SUMMARY REPORT 2021

ESTABLISHING A FERTILIZER PLANT IN NEPAL:
A COMPARATIVE STUDY AND ANALYSIS OF NATURAL GAS VS WATER ELECTROLYSIS TECHNOLOGY

GOVERNMENT OF NEPAL
INVESTMENT BOARD NEPAL

10 YEARS OF
INVESTMENT BOARD NEPAL
PARTNERING FOR ECONOMIC PROSPERITY

ESTABLISHING A FERTILIZER PLANT IN NEPAL:
A COMPARATIVE STUDY AND ANALYSIS OF NATURAL GAS VS WATER ELECTROLYSIS TECHNOLOGY

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FOREWORD

> The Government of Nepal (GoN) has prioritized the establishment of a chemical fertilizer plant owing to the perennial shortage of fertilizers and increasing concerns over food security.

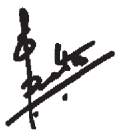
Investment Board Nepal (IBN), as an apex government agency, remains committed to contributing in realizing the objectives of socio-economic development through the implementation of mega-projects. Over a decade, it has facilitated several largescale PPP and private investment projects which remain critical to bolstering sustainable economic growth and development. Among multiple projects in different sector of economy, the establishment of a chemical fertilizer plant in Nepal is one of the transformative projects under IBN purview for development.

The Government of Nepal (GoN) has prioritized the establishment of a chemical fertilizer plant owing to the perennial shortage of fertilizers and increasing concerns over food security. The relevant government agencies and the current fiscal budget have also highlighted the necessity of such a project in Nepal. Furthermore, the budget speech of fiscal year (FY) 2021/22 envisioned establishing a chemical fertilizer plant within three years.

In this context, there were two different studies carried out by JICA and IDecK to study the prospect of establishing a urea-based chemical fertilizer plant in 1984 and 2017 respectively. JICA study emphasized water electrolysis technology, while IDecK focused on natural gas technology for manufacturing urea. Against this backdrop, an in-house team of multidisciplinary experts at OIBN undertook this study to compare the two different urea production technologies. The study has also considered the changing times and technologies to determine the technology and other relevant information required for the two different fertilizer production technology and suitability.

The development modality for the establishment of a chemical fertilizer plant best fits public-private partnership as it is directly related to the nation's food security and the construction of a plant requires national resources and decision interventions. However, determining the type of PPP contract would need further deliberation in the upcoming days.

I believe that this comparative analysis shall provide substantial inputs for informed decision-making in opting for an appropriate approach for project development through further analysis and wider discussion with stakeholders.



Sushil Bhatta
Chief Executive Officer
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INTRODUCTION

The Government of Nepal (GoN) has prioritized the establishment of a chemical fertilizer plant because of a perennial shortage of fertilizers and increasing concerns over food security. Relevant government agencies and the current fiscal budget have highlighted the necessity for such a project in Nepal. The GoN had also pointed out the need for a detailed study on the electrolysis of water, an innovative green technology, for fertilizer production. The budget speech of fiscal year (FY) 2021/22 envisions establishing a chemical fertilizer plant within three years. A plan to conduct a comparative study and analysis of natural gas vs water electrolysis technology is also included in the Office of the Investment Board Nepal (OIBN) Annual Plan for FY 2021/22.

The GoN has undertaken two major studies on the prospect of establishing a chemical fertilizer plant in Nepal. The first, a feasibility study conducted by Japan International Cooperation Agency (JICA) in 1984, focused on using water electrolysis technology to produce urea fertilizer. The second study was done in 2015 by the consortium of Infrastructure Development Corporation (Karnataka) Ltd., India, the Institution of Agricultural Technologists, and Shah Consult International Pvt. Ltd. (IDeck). The study focused on using natural gas technology as a suitable option to produce urea in Nepal and compared three feedstock options – natural gas, coal, and water using electrolysis for ammonia and urea synthesis. The factors used to determine suitability were technology, energy intensity, and production cost.

Each of the studies conducted by JICA and IDeck for manufacturing urea focused on water electrolysis and natural gas respectively. OIBN conducted this study to compare the two different urea production technologies. It takes into consideration the technical knowledge, the changing global context, and available technologies to analyze the two different fertilizer production processes.

> "Each of the studies conducted by JICA and IDeck focused on a single method for manufacturing urea, water electrolysis and natural gas respectively.

The primary objective of this study is to assess the most suitable technology and development options for the establishment of a chemical fertilizer plant in Nepal. The specific objectives of the study are:

(i) To conduct a comparative analysis of two different technologies (natural gas and water electrolysis) used in the fertilizer production process
(ii) To understand the technical knowledge required for the two different fertilizer production processes (natural gas and water electrolysis)
(iii) To analyze the physical and other infrastructure facilities required for the different fertilizer production processes
(iv) To determine the financial viability of the project, and
(v) To understand the appropriate technology and development models while considering international market trends, national interests, and national requirements.

The study uses a literature review and key informant interviews (KII) as part of its research methodology. A literature review of the JICA, IDeck and other available reports, including various online journals, was conducted. Similarly, the study team conducted KIIs with representatives from relevant government line agencies and other concerned stakeholders to obtain the required primary information.

LITERATURE REVIEW ON STUDIES

Review of the detailed feasibility study report (DFSR) on a urea fertilizer plant in Nepal - IDeck

The GoN envisions establishing an ammonia urea complex in Nepal. To determine if this project has merit, the GoN through OIBN carried out a detailed feasibility study (DFS) for setting up a fertilizer complex.

The OIBN conducted a DFS to explore the technical and financial feasibility of whether a urea plant could be established in Nepal. The consortium of Infrastructure Development Corporation (Karnataka) Ltd., India in association with the Institution of Agricultural Technologists and Shah Consult International Pvt. Ltd. (IDeck) was selected to conduct the study on the proposed chemical fertilizer plant in Nepal. The contract between the consortium and IBN was signed on December 18, 2015. The DFS was conducted and submitted to OIBN in June 2017.

