“Green is Seen in Fertilizers”

Municipal Solid Waste Management

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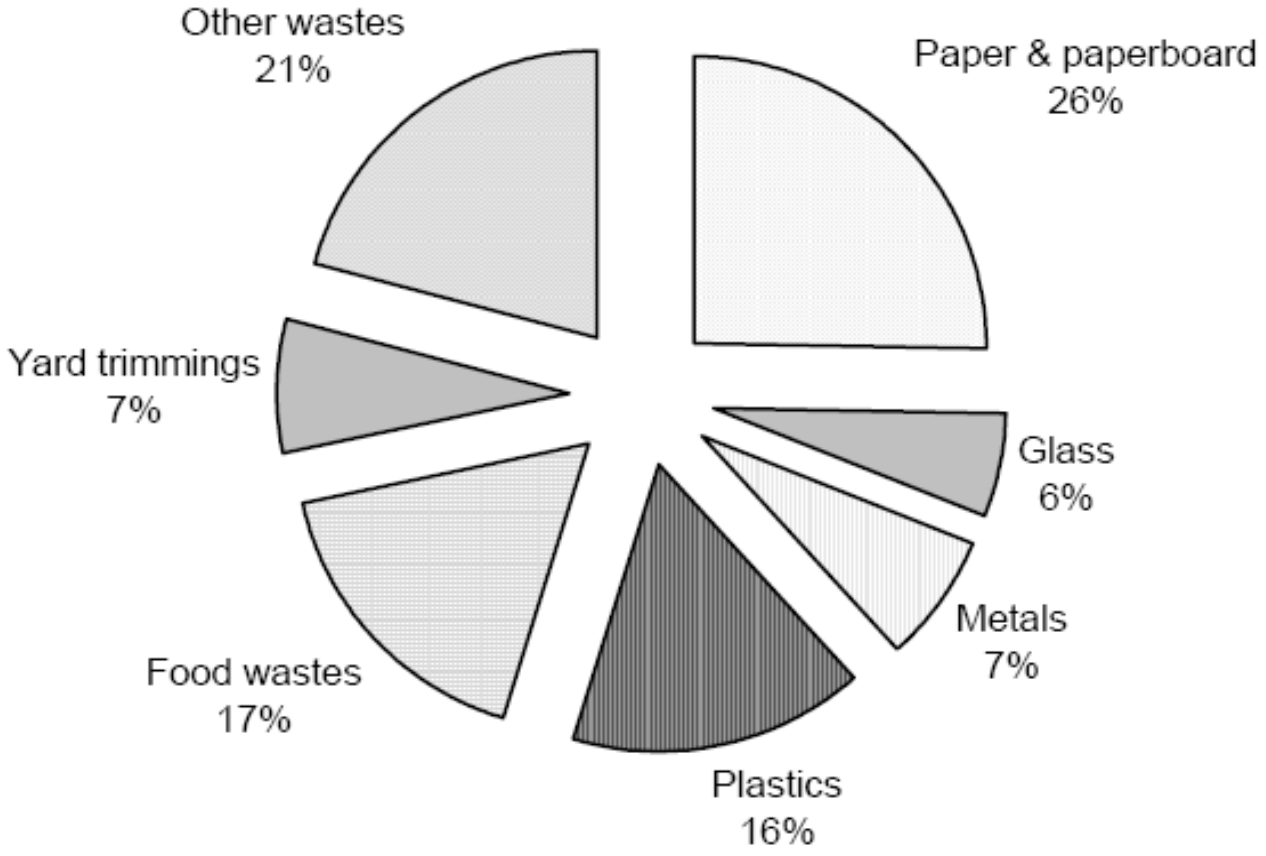
May 1, 2007

MSW Overview
EPA 2005 Facts and Figures

U.S. Waste Produced = 245.7 million ton



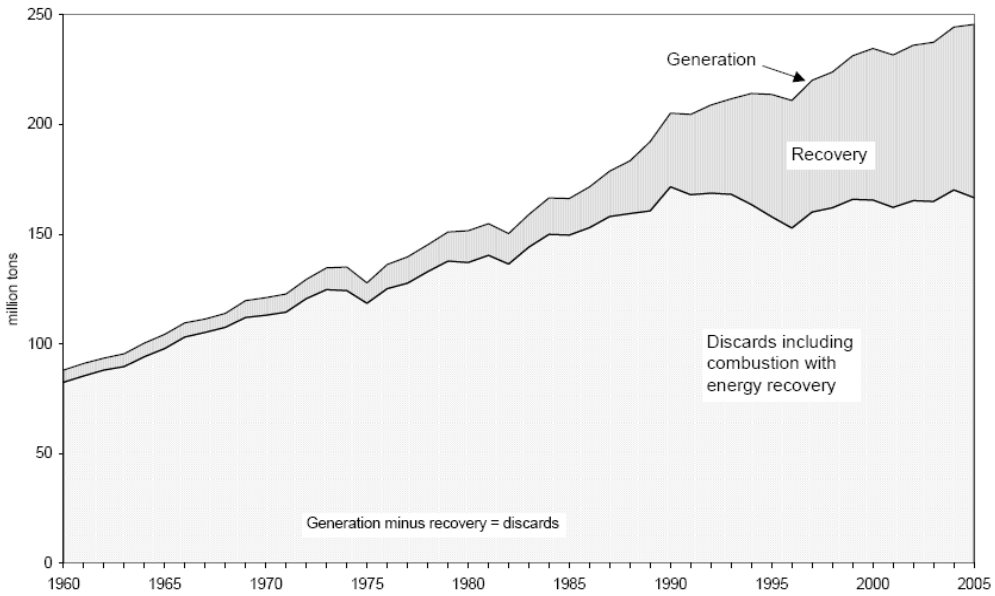
Municipal Solid Waste

- Composition is highly variable
- Poor quality fuel
  - Low heating value
  - High moisture content
- Difficult to handle and feed to process equipment

Landfilling

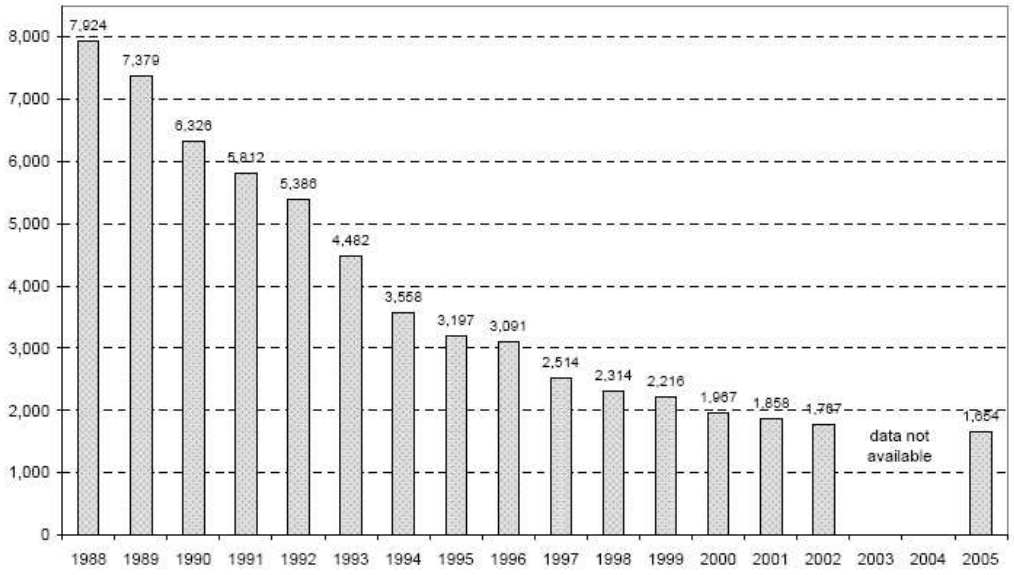
- Waste is deposited and buried
  - Produces leachate
    - Groundwater pollutant
  - Greenhouse gas emissions
    - Methane and CO_2
  - Costs cities $10 to $70 per ton
  - Reduces nearby land property value
  - 2005: Landfill Waste
    - 133.3 million tons

Figure 11. Recovery and discards of materials in MSW, 1960 to 2005



Municipal solid waste has steadily increased throughout the past 45 years.

Figure ES-5: Number of Landfills in the United States, 1988-2005



The number of landfills has steadily decreased throughout the past 17 years.

