“Energy-Mix” for Sustainable Environment in View of Fertilizer/Agricultural/Utility Industries

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1.0 Abstract

Natural gas and coal have been the preferred choice of fertilizer and utility industries in particular for hydrogen production and electricity generation. This is, of course, looked at more from an economical aspect rather than from an environmental impact point of view.

Currently, most of the world's hydrogen need and electricity generation are from fossil fuels that cause greenhouse gas emissions resulting in global warming of the earth's atmosphere.

CO_2 emissions from energy use in the United States is estimated at about 6000 million metric tons and it is expected to increase 8000 million metric tons by the year 2030 and coal plants are responsible for nearly 40% of U.S. CO_2 emissions. For hydrogen to have a future role as an energy carrier as well as a commodity in the marketplace, it must be produced from nuclear and renewable energy sources (solar, wind, water, electrolysis, biomass, etc.) for a sustainable environment. This would imply carbon capture and sequestration of CO_2 on a very large scale basis.

This paper discusses hydrogen production technologies and green power from "tree" crop production in fertilizer/agricultural/utility industries and economics by reviewing renewable energy options and "energy-mix for a sustainable future environment.

2.0 Introduction

With growing global population increase from 1.6 to 6 billion, the overall use of oil now exceeds 11 million metric tons per day to meet the demands for food, fiber, fuel, fertilizer, etc. and standard of living. Current energy consumptions and concern of depletion of finite reserves of oil and gas are driving its prices to rise and are pushing coal as a feed stock for electricity generation and ammonia production for utility and fertilizer sectors respectively. Coal prices at present are stable at \$1-\$2 per million BTU vs. natural gas price at \$7-\$7.75 per million BTU and crude oil at \$60-\$66 per barrel or \$10.34 - \$11.38 per million BTU.

Due to the increase in oil and gas prices, there was a down-turn in the fertilizer industry between 2000-2003 leading to closure of many plants and meeting the domestic demand of fertilizer by import.

With a world population exceeding 6 billion and still growing and increasing use of fossil fuels, CO_2 emissions have been increasing to cause global warming and climate change, which is incontrovertible. According to the International Panel on Climate Change (IPCC), CO_2 emissions must be cut by 60% just to stabilize CO_2 concentration at present levels.

In that respect, by use of hydrogen technologies and renewable energy combined with energy efficient technology, a major decrease in oil use by the United States would significantly reduce world oil prices. Successful development of coal projects such as clean coal technology (CCT), coal to liquid (CTL) and carbon capture and sequestration (CCS) would revitalize the North American manufacturing industries. Also, bio-fuel development primarily by fermentation conversion of agricultural products to ethanol and butanol for transport fuel mix are evolving without any CO_2 emissions. All these efforts are already showing promise to boost world as well as U.S. economy.

3.0 Global Climate Change Perspectives

Global climate change has been of much concern due to increasing greenhouse gas emissions (CH_4, N_2O, CFC, CO_2, etc.) in the earth's atmosphere and the global warming effect. This would destroy our eco-system and cause storms, hurricanes and the melting of polar ice caps with a resulting increase in sea level. Also, due to warming of the oceans, more precipitations are possible to cause flooding of low lying areas e.g. Bangladesh, Netherlands and other parts of the world.

The International Panel on Climate Change (IPCC) collected data to show that the earth's surface temperature in the 20th century was the largest in the past 1000 years as well as CO_2 concentration that reached 370 ppm in 2000 vs. 315 ppm in 1960 and 280 ppm before the industrial era.

The relative contributions of gases to the increased greenhouse effect by human activity are CO_2 at 60%, CH_4 at 20% CFC-HFC-HCFC at 14% and N_2O at 6%. Data from IEA sources (2002) claims that the United States alone shares about 24% of the world total CO_2 emissions as shown in the table below.

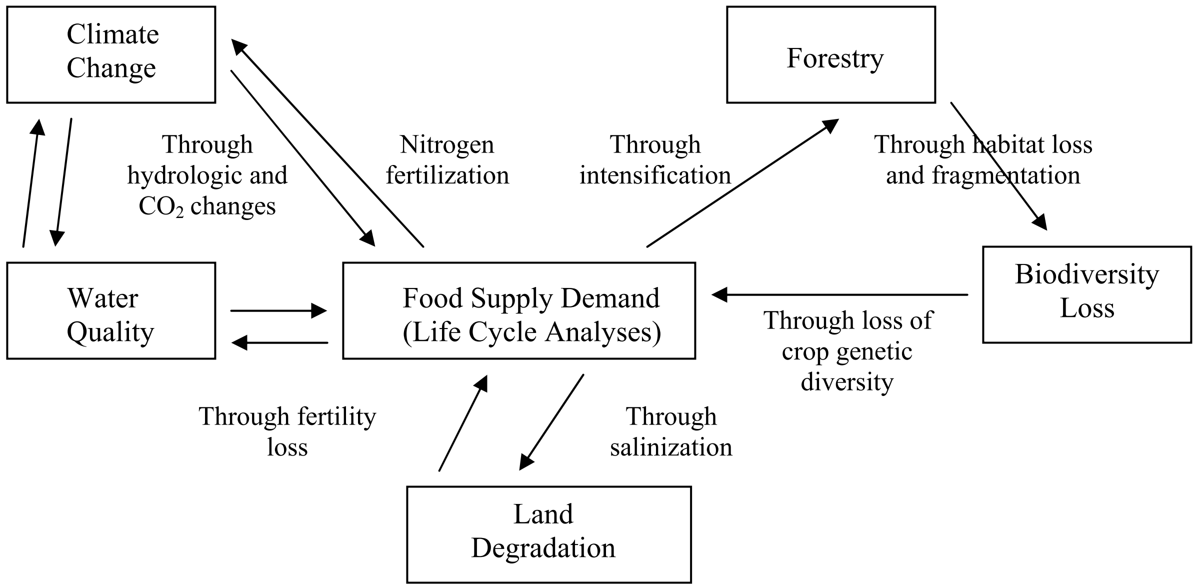
Table 1

CO_2 Emissions from Different Regions in the World

Country	**World Total Energy Related CO_2 Emissions (M tons)**	**Percent (%)**
United States	5,784	24
China	3,374	14
Russia	1,446	6
Japan	1,205	5
India	964	4
Germany	843	3.5
Canada	530	2.2
U.K.	482	2.0
Korea	434	1.8
Italy	362	1.5

