Sustainable Fertilizer and Crop Production from Energy Security Perspective – An Overview

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1.0 ABSTRACT

Sustainable fertilizer and crop production are fundamental and critical to meet the needs of food, fiber, fertilizer and fuel demands due to the rising living standards of the current world population of 5.8 billion and the future population of 8 to 12 billion.

The concept of sustainability, however, can only be valued by:

- Economic efficiency
- Conservation of natural resources and waste reduction
- Minimizing impacts on environment and bio-diversity
- Energy efficiency in order to achieve food and energy security for the present and future generations

The common challenges and opportunities are to consider and adopt technologies with a comprehensive approach for the best interests of the industries and stakeholders.

This paper presents an overview of potential clean technologies toward sustainable fertilizer and crop production in order to improve the present situation of increasing energy demand and cost.

2.0 INTRODUCTION

Malthusian concerns about the world's carrying capacity for humans were about land and food sufficiency in the eighteenth century. This could be alleviated by green revolution in crop production due to technological advances in fertilizer and agricultural developments. However, most agricultural lands are completely developed and the use of technology is becoming more and more expensive due to the escalating cost of energy and its availability locally.

According to Bruntland's report at the world commission on Environment and Development (1987), global energy demand will increase from 40% to 500% in the next 40 years. This will cause escalation in price as well as damage to the environment and ecology, and the prospect of sustainability will diminish. In addition, the demands for food, fiber, and fertilizer have been growing steadily with the increase in population to 8.5 million by 2025 and 12 billion by the end of this century to avoid hunger as well as improve the standard of living in countries with emerging economies.

With limited land and limited fossil energy availability, other resources combined with technological innovations and its correct assessments and applications in terms of fertilizer and energy efficiency and flexibility of operations are essential for sustaining fertilizer and crop productions as a whole.

3.0 WORLD ENERGY OUTLOOK

Global energy demand increased from 207 quadrillion BTU during the first energy scarcity felt in 1970 to 412 quadrillion BTU in 2002. It is expected to increase by 57% between 2002 and 2025 or 645 quadrillion BTU according to the EIA (International Energy Outlook 2005).

Growth in demand will continue to rise in countries of emerging economy and share two thirds of the increase in the world. More so, it is expected to surpass energy use in developed and mature markets (e.g. USA, Western Europe, Canada, Japan, Australia, New Zealand and Mexico) by 2020. The average annual percentage change in world energy consumption shows an increase in demand from 1.4% (1990-2002) to 2.0% (2002-2025), whereas the annual demand rate is highest at 3.5% in Asia and fossil fuels dominate as a major non-renewable resource for that.

Accordingly, crude oil demand was steadily rising from 100 to 165 quadrillion BTU energy equivalents between 1970 and 2002. It is expected to increase about 245 quadrillion BTU by 2025. Next to crude oil, coal and natural gas are, by far, the fastest growing primary energy sources worldwide. The largest increases in coal usage are projected for China and India. This will account for 71% of the total coal demand by 2025 on a BTU basis.

Table 1

World Energy Consumption (1990-2025)

Region	1990	2002	2015	2025	Avg. Annual % Change 1990-2002	Avg. Annual % Change 2002-2025
Mature Market Economies	183.6	213.5	247.3	271.8	1.3	1.1
Emerging Economies	88.4	144.3	237.8	295.1	4.2	3.2
Asia	51.5	88.4	155.8	196.7	4.6	3.5
Middle East	13.1	22.0	32.4	38.9	4.4	2.5
Africa	9.3	12.7	19.3	23.4	2.7	2.7
Central & South America	14.5	21.2	30.4	36.1	3.2	2.3
Transitional Economies	76.2	53.6	68.4	77.7	2.9	1.6
World Total	**348.2**	**411.5**	**553.5**	**644.6**	**1.4**	**2.0**

Table 2

World Coal Consumption (1970-2025), Billion Short Tons

Region	1970	1980	1990	2002	2015	2025
Mature Market Economies	1.45	1.90	2.00	2.10	2.15	2.21
Emerging Economies	0.80	1.00	2.00	2.50	4.00	5.00
Transitional Economies	1.05	0.80	1.00	0.60	0.40	0.40
World Total	**3.30**	**4.00**	**5.00**	**5.20**	**7.24**	**8.23**

