Producing Urea From Lake Kivu Methane

A Preliminary Assessment of Feasibility

IFDC

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List of Acronyms

BFPL	Burrup Fertilisers Pty Ltd
Btu	British Thermal Unit
CO_2	Carbon Dioxide
DAP	Diammonium Phosphate
EPC	Engineering, Procurement, and Construction
FEED	Front-End Engineering and Design
FOB	Free on Board
GJ	Gigajoule
ha	Hectare
HHV	Higher Heating Value
IRR	Internal Rate of Return
KBR	Kellogg Brown & Root
km	Kilometer
kWh	Kilowatt Hour
LCA	Leading Concept Ammonia
m	Thousand(s)
mm	Million(s)
MM Btu	Million Btu
mt	Metric Tons
mtpd	Metric Tons Per Day
mtpy	Metric Tons Per Year
MW	Megawatt
Nm^3	Normal Cubic Meter
REC	Regional Economic Community
scf	Standard Cubic Feet
SEC	Stokes Engineering Company
UNIDO	United Nations Industrial Development Organization

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Summary and Conclusions

Lake Kivu water contains a large quantity of dissolved gases—mostly carbon dioxide (CO_2) and methane (CH_4)—that increase in concentration with the lake's depth. If dislodged by an earthquake or other unforeseen event, the gases could prove to be hazardous. It is generally accepted that Lake Kivu's gas should be drawn down to reduce the danger that currently exists to the people living nearby. A drawdown is about to begin on a pilot scale, and the recovered gas will generate 4.5 Megawatts (MW) of electricity, while a second unit of 3.6 MW is expected in mid-2009. This electricity production may quickly ramp up to 150 MW or more. There are also advanced plans to convert gas to liquid for production of fuel.

A possible next step can then be to produce urea from the methane component of the lake's gas. Urea is the primary nitrogen fertilizer used globally. A new ammonia/urea plant close to the lake would be well located to supply urea to the agricultural sector of Rwanda as well as to the surrounding countries, none of which produce urea. This present study considers the possibility of setting up a facility close to Lake Kivu to produce ammonia from the gas and then urea from the ammonia and carbon dioxide. Mr. Jorge R. Polo, Senior Technical Specialist of the Research Development Division, was appointed to undertake the study with the assistance of Mr. Keith J. Stokes, President of Stokes Engineering Company (SEC).

In preparing this study, IFDC met with representatives from the Ministry of Infrastructure, the Ministry of State, the Rwanda Energy Company, the Fair Construction Company, and the Rwanda Investment and Export Promotion Agency and visited Lake Kivu at Gisenyi. The study's preliminary conclusions are:

- Lake Kivu has enough extractable methane for an ammonia plant and the proposed power generation units.
- Kivu gas is technically suitable for producing ammonia/urea.

- The gas-extraction technology that has been piloted so far appears to be capable of eventually supplying gas reliably in the required quantities.
- The gas-extraction technology should evolve and improve over the coming months.
- A market for urea barely exists in Rwanda at present. Developing the market to rapidly absorb the new plant's urea production will be necessary.
- This study shows that, if a sustainable market can be developed within Rwanda and surrounding countries for the plant's urea production, then, the construction and operation of the plant can be a successful and economically sound investment. Under such circumstances and at 2008's high urea prices, investing in a 1,000-mtpd granular urea plant near Lake Kivu would provide an excellent internal rate of return (IRR) on the total, unleveraged investment. At 2007's urea prices, which were about half the prices in 2008, the IRR for the 1,000-mtpd plant would be much lower but still acceptable.
- Investing in a 776-mtpd urea plant would provide a lower but still acceptable IRR to total, unleveraged investment, and will require access to a smaller-size market to reach optimum (least cost) production capacity utilization. However, investing in a 380-mtpd unit would have an unacceptable IRR on investment.
- Plants that produce 1,000 mtpd of urea, and the associated 600 mtpd of ammonia, exist and can be built in Rwanda. A 776-mtpd urea/450-mtpd ammonia facility could also be built in Rwanda, but smaller plant sizes are questionable.

The preliminary assessment of market potential and economic feasibility indicates that investing in the 776-mtpd unit may be viewed as a less risky and more attractive investment given the challenges that must be confronted to rapidly achieve market growth, the size of the investments, and construction difficulties. However, before such a decision is made, a more in-depth assessment of market potential and a comprehensive prefeasibility study should be conducted. The feasibility and economic success of this investment depends essentially on the rapid transformation of a potential urea market into an effective sustainable market for the urea to be produced by the plant. A more comprehensive prefeasibility study should address these issues and the interventions/policies that development agencies and governments should take to achieve rapid sustainable growth in the market for the plant's urea. This study should also include sensitivity analyses of financial/economic feasibility to alternative scenarios of effective market size and urea comparable prices.

The preliminary results shown here are very encouraging and clearly indicate that concerted efforts by governments, development agencies, and donors to facilitate the implementation of such investment are highly desirable. The synergies and beneficial spillovers that result from a successful investment in this plant and facilities will contribute substantially to the economic development and welfare of the countries and population in the region. In this regard, it is important to note that estimates of financial/economic feasibility presented here include only direct returns to investment and do not account for the substantial benefits that such an investment will bring to farmers, consumers, and the economies of Rwanda and other countries in the region. The large magnitude of such benefits should easily justify and energize interventions and support from governments, development agencies, donors, and financial institutions to facilitate the implementation of this investment.

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Introduction

According to information provided by the Ministry of Infrastructure, Lake Kivu contains 50–55 billion normal cubic meters of methane in a raw gas mixture consisting of approximately 25% methane, 73.5% carbon dioxide, 1.5% inert gases, and traces of hydrogen sulfide. The Government of Rwanda is considering using some of the methane to produce urea. Since Rwanda is landlocked and its road systems are not well developed, Rwanda's farm-gate fertilizer prices are much higher than world prices. The situation was made worse in 2008 by a spike in world prices. A similar situation is encountered in Burundi, the Democratic Republic of Congo, Uganda, and Tanzania, which are relatively close to Lake Kivu and can take advantage of lower transport costs. Thus, a urea fertilizer production unit based on Lake Kivu gas, which would have a market price lower than imports, could also provide fertilizer for these countries.

Scope

The Government of Rwanda asked IFDC to study the feasibility, on a preliminary basis, of producing urea from Lake Kivu gas and examine the impacts of several variables, including scale of operation, fixed capital investment, cost of gas, and capacity utilization on production costs. The study also considers the main environmental issues associated with constructing and operating a urea/ammonia complex and scenarios of a potential market.

Safety

The risk of a severe gas eruption in Lake Kivu is an urgent safety issue that, on its own merit, would justify removing methane from the lake. As recently as 2002, a volcanic eruption poured molten lava into the lake, which could have destabilized the lake. The lives of more than a million lake-side Rwandans and Congolese are at risk.

A few years ago, Cameroon's Lake Nyos erupted, sending carbon dioxide clouds to several cities and killing thousands of people. If a similar situation occurs at Lake Kivu, the clouds of gas might not only asphyxiate people but could also cause methane explosions. Therefore, removing the gas from Lake Kivu is important. Although this could be done by venting the gas, producing urea and electricity would benefit agriculture in Rwanda and generate export revenues.

The safety of the personnel who will operate the plant should receive special consideration because they will be exposed to the danger of a gas eruption. Safety measures should be determined and will probably include:

- Gas detectors strategically located around the lake.
- An emergency shutdown system.
- An earthquake detector/alarm in the control room.
- Sirens triggered by the detectors.
- Oxygen masks issued to all personnel.
- Oxygen refueling stations for the masks.
- Escape routes clearly sign-posted.

Environmental Issues

The plant should include proper environmental measures to prevent polluting the lake water or damaging the environment. These measures should include a sewage treatment unit and urea process condensate hydrolyzer. The urea plant's pressure safety valves should exhaust to a header system and flare stack. In general, the facility should comply with international standards for protecting the environment.

Lake Kivu's carbon dioxide (estimated to be 73.5%) and methane (25%) are greenhouse gases. Methane is 20 times more potent than carbon dioxide. Removing methane from the lake for its energy value should help to avert a natural release of greater proportions.

It is expected that approximately 35% of the total methane used in the ammonia/urea factory will be burned as fuel and will discharge carbon dioxide into the atmosphere. A modern ammonia plant uses about 32,000 scf of methane per metric ton of ammonia; therefore, the emission will be roughly 11,200 scf (0.59 mt) of carbon dioxide per metric ton of ammonia produced. This figure does not include the carbon dioxide that will be extracted from the lake along with the methane, which will be roughly 90,000 scf of carbon dioxide per metric ton of ammonia.

Technology for Producing Ammonia and Urea

The production of urea requires the production of ammonia and carbon dioxide, which happens in the same ammonia production plant. Figure 1, which has been reproduced from the "Fertilizer Manual" prepared by UNIDO and IFDC, shows a simplified flow sheet for a typical ammonia production facility. In the ammonia plant, natural gas (the methane gas in the case of Lake Kivu) is first catalytically reformed with steam in a primary reformer and subsequently with air in a secondary reformer. As a result, the hydrocarbons are broken down into hydrogen, carbon monoxide, carbon dioxide, some unreacted methane, nitrogen, and argon (which are present in the air and do not react in the process). The carbon monoxide present in the process gas is then converted to carbon dioxide in a two-step catalytic reactor.

The process gas mixture then consists of hydrogen, nitrogen, carbon dioxide, and small quantities of unreacted carbon monoxide, methane, and argon. The carbon dioxide is then removed in a carbon dioxide removal unit. The remaining traces of carbon dioxide and carbon monoxide are subsequently converted into methane in a catalytic reactor. The gas stream now consists of hydrogen, nitrogen in the ratio of 3 to 1 with small quantities of methane and argon.

The process gas is then converted into ammonia at a higher pressure, and the small quantities of methane and argon are purged from the process and burned as fuel in the primary reformer. The ammonia is liquefied and introduced into the urea plant. Figures 2, 3, and 4 show three typical processes for producing urea. These figures have also been taken from the "Fertilizer Manual" prepared by UNIDO and IFDC.

The raw materials for the urea plant are ammonia and carbon dioxide, so the carbon dioxide removed from the process gas in the ammonia unit is used in the urea plant as feedstock. This carbon dioxide is compressed to a pressure of around 150 bars. The liquid ammonia from the ammonia plant is pumped to a similar pressure.

These raw materials are both introduced into the high-pressure section of the urea plant. The ammonia and carbon dioxide are partially converted to urea and water. The unconverted components are then separated from the urea solution, first at high pressure and then at much lower pressure. The unconverted components (ammonia and carbon dioxide) are recycled back to the reactor. The urea solution is then concentrated to 96%–97% in the evaporation section. The water with some small quantities of ammonia and carbon dioxide is treated in the wastewater treatment section of the urea plant and after treatment can be used as boiler feed water in the steam generation system.

The 96%–97% urea solution is transferred to the granulation unit where small quantities of urea formaldehyde are added and the liquid product is converted into a solid product by a granulation process. The final urea product is transferred to the bulk storage for further handling.

Gas

A 4.5 MW Kivu gas project is expected to begin generating electricity very soon. A floating 1.6-km pipeline transports the gas at about two bars pressure from the offshore rig to the onshore power generation modules. Plans are in place to build an electricity production unit with 150–250 MW of generating capacity. The manufacturing cost of electricity is currently expected to be US $.05/kWh, but the cost should come down as the scale of operations increases. For the calculations made in this study, a gas price of US $2.00/MM Btu was used based on preliminary information provided by the Ministry of Infrastructure. However, US $4.00/MM Btu and US $5.00/MM Btu values were also used for comparison purposes.

The calculations used in this report consider that the ammonia/urea facility will co-generate the electricity needed for its operation. However, no further electricity production was considered in the analysis.

Pending a full gas analysis per standard industry practice, the gas composition appears to be normal and, therefore, the gas is suitable for reforming in the ammonia plant's primary reformer.

The pilot work in progress at Lake Kivu indicates that the water-scrubbed gas will be approximately 60% methane, 37% carbon dioxide, 3.0% inert gases, and will contain a trace of hydrogen sulfide. The landed gas pressure is expected to be in the order of 2 to 4 bars. An ammonia plant requires a pressure of about 42 bars, so a compressor will be necessary to boost the pressure. Also, an absorption column will reduce the carbon dioxide to about 2% (the design basis should be finalized later). The absorber, regenerator system will circulate a physical solvent, such as Selexol. A portion of the carbon dioxide might be recovered under pressure (to save energy) and supplied to the urea plant. Preliminary estimates indicate that the compression and absorption system would use less than 1.0 MM Btu/mt of ammonia.