Incineration

- Waste is completely combusted
  - Minimizes land required by landfills
    - Reduces weight by up to 90%
  - Waste-to-energy
  - Pollutants
    - Greenhouse gases
    - Toxic ash
  - High operation costs
  - 2005: Waste combusted with energy recovery
    - 33.4 million tons

Pyrolysis/Gasification

- Partial combustion
  - Limited (less than stoichiometric) amount of oxygen
  - Thermally self-sustaining
    - Combust a small portion of the feed to generate heat for pyrolytic reactions

$$C + O_2 \rightarrow CO_2 \qquad \Delta H = -406 MJ / kmol$$

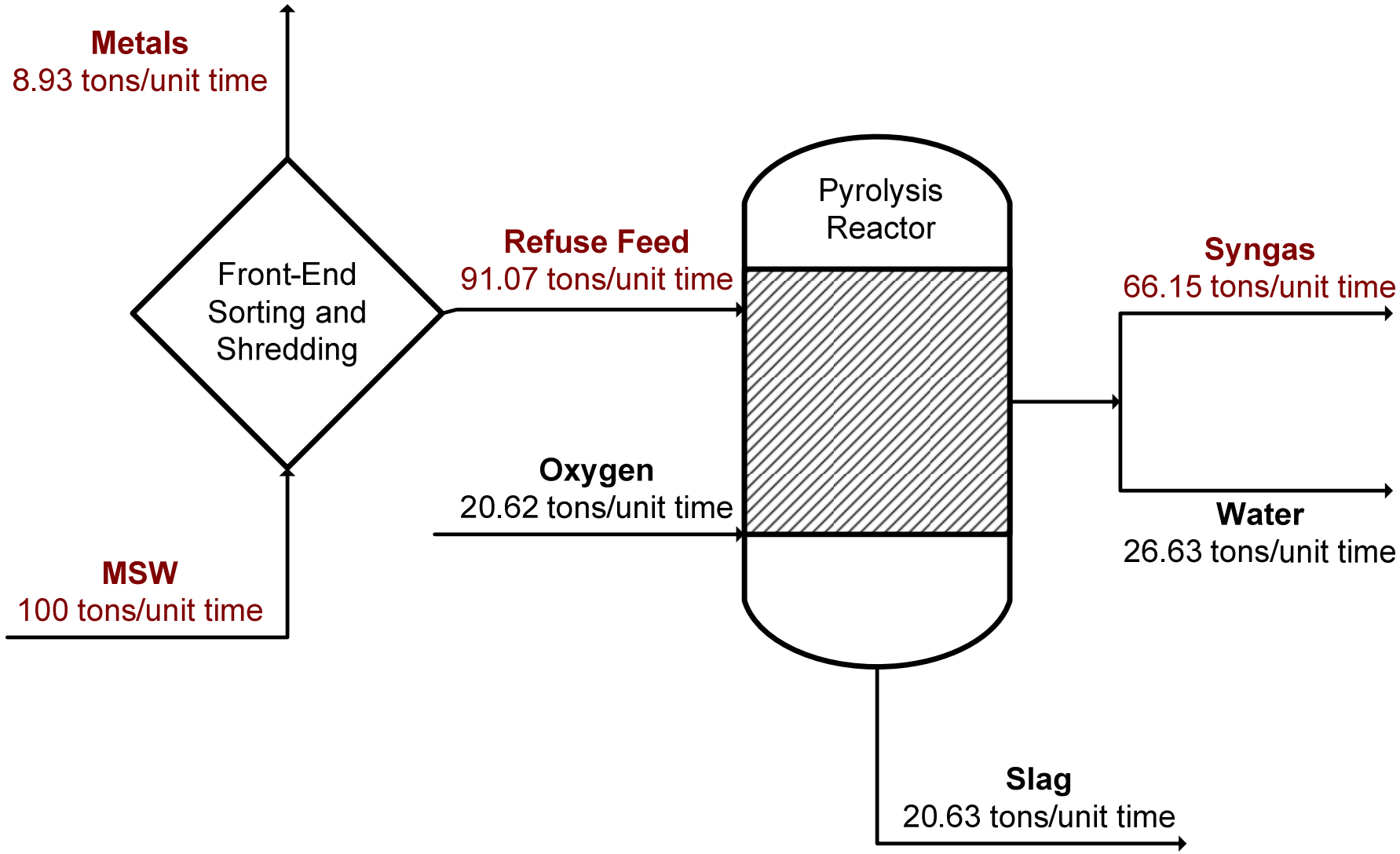
$$C + H_2O \rightarrow CO + H_2 \qquad \Delta H = 131 MJ / kmol$$

$$C + CO_2 \rightarrow 2CO \qquad \Delta H = 173 MJ / kmol$$

Benefits of Pyrolysis/Gasification

- Potential to be profitable
  - Produce fuel or chemicals
- Reduce quantity and improve quality of solid discards
  - Remedy municipal solid waste management problems

Pyrolysis Mass Balance



Pretreatment Processing

- Shredding to reduce MSW particle size
- Air/density separator
  - Heavy fraction exits bottom
    - 90% of ferrous removed in magnetic separator
    - 66% of aluminum removed in eddy current aluminum separator
  - Light fraction, mostly organic, exits the top
    - Cyclone removes particulates

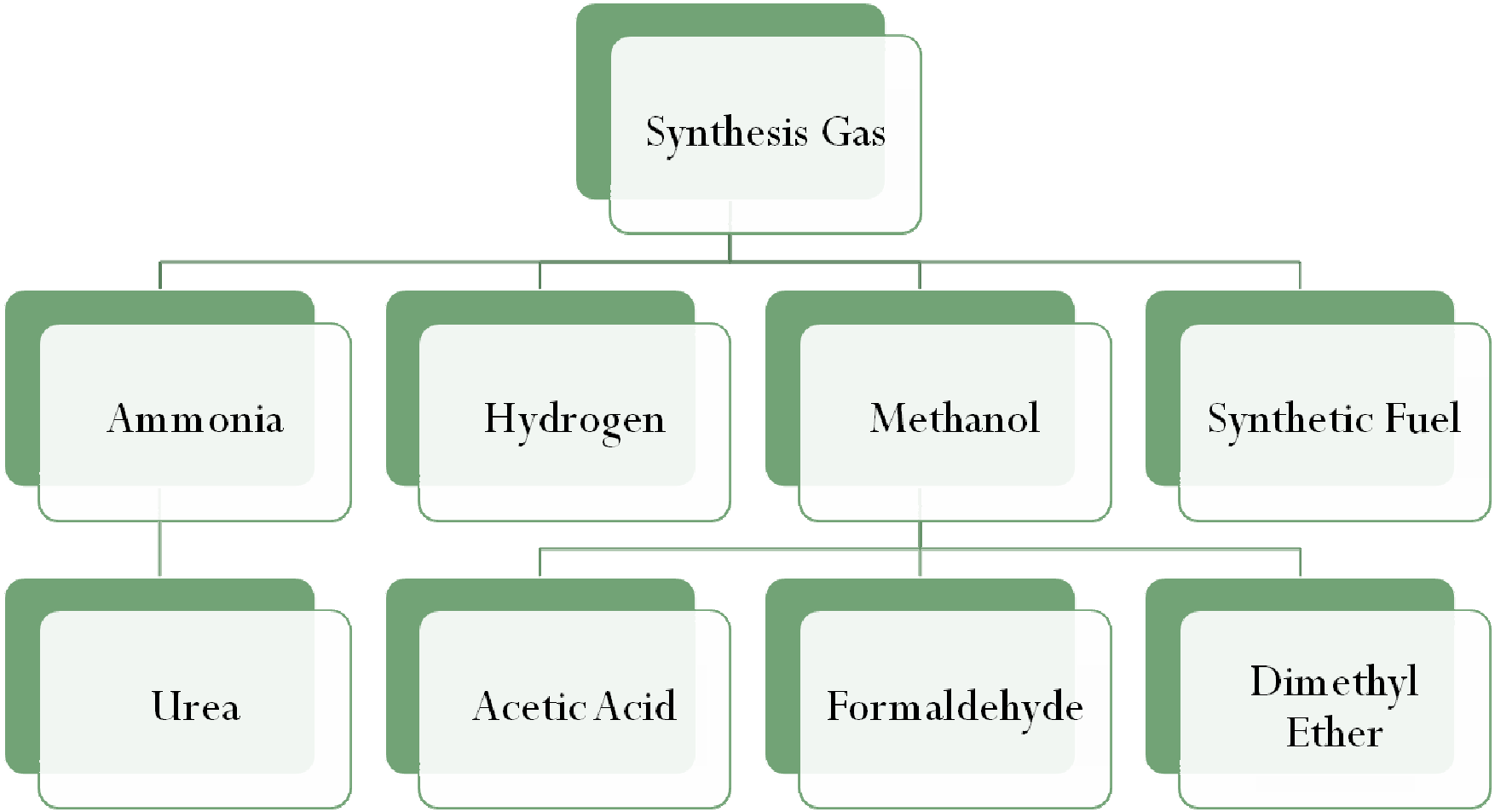
Pyrolysis/Gasification

- Exothermic reactions in oxidative zone
- High temperature endothermic reactions in the reduction zone
  - In the absence of oxygen
- Produces two products
  - synthetic gas
  - slag