The DFS estimates that demand for urea in Nepal is about 700,000 metric tons per year as per GoN's data. This was estimated based on the total cultivable land available in Nepal, the major crops in the country, and their cropping patterns via-a-vis productivity. It states that certain interventions like awareness programs on the use of urea, adopting best practices in the administration of urea, etc. can be adopted by the government to efficiently and effectively use urea manufactured in Nepal. The capacity of the proposed fertilizer plant with a production capacity of 700,000 metric tons per year is based on the demand estimation made by the government.

The study for a suitable site for setting up the urea fertilizer plant was confined to the potential areas identified by the government. The study recommended the alternative 2 site in Dhalkebar as a suitable location for the plant. It estimated that approximately 400 acres of land would be required to set up the plant.

Three feedstock options – natural gas, coal, and water using electrolysis – for ammonia and urea synthesis were assessed for the fertilizer plant. The study concluded that

> "The project cost for setting up a urea plant using the three feedstock options was evaluated. The total capital cost of the project was worked out to be USD 665 million for natural gas, USD 953 million for coal gasification, and USD 1,305 million for water electrolysis.

natural gas was the most suitable feedstock in terms of technology, energy intensity, and product cost point competitiveness. Possible means for procuring and sourcing natural gas from across the borders of Nepal are discussed in the report.

The project cost for setting up a urea plant using the three feedstock options was evaluated. The total capital cost of the project was worked out to be USD 665 million for natural gas, USD 953 million for coal gasification, and USD 1,305 million for water electrolysis. This includes costs towards inside battery limit (ISBL), outside battery limit (OSBL), and off-site facilities.

The cost-benefit analysis was carried out to assess the option of importing fertilizers vis-à-vis domestic production. It estimated that the net annual outflow after setting up a 700,000 metric ton per year capacity urea plant would be about USD 86.6 million which is significantly less than the corresponding outflow when importing urea. The current GoN figures for net outflow is as high as USD 186 million per annum.

The government must make an equity investment of USD 221.74 million in the project during the construction period and provide a subsidy outflow of USD 86.60 million per annum during the operations period under the base case to make the urea affordable to farmers.

If the GoN intends to implement the project through private sector participation, it might require the government to offer additional incentives (grant financing as a percentage of the estimated project cost) to the tune of USD 66.16 million, USD 131.5 million, and USD 196.24 million as a grant for 10 percent, 20 percent, and 30 percent of the total project cost respectively during the construction period to attract private investment.

Review of 'A Feasibility Study Report on the Establishment of Urea Fertilizer Plant in the Kingdom of Nepal – JICA'

In 1984, the then GoN envisioned establishing a urea fertilizer project in Nepal as the agriculture sector contributed to around 60% of the nation's gross domestic product (GDP). The main purpose was to promote the domestic production of fertilizers through the efficient utilization of indigenous resources, primarily water and hydropower.

For this, Nepal had requested the Government of Japan for technical assistance to conduct a feasibility study on the establishment of a urea fertilizer plant. The project cost was estimated to be USD 144.79 million (with USD 119.87 million in foreign investments and USD 24.92 million in local investments) with a financing plan of 30 percent equity and 70 percent loan.

In 1982/83, the estimated chemical fertilizer consumption was 22,900 Nutrient tons of Nitrogen, 7,200 Nutrient tons of phosphorus, and 900 Nutrient tons of potassium. Against this backdrop, the consumption of nitrogen had increased steadily with an annual growth of 17 percent averaged for the period between 1966/67 to 1982/83, while that of phosphate fertilizer was stagnant, and that of potassium decreased. The demand for Nitrogen was projected to grow to 33,383 tons by the year 2000 corresponding to 72,600 tons of urea.

Although the financing source had not been identified, the interest rate for the 70 percent loan proportion of the total project cost was estimated at 5 percent of the base project cost and price contingency estimated at an escalation of 3.5 percent of foreign currency. The repayment period for the foreign loan was estimated to be 15 years from the date of commercial operation. The interest rate for short term financing was 15 percent per annum with a repayment period of one year.

The production process, as mentioned in the feasibility study for urea production, was to react ammonia (produced from the reaction of hydrogen and atmospheric Nitrogen) with carbon dioxide recovered from the cement plant flue gas. The hydrogen is produced from water electrolysis method.

The study concluded that construction of a urea fertilizer plant with a 275 metric ton per day capacity was possible which would be in Hetauda with an area of 500 m x 200 m on the west side of Hetauda Cement Limited. The on-stream target for the chemical fertilizer plant was set for 1991. The assumption was based on access to electric power of 76.1 MW by Nepal Electricity Authority, 32,450 Nm3/h cement plant flue gas supplied through Hetauda Cement Industry, 76.8 metric ton per day coal imported through India, and the self-supply of industrial water and atmospheric air.

Policy History in the Fertilizer Sector in Nepal

The events and policies related to fertilizer sector in Nepal are highlighted below in chronological order (Source: World Bank, 2016).

- 2009 to 2022 BS - The National Trading Centre imported fertilizers to Nepal from Russia and China.

- 2023 to 2030 BS - The government formed the Agriculture Inputs Company (AIC) to import and distribute fertilizers at commercial terms without subsidies. The major sources for AIC to import fertilizers were India and other international markets. The use of fertilizer was low in the hills and mountain areas due to high costs.

- 2031 to 2055 BS - The government introduced and provided subsidies for the transportation and use of chemical fertilizers. The price subsidies on chemical fertilizers were applicable to all farmers, whereas transport subsidies were only applicable to farmers from the hill and mid-hill regions.

- 2052 BS - The government published the Agriculture Perspective Plan, where fertilizers were recognized as a primary input to enhance agricultural productivity, and set a target to increase fertilizer use to 131 kilograms per hectare by 2015 AD(2072 BS).