It is expected that unplanned gas supply interruptions will not generate any technical problems in the ammonia/urea plant. The reliability of the gas extraction process has yet to be demonstrated, but the pilot unit that has been set up for electricity generation indicates that the system will work.

Several other lakes in the region have carbon dioxide in them. Kivu is the only one to have both methane and carbon dioxide.

Gas Availability

According to information provided by the Ministry of Infrastructure, the lake has sufficient gas for power generation and ammonia/urea production as shown below. The gas left over might be sufficient for a gas-to-liquids plant, but this researchable subject is not part of this evaluation. Also, it is important to note that Lake Kivu is constantly being replenished with additional gas (not included below).

<u>Supply (Existing)</u>:

Total methane in the lake	50–55 billion Nm^3
Extractable methane	40 billion Nm^3
Less Congo's 50% share	-20 billion Nm^3
Gas available on Rwanda's side	20 billion Nm^3, or 760 billion scf

<u>Demand (Over 20 Years)</u>:

Ammonia/urea, 1,000 mtpd urea: 1,000 x 330 x 20 x 22,000 = 145 billion scf

Power generation:

REC	50 MW	(50 x 3,414/0.45) x 24 x 330 x 20 =	60 billion scf
Contour Global	100 MW		200 billion scf
Other	100 MW		<u>200 billion scf</u>
Total			605 billion scf

Site

The lake-shore has numerous potential plant sites. The site should be large enough to accommodate the facilities to be built onsite, which should include:

- Ammonia plant.
- Ammonia storage (10 days).
- Urea solution plant.
- Urea granulation unit.
- Urea bagging unit.
- Power generation unit.

- Sewage treatment unit.
- Urea warehouse (bulk product, 20 days; bagged 10 days).
- Maintenance shop.
- Control room and offices.
- Lay-down area for storing materials during construction.
- Residential area for operators as required.
- Vehicle parking.
- Loading and unloading areas.

The site should include land for future construction and be protected against expansion of the local community housing. It is expected that the size of the site should be about 10 ha. Since the gas and cooling water will come from the lake, the plant should be located as close as possible to the lake.

Plant Size

Export-based urea plants being built today are typically 3,500 mtpd capacity. A 1,000-mtpd plant is considered small. Plants smaller than 1,000 mtpd are not commonly being built, but would be considered micro-size.

Setting urea market-size considerations aside, the best plant-size combination for Rwanda is 600 mtpd ammonia/1,000 mtpd urea because:

- 600 mtpd plant designs use centrifugal compressors, which are the universal industry standard. Smaller plant sizes do not use conventional centrifugal compressors.
- The top ammonia plant designers (KBR, Uhde, Topsoe, and a Linde/Casale combination) have all designed 600-mtpd designs in the last 10 years. This fact is crucial in today's over-heated engineering and construction environment, because Engineering, Procurement, and Construction (EPC) contractors do not want to take on new design projects. They would much rather replicate an existing project. Typically, the front-end engineering and design

(FEED) cost of a duplicate ammonia project is US $3 million. By comparison, the FEED cost of a new ammonia plant size might be US $12 million.

- Stamicarbon, Snamprogetti, and Toyo can supply the 1,000-mtpd urea granulation plant design.

If the market dictates a small-plant size, the ammonia plant options are limited to:

- Johnson Matthey's 450-mtpd leading concept ammonia (LCA) design. Currently, Stokes Engineering is helping Dyno Nobel (now owned by Incitec Pivot Ltd.) install an LCA plant in Moranbah, Queensland. The LCA design does not recover carbon dioxide. Instead, it removes a mixture of carbon dioxide, carbon monoxide, and methane by pressure swing adsorption. However, the Lake Kivu gas can supply the carbon dioxide needed for urea manufacture. Combining 450 mtpd ammonia with 627 mtpd of Lake Kivu carbon dioxide would produce 776 mtpd urea. The existence of a recently built 776 mtpd urea is not known at this time. Small plants are inherently less energy efficient than larger plants—at least 1.0 MM Btu/mt.
- Linde designed a 220-mtpd ammonia plant that is operating in Moura, Queensland. The plant also uses pressure swing adsorption and, therefore, would need carbon dioxide from Lake Kivu.

Stamicarbon, Snamprogetti, and Toyo could design the granular urea plant but they have not designed a small plant recently. Casale, which specializes in urea plant revamps, might be able to offer a design.

Cost Estimation

The prices of ammonia and urea plants in U.S. dollars rose steeply in the last few years**.** Most gas-based new urea capacity is being built in the Middle East. Two projects currently under construction in Saudi Arabia and Algeria involve 2,000 mtpd ammonia/3,500 mtpd urea plants, and the industry expects them to cost about US $1.2 billion. Using these Middle Eastern projects as a basis and an Australian project as a cross-check (a contractor recently quoted

US $720 million to build a duplicate of BFPL's 2,200-mtpd standalone ammonia plant in northwest Australia), we have estimated the investment costs of the three urea plant sizes in Rwanda: 1,000 mtpd, 776 mtpd, and 380 mtpd. The report assumes that, in a balanced (when all the ammonia goes to make urea) ammonia/urea complex, the urea plant would cost about 70% of the ammonia plant. Northwest Australia was an expensive construction site when the US $720 million estimate was made, but Rwanda seems likely to be expensive also because of its distance from the east coast and its lack of any previous oil, gas, or chemical work.

In performing a feasibility study, such as this one for the production of fertilizers using the methane gas from Lake Kivu, it is necessary that the costs estimated in the analysis are properly calculated. In performing this activity, the standards set by the "Manual for the Preparation of Industrial Feasibility Studies" published by the International Centre for Industrial Studies of the United Nations Industrial Development Organization (UNIDO) were followed as indicated in the next sections of this report.

In the preparation of investment costs, the following items were considered and included, as recommended in the UNIDO document listed above:

- Land and site preparation and development.
- Plant machinery and equipment:
    - For fertilizer production.
    - For facilities to produce electricity and other services.
    - Auxiliary equipment as needed.
    - Spare parts, wear and tear parts, and tools.
    - Needed vehicles.
- Buildings and civil works, including site preparation and outdoor works.
- Construction of production facilities.
- Pre-production and capital expenditures:
    - Preliminary and capital issue.
    - Pre-production.
    - Trial runs, startup, and commissioning.
- Working capital.

Evolution of investment expenditures (cash flow).

In the calculations of manufacturing costs, the following items were considered and included, as also recommended in the UNIDO document.

Variable costs:

- Natural gas used.
- Catalysts, chemicals, and supplies.
- Formaldehyde.
- Boiler feed water for steam.
- Make up cooling water.
- Bags.
- Bagging labor.

Fixed costs:

- Operating labor and supervision.
- Administrative expenses and overhead.
- Cost of maintenance.
- Insurance.
- Fixed capital recovery.
- Interest on working capital, based on the following working capital items:
  - 20 days of bulk product in storage.
  - 10 days of bagged product in storage.
  - Cash on hand (based on 45 days of conversion cost).
  - Spare parts on hand.

For each of the cases, the production cost was determined by first prorating the investment cost and then calculating the manufacturing cost for ammonia and urea.

Investment Cost Estimate

The investment costs for the Rwandan plants were prorated from the US $1.2 billion mentioned above by using a capacity ratio to a 0.65 exponent. These calculations gave investment costs as shown below. A breakdown of the expected investment cost for the

600-mtpd ammonia facility is shown in Table 1a and for the 1,000-mtpd urea facility in Table 1b. The current financial crisis, developing recession, strengthening U.S. dollar, and falling steel prices could cause these costs to fall. A summary of the investment costs follows:

Total Investment for Fertilizer Units				
Ammonia		Urea		Ammonia and Urea
Capacity	Fixed Investment	Capacity	Fixed Investment	Total Fixed Investment
(mtpd)	(millions US $)	(mtpd)	(millions US $)	(millions US $)
600	290	1,000	200	490
450	240	776	160	400
220	150	380	96	246

Manufacturing Cost Estimate

The calculation of the manufacturing cost for the ammonia/urea complex for the 1,000 mtpd of urea production is shown in Table 2a. In performing these calculations, the following assumptions were made:

Price of natural gas	US $2/MM Btu
Natural gas used in ammonia plant as electricity or steam	US $36.23/mt of urea
Natural gas used in urea plant as electricity or steam	US $2.00/mt of urea
Catalysts, chemicals, and supplies	US $5.5/mt of urea
Boiler feed water	US $0.6/mt of urea
Cost of bags	US $10.0/mt of urea
Bagging labor	US $3.0/mt of urea
Operating labor and supervision	US $800,000/year
Administrating expenses and overhead	100% of labor and supervision
Maintenance	1.38% of direct plant cost
Insurance	2.00% of direct plant cost
Fixed capital recovery	11.7% of fixed investment
Interest on working capital	8.0% annually
Interest on long-term investment	8.0% annually
Project life	15 years

Using these assumptions, the production or manufacturing cost for the ammonia and urea units that will make 1,000 mtpd of urea was determined to be US $278/mt when operating at 100% capacity, US $350/mt when operating at 75% capacity, and US $494/mt when operating at 50% capacity (Table 2b). The manufacturing cost accounts for all cost involved in transforming raw material (including raw materials cost) into a final product. Table 2c presents the conversion cost at different capacities where conversion cost represents only the cost of transforming raw materials into a final product. This cost excludes the cost of raw materials. The production cost calculations for the 776-mtpd and 380-mtpd units are shown in Tables 3a–c and Tables 4a–c, respectively. A summary of these values follows:

	Production Cost for the Three Unit Sizes		
	1,000-mtpd Unit	776-mtpd Unit	380-mtpd Unit
	(US $/mt)		
Operating at 100% capacity	278	290	354
Operating at 75% capacity	350	366	451
Operating at 50% capacity	494	519	645

Urea Production Cost in the Middle East:

Basis: 2,000 mtpd ammonia/3,500 mtpd urea; un-depreciated; gas US $1.5/MM Btu HHV; FOB as bulk granular material.

It is expected that the cost will be approximately US $216/mt of urea and comprise:

Cash costs	US $100
Capital	US $66
Interest @ 10%	US $50

Alternative Investment and Cost Scenarios

Calculations were made determining the production cost for a longer plant lifespan, for a higher capital investment, and for a greater number of operating days per year. For these alternatives, the following 1,000 mtpd production costs at 100% capacity were determined:

- For a 30-year project life, the production cost decreased from US $278.1/mt to US $235.7.
- For a 30-year project life but increasing the operating days per year to 346, the production cost decreased to US $227.6/mt.
- For a total investment of US $613 million, equivalent to a 25% increase, but retaining the 15 years project life, the production cost increased to US $330.6/mt.

Table 1a. Investment Cost Estimate
Ammonia Plant (Rwanda)—Capacity: 600 mtpd
Assuming New Plant at New Site

	Cost
	(US $'000)
Battery Limits Cost	
Process Equipment:	39,064
Delivery of Equipment[a]	9,766
Equipment Installation[b]	20,996
Piping and Ducts[c]	24,415
Instrumentation[d]	9,766
Insulation[e]	2,442
Electrical[f]	5,860
Process Structures and Building[g]	19,532
Battery Limits Cost	131,842
Other Physical Installations Cost	
Site Development and Offsite Facilities[h]	7,324
Utilities Installations[i]	19,531
Raw Materials Storage[j]	0
Bulk Product Storage[k]	4,883
Bagged Product Storage[l]	0
Administrative and Service Buildings[m]	4,883
Other Physical Installations Cost	36,621
Contingencies[n]	16,846
Total Direct Plant Cost (Installed Cost)	185,309
Engineering and Project Management[o]	27,634
Construction Overhead and Expenses[p]	18,775
Preoperational and Startup Expenses[q]	7,966
Subtotal	54,375
Total Plant Cost	239,684
Contractor's Fee[r]	11,000
Interest During Construction[s]	39,316
Subtotal	50,316
Total Fixed Investment	290,000

Notes:

a. 25% of process equipment cost.
b. 43% of delivered equipment cost.
c. 50% of delivered equipment cost.
d. 20% of delivered equipment cost.
e. 5% of delivered equipment cost.
f. 12% of delivered equipment cost.
g. 40% of delivered equipment cost.
h. 15% of delivered equipment cost.
i. 40% of delivered equipment cost.
j. 0% of delivered equipment cost.
k. 10% of delivered equipment cost.
l. 0% of delivered equipment cost.
m. 10% of delivered equipment cost.
n. 10% of battery limits plus other physical installations cost.
o. 17% of total direct plant cost.
p. 11% of total direct plant cost.
q. 7% of total direct plant cost.
r. 5% of total plant cost.
s. 15.7% of total plant cost plus contractor's fee.