Synthesis Gas

- Molar composition
  - Carbon monoxide – 40%
  - Hydrogen – 24%
  - Carbon dioxide – 24%
  - Other gases – 12%
- Typically produced from coal or hydrocarbons
- Syngas composition can be altered depending on desired end product

Product Options



Product Selection

- Criteria
  - Profitability based on NPW and IRR
    - Varied MSW capacity
  - Current and Future Market
- Estimated using information in literature and current journals
  - Total Capital Investment
  - Product Price
  - Operating Cost

Economic Assumptions

- Total Capital Investment

$$C_{New} = C_{Old} R^{0.65}$$

- Operating Cost and TCI scaled up using cost indices
- Product Price
  - Most Current Available Prices
- Neglected
  - Front End Processing
  - Waste Revenue
  - Taxes, Depreciation, Inflation

Economic Model: Acetic Acid Production

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Total Capital Investment	$130,563,377	Acetic Acid Production	177,294,150 lbs/year	0.00%	Inflation
Tax Rate	0%	Acetic Acid Price	$0.31/lb	0.00%	Inflation
Main Display Discount Rate	10%	Operating Cost	$36,199,558/year	0.00%	Inflation

Year	Total Capital Investment	Acetic Acid Yearly Production (lbs)	Acetic Acid Price ($/lb)	Gross Revenue	Annual Product Cost	Net Profit After Taxes	Depreciation	Annual Cash Flow	Cumulative Cash Flow	10% Discounted Cash Flow
0	$130,563,377	0		$0	$0	$0	$0	-$130,563,377	-$130,563,377	-$130,563,377
2007		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	-$111,801,749	$17,056,026
2008		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	-$93,040,120	$15,505,478
2009		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	-$74,278,492	$14,095,889
2010		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	-$55,516,864	$12,814,445
2011		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	-$36,755,235	$11,649,495
2012		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	-$17,993,607	$10,590,450
2013		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	$768,021	$9,627,682
2014		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	$19,529,650	$8,752,438
2015		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	$38,291,278	$7,956,762
2016		177,294,150	$0	$54,961,186	$36,199,558	$18,761,628	$0	$18,761,628	$57,052,907	$7,233,420
S_v	$0	0		$0	$0	$0	$0	$0	$57,052,907	$0
Total:		1,772,941,497		$549,611,864	$361,995,580	$187,616,284	$0	$57,052,907	$57,052,907	-$15,281,293

Economics Summary

Net Present Worth Table:

0%	$57,052,907	40%	($85,280,856)
5%	$14,308,944	50%	($93,690,831)
8%	($4,671,324)	60%	($99,578,390)
10%	($15,281,293)	70%	($103,893,999)
15%	($36,403,105)	80%	($107,177,025)
20%	($51,905,774)	90%	($109,751,124)
30%	($72,561,062)	100%	($111,820,071)

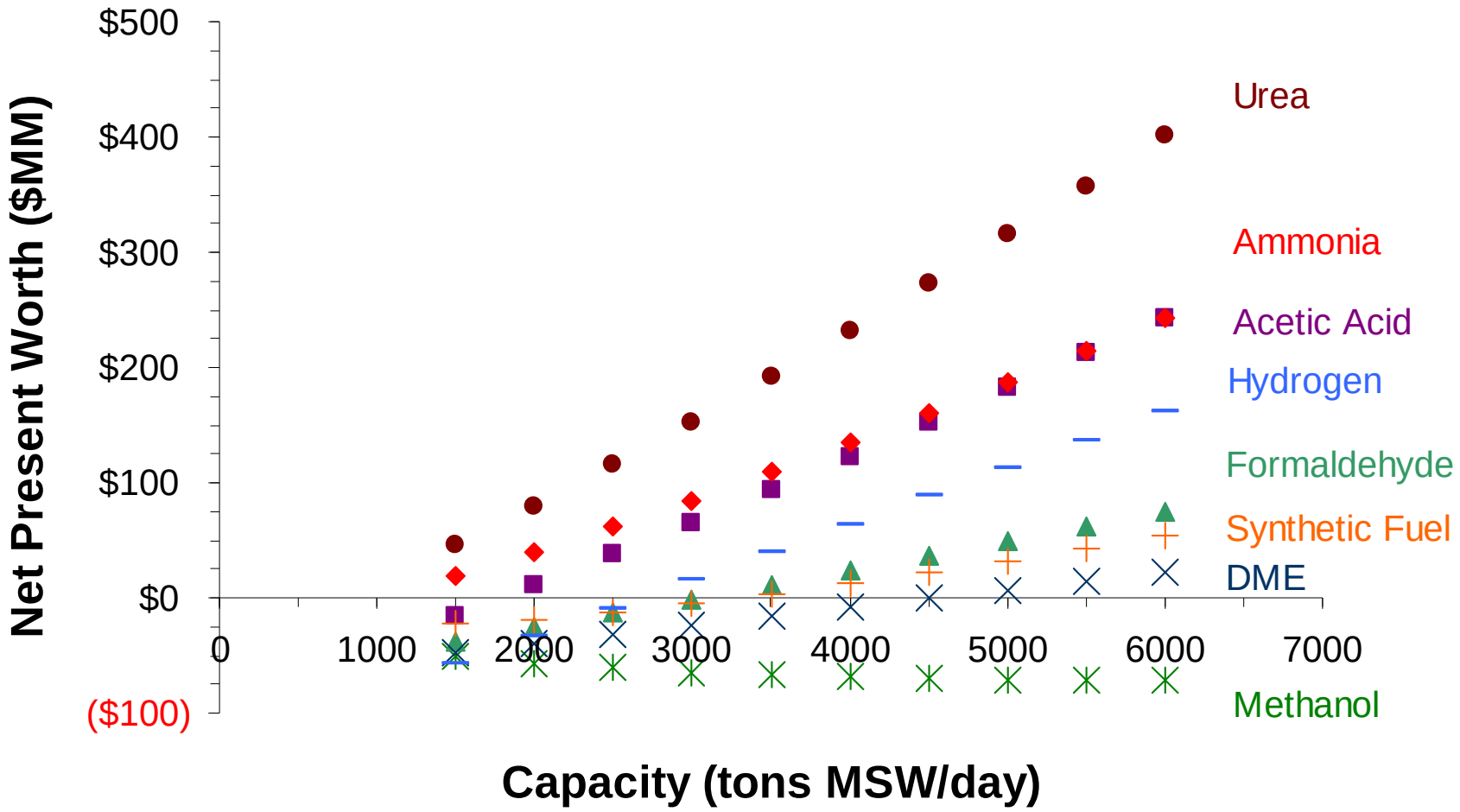
Economics Information:

Payout Time:	6.96 years
Rate of Return:	7.20%
Return on Investment:	0.44
Disc. Return on Investment:	-0.12