- 2056 to 2067 BS - Government subsidies were withdrawn and the market liberalized following the Agriculture Perspective Plan. Liberalization was marked by:

- o Informal imports of fertilizers of unknown and unverified quality
- o Increased private sector participation in fertilizer importation and distribution.
- o A remarkable decline in formal imports of fertilizers after liberalization
- o Rising fertilizer prices further opened the market for cheap fertilizers of unknown quality.
- o During this time, around 80 percent of subsidized fertilizers were sold in the Kathmandu valley.

- 2059 BS - The government formed the Agriculture Inputs Company Limited (AICL) to import and distribute fertilizer, and the National Seed Company Limited was charged with seed distribution.

- 2067 BS to present - After the decrease in agriculture inputs seen during the liberalization era, the government reintroduced subsidies. The government assigned AICL and the Salt Trading Corporation to sell fertilizers via cooperatives to farmers at subsidized rates. These subsidies were initially targeted at marginal farmers, who had land-holding of less than 4 hectares in the Terai and less than 0.75 hectares in the hills. Paddy, wheat, maize, and millet were initially the targeted crops. After the reintroduction of subsidies, private companies could not compete with the government's subsidized price of fertilizers.

- 2068 BS to present - The government relaxed its focus on marginal farmers and specific crops of paddy, wheat, maize, and millet and all types of farmers began benefitting from the subsidies program. The government also issued the Organic Fertilizer Subsidy Directives and the Organic and Biofertilizer Working Procedure. These policies provide subsidies on the purchase of domestically produced fertilizers that meet their criteria. A high-level subsidy distribution management committee decides the rate and quantity. District-level committees are responsible for the actual distribution. The main organic fertilizer distributed under this program is Vermi-Compost Manure.

LAND DISTRIBUTION, CROPPING PATTERNS, AND FERTILIZER CONSUMPTION IN NEPAL

According to the Agriculture and Livestock Diary (2076), Nepal has a total cultivated area of 3,091,000 hectares which is 21 percent of the total land available. Similarly, an additional 1,030,000 hectares of land is available for cultivation (i.e., 7 percent of total land). As per the Irrigation Master Plan (2019) there are 11 different projects out of which five projects have alternative infrastructure variants to increase water supply and expand irrigated land. As per the National Planning Commission (2018), 2,265,000 hectares are irrigable out of 2,641,000 hectares of arable land. As of FY 2018/19, infrastructure had been built to irrigate 1.43 million hectares of land.

Major crops are determined by their area of cultivation, productivity and profitability. Considering these factors, rice is the major crop produced in Nepal followed by wheat, maize, and vegetables. Rice yield is expected to grow to 3,840 kg/ha by 2031 and 3,903 kg/ha by 2043 respectively. In comparative terms, rice production is expected to increase by 14.99 percent in 2043 from 2014/15 level while wheat and maize are expected to increase by 14.38 percent and 7 percent respectively. In terms of demand projection, the demand for rice is expected to increase from 4,478.2 thousand tons in 2020 to 5,638.1 thousand tons by 2035. This indicates an increase in rice demand by 26 percent. Similarly, demand for wheat, maize, and potato is expected to increase by 26 percent, 26 percent, and 39 percent respectively.

Contribution of Inputs in Yield Increment

An increase in the production of these major agro-products is subject to the availability of year-round irrigation facility, fertilizers, and improved seed quality among other things. These pre-requisites are dependent on the level of research and the extension of agricultural services. The contribution of a variety (improved seed), irrigation, and their interaction (irrigation * variety) to yield an increment was 30 percent, 29 percent, and 41 percent respectively (Thapa and Pokhrel, 2003).

"In terms of demand projection, the demand for rice is expected to increase from 4,478.2 thousand tons in 2020 to 5,638.1 thousand tons by 2035. This indicates an increase in rice demand by 26 percent.

Pattern of Chemical Fertilizer Consumption in Nepal

Fertilizer consumption measures the amount of nutrients used per unit of arable land. The agriculture perspective plan (1995-2015) aimed to increase consumption to 150 kg/ha by 2015. However, the consumption pattern of fertilizers from 1999-2018 shows the use of fertilizers gradually declined from 1999 to 2008. A major factor for this was the removal of subsidies on the price and transportation (for selected hill and mid-hill districts) of chemical fertilizers. This led to an increase in the price of fertilizers. As farmers were obliged to purchase chemical fertilizer on their own, fertilizers became less affordable which ultimately led to a dwindling in their use. However, on March 25, 2009, the GoN reintroduced the fertilizer subsidy program which again led to an increase in fertilizer consumption. The demand for fertilizers is high in the Terai region followed by the hills and high hills region. Among major crops, rice production requires significantly higher fertilizers followed by maize and wheat. In the case of Nepal, rice accounts for 65 percent of total fertilizer consumption. For rice production, 20 kg/h of nitrogen, 100 kg/h of DAP, and 60 kg/h of Potash is required.

Types of Chemical Fertilizers in Nepal

There are seven types of fertilizers being used in Nepal: urea, diammonium phosphate (DAP), muriate of potash (MOP), ammonium sulphate (AS), single super phosphate (SSP), ammonium phosphate sulphate (APS), and nitrogen, phosphorous and potassium (NPK). Among them, the GoN has subsidized 3 types of chemical fertilizers (urea, DAP, and MOP) for distribution through AICL and STC. Urea is the most consumed chemical fertilizer in Nepal followed by DAP and MOP.

Import Price, Sales Price, and Subsidy on Major Chemical Fertilizers in Nepal

The current price to import urea is NPR 112 per kg, DAP is NPR 114 per kg, and Potash is NPR 98 per kg. Similarly, the sales price of urea is NPR 15 per kg, DAP is NPR 44 per kg, and Potash is NPR 32 per kg. Overall, the subsidy provided on Urea is NPR 97 per kg which is 86.6 percent of the import price. For DAP, the subsidy provided is NPR 70 per kg which is 61.4 percent of the import price, and for Potash, it is NPR 66 per kg which is 67.34 percent of the import price (Source: AICL).

PROJECT REQUIREMENTS

The infrastructure required for both natural gas and electrolysis technology is discussed in this chapter.

