journal [9] which showed that the highest quantities of fertilizer imported between the years 1998/99 and 2008/09 was in the year 1998/99 when 219038 MT of fertilizer was imported out of which 168906 was Urea and the rest was DAP. Other data sources disagree but quote numbers even lower.

Based on his experience, Mr. Khatiwada estimated that the ideal fertilizer consumption of Nepal would have 400,000 MT of Urea as the absolute maximum. He also suggested that 300,000 MT of Urea per year should be sufficient to satisfy Nepal's Urea needs. Furthermore, he mentioned that the distribution of chemical fertilizer demand should be 60% Urea, 30% DAP and 10% Potash. This is corroborated by the MSc. Thesis of Mr. Bharat Ghimire [10] where he writes that the demand for chemical fertilizer in Nepal in the year 2011 was roughly 67% Urea, 30% DAP, and 3% Potash.

Based on the above figures, if we go with a required annual capacity of 400,000 MT per year, we need a plant with urea production capability on the order of 1000 TPD or more (up to 1400 TPD, allowing from downtime and excess capacity).



## 4 Review of Existing Urea Plants and Commercial Technologies

[Back to Table of Contents](#)

World leaders in Ammonia and Urea technologies:

- Ammonia - Haldor Topsoe (Denmark)
- Urea - Stamicarbon (Netherlands)
- Plant Construction - Saipem (Italy)
- Plant Construction - Kellogg (KBR), ThyssenKrupp Uhde, FosterWheeler

### 4.1 Existing Plant Specs

#### 4.1.1 HABAC Nitrogenous Fertilizer and Chemicals Company - Bac Giang, Vietnam

- Capacity: 445 TPD Urea, 275 TPD Ammonia
- Capital Investment: \$40 million
- Commissioning date: 1995, construction started 1992
- Personnel: 3 shifts of 600 workers each
- Process : Coal gasification and steam reformation
- Raw material: 1300 TPD Coal
- Catalyst:  $\text{Fe}_3\text{O}_4$ ,  $\text{MoS}_3$ ,  $\text{CoS}$ ,  $\text{K}_2\text{CO}_3$
- Water requirements:
  - Process: 300 m<sup>3</sup> per day
  - Cooling: 280,000 m<sup>3</sup> per day
  - Other: 33,000 m<sup>3</sup> per day
  - Daily discharge: 192,000 m<sup>3</sup> per day
- Solid waste: 320 TPD cinder

#### 4.1.2 Nagarjuna Chemicals and Fertilizer Ltd., Kakinada, India

- Capacity: 2 × 1810 TPD Urea, 2 × 1050 TPD Ammonia
- Process: Natural gas + Naphtha steam reformation
- Land use : 121 acres

#### 4 Review of Existing Urea Plants and Commercial Technologies

- Water requirements: 21,000  $m^3$  per day drawn from Godawari river. 70% used for cooling, 15% for process. Specific consumption: 5.5  $m^3$  per ton Urea
- Energy consumption:  $5.6 \times 10^6$  kCal / ton Urea. Volume of gas can be estimated using the heating value of natural gas (approx 8200 kCal/Sm<sup>3</sup>, source: <http://fert.nic.in/node/1415>).

##### 4.1.3 Indian Farmers Fertilizer Cooperative Limited - Phulpur Unit I, Allahabad, India

- Capacity : 1500 TPD Urea, 900 TPD Ammonia
- Commissioning date: 1981
- Process: Naphtha and Natural gas steam reformation
- Technology: MW Kellogg, Snamprogetti
- Energy Consumption:  $7.5 \times 10^6$  kCal/ton Urea
- Water Consumption : 5490 liters per ton Urea

##### 4.1.4 Indian Farmers Fertilizer Cooperative Limited - Aonla, India

- Capacity : Dual urea plants with combined capacity 1520 TPD Ammonia and 2620 TPD Urea
- Commissioning date: 1988 with second plant added in 1996
- Process: Natural gas + Naphtha
- Technology: Haldor Topsoe
- Energy Consumption: 5.7 Gcal/ton Urea, 7.7 Gcal/ton Ammonia
- Approx land area: 1 sq. km plant area, 2.5 sq. km. including surrounding greenery. (estimated with google earth)

##### 4.1.5 Tata Chemicals, Babrala Urea Plant- Babrala, India

- Capacity : Dual urea plants with combined capacity 1500 TPD Ammonia and 2600 TPD Urea
- Process: Natural gas + Naphtha
- Technology: Haldor Topsoe, Giammarco Vetrocoke
- Energy Consumption: 5.25 Gcal/ton Urea
- Water Consumption: 4.6  $m^3$  per ton Urea
- Wastewater Generation: 0.6  $m^3$  per ton Urea
- Approx land area: 1 sq. km plant area, 2.5 sq. km. including surrounding greenery. (estimated with google earth)

#### 4.1.6 Chambal Fertilizers and Chemicals Limited Urea Plant - Gadepan, India

- Capacity: Dual urea plants with combined capacity of 2600 TPD Urea
- Commissioning date: Gadepan I in 1994 and Gadepan II in 1999
- Process: Natural Gas + Naphtha
- Technology: Haldor Topsoe, Giammarco Vetrocoke
- Energy Consumption: 5.6 Gcal per Ton Urea, 8 Gcal per ton Ammonia
- Water Consumption: 5.14 m<sup>3</sup> per ton Urea
- Approximate land area: 1 sq. km, estimated using google maps

## 4.2 General Energy and Water Usage Figures

### 4.3 Energy Consumption

The average energy consumption figures for ammonia and urea plants worldwide is summarized in the table below:

Process	India average (2003)	World (1998)	Europe (1997)	US (1995)
Ammonia	9.9902	8.7474	8.4845	8.8669
Urea	6.7876	6.1662	5.8555	7.2656

Table 4.1: Average specific energy consumption by region (Gcal / MT). Source: Mr. Chandra P. Mohan, Nagarjuna Fertilizers and Chemicals Ltd.

The energy consumption of urea plants depends on the feedstock/ful used for production. Natural gas is the most suitable feedstock as it results in the most efficient use of energy. It is followed by Naphtha, with coal being the worst hydrocarbon source for urea production.

Feedstock wise Capacity and Energy Consumption in Operating Ammonia Plants (2007-08)			
Feed stock	No. of Plants	Effective Capacity ('000 MT)	Energy Consumption (GCal/MT)
Gas	24	9646.6	8.49
Naphtha	5	1411.3	9.85
Fuel Oil	4	1386.0	11.72
<b>Total</b>	<b>33</b>	<b>12299.9</b>	<b>8.97</b>

Figure 4.1: Feedstock-wise capacity and energy consumption of ammonia plants in India, Source: Mr. Chandra P. Mohan, Nagarjuna Fertilizers and Chemicals Ltd.

## 4.4 Summary

Based on research into several individual urea plants outlined above, the average water and energy consumption of several plants is outlined in the table below. Specific energy and water requirements (water/energy required per metric ton of urea produced) are listed.

Plant	Capacity	Sp. Energy	Sp. Water	Feed/Fuel	Land Area
Nagarjuna, Kakinada, India	3620 TPD	5.6 GCal(6.5 MWh)	5500 l	NG + Naphtha	0.5 sq. km.
IFFCO, Alla- habad, India	1500 TPD	7.5 GCal(8.7 MWh)	5500 l	NG + Naphtha	?
IFFCO, Aonla, India	2620 TPD	5.7 GCal(6.6 MWh)	?	NG + Naphtha	1 sq. km.
Tata, Babrala, India	2600 TPD	5.25 GCal(6.1 MWh)	4600 l	NG + Naphtha	1 sq. km.
Chambal, Gadepam, India	2600 TPD	5.6 GCal(6.5 MWh)	5140 l	NG + Naphtha	1 sq. km

Table 4.2: Summary of research into individual plants for energy, water consumption and land usage. Energy and water consumption are per MT Urea. NG = Natural Gas.

In addition to the above data, we can also find general trends between plant capacity and energy efficiency as shown below:

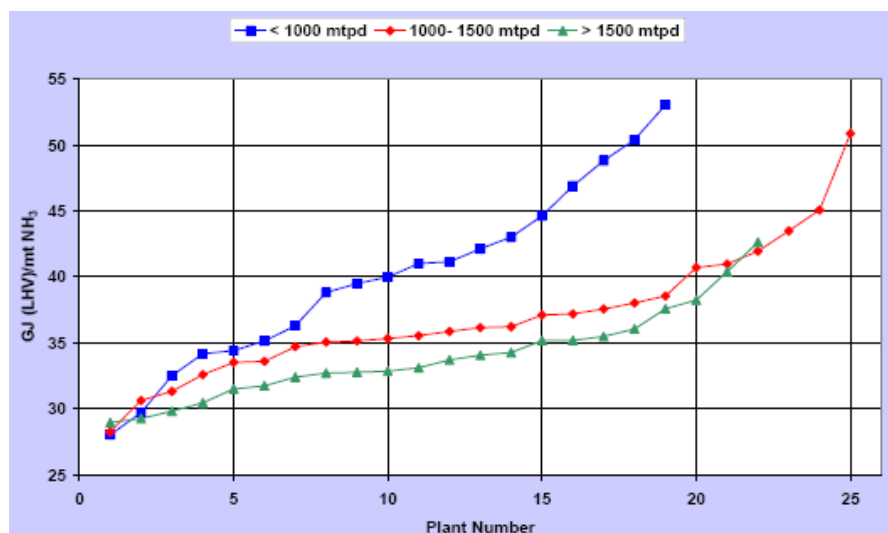


Figure 3.6 Net energy efficiency of 66 Ammonia plants cf. benchmark of PSI [GJ/t NH<sub>3</sub>]

Source: Williams and Al-Ansari, 2007.

Figure 4.2: Energy efficiency trends vs. size of ammonia plants. Source: P. Lako, Energy conservation potential of the nitrogen fertiliser industry, Energy research Centre of the Netherlands (2009).

As we can see from the data above, although the general trend is that larger plants are more

energy efficient, we can also see that all plant sizes have roughly the same figure for the highest achieved efficiency. Based on this, we can conclude that state of the art technology is likely to give the same plant efficiency regardless of the size of the plant.

Based on the summary data, a plant with a capacity between 1000 and 1500 TPD urea would likely have a specific energy consumption of 5.5 GCal/MT and use around 5.5 m<sup>3</sup> water per ton of urea produced while occupying an area of around 1 sq. km. Note that since all of the studied plants use natural gas as the fuel and feedstock, they also incorporate a captive electric power plant. The specific energy consumption figures thus also take into account the electrical energy that is consumed.



## 5 Hydrocarbon and Natural Gas Availability in Nepal

[Back to Table of Contents](#)

According to the information provided on the website of the department of mines and geology [12], there are no known reserves of petroleum in Nepal in spite of various surveying efforts from domestic and foreign parties. Availability of coal is small with 19 small scale mines in operation in Dang, Salyan, Rolpa, and Palpa districts. In total, the coal production from these mines amounts to only 100 - 200 TPD and is therefore insignificantly small.

The department of mines and geology mentions deposits of 316 million cubic meters of methane gas in Kathmandu valley and this reserve is as of yet untapped. The DMG has invited proposals for the development of this resource but there has not been any interest from investors so far.

According to an article titled “Prevailing Situation of Natural Gas/ Cleaner Fuels in Nepal” by Mr. M.R. Sharma, managing director of Nepal Oil Corporation, there is also interest in obtaining natural gas from Bangladesh’s vast reserves [13]. From the article:

“In Nepal, the study of Natural gas goes back to the year 1978. JICA (Japan International Co-operation Agency) initiated the exploration of Natural gas with the help of three wells in one part of Kathmandu Valley and found the existence of a gas reserve of 47 million cubic meter within 4 sq. km area of Teku-Tripureshor zone of Kathmandu valley.

A model gas plant of 500 m<sup>3</sup> capacity under pressure of 5 kg/cm<sup>2</sup> was installed at the valley in 1983 and the gas was supplied to one hospital and some government offices nearby to that plant.”

“Again, in 1996, HMG/DMG decided to conduct the Detailed Feasibility study on commercial utilization of Natural gas resources of Kathmandu valley.

The objective of the study was to undertake a detailed techno-economic feasibility study on commercial utilization of Natural gas including economic viability analysis for different utilization purposes such as domestic, commercial, industrial, power generation and as a compressed gas.

CMDC Design Private Limited, India and SILT Consultants(p) Ltd., had been appointed as a consultant for carrying out the study for four (4) months. The consultants suggested for the economic viability of utilization of gas in commercial domestic sector. According to them, LPG can be substituted with 12,960 m<sup>3</sup> of gas/day, which will result in saving of US \$ 1,485,988 per year.”

The article suggests that there may be viable but untapped reserves of natural gas, at least in the Kathmandu valley.