Calculation of Interest During Construction		
		(US $'000)
Total Plant Cost		239,685
Contractor's Fee		11,000
Amount Financed		250,685
Annual Interest Rate	10%	
	Investment Schedule	Interest
First Year of Construction	30%	20,235
Second Year of Construction	40%	15,411
Third Year of Construction	30%	3,671
Total Interest Paid		39,316

Table 1b. Investment Cost Estimate

Urea Plant (Rwanda)—Capacity: 1,000 mtpd Urea
Assuming New Plant at New Site

	Cost
	(US $'000)
Battery Limits Cost	
Process Equipment:	29,504
Delivery of Equipment[a]	7,376
Equipment Installation[b]	15,859
Piping and Ducts[c]	18,441
Instrumentation[d]	7,376
Insulation[e]	1,845
Electrical[f]	4,425
Process Structures and Building[g]	14,752
Battery Limits Cost	99,577
Other Physical Installations Cost	
Site Development and Offsite Facilities[h]	5,532
Utilities Installations[i]	0
Raw Materials Storage[j]	0
Bulk Product Storage[k]	3,688
Bagged Product Storage[l]	3,688
Administrative and Service Buildings[m]	3,688
Other Physical Installations Cost	16,596
Contingencies[n]	11,618
Total Direct Plant Cost (Installed Cost)	127,791
Engineering and Project Management[o]	19,056
Construction Overhead and Expenses[p]	12,947
Preoperational and Startup Expenses[q]	5,494
Subtotal	37,497
Total Plant Cost	165,288
Contractor's Fee[r]	7,597
Interest During Construction[s]	27,115
Subtotal	34,712
Total Fixed Investment	200,000

Notes:

a. 25% of process equipment cost.
b. 43% of delivered equipment cost.
c. 50% of delivered equipment cost.
d. 20% of delivered equipment cost.
e. 5% of delivered equipment cost.
f. 12% of delivered equipment cost.
g. 40% of delivered equipment cost.
h. 15% of delivered equipment cost.
i. 0% of delivered equipment cost.
j. 0% of delivered equipment cost.
k. 10% of delivered equipment cost.
l. 10% of delivered equipment cost.
m. 10% of delivered equipment cost.
n. 10% of battery limits plus other physical installations cost.
o. 17% of total direct plant cost.
p. 11% of total direct plant cost.
q. 7% of total direct plant cost.
r. 5% of total plant cost.
s. 15.7% of total plant cost plus contractor's fee.

Calculation of Interest During Construction		
		(US $'000)
Total Plant Cost		165,286
Contractor's Fee		7,597
Amount Financed		172,883
Annual Interest Rate	10%	
	Investment Schedule	Interest
First Year of Construction	30%	13,955
Second Year of Construction	40%	10,628
Third Year of Construction	30%	2,531
Total Interest Paid		27,114

Table 2a. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 1,000 mtpd Urea
Assuming New Plant at New Site

Basis of Estimate		
Total Direct Plant Cost (US $'000)	313,101	
Total Fixed Investment (US $'000)	490,001	
Working Capital (US $'000)	22,096	
Daily Production Capacity (mt)	1,000	
Operating Days per Year	330	
Annual Production (mt)	330,000	
Manufacturing Cost Item		
	(US $'000/year)	(US $/mt product)
Variable Cost		
Natural Gas, at US $2.00 /MM Btu		
and 31.3 MM Btu/mt NH_3		
plus 1.0 MM Btu/mt Urea		
or US $1.90 /GJ		
and 33.0 GJ/mt NH_3	11,957	36.23
1.1 GJ/mt Urea	660	2.00
Catalysts, Chemicals, and Supplies	1,815	5.50
Formaldehyde	1,634	4.95
Conditioner (clay, oil, etc.)	0	0.00
Electricity	0	0.00
Boiler Feed Water for Steam	198	0.60
Fuel	0	0.00
Makeup Cooling Water	7	0.02
Diesel Fuel	0	0.00
Bags	3,300	10.00
Bagging Labor	990	3.00
Subtotal	20,561	62.30
Fixed Cost		
Operating Labor and Supervision	800	2.42
Administrating Expenses and Overhead	800	2.42
Maintenance	4,327	13.11
Insurance	6,262	18.98
Fixed Capital Recovery	57,247	173.48
Interest on Working Capital	1,768	5.36
Subtotal	71,204	215.77
Total Manufacturing Cost (at 100% Capacity Utilization)	91,765	278.07

Table 2a. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 1,000 mtpd Urea
Assuming New Plant at New Site
(Continued)

Assumptions Used in Cost Calculations		
Item	**Consumption**	**Unit Cost**
Catalysts, Chemicals, and Supplies	2.4 kg/mt	US $2.32/kg
Formaldehyde (37%)	11.0 kg/mt	US $0.45/kg
Conditioner (clay, etc.)	0.0 kg/mt	US $1.00/kg
Conditioning Vehicle (oil, etc.)	0.0 kg/mt	US $0.4/kg
Electricity (included in gas usage)	0 kWh/mt	US $0.05/kWh
Boiler Feed Water for Steam	0.3 mt/mt	US $2.00/mt
Fuel (included in gas indicated above)	0.0 GJ/mt	US $1.90/GJ
Makeup Cooling Water	0.17 mt/mt	US $0.1/mt
Diesel Fuel (for emergency generator)	0.2 kg/mt	US $0.25/kg
Bags	20.5 units/mt	US $0.49/unit
Item	**Calculating Procedure**	
Administrating Expenses and Overhead	100% of Labor and Supervision	
Maintenance	1.38% of Total Direct Plant Cost	
Insurance	2.0% of Total Direct Plant Cost	
Fixed Capital Recovery	11.7% of Total Fixed Investment	
Interest on Working Capital	8.0% annually	
Interest on Long-Term Investment	8.0% annually	
Project Life	15 years	

Calculation of Working Capital		
Item	**Basis for Calculation**	**Amount**
		(US $)
Raw Materials	0 Days in Storage	0
Bulk Product	20 Days in Storage	5,301,400
Bagged Product	10 Days in Storage	2,780,700
Cash on Hand	45 Days of Conversion Cost	10,882,715
Spare Parts	1.0% of Total Direct Plant Cost	3,131,010
Total Required Working Capital		22,095,825

Table 2b. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 1,000 mtpd Urea
Assuming New Plant at New Site

Manufacturing Cost At Different Capacity Utilizations			
Capacity Utilization	**Production Rate**	**Manufacturing Cost**	
(%)	(mtpy)	(US $/year)	US $/mt
5	16,500	72,232	4,377.7
10	33,000	73,260	2,220.0
15	49,500	74,288	1,500.8
20	66,000	75,316	1,141.1
25	82,500	76,344	925.4
30	99,000	77,372	781.5
35	115,500	78,400	678.8
40	132,000	79,428	601.7
45	148,500	80,456	541.8
50	165,000	81,484	493.8
55	181,500	82,511	454.6
60	198,000	83,539	421.9
65	214,500	84,567	394.3
70	231,000	85,595	370.5
75	247,500	86,623	350.0
80	264,000	87,651	332.0
85	280,500	88,679	316.1
90	297,000	89,707	302.0
95	313,500	90,735	289.4
100	330,000	91,763	278.1

Table 2c. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 1,000 mtpd Urea
Assuming New Plant at New Site

Conversion Cost At Different Capacity Utilizations			
Capacity Utilization	**Production Rate**	**Conversion Cost**	
(%)	(mtpy)	(US $/year)	(US $/mt)
5	16,500	71,634	4,341.5
10	33,000	72,064	2,183.8
15	49,500	72,494	1,464.5
20	66,000	72,924	1,104.9
25	82,500	73,355	889.1
30	99,000	73,785	745.3
35	115,500	74,215	642.6
40	132,000	74,645	565.5
45	148,500	75,075	505.6
50	165,000	75,505	457.6
55	181,500	75,935	418.4
60	198,000	76,365	385.7
65	214,500	76,796	358.0
70	231,000	77,226	334.3
75	247,500	77,656	313.8
80	264,000	78,086	295.8
85	280,500	78,516	279.9
90	297,000	78,946	265.8
95	313,500	79,376	253.2
100	330,000	79,806	241.8

Table 3a. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 776 mtpd Urea
Assuming New Plant at New Site

Basis of Estimate		
Total Direct Plant Cost (US $'000)	255,596	
Total Fixed Investment (US $'000)	400,001	
Working Capital (US $'000)	17,990	
Daily Production Capacity (mt)	776	
Operating Days per Year	330	
Annual Production (mt)	256,080	
Manufacturing Cost Item		
	(US $'000/year)	(US $/mt product)
Variable Cost		
Natural Gas, at US $2.00 /MM Btu		
and 31.3 MM Btu/mt NH_3		
plus 1.0 MM Btu/mt Urea		
or US $1.90 /GJ		
and 33.0 GJ/mt NH_3	9,278	36.23
1.1 GJ/mt Urea	512	2.00
Catalysts, Chemicals, and Supplies	1,408	5.50
Formaldehyde	1,268	4.95
Conditioner (clay, oil, etc.)	0	0.00
Electricity	0	0.00
Boiler Feed Water for Steam	154	0.60
Fuel	0	0.00
Makeup Cooling Water	5	0.02
Diesel Fuel	0	0.00
Bags	2,561	10.00
Bagging Labor	768	3.00
Subtotal	15,954	62.30
Fixed Cost		
Operating Labor and Supervision	800	3.12
Administrating Expenses and Overhead	800	3.12
Maintenance	3,532	13.79
Insurance	5,112	19.96
Fixed Capital Recovery	46,732	182.49
Interest on Working Capital	1,439	5.62
Subtotal	58,415	228.10
Total Manufacturing Cost (at 100% Capacity Utilization)	74,369	290.40

Table 3a. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 776 mtpd Urea
Assuming New Plant at New Site
(Continued)

Assumptions Used in Cost Calculations		
Item	**Consumption**	**Unit Cost**
Catalysts, Chemicals, and Supplies	2.4 kg/mt	US $2.32/kg
Formaldehyde (37%)	11.0 kg/mt	US $0.45/kg
Conditioner (clay, etc.)	0.0 kg/mt	US $1.00/kg
Conditioning Vehicle (oil, etc.)	0.0 kg/mt	US $0.4/kg
Electricity (included in gas usage)	0 kWh/mt	US $0.05/kWh
Boiler Feed Water for Steam	0.3 mt/mt	US $2.00/mt
Fuel (included in gas indicated above)	0.0 GJ/mt	US $1.90/GJ
Makeup Cooling Water	0.17 mt/mt	US $0.1/mt
Diesel Fuel (for emergency generator)	0.2 kg/mt	US $0.25/kg
Bags	20.5 units/mt	US $0.49/unit
Item	**Calculating Procedure**	
Administrating Expenses and Overhead	100% of Labor and Supervision	
Maintenance	1.38% of Total Direct Plant Cost	
Insurance	2.0% of Total Direct Plant Cost	
Fixed Capital Recovery	11.7% of Total Fixed Investment	
Interest on Working Capital	8.0% annually	
Interest on Long-Term Investment	8.0% annually	
Project Life	15 years	

Calculation of Working Capital		
Item	**Basis for Calculation**	**Amount**
		(US $)
Raw Materials	0 Days in Storage	0
Bulk Product	20 Days in Storage	4,305,248
Bagged Product	10 Days in Storage	2,253,504
Cash on Hand	45 Days of Conversion Cost	8,875,551
Spare Parts	1.0% of Total Direct Plant Cost	2,555,960
Total Required Working Capital		17,990,262

Table 3b. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 776 mtpd Urea
Assuming New Plant at New Site

Manufacturing Cost At Different Capacity Utilizations			
Capacity Utilization	**Production Rate**	**Manufacturing Cost**	
(%)	(mtpy)	(US $/year)	US $/mt
5	12,804	59,213	4,624.5
10	25,608	60,010	2,343.4
15	38,412	60,808	1,583.0
20	51,216	61,606	1,202.9
25	64,020	62,403	974.7
30	76,824	63,201	822.7
35	89,628	63,999	714.0
40	102,432	64,797	632.6
45	115,236	65,594	569.2
50	128,040	66,392	518.5
55	140,844	67,190	477.0
60	153,648	67,987	442.5
65	166,452	68,785	413.2
70	179,256	69,583	388.2
75	192,060	70,380	366.4
80	204,864	71,178	347.4
85	217,668	71,976	330.7
90	230,472	72,773	315.8
95	243,276	73,571	302.4
100	256,080	74,369	290.4

Table 3c. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 776 mtpd Urea
Assuming New Plant at New Site