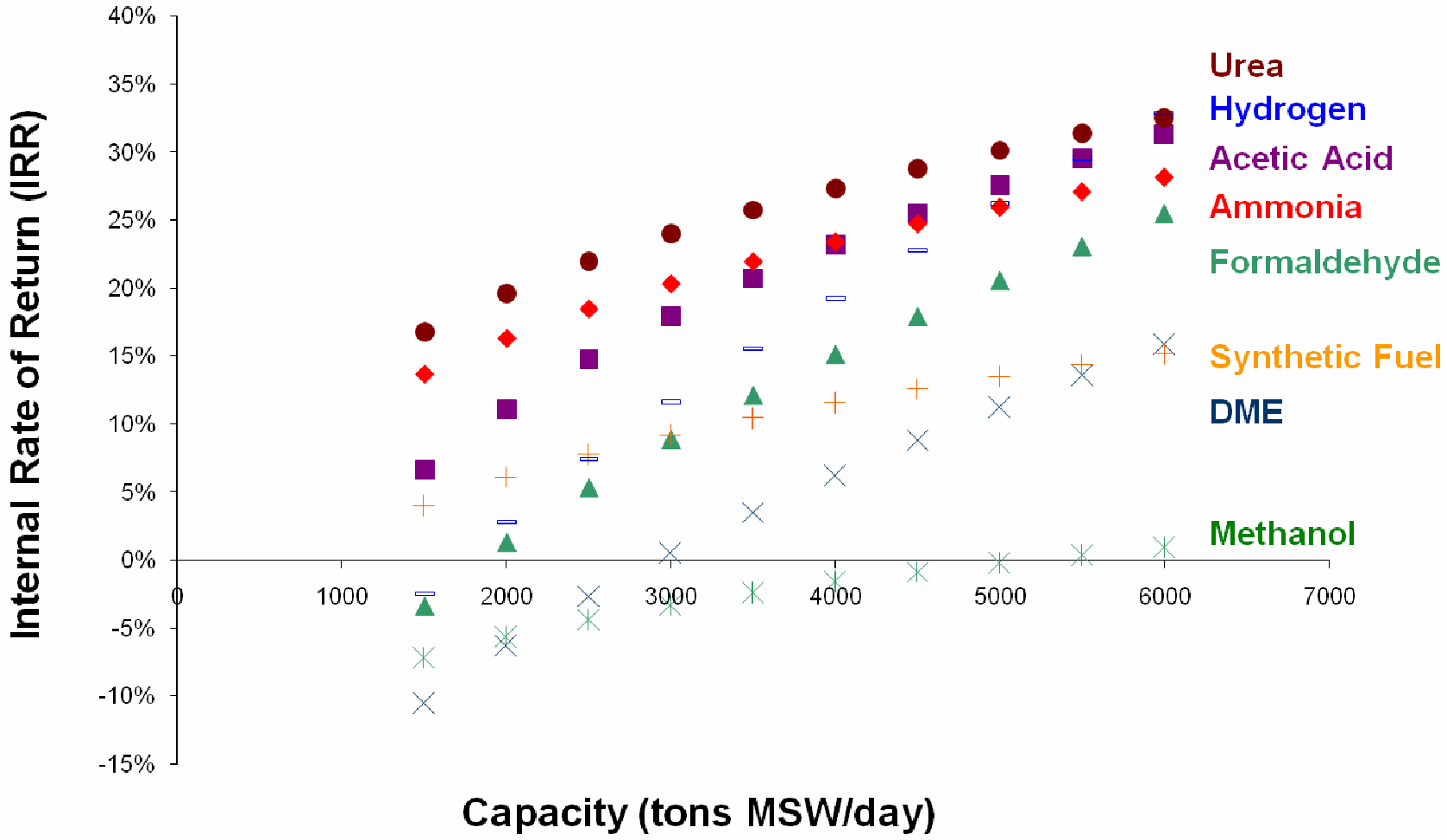
Product Comparison – 1500 TPD

Product	Production (unit/day)	Price ($/unit)	Operating Cost ($/year)	Net Revenue ($/year)	Total Capital Investment $	Net Present Worth $
Methanol (gal)	39,212	$1.02	$8,973,769	$5,555,679	$84,530,800	($49,545,577)
Acetic Acid (lb)	485,737	$0.31	$36,199,558	$18,761,628	$141,194,727	($30,523,926)
Formaldehyde (lb)	242,909	$0.21	$11,882,176	$6,736,810	$90,784,183	($51,045,195)
Ammonia (ton)	277	$275	$7,204,301	$20,620,952	$107,435,351	$17,016,429
Urea (ton)	489	$223	$9,381,341	$30,437,687	$140,975,657	$42,261,195
Hydrogen (m^3)	549,732	$0.08	$4,013,046	$11,877,158	$130,762,286	($60,701,493)
Synthetic Fuel			$5,207,041	$11,565,243	$93,765,169	($22,701,754)
Diesel (gal)	16,312	$1.98				
Naphtha (gal)	8,341	$1.63				

Product NPW vs. MSW Capacity

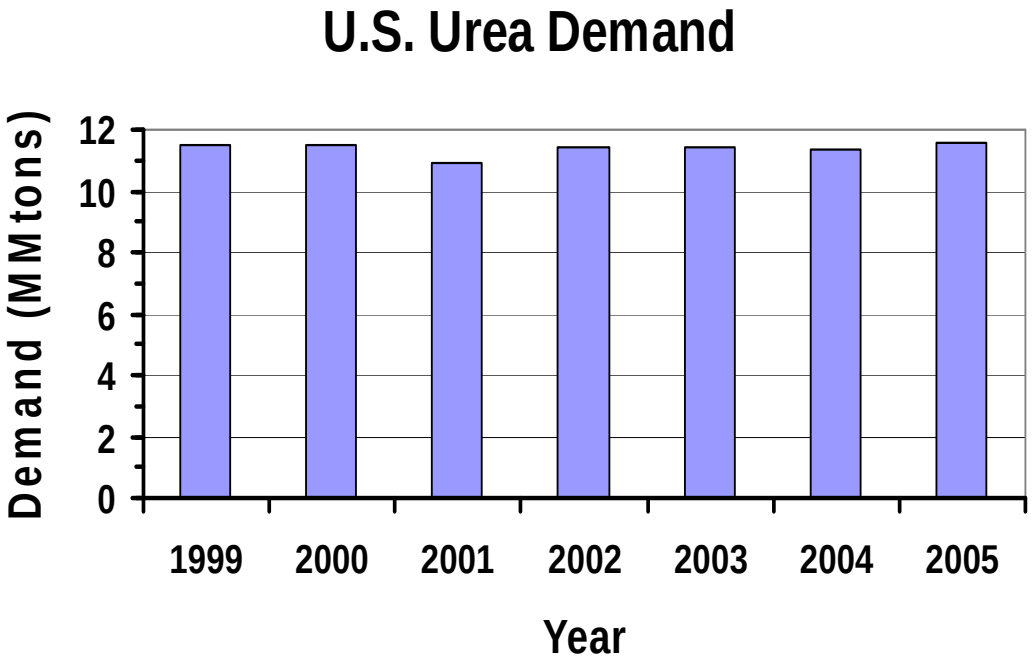


Product IRR vs. MSW Capacity



Future Urea Market

- U.S. fertilizer usage to increase 10-15% in 2008
- Dependent on Crops
  - Corn – 41% of usage



Green is seen in fertilizers

JOSEPH CHANG

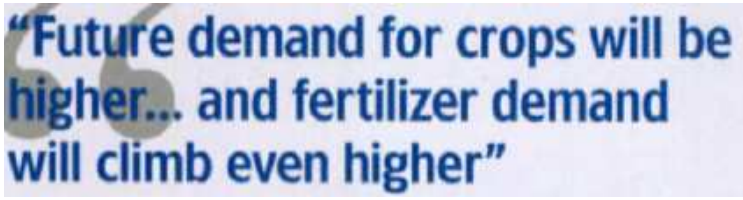
MERRILL LYNCH sees fields of green in the fertilizer sector. Analyst Steve Byrne has initiated coverage of CF Industries and Terra Industries with "buy" ratings and sees 20%+ upside potential in the shares of both companies in the next few quarters, driven by improving nitrogen margins.

Shares of Terra traded up 24 cents to $7.95 on the coverage.

Wall Street sees a big harvest for fertilizer firms

$10/tonne of margin gain for all nitrogen products," says the analyst. "Similarly, a $10/tonne increase in phosphate fertilizer/MAP margins translates into a 22 cent EPS benefit."

The company has extensive distribution assets in the all-important Cornbelt, including 23 ammonia terminals, 23 UAN terminals and 12 dry storage terminals for urea and phosphate fertilizers.