By continuing to emit greenhouse gases by human activities in the world, there is a potential increase in average temperature from 1.4° C to 5.8° C and atmospheric CO_2 concentrations increase from 540 ppm to 970 ppm in the 21st century.j

The climate change study was conducted under the UNEP/NASA/World Bank (1998) program showing linkages between food supply/demand security and other influences such as forestry, climate, water and biodiversity with global environmental issues.



It is estimated that approximately 24 billion m tons of top soil are lost annually due to agricultural practices and approximately 2 million hectares of irrigated agricultural lands are lost because of salinization due to overuse of ground water.

Conservation and efficiency improvements are a continuing process that industries have been working on for economic benefits as well as CO_2 emission reductions by the development of technologies and their applications wherever feasible.

With the finite resources of fossil fuels, alternative fuels and nuclear, solar, wind and hydro-power are under consideration depending on feasibility and economics. Carbon capture and CO_2 sequestration or recycle and other options may be soon realized for the reduction/removal of CO_2 and lowering the global surface temperature in order to receive a future tax credit.

4.0 Fossil Fuels and Hydrogen Economy

A. Fossil Fuels

The world proven fossil fuel reserves of oil and gas are estimated about 346 billion tons vs. 1001 billion tons of coal. At the current rate of consumption, availability of oil and natural gas is expected to be 43 years and 66.7 years respectively, based on January 1, 2006 estimates of 1292.5 billion barrels of oil and 6040 trillion cu ft of natural gas (EIA – 2006 Annual Energy Outlook). On the other hand, the expected life of coal reserves is estimated to be 190 years at 5.26 billion tons of coal consumption per year.

The demands for oil and gas are increasing and proven oil and gas reserves are leveling off. Similarly, proven coal reserves have also been falling from 1167 billion tons to 1001 billion tons in 2003.

Table 2

Proven Oil and Natural Gas Reserves (Billion Tons of Oil Equivalent)
Source: BP Statistical Review of World Energy – June 2004

Year	Oil	Natural Gas
1960	47.30	16.80
1965	55.00	24.60
1970	85.50	36.60
1975	96.10	60.50
1980	99.70	76.80
1986	104.70	95.60
1987	133.30	100.50
1988	136.20	104.70
1989	150.50	105.80
1990	150.20	118.20
1993	153.50	139.70
2002	172.00	173.40
2003	172.40	174.00

Table 3

Worldwide Oil Reserves as of January 1, 2006 (Barrels Billion)

Region	Proven Oil Reserve	Percent
Western Hemisphere	316.4	24.48
Western Europe	14.8	1.14
Asia-Pacific	35.9	2.78
Eastern Europe and FSU	79.4	6.14
Middle East	743.4	57.52
Africa	102.6	7.94
Total Regions	1292.5	100.00
(Total OPEC)	(901.7)	(69.76)

Table 4

Worldwide Natural Gas Reserves (Based on Regions of Economy)
Production/Consumption (Trillion cu ft)

Regions	Reserve	Production	Consumption Present	Consumption 2025
Major Economy	540	40	50	70.5
Emerging Economy	3500	35	25	38.0
Transient Economy	2000	30	25	40.0
Total	6040	105	100	148.5

As in the case of oil, the largest natural gas reserves are in Western Siberia (26.7% Russia) and the Persian Gulf (40.6%), whereas North America and Europe represent only about 4% each.

Global demand for oil has been rising from 77 MMb in 2000 to 82 MMb per day now and is expected to increase 96 MMb in 2010 and 115 MMb per day in 2020. The U.S. consumes about 25% of the total primary energy supply or the equivalent of about 86 billion barrels of oil (2004).

Most of the demand for natural gas is also concentrated in North America and Europe where the proven reserves are only 4.1% and 3.8% respectively. Worldwide, consumption of natural gas is estimated to increase from 92 trillion cu ft to 156 trillion cu ft between 2002 and 2025, and Europe, the former Soviet Union (FSA) and North America combined are projected to share maximum increase in consumption.

Table 5

Increases in Natural Gas Consumption by Region and
Country Group 2002-2025 (EIA/IE '05)

Region	Trillion Cu Ft	Percent (%)
EE/FSU	15	23.4
Emerging Asia (China, India, etc.)	13	20.3
North America	11	17.2
Middle East	8	12.5
Western Europe	7.5	11.7
Central/S. America	4	6.3
Africa	3.5	5.5
Mature Market Asia	2.0	3.1
Total	64.0	100.0

Due to declining rates of production, North America is relying on import of natural gas (LNG) from Africa, the Middle East, Trinidad and Tobago as reserve to production ratio of the Middle East exceeds more than 100 years and Africa 96.9 years (EIA/IEO 2005 report). However, due to the progressively declining rate of oil and natural gas as finite resources, alternative resources are already being considered to produce hydrogen for nitrogenous and phosphate fertilizer as well as energy for other sectors.

B. Hydrogen

Hydrogen for ammonia manufacture and refining, etc. has long been established. Lately, it has gained interest in the transportation sector due to concerns about depleting proven oil and gas reserves and increasing CO_2 concentration in the earth's atmosphere. Currently, 96% of hydrogen production is from fossil fuels and almost half being generated from natural gas by steam reforming. The balance of 4% is available from electrolysis of water.