Coal consumption growth in countries of emerging economies has increased from about 0.8 to 2.5 billion s.tons between 1970-2002 and is projected to double by 2025. However, the United

States consumed about 1.0 billion s.tons of coal in 2002 and our consumption is projected to increase to 1.5 billion s.tons by 2025 (Coal is projected to provide 53% of total electricity generation). Natural gas remains an important supply source for new electricity generation worldwide due to its efficiency, low carbon content, and low emissions of greenhouse gasses.

Table 3

World Natural Gas Reserves by Country as of January 1, 2005

Country	Reserves (Trillion cubic ft.)	Percent of World Total
World	6,040	100
Top 20 Countries	5,391	89.3
Russia	1,680	27.8
Iran	940	15.6
Qatar	910	15.1
Saudi Arabia	235	3.9
United Arab Emirates	212	3.5
United States	189	3.1
Nigeria	176	2.9
Algeria	161	2.7
Venezuela	151	2.5
Iraq	110	1.8
Indonesia	90	1.5
Malaysia	29	0.5
Norway	75	1.2
Turkmenistan	74	1.2
Uzbekistan	71	1.2
Kazakhstan	66	1.1
Netherlands	65	1.1
Canada	62	1.0
Egypt	57	0.9
Ukraine	40	0.7
Remaining countries of the world	649	10.7

World natural gas reserves are located in the top twenty countries (5,391 trillion cubic feet). Of those countries, Russia, Iran and Qatar account for 58% (combined) and three quarters of the total reserves are located in the Middle East and the countries with transitional economies (Eastern Europe and the Former Soviet Union).

The estimate of expected supply worldwide is 60 years, based on 100 trillion cubic feet of gas consumption per year. By contrast, the expected life of U.S. reserves is estimated at 8 years, based on current consumption of approximately 23 trillion cubic feet of gas per year.

Based on proven coal reserves of 1,001 billion short tons, the estimated life expectancy is about 190 years under 5.262 billion tons of coal consumption. Both coal and natural gas are projected to fuel 64% of the world's electricity generation and coal is expected to continue to retain the largest market share for electricity generation, particularly in the U.S., China and India.

In the United States, natural gas demand will grow from 29% to 31% by 2025 for electricity generation. Renewables are expected to retain an 8% share of total energy consumption between 2002-2025 due to large hydro electric power projects in China, India and Laos, along with nuclear power plants in China, India and South Korea.

4.0 FERTILIZER AND ENERGY REVIEW

Fertilizer Production

Fertilizer is a major factor in increasing food demands through agricultural input/output for crop production. The world crop production was projected to increase by 57% during 1995/1997 to 2030 (34 years) by Food and Agricultural Organization (FAO) and demand for cereals is expected to be approximately 2,750 million short tons by 2020. The rate of increase in demand will be greater in Asia, China and India, etc. between 1997-2020 according to IFPRI.

Table 4

Regional Shares of Increased Cereal Demand (1997-2020)

Region	Percent Increase
China	27%
India	12%
Other Asian Countries	17%
Developed Countries	15%
Middle East/North Africa	10%
Sub Saharan Africa	9%
Latin America	10%

According to FAO (2000), it was forecast that total fertilizer nutrients demand would increase from 100 million short tons of $N+P_2O_5+K_2O$ to 219 million short tons per year by 2030. Fertilizer consumptions were accounted for China at 27%, India at 16%, North America (mostly the U.S.) at 17% versus Western Europe at 12%, Latin America at 9% and Sub-Saharan Africa (excluding South Africa) at 1% between 1998/1999 and 2000/2001. Nitrogen production worldwide also increased in Asia according to population growth between 1998-2001. China and India, together with the United States, are the largest producers of nitrogen fertilizers.

Table 5

Regional Shares of Nitrogen Production (1998/1999 – 2000/2001)

Region	Percent
China	26%
India	16%
Indonesia/Japan	4%
North America	17%
Western Europe	10%
Central Europe	4%
Former Soviet Union	10%
Middle East	7%
Others	6%

New nitrogen producing plants are being built in the gas rich countries of the Middle East. Production capacity continues to expand in other gas rich countries such as Trinidad and Venezuela.