### 5.1 Sufficiency of estimated Kathmandu valley reserves of natural gas for the purposes of the Urea plant

According to the research described in chapter 4, a typical natural gas based urea plant consumes 5.5 Gcal of natural gas per metric ton of urea fertilizer produced. The heating value of natural gas, according to the Gas Authority of India Limited, is approximately 8.2 MCal/m<sup>3</sup>. Using

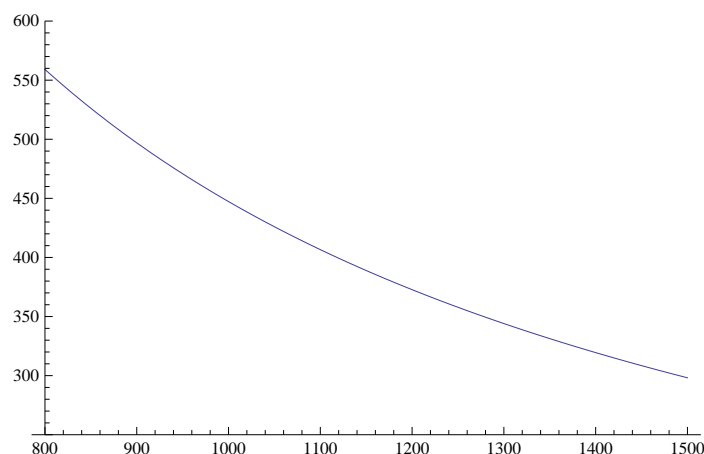


Figure 5.1: Estimated number of days that natural gas reserves of Kathmandu would last based on the capacity of the urea plant (Tons per Day)

this information, we can make a plot of the number of days that a purported 300 million cubic meter reserve of natural gas will last as a function of the amount of urea produced.

As we can see from Figure 5.1, there is not nearly enough natural gas in the valley to make a urea fertilizer plant of the targeted capacity (1000 TPD or higher) viable. As a consequence, we must look to import natural gas from foreign countries (most likely India or Bangladesh) in order to construct a natural gas based urea plant in Nepal.

## 5.2 The Indian Natural Gas Pipeline Network

The following figures show the natural gas pipeline network of India. Figure 5.2 shows the pipeline network along with the locations of existing Urea plants. Figure 5.3 shows the pipeline network along with proposed future pipelines.

As we can see from Figure 5.2, the fertilizer plant at Aonla, which is one of the largest plants of India, and whose characteristics have been described in chapter 4 is quite close to the Nepal border. Furthermore the Babrala plant, which is also a very large urea plant, is located nearby and receives its natural gas from the same trunk line. This indicates that the pipeline supplying these plants may be of enough capacity to support another fertilizer plant at the western tip of Nepal. A detailed feasibility study would have to be conducted to investigate the possibility of constructing a natural gas pipeline from this location to somewhere within Nepal where the proposed Urea plant would be located. Unfortunately the far western region of Nepal is not the ideal location for the fertilizer plant since it is far from the agriculture centre of Nepal and any fertilizer produced there would have to be transported a long distance to the central and eastern regions where most of the agricultural activity takes place (see figure 5.4).

The proposed Barauni-Guwahati pipeline (see figure 5.3) will run very close to the tip of eastern Nepal. The construction of this pipeline will make it more feasible to construct a fertilizer plant in the southeastern part of Nepal where it will be more suitable. The proposed capacity of the pipeline is 32 million  $\text{m}^3$  per day. The natural gas requirement for a 1000 TPD urea plant is approximately 700,000  $\text{m}^3$  which is roughly 2% of the pipeline capacity. The existence of this natural gas pipeline should make it technically feasible to locate a urea plant on the southeastern Indo-Nepal border.

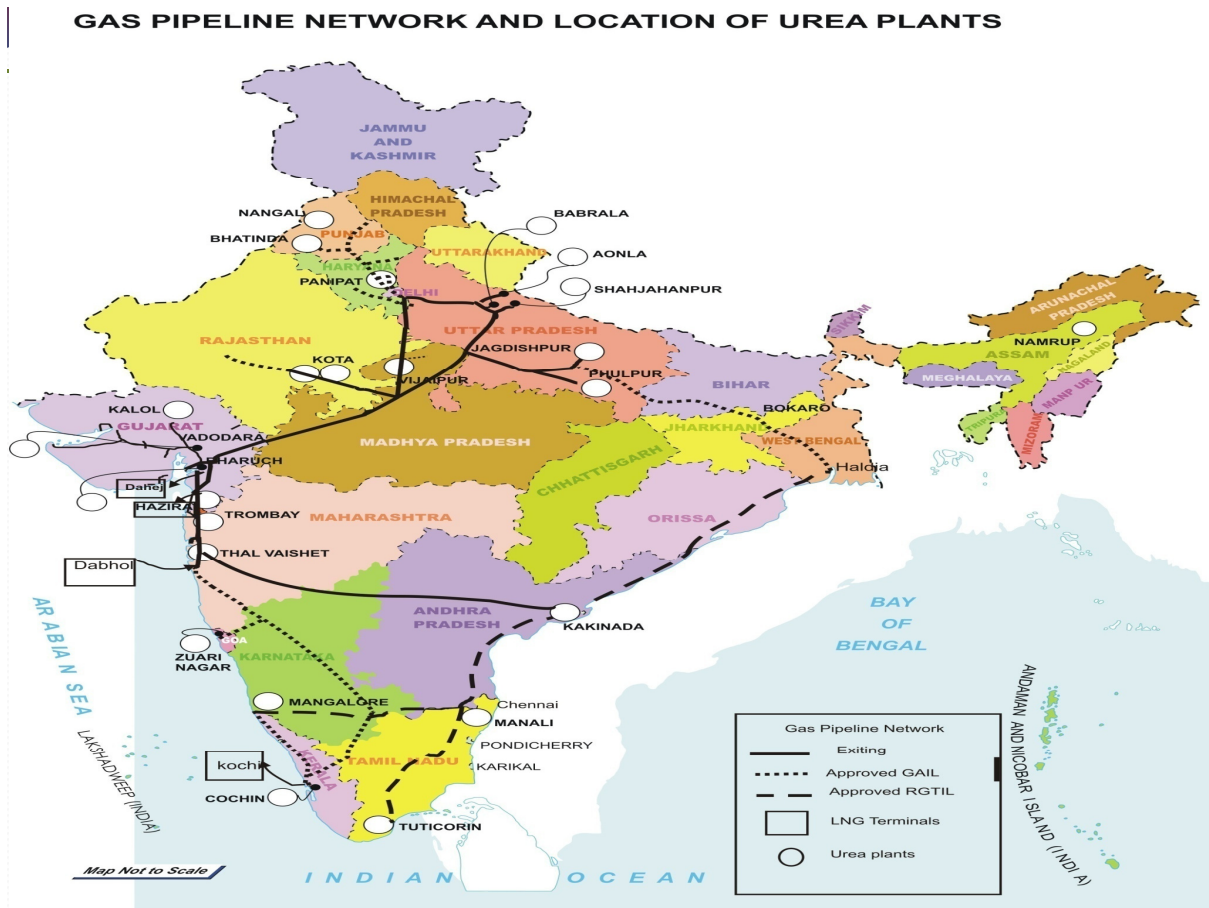
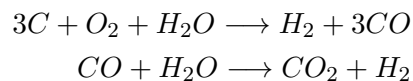


Figure 5.2: The Indian natural gas pipeline network and locations of urea plants. Source: Dr. S. Nand, The Fertiliser Association of India, “Availability and Pricing of Feedstocks and Raw Materials” (2010)

### 5.3 Coal Gasification

When natural gas is not available, coal gasification is a technology that can be employed to produce hydrogen gas. In this process, carbon (coal) is reacted with oxygen and steam to produce hydrogen gas and carbon monoxide. The carbon monoxide can be further reacted with water to produce additional hydrogen and carbon dioxide, as shown in the following reactions:



As we can see, three moles of carbon produce four moles of hydrogen ( $H_2$ ) by this process. According to the US Energy Information Administration [19], the total coal reserve of Nepal is around 1 million metric tons, which is very small and insignificant by global standards. On top of that, the quality of this coal is poor, having high moisture content and may only contain up to 15% carbon [20]. This means that up to 2700 tons of coal per day might be required to obtain the amount of carbon necessary for 1000 tons of urea. In addition to this, we would need to derive additional energy (at least 200 MW) to operate the rest of the plant which would need approximately 2000 tons of coal (assuming a heating value of lignite of  $\sim 15$  MJ/kg). In total, the urea plant would consume 4700 tons of coal each day in order to produce 1000 tons of urea.

5 Hydrocarbon and Natural Gas Availability in Nepal

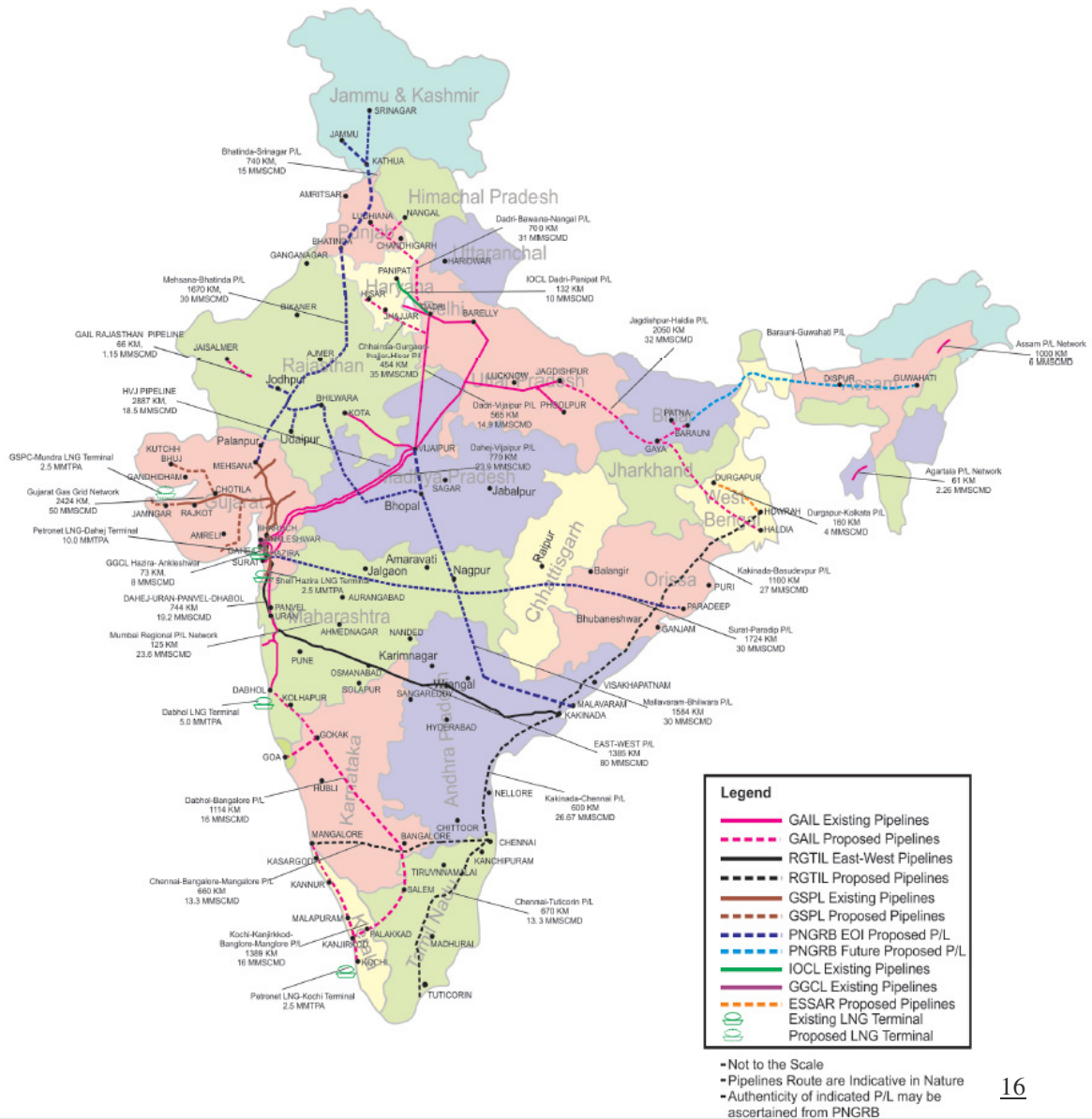


Figure 5.3: The Indian natural gas pipeline network and proposed lines. Source: Dr. S. Nand, The Fertiliser Association of India, “Availability and Pricing of Feedstocks and Raw Materials” (2010)

At this rate of consumption, the 1 million ton reserve of Nepal would only last a little over 200 days, thus making coal gasification infeasible as a source of hydrogen for urea manufacture.