Urea Production Reactions

Water Gas Shift

$$CO + H_2O \rightarrow CO_2 + H_2$$

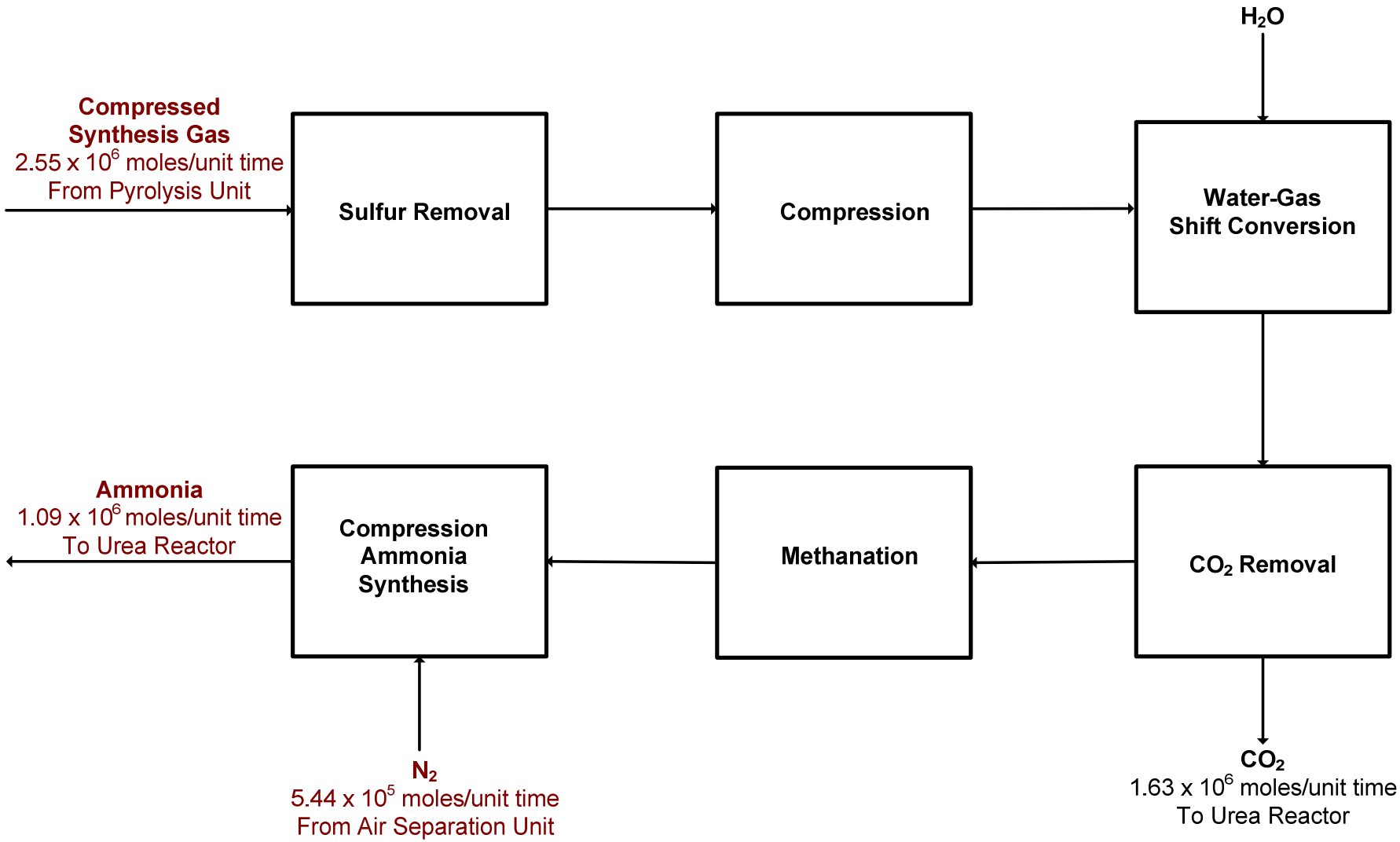
Ammonia Synthesis

$$3H_2 + N_2 \rightarrow NH_3$$

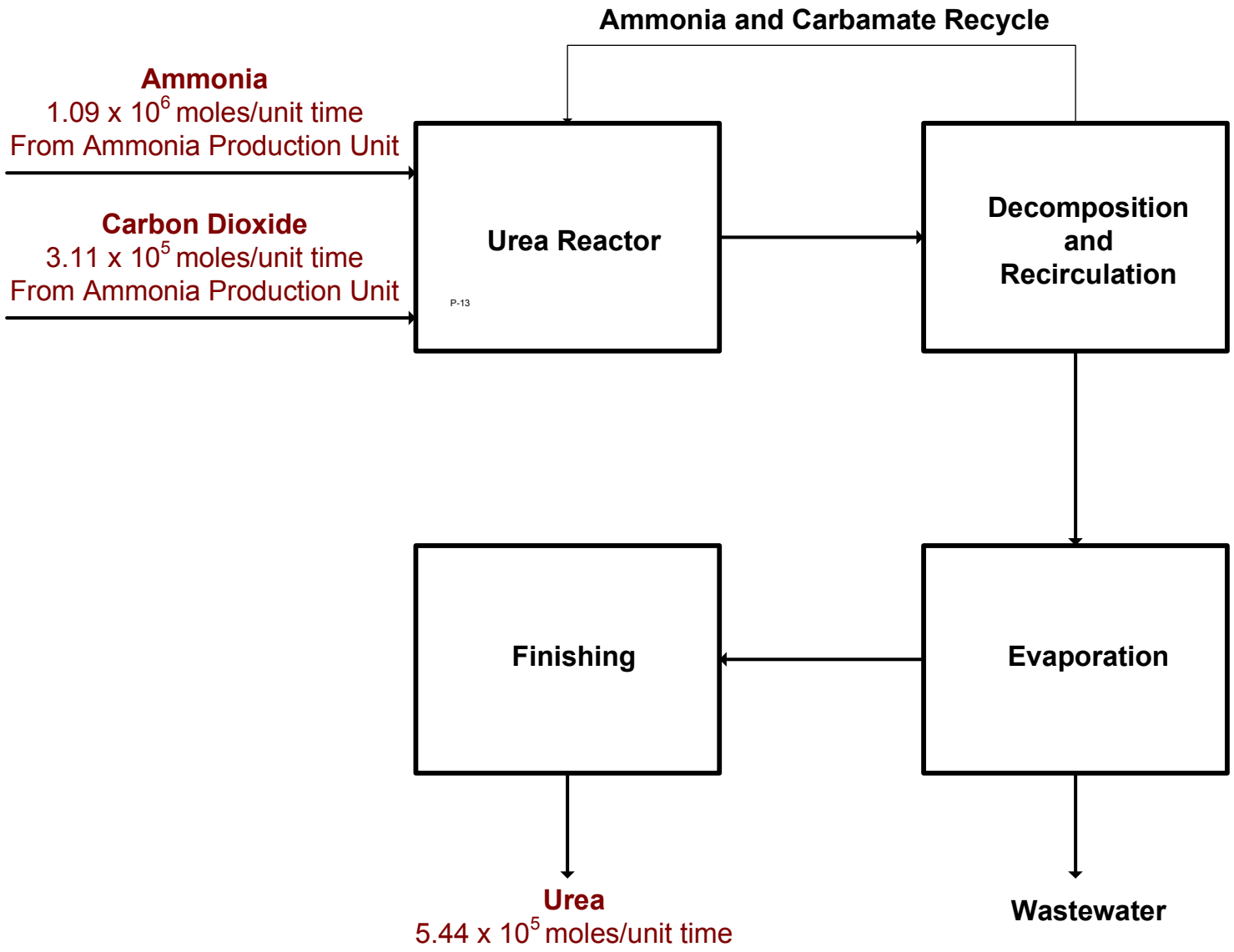
Urea Synthesis

$$2NH_3 + CO_2 \rightarrow NH_2COONH_4 \rightarrow NH_2CONH_2 + H_2O$$

Syngas to Ammonia



Ammonia to Urea



Operating Cost

Direct Cost	**$/ton of Urea**
Utilities	
steam (10^3-10^4 kPa), m^3	12.84
cooling water, m^3	13.95
Labor, personnel shift ($28/h)	5.72
Supervision	0.86
Catalyst cost	2.31
Maintenance and Repairs	14.92
Operating Supplies	2.24
Laboratory Charges	0.86
Fixed Cost	
Insurance	3.48
Property Taxes	9.95
Overhead	12.90
General Cost	
Administrative Costs	4.30
Distribution and Marketing Costs	5.4
Total Operating Cost	89.74