5.0 ENERGY CONSUMPTION

Fertilizer contributes 45% of the commercial energy used in agricultural production for the world and an increase in energy prices directly influences prices for both fertilizer and food. Agricultural production, however, uses approximately 3.5% of total commercial energy consumption worldwide (including fertilizer) and nitrogen use as a portion of total nutrient consumptions in fertilizer has been more than 51% worldwide (45% of the developed countries and 66% for Asian and other countries).

Ammonia, being the main source as a nitrogen nutrient in fertilizer, uses approximately 82% of natural gas as feed stock and 18% as fuel and accounts for 1.2% of the world's fossil fuel consumption. The total energy consumption for ammonia manufacture declined 24% from approximately 41MM BTU/s.ton NH_3 to 31MM BTU/s.ton NH_3 between 1980 and 2000.

In the new generation ammonia plants using natural gas as a feed stock, an additional reduction of 6 million BTU was recently claimed using natural gas, compared to coal using 41.5 MM BTU/s.ton in the partial oxidation process.

Table 6

Ammonia Production Costs (660,000 s.ton Ammonia/year)

Feed Stock Process vs. Natural Gas Steam Reforming

Feed Stock Price, $/MM BTU	6		7		8		9		10	
Total Energy Use, MM BTU/s.ton	31	25	31	25	31	25	31	25	31	25
Feed Stock & Energy Costs, $/s.ton NH_3	186	150	217	175	248	200	279	225	310	250
Other Cash Costs, $/s.ton NH_3	26	26	26	26	26	26	26	26	26	26
Total Cash Costs, $/s.ton NH_3	212	176	243	201	274	226	305	251	336	276
Capital Related Costs, $/s.ton NH_3	75	75	75	75	75	75	75	75	75	75
Total Costs, $/s.ton NH_3	287	251	318	276	349	301	380	326	411	351
Total Capital, $MM	250	250	250	250	250	250	250	250	250	250

- $62.18/s.ton NH_3 (1998) is equivalent to $74.61~$75.0 (2005) based on the following: Debt/Equity ratio: 60:40, Depreciation 6%, Interest on Debts 8%, and 16% ROI on Equity
- Total Capital (2005) includes ‘LSTK’ price for plant and storage, spare parts, catalysts, working capital, etc.

A revamping project of $40 MM capital can be attractive based on cash cost differentials shown in the table above.

Table 7

Ammonia Production Costs (660,000 s.ton Ammonia/Year)

	Coal (Bituminous, 13,000 BTU/lb) Partial Oxidation					
Feed Stock Price, $/s.ton	25	30	35	40	45	50
Feed Stock Price, $/MM BTU	0.962	1.154	1.346	1.538	1.731	1.923
Total Energy Use, MM BTU/s.ton	41.36	41.36	41.36	41.36	41.36	41.36
Feed Stock Energy Costs, $/s.ton NH_3	39.80	47.73	55.67	63.61	71.59	79.53
Other Cash Costs, $/s.ton NH_3	53.64	53.64	53.64	53.64	53.64	53.64
Total Cash Costs, $/s.ton NH_3	93.44	101.37	109.31	117.25	125.23	133.17
Capital Related Costs, $/s.ton NH_3	156.33	156.33	156.33	156.33	156.33	156.33
Total Costs, $/s.ton NH_3	249.77	257.70	265.64	273.58	281.56	289.50
Total Capital, $MM	500	500	500	500	500	500

- \$130.27/s.ton NH_3 (1998) is equivalent to \$156.33 (2005) based on the following: Debt/Equity ratio: 60:40, Depreciation 6%, Interest on Debts 8% and 16% ROI on Equity
- Total Capital (2005) includes 'LSTK' price for plant and storage, spare parts, catalysts, working capital, etc.

The coal gasification process may become attractive in the long run based on the total cost of \$250 (Table 7) vs. the current market price at \$300/s.ton NH_3 for an annual revenue of \$33 MM.