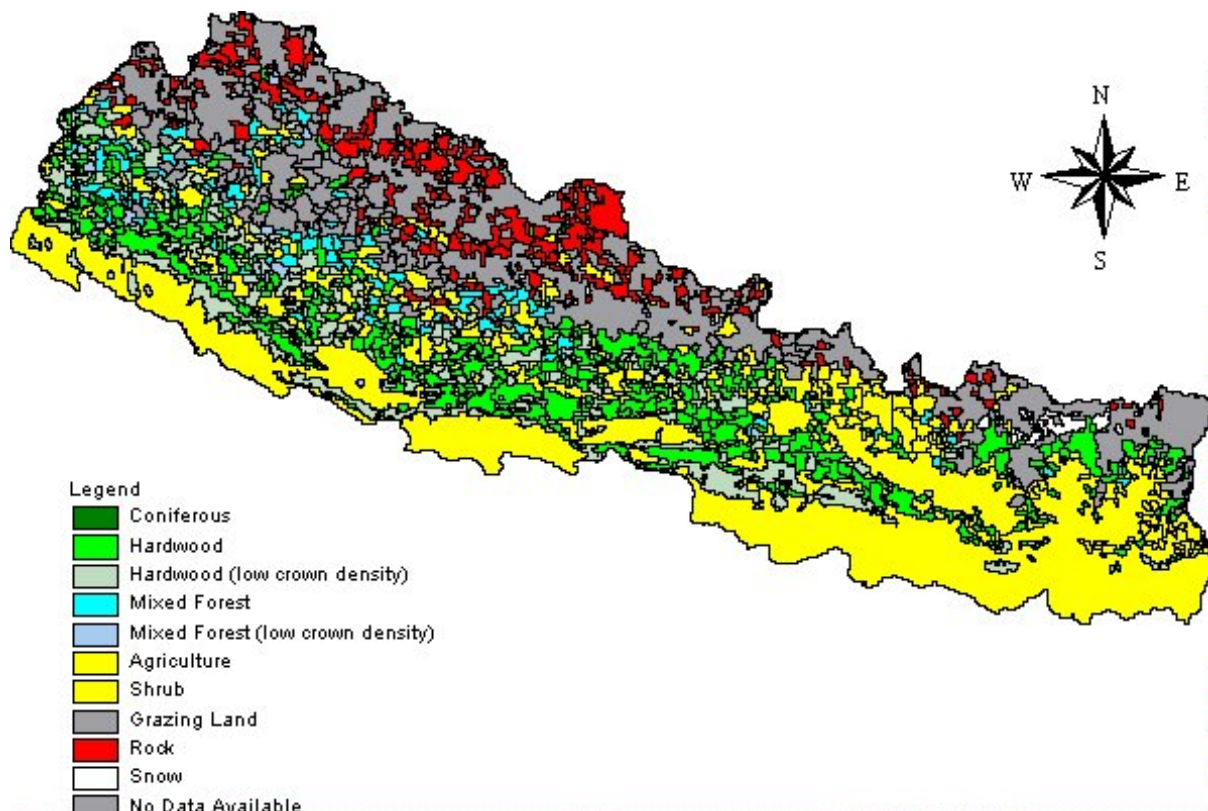


Figure 5.4: Classified land cover map of Nepal. Source: <http://www.ess.co.at/GAIA/CASES/TAI/cst-np.html>



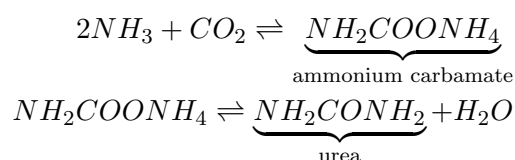
# 6 Urea Manufacturing Technologies

[Back to Table of Contents](#)

In this chapter we will discuss the various technologies that are commonly used for the production of urea fertilizer.

## 6.1 Bosch-Meiser Process

This was the only proven industrial process that could be found from literature and patent search for the synthesis of urea ( $\text{NH}_2\text{CONH}_2$ ). In this process, urea is manufactured from precursors ammonia ( $\text{NH}_3$ ) and carbon-dioxide ( $\text{CO}_2$ ) at high temperature and pressure. [2]



The overall scheme of the industrial process is as follows.

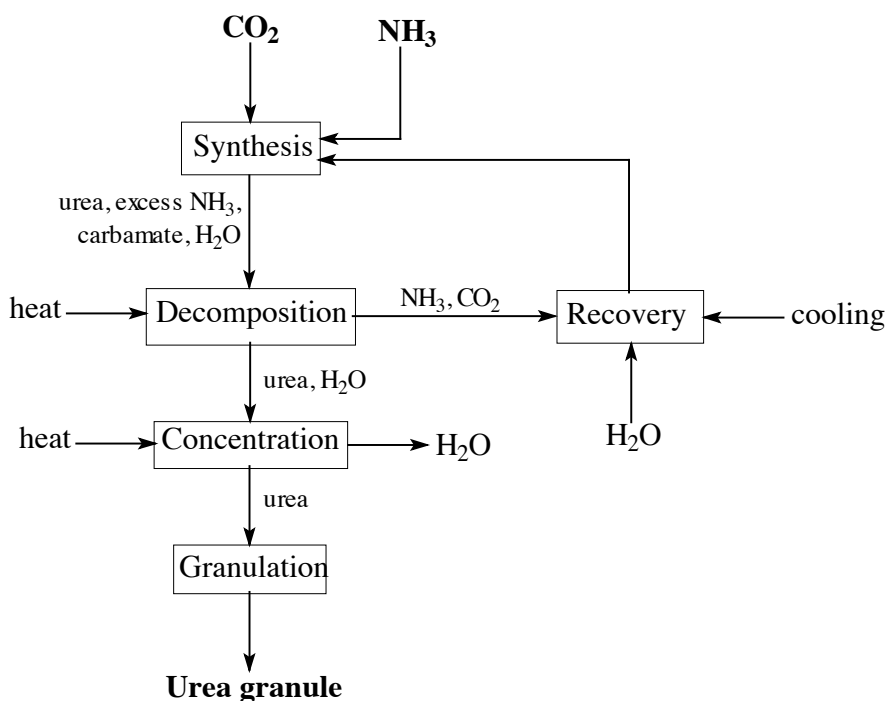


Figure 6.1: Standard urea manufacturing process from carbon-dioxide and ammonia. Source: J.C. Copplestone et. al. [2]

Since the only available urea production technology is the Bosch-Meiser process described above, we will concentrate on ammonia and carbon-dioxide production processes.

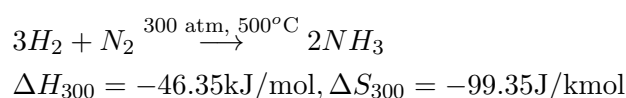
## 6.2 Ammonia Manufacturing Technologies

Ammonia is one of the most heavily manufactured chemicals in the world because of its necessity in many other chemical processes as well as fertilizer production. China, India, Russia, and the USA are some of the world's largest producers of the gas.

Two manufacturing processes have been identified for ammonia synthesis at the industrial scale - Haber-Bosch Process (which is the oldest, proven, and exclusively used at the industrial scale), and Solid-State Ammonia Synthesis (which is relatively new). The Haber process involves reacting gaseous nitrogen with gaseous hydrogen at very high temperatures and pressures to produce ammonia gas.

## 6.3 The Haber-Bosch Process

The chemical equation for the Haber process is as follows [2]:



Claims for conversion efficiency vary, with anywhere between 10% and 15% of the input gases reported to be converted to ammonia in a single pass which is condensed to liquid form by cooling to 30°C before extraction. The unreacted gases are recycled and fed back through the reactor.

The overall scheme of the industrial process is as follows.

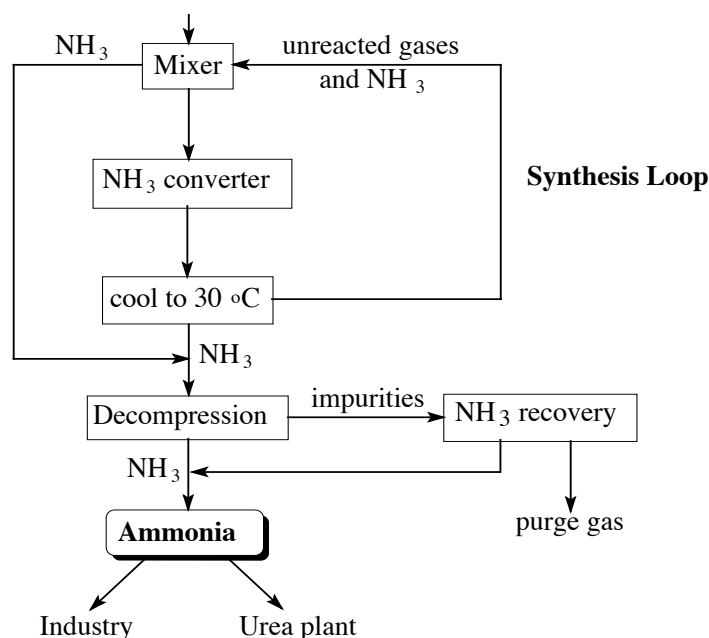


Figure 6.2: Standard ammonia manufacturing process from nitrogen and hydrogen. Source: J.C. Copplestone et. al. [2]

## 6.4 Solid-State Ammonia Synthesis

In solid-state ammonia synthesis, hydrogen and nitrogen are combined to produce ammonia in an electrochemical cell via redox reactions. The half-cell reactions for the process are [3]:



The first demonstration of this reaction was carried out in 1998 at 570°C and specialty materials such as SCY (Strontia-Ceria-Ytterbia) perovskite were required to form the electrode in the cited paper. The major benefit of this process compared to the Haber process is that the reaction can be conducted at atmospheric pressure. Furthermore, catalytic conversion is limited to around 20% conversion whereas this process was demonstrated to convert 78% of the available protons to ammonia.

The schematic of the solid state ammonia synthesis process is shown below.

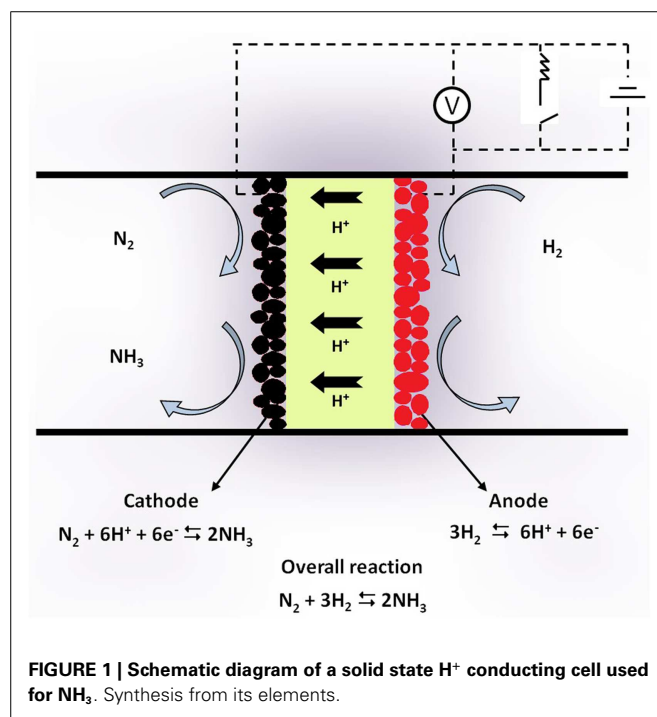


Figure 6.3: Schematic diagram for solid state ammonia synthesis. Source: I. Garagounis et. al. [4]

Although the original demonstration used gaseous hydrogen and nitrogen, the state of the art experiments can use water (in the form of steam) as the hydrogen source. As with the hydrogen-based process, water-based processes are also more effective at higher temperatures. The technology is still in its infancy and one of the major challenges is that high proton conductivity and high catalytic activity have been found to be trade-offs. Materials that have been tested thus far display increased catalytic activity at elevated temperatures but much reduced proton conduction.[4].

### 6.4.1 Commercial Status

There is no commercial plant in operation today that is producing ammonia via an electrochemical process. The technology that is closest to doing so is from a company called NHThree, which is proposing to pilot the first small scale generator for such a process in Alaska capable of producing ammonia at a rate of 3 to 15 kg NH<sub>3</sub> per day. The company claims that their SSAS process can generate ammonia at a total energy cost of 8000 kWh per ton compared to around 12,000 kWh per ton for the electrolysis-driven Haber process (hydrogen generation by electrolysis followed by the Haber process for ammonia synthesis)[5].

Since there is no currently functioning commercial plant using solid-state ammonia synthesis, as a practical matter it is suitable to assume that the Haber process is the only commercially viable process for producing ammonia. Since hydrogen is a precursor to the Haber process, the next section will investigate the industrially viable processes for hydrogen production.

## 6.5 Hydrogen Manufacturing Technologies

[Back to Table of Contents](#)

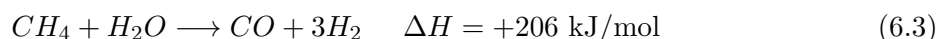
The key distinction between various technologies for urea production is in the way that they obtain the hydrogen necessary for ammonia production. There are several technologies for hydrogen manufacture which can be broadly divided into two categories - (a) Hydrogen from hydrocarbons and (b) Hydrogen from water. These will be discussed here.

### 6.6 Hydrogen from hydrocarbons

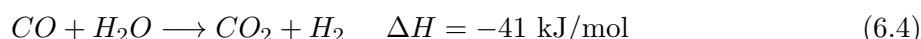
At the industrial scale, these technologies are the least expensive and the most widely used for the manufacture of industrial quantities of hydrogen. The most prominent hydrocarbon-based hydrogen generation technologies are discussed here.