Land Availability

According to iDeck's report, 400 acres of land is required for a urea plant (producing 701,250 metric tons of urea per year) using natural gas technology at the two proposed sites at Dhalkebar – Alternative I and Alternative II. On the other hand, urea production with electrolysis mainly requires power, water, and carbon dioxide. So, the project site needs to be planned based on their availability in the proximity of the urea plant. The study team assumes that approximately 500 acres of land is required for a urea plant using electrolysis.

Electricity Required

The electricity required for a urea plant running on natural gas would be 180,000 unit per day whereas a urea plant running on electrolysis will need 10,800,000 unit per day. This has been elaborated below.

Electricity required to produce 1 metric ton of hydrogen: The electricity required to produce 1 metric ton of hydrogen from electrolysis is in the range of 48,950 to 50,000 units of electricity.

Electricity required to produce 1 metric ton of ammonia: Historically, the energy consumed by the Haber-Bosch process for synthesizing ammonia to produce a metric ton is about 12 MWh (i.e., 12,000 units of electricity).

Electricity required to produce 1 metric ton of urea: To produce 1 metric ton of urea from the reaction of NH_3 and CO_2, 160 units of electricity is required.

The proposed plant has a capacity of producing 2,125 metric tons of urea per day. So, to produce this quantity of urea through the electrolysis process, the total electricity required would be around 10,800 MWh per day (around 450 MW per day).

> Urea production with electrolysis mainly requires power, water, and carbon dioxide. So, the project site needs to be planned based on their availability in the proximity of the urea plant.

Water Required

The chemical fertilizer plant should have access to water sources, a running river and ground water are both required to go through the water treatment plant prior to the manufacturing process.

Requirement of water to produce one metric ton of hydrogen: According to The Energy and Resources Institute (TERI) (2020), electrolysis requires nine liters of fresh water to produce one kilogram of hydrogen (and eight kilograms of oxygen). To produce one metric ton of hydrogen through water electrolysis, 9,000 liters of fresh water is required. According to IDeck, the production of one metric ton of hydrogen through electrolysis requires 11,126 liters of fresh water.

Requirement of water to produce one metric ton of ammonia: It was found that 1,500 liters of water is required to produce one metric ton of ammonia.

Hence, it can be concluded that to produce one metric ton of hydrogen, one metric ton of ammonia and one metric ton of urea using water electrolysis, the cumulative water required is around 21,906 liters. On the other hand, the water required for the natural gas process is 9,280 liters per ton of urea production.

A blacktopped road with a minimum width of 40 feet is required for a chemical fertilizer plant.

A natural gas-based fertilizer plant requires around 15 MW of electricity for the same manufacturing capacity. A 400 kV transmission line is needed for urea production using green hydrogen.

For natural gas technology, establishing a centralized effluent water treatment plant as a component of chemical fertilizer plant is more appropriate. IDeck's report states that the International Finance Corporation (IFC) has set wastewater generation standards for straight run nitrogenous fertilizer urea at five cubic meters per metric ton of urea produced or its equivalent, and consumption at 15 cubic meters per metric ton of urea produced or its equivalent.

A urea plant that uses natural gas as feedstock will require human resources from other countries. For instance, human resources with such expertise are available in India as the technology is being used and is well known there.

PRODUCTION PROCESS

Production of Urea Using Natural Gas

Urea can be produced artificially through the synthesis reaction of carbon dioxide with ammonia at a pressure of 21 MPa and temperature of 180 C. For commercial use, urea is mainly produced in a solid form, either as prills or granules depending on the finishing process being used. Urea was first produced industrially by hydrating calcium cyanamide (CaCN), but the easy availability of ammonia led to the development of the ammonia/carbon dioxide technology.

Ammonia is synthesized from hydrogen (from natural gas) and nitrogen (from the air). Natural gas contains some sulfurous compounds which can damage the catalysts used in this process. These are removed by using zinc oxide. The methane from the natural gas (natural gas mostly comprises of methane) is then converted to hydrogen through steam reforming.

$$CH_4 + H_2O \rightleftharpoons 3H_2 + CO$$
$$CH_4 + 2H_2O \rightleftharpoons 4H_2 + CO_2$$
$$CO + H_2O \rightleftharpoons H_2 + CO_2$$

Water, carbon monoxide, and carbon dioxide (all of which poison the iron catalyst used in ammonia synthesis) are removed. The carbon monoxide is converted to carbon dioxide for use in urea production:

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

Remaining traces of CO and CO2 are converted to methane and the gases are then cooled until the water becomes liquid and can be easily removed. The nitrogen and hydrogen are then put under high temperature and pressure using an iron catalyst to form ammonia through the Haber-Bosch process.

Urea is made from ammonia and carbon dioxide. The ammonia and carbon dioxide are fed into the reactor at high pressure and temperature, and the urea is formed in a two-step reaction.

$$2NH_3 + CO_2 \rightleftharpoons NH_2COONH_4 \text{ (ammonium carbamate)}$$
$$NH_2COONH_4 \rightleftharpoons H_2O + NH_2CONH_2 \text{ (urea)}$$

"Urea is made from ammonia and carbon dioxide. The ammonia and carbon dioxide are fed into the reactor at high pressure and temperature, and the urea is formed in a two-step reaction.

The urea contains unreacted ammonia, carbon dioxide, and ammonium carbamate. As the pressure is reduced and heat applied, the NH2COONH4 decomposes to NH3 and CO2. The ammonia and carbon dioxide are recycled. The urea solution is then concentrated to give 99.6 percent weight by weight molten urea and is then granulated for use as a fertilizer and chemical feedstock.

Natural gas (NG) or Re-gasified Liquid Natural Gas (RLNG) is the most widely used feedstock to manufacture ammonia. The Wobbe Index for natural gas falls between 12,800 and 11,500 Kcal/Nm3. The only other gas which has a comparable Wobbe Index is Methane which falls between 12,700 and 11,500 Kcal/Nm3. Natural gas primarily comprises of up to 96 percent to 98 percent of methane. It is considered to be the best possible feedstock to manufacture both ammonia and carbon dioxide and thereby, urea. However, there are currently no known sources of natural gas available in Nepal. This means natural gas would need to be transported to the project site from other countries like India or Bangladesh in the Indian sub-continent through pipelines.