Table 6

World Hydrogen Consumption
Total 50 MM tons/year (2004)

Industrial Sector	Quantity, MM tons/year
Ammonia	25.3 (142.5 MM tons NH_3)
Refining	17.5
Methanol	4.1
Others	3.1

With the depleting oil and gas reserves in mind and having the largest coal reserves in the world in the U.S. and China, hydrogen production with electricity generation is expected to grow using "clean coal" technology in the future. In a coal gasification plant, hydrogen production cost is estimated at \$2.08 vs. \$1.08 per lb. hydrogen using natural gas by steam reforming. However, conversion cost of a steam reforming plant by partial-oxidation process using petroleum coke could be a viable option particularly at a price of \$12 or less per ton petroleum coke.

The principal commercially established processes for hydrogen production from hydrocarbons and water are:

Process	Reaction
Steam reforming	$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2O$
Naphtha reforming	$C_nH_{2n} + 2nH_2O \rightarrow nCO + (2n + 1)\ H_2$
Fuel oil oxidation	$CH_{18} + 0.98\ H_2O + 0.51\ O_2 \rightarrow CO_2 + 1.88\ H_2$
Coal/coke gasification	$CH_{0.8} + 0.6\ H_2O + 0.7\ O_2 \rightarrow CO_2 + H_2$
Water electrolysis	$2H_2O \rightarrow 2H_2 + O_2$

The other processes using nuclear energy and solar, wind, hydro, geothermal, oceans and biomass as renewable energy have been developed or are under review for the production of hydrogen. New generation IV reactors are planned to operate at a higher temperature around 1200° F or more than the existing nuclear power reactors to produce hydrogen from high temperature steam electrolysis. Other electrolysis processes use either agnous KOH or a solid polymer 'Na fion' by Dupont at a higher temperature to improve efficiency 40% above the standard water electrolysis process.

Among several processes, thermo-chemical cycles of sulfur-iodine/sulfur-bromine have been studied using nuclear and other renewable energy sources. Two of these processes considered electrolysis steps that use much less electrical energy than water electrolysis (Westinghouse S cycle and JRC Euratom Mark 13).

Process steps:

Westinghouse S cycle

$SO_2 + 2H_2O \rightarrow H_2SO_4 + H_2$ (77° F, 0.17V)

$H_2SO_4 \rightarrow H_2O + \frac{1}{2} O_2 + SO_2$ (1600° F)

JRC Euratom Mark 13

$2\,HBr \rightarrow H_2 + Br_2$ (175° F - 480° F, 1.066V)

$H_2\,SO_4 \rightarrow H_2O + SO_2 + \frac{1}{2} O_2$ (1200° F - 1560° F)

$Br_2 + SO_2 + 2\,H_2O \rightarrow 2\,HBr + H_2SO_4$ (68° F – 250° F)

The Mark 13 process claims about 40% overall efficiency with electrolysis. The Sulfur-Iodine cycle as studied by General Atomics also requires sulfuric acid decomposition at a high temperature of 1600° F and iodine-SO_2 reaction at a lower temperature of 77° F in the presence of water.

General Atomics

$I_2 + SO_2 + 2\,H_2O \rightarrow 2HI + H_2SO_4$ (77° F)

$H_2SO_4 \rightarrow H_2O + SO_2 + \frac{1}{2} O_2$ (1600° F)

$2HI \rightarrow H_2 + I_2$ (575° F)

The thermo-chemical heat requirement can be available from nuclear facilities using high temperature nuclear reactors to provide temperatures between 1650° F-1850° F.

Table 7

Hydrogen Production Costs for Various Processes
Capacity 247 s.tons/day (86,450 s.tons/year)

Process	**Steam Reforming**	**Partial Oxidation**	**Coal Gasification**		**Water Electrolysis**
Feed Stock	Natural Gas	Refinery Oil	Coal (Bituminous)	Coke (Petroleum)	Water and electricity
Efficiency %	83	70-80	63	70	27
Consumption (per ton hydrogen)	157.1 MM BTU	146 cu ft	940 lb	940 lb	49.240 kwh
By-product production per ton hydrogen	14 lb steam	243 lbs sulfur	567 lbs sulfur	567 lbs sulfur	2.813 tons oxygen
Capital Cost ($, MM)	250	650	950	600	400
Production Cost, $/100 lbs hydrogen					
Feed	58.91	51.10	14.10	5.64	61.55
Unit Cost	$7.5/MM BTU	$7.0/cu ft	$30/ton	$12/ton	$ .025/kwh
Operation & Maintenance	12.73	32.80	55.84	55.84	14.64
Capital	36.78	96.83	140.00	88.27	58.85
By-product Credit	(-) 0.90	(-) 0.39	(-) 2.26	(-) 2.26	(-) 4.50
Total $/100lbs hydrogen	107.52	180.34	207.68	147.49	130.54
Total $/lb hydrogen	1.08	1.80	2.08	1.47	1.31

Water splitting by electrolysis may also become a viable option if integrated with a nuclear or hydro-power electricity generation unit. It is a “clean” process and does not require any CO_2 capture or CO_2 sequestration step.