#### 6.6.1 Steam-Methane Reformation

Steam-methane reformation is by far the most extensively used technology for pure hydrogen production in modern industrial processes. It is 70 to 80 % efficient, low in cost and about 48% of total global hydrogen production comes from this process [7]. Natural gas (methane) is first purified to remove contaminants such as sulfur. It is then reacted with water at high temperature and moderate pressure in a highly endothermic reaction to produce synthesis gas (syngas) which is a mixture of carbon monoxide and hydrogen [6] :



The syngas and hydrogen mixture is then further subject to the water gas shift reaction in which the carbon monoxide and water react further to produce hydrogen and carbon dioxide:



In an industrial ammonia process, air may be introduced into the reformer and the oxygen burned so that a 3:1 stoichiometric ratio of Hydrogen:Nitrogen is available for the ammonia synthesis process.

The total power requirement for a 1000 TPD urea plant which takes natural gas (methane) as the input is around 266 MW (note that this is total power, not just electrical power). This power requirement is estimated on the basis of the study done in chapter 4 by taking the average specific energy consumption of the plants and multiplying by 1000.

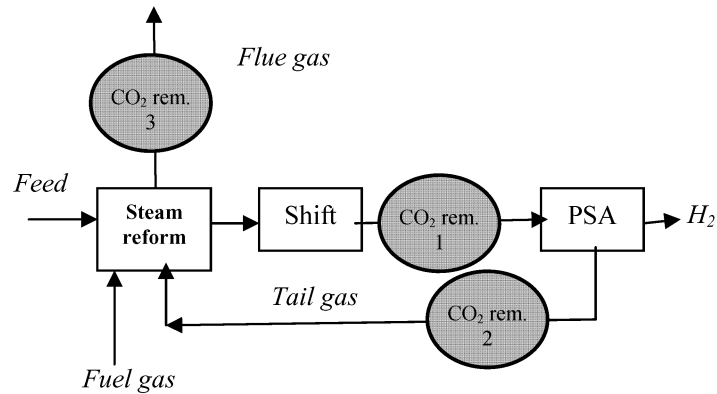
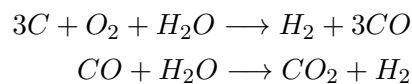


Figure 6.4: Schematic diagram for hydrogen production via steam reformation of methane. Source: G.Collodi et. al. [6]

### 6.6.2 Coal Gasification

In places where natural gas is not available, coal gasification is often used to generate the hydrogen necessary for ammonia synthesis. The produced ammonia can then be subsequently used for urea production. In coal gasification, coal (carbon) is reacted with oxygen and water to produce hydrogen and carbon-monoxide. The produced carbon monoxide is then further subjected to the water-gas shift reaction to produce more hydrogen. The oxygen required for the process is typically separated from air.



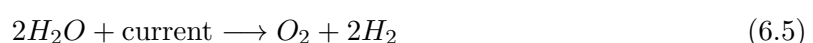
The coal requirement for a coal gasification process is strongly dependent on the quality of coal which can vary significantly. Furthermore, the design of the plant itself can be a strong function of the quality of the coal. Assuming that the coal that is involved in producing hydrogen supplies no energy and that the power required for the process (266 MW) is obtained by burning additional coal, the total daily coal requirement for a 1000 TPD urea plant can be anywhere between 2230 TPD and 2400 TPD. This calculation is based on the energy content of Indian grade 6 coal of 5800 KJ/Kg and a carbon content of 35% by weight.

Coal India Limited sells this grade of coal for a price of  $\sim$  \$ 26 per metric ton which results in a total cost of coal of around \$67 per ton of urea produced. Note that this is the price of coal in India, the price of coal in Nepal could be significantly higher after import.

## 6.7 Water Electrolysis

When natural gas or other cheap hydrocarbon sources are not readily available but cheap electric power is, splitting water with electricity is a viable option to produce the hydrogen that is necessary for ammonia manufacture. Out of all the hydrogen produced in the world, approximately 96% is produced from fossil fuels while 4% is generated from water [7].

Water electrolysis involves circulating a direct current through water in order to separate water molecules into hydrogen and oxygen (See equation 6.5).



There are three main technologies for hydrogen production via electrolysis:

- Alkaline
- Polymer electrolyte membrane
- Solid oxide electrolyte

Out of these three technologies, the alkaline process is the most commercially suitable for large scale production. Polymer membrane technology is so far only used for small-scale generators while the solid oxide electrolyte process is still in the R & D stage [7]. While electrolytically produced hydrogen was more commonly used in the early days of chemical fertilizer production, the development of mega scale natural gas production and distribution systems and accompanying economy compared to electricity has meant that hydrogen generation for chemical fertilizer production has entirely shifted to methane-based technologies. Nevertheless, in a country with no known reserves of methane or other hydrocarbons but potentially abundant hydroelectricity, it is very worthwhile to look at the possibility of generating hydrogen via electrolysis. The downstream processes for ammonia synthesis and urea production would still remain the same.

In an alkaline electrolytic process, a relatively concentrated solution (20 - 30 % by wt.) of KOH ( Potassium Hydroxide) is used as the electrolyte in order to enhance the conductivity of water. The electrodes need to be resistant to corrosion, have excellent electrical conductivity and catalytic properties, and show suitable structural integrity. A diaphragm must be used to separate the electrodes so that the hydrogen produced at the cathode does not recombine with the oxygen produced at the anode to produce water. [7]

In terms of electrical energy consumed, electrolysis becomes more and more efficient at higher temperatures as shown below. The amount of electrical energy required is equivalent to the change Gibbs free energy given by equation 6.6.

$$\Delta G = \Delta H - T\Delta S \quad (6.6)$$

The minimum voltage required for electrolysis is known as the reversible cell voltage, given by:

$$\begin{aligned} V_{\text{rev}} &= \frac{\Delta G}{zF} \\ &= \frac{\Delta H}{zF} - \frac{T\Delta S}{zF} \end{aligned}$$

The change in enthalpy in electrolysis is positive and since the change in entropy is also positive, an increase in temperature leads to a lower reversible cell voltage. Although the amount of electrical energy decreases as the temperature is increased, the total amount of energy required remains roughly constant or even increases slightly when the temperature is above 100°C. Therefore, it is advisable to carry out the electrolysis at high temperatures only if a cheap source of heat is available. If the heat source is also electrically driven, it is not beneficial to carry out the process at temperatures above 100° C.

At standard temperature and pressure (298.15 K, 1 atm), key parameters are:

- $\Delta G^\circ = 237.21 \text{ kJ/mol}$
- $\Delta S^\circ = 0.1631 \text{ kJ/mol K}$
- $\Delta H^\circ = 285.84 \text{ kJ/mol}$

Using the value of the Faraday constant = 96485 C mol<sup>-1</sup>, we obtain the reversible cell voltage at standard conditions to be 1.23V. Therefore, a minimum potential difference of 1.23 V is necessary for electrolysis to occur. The  $I - V$  curve of an electrolytic cell is nonlinear but

follows the same pattern as an ohmic conductor - with higher voltages leading to higher currents. Increasing the voltage therefore increases the production rate of Hydrogen, but the voltage in excess of the reversible cell voltage goes towards increasing the temperature of the cell and must be taken away by a cooling system.

If the temperature of the cell is increased by some means other than the electrode current itself, it will be found that the  $I - V$  curve shifts downwards, therefore indicating that less electrical power needs to be supplied.

The specific energy consumption or  $C_E$  is defined as the energy consumed per unit volume of Hydrogen produced (kWh/Nm<sup>3</sup>) and typically increases with the production rate of Hydrogen. The overall efficiency of the process is given by:

$$\eta_E = \frac{\text{HHV of } H_2}{C_E} \times 100\% \quad (6.7)$$

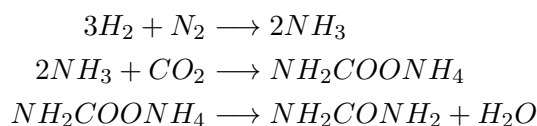
where the HHV (High Heating Value) of hydrogen is equal to 3.54 kWh per Nm<sup>3</sup>. Typical values of electrolyzer efficiency range from 47% to 82%.

According to a paper [7], one of the most commercially available electrolyzers in the market is manufactured by Hydrogen Technologies and has a production rate of 500 Nm<sup>3</sup> per hour with an efficiency of 4.3 kWh per N m<sup>3</sup> (82%) at atmospheric pressure.

## 6.8 Basic Material and Energy Requirements for Electrolysis-Based Urea Plant

### 6.8.1 Hydrogen Requirement

The path that hydrogen takes for urea production is as follows:



As we can see from the above chain of equations, three moles of hydrogen gas ( $H_2$ ) are required to produce one mole of urea. Based on the molar mass of urea, 1000 tons of urea is equivalent to  $1.67 \times 10^7$  moles. This in turn means that  $5 \times 10^7$  moles of hydrogen gas are required. Based on the ideal energy requirement of electrolysis: 237.21 kJ/mol  $H_2$ , this is equivalent to 3294 MWh of electricity. Since 1000 tons of urea is to be produced over a period of 24 hours, this amounts to an ideal power plant capacity of 137 MW for producing the hydrogen necessary for a 1000 TPD urea plant.

If we use some of the largest electrolyzers in the world of capacity 500 Nm<sup>3</sup>/h, and efficiency 4.3kWh/Nm<sup>3</sup> hydrogen[7] which is equivalent to about 2 million moles of hydrogen per hour per electrolyzer, we would need a bank of about 100 such electrolyzers in order to generate the hydrogen necessary for the urea plant. Furthermore, the actual power requirement will be around 200 MW for a 1000 TPD plant, instead of the ideal 137 MW calculated above.

### 6.8.2 Water Consumption and Oxygen Production

Producing one mole of hydrogen gas consumes one mole of water and produces 1/2 mole of oxygen gas as by-product. Using the molar mass of water = 18, a 1000 TPD urea plant will consume 900 TPD water which is equivalent to 37,500 liters of water per hour. Aside from this consumption, a typical gas-based urea plant consumes around 5,500 liters of water per tonne which for a 1000 TPD plant amounts to 229,000 liters of water per hour. It is not known

what fraction of this water is lost as steam but it is easy to see that a water source capable of providing more than 250,000 liters of water per hour will be required.

While the urea plant consumes water, it also produces pure oxygen as a by-product. A 1000 TPD plant will produce 800 TPD oxygen gas through electrolysis. The cost of bulk liquid oxygen is roughly \$ 200 per ton [21], and therefore the oxygen by-product can be sold to generate some revenue. Note that the cost of liquefying the produced oxygen will need to be factored in in order to understand whether it is economically sensible to do so.

### 6.8.3 Nitrogen Requirement

Based on the same set of chemical equations, we can see that one mole of nitrogen gas ( $N_2$ ) is required to produce one mole of urea. Nitrogen is obtained by compressing atmospheric air into liquid form and then distilling the resulting liquid to separate the nitrogen from oxygen, carbon-dioxide, and other trace gases. Based on [15], the energy cost of the process to obtain gaseous nitrogen from atmospheric air is roughly 250 kWh per tonne.

Since one mole of Nitrogen (molecular weight 28) is required to produce one mole of urea, a 1000 TPD urea plant requires 233.8 TPD of nitrogen. This in turn requires 58 MWh of electricity or an equivalent power plant capacity of 4.8 MW.

In addition, the process of liquefying air also produces oxygen as a by-product (around 145 TPD). However, this oxygen will require further separation from other air components such as  $CO_2$  and Argon and will likely not be as pure as the oxygen obtained from electrolysis.

### 6.8.4 Carbon-Dioxide Requirement

One mole of carbon-dioxide gas is required to produce one mole of urea fertilizer. Using the molar mass of  $CO_2 = 44$ , we can calculate that 733 tons of carbon-dioxide will be required per day. The only viable source of large amounts of carbon-dioxide in Nepal is cement plants. A typical cement plant produces 90 tons of  $CO_2$  per 100 tons of cement produced [16]. This means that we will need a cement plant of capacity at least 800 TPD in order to obtain the 733 tons of carbon-dioxide necessary for the urea plant. This is assuming that the  $CO_2$  capture process is 100% efficient. In practice,  $CO_2$  capture technologies are about 75% to 95% efficient [17].

Both Hetauda and Udayapur cement factories are of capacity 750 TPD which is not large enough to generate the amount of carbon dioxide necessary for the operation of a 1000 TPD urea plant. The largest cement plant in Nepal is the Ghorahi cement factory located in Dang which is of target capacity 1000 TPD [28]. This plant would be sufficient to provide enough carbon-dioxide for the operation of a 1000 TPD urea plant.

### 6.8.5 Overall Power Requirement

The overall power requirement of an electrolysis based power plant is the sum of the power requirements of the following:

- Electrolysis plant for hydrogen generation
- Air separation plant for nitrogen generation
- Carbon-dioxide capture plant for carbon dioxide generation
- Ammonia synthesis
- Urea synthesis

The power requirement for Hydrogen generation is 137 MW under ideal conditions but practical energy requirement for a typical electrolyzer results in power consumption of 200 MW [7].

The power requirement for Nitrogen generation is roughly 5 MW [15].

The energetic cost of carbon-dioxide capture from flue gas is on the order of 0.2 kWh/kg of CO<sub>2</sub> captured [18]. Since a 1000 TPD urea plant required CO<sub>2</sub> capture of around 800 TPD, the power requirement of the process ends up being 7 MW.