6.0 AMMONIA PLANT REVAMPING OPTIONS

About 40% of the world's ammonia plants are more than 20 years old. This suggests that there is a major potential for economic recovery by revamping existing natural gas steam forming process plants and lowering energy consumption to 25 MM BTU/s.ton NH_3.

Table 8

Energy Analysis of a Low Energy Ammonia Plant (MM BTU/s.ton Ammonia)

Natural Gas Consumption		
Input	**HHV (High Heating Value)**	**LHV (Low Heating Value)**
Reformer Feed	21.25	19.19
Reformer Fuel	6.45	5.85
Auxiliary Boiler Fuel	0.29	0.25
A. Total Consumption	**27.99**	**25.28**
Losses	**HHV (High Heating Value)**	**LHV (Low Heating Value)**
Reforming	0.33	0.33
Steam Generation	0.28	0.28
Shift CO2 Removal, Methanation	1.12	1.12
Synthesis	1.46	1.46
Turbines/Compressors	5.60	5.60
Stack, etc. Losses	1.12	1.12
B. Total Losses	**9.91**	**9.91**
C. Ammonia Product (A-B)	**18.08**	**15.37**
D. Efficiency, %	**64.3**	**60.80**

The first part of the revamping option to increase plant capacity is the de-bottlenecking of the primary reformer/combustion, air preheating, and using either Kellogg 'KRES' exchanger reformer or a similar system. In addition, other measures of using improved catalysts in various process steps benefits H_2 loss (methanation), lower residual CO content, and inert content of the make-up gas. Replacement of current MEA solvent with the promoted aMDEA solution provides a more effective CO_2 removal option. Details of revamping options are available in previous presentations and other literature for this purpose.

7.0 ENERGY CONSERVATION FOR NITROGEN FERTILIZER

Lower energy inputs will result for nitrogen/phosphate fertilizers if ammonia plant energy use is reduced from 30 MM BTU/s.ton NH_3 to 25 MM BTU/s.ton NH_3 by revamping existing ammonia plants using a natural gas in steam reforming process.

Table 9

Energy Conservation for Nitrogen Fertilizers

Product	% Nitrogen	Energy Input MM BTU/s.ton N		% Energy Savings
		Before	After	
Ammonia	82	36.58	30.49	16.65
Urea				
A. Prilling	46	49.30	43.13	12.50
B. Granulation	46	52.14	48.39	7.20
Ammonium Nitrate @ NH_3 use 0.434 t/t $AmNO_3$				
A. Prilling	34	45.30	38.94	14.00
B. Granulation	34	43.70	37.34	14.60
UAN Solution	30	12.57	10.72	14.70
Ammonium Sulfate (Synthetic)	21	8.2	7.0	14.60
Ammonium Phosphate 46% P_2O_5 (18-46-0)	18	46.80	39.60	15.30

Numerous modernization schemes are available for partial oxidation plants using coal, etc. as a feed stock. The improvement of the synthetic loop and converter design is common to both processes by using either the Series 200 Topsoe system or the Kellogg split-flow configuration system.

8.0 ENERGY CONSUMPTION IN PHOSPHATE FERTILIZER

Energy use in phosphoric acid manufacturing by the dihydrate method is about 2.0 MM BTU/s.ton of P_2O_5. Whereas, it reduces to less than 0.5 MM BTU/s.ton P_2O_5 if the 'hemi-hydrate' process is adopted.

Table 10

Energy Consumption in Phosphoric Acid Process (MM BTU/s.ton P_2O_5)

Process	Dihydrate	Hemi-Hydrate
Reaction/Filtration	-0.90	-0.90
Evaporation	2.88	1.30
Clarification/Storage	0.03	0.02
Total	**2.01**	**0.42**

Table 11

Energy Consumption in Triple Phosphate Process (MM BTU/s.ton TSP Product)

Phosphoric Acid Process	Dihydrate	Hemi-Hydrate
Phosphate Rock	0.15	0.15
Phosphoric Acid	0.68	0.14
Process Energy	0.71	0.71
Total	**1.54**	**1.00**

Table 12

Energy Consumption in Ammonium Phosphate Process
(MM BTU/s.ton DAP [18-46-0] Product)