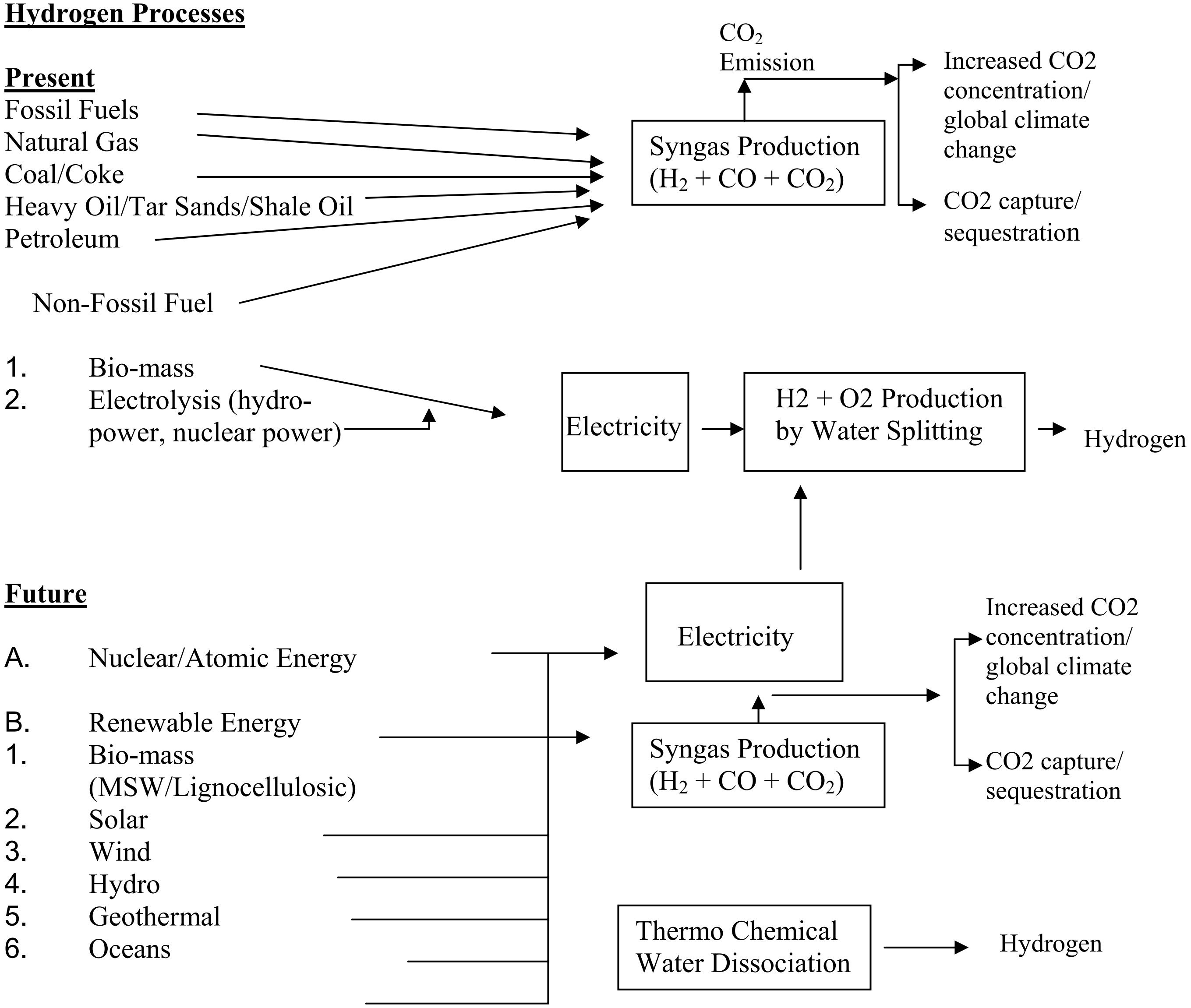
Due to global warming concerns, more processes are being developed and several are tested for hydrogen production not only in the industrial sector but also in the transportation sector as well. Large-scale demonstration of solar and wind power to produce hydrogen by standard water electrolysis is underway.

Table 8

U.S. DOE Goals for Future Hydrogen Cost

Technology	Goal	Target Year
Hydrogen from natural gas and liquid fuels	Delivered cost of \$1.50/kg (\$0.68/lb)	2010
Electrolysis	Delivered cost of \$2.50/kg (\$1.14/lb)	2010
Photo electro-chemical water splitting	Delivered cost of \$5/kg (\$2.27/lb)	2015
Biomass	Delivered cost of \$2.60/kg (\$1.18/lb)	2015
Biological system	Delivered cost of \$10/kg (\$4.54/lb)	2015
Thermo-chemical cycles using nuclear heat	Demonstration of technical capability with gasoline	2015
Other	Evaluate new production technology	2015

Hydrogen Processes



5.0 Ammonia and Fertilizer Outlook

Ammonia production in the U.S. declined 37% from 14.5 million tons of nitrogen to 9.16 million tons during the past eight years (1996-2004) due to increased oil and natural gas prices (at $7.5 per MM BTU) between these periods. The supply of nitrogen fertilizer to the U.S. was adequate by 43% in import and 7% in agricultural consumption of fertilizer. Eight U.S. nitrogen manufacturers shut down their plants. On the other hand, world production of urea increased 3.5% in 2006 over 2005 and China alone contributed about 60% of this increase. The global demand for urea is forecast to grow by 4% in 2007 and 3% between 2007-2015 and will continue to grow throughout the present decade.

The current increasing trend of demand for urea and other nitrogenous and phosphate fertilizers (e.g. $AmNO_3$, CAN, DAP/MAP/N-P-K) are due to high corn prices for production of bio-fuel (bioethanol, biodeisel, etc.) due to a current $4.50 per bushel. Farmers seem unconcerned about high fertilizer prices if they can boost earnings at an increased crop price using 88-90 million acres of land.