Conversion Cost At Different Capacity Utilizations			
Capacity Utilization	**Production Rate**	**Conversion Cost**	
(%)	(mtpy)	(US $/year)	(US $/mt)
5	12,804	58,749	4,588.3
10	25,608	59,083	2,307.2
15	38,412	59,416	1,546.8
20	51,216	59,750	1,166.6
25	64,020	60,084	938.5
30	76,824	60,418	786.4
35	89,628	60,751	677.8
40	102,432	61,085	596.3
45	115,236	61,419	533.0
50	128,040	61,753	482.3
55	140,844	62,087	440.8
60	153,648	62,420	406.3
65	166,452	62,754	377.0
70	179,256	63,088	351.9
75	192,060	63,422	330.2
80	204,864	63,755	311.2
85	217,668	64,089	294.4
90	230,472	64,423	279.5
95	243,276	64,757	266.2
100	256,080	65,091	254.2

Table 4a. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 380 mtpd Urea
Assuming New Plant at New Site

Basis of Estimate		
Total Direct Plant Cost (US $'000)	157,179	
Total Fixed Investment (US $'000)	246,000	
Working Capital (US $'000)	10,932	
Daily Production Capacity (mt)	380	
Operating Days per Year	330	
Annual Production (mt)	125,400	
Manufacturing Cost Item		
	(US $'000/year)	(US $/mt product)
Variable Cost		
Natural Gas, at US $2.00 /MM Btu		
and 31.3 MM Btu/mt NH_3		
plus 1.0 MM Btu/mt Urea		
or US $1.90 /GJ		
and 33.0 GJ/mt NH_3	4,543	36.23
1.1 GJ/mt Urea	251	2.00
Catalysts, Chemicals, and Supplies	690	5.50
Formaldehyde	621	4.95
Conditioner (clay, oil, etc.)	0	0.00
Electricity	0	0.00
Boiler Feed Water for Steam	75	0.60
Fuel	0	0.00
Makeup Cooling Water	3	0.02
Diesel Fuel	0	0.00
Bags	1,254	10.00
Bagging Labor	376	3.00
Subtotal	7,813	62.30
Fixed Cost		
Operating Labor and Supervision	800	6.38
Administrating Expenses and Overhead	800	6.38
Maintenance	2,172	17.32
Insurance	3,144	25.07
Fixed Capital Recovery	28,740	229.19
Interest on Working Capital	875	6.98
Subtotal	36,531	291.32
Total Manufacturing Cost (at 100% Capacity Utilization)	44,344	353.62

Table 4a. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 380 mtpd Urea
Assuming New Plant at New Site
(Continued)

Assumptions Used in Cost Calculations		
Item	**Consumption**	**Unit Cost**
Catalysts, Chemicals, and Supplies	2.4 kg/mt	US $2.32/kg
Formaldehyde (37%)	11.0 kg/mt	US $0.45/kg
Conditioner (clay, etc.)	0.0 kg/mt	US $1.00/kg
Conditioning Vehicle (oil, etc.)	0.0 kg/mt	US $0.4/kg
Electricity (included in gas usage)	0 kWh/mt	US $0.05/kWh
Boiler Feed Water for Steam	0.3 mt/mt	US $2.00/mt
Fuel (included in gas indicated above)	0.0 GJ/mt	US $1.90/GJ
Makeup Cooling Water	0.17 mt/mt	US $0.1/mt
Diesel Fuel (for emergency generator)	0.2 kg/mt	US $0.25/kg
Bags	20.5 units/mt	US $0.49/unit
Item	**Calculating Procedure**	
Administrating Expenses and Overhead	100% of Labor and Supervision	
Maintenance	1.38% of Total Direct Plant Cost	
Insurance	2.0% of Total Direct Plant Cost	
Fixed Capital Recovery	11.7% of Total Fixed Invest	
Interest on Working Capital	8.0% annually	
Interest on Long-Term Investment	8.0% annually	
Project Life	15 years	

Calculation of Working Capital		
Item	**Basis for Calculation**	**Amount**
		(US $)
Raw Materials	0 Days in Storage	0
Bulk Product	20 Days in Storage	2,588,712
Bagged Product	10 Days in Storage	1,343,756
Cash on Hand	45 Days of Conversion Cost	5,427,337
Spare Parts	1.0% of Total Direct Plant Cost	1,571,786
Total Required Working Capital		10,931,591

Table 4b. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 380 mtpd Urea
Assuming New Plant at New Site

Manufacturing Cost At Different Capacity Utilizations			
Capacity Utilization	**Production Rate**	**Manufacturing Cost**	
(%)	(mtpy)	(US $/year)	US $/mt
5	6,270	36,922	5,888.6
10	12,540	37,312	2,975.5
15	18,810	37,703	2,004.4
20	25,080	38,093	1,518.9
25	31,350	38,484	1,227.6
30	37,620	38,875	1,033.4
35	43,890	39,265	894.6
40	50,160	39,656	790.6
45	56,430	40,047	709.7
50	62,700	40,437	644.9
55	68,970	40,828	592.0
60	75,240	41,218	547.8
65	81,510	41,609	510.5
70	87,780	42,000	478.5
75	94,050	42,390	450.7
80	100,320	42,781	426.4
85	106,590	43,172	405.0
90	112,860	43,562	386.0
95	119,130	43,953	368.9
100	125,400	44,343	353.6

Table 4c. Manufacturing Cost Estimate
Ammonia/Urea Complex (Rwanda)—Capacity: 380 mtpd Urea
Assuming New Plant at New Site

Conversion Cost At Different Capacity Utilizations			
Capacity Utilization	**Production Rate**	**Conversion Cost**	
(%)	(mtpy)	(US $/year)	(US $/mt)
5	6,270	36,694	5,852.4
10	12,540	36,858	2,939.2
15	18,810	37,021	1,968.2
20	25,080	37,185	1,482.6
25	31,350	37,348	1,191.3
30	37,620	37,512	997.1
35	43,890	37,675	858.4
40	50,160	37,839	754.4
45	56,430	38,002	673.4
50	62,700	38,165	608.7
55	68,970	38,329	555.7
60	75,240	38,492	511.6
65	81,510	38,656	474.2
70	87,780	38,819	442.2
75	94,050	38,983	414.5
80	100,320	39,146	390.2
85	106,590	39,310	368.8
90	112,860	39,473	349.8
95	119,130	39,636	332.7
100	125,400	39,800	317.4

The Market and Potential Urea Market Scenarios

Favorable agroclimatic conditions for farming in the Great Lakes Region have contributed significantly to the increased use of land for agriculture and the high population density in the region, one of the highest in Africa. However, fertilizer use in the region is one of the lowest in the world. Such a situation is mainly due to the lack of proper fertilizer supply to farmers in the region, i.e., lack of a timely supply of suitable fertilizers to farmers at prices that promote their use by increasing farmers' profits and income. The supply of fertilizers produced in Rwanda or a neighboring country will substantially contribute to overcoming such a constraint to fertilizer use. According to estimates from government-managed warehouses, countrywide fertilizer sales in Rwanda for September 2007 through May 2008 were 674 mt of urea, 3,527 mt of DAP, 2,097 mt of 17-17-17, and 620 mt of 25-5-5. Rwanda's current annual urea consumption is probably about 1,000 mt.

Rwanda's urea consumption is very low, partly because of the high freight cost between east coast ports and Kigali (trucks take 6 days to make the journey each way and most often return empty). If urea was produced near Kivu, the distribution costs to different parts of the country would be much less than current freight costs and would promote increased fertilizer use. Imported urea carries a freight cost of about US $350/mt and distribution costs for locally made urea should be about US $60/mt. This freight advantage should also help Rwanda sell urea to some neighboring countries. The profitability of fertilizer use in crop production in the region, and thereby a great potential market for urea and other fertilizers, is adversely affected and limited by the high prices of fertilizers and very limited availability. Production of urea near Kivu will reduce the cost and increase the availability of urea to farmers. Current very low rates of adoption and use by farmers should increase substantially at a rapid pace as a result of such investment.

The size of the market can seriously affect the economic and financial feasibility of a fertilizer manufacturing plant. Because of economies of scale associated with investing in these plants, access to reasonable large markets is essential for these plants to produce urea at low costs and be economically competitive and a financially/economic sound investment. In the following two sections, the financial feasibility of investing in facilities to produce urea near Lake Kivu take in consideration the investment requirements and cost estimates described above and the following two main potential urea market scenarios:

1. *Ideal Market Scenario*—The market for urea in Rwanda will grow at close to 50% per year over the first 10–15 years of operation and all production in excess of Rwanda's projected demand will be exported to neighboring countries beginning the first year of operations.
2. *Regional Projections Base Market Scenario*—Projections of fertilizer-N demand in the Eastern Sub-Saharan Africa subregion produced by IFDC's FertTrade model for 2010–2024 are used to assess in a more realistic way the potential market for the Lake Kivu's urea plant production.

Financial/Economic Assessments Under Two Market Scenarios

1. Ideal Market Scenario—Financial/Economic Assessment

Table 5 shows the amounts of urea that would need to be exported on a yearly basis for three plant sizes having urea production rates of 1,000 mtpd, 776 mtpd, and 380 mtpd. These plant sizes were considered because such plants are available. The amounts of exportable urea calculated in Table 5 show only one of many possible scenarios and assume the plant will have to export most of its output to the surrounding countries. The plant's lower costs will encourage domestic consumption.

Internal Rate of Return

Based on the information shown above, the IRR was calculated for each of the three unit sizes. In performing these calculations, it was assumed that each new unit would operate at a rate of 50% capacity for the first year, at 75% capacity for the second year, and at 100% from there on. For calculating the IRR, it is necessary to introduce the price at which the material will be sold at the factory gate. For these calculations, two selling prices were assumed. The first was based on the price at which urea was being sold in the Middle East (US $710/mt, *Green Markets*, September 29, 2008) plus the cost of transporting that material to agricultural destinations in Rwanda (US $350/mt), less what it would cost to transport the Rwanda-produced urea to the agricultural sites (US $60/mt), which gives a comparable price of US $1,000/mt. The other selling price assumed for determining the IRR was calculated similarly but used the 2007 urea price in the Middle East, which was in the order of US $320/mt (*Green Markets*, September 2007) instead of US $710/mt. Based on the 2007 prices, the comparable selling price of the Rwanda-produced urea would be US $610/mt.

The IRR for the three units, based on the two mentioned selling prices, is shown in Tables 6, 7, 8, 9, 10, and 11. In summary, the IRR results are:

	IRR Calculated for the Three Unit Sizes		
	1,000-mtpd Unit	776-mtpd Unit	380-mtpd Unit
	(%)		
Using selling price of US $1,000/mt	31	29	24
Using selling price of US $610/mt	20	19	15

The values of 19% and higher indicate that the project may be attractive for investors, but the values showing 15% is rather low and not attractive. Because of this, it may be deduced that the small 380-mtpd unit should not be considered, but the other two units can be.

Table 5. Production and Consumption Balance

Urea Balance if a 1,000-mtpd Unit is Installed			
Year	Expected Production	Expected Consumption in Rwanda	Exports to Neighboring Countries
	(mtpy)[a]	(mtpy)[b]	(mtpy)
1	165,000	1,000	164,000
2	247,500	1,495	246,005
3	330,000	2,236	327,764
4	330,000	3,344	326,656
5	330,000	5,000	325,000
6	330,000	7,477	322,523
7	330,000	11,180	318,820
8	330,000	16,719	313,281
9	330,000	25,000	305,000
10	330,000	37,384	292,616
Urea Balance if a 776-mtpd Unit is Installed			
	(mtpy)[a]	(mtpy)[b]	(mtpy)
1	128,000	1,000	127,000
2	192,000	1,495	190,505
3	256,000	2,236	253764
4	256,000	3,344	252,656
5	256,000	5,000	251,000
6	256,000	7,477	248,523
7	256,000	11,180	244,820
8	256,000	16,719	239,281
9	256,000	25,000	231,000
10	256,000	37,384	218,616
Urea Balance if a 380-mtpd Unit is Installed			
	(mtpy)[a]	(mtpy)[b]	(mtpy)
1	62,700	1,000	61,700
2	94,050	1,495	92,555
3	125,400	2,236	123,164
4	125,400	3,344	122,056
5	125,400	5,000	120,400
6	125,400	7,477	117,923
7	125,400	11,180	113,820
8	125,400	16,719	108,681
9	125,400	25,000	100,400
10	125,400	37,384	88,016

a. Assuming only 50% production the first year and 75% the second.
b. Assuming a consumption increase of almost 50% per year.