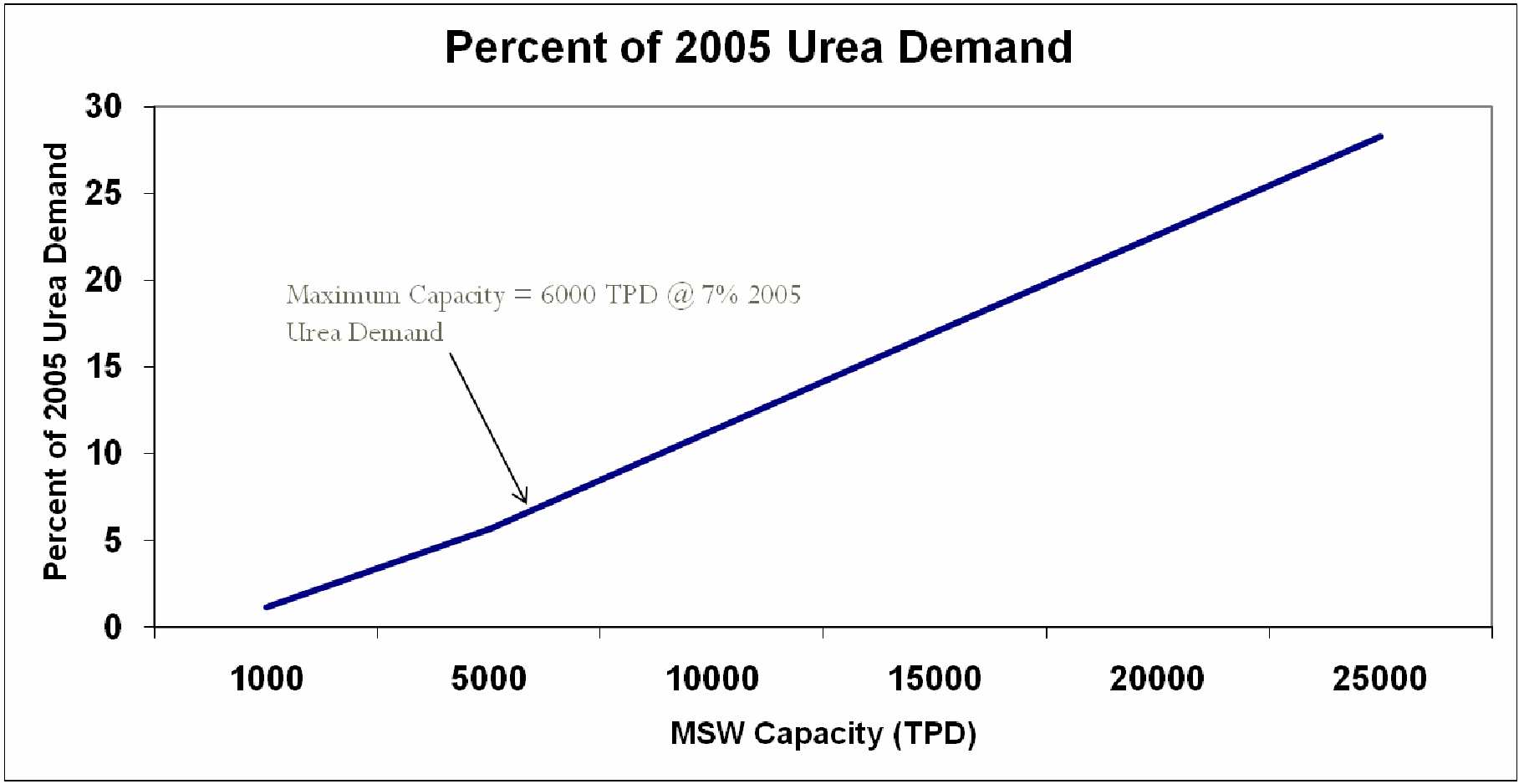
Plant Location: New York City

- Generates about 25,000 TPD waste
- Contains no landfills, incinerators or resource recovery facilities
  - All MSW is transferred out of the city
    - About 70% is sent to out-of-state landfills
    - Costs up to $70/ton
- Growing population

Waste Disposal Contracts

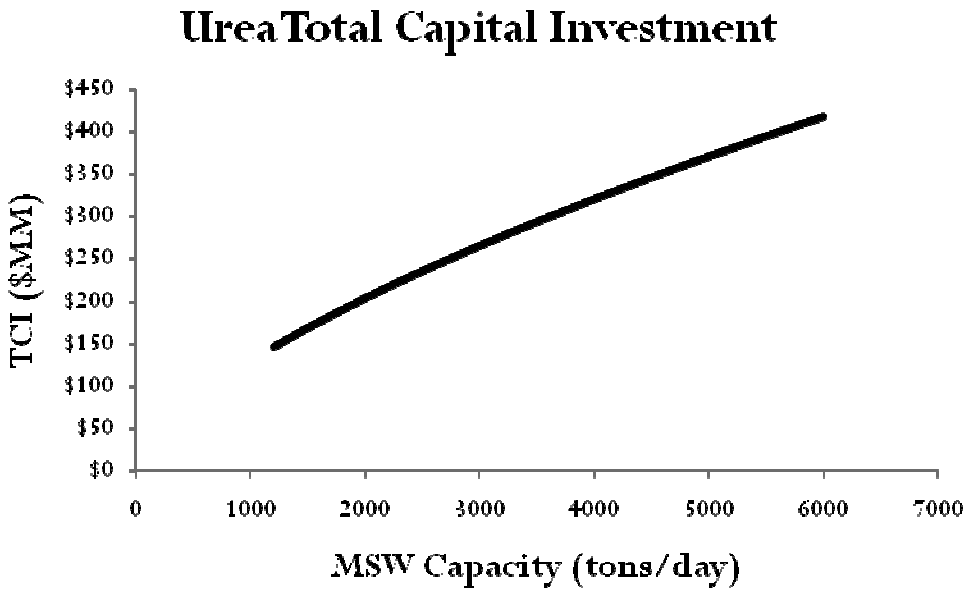
- Waste dropped at transfer station, then transported to landfills or incineration facilities
  - 3 year contracts
  - Option for two 1 year extensions

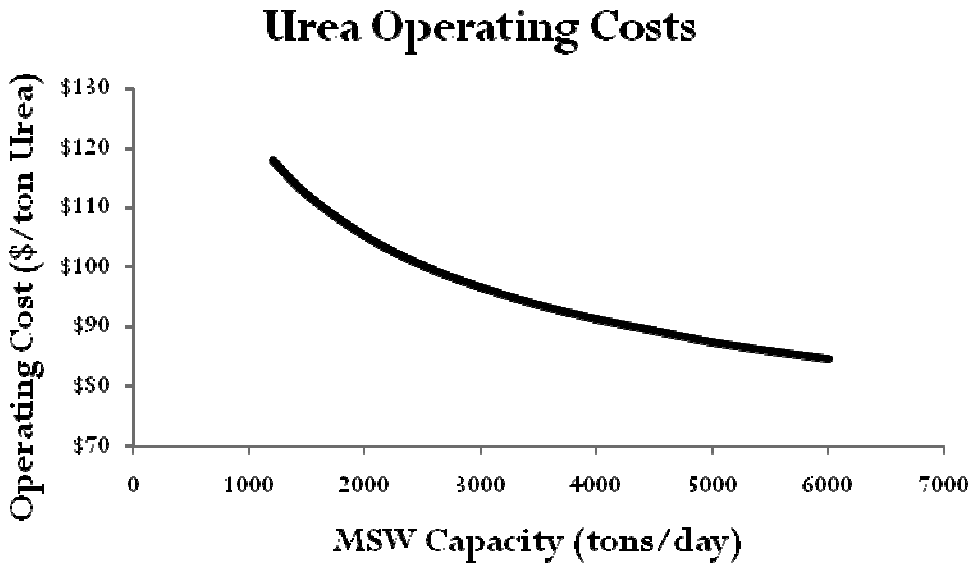
Available TPD from Expiring Contracts				
Year	2000	2001	2002	2003
Available Capacity (TPD)	1700	2500	3160	2350
Average	2428 TPD			
Standard Deviation	599 TPD			
Annual Expansion Opportunity	**1800 TPD**			