Table 9

Year	FOB Urea Price ($/ton)	Corn Price ($/bu)
1990	125	2.5
1993	100	2.5
1995	175	3.25
1997	100	2.30
1999	100	2.20
2001	100	2.25
2003	125	2.40
2005	220	2.50
2006	275	3.50
2007 (March)	325	4.40

With modernization, a 2000 tpd ammonia plant using natural gas steam reforming can lower its current energy consumption from 31 MM BTU to 27 MM BTU or lower per ton of ammonia. The modernization cost is expected to pay off within a period of three years from energy savings at the current gas price of $7.5 per MM BTU

$$\left(4\ \frac{\text{MM BTU}}{\text{ton}} \times \frac{\$7.5}{\text{MM BTU}} \times \frac{660{,}000\ \text{tons}}{\text{year}} = \$19.80\ \text{MM/yr}\right)$$

at investment cost of $60 MM. Urea plant energy reduces and reaps $17 savings per ton urea from modernization. In addition, profit margin improves at urea price of $325 per ton due to the current market situation which is expected to continue due to demand for increased crop production.

World cereal production as well as stocks decreased between 2004-2006 and global cereal consumption is expected to increase according to FAO. This will cause cereals to stock ratio to fall (which is estimated at 16%) to its lowest level and the need for more fertilizer consumption will result.

Table 10

World Cereal Production/Stocks (million m.tons)
Source: IEA

Year	Wheat	Rice (Milled)	Grains (Coarse)	Total
2006/2007	587 (118.8)	417 (78.8)	965 (121.7)	1969 (319.3)
2005/2006	619 (147.1)	416 (80.6)	975 (167.1)	2010 (394.8)
2004/2005	629 (151.4)	401 (78.1)	1105 (179.0)	2135 (408.5)

Table 11

World Bio-fuel Production, 2005 (billion liters)
Source: IEA

Country	Ethanol	Biodiesel	Total
World	33.6	3.7	37.3
United States	14.7	0.3	15.0
EU	0.9	3.2	4.2
China	1.0	-	1.0
India	0.3	-	0.3
Brazil	16.1	0.1	16.1

The total effect of low cereal to consumption, high crop prices and higher biofuel/biodiesel production has pushed the current price of ammonia to $350, urea to $360 per ton and DAP $400/ton and 2006 has become a very good year. The global demands for phosphoric acid and phosphate fertilizers are strong as global demand increased by 3.3% in 2006, reversing the decline of 0.4% seen in 2005.

Table 12

Ammonia Production in the U.S. and Other Regions
During 2002-2004 ('000 M tons of N)
Source: TFI Data

Region	**Period**		
	2002	**2003**	**2004**
World	117,300.0	108,010.9	107,664.6
EU 25	11,862.2	12,513.0	12,878.3
United States	10,338.0	8,605.0	9,160.0
West Asia (Middle East)	8,524.6	8,036.9	8,043.9
Asia	19,769.0	20,211.4	20,730.8
East Asia (China)	28,983.0	30,207.0	34,704.8
Asia (India)	9,827.0	10,047.8	10,717.6

Table 13

Phosphate Fertilizers and Phosphoric Acid Capacity Forecast (Global)
Between 2006-2009, ('000 t/a P_2O_5)

Fertilizer	**Year**			
	2006	**2007**	**2008**	**2009**
DAP	20,798	21,359	22,189	22,544
MAP	7,824	7,643	8,090	8,184
TSP	3,575	3,240	3,279	3,279
Phosphoric Acid	43,121	43,147	45,325	46,404

6.0 Alternative Fuels

Bio-Fuel (Ethanol) and Lignin

Cellulose, hemicellulose and lignin are the organic compounds which make up the biomass of trees and are produced in the largest quantity by natural processes such as photosynthesis. Cellulosic biomass or lignocellulosic biomass is available as a feed stock for bio-conversion to renewable fuel from wood crop residues, grains, etc.

Eucalyptus trees as tested in a commercial planting demonstration program suggested a low yield of 20 green tons (10 dry tons)/acre/year. That may be converted to produce ethanol with a yield of about 80 gallons of ethanol/ton or 800 gallons/acre per year by using data from common wood species such as poplar. The conversion process with continuous dynamic immobilized bio-catalyst bio-reactor (CDIB) and Simultaneous Saccharification and Fermentation (SSF) process is economically attractive (with a return on investment of 13% - 21%) and environmentally friendly with 'lignin' (Co-product) price $0.25/lb and ethanol price between $2.00-$2.50/gal.

Ethanol Production Cost and Return on Investment (ROI)

Annual Ethanol Production	5 MM gallons
Annual Lignin Production	11,000 tons
Plant Capital Cost	$25 MM
Working Capital	$5 MM

A. Operating cost ($, MM/year) $6.50 MM ($1.30/gal)

Feed Wood	2.00
Chemicals	0.75
Utilities	0.75
Maintenance/Labor	2.00
Supervision	1.00

B. Capital Charges ($, MM/year) $5.00 MM ($1.00/gal)

Amortization	2.10
Interest on Capital	1.26
Interest on Construction	1.26
Interest on Work Capital	0.38

C. Annual Income

(i) Ethanol (@ $2.50/gal) = $12.50 MM
Lignin (@ $0.25/lb) = 5.50 MM
Total $18.00 MM

$$\% \text{ ROI} = \frac{(\$18.00 - \$6.50 - \$5.00) \text{ MM x100}}{\$30 \text{ MM}}$$

= 21.66

(ii)

Ethanol (@ \$2.00/gal) =	\$10.00 MM
Lignin (@ \$0.25/lb) =	5.50 MM
Total	\$15.50 MM

$$\% \text{ ROI} = \frac{(\$15.50 - \$6.50 - \$5.00) \text{ MM}}{\$30 \text{ MM}}$$