Table 6. Calculation of Internal Rate of Return
Ammonia/Urea Complex (Rwanda)—Capacity: 1,000 mtpd Urea
Based on a Possible Selling Price of US $1,000/mt
Assuming New Plant at New Site

Year	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% installation	30	40	30															
Installation cost, mm US $	147	196	147															
% capacity				50	75	100	100	100	100	100	100	100	100	100	100	100	100	100
Margin, US $/mt				506	650	722	722	722	722	722	722	722	722	722	722	722	722	722
Production, m mtpy				165	248	330	330	330	330	330	330	330	330	330	330	330	330	330
Margin, mm US $				84	161	238	238	238	238	238	238	238	238	238	238	238	238	238
Capital Recovery				57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
Depreciation				33	30	28	27	25	23	22	20	19	18	16	15	14	13	12
Net Profit Before Tax				108	188	267	269	271	272	274	275	277	278	279	280	281	282	283
Tax				22	38	53	54	54	54	55	55	55	56	56	56	56	56	57
Net Profit After Tax				86	150	214	215	217	218	219	220	221	222	223	224	225	226	226
Depreciation				33	30	28	27	25	23	22	20	19	18	16	15	14	13	12
Interest on WC				2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Net Cash Flow				121	182	244	243	243	243	242	242	242	242	241	241	241	241	241
Residual, mm US $																		196
Yearly Sums, mm US $	-147	-196	-147	121	182	244	243	243	243	242	242	242	242	241	241	241	241	437

Urea production cost at 100% capacity, US $278/mt
Urea production cost at 75% capacity, US $350/mt
Urea production cost at 50% capacity, US $494/mt
Urea selling price in Kigali is Mid East price (US $710) plus freight (US $350), US $1,060/mt
Estimated internal transportation cost, US $60/mt
Comparable selling price, US $1,000/mt
Margin at 100% capacity, US $722/mt
Margin at 75% capacity, US $650/mt
Margin at 50% capacity, US $506/mt
Total plant installation cost, US $490 million (mm)
Residual value after 15 operating years, US $196 million (mm)
WC = working capital Production thousands (m) metric tons per year (mtpy)

IRR	31%

Table 7. Calculation of Internal Rate of Return
Ammonia/Urea Complex (Rwanda)—Capacity: 776 mtpd Urea
Based on a Possible Selling Price of US $1,000/mt
Assuming New Plant at New Site

Year	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% installation	30	40	30															
Installation cost, mm US $	120	160	120															
% capacity				50	75	100	100	100	100	100	100	100	100	100	100	100	100	100
Margin, US $/mt				481	634	710	710	710	710	710	710	710	710	710	710	710	710	710
Production, m mtpy				128	192	256	256	256	256	256	256	256	256	256	256	256	256	256
Margin, mm US $				62	122	182	182	182	182	182	182	182	182	182	182	182	182	182
Capital Recovery				47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Depreciation				27	25	23	22	20	19	18	16	15	14	13	12	12	11	10
Net Profit Before Tax				82	144	205	207	208	210	211	212	213	214	215	216	217	218	218
Tax				16	29	41	41	42	42	42	42	43	43	43	43	43	44	44
Net Profit After Tax				65	115	164	165	167	168	169	170	170	171	172	173	173	174	175
Depreciation				27	25	23	22	20	19	18	16	15	14	13	12	12	11	10
Interest on WC				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Net Cash Flow				93	141	189	189	188	188	188	187	187	187	187	187	187	186	186
Residual, mm US $																		160
Yearly Sums, mm US $	-120	-160	-120	93	141	189	189	188	188	188	187	187	187	187	187	187	186	346

Urea production cost at 100% capacity, US $290/mt
Urea production cost at 75% capacity, US $366/mt
Urea production cost at 50% capacity, US $519/mt
Urea selling price in Kigali is Mid East price (US $710) plus freight (US $350), US $1,060/mt
Estimated internal transportation cost, US $60/mt
Comparable selling price, US $1,000/mt
Margin at 100% capacity, US $710/mt
Margin at 75% capacity, US $634/mt
Margin at 50% capacity, US $481/mt
Total plant installation cost, US $400 million (mm)
Residual value after 15 operating years, US $160 million (mm)
WC = working capital Production thousands (m) metric tons per year (mtpy)

IRR	29%

Table 8. Calculation of Internal Rate of Return
Ammonia/Urea Complex (Rwanda)—Capacity: 380 mtpd Urea
Based on a Possible Selling Price of US $1,000/mt
Assuming New Plant at New Site

Year	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% installation	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Installation cost, mm US $	30	40	30															
% capacity	74	98	74															
Margin, US $/mt				50	75	100	100	100	100	100	100	100	100	100	100	100	100	100
Production, m mtpy				355	549	646	646	646	646	646	646	646	646	646	646	646	646	646
Margin, mm US $				63	94	125	125	125	125	125	125	125	125	125	125	125	125	125
Capital Recovery				22	52	81	81	81	81	81	81	81	81	81	81	81	81	81
Depreciation				29	29	29	29	29	29	29	29	29	29	29	29	29	29	29
Net Profit Before Tax				16	15	14	13	12	12	11	10	9	9	8	8	7	7	6
Tax				35	65	96	96	97	98	99	100	100	101	102	102	103	103	104
Net Profit After Tax				7	13	19	19	19	20	20	20	20	20	20	20	21	21	21
Depreciation				28	52	76	77	78	79	79	80	80	81	81	82	82	82	83
Interest on WC				16	15	14	13	12	12	11	10	9	9	8	8	7	7	6
Net Cash Flow				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Residual, mm US $				45	68	92	91	91	91	91	91	91	90	90	90	90	90	90
Yearly Sums, mm US $																		98

Urea production cost at 100% capacity, US $354/mt
Urea production cost at 75% capacity, US $451/mt
Urea production cost at 50% capacity, US $645/mt
Urea selling price in Kigali is Mid East price (US $710) plus freight (US $350), US $1,060/mt
Estimated internal transportation cost, US $60/mt
Comparable selling price, US $1,000/mt
Margin at 100% capacity, US $646/mt
Margin at 75% capacity, US $549/mt
Margin at 50% capacity, US $355/mt
Total plant installation cost, US $246 million (mm)
Residual value after 15 operating years, US $98 million (mm)
WC = working capital Production thousands (m) metric tons per year (mtpy)

IRR	24%

Table 9. Calculation of Internal Rate of Return
Ammonia/Urea Complex (Rwanda)—Capacity: 1,000 mtpd Urea
Based on a Possible Selling Price of US $610/mt
Assuming New Plant at New Site

Year	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% installation	30	40	30															
Installation cost, mm US $	147	196	147															
% capacity				50	75	100	100	100	100	100	100	100	100	100	100	100	100	100
Margin, US $/mt				116	260	332	332	332	332	332	332	332	332	332	332	332	332	332
Production, m mtpy				165	248	330	330	330	330	330	330	330	330	330	330	330	330	330
Margin, mm US $				19	64	110	110	110	110	110	110	110	110	110	110	110	110	110
Capital Recovery				57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
Depreciation				33	30	28	27	25	23	22	20	19	18	16	15	14	13	12
Net Profit Before Tax				44	91	138	140	142	144	145	147	148	149	150	151	153	153	154
Tax				9	18	28	28	28	29	29	29	30	30	30	30	31	31	31
Net Profit After Tax				35	73	111	112	114	115	116	117	118	119	120	121	122	123	123
Depreciation				33	30	28	27	25	23	22	20	19	18	16	15	14	13	12
Interest on WC				2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Net Cash Flow				69	105	141	141	140	140	140	139	139	139	138	138	138	138	138
Residual, mm US $																		196
Yearly Sums, mm US $	-147	-196	-147	69	105	141	141	140	140	140	139	139	139	138	138	138	138	334

Urea production cost at 100% capacity, US $278/mt
Urea production cost at 75% capacity, US $350/mt
Urea production cost at 50% capacity, US $494/mt
Urea 2007 selling price in Kigali was Mid East price (US $320) plus freight (US $350), US $670/mt
Estimated internal transportation cost, US $60/mt
Comparable selling price, US $610/mt
Margin at 100% capacity, US $332/mt
Margin at 75% capacity, US $260/mt
Margin at 50% capacity, US $116/mt
Total plant installation cost, US $490 million (mm)
Residual value after 15 operating years, US $196 million (mm)
WC = working capital Production thousands (m) metric tons per year (mtpy)

IRR	20%

Table 10. Calculation of Internal Rate of Return
Ammonia/Urea Complex (Rwanda)—Capacity: 776 mtpd Urea
Based on a Possible Selling Price of US $610/mt
Assuming New Plant at New Site

Year	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% installation	30	40	30															
Installation cost, mm US $	120	160	120															
% capacity				50	75	100	100	100	100	100	100	100	100	100	100	100	100	100
Margin, US $/mt				91	244	320	320	320	320	320	320	320	320	320	320	320	320	320
Production, m mtpy				128	192	256	256	256	256	256	256	256	256	256	256	256	256	256
Margin, mm US $				12	47	82	82	82	82	82	82	82	82	82	82	82	82	82
Capital Recovery				47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Depreciation				27	25	23	22	20	19	18	16	15	14	13	12	12	11	10
Net Profit Before Tax				32	69	105	107	108	110	111	112	113	114	115	116	117	118	118
Tax				6	14	21	21	22	22	22	22	23	23	23	23	23	24	24
Net Profit After Tax				25	55	84	86	87	88	89	90	91	91	92	93	94	94	95
Depreciation				27	25	23	22	20	19	18	16	15	14	13	12	12	11	10
Interest on WC				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Net Cash Flow				54	81	109	109	108	108	108	108	107	107	107	107	107	106	106
Residual, mm US $																		160
Yearly Sums, mm US $	-120	-160	-120	54	81	109	109	108	108	108	108	107	107	107	107	107	106	266

Urea production cost at 100% capacity, US $290/mt
Urea production cost at 75% capacity, US $366/mt
Urea production cost at 50% capacity, US $519/mt
Urea 2007 selling price in Kigali was Mid East price (US $320) plus freight (US $350), US $670/mt
Estimated internal transportation cost, US $60/mt
Comparable selling price, US $610/mt
Margin at 100% capacity, US $320/mt
Margin at 75% capacity, US $244/mt
Margin at 50% capacity, US $91/mt
Total plant installation cost, US $400 million (mm)
Residual value after 15 operating years, US $160 million (mm)
WC = working capital   Production thousands (m)   metric tons per year (mtpy)

IRR	19%

Table 11. Calculation of Internal Rate of Return
Ammonia/Urea Complex (Rwanda)—Capacity: 380 mtpd Urea
Based on a Possible Selling Price of US $610/mt
Assuming New Plant at New Site

Year	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% installation	30	40	30															
Installation cost, mm US $	74	98	74															
% capacity				50	75	100	100	100	100	100	100	100	100	100	100	100	100	100
Margin, US $/mt				-35	159	256	256	256	256	256	256	256	256	256	256	256	256	256
Production, m mtpy				63	94	125	125	125	125	125	125	125	125	125	125	125	125	125
Margin, mm US $				-2	15	32	32	32	32	32	32	32	32	32	32	32	32	32
Capital Recovery				29	29	29	29	29	29	29	29	29	29	29	29	29	29	29
Depreciation				16	15	14	13	12	12	11	10	9	9	8	8	7	7	6
Net Profit Before Tax				10	28	47	48	48	49	50	51	51	52	53	53	54	54	55
Tax				2	6	9	10	10	10	10	10	10	10	11	11	11	11	11
Net Profit After Tax				8	23	37	38	39	39	40	41	41	42	42	43	43	43	44
Depreciation				16	15	14	13	12	12	11	10	9	9	8	8	7	7	6
Interest on WC				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Net Cash Flow				25	39	52	52	52	52	52	52	51	51	51	51	51	51	51
Residual, mm US $																		98
Yearly Sums, mm US $	-74	-98	-74	25	39	52	52	52	52	52	52	51	51	51	51	51	51	149

Urea production cost at 100% capacity, US $354
Urea production cost at 75% capacity, US $451
Urea production cost at 50% capacity, US $645
Urea 2007 selling price in Kigali was Mid East price (US $320) plus freight (US $350), US $670/mt
Estimated internal transportation cost, US $60/mt
Comparable selling price, US $610/mt
Margin at 100% capacity, US $256/mt
Margin at 75% capacity, US $159/mt
Margin at 50% capacity, US $-35/mt
Total plant installation cost, US $246 million (mm)
Residual value after 15 operating years, US $98 million (mm)
WC = working capital   Production thousands (m)   metric tons per year (mtpy)

IRR	15%

2. Projections-Based Market Scenario—Financial/Economic Assessment

Projections of fertilizer-N demand in the Eastern Sub-Saharan Africa subregion produced by IFDC's FertTrade model for 2010–2024 are used here to assess the potential market for Lake Kivu's urea plant production. The Eastern Sub-Saharan Africa subregion includes five countries—Burundi, Kenya, Rwanda, Tanzania, and Uganda. In this assessment, the projected total subregional demand for urea-N may be viewed as an estimate of demand well above the upper limit of what may be considered the actual market for the urea-N produced by the Kivu plant. As shown in Table 12a, the demand for fertilizer-N in the five-country subregion is projected to increase from about 198,600 mtpy in 2015 to 305,500 mtpy in 2024 or in terms of quantities of urea, from 431,700 mtpy in 2015 to 664,000 mtpy in 2024. Thus, total projected quantities of regional demand for urea are well beyond the expected levels of production by the Kivu plant even if a urea production capacity unit of 1,000 mtpd is installed.