The power requirement for the ammonia synthesis and urea synthesis processes are difficult to estimate because they are highly dependent on the nature of the selected process. Furthermore, estimates based on natural gas driven technology will be inaccurate because the efficiency of electricity-driven equipment is higher than the efficiency of heat-driven equipment. For this reason, Saipem, a world-leader in urea plant construction, was consulted to provide a rough estimate of power consumption (see Appendix for their report). According to their estimation, the electrical power requirement of air-separation + ammonia synthesis + urea synthesis and granulation is roughly 25 MW. However, this is not including the power required for heat since they assumed the presence of a fossil-fuel powered steam system.

Since an accurate estimate for the power requirement for the ammonia-urea system was not available, the total power required was estimated in the following manner. For the sake of simplicity, it was assumed that the energy requirement for the ammonia-urea portion would be roughly the same for both the natural gas process and the electrolysis process. Thus we may think of the electrolysis based plant as being the same as the natural gas based plant with additional Hydrogen, Nitrogen, and Carbon-dioxide generation stages but with the removal of the primary and secondary reformation stages.

The power requirement for Hydrogen generation is 137 MW under ideal conditions but practical energy requirement for a typical electrolyzer results in a power consumption of 200 MW. On the positive side, the primary and secondary reformation steps from the conventional urea process can be eliminated. Steam reformation is typically typically around twice as energy efficient as electrolysis in practice [29] therefore steam reformation would cost around 100 MW. Since SRM and ammonia synthesis consume around 216 MW of energy [30] (33 GJ/Ton NH<sub>3</sub>), around 116 MW is required for ammonia synthesis in a conventional process.

This means that the total power requirement is very roughly approximated by:

$$\begin{aligned} \text{Total Power} &= \text{Electrolysis} + \text{Carbon Capture} + \text{Nitrogen Generation} + \text{Ammonia Synthesis} + 25 \text{ MW for Urea} \\ &= 200\text{MW} + 7 \text{ MW} + 5 \text{ MW} + 116 \text{ MW} + 25 \text{ MW} \\ &\sim 350 \text{ MW} \end{aligned}$$

This is likely to be an overestimate of the total power consumption because heat integration between ammonia and urea sections is not taken into account, and extrapolation from the energy consumption calculated in the JICA 1984 report would give a power requirement of 300 MW. Nevertheless, we can proceed with 350 MW as an upper bound of the power consumption of the urea plant.

### 6.8.6 Summary Characteristics of Electrolysis Based Plant

Total Electric Power Consumption	350 MW
Water Consumption	250,000 LPH
Land Requirement	1 sq. km.
Cement Plant Required	>1000 TPD

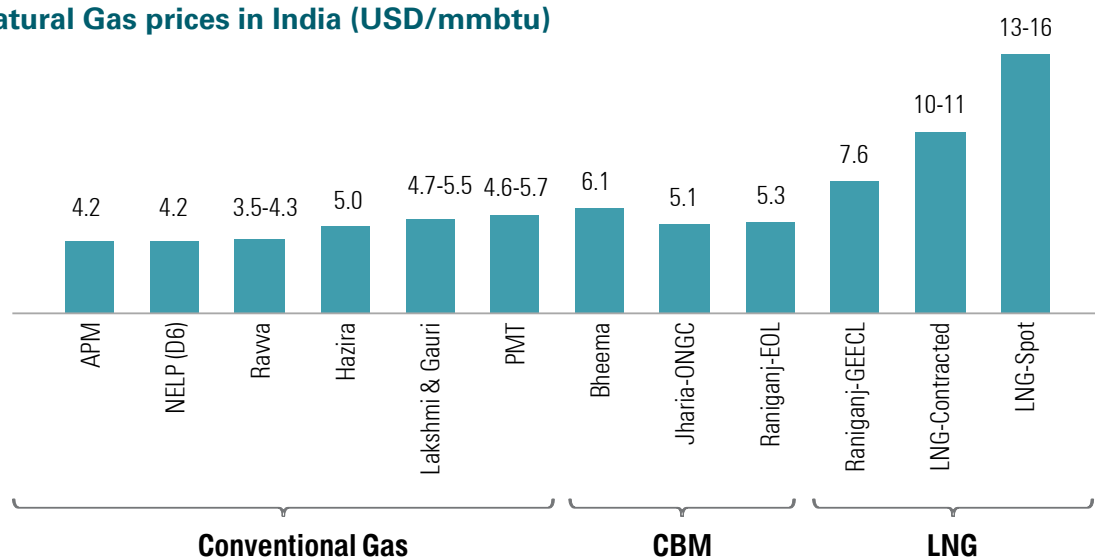


## 7 Trends in Prices of Natural Gas and Urea

### 7.1 Cost of Natural Gas

Up-to-date trends in the natural gas prices in India have been difficult to obtain. Furthermore, there have been recent reports on the revision of natural gas pricing mechanisms in India making it difficult to obtain reliable information. The commodity price of natural gas in India is around Rs. 270 per million BTU [14] which is equivalent at the current exchange rate to 4.5 US Dollars per million BTU. This agrees well with the data shown in figure 7.1 that was published by KPMG in 2012.

**Natural Gas prices in India (USD/mmbtu)**



**Note:** The prices above are well-head/FOB and do not include transportation tariff, marketing margins and taxes  
**Source:** Ministry of Petroleum and Natural Gas

Figure 7.1: Natural Gas Prices in India (2012). Source: KPMG Publication.

Based on the energy conversion matrix provided by [GAIL India](#), one MMBTU of natural gas is equivalent to 25.2 SCM. Based on the calculation in chapter 5, a urea plant producing 1000 TPD Urea would consume 700,000 SCM per day. Using energy efficiency figures of 5.5 GCal/MT, the cost of natural gas per ton urea becomes \$98 /MT.

### 7.2 Trends in Urea Prices

Based on data obtained for 40 districts from the website of [Agriculture Inputs Corporation Limited](#), the average current fertilizer price for Urea in Nepal (subsidized) is approximately NRs.19,500 (\$203) per metric ton. In India, the same Urea costs around NRs. 10,000 because

the subsidy level for Urea is much higher in India than in Nepal. The trend in fertilizer price until year 2008 is shown in figure 7.2.

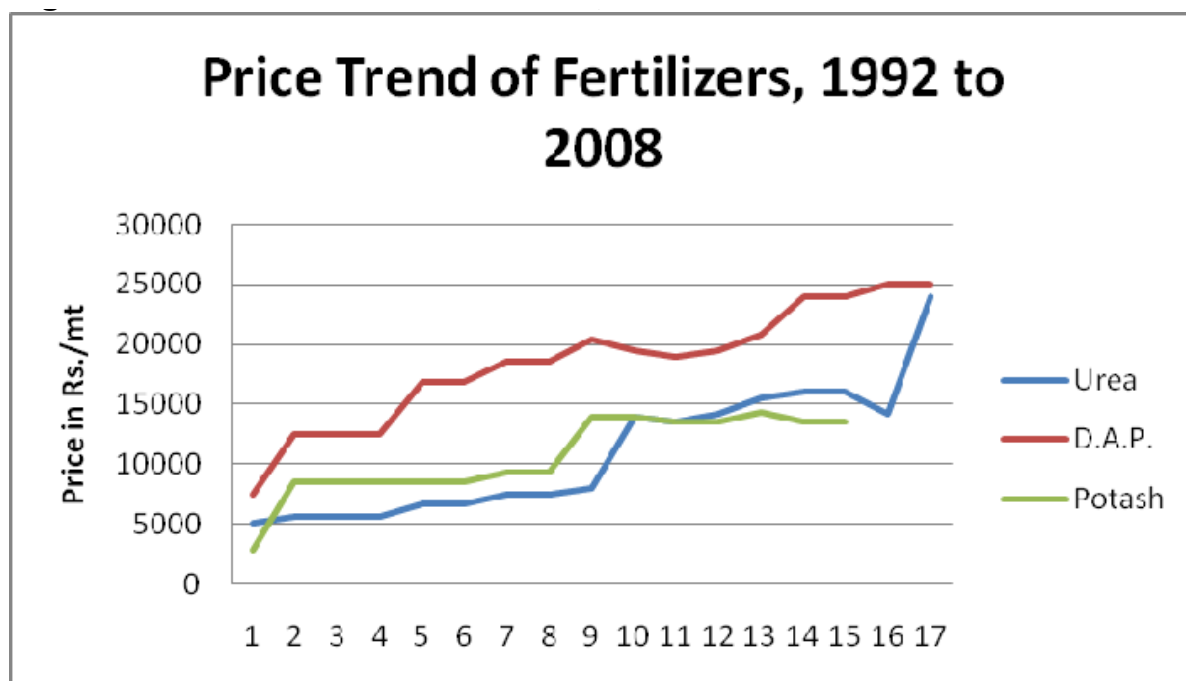


Figure 7.2: Trend in the retail price of Urea in Nepal. Source: FAO Report - Pricing Policies for Agricultural Inputs and Outputs in Nepal (2010).

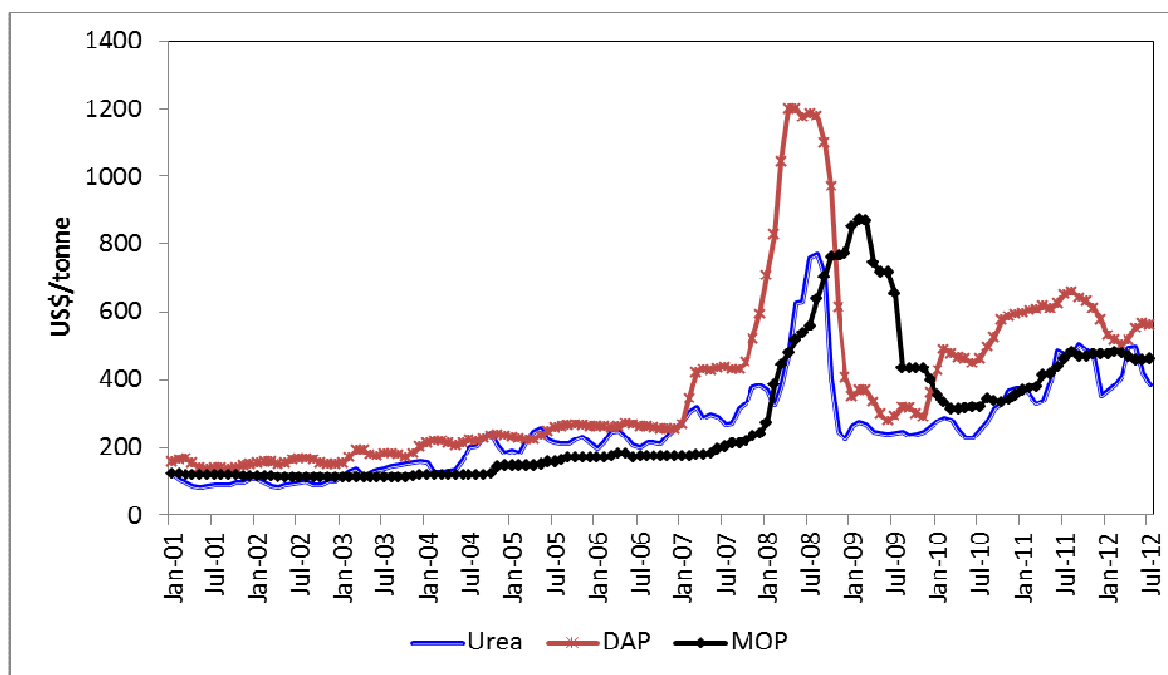
If the proposed urea plant were to sell the urea at the current government-established market price of \$203 per ton at the Indian average natural gas price of \$4.5 per MBTU, it would at least be able to pay for the natural gas (which costs \$98 per ton of Urea produced). However, if it were to attempt to sell the urea at the Indian market price of NRs. 10,000 per ton, (\$ 104), it would barely be able to pay for just the natural gas.

The government of Nepal also subsidizes fertilizer imports, spending approximately Rs. 3.5 billion per year in the process. The total budget allocated for chemical fertilizer subsidies is around Rs. 5 billion per year. When purchasing urea, the AICL (Agricultural Inputs Corporation Limited) pays the international market price of urea which hovers around \$350 per tonne as shown in figure 7.3.

### 7.3 Inflation Rate of Urea Prices

The domestic and international rates of inflation of urea prices can be estimated based on figures 7.2 and 8.3 by solving a geometric series. The results are summarized in the following table:

	Year	Price	Year	Price	Inflation Rate
Domestic	1992	NRs. 5000	2014	NRs. 19,500	6.7%
International	2001	\$150	2012	\$350	7.3%



Source: World Bank (2012)

Figure 7.3: Trend in the retail price of Urea in the international market.