Period	Present @ 30 MM BTU/s.ton NH_3	Future @ 25 MM BTU/s.ton NH_3
Ammonia Input	6.60	5.50
Urea Input	0.25	0.20
Total	**6.85**	**5.70**

Table 13

Energy Conservation in Single Superphosphate Process (MM BTU/s.ton SSP Product)

Phosphate Rock	0.27
Sulfuric Acid	-0.90
Process Energy	0.35
Total	**-0.36**

9.0 ENERGY CONSERVATION IN AGRICULTURE

By reducing energy use in an ammonia plant from 34 MM BTU to 31.6 MM BTU per s.ton of ammonia, energy savings in agriculture were estimated to be 10.8% in previous presentation (2005). An additional 10% or more energy savings is estimated if the revamping of ammonia plants option is chosen to reduce energy use from 30 MM BTU to 25 MM BTU per s.ton of ammonia using the following formula:

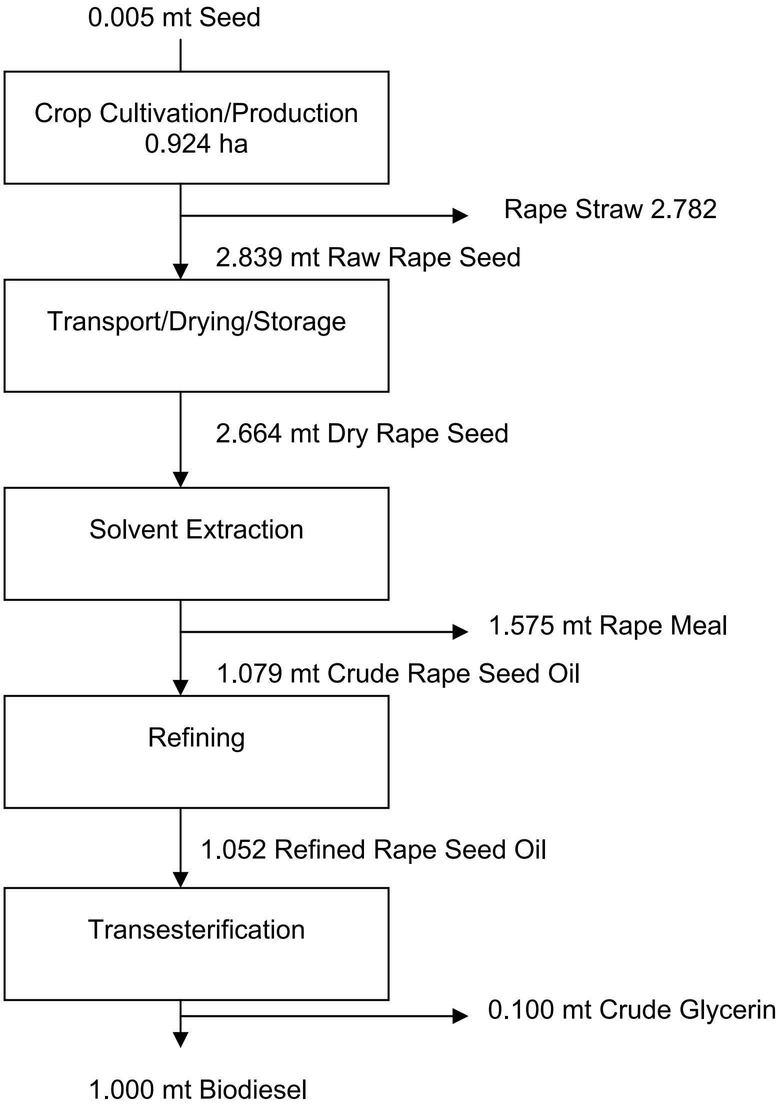
$E = F \bullet G$ where E = fertilizer energy consumption of a given crop/hectare, MM BTU
F = fertilizer use rate, s.ton/hectare
G = fertilizer energy use rate, MM BTU/s.ton

The commercial energy used in agricultural production is mainly in the form of fertilizer, pesticides/farm chemicals, irrigation and fuel to operate the farm machinery. Agriculture accounts for 3.5% of the world's total commercial consumption including fertilizer that accounts for 1.2% of the total commercial energy used. Thus, energy efficient agricultural inputs will lower the production costs for agricultural products and try to sustain fertilizer and crop production.