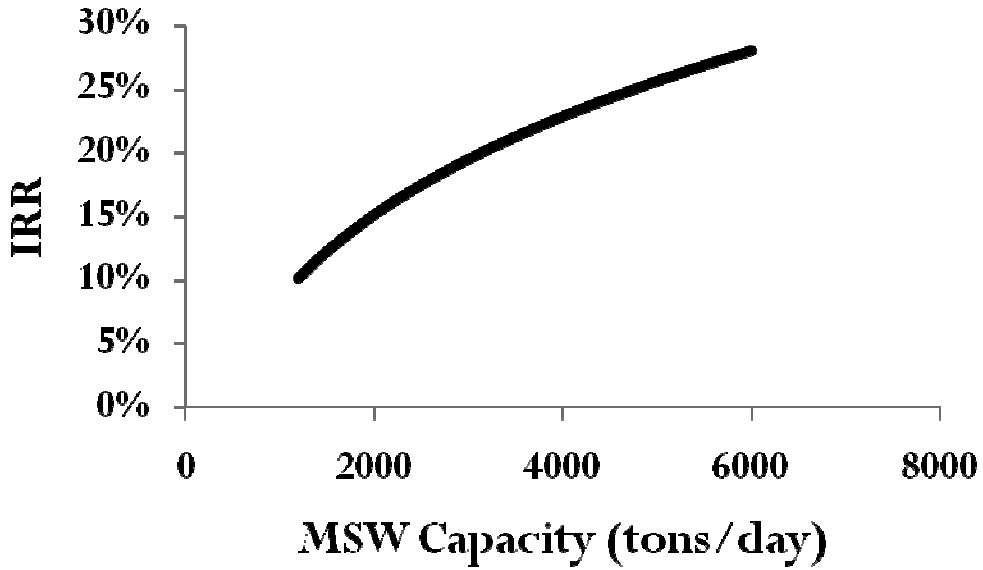
*Current Urea Demand: 11.6 MMtons/year

Urea Economics

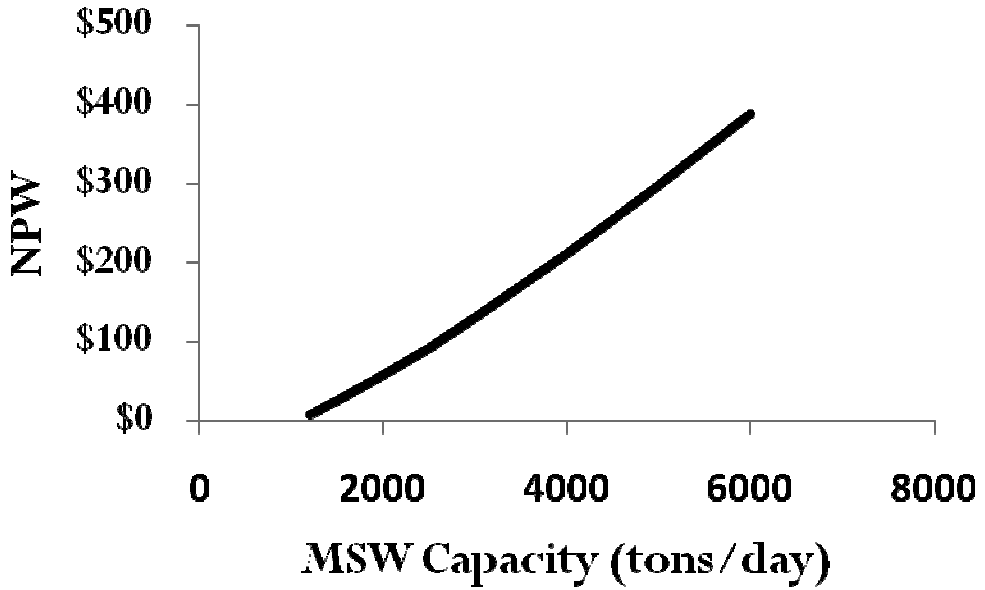




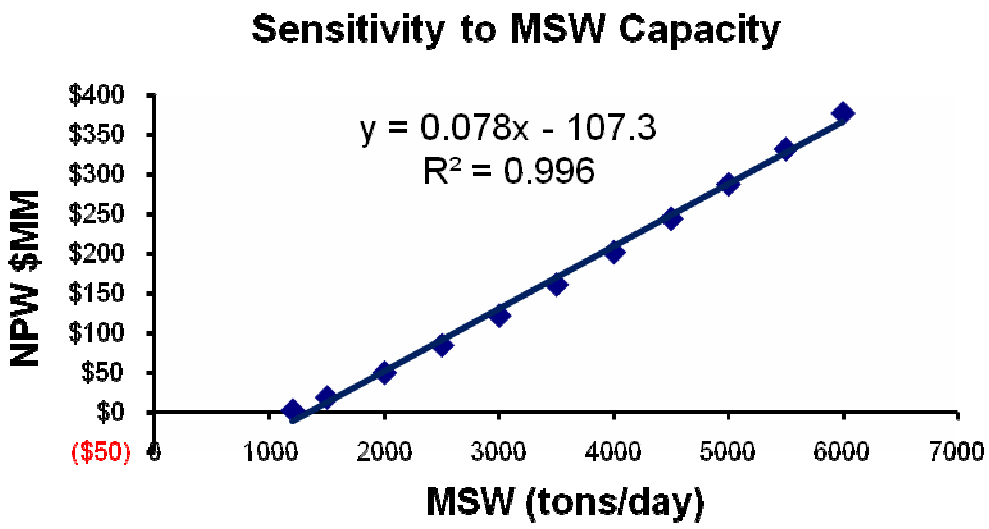
Urea Internal Rate of Return

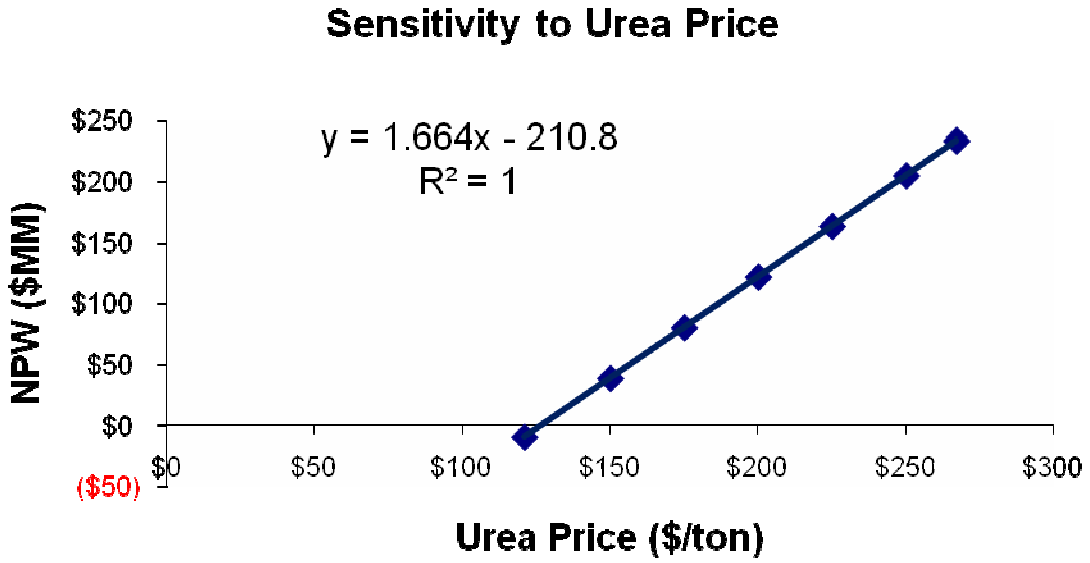


Urea Net Present Worth



Urea Profitability Sensitivity





Urea Regret Analysis

- Prices
  - 2006 average = $223/ton
  - 2000-2004 average = $121/ton
  - 2006 August Spot Price = $267/ton
- 2005 Urea Market
  - 1.4% (1200 TPD)
  - 4.0% (3500 TPD)
  - 6.8% (6000 TPD)

Regret Analysis

NPW				
Design	**$121**	**$223**	**$267**	**Average**
1 (1200 tpd)	($57,374,392)	$819,929	$25,923,361	-10,210,367
2 (3500 tpd)	($9,528,310)	$160,205,125	$233,423,470	128,033,428
3 (6000 tpd)	$86,003,977	$376,975,580	$502,492,742	321,824,100

Regret				
Design	**$121**	**$223**	**$267**	**Max**
1 (1200 tpd)	143,378,369	376,155,651	476,569,381	476,569,381
2 (3500 tpd)	95,532,287	216,770,455	269,069,272	269,069,272
3 (6000 tpd)	0	0	0	0
			Min	0

Optimum Capacity = 6000 TPD MSW

Economic Model: Urea Production

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Total Capital Investment	$417,978,064
Fixed Capital Investment	$355,246,112
Working Capital	$62,731,952
Tax Rate	35%
Main Display Discount Rate	10%

Urea Production	1,957	tons/day		
Urea Price	$223	/ton	0.00%	Inflation
Municipal Solid Waste	**6,000**	tons/day		
MSW Charge	$40	/ton		
Operating Cost	$85	/ton Urea	0.00%	Inflation