There is a need to procure and secure natural gas, on a long-term basis, of up to 1.33 million standard cubic meters per day. Provision for expansion must be made in line with this capacity. If the plant is to operate with a 10% higher capacity margin, a corresponding provision for approximately 1.46 million standard cubic meters of gas per day must be made available.

Production of Urea Using Water Electrolysis

Hydrogen Production from the Electrolysis of Water: Electricity from AC power, excluding solar power, needs to be converted into DC power via a rectifier which then splits the water into hydrogen and oxygen in a fuel cell with electrolytes (mostly alkaline electrolytes such as KOH & NaOH). The hydrogen that is produced is dried and stored in a tank. The oxygen is sent into the atmosphere. The system does not capture oxygen gas but capturing the highly pure oxygen gas is a possibility, allowing it to be supplied as a by-product. The plant is expected to function at least 23 hours a day and at a maximum 24 hours a day over 330 days in a year.

Production of Ammonia: Essentially, all the processes employed for ammonia synthesis are variations of the Haber-Bosch process developed in Germany from 1904-1913. This process involves the reaction of hydrogen and nitrogen under high temperatures and pressures with an iron-based catalyst. The source of nitrogen is always air.

Production of Urea: The manufacturing of urea is possible using water electrolysis. However, to manufacture urea, water electrolysis alone will not suffice as the urea is manufactured through a combination of ammonia and carbon dioxide. In the water electrolysis process there is no carbon compound unlike in other technologies that uses natural gas and coal gasification where the CO2 is generated as part of the process and is consumed to manufacture the urea. Hence, there is a challenge in sourcing carbon dioxide.

A possible solution could be the recovery of carbon dioxide from nearby flue gases of power plants, cement plants, or similar such process units. Such a process is called carbon capture and storage (CCS).

Carbon Capture and Storage (CCS): The worldwide installed capacity of CCS is around 40 metric tons per annum. Typically, CCS design and construction costs are in the hundreds of millions, sometimes billions, of US dollars.

Flue gases from cement kilns are good candidates for CCS. Their typical CO2 concentrations are around 14-33 percent higher than from conventional coal-fired combustion. To manufacture 2,125 metric ton per day of urea, 1,573 metric ton per day of CO2 is required (i.e., for 1 metric ton per day of urea, 0.7402 metric ton per day of CO2 is required).

The total CO2 emission from cement productions in Nepal for 2019 was estimated at 3.45 0.50 million metric tons (Thakuri, et. al, 2021). A cement plant with an installed capacity of about 2,400 metric ton per day can generate flue gas from which 1,573 metric ton per day of CO2 could be extracted (IDeck, 2016). Hence, 3,932.5 metric ton per day CO2 could be extracted from Cement plants like Hongshi with a capacity of 6,000 metric tons per day. As per the internal study conducted by OIBN in July 2020, the total production of clinker from 20 clinker producing cement industries is around 21,109 metric ton per day. So, the total amount of CO2 that could be extracted from such cement industries is around 13,835 metric ton per day.

Based on the provided data, a study was conducted by Kathmandu University for a system which was designed for 250,000 ton/year carbon capture, and it was found that for 700,000 tons of urea, 1,200,000 metric tons per year CO2 capture is needed. The cost of capturing is USD 0.086 per kg of CO2 but cost will be lower when done at a larger scale. The data that was used for simulation comprised of 15 percent CO2 by weight, but usually cement flue gas has 25-30 percent CO2.

Based on the IDecK report and the study conducted by Kathmandu University, the daily requirement of CO2 for 1 metric ton of urea is found to range from 0.7402 metric ton to 1.71 metric ton.

Experimental CCS Facility in a Cement Plant: An experimental CCS facility is installed in one of the cement plants in Belgium as part of a European research project that aims to capture carbon with the process namely “Direct Separation”. The cement factory covers about 70 hectares and employs 180 workers which produces 1.4 million tons of cement per year. According to Jan Theulen (Director of Alternative Resources, Hiedelberg Cement, Germany), with the production of 1 ton of cement, 0.6 ton of CO2 is generated which mainly comes from the raw materials. So, to capture such CO2, a research project is being executed in the premises of the cement factory that has installation of 60 m tall structure (i.e., reactor) that is trapping 5 percent of the total emitted CO2 of the cement plant. The researchers aim to trap 95 percent of CO2 in the coming days. In addition to this, there are other experimental plants of carbon capture in Norway and China with the process namely “Chemical Absorption”.

FINANCIAL ANALYSIS

A detailed and comprehensive financial model was prepared and various financial inputs on technology, project cost, source of financing, debt arrangements, revenues, operating costs, working capital requirements, and cost of capital is estimated to compute financial output parameters like the internal rate of return (IRR), net present value (NPV), project payback period, debt service coverage ratio (DSCR), cost of production, and a breakeven analysis.

Project Construction Cost

The total project construction cost under the natural gas option includes the main plant equipment cost, other equipment cost, offsite facilities cost, engineering fee cost, project management charges, land development fees, net commissioning expenses, and contingency expenses. The total project construction cost including interest during the construction period is estimated at USD 1,251 million.

The total project construction cost under the water electrolysis option includes the main plant equipment cost, other equipment cost, offsite facilities cost, engineering fee cost, project management charges, land development fees, net commissioning expenses, and contingency expenses. The estimated project construction cost including all the components mentioned above and interest during the construction period is estimated at USD 1,897 million.

Cost of Production

Cost of production refers to the costs a company incurs from manufacturing a product or providing a service that generates revenue for the company. Production costs can include a variety of expenses, such as labor, raw materials, consumable manufacturing supplies, and general overhead. The cost of production per metric ton at 100 percent plant capacity (i.e. 701,250 metric ton of urea fertilizer per annum), is calculated at USD 278.88 under the natural gas option and USD 656.31 under the water electrolysis option during the initial year of operation. The cost of production per unit of urea from water electrolysis is 2.36 times higher than production through natural gas.