Operation of the Kivu plant at optimum rates of production capacity utilization will depend on access to the regional and export market, i.e., on capturing specific shares of the total projected market for urea in the five-country Eastern Sub-Saharan Africa subregion. The size of such shares is affected by (1) the production capacity of the urea production unit installed—1,000- or 776-mtpd units; (2) the operational levels of urea production attained during the initial years of the plant's operation; and (3) the projected growth of demand for urea in the Eastern Sub-Saharan Africa subregion derived from projections generated by the FertTrade model.

Projections of the regional market shares required for attaining optimum capacity utilization of the plant during 2015–2024 are presented in Tables 12a–b and depicted in Figure 5 when 1,000- or 776-mtpd urea production units are installed. These estimates are based on the demand projections for the subregion through 2024 and assume that only 50% and 75% of the optimum production levels would be attained in the first and second years of operation, respectively. Optimum expected rates of production, 330,000 mtpy for the 1,000-mtpd unit and 256,000 mtpy for the 776-mtpd unit, would be attained only on the third year of operation to continue through 2024 and the lifespan of the plant. This implies that a very rapid growth in the capturing of regional market shares must be attained during the first 3 years of operation. The share of the regional market that the Lake Kivu plant should capture during the first 3 years of operation to sell its urea production while operating at optimum rates of capacity utilization depends on the size of the urea production unit installed. If a 1,000-mtpd unit is installed, its market share should increase from 38% or 165,000 mtpy in 2015 to 69% or 330,000 mtpy in 2017. If a 776-mtpd unit is installed, its market share should increase from only 30% or 128,000 mtpy in 2015 to 54% or 256,000 mtpy in 2017. Efforts and targets for increased market share in the regional market will be smaller and more attainable with a 776-mtpd unit installed.

Market Growth and Urea Manufacturing Cost—At optimum rates of production and capacity utilization, average costs of urea manufacturing for the 1,000- and 776-mtpd urea production units are estimated to be US $278.1/mt and US $290.4/mt, respectively. However, average manufacturing costs depend on the rates of production capacity utilization, which are ultimately determined by the amounts of urea the plant can efficiently produce and sell, i.e., internal operating efficiency in production and sustainable access to the market for urea. In the best ideal scenario, the plant could achieve optimum rates of production and the least average manufacturing costs in 3 years of operation. However, this is not easy to achieve when significant efforts over a period of time must be made to capture market share in the five-country Eastern Sub-Saharan Africa region. Thus, more conservative scenarios targeting regional market shares to be captured over 6–7 years are evaluated here.

For the 1,000-mtpd urea production unit (Table 12a), a scenario is evaluated targeting 25% (107,934 mtpy) of the regional market in the first year (2015) and then gradually increasing the share by 5% per year to reach a regional market share of 50% (275,170 mtpy) in the sixth year (2020), and then maintaining a 50% market share throughout the lifespan of the plant. This scenario implies that the plant will achieve optimum production capacity utilization at 330,000 mtpy and the least average urea manufacturing cost of US $278.1/mt by 2024. Average urea manufacturing cost will gradually decline from US $719.9/mt in 2015 to US $493.8/mt and US $287.1/mt in 2017 and 2023, respectively.

For the 776-mtpd urea production unit (Table 12b), a scenario is assessed targeting 25% (107,934 mtpy) of the regional market in the first year (2015) and then gradually increasing the share by 5%–2% per year to reach a regional market share of 39% (212,155 mtpy) in the sixth year (2020), then maintaining a 39% market share throughout the lifespan of the plant. This scenario implies that the plant will achieve optimum production capacity utilization at 256,000 mtpy and the least average urea manufacturing cost of US $290.4/mt by 2024. Average urea manufacturing cost will gradually decline from US $608.6/mt in 2015 to US $450.9/mt and US $302.4/mt in 2017 and 2023, respectively.

Projected 2015–2024 levels of production in metric tons per year that the 1,000- and 776-mtpd urea production units will have to achieve in order to meet the targeted market shares corresponding to the scenarios described above are illustrated in Figure 6. It shows rapid increases in production through 2020 and then more moderate annual increases during 2021–2024. Average urea manufacturing costs in U.S. dollars per metric ton associated with those production levels by the two production unit sizes are depicted and contrasted with the comparable selling price of US $610/mt in Figure 7. This figure shows that (1) up to 2019, the 776-mtpd unit would allow the production of urea at a lower average cost than the 1,000-mtpd unit, i.e., it would be more cost-effective through 2019; and (2) after 2019, the 1,000-mtpd unit would allow the production of urea at a lower average cost than the 776-mtpd unit, i.e., it would be more cost-effective through 2024 and beyond, as a result of projected demand growth and economies of scale in urea production. If the 776-mtpd unit is installed, projected average urea manufacturing costs will be lower than the comparable urea selling price of US $610/mt for all years (2015–2024). But if the 1,000-mtpd unit is installed, projected average urea manufacturing costs will be higher than the comparable urea selling price of US $610/mt in the first year of operation (2015) and then increasingly lower from 2017 through 2024.

This preliminary assessment of market potential and economic feasibility indicate that, given the challenges that must be confronted to achieve market growth, the size of the investments, and construction difficulties, investing in the 776-mtpd unit may be viewed as a less risky and more attractive investment. However, before such a decision is made, a more in-depth assessment of market potential and comprehensive feasibility study should be conducted. The preliminary results shown here clearly indicate that such an effort is highly desirable and has great potential to promote the economic development and welfare of the countries and population in the region.

Finally, it is important to note that estimates of financial/economic feasibility presented here include only direct returns on investment and do not account for the substantial benefits that such an investment will bring about to farmers, consumers, and the economies of Rwanda and other countries in the region. The large magnitude of such benefits should energize interventions and support from governments, development agencies, donors, and financial institutions to facilitate the implementation of this investment.

Table 12a. Plant Production Capacity, Market Size, Capacity Utilization, and Average Urea Manufacturing Cost

Urea Production if a 1,000-mtpd Unit is Installed			Projected Demand of Eastern Sub-Saharan Africa Region[b]		Regional Market Share Required for Optimum Capacity Utilization	Regional Market Share Targeted	Production to Meet Demand of Market Share Targeted	Production Capacity Utilization	Average Urea Manufacturing Cost
Year	Year of Operation	Expected Production[a]	N	Urea			Urea		
		(mtpy)	(mtpy)	(mtpy)	(%)	(%)	(mtpy)	(%)	(US $/mt)
2015	1	165,000	198,599	431,738	38%	25%	107,934	33%	719.9
2016	2	247,500	208,514	453,291	55%	30%	135,987	41%	589.7
2017	3	330,000	218,904	475,878	69%	35%	166,557	50%	493.8
2018	4	330,000	229,790	499,542	66%	40%	199,817	61%	416.4
2019	5	330,000	241,193	524,333	63%	45%	235,950	71%	366.4
2020	6	330,000	253,138	550,299	60%	50%	275,150	83%	322.5
2021	7	330,000	265,352	576,852	57%	50%	288,426	87%	310.5
2022	8	330,000	278,127	604,623	55%	50%	302,312	92%	297.0
2023	9	330,000	291,485	633,664	52%	50%	316,832	96%	287.1
2024	10	330,000	305,452	664,026	50%	50%	330,000	100%	278.1

a. Assuming only 50% production the first year and 75% the second.

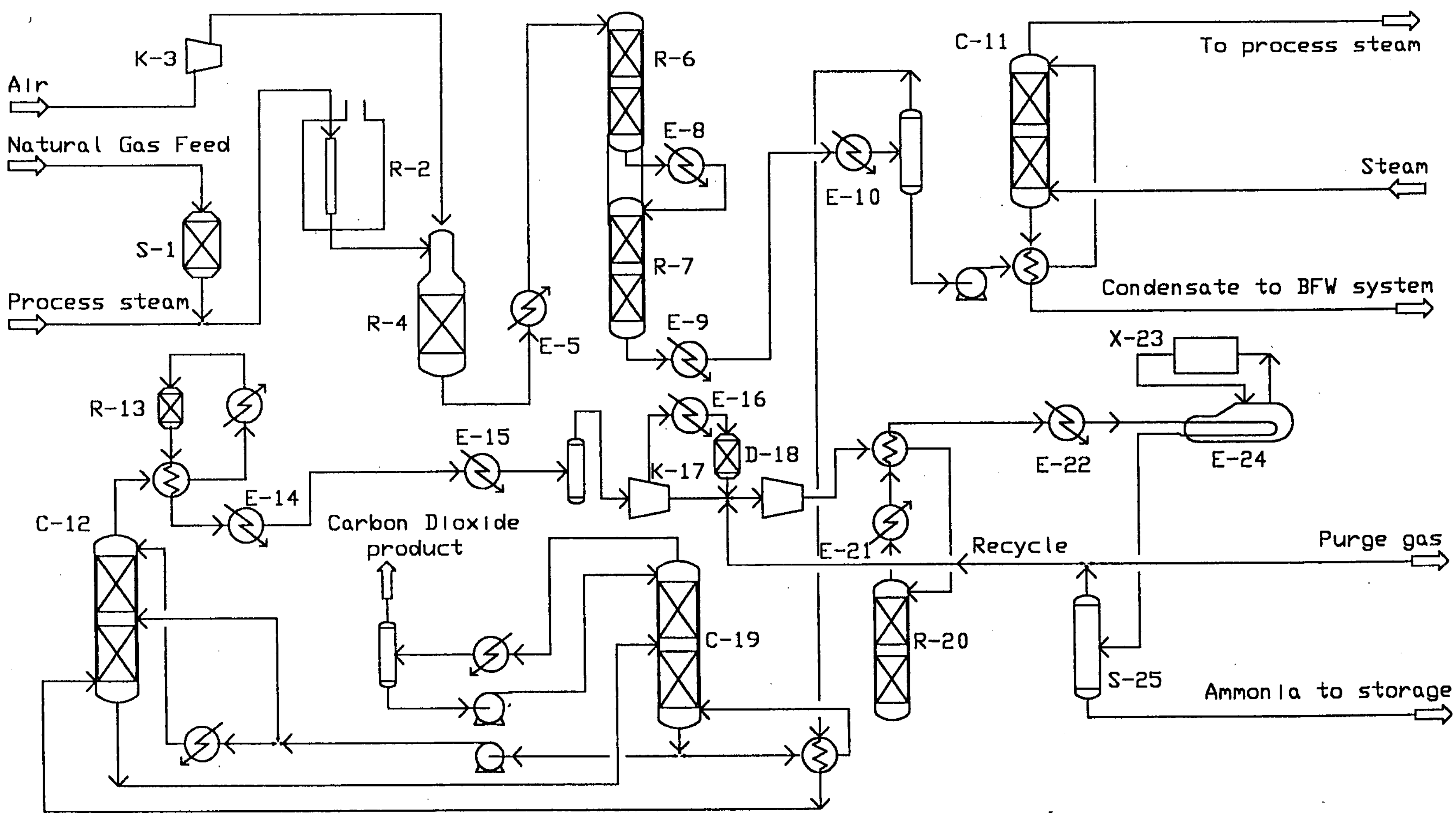
b. Projections produced by IFDC's FertTrade model for the Eastern Sub-Saharan Africa Region, which includes Rwanda, Burundi, Kenya, Tanzania, and Uganda.