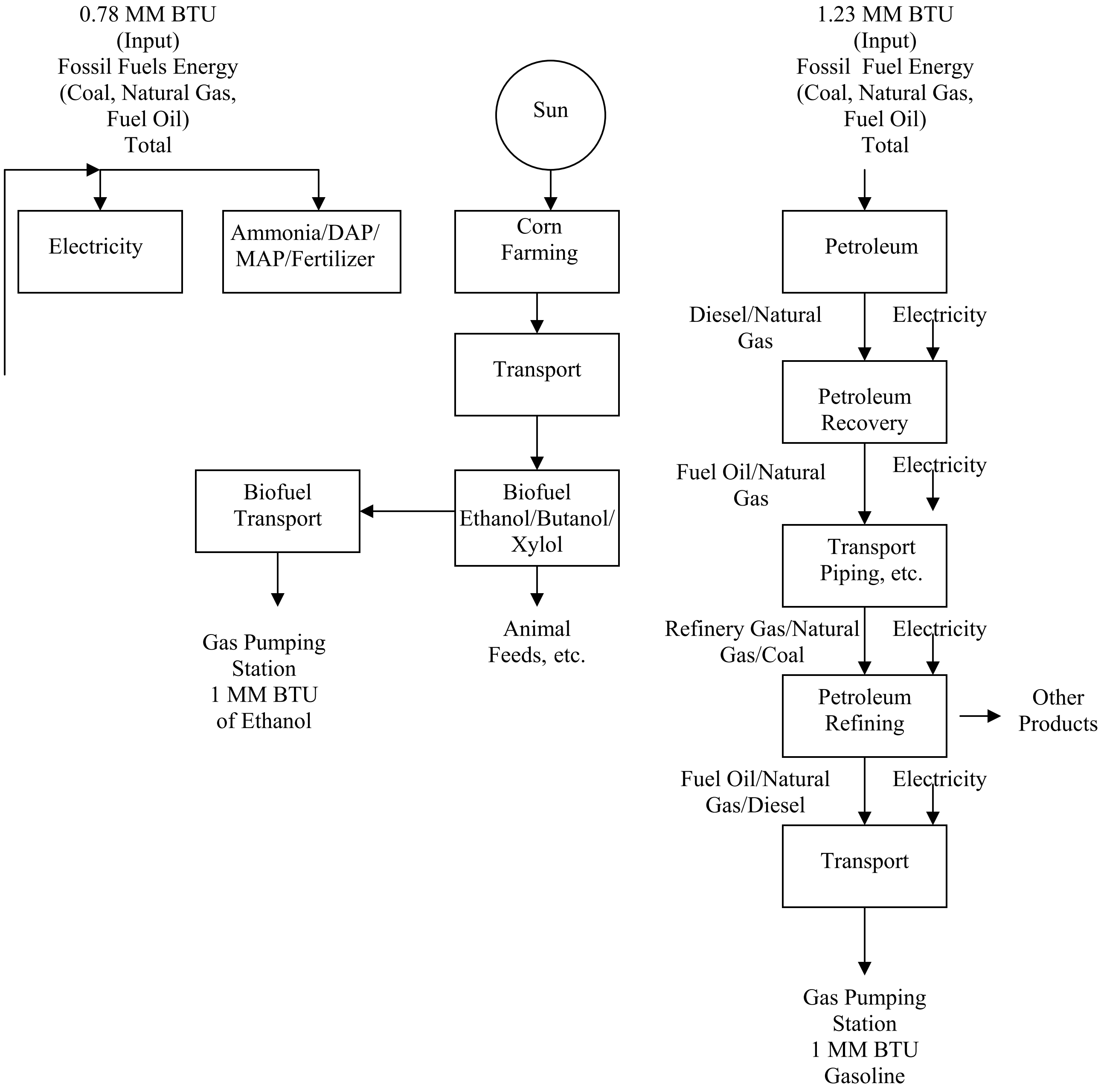
= 13.33

In summary, utilizing mined phosphate land by ‘tree’ crop plantation would minimize global warming and eliminate cogongrass, provide renewable energy, permanent carbon storing and soil building.

Bio-Butanol

Among advanced biofuels, bio-butanol ranks first due to its compatibility with existing fuel supply/distributions and gasoline-biofuel mix in increased proportion. It has a lower vapor pressure complete miscibility with diesel fuel even at lower temperature and better fuel economy.

Butanol production is aimed at developing a significant part, possibly up to 20%-30% of the transport-mix in future. It is expected to convert about 100,000 tons/year of sugar into 30,000 tons/year of butanol. Dupont is working on improvement of the fermentation process that is currently known as the ABE (Acetone-Butanol-Ethanol) process by carbohydrate fermentation using sugarbeets, cereals and sugarcane, beets, corn, wheat, cassava, etc. in the future.


0.78 MM BTU (Input) Fossil Fuels Energy (Coal, Natural Gas, Fuel Oil) Total
Electricity
Ammonia/DAP/MAP/Fertilizer
Sun
Corn Farming
Transport
Biofuel Ethanol/Butanol/Xylol
Biofuel Transport
Gas Pumping Station 1 MM BTU of Ethanol
Animal Feeds, etc.
1.23 MM BTU (Input) Fossil Fuel Energy (Coal, Natural Gas, Fuel Oil) Total
Petroleum
Diesel/Natural Gas
Electricity
Petroleum Recovery
Fuel Oil/Natural Gas
Electricity
Transport Piping, etc.
Refinery Gas/Natural Gas/Coal
Electricity
Petroleum Refining
Other Products
Fuel Oil/Natural Gas/Diesel
Electricity
Transport
Gas Pumping Station 1 MM BTU Gasoline

7.0 Tree-Crop Plantations

The co-firing concept for existing electric power plants in central Florida was pilot-tested in 50 ha of phosphate mined lands and unimproved pastures on a clay settling area (CSA) near Lakeland, Florida. The data documented (a) real world 'SRWC' costs (b) developed guidelines for establishing and managing SRWC on CSA and (c) evaluated genetic, cultural and harvesting options for further improving the cost effectiveness of cotton wood (PD, Populus deltoides), Eucalyptus grandis (EG) and E. amplifolia (EA).