"The estimated project construction cost under water electrolysis techonology including all the components mentioned and interest during the construction period is estimated at USD 1,897 million.

Source of Finance

The funds that will be required to construct the project would be raised through debt and equity. It is assumed that 75 percent of the total fund requirement would be covered by debt and the remaining 25 percent by equity stocks. The funds will initially be raised as equity while the remaining portion of the cost will be covered by debt.

FEEDSTOCK REQUIREMENTS

Raw Material for the Natural Gas Option.

The primary raw material required under this alternative is natural gas. It is estimated that 14,377,886 metric million British thermal units (MMBtu) natural gas per year will be required for the manufacture of urea from the fertilizer plant. The consumption of natural gas is computed based on the estimated energy consumption of the fertilizer plant running at 100 percent capacity. The unit price of natural gas is considered at USD 2.80 per MMBtu with an inflation rate of 3 percent per year which is the price available and expected in the global market, particularly the United States. In addition to this, 65,078 units of 100 cubic meters of raw water is required yearly for production at the expected rate of USD 2.75 per 100 cubic meters.

Raw Material for Water Electrolysis Option

Energy and water are the fundamental raw materials required under the water electrolysis option. It is estimated that electricity of 5,080 kWh per metric ton is required per year under the water electrolysis method. The tariff rate per kWh of energy is calculated at USD 0.07 based on the industrial tariff rate in Nepal. Additionally, 80,000 units of 100 cubic meter of raw water are required yearly for the plant at the rate of USD 2.75 per 100 Cubic Meter.

Sales price of urea

The cost-plus pricing method is used to compute the sales price of urea under both options. Cost-plus pricing, also called markup pricing, is a method for determining the cost of a product to a company. It is the sum of fixed and variable operating costs, adding a percentage on top of that price to determine the sales price set for the consumer. The fair sales price for urea is set at a 16 percent markup above the cost of production for both the natural gas and electrolysis method for the project to be self-sustaining while also removing the need for government fertilizer subsidies. Based on this, the sales price of urea is taken at USD 324 per metric ton for the natural gas method and USD 761 per metric ton for the water electrolysis method. The sales price of urea under the water electrolysis option is 2.35 times the sales price of the natural gas option, which does not seem feasible.

The annual demand for chemical fertilizers in Nepal was 700,000-800,000 metric tons in 2011/12 (Source: Nepal Economic, Agriculture and Trade Activity (NEAT)). This demand has gradually increased over the years. However, no research has been conducted to determine the actual demand of chemical fertilizers in the recent years. In Nepal, urea is currently imported, and the AICL & STC procure and distribute it to farmers at a fixed price that is lower than the price at which urea is imported. The government pays AICL a subsidy for the difference. The plant's overall urea production capacity is 2,125 metric tons per day. It is assumed that 100 percent of the urea generated will be purchased by government agencies and consumed in the local market.

Levelized Cost

The levelized cost of the fertilizer manufacturing asset can be thought of as the average total cost of building and operating the asset per unit of urea fertilizer produced over an assumed lifetime. The levelized cost is related to the concept of assessing a project's net present value. It is a measure of the average net present cost of fertilizer production for a manufacturing plant over its lifetime. The levelized cost per unit of urea production under both options is calculated to assess and compare the two methods of urea production. The levelized cost per metric ton of urea is calculated at USD 363 and USD 694 under natural gas and water electrolysis respectively. The levelized cost per metric ton of urea production through the water electrolysis process is 1.91 times higher than through the natural gas technique.

Viability Gap Funding

The equity IRR of the fertilizer plant under natural gas option is computed at 7.06 percent which is less than the cost of capital of the project. Hence, there is a need for viability gap funding (VGF) to make the project attractive and viable to the private sector. It is estimated that no VGF is required for the electrolysis option since the sales price is very high due to the higher cost of production. A VGF amounting to 30 percent of the project's capital cost results in an equity IRR of 15.36 percent and would be viable to attract private investors in the natural gas technique.

ALTERNATIVE CASE STUDIES

I. Natural Gas technique

- Based on the assumption that the natural gas pipeline cost will be borne by Nepal Oil Corporation (NOC), the total project construction cost is calculated at USD 714 million, and the cost of production is computed at USD 204 per metric ton.

- If the pipeline cost is included, the project seems to be financially viable at a sales price of USD 392 per metric ton without the need for viability gap funding.

- If the pipeline cost is excluded, the project seems to be financially viable at a sales price of USD 312 per metric without the need for viability gap funding.

II. Water Electrolysis technique

- Based on the assumption that power will be available to the fertilizer plant at a subsidized rate of NPR 3 per kWh, the cost of production is computed at USD 436 per metric ton. The project seems to be financially viable at a sales price of USD 507 per metric ton without the need of viability gap funding.

- Based on the assumption that power will be made available to the fertilizer plant at free of cost, the cost of production is computed at USD 308 per MT. The sales price of the Urea after adding 16% mark up on cost of production is calculated at USD 358 per MT. At this sales price, the equity IRR is computed to be 12.5% and seems to be feasible without the need of viability gap funding. The payback period is calculated at 11.30 years.

ECONOMIC ANALYSIS

The Nepalese economy is mostly dependent on agriculture, with agriculture accounting for roughly one-third of the country's gross domestic product (GDP). Agriculture is the primary source of income for around two-thirds of the country's population. The demand for agrochemicals has been steadily increasing as agriculture has become more commercialized in recent years. Chemical fertilizers are the most significant agricultural input, however, fertilizers are frequently unavailable. Even if fertilizers are available, the quantity supplied is not enough. This seriously impacts agriculture yield.