## 7.4 Capital Required for Construction of Urea Plant

The cost of construction of a urea plant depends on the technology employed and where it is constructed. Some examples are listed below:

- Toyo Engineering, Mozambique, 2012, 1725 TPD Urea, Natural Gas, \$1173 million [22]
- Haldor Topsoe, Engro Fertilizer, Pakistan, 2011, \$1.1 billion, 3500 TPD Urea , natural gas[23]
- Dakota Gas, 1100 TPD Urea, ND, USA , \$ 400 million (projected), 2013, natural gas, [24]
- Wentworth, Cove, 2000TPD Urea, Tanzania, \$1.5 billion (projected), 2012, natural gas [25]
- Gabon Fertilizer Company, 2013, 3800 TPD Urea \$1.5 - 2 billion (projected) , natural gas [26]
- Nih Binh Nitrogenous Fertilizer Plant, 2010, 1760 TPD Urea, coal gasification \$700 million (projected) [27]

As we can see above, the cost of construction of a plant can vary significantly based on the location and technology used. In addition, there are no good precedents for estimating the cost of construction for a plant that utilizes electrolysis technology for hydrogen production and CO<sub>2</sub> capture for urea synthesis. A much more detailed study by domain experts will be necessary to arrive at a realistic estimate for the cost of construction of a urea plant (of any technology) in Nepal. As a rough estimate, \$500 million to \$700 million may be required to construct a 1000 TPD urea plant.

According to Saipem (see Appendix), the estimated cost of construction of a urea plant, not including the electrolysis plant, land acquisition, construction facilities, and other costs, in

## *7 Trends in Prices of Natural Gas and Urea*

Nepal will be Eur. 253 million which is roughly USD 350 million. After adding the cost of the electrolysis plant (not yet known) and margins for other expenses, the total cost of the plant will likely be between \$500 and \$700 million, as estimated.

## 8 Summary

The most prominent features of all three technologies (natural gas, coal gasification, electrolysis) are summarized in the table below.

–	Natural Gas	Coal	Electrolysis
Total Power Required	266 MW	>600 MW	350 MW
Energy cost per MT Urea	\$98 - \$116	\$67	\$420 based on Rs.5/kWh
Water use per MT Urea	5500L	> 5500L	~ 6000 L
Construction Cost	Cost of plant + pipeline	Cost of plant + transport	Cost of plant + cost of power plant
Raw materials	Import from India	Import from India/China	Domestic
CO <sub>2</sub> emissions per ton Urea	1 MT	2 MT	Negative
Other challenges	Locate near border, build pipeline	Transport > 2200 TPD coal	Build power plant/transmission line

Based on the characteristics above, it is clear that the only solution that addresses the issue of food security and fertilizer availability in Nepal is the electrolysis-based urea plant. Although the cost of energy is very high for this process, it may be possible for the government to justify the investment due to the importance of this project. Another reason is that since the electricity is to be obtained through hydroelectric means, the variable cost of production of the electricity is effectively zero and hence the cost of energy can be taken as zero. Instead, the capital cost of construction of the necessary hydroelectric power plant can be combined with the cost of construction of the urea plant as total capital investment.

### 8.1 Financial Calculations

In order to estimate the financial details of the project, we are going to start with some base estimates and investigate what happens as we vary the parameters:

#### 8.1.1 Base Case

- Urea Production : 1000 TPD
- Specific Energy Consumption : 0.35 MW/Ton (Range: between 0.3 and 0.4 MW per ton of urea)
- Capital Investment: \$ 1 billion (Range: 500 million to 1.5 billion USD)
- Electricity Price: NRs. 5/ kWh (Range: NRs. 0 to NRs. 10 /kWh)

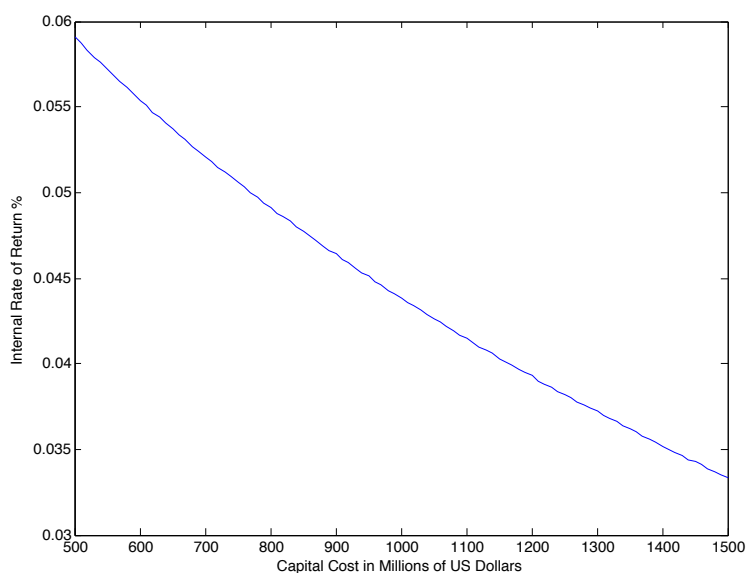
## 8 Summary

- Project Lifetime: 50 years
- Urea Selling Price : NRs. 19500 / MT (Range: NRs. 10000 to NRs. 35000 per metric ton)
- Number of Employees: 500
- Average employee salary : NRs. 30,000
- Annual average salary increase : 8%
- Administrative expense overhead: 70% of salary
- Annual urea price inflation: 6% (Actual domestic price inflation has been 6.7% so this is conservative).
- Operation and Maintenance costs: 3.5% of CAPEX per year
- Exchange rate: NRs. 95 = 1 USD

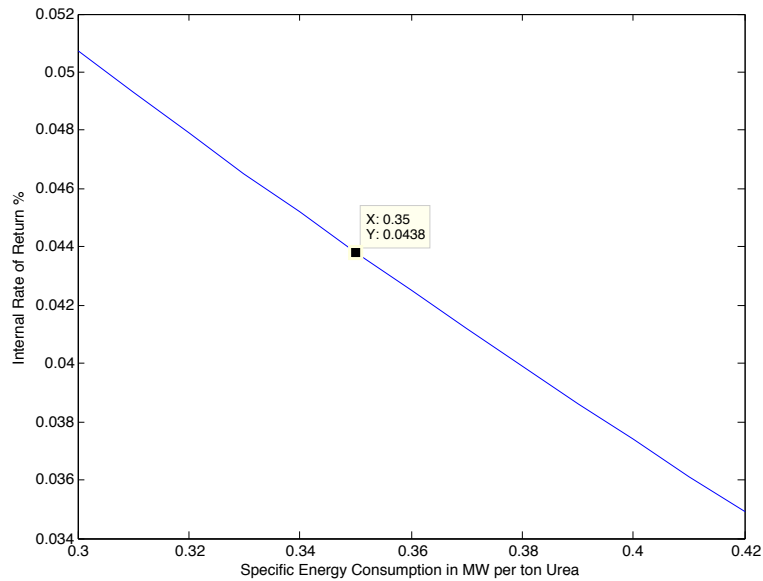
Using the above parameters, we can estimate the internal rate of return to be 4.4%.

### 8.1.2 Sensitivity to capital cost

Keeping all other parameters constant, we can look at how the IRR varies as the cost of capital is varied throughout its range: 500 million to 1.5 billion. The result is shown in the following figure:



As we can see from the figure, as the capital cost of the plant increases from 900 million to 1100 million (an increase of 22%), the IRR decreases from 4.64% to 4.15%, a 10.6% decrease. The sensitivity of IRR to capital cost is therefore  $-10.6/22.22 \sim -0.48$ .



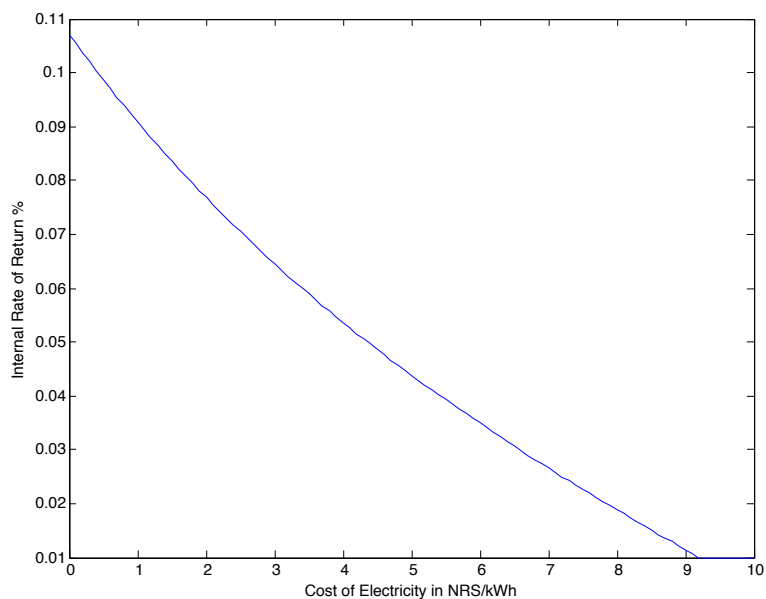
### 8.1.3 Sensitivity to Specific Energy Consumption

Keeping all other parameters constant, we can look at how the IRR varies as the specific energy consumption varies between 0.3 and 0.4 MW per ton of urea. The result is shown in the above figure.

As we can see from the figure, as the specific energy increases from 0.34 MW to 0.36 MW (a 5.6% increase), the IRR decreases from 4.52% to 4.25%, a 6% decrease. The sensitivity of IRR to specific energy consumption is therefore  $-5.6/6 \sim -0.93$ .

### 8.1.4 Sensitivity to the Price of Electricity

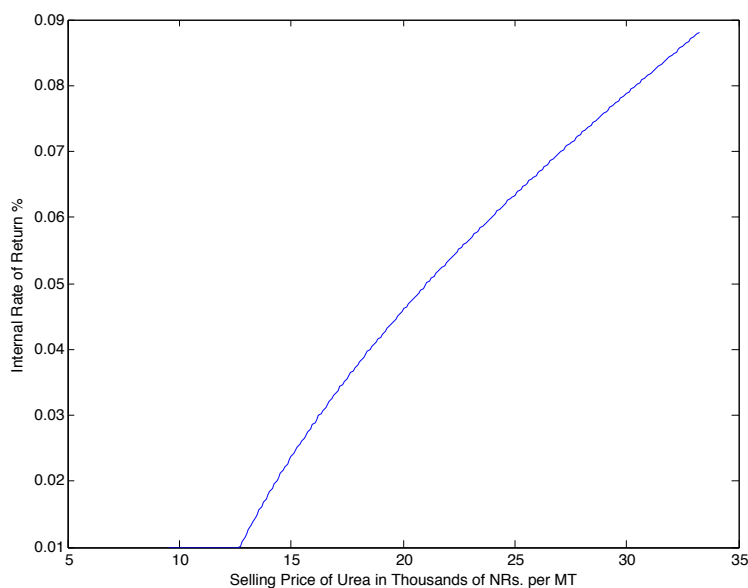
Keeping all other parameters constant, we can look at how the IRR varies as the price per kWh of electricity varies between NRs 0 and NRs 10. The result is shown in the following figure.



As we can see from the figure, as the price of electricity increases from Rs. 4 to Rs. 6 per kWh (a 50%) increase, the IRR decreases from 5.36% to 3.49%, a 35% decrease. The sensitivity of IRR to the price of electricity is therefore  $- 35/50 \sim - 0.7$ .

### 8.1.5 Sensitivity to the Selling Price of Urea

Keeping all other parameters constant, we can look at how the IRR varies as the selling price of urea varies between NRs. 10,000 per MT and NRs. 35,000 per MT. The result is shown in the following figure.



As the selling price of urea increases from NRs 15,000 to NRs. 21,000 per MT, a 40% increase, the IRR increases from 2.37% to 4.96%, a 109% increase. The sensitivity of IRR to the selling price of urea is therefore  $109/40 \sim 2.72$ . The internal rate of return of the project is therefore the strongest function of the selling price of Urea.

### 8.1.6 Summary of Sensitivity Analysis

Criteria	Sensitivity of IRR
Capital Cost	-0.48
Specific Energy Consumption	-0.93
Electricity Price	- 0.7
Selling Price of Urea	2.72

The above table indicates that the internal rate of return is the strongest function of the specific energy consumption of the plant and the selling price of urea, with the price of electricity third on the list. The specific energy consumption, however, is a quantity that we have the tightest estimate on, of around .35 MW/MT. This then leaves the price of electricity and the selling price of urea as the two handles that will have the greatest impact.

## 8.2 Feasibility Analysis of 1000 TPD plant as Function of Electricity Price and Selling Price of Urea

This section investigates what the internal rate of return of a 1000 TPD urea plant will be under different costs of electricity and different selling prices of urea. Plots are drawn which show the internal rate of return as a function of the price of electricity and the selling price of urea. Different cases corresponding to different capital costs are investigated. The specific energy consumption is assumed to be 0.25 MW per MT urea throughout. The project lifetime is assumed to be a more realistic 35 years and the rest of the financial parameters - labor cost, inflation, maintenance expenses, etc. are kept at the same values as listed earlier in the chapter. These parameters are mentioned below:

- Urea Production : 1000 TPD
- Specific Energy Consumption : 0.35 MW/Ton
- Capital Investment: 500 million, 700 million, and 1 billion USD
- Electricity Price: NRs. 0 to NRs. 10 /kWh (**This will be assumed to be constant, i.e. no inflation for the duration of the project**)
- Project Lifetime: 35 years
- Urea Selling Price : NRs. 10000 to NRs. 35000 per metric ton
- Number of Employees: 500
- Average employee salary : NRs. 30,000
- Annual average salary increase : 8%
- Administrative expense overhead: 70% of salary
- Annual urea price inflation: 6% (Actual domestic price inflation has been 6.7% so this is conservative).
- Operation and Maintenance costs: 3.5% of CAPEX per year
- Exchange rate: NRs. 95 = 1 USD

In order to compare with the current situation of Rs 5 billion in fertilizer subsidy every year, two cases are presented side by side. In the first case the internal rate of return of the project is shown without any consideration to subsidies. In the second case, the internal rate of return of the project is shown for the case if Rs 5 billion in subsidy is made available to the fertilizer plant the first year and inflated by 6% every year after that. This is done so as to fairly evaluate the economic feasibility of the fertilizer plant (in the absence of which the government would be spending Rs 5 billion per year in subsidy anyway). We will also assume that an IRR of 8% would be the minimum necessary for investment into this project to be reasonable.