In this and other field studies and/or commercial scale plantings, EG and EA grew well and production of EA on CSA's looked profitable. EG and EA SRWCs appeared (a) to improve CSA soil characteristics (b) exclude cogongrass (c) facilitate the establishment of native plants and (d) EG and PD dominated portions had much more favorable soil than cogongrass-dominated areas as ten- and four-fold increases in soil nitrogen and carbon respectively were noted in the EG commercial planting.

SRWC may thus serve as 'bridge crops' to restore cogongrass infested CSA's to native forest or productive agricultural lands while maintaining or even augmenting forestry's current $685 million annual value and 6,800 jobs in Polk County. These results also emphasize both the potential for SRWCs on CSA's to mitigate atmospheric CO_2 and for CO_2 mitigation incentives to contribute to SRWC profitability.

While EG and EA growth can be quite high, SRWC cost competitiveness depends on establishment success, yield improvements, harvesting costs, markets, incentives and ultimately public and private partnering is necessary for commercializing SRWC's on ~116,000 acres of reclaimed phosphate mined lands for co-firing in central Florida.

Choosing Central Florida

Florida is the third largest electricity market in the U.S. with a warm climate and a long growing season resulting in high crop yields, extensive coal power plants that can co-fire biomass fuels and a large land base of unutilized/marginal lands (Rockwood et al, 2004). Closed phosphate mined lands are the most unused and lowest valued land base in central Florida and ~40% of all mined lands are CSAs, which are composed of clay slurries in 30' to 60' deep mining pits. Currently, there are ~65,000 ha of CSA's that are largely undeveloped. Prior research has shown that CSA's are extremely fertile, high in K and P (Stricker et al, 2000). When use has occurred on CSAs, it is primarily low financial return cattle grazing (land lease rates of $15 to $30 per acre per year).

Demonstration Energy Farm (Closed Loop Biomass)

In conjunction with numerous public and industry partners, a ~50 ha SRWC (closed loop biomass) Energy Farm was established near Lakeland in central Florida to demonstrate and commercialize SRWCs. The site was a cogongrass infested CSA before site preparation in Spring 2000. The Energy Farm primarily consisted of non-invasive EG and EA progenies resulting from decades of genetic improvement by UF and others

(Meskimen et al, 1987, Rockwood et al, 1993) and PD native to the southeast including Florida.

A key consideration in siting the Energy Farm in Lakeland was close proximity (2 to 40 miles via truck and/or rail) to power plants including Lakeland Electric's 365 MW McIntosh Unit (pulverized coal), Tampa Electric's 250 MW Polk Power Station (coal gasification IGCC) and Wheelabrator Ridge Generation's 40 MW Station (stroker boiler). All of these units except the Polk Power Station have been permitted by the FDEP to co-fire SRWC fuel.

Methodology

Studies established at the Energy Farm included a clone-configuration-fertilizer study (SRWC-90), a PD clonal nursery and demonstration and commercial plantings. SRWC-90 involved Pd, EG and EA, each representing up to six genotypes, two planting configurations (single or double rows per bed) and two fertilizer levels (0 or 100 lbs/acre of ammonium nitrate) in a split-plot design with configuration main plots, species subplots and genotypes in 6-tree row subplots (Segrest et al, 2004). The initial planting was done in March 2001 and fertilizer treatments were implemented in June 2002. Tree size and survival were measured periodically. EG, EA and five PD clones were planted in two configurations in a demonstration area in April 2001. After periodic size and survival measurements, approximately half of each block was felled in February 2002. Mulching and compost treatments were superimposed on harvested areas in May 2002. Several commercial scale plantings were made.

Results and Discussion

Growth Performance

The PD in SRWC-90 was greatly impacted by drought after hand planting in March 2001. Survival dropped to about 30% as the surface soil dried before the cuttings could develop effective root systems. Consequently, PD compared poorly to EA and EG after 28 months. PD survival was less than 40% in all fertilizer and planting density combinations.

EA and EG seedlings typically have survival rates exceeding 80%, and EA usually has a survival rate over 90% even at double row configuration. EA, although not necessarily as vigorous as EG, tended to have the highest productivity. However, peak productivity of EA, and by extension the other two species, may be a year or more away even with fertilization and double rows. "Preliminary" estimates of yields in the commercial plantings suggested a low of 20 green tons (10 dry tons)/acre/year and a high of 32 green tons (16 dry tons)/acre/year for eucalyptus with high survival at the end of a rotation.

EA can be expected to have high survival on well-prepared bedded CSAs, respond favorably to fertilization, tolerate high stand densities and coppice reliably. EA tends to be more dens and contain less water than EG (Rockwood et al, 1995), but variation within EG may be useful in improving these properties (Wang and Rockwood, 1989). EG has the potential to be the most productive species with thorough site preparation and fertilization and properly timed harvesting. EG is best suited for immediate commercialization because of its ample availability of seed, while seed of EA is limited and PD cuttings are in high demand.

Economic Analysis

Analyses for PD and EG in a sewage effluent study near Orlando (Rockwood et al, 2004) provide a reference for growth and economics on phosphate mined lands. PD coppice yields were roughly equivalent to those of EG, but PD first rotation yields were considerably less.

Based on a mulch wood stampage price of $10/green ton, average EG 'without coppice' produced the least return, and EG average with coppice was more profitable since coppicing was more beneficial than replanting after the first rotation. Faster growing progenies such as EG 3309 increased profitability, especially without coppicing, as land expectation value was $2,967/acre and equalized annual earning was $118/acre/year. While landscape mulch is a present use of EG and mulch companies may offer up to $15 per green ton, an increasing number of companies may offer up to $15 per green ton, increasing demand for energy wood by public utilities is likely to increase stumpage prices if tax credits are enacted for co-firing.