Year	Total Capital Investment	Urea Yearly Production (tons)	Urea Price ($/ton)	MSW Yearly Take (tons)	MSW Charge ($/ton)	Gross Revenue	Annual Product Cost	Net Profit After Taxes	Annual Cash Flow	Cumulative Cash Flow	10% Discounted Cash Flow
0	$417,978,064								-$417,978,064	-$417,978,064	-$417,978,064
2009		214,273	$223	657,000	$40	$74,062,879	$23,064,136	$35,014,070	$35,014,070	-$382,963,994	$31,830,973
2010		428,546	$223	1,314,000	$40	$148,125,758	$39,949,318	$74,044,460	$74,044,460	-$308,919,534	$61,193,769
2011		642,818	$223	1,971,000	$40	$222,188,414	$55,457,781	$114,591,718	$114,591,718	-$194,327,815	$86,094,454
2012		714,243	$223	2,190,000	$40	$246,876,114	$60,441,455	$127,399,335	$127,399,335	-$66,928,480	$87,015,460
2013		714,243	$223	2,190,000	$40	$246,876,114	$60,441,455	$127,399,335	$127,399,335	$60,470,855	$79,104,964
2014		714,243	$223	2,190,000	$40	$246,876,114	$60,441,455	$127,399,335	$127,399,335	$187,870,190	$71,913,603
2015		714,243	$223	2,190,000	$40	$246,876,114	$60,441,455	$127,399,335	$127,399,335	$315,269,525	$65,376,003
2016		714,243	$223	2,190,000	$40	$246,876,114	$60,441,455	$127,399,335	$127,399,335	$442,668,860	$59,432,730
2017		714,243	$223	2,190,000	$40	$246,876,114	$60,441,455	$127,399,335	$127,399,335	$570,068,195	$54,029,755
2018		714,243	$223	2,190,000	$40	$246,876,114	$60,441,455	$127,399,335	$127,399,335	$697,467,530	$49,117,959
S_v	$53,286,917					$53,286,917	$0	$34,636,496	$34,636,496	$732,104,026	$12,139,881
Total:		6,285,336				$2,225,796,764	$541,561,420	$1,150,082,090	$732,104,026	$732,104,026	$239,271,486

Economics Summary

Net Present Worth Table:

0%	$732,104,026	40%	($207,514,262)
5%	$438,572,962	50%	($256,295,863)
8%	$310,284,627	60%	($289,089,502)
10%	**$239,271,486**	70%	($312,193,777)
15%	$99,754,422	80%	($329,109,814)
20%	($649,784)	90%	($341,895,234)
30%	($130,651,434)	100%	($351,818,533)

Economics Information:

Payout Time:	4.53	years
Rate of Return:	**19.96**	**%**
Return on Investment:	1.75	
Disc. Return on Investment:	0.57	

Economic Conclusion

- Plant Size = 6,000 tons MSW/day
- TCI = $418,000,000
- NPW = $239,000,000 @ 10% discount
- IRR = 20%
- Urea Break-even Price = $65/ton

Questions?

Pyrolysis Reactor

- Vertical shaft reactor
  - Solid waste enters through the top
  - Purified oxygen from air separator fed through the bottom
- Solid waste dried by upward flowing gases at top of reactor
  - Exiting gas therefore cooled to between 93°C and 315°C
- Pyrolysis occurs in the middle zone at temperatures above 1500°C
  - Combustion of char in oxidative zone at the bottom of the reactor produces the heat necessary for the pyrolytic reactions
- Operates between 2100 and 2200psia

Gas Cleaning

- Syngas flows through spraying water scrubber
- Electrostatic precipitator removes particulates and pyrolytic oils
  - These components are recycled back to the reactor
- Water removed in a shell and tube condenser

Operating Cost

- Utilities, labor and catalyst costs estimated from data in the *Encyclopedia of Chemical Technology*
- Other operating costs estimated from reasonable percentages in *Plant Design and Economics for Chemical Engineers*
  - Supervision: 15% of labor
  - Maintenance and repairs: 3% of FCI
  - Operating supplies: 15% of maintenance and repairs
  - Laboratory charges: 15% of labor
  - Insurance: 0.7% of FCI
  - Property taxes: 2% of FCI
  - Overhead: 60% of labor, supervision, and maintenance and repair costs
  - Distribution and marketing: 6% of total operating cost

Carbon Dioxide

- Process produces 4,305 tons/day
- Urea synthesis requires 3.5:1 ratio of ammonia to urea in the reactor feed
  - Process uses 820 tons/day carbon dioxide
- Net carbon dioxide production: 3,485 tons/day
  - Implementation of $25/ton carbon tax would increase operating cost by $45/ton urea
  - CO_2 sequestration estimated at $35/ton would increase operating cost by $62/ton urea
- Reduces project profitability but does not change project results

Methanol

$$2H_2 + CO \rightarrow CH_3OH$$

$$3H_2 + CO_2 \rightarrow CH_3OH + H_2O$$

- Reactant Ratio : $\frac{H_2}{2CO + 3CO_2} = 1$
- Low Temperatures and High Pressures favor Methanol formation
- Methanol can be sold as a product or used as an intermediate to produce alternative products

Ammonia

$$3H_2 + N_2 \rightarrow 2NH_3$$

- Reactant Ratio: $\frac{H_2}{N_2} = 3$
- Used in fertilizers and refrigeration
- Reaction occurs at high temperature and pressure

Synthetic Fuel

$$2H_2 + CO \rightarrow \text{-}CH_2\text{-} + H_2O$$

- Reactant Ratio: $\frac{H_2}{CO} = 2$
- Fischer-Tropsch synthesis
- Converts H_2 and CO into straight chain hydrocarbons using metal catalysts
  - Diesel and naphtha

Hydrogen

$$(1)\quad H_2O + CH_4 \rightarrow 3H_2 + CO$$

$$(2)\quad H_2O + CO \rightarrow H_2 + CO_2$$

- Reactant Ratio: $\frac{H_2O}{CO + CH_4} = 1$
- Steam reformation (1) is used to convert methane into CO and H_2
- Water gas shift reaction (2) is used to produce additional H_2
- Main fuel source for Hydrogen fuel cells

Economic Model: Urea Production

3/6/2007

Total Capital Investment	$169,751,842
Fixed Capital Investment	$144,274,753
Working Capital	$25,477,089
Tax Rate	35%
Main Display Discount Rate	10%

Urea Production	489	tons/day		
Urea Price	$223	/ton	0.00%	Inflation
Municipal Solid Waste	1500	tons/day		
MSW Charge	$40	/ton		
Operating Cost	$112	/ton Urea	0.00%	Inflation

Year	Total Capital Investment	Urea Yearly Production (tons)	Urea Price ($/ton)	MSW Yearly Take (tons)	MSW Charge ($/ton)	Gross Revenue	Annual Product Cost	Net Profit After Taxes	Annual Cash Flow	Cumulative Cash Flow	10% Discounted Cash Flow
0	$169,751,842								-$169,751,842	-$169,751,842	-$169,751,842
2009		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	-$140,114,628	$26,942,922
2010		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	-$110,477,414	$24,493,565
2011		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	-$80,840,199	$22,266,878
2012		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	-$51,202,985	$20,242,616
2013		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	-$21,565,771	$18,402,378
2014		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	$8,071,443	$16,729,435
2015		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	$37,708,658	$15,208,577
2016		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	$67,345,872	$13,825,979
2017		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	$96,983,086	$12,569,072
2018		178,561	$223	547,500	$40	$61,719,028	$20,007,634	$29,637,214	$29,637,214	$126,620,300	$11,426,429
S_v	$21,641,213					$21,641,213	$0	$14,066,788	$14,066,788	$140,687,089	$4,930,324
Total:		1,785,607				$638,831,497	$200,076,345	$310,438,931	$140,687,089	$140,687,089	$17,286,333

Economics Summary

Net Present Worth Table:

0%	$140,687,089	40%	($97,872,957)
5%	$67,323,430	50%	($111,342,696)
8%	$35,149,282	60%	($120,725,773)
10%	**$17,286,333**	70%	($127,581,935)
15%	($17,985,960)	80%	($132,787,195)
20%	($43,605,428)	90%	($136,863,239)
30%	($77,342,317)	100%	($140,136,702)

Economics Information:

Payout Time:	5.73	years
Rate of Return:	**12.24**	%
Return on Investment:	0.83	
Disc. Return on Investment:	0.10	