### 8.2.1 Best Case Scenario: Capital Cost USD 500 Million

The best case scenario is when the capital cost is at the low-end of its range. As can be seen from the following figure, it is possible to obtain an IRR of 8% and sell urea at the current subsidized rate of NRs 19500/MT if electricity can be obtained at a price point of less than Rs. 3/kWh (for the economic lifetime of the plant) for a completely unsubsidized fertilizer plant.

If the current subsidy level of Rs 5 billion per year, escalated for inflation is made available to the fertilizer plant, it will be giving a 14% rate of return at an electricity price of Rs. 3/kWh and the current subsidized urea price of NRs. 19500/MT. An IRR of 8% will be achievable even at electricity prices of up to NRs. 6 per kWh.

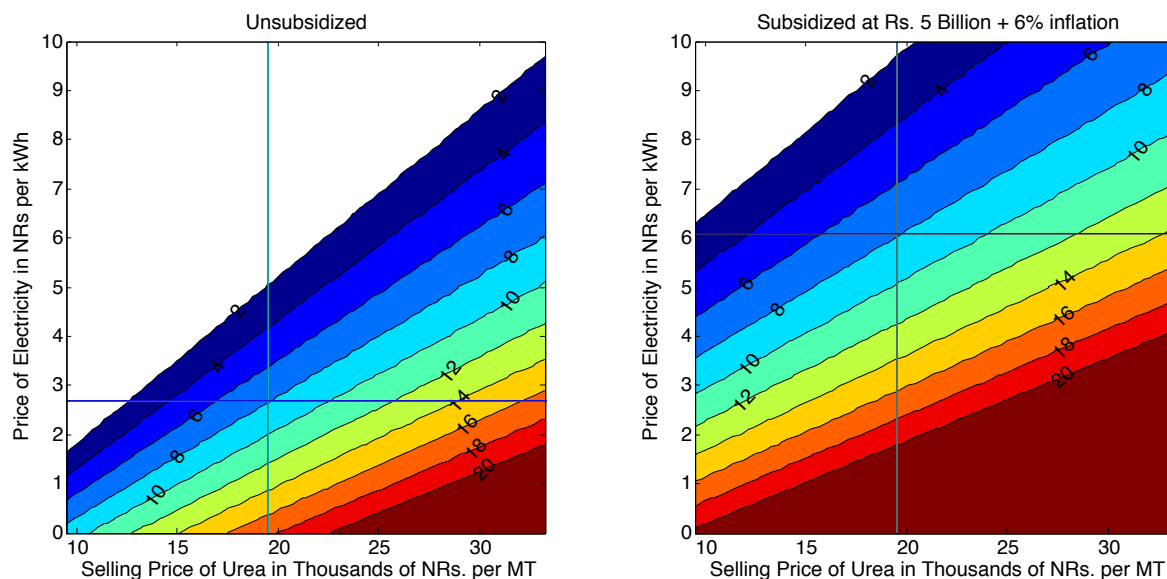


Figure 8.1: Lines represent contours of constant IRR and the number on the line is the IRR in percentage. The vertical line represents the current subsidized price of urea in Nepal (Rs. 19,500 per MT). The horizontal line shows the price of electricity at which an IRR of 8% is achieved.

### 8.2.2 Intermediate Scenario: Capital cost USD 700 Million

In this scenario, if the plant were completely unsubsidized, the price of electricity would have to be NRs. 2 per kWh for the project to generate an IRR of 8% at the prevailing market price of urea of NRs. 19,500 per MT.

On the other hand, if the same amount of subsidy were provided to the plant as we provide for chemical fertilizer import (Rs. 5 billion per year), the project shows reasonable return of 8% at electricity prices of around NRs. 5 per kWh. If we lower the price of electricity further, the project looks even better, generating a maximum IRR of more than 20% when the price of electricity is zero.

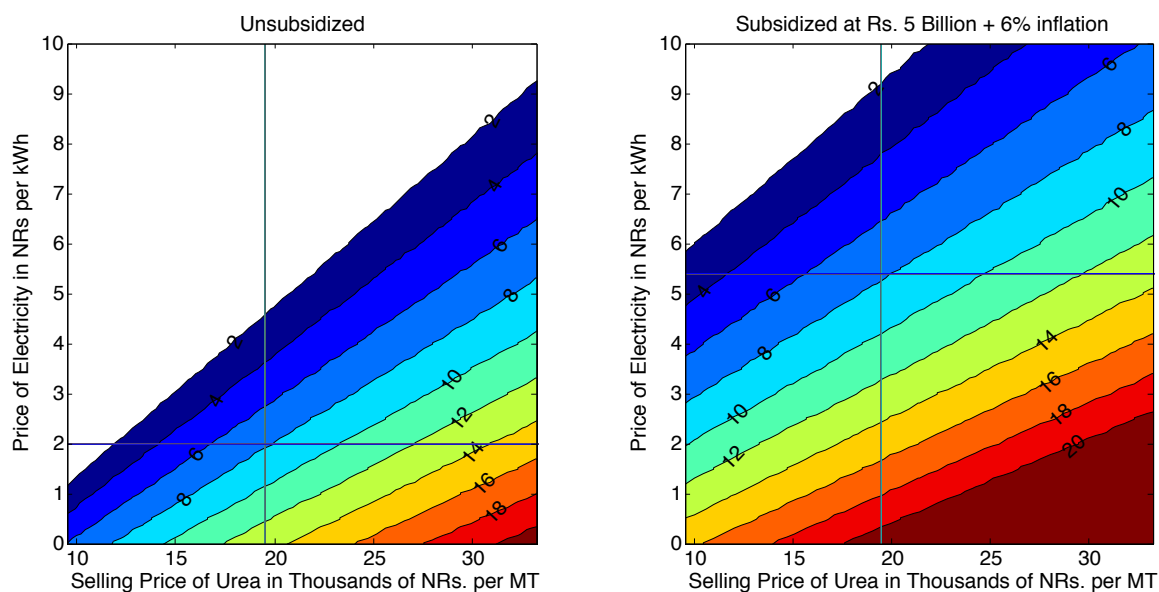


Figure 8.2: Lines represent contours of constant IRR and the number on the line is the IRR in percentage. The vertical line represents the current subsidized price of urea in Nepal (Rs. 19,500 per MT). The horizontal line shows the price of electricity at which an IRR of 8% is achieved.

### 8.2.3 Worst case scenario: Capital cost USD 1 billion

In this scenario, if the plant were completely unsubsidized, the price of electricity would have to be really cheap (a little less than one Rupee per kWh) for the project to generate an IRR of 8% at the prevailing market price of urea of NRs. 19,500 per MT.

On the other hand, if the same amount of subsidy were provided to the plant as we provide for chemical fertilizer import (Rs. 5 billion per year), the project shows reasonable return of 8% at an electricity price of NRs. 4 per kWh. If we lower the price of electricity further, the project looks even better, generating a maximum IRR of  $\sim 16\%$  when the price of electricity is zero.

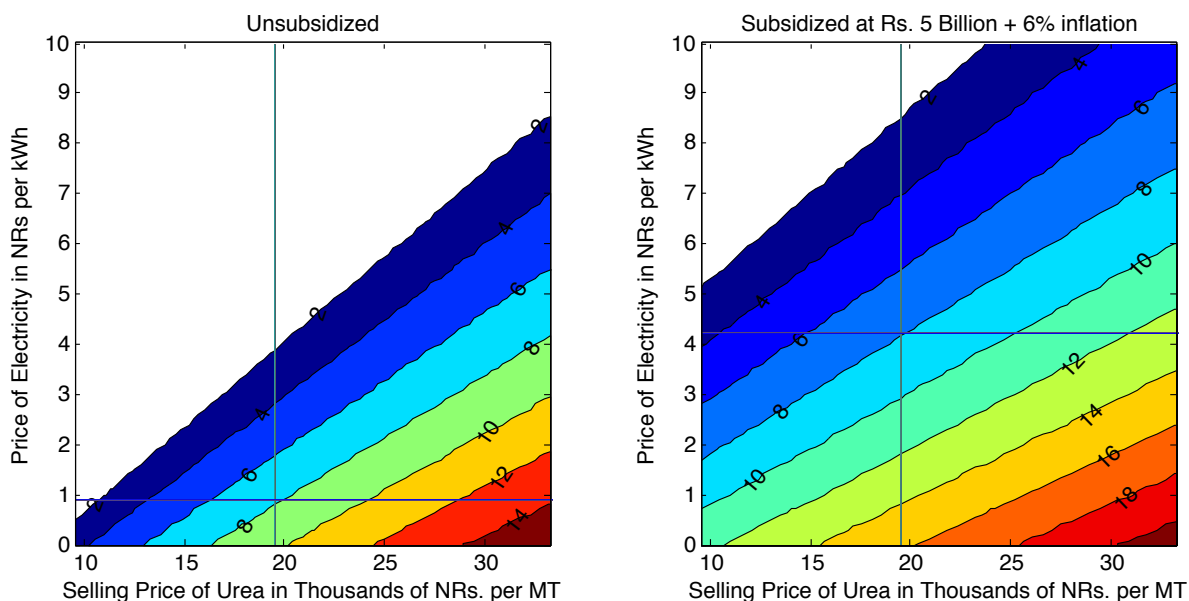


Figure 8.3: Lines represent contours of constant IRR and the number on the line is the IRR in percentage. The vertical line represents the current subsidized price of urea in Nepal (Rs. 19,500 per MT). The horizontal line shows the price of electricity at which an IRR of 8% is achieved.

### 8.3 Effect of Oxygen Sales

We have so far carried out the financial analysis under the assumption that Urea is the only marketable product from the electrolysis-based plant. However, oxygen is a significant by-product of the electrolysis process as well as of the separation of nitrogen from the air. Calculations show that every ton of Urea produced generates around 0.95 tons of oxygen as by-product. The oxygen stream from the electrolysis process is highly pure and the market price of oxygen is around \$ 200 per metric ton (compare to the target urea market price of \$ 205 per metric ton). If indeed the generated oxygen can all be sold at the international market price, this would double the calculated revenue of the fertilizer plant and make the proposition very lucrative. The market for oxygen produced in Nepal, however, is unknown and further study would need to be done in order to ascertain its value. This is the reason why the sale of oxygen has not been included in this study. Typical consumers of pure oxygen are steel plants and certain chemical plants.

## 8.4 Macroeconomic Effects

Thus far the project has been analyzed from a very isolated financial standpoint. The primary reasons for studying the feasibility of the fertilizer plant, however are not financial but macroeconomic: such as food security and the effect of reliable fertilizer availability on our agriculture sector. Currently we subsidize imports by NRs. 5 billion per year, which means that we would reduce our trade deficit by over \$50 million per year because of domestic fertilizer production.

Reliable availability of fertilizer in the necessary quantities would obviously increase our agricultural output, probably by a very significant amount although a detailed study would be needed to address this issue. Since a very significant portion of Nepal's GDP is dependent on agriculture, this could have a very significant impact on the overall economy.

The fertilizer plant has been assumed to employ 500 people at a salary of NRs. 30,000 per month. Taking into account the fact that the marginal propensity to consume is 0.9, this results in a cumulative effect of NRs. 1.8 billion per year for the Nepalese economy.

In addition to these economic impacts, a chemical fertilizer plant is a very significant engineering undertaking and the establishment of such a plant would necessarily result in the development and employment of engineers, scientists and other highly skilled human resources. The spillover effects of the availability of such skilled manpower for other sectors of the economy could be incalculable. In addition, it could also provide the foundations for the development of other bodies such as environmental protection, soil testing, and occupational health and safety which would benefit the entire country. Furthermore, the establishment of such a plant would send a strong signal to foreign investors that Nepal is ready for large-scale investment in technologically driven industries.

## 8.5 Conclusions and Recommendations

The availability of chemical fertilizer has been a long-standing concern for the government of Nepal. Despite being situated next to two of the largest producers of chemical fertilizer in the world (China and India), Nepal is plagued with chronic shortage of fertilizer. Estimates of the annual requirement of chemical fertilizer in Nepal range anywhere from 300,000 MT to over 700,000 MT while the highest amount of fertilizer import has been a little over 200,000 MT. Out of the overall demand for chemical fertilizer, demand for Urea makes up 60% of the overall demand.