In Nepal, the supply of fertilizers continues to fall far short of demand. The state-owned AICL and the public corporation STC, the two government bodies responsible for the import and distribution of chemical fertilizers are unable to supply and distribute fertilizer in a timely, reliable, and commercial manner. Another noticeable hindrance is that a huge amount of chemical fertilizer is being imported from India through illegal means, since there is a huge gap between the prices of chemical fertilizers between the two countries. Much of these fertilizers imported through illegal means are adulterated.

According to Nepal Rastra bank, Nepal's foreign exchange reserves fell to USD 11.42 billion from USD 11.75 billion in the first month of the new fiscal year 2021/22, while imports increased by 75.7 percent to NPR 150.73 billion (USD 1.26 billion). Similarly, the Department of Customs reported that imports increased by 75.86 percent to NPR 314.51 billion (USD 2.64 billion) in the second month of the current fiscal year 2021/22. Further, in the fiscal year 2020/21, Nepal increased its agricultural commodities import bill by 30 percent year on year, bringing it to a whopping NPR 325 billion. Previously, Nepal's agricultural imports in fiscal year 2019/20 were estimated to be worth around NPR 250 billion. While overall imports surged by 28.66 percent to NPR 1.53 trillion in the fiscal year 2020-21, the import of agricultural goods increased by more than 30 percent, bringing agro products' portion of the total import bill to 21 percent. Following edible oil, cereal imports climbed by NPR 22.71 billion in a year, surpassing the NPR 79 billion in fiscal year 2020/21. Maize and wheat imports totaled NPR 16 billion and NPR 12 billion in 2020/21 respectively, which is a significant amount for a small economy. Imports increased to NPR 1.53 trillion, but exports stayed at NPR 141 billion. In 2009-10, the cost for agricultural commodities imports was NPR 44.43 billion. In the last ten years, it has increased by roughly eightfold. Over the course of a year, the trade imbalance increased by 27.26 percent. The worrying depletion of the country's foreign exchange reserves due to excessive imports and minimal exports have clearly necessitated the implementation of efficient measures to cut imports. It seems crucial that the government's import-driven strategy needs to be replaced with a production-driven program.

> "The present value of subsidies on the import of urea over the project term of 27 years is computed at USD 2,625 million whereas the VGF at 30% of the project cost amounts to USD 355 million.

Built Vs Buy

According to the Customs Department's records, a total of 274,202 metric tons of urea was imported into Nepal in 2077/78, totaling NPR 13.09 billion. The import price per unit of Urea is calculated at USD 401, ignoring additional costs such as shipping, handling charges, dealer profit, and so on. The imported urea is subsequently sold to consumers at a minimum price of USD 115 per metric ton. As a result, the government suffers a significant subsidy cost of USD 287 per metric ton during fertilizer sales. The value of imported goods and the government's subsidy outflow have both increased in recent years. Despite the fact that the government has a large outflow of subsidies every year, chemical fertilizer related issues such as inadequacy, poor availability, quality, and so on have not changed significantly over time. The establishment of a chemical fertilizer facility in Nepal will be critical in removing the present barriers that farmers face.

The cost of producing urea under water electrolysis method is higher than the cost of producing urea by natural gas method. Whereas it is evident that the cost of producing urea fertilizer by natural gas method is cheaper than the cost of importing it. The cost of producing urea fertilizer is predicted to be further reduced by a viability gap funding of 30 percent in the natural gas method. Similarly, unlike annual subsidy payments, viability gap financing is a one-time expenditure that the government is required to cover during the project's construction phase as a proportion of the total cost. Further, the cost of the VGF is significantly lower for the government than the cost of subsidies. The present value of subsidies on the import of urea over the project term of 27 years is computed at USD 2,625 million whereas the VGF at 30% of the project cost amounts to USD 355 million.

In comparison to the subsidized sales price from import, the sales price of urea produced by fertilizer plants is higher. However, the production of chemical fertilizers in house will be critical in overcoming the country's present fertilizer system challenges. Given the additional financial and economic benefits that fertilizer manufacturing in the country would offer in the coming years, the sales price of the urea produced under natural gas is assessed to be competitive and marketable to consumers. However, the availability and transport of gas to the project site in the natural gas method poses a huge challenge due to lack of pipeline infrastructures, and the difficulties in importing natural gas from Western countries to Nepal.

The sales price of urea produced through water electrolysis is high and poses marketability risks to the fertilizer produced.

SOCIO-ENVIRONMENTAL IMPACT ANALYSIS

Chemical fertilizer industries may cause several environmental and social impacts. Emissions from urea prilling towers, wastewater generated from the urea plant, solid wastes including hazardous wastes, public opposition due to various factors such as air pollution and the smell from ammonia, are some of the concerns that need to be mitigated. These impacts would, however, be studied in detail in the Initial Environmental Examination (IEE) phase, as mandated by Environmental Protection Rules 2020. While conducting due diligence for site selection, environmental and social factors also need to be considered. These would include avoiding or keeping a safe distance from environmentally sensitive areas and dense vegetation, studying the impact of potential hazards from landslides, flooding, and proximity to water resources, etc. The site should consider resettlement issues so that the land acquisition process is easier. Ideally, the plant should be situated far away from major settlements to avoid any potential social issues in the locality.

"The site should consider resettlement issues so that the land acquisition process is easier.

In terms of water consumption for urea fertilizer production, the water electrolysis process is more water intensive (cumulatively consuming approx. 21,906 liters of water for 1 metric ton of hydrogen, 1 metric ton of ammonia, and 1 metric ton of urea) than natural gas process (consuming approx. 9,280 liters of water for 1 metric ton of urea). While comparing the Green House Gas emissions, water electrolysis produces considerably less carbon dioxide emissions when producing ammonia (approximately 0.38 t CO2 eq. per ton of ammonia) than through natural gas using Haber Bosch process (approximately 1.5 t CO2 eq. per ton of ammonia). Although mitigation projects funded through international climate financing such as the Green Climate Fund and Global Environmental Facility do not address green hydrogen projects currently, there is huge potential for such projects to be considered in climate financing instruments in the future. In addition, green hydrogen projects may also generate revenues from clean development mechanisms through the sale of emission credits, provided the international carbon price becomes attractive.