Table 12b. Plant Production Capacity, Market Size, Capacity Utilization, and Average Urea Manufacturing Cost

Urea Production if a 776-mtpd Unit is Installed			Projected Demand of Eastern Sub-Saharan Africa Region[b]		Regional Market Share Required for Optimum Capacity Utilization	Regional Market Share Targeted	Production to Meet Demand of Market Share Targeted	Production Capacity Utilization	Average Urea Manufacturing Cost
Year	Year of Operation	Expected Production[a]	N	Urea			Urea		
		(mtpy)	(mtpy)	(mtpy)	(%)	(%)	(mtpy)	(%)	(US $/mt)
2015	1	128,000	198,599	431,738	30%	25%	107,934	42%	608.6
2016	2	192,000	208,514	453,291	42%	30%	135,987	53%	495.0
2017	3	256,000	218,904	475,878	54%	32%	152,281	59%	450.9
2018	4	256,000	229,790	499,542	51%	35%	174,840	68%	399.0
2019	5	256,000	241,193	524,333	49%	37%	194,003	76%	362.8
2020	6	256,000	253,138	550,299	47%	39%	212,155	83%	337.9
2021	7	256,000	265,352	576,852	44%	39%	222,392	87%	325.0
2022	8	256,000	278,127	604,623	42%	39%	233,099	91%	313.2
2023	9	256,000	291,485	633,664	40%	39%	244,295	95%	302.4
2024	10	256,000	305,452	664,026	39%	39%	256,000	100%	290.4

a. Assuming only 50% production the first year and 75% the second.

b. Projections produced by IFDC's FertTrade model for the Eastern Sub-Saharan Africa Region, which includes Rwanda, Burundi, Kenya, Tanzania, and Uganda.



Legend:

S-1 Sulfur removal	R-6 HT shift converter	R-13 Methanator	D-18 Dryer
R-2 Primary reformer	R-7 LT shift converter	E-14, E-21 Heat recovery	C-19 CO2 stripper
K-3 Air compressor	E-10 Cooler	E-15, E-22 Cooler	R-20 Ammonia converter
R-4 Secondary reformer	C-11 Condensate stripper	E-16 Syn-gas cooler	X-23 NH3 refrigeration
E-5, E-7, E-8 Heat recovery	C-12 CO2 absorber	K-17 Syn-gas compressor	E-24 Chiller
			S-25 HP separator