The international market price of Urea fertilizer is around USD 350 per metric ton. The market price in bordering regions of India is around USD 100 per metric ton, but India has severe restrictions on fertilizer export and fertilizer can only be procured from India with special permission from their government. This places the Nepalese farmers at a serious disadvantage as they must fertilize their fields at the international price while their counterparts in India have access to heavily subsidized fertilizer. In order to assist the Nepalese farmers so that their produce may compete with Indian produce, the government allocates around NRs 5 billion per year for fertilizer subsidy. Fertilizer is procured via a global tender at the internationally available price and subsidized so that it is available in the Nepalese market at around USD 200 per metric ton. Even at this expensive price, the amount of fertilizer that can be imported under subsidy is insufficient and some fraction of the shortfall is made up via unofficial smuggling across the Indo-Nepal border. The quality of fertilizer imported via such means is dubious.

Because of these difficulties, setting up a domestic Urea plant has been a long-standing wish of the government of Nepal. A prior feasibility study conducted in 1984 by JICA (Japan International Co-operation Agency) showed that a small electrolysis-based plant could be marginally feasible although the electrical power and cement production at the time were insufficient for such an undertaking.

The current state of the art process worldwide for urea production is methane-based. The

advantage of this process is that methane is cheap in many hydrocarbon-rich countries. In addition, the carbon-dioxide required for urea production is obtained as a by-product of the process leading up to ammonia production. Current plants are built for an output of up to 3000 metric tons per day which allows the process to realize large economies of scale. In countries where natural gas is not available, coal gasification has been the second-choice for urea production. The demand for fertilizer in Nepal is not sufficient to establish plants of such high capacity therefore the greatest economies of scale will not be realized.

Nepal has no natural gas or coal reserves of any significance. The nearest source of import for both items is India. Unfortunately, India itself faces significant shortages of natural gas and it is unlikely that Nepal would be able to source cheap natural gas from that direction. Even if it were possible, the cost of installing and maintaining a pipeline would be high and it would not address the concern of fertilizer security since the primary raw material for the fertilizer - natural gas, would be under foreign control. Coal imports face the same concern because the logistical challenges of importing such large quantities of coal as would be necessary to produce sufficient fertilizer for Nepal's requirements would be enormous.

In light of these difficulties, this report concludes that the most suitable technology for urea production in Nepal is through the electrolysis of water. In this process, electricity is used to split water into hydrogen and oxygen. The hydrogen is combined with nitrogen extracted from the air to produce ammonia which is then reacted with carbon-dioxide from a cement plant to produce urea. The oxygen, up to 1000 TPD of which is obtained as by-product, can also be sold to industries such as healthcare, steel plants, and other chemical processes at a significant price of \$200 per MT. The establishment of such a plant necessarily entails co-location adjacent to a cement plant. This report finds that at least one cement plant - namely Ghorahi cement factory in Dang has sufficient theoretical cement production to supply enough carbon-dioxide for an electrolysis-based urea plant to produce up to 1000 metric tons per day urea.

An electrolysis-based plant producing 1000 TPD urea would require an estimated 350 MW of electrical power and no other source of energy. It would also require no raw material other than water and carbon-dioxide. The cost of establishing such a plant has been the most uncertain aspect of the report and it could range anywhere between 500 million dollars to more than a billion dollars. Domain experts involved in the construction of fertilizer plants would be able to provide a better estimate. Saipem, a global leader in Urea plant construction estimated the cost of the ammonia-urea complex (not including, land, electrolysis plant, labor, construction-related structures) to be around USD 350 million with 40% error margin (See Appendix).

Using reasonable financial estimates, under the best case scenario of high energy-efficiency and the minimum capital investment of 500 million dollars, an unsubsidized urea plant could sustain a moderate internal rate of return of 8% if the price of electricity were less than NRs. 3 per kWh. If the current subsidy level of NRs. 5 billion were provided to this plant, it can provide that rate of return even if the price of electricity were NRs. 6 per kWh and can provide nearly a 12% rate of return if the price of electricity were NRs. 4 per kWh. For a project of high national priority such as this, and with a very high continuous power requirement, it may be possible to : (a) provide significant discount for the electricity price, even provide it for free or (b) build a dedicated hydro-power plant and absorb the cost of construction of the hydro-power plant into the cost of construction of the fertilizer plant, treating both as the same project. The cost of the urea plant as well as the cost of the requisite hydro-power plant as well as the opportunity cost of the produced electricity would need to be better quantified to analyze the financial feasibility in detail.

Given that there are situations - namely reasonable subsidy and reasonably low price of electricity under which a urea plant based on water electrolysis could be financially feasible, a detailed feasibility study of an electrolysis-based urea plant is warranted. Although Nepal currently faces a shortage of electricity and the calculated electric power requirement is more than a quarter of Nepal's total current production, the situation could change within the next

decade if many of the hydropower projects currently in discussion such as Upper Karnali, Arun 3, and Pancheswar are taken to fruition. It would behoove the authorities to take a long term view and think about dedicating some percentage of the power generated from these projects for consumption by a fertilizer plant. If a firm schedule of construction of such projects can be established, construction of the fertilizer plant can proceed simultaneously.

In addition to the financial feasibility, the effects on the wider economy due to employment generation, development of skilled manpower and regulating agencies, increase in agricultural output, reduction in trade deficit and the signaling effect to foreign investors should also be considered as these could be very significant. This also indicates that a more detailed study of the macro-economic effects of the establishment of a urea plant in Nepal needs to be conducted.

Based on these findings, this report provides the following recommendations:

## 8.6 Recommendations

- Accurately obtain the actual nitrogenous fertilizer requirement of Nepal. Study the potential for establishing an ammonium nitrate plant, which is also a nitrogenous fertilizer but does not require carbon-dioxide and hence would not require co-location with a cement plant, simplifying the details of construction and feasibility considerably. Furthermore, there is precedent for electrolysis-based ammonium nitrate plant. Sable fertilizer company based in Zimbabwe produces ammonium nitrate from electrolysis. The energy efficiency of ammonium nitrate production may also be better than urea production since the amount of hydrogen required per ton ammonium nitrate is less than that for urea. The suitability of ammonium nitrate as the primary nitrogenous fertilizer for Nepal will also need to be established.
- Establish the actual CO<sub>2</sub> emission and capture capability from a suitable cement plant in Nepal. If the cement plant does not produce enough CO<sub>2</sub> for 1000 TPD urea, the capacity of the urea plant will need to be revised downwards, which will adversely affect the economics.
- Study the possibility of securing natural gas from India at low cost for a natural-gas based plant. Such a study must take into account the cost of building and maintaining the gas pipeline and also long term security of natural gas.
- Conduct a detailed feasibility study for an electrolysis-based fertilizer plant, inviting firms experienced in plant construction such as Saipem, Uhde, KBR, Toyo, Haldor Topsoe, etc. to conduct the study.
- Feasibility study must accurately establish the capital cost of construction of the plant.
- Feasibility study must study if it is possible to economically design the plant to be able to take advantage of surplus electricity available during the wet season.
- Study the possibility of obtaining free or cheap electricity for the fertilizer plant. Look at the load profile and identify times where there is surplus electricity. Build the plant with enough hydrogen storage that it can take advantage of surplus power.
- Consider building a dedicated power plant to supply power to the fertilizer plant. Analyze the financial implications of absorbing the cost of construction of the power plant into the cost of construction of the fertilizer plant.
- Capital, energy and CO<sub>2</sub> permitting, build the largest fertilizer plant possible to realize economies of scale.

## 8 Summary

- Take a pro-active and long term view of the project and start the homework early in anticipation of completion of some of the mega hydro projects. Electricity from these projects may be able to be allocated for fertilizer plant use at guaranteed prices.
- Other than the price of urea, the price of electricity is the strongest driver of project feasibility. The project will be feasible if electricity can be provided at low enough cost.
- Maintain the NRs. 5 billion subsidy (adjusted for inflation), allocating it to the fertilizer plant instead of purchasing fertilizer. This will help in maintaining financial viability. Such a subsidy will also net much more fertilizer than purchasing at the international market price.
- Investigate the market for oxygen. A 1000 TPD urea plant based on electrolysis will produce roughly 1000 TPD oxygen which sells for \$ 200 per MT. This could provide a revenue stream significant enough to make or break the financial viability of the project. Sable fertilizer in Zimbabwe, which is also an electrolysis-based plant producing ammonium nitrate, pipes its oxygen to nearby steel smelting plants.

## 9 Appendix

# Note

## Chemical fertilizer plant

### in Nepal

- August 2014 -



**Saipem S.P.A.**

**[www.saipem.com](http://www.saipem.com)**

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# CHEMICAL FERTILIZER PLANT IN NEPAL

## Note

00	Issued	L.Chianese	S.Dallera	P.Ranghetti	07/08/2014
Rev.	Description	Prepared	Checked	Approved	Date

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**TABLE OF CONTENTS**

1	INTRODUCTION.....	4
2	SCOPE OF WORK.....	4
3	MAIN ASSUMPTION.....	4
4	PROJECT PROCESS OVERVIEW.....	5
5	POWER REQUIREMENT.....	6
6	CAPITAL COST ESTIMATE.....	6

## 1 INTRODUCTION

The present document has been prepared by Saipem in response to the request for information related an urea plant of Mr. Prashant Luitel, dated 23/07/2014.

Mr. Prashant Luitel is working for the Investment Board of Nepal.

The government has requested the Investment Board to investigate the possibility of establishing a chemical fertilizer plant in Nepal.

The plant would produce 1000 TPD of Urea by generating Hydrogen through the electrolysis of water and obtaining its carbon-dioxide through flue gas capture from a cement plant.

This is in light of the fact that Nepal has negligible hydrocarbon resources but abundant hydroelectric potential. Several large-scale hydro projects are currently in negotiation and there could be the possibility of obtaining hundreds of megawatts of very cheap electricity from these projects.

The following information was requested by Client for a 1000 metric tons per day urea plant:

- a very roughly power requirement;
- a preliminary estimate for the capital cost.

## 2 SCOPE OF WORK

The Scope of Work (SoW), subject of this Note, is to develop an approximate power requirement and a preliminary capital cost estimate for the following case:

- Ammonia /Urea Complex to produce 1000TD of Granulated Urea.

## 3 MAIN ASSUMPTION

It has been assumed that the complex shall generate internally the utilities required for complex operations (except for electric power) and the feedstock shall be CO<sub>2</sub>, Air and

pressurized H<sub>2</sub> (preliminarily the pressure of the Hydrogen coming from the electrolysis of water has been assumed 20 bar).

Compressors have been assumed moved by electric motors while the steam produced in the ammonia units has been assumed to export.

## 4 PROJECT PROCESS OVERVIEW

The fertilizer plant will be an Ammonia-Urea plant, designed to produce 600 MTPD of Ammonia and 1000 MTPD of granulated Urea on continuous basis.

The plant will produce Urea for export and Ammonia will be an intermediate product.

The plant will receive 106 TPD of pressurized Hydrogen from the electrolysis plant (excluded from SoW) and 731 TPD of carbon dioxide from a cement plant ; all utilities generation systems will be provided except for electric power.

The fertilizer plant includes the following process unit:

- Air separation;
- Ammonia Synthesis;
- Urea Synthesis;
- Urea Granulation;

The preliminary list of Utilities and Off-sites included in the Project is here below indicated:

- Potable Water System
- Steam & BFW System
- River Water Intake System
- Cooling Water System
- Instrument & Plant Air System
- Nitrogen Unit

- Emergency Diesel Generation
- Flare & Blowdown System
- Diesel Oil Storage & Handling
- Fire Fighting System
- Ammonia storage system
- Urea Bagging and Handling System

## 5 POWER REQUIREMENT

The estimated power requirement is roughly **25 Mw**, in this stage of the project it has been calculated assuming compressors moved by electric motors while the steam produced in the ammonia units will be exported. During the feasibility study phase the steam system should be optimized and the electricity is expected to decrease.

## 6 CAPITAL COST ESTIMATE

The capital cost estimate corresponds to:

**€253,000,000 (two hundred fifty three million Euro)**

The capital cost estimate is limited to EPC portion of the Project and has been prepared on the basis of in-house data taken from fertilizer plants under construction or already implemented.

The capital cost estimate refers to 2<sup>nd</sup> quarter 2014 and the expected accuracy is of plus or minus 40%, that represents the internationally recognized accuracy for cost estimates of industrial complexes or groups of units at this stage of the project.

### Capital Cost Inclusions

The capital cost estimate includes:

- Grant of license and process design package for the licensed technology;
- Basic and detailed engineering;
- Procurement and supply at site of equipment and materials (including inspections);
- Engineering, procurement and post order management;
- Construction, erection works and Supervision, including civil works, mechanical erection, electrical and instrument installation, insulation and painting;
- Precommissioning, commissioning, start-up and performance tests;
- First filling, chemicals and lubricants;
- Commissioning spare parts.

#### Capital Cost Exclusions

The capital cost estimate excludes:

- Soil investigation;
- Site land for the project and temporary construction facilities;
- Site preparation and levelling;
- Facilities other than those indicate in paragraph 4;
- Training for Company personnel;
- Two years and capital spare parts;
- Site temporary construction facilities;
- Acquiring permits/authorization to be obtained in the name of the Company;
- Local Taxes, with-holding taxes, custom duties and any other local duties, levies, etc;
- Provision for contingencies and escalation on materials and labor prices;
- Company's costs (financing, bank charges, pre-production costs, costs for Company's personnel living, lodging, travel and the like).

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