10.0 BIOFUELS (BIODIESEL/BIOETHANOL)

Biofuels (Biodiesel/Bioethanol) are a direct result of energy recovery by crops that depend on the input of mineral fertilizer. Photosynthesis, the central process of energy binding in crop plants, involves the absorption of radiation energy from sunlight and its chemical fixation. The present cropping systems are provided with additional input of fossil energy through mineral fertilizers in order to increase productivity.

Flow Chart for the Production of Biodiesel from Rape Seed Oil



ha = hectare

Chemistry

$$\text{Triglycerides} + 3\,\underset{\text{(methanol)}}{CH_3OH} \rightleftarrows \underset{\text{(methyl ester)}}{3(CH_3)COO)_3\,R_1R_2R_3} + \underset{\text{(glycerine)}}{C_3O_3H_8}$$

Biodiesel Process Feed Stocks

Rape Seed (canola), sunflower, safflower, mustard, cottonseed, palm seed (kernel), coconut, jatropha, soybean, beef tallow, pork fat, poultry fat, recycled restaurant grease

Biodiesel vs. Petroleum Diesel

- Biodiesel generates 3.2 units for every 1 unit of fossil fuel energy vs. petroleum diesel which generates 0.8 units of energy
- Renewable from crops/animals
- Increases the value of agricultural products
- Environment-friendly
- Better energy balance

Biodiesel Specifications

Density = 0.88 kg/l ~

Net Caloric Value = 37.27 MJ/kg (117,512 BTU/gal) vs. Petro-diesel 142,000 BTU/gal

Gross Caloric Value = 37.84 MJ/kg (119,309 BTU/gal)

Table 14

Primary Energy Input/Output for Biodiesel

	Input %	**Output %**			
		CO_2	**CH_4**	**N_2O**	**Total 'GHG'**
N fertilizer	24	20	34	99.5	50
Other cultivation/harvesting	11	11	2	0.5	6
Transport drying/storage	8	10	5	0	6
Solvent Extraction	15	12	24	0	8
Refining	3	3	3	0	2
Transesterification	35	40	32	0	25
Plant and Distribution	4	4	0	0	3
Total	100	100	100	100	100

(Source: IFS 510-03 Proc. 510)

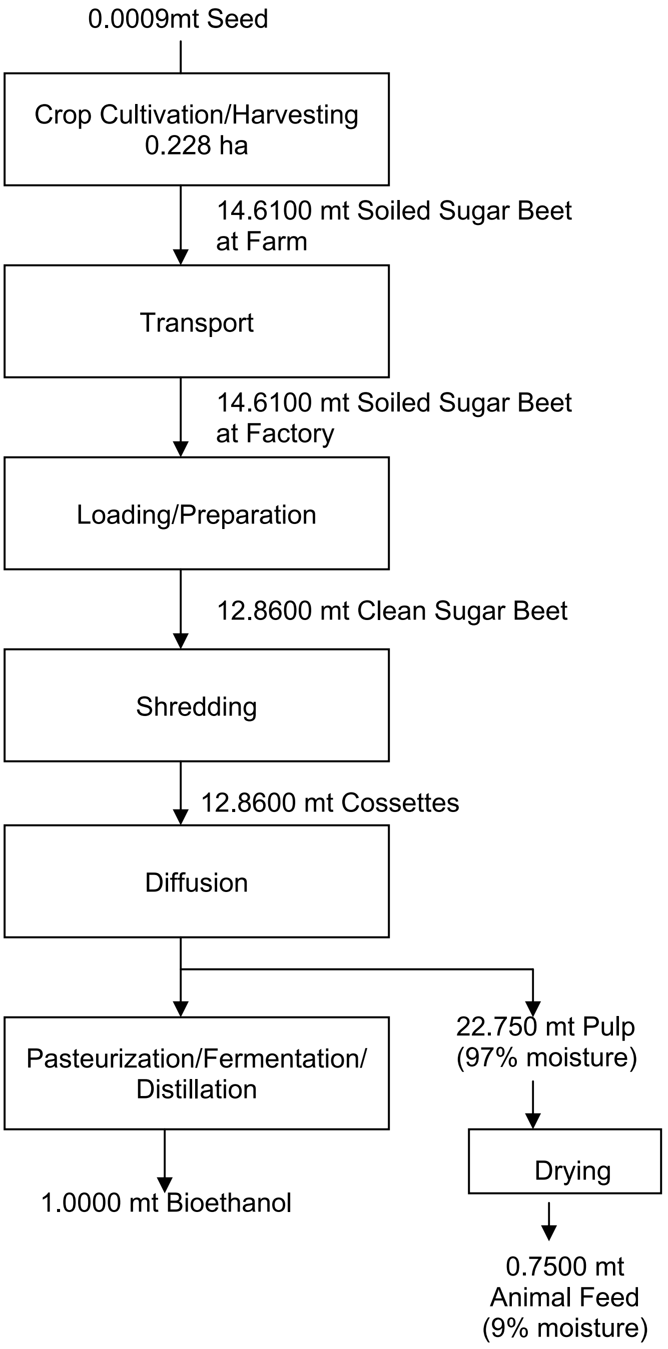
By lowering energy input through 'N' fertilizer, 'GHG' emissions as well as the cost of biodiesel will be reduced. As a result, biodiesel will become more competitive than petro-diesel. The physical properties of biodiesel are similar to those of petro-diesel.