FINDINGS & CONCLUSION

This study has concluded that the production of urea with natural gas technology and water electrolysis are subjected to various conditions based on the nature of the plant. There is a natural gas pipeline planned by NOC, from Bhairahawa (Lumbini Province, Nepal) to Gorakhpur (Uttar Pradesh, India) covering 129 kilometers. It is difficult for NOC to make a clear choice in constructing the pipeline since the quantity and scale of businesses such as steel, urea, and ammonia are not able to guarantee natural gas demand. In the case of adopting natural gas technology, NOC stated that continuity for natural gas flow seems more reliable from the Jhapa section of Province No.1 by tapping into the Eastern India (i.e., Patna [Bihar]-West Bengal-Guwahati [Assam]) section.

Considering various factors such as the availability of water sources, electric sub-stations, and access roads, the establishment of a chemical fertilizer plant in Dhalkebar of Province No. 2 seems most appropriate. This shall require a natural gas pipeline to be constructed from India to Amlekhgunj (Bara district) to Dhalkebar (Dhanusha) section. The pipeline distance from Amlekhgunj to Dhalkebar rounds up to around 108 kilometers. This shall require government-to-government (G2G) cooperation on the development of the infrastructure. The pre-existing constraints to establish a natural gas based chemical fertilizer plant are:

- The tentative cost for developing a natural gas pipeline is around USD 4.75 million per kilometer and requires significant financial and technical resources. It needs to be constructed before establishing the chemical fertilizer plant.
- The location of the project site and access point for the gas pipeline to the project site should also be carefully considered. Similarly, the route, construction, and operation of the pipeline remains a crucial factor which needs to be scrutinized further.
- A regular supply of natural gas requires GoN to sign a long-term tripartite agreement with the sourcing country and connecting country (India) on a long term basis.

" The manufacturing of urea using water electrolysis is not technically and commercially feasible at present because the carbon capture technology is still in an early phase.

The production of hydrogen using water electrolysis is gradually becoming technically and commercially viable in the global scenario. The cost of green hydrogen production using water electrolysis is also predicted to reduce drastically by 2030. However, the manufacturing of urea using water electrolysis is not technically and commercially feasible at present because the carbon capture technology is still in an early phase. However, ammonia-based fertilizers other than urea can be produced using green hydrogen. In addition, hydrogen (gas/liquid) can be exported to neighboring countries. In the meantime, hydrogen fuel can be used as an alternative to power fuel-cell vehicles. There is a need to conduct a separate comprehensive study to explore the possibility of hydrogen fuel in Nepal.

There is no doubt that green hydrogen produced through water electrolysis is a growing future technology to adopt climate friendly practices and utilize resources sustainably. However, adopting a pre-matured technology for urea production at present should be a subject for deeper analysis and wider discussion with stakeholders. On the other hand, possibilities exist for the production of ammonia-based fertilizers (through water electrolysis) which can later serve as the raw material for urea production as carbon capture technologies mature.

Nepal is expected to be in a state of hydro-electric surplus within a few years after the completion of some mega hydropower projects. In this context, there is an ongoing discussion in Nepal on maximizing the utilization of electricity within the domestic market to reduce fossil fuel imports and minimize the trade deficit. The proposed project via water electrolysis will be financially sound if the existing power tariff rate is subsidized. There are a few limitations related to urea production through water electrolysis method which are as follows:

- Carbon capture technology is still under research and development with recorded evidence of a mere 5 percent CO2 capture out of the total CO2 emitted in case of a direct separation process, whereas in a chemical absorption process, there are claims that more that 5 percent CO2 has been captured.
- As electricity price substantially impacts financial viability, the existing rate of NPR 8.16 per Kilowatt Hour (kWh) is not financially feasible and needs to be revised at a subsidized rate of around NPR 3.00 per kWh.
- Chemical fertilizer plants based on water electrolysis technology are energy intensive and requires around 10,800 MWh of electricity per day (around 450 MW per day) of dedicated and uninterrupted energy supply.

The development modality for the establishment of a chemical fertilizer plant would be a public private partnership (PPP) as it is directly related to the nation's food security and the construction of the plant requires national resources and decision interventions. However, determining the type of PPP contract would need further deliberation in the coming days. The government might need to allocate fiscal incentives, viability gap funding, and other incentives as needed.

Concluding Note

The following summary drawn from overall deliberation and comparative analysis made in the previous chapters can be the basis for considering pathways to develop chemical fertilizer plant in Nepal.

Chemical Fertilizers using Natural Gas as the Primary Feedstock

While the technology behind harnessing natural gas as feedstock to produce urea is commercially available in the international market and is comparatively cheaper in terms of capital expenditure and cost of production, natural gas is not available in Nepal. This feedstock must be arranged from international markets, for Nepal's case – India, and must be brought into the country through a cross-border pipeline. This can only be done through the private sector when policy infrastructure between the two countries on the import of natural gas through a cross border pipeline is in place. Natural gas, in the international market, is not only considered a feedstock for chemical fertilizers but it is also a source of energy and is considered as strategic commodity. The price of basic energy resources is generally more volatile than the price of other commodities. Two aspects – a dependency on the international market for the import of feedstock (natural gas) and its volatile price – will always pose a threat to the sustainability of a chemical fertilizer plant that uses natural gas as feedstock.

Chemical Fertilizers using Water as the Primary Feedstock (Electrolysis)

While the technology of using water as feedstock to produce hydrogen and subsequently ammonia is commercially available in the international market (though at a relatively higher cost to capital and production, because of electricity prices), the technology of converting ammonia through a carbon capture and storage process to produce urea is still in the development stage and is not commercially available. Given the gradual increase in electricity production within the country, electrolysis technology could be adopted to at least produce ammonia based chemical fertilizers other than urea. There is the possibility of expanding such fertilizer plants to produce urea in the future, once the technology related to carbon capture and storage is fully developed and commercially available. This approach, though relatively costly, will completely avoid dependency on natural gas to produce fertilizers.

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