Figure 1. Simplified Flowsheet of Ammonia Production

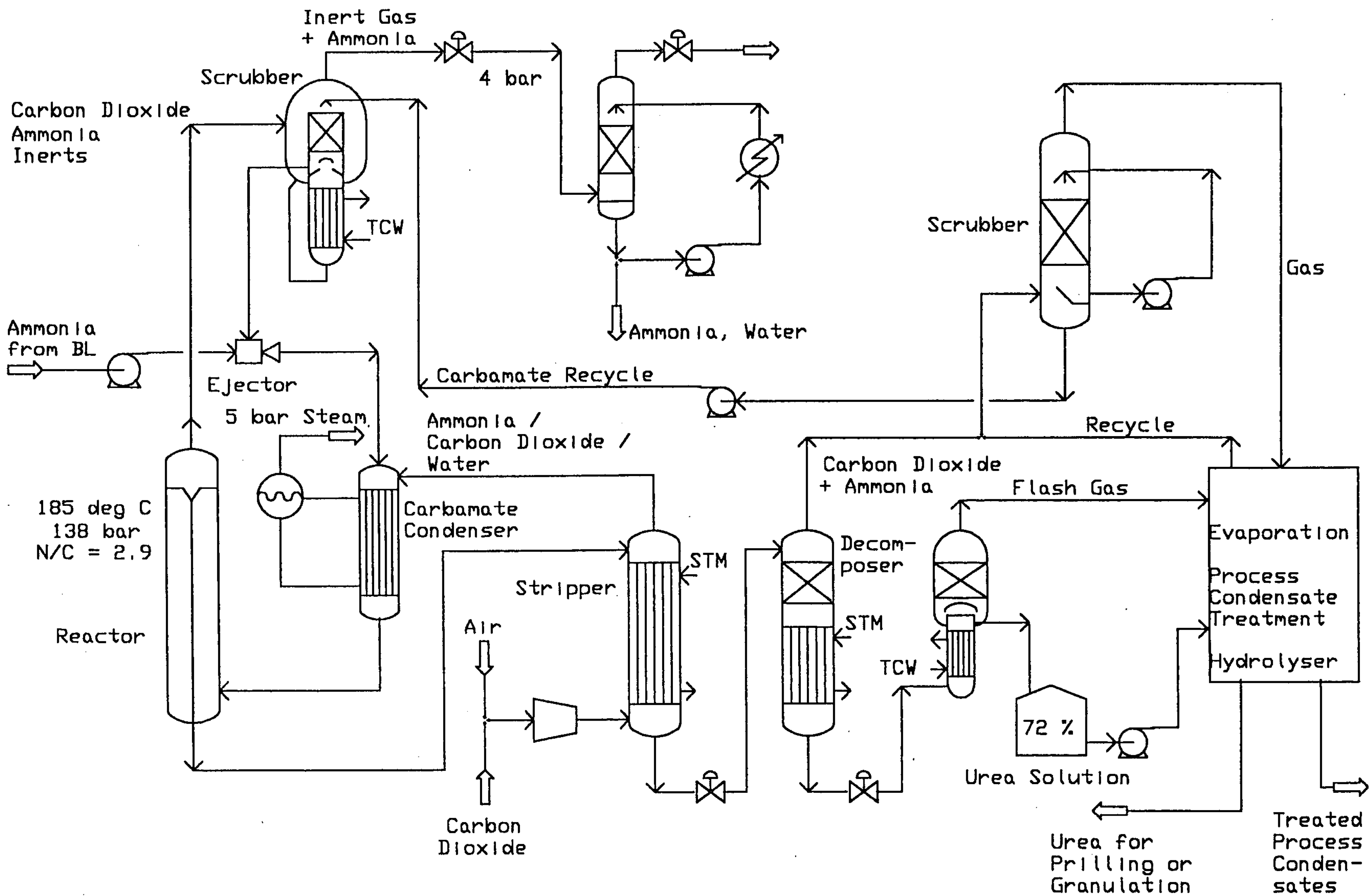


Figure 2. Flowsheet of Urea Production by CO_2 Stripping Process

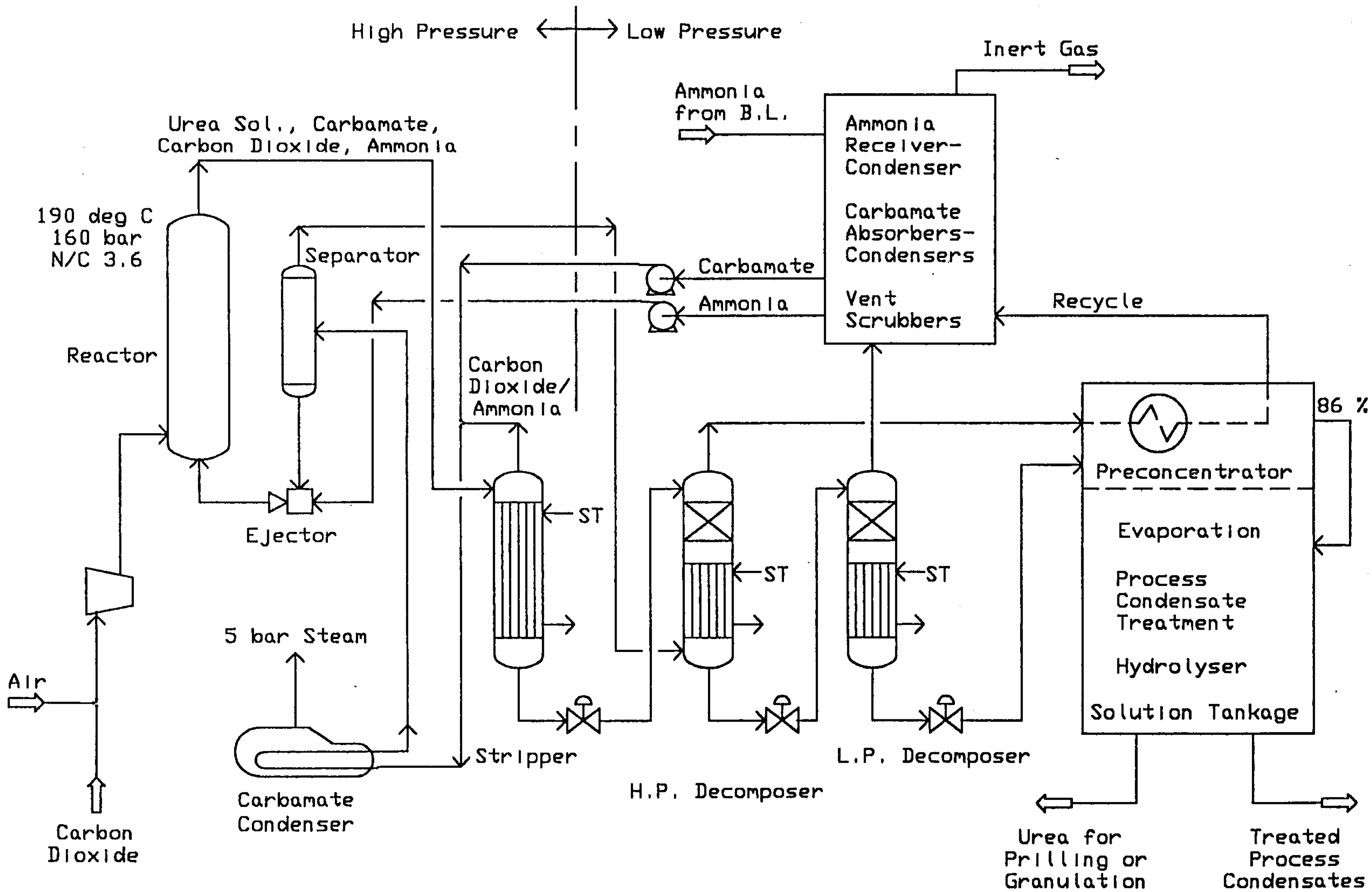


Figure 3. Flowsheet of Urea Production by Thermal Stripping Process

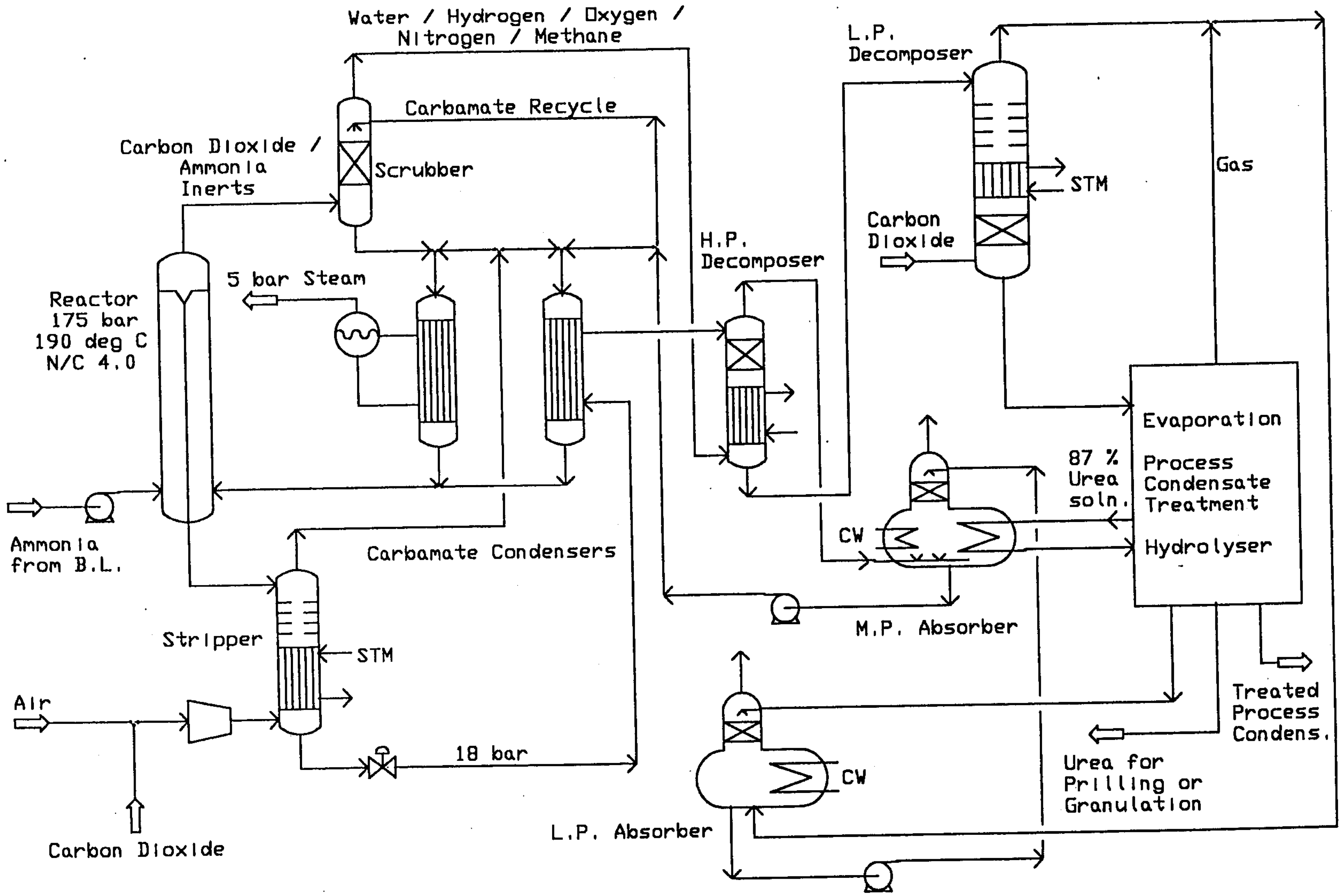


Figure 4. Flowsheet of Urea Production by the TEC ACES Process

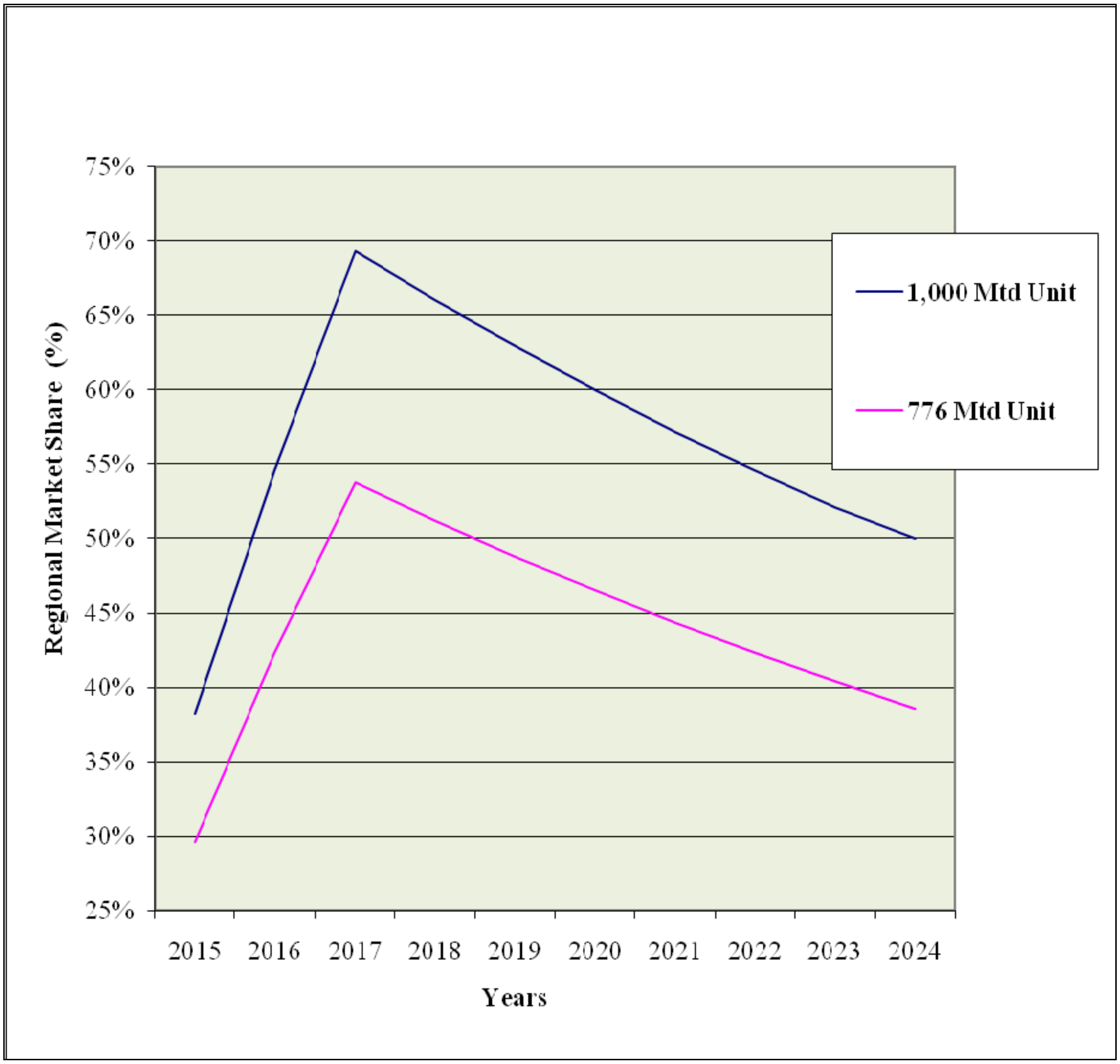


Figure 5. Regional Market Shares Required for Optimum Capacity Utilization

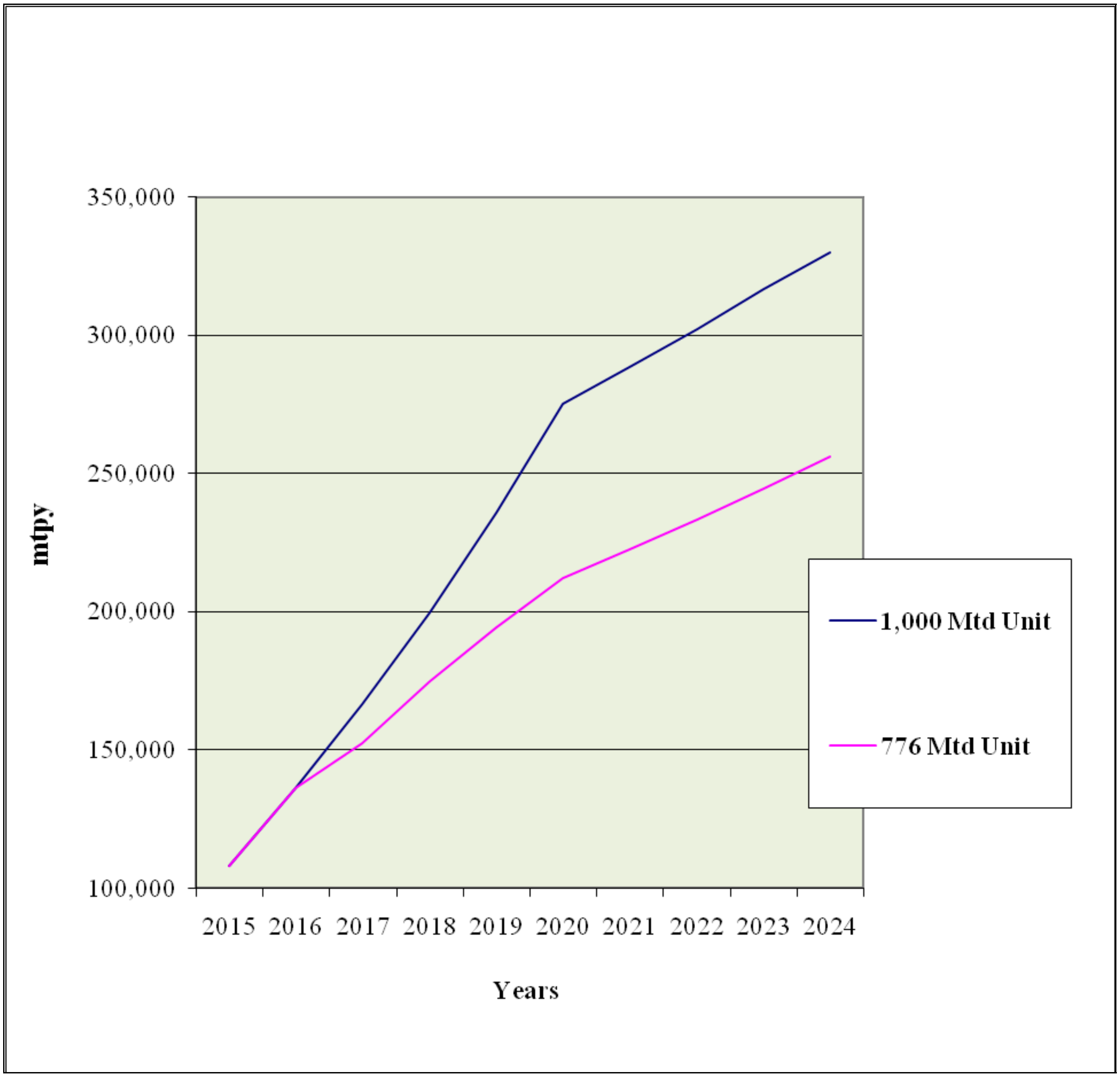


Figure 6. Urea Production Required to Meet Demand of Regional Market Shares Targeted

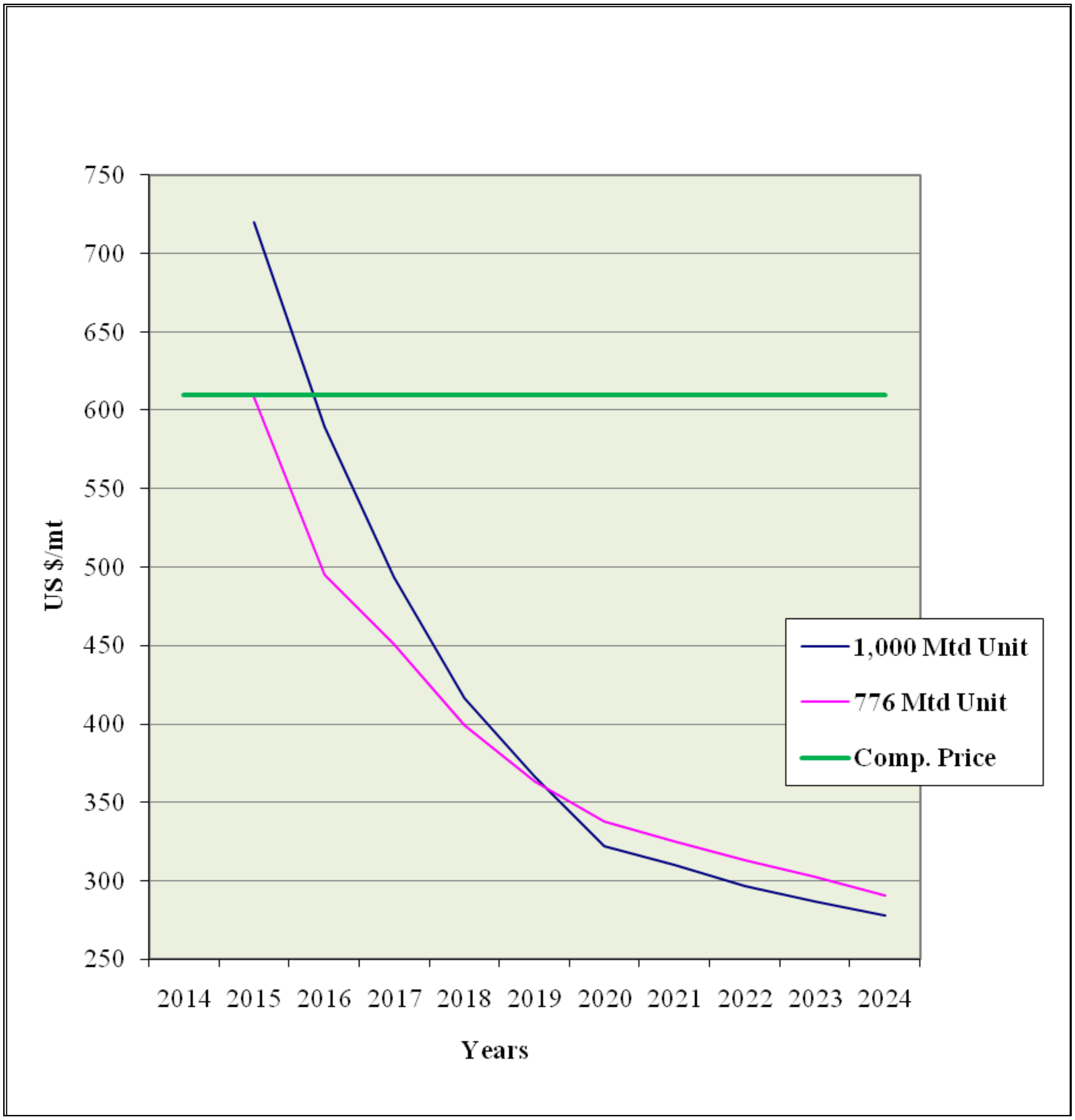


Figure 7. Projected Average Urea Manufacturing Cost and Comparable Urea Price