Table 15

Physical Properties (Biodiesel)

	ASTMD-6751	**Lurgi Process**
Density	0.87-0.89 kg/liter	0.88 kg/liter
Viscosity @ 40° C	1.9-6.0 mm^2/sec	4.2 mm^2/sec
Flash Point	130° C	175° C
Water ε- Sediment	0.050 max, % vol.	0.020% vol.
Acid No.	0.8	0.20
Free Glycerine	0.02	0.015
Cetane	47 min.	56 min.
Carbon Residue	0.05% max	0.025%
Cloud Point	Unspecified	-22° C

Flow Chart for the Production of Biodiesel from Sugar Beet



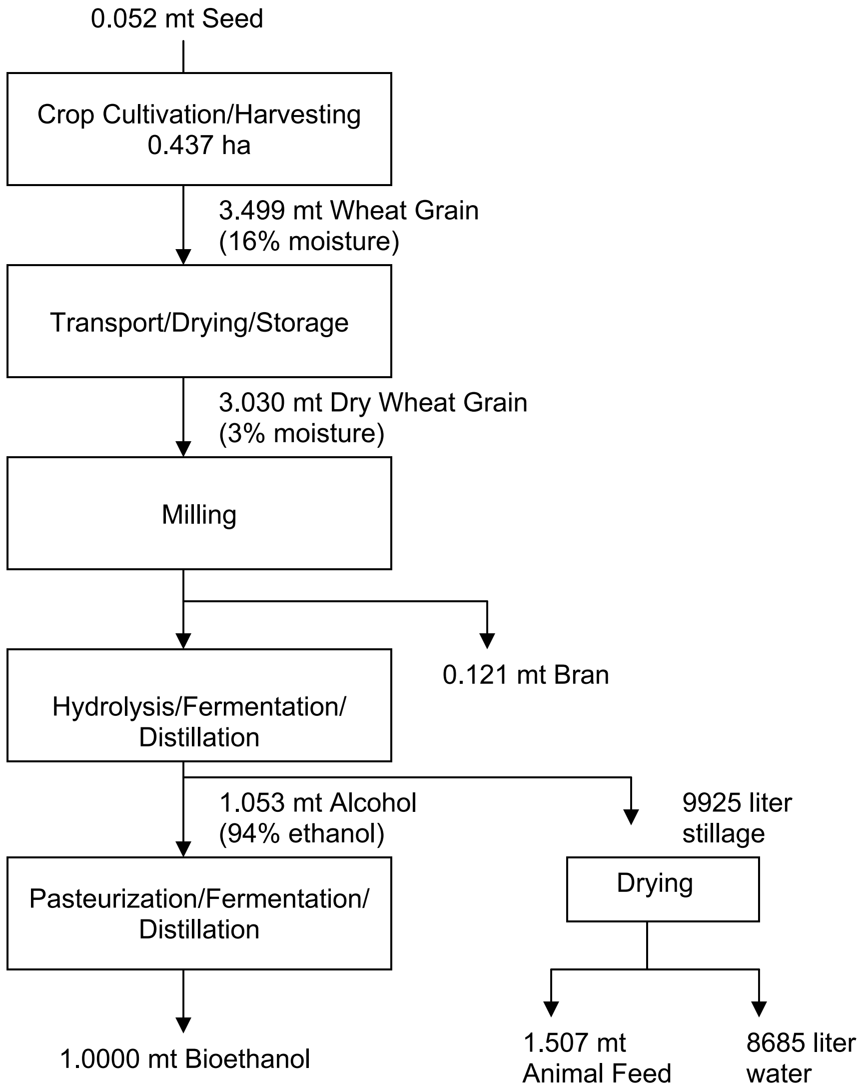
<u>Bioethanol Specifications</u>

Density = 0.79 kg/l

Net Caloric Value = 26.72 MJ/kg (84,406 BTU/gal)

Gross Caloric Value = 29.74 MJ/kg (93,946 BTU/gal)

Flow Chart for the Production of Bioethanol from Wheat



Corn has been the principal feed stock for ethanol production in the United States because it is readily available, stores well facilitating year-round production, and has been relatively inexpensive. The basic steps of processing corn into ethanol are milling, separation of starch, conversion to sugar, fermentation, distillation and dehydration. The by-products from this process are corn oil, protein feeds and CO_2 generation. Dry milling generates distillers dried grains (DDG) as a supplemental of animal feed, whereas wet milling generates a greater variety of products along with high fructose corn syrup, beverage sweeteners and ethanol, corn gluten meal, etc.

Economics

The cost of producing ethanol depends highly on the variable purchase price of corn and the selling prices for by-products. Higher by-product prices can partially recoup the variation in corn costs for ethanol products.

Table 16

Corn Price vs. Crude Oil Price

Crude Oil Price $/Barrel	**Corn Price, $/Bushel**			
	With Federal Subsidy			Without Federal Subsidy
Technology	New	State of the Art	Existing	State of the Art
10	0.80	0.50	0.10	-
20	2.50	2.00	1.50	-
30	4.00	3.50	2.75	0.50
40	5.50	5.00	4.50	2.00