The high cost of establishment and harvesting/chipping in the 'high cost scenario' (Table 14) make SRWCs at $32/green ton or $3.55/MM BTU with a wood yard, non-competitive with coal. A large component ($340/acre) of this cost was control of cogongrass, one of the world's ten worst invasive weeds, through disking and two applications of herbicide to kill rhizomes.

Table 14

Estimated Delivered Cost ($ per Green Ton and MM BTU) for Three SRWC Scenarios

Cost Component	**Scenario**		
	High Cost	Low Cost	Target Case
Tree Establishment	4/0.45	0/0	2/.20
Harvesting/Chipping	15/1.65	8/.90	10/1.10
Transportation	5/.55	3/.35	4/.45
Total w/o Wood Yard	24/2.65	11/1.25	16/1.75
Total with Wood Yard	32/3.55	15/1.70	20/2.20

The “low cost” scenario assuming entirely reimbursed establishment costs and reduced harvesting cost makes SRWCs at $15/green ton or $1.70/MM BTU with a wood yard competitive with coal. Delivered energy crop fuel using traditional methods is dominated by harvesting costs – up to 70% of total tree fuel costs. Using the traditional harvesting equipment as is used in the forest and sugar cane industries has considerable potential for improving the economic viability of SRWCs.

The “target case” scenario, our general best estimate of achievable costs, puts SRWCs in the range of coal. It reflects either partially subsidized establishment costs or establishment is on more typical agriculture land and use of traditional harvesting equipment.

The Section 45 Federal Tax Credit for Wind and Closed Loop Biomass can dramatically improve SRWC economics. The Polk Power Station and the Ridge Generation Unit qualify for Section 45. Tampa Electric is the only electric utility in the U.S. currently marketing green energy to its customers from biomass co-firing, which is viewed favorably by Florida homeowners (Adams, 2003). However, residential/commercial subscription rates are extremely low (well below 1%), suggesting that only Federal or State of Florida renewable energy legislation will likely result in any meaningful demand for SRWC fuel.

Another competitive advantage of SRWCs is that the ash content (entrained dirt) of the delivered fuel can be 3 to 4 times lower than wood wastes. With lower ash content, operation/maintenance costs on existing handling equipment at power plants would likely be reduced.

Our Energy Farm also demonstrates environmental and cost benefits of developing SRWCs on un/underutilized marginal lands. With SRWCs growing up to 20’ per year, 1) a forest canopy quickly forms to very effectively control “shade intolerant” cogongrass, and 2) a dramatic decrease in soil pH from ~8 initially to 6.5 occurs, much more conducive not only to tree growth but native flora. SRWC economics would significantly improve if SRWCs qualified for state and federal funding avenues for reclamation/remediation.

Co-firing SRWCs at coal power plants has special significance for global warming. Most renewable energy technologies generally have operating characteristics (e.g.., capacity factors, load curves) representative of peaking and intermediate units, thus typically displacing natural gas generation from an integrated resource grid. Clearly, this is the case for solar and also wind energy projects where most kWh generation would occur during daylight hours. Conversely, biomass cofiring unquestionably displaces coal use (typically base load units). Approximately 90% of all CO_2, NOx, and SO_2 emissions from electric utilities come from coal generation. Generally, biomass fuels used in cofiring applications at coal power plants are carbon cycle neutral (just like wind or solar power).

However, SRWC fuels have an additional CO_2 reduction component that other renewable energy options do not have, as the below ground carbon storing of 40% of whole tree biomass at our Energy Farm, illustrates. On environmentally damaged lands (e.g., mined lands), existing organics/carbon levels in soils can be extremely low or almost non-existent. Any carbon storing on environmentally damaged lands up to the carbon soil saturation level would be permanent.

8.0 Conclusions

- The climate change due to global warming and increase in CO_2 concentration in the earth's atmosphere by human activities is real and the U.S. shares about 24% of the world's total energy related CO_2 emissions.
- Depletion of finite reserves of oil and gas may work in favor of reduction of the impact due to CO_2 emissions subject to the success of clean coal technologies (CCT), coal to liquid (CTL) and carbon capture and sequestration (CCS) processes.
- Among five proven hydrogen technologies for ammonia in fertilizer and transportation sectors, (i) steam reforming of natural gas process is most economical with the lowest hydrogen production cost at $1.08 per lb (even at a current natural gas price of $7.50/MM BTU). It is expected to be lower than a dollar per pound by using new energy conservation design features, (ii) standard water electrolysis process is both economical (hydrogen production cost of $1.31 per lb) and environmentally friendly if electricity is available from a 'hydro', nuclear or solar photo-voltaic source, (iii) petroleum coke gasification process is economical for hydrogen production of $1.47 per lb at feed stock price of $12/ton which is suitable for Gulf Coast plants.
- An alternative fuel process for ethanol and 'lignin' production using lignocellulosic materials from wood shows a return on investment (ROI) between 13%-21% at ethanol price of $2.00-$2.50 per gallon and 'lignin' price of $0.25 per lb. It looks like 'bio-butanol' may also be attractive in the future for transport fuel-mix by using various forest tree feed stocks due to its compatibility with gasoline.
- The economic benefits from studies of demonstration program for 'SRWC' e.g. eucalyptus in phosphate-mined land are attractive in Florida in particular, based on green wood cost of $1.67-$2.22 per MM BTU for biofuel production and 'bio-mass' cofiring (that has a special significance for global warming) in coal-fired boilers in utility industries. SRWC fuels have an additional CO_2 reduction capability as the below ground carbon storing of 40% of the whole tree bio-mass as the Energy Farm illustrates.

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