50	7.25	6.50	5.50	3.75
60	9.25	8.50	7.25	5.00
70	11.25	10.00	9.00	6.75

11.0 SUMMARY AND CONCLUSIONS

1. Population growth and energy demands for food, fiber, fertilizer and fuel are increasing to avoid hunger and improve the standard of living in Asia and countries of emerging economy. Worldwide, coal and natural gas are the fastest growing energy sources. Natural gas demand has been steadily rising for new electricity generation in countries of emerging economies. The expected life of natural gas reserves is estimated at 60 years only relative to 190 years for coal worldwide.
2. With the price increase of crude oil at $70 per barrel and natural gas at $6-$7 per million BTU, revamping options for older ammonia plants built during 1970-1980 are important to reduce the production cost of ammonia and fertilizer energy input in order to sustain fertilizer and agricultural productions.
3. Energy conservation by reducing energy consumption from 30 MM BTU to 25 MM BTU per short ton of ammonia in natural gas steam reforming plants is economical to pay back $40 MM capital investment within a period of three years. Alternatively, the choice of clean coal technology may become more attractive in the future if natural gas prices escalate to $10 or more per MM BTU.
4. Similarly, energy conservation by conversion of a dihydrate to a hemi-hydrate process in existing plants would be appropriate for flexibility as well as lowering energy costs in phosphate fertilizers and agricultural products.
5. Biofuels (e.g. biodiesel and bioethanol) are alternative sources of green energy that provide energy security for the future. In addition, there is enough biomass available as a renewable, permanent feed stock for bioconversion to fuel ethanol to ensure energy security for sustainable fertilizer and crop productions.

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