Production Economics of Ammonia from Wind, Water and Air

Renewable Fertilizer Conference
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Total Energy Directly and Indirectly Consumed on U.S. Farms in 2002 was 1.7 Quadrillion Btu

- Pesticides: 6.3%
- Fertilizers: 29.0%
- Electricity: 20.7%
- Natural Gas: 3.6%
- LP Gas: 4.5%
- Diesel: 27.3%
- Gasoline: 8.5%

U.S. Nitrogen Production as Ammonia and Urea (Tons of N)

Source: U.S. EPA

NH₃ Production (ton)  Urea Production (ton)
NITROGEN FERTILIZER IN CORN PRODUCTION

- Dominant Source of Imbedded Energy
- Largest Source of GHG Emissions in Corn Production
- Fertilizer on Corn costs $149/A. was less than rent ($225) and more than seed ($115) in 2012 on cash rented land reported by SWMFMA. (Staff Paper P13-2)

Source: www.countrysidefarmsimplements.com

Annual Prices of Anhydrous Ammonia and Corn
Per Ton from 1984-2012
Sources: National Ag. Statistical Service and Economic Research Service

Corn Price ($ per Ton)

Ammonia ($/Ton)
Cost of Natural Gas & Gross Margin in Sale Price of Anhydrous Ammonia

Derived by using Citygate natural gas prices and assuming 32.7 decatherms per ton of ammonia

Douglas G. Tiffany, University of Minnesota Extension

Gross Margin per Ton of Ammonia
Natural Gas Cost per Ton of Ammonia
ECONOMIC EVALUATION OF DEPLOYING SMALL- TO MODERATE-SCALE AMMONIA PRODUCTION PLANTS IN MINNESOTA USING WIND AND GRID-BASED ELECTRICAL ENERGY SOURCES
PROJECT ECONOMICS TASKS

- Cost of Production of Current Unit
  - Energy Required for Stages of Production
  - Water Deionizing
  - Hydrogen Extraction from Water Hydrolysis
  - Nitrogen Extraction from Air
  - Ammonia Synthesis
  - Storage and Transportation
ADDITIONAL TASKS

- Consider Impact of Carbon Taxes on Ammonia
- Consider Economic Scale or Production
- Consider Effects of Improved Catalyst Performance
GREENHOUSE GAS EMISSIONS
DYNAMIC FLUXES OF GHG

U.S. GREENHOUSE GAS EMISSIONS

Figure 1. U.S. Greenhouse Gas Emissions by Gas, 1990–2010

GREENHOUSE GAS EMISSIONS

Figure 2. U.S. Greenhouse Gas Emissions and Sinks by Economic Sector, 1990–2010

SOURCES OF GREENHOUSE GAS EMISSIONS OF DRY-GRIND ETHANOL: NOTE THE BIG 3

Carbon Taxes around the World

<table>
<thead>
<tr>
<th>Country</th>
<th>Carbon Tax (USD/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>$150</td>
</tr>
<tr>
<td>British Columbia, Canada</td>
<td>$30</td>
</tr>
<tr>
<td>Finland</td>
<td>$26</td>
</tr>
<tr>
<td>Australia</td>
<td>$23</td>
</tr>
<tr>
<td>Ireland</td>
<td>$20</td>
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<tr>
<td>Denmark</td>
<td>$18</td>
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<tr>
<td>California</td>
<td>$10</td>
</tr>
<tr>
<td>Quebec, Canada</td>
<td>$4</td>
</tr>
<tr>
<td>Japan</td>
<td>$3</td>
</tr>
<tr>
<td>India</td>
<td>$1</td>
</tr>
</tbody>
</table>
RFS GHG EMISSIONS STANDARDS

- Renewable Ethanol ---- 20% reductions
- Advanced Biofuels ---- 50% reductions
- Cellulosic Ethanol ---- 60% reductions
- RINS validate RFS compliance
- Different renewable fuels have equivalence in RINS to facilitate trading
- Carbon Taxes on Emissions or Credits for substitute fuels emitting less could be a compliance mechanism
Carbon Taxes Applied Per Ton of Anhydrous Ammonia Based on Alternative Carbon Permit Fees Based on GHG Emissions of 1.2 Ton CO2e per Ton.
SCALE ECONOMIES

Source: http://pinterest.com/pin/55943220341431594/
# NITROGEN FERTILIZER MARKET IN MINNESOTA

<table>
<thead>
<tr>
<th>Crop</th>
<th>Statewide Acres*</th>
<th>Avg. Yield/Ac (bu.)*</th>
<th>Statewide Yield (bu.)</th>
<th>Estimated N Required (lbs NH3)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>8,234,507</td>
<td>146.0</td>
<td>1,201,898,815</td>
<td>901,424,111</td>
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<tr>
<td>Barley</td>
<td>108,268</td>
<td>53.6</td>
<td>5,801,418</td>
<td>4,351,063</td>
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<tr>
<td>Wheat</td>
<td>1,718,565</td>
<td>48.1</td>
<td>82,554,282</td>
<td>61,915,712</td>
</tr>
</tbody>
</table>

Total NH3 Req. (lbs) 967,690,886

Total NH3 Req. (tons) 483,845

Retail Value ($800 / ton) $387,076,354

*Production Data from USDA NASS (2007)

**Based on a requirement of 0.75 lbs of NH3 per bushel of yield
Production Capacity of 27 U.S. Ammonia Plants
Source: U.S. EPA, Office of Air and Radiation, 2009
SCALE-UP METHODOLOGY

- Start with known capital cost for a capacity
- Determine Scale Factor of Increase
- Raise to appropriate exponent (.75, .7, .67)
- Determine project cost per unit of capacity
- Example: A 50 Million Gallon per year ethanol plant can be built for $2.25 per gallon of capacity. What will be the estimated cost of a 100 million gallon plant?

  - $112.5 MM X (2.0)^.7 = $182,756,789 for plant
  - Ans: $182,756.789 /100MM = $1.8275/ gal.
Estimated Installed Capital Cost per Ton of Capacity for Ammonia Production Using Electrolyzed Water and Scale up Exponent of .75, Excluding Wind Turbines

Morris Facility

- $98,714
- $17,554
- $9,871
- $0
- $20,000
- $40,000
- $60,000
- $80,000
- $100,000
- $120,000

Tons of Annual Capacity

$0, 26, 263, 2,628, 26,280, 262,800, 500,000, 1,000,000
## Ammonia Synthesis and Storage Pro forma

<table>
<thead>
<tr>
<th>Capital Cost/Ton of Ann. Cap.</th>
<th>$98,714.00 per Ton</th>
<th>26.28 T/yr</th>
<th>$2,594,204</th>
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<tbody>
<tr>
<td>Percent equity</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent debt</td>
<td>0.40</td>
<td></td>
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</tr>
<tr>
<td>Interest Rate on Debt</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### NH3 Production

- **Capacity Factor:** 1.0
- **NH3 Price and Annual Revenue**
  - Price per Ton: $700.00
  - Price/lb N.: $0.427
  - Tons: 26.28

### Operating Expenses

- **Electricity Purchase Price**
- **Water Treatment and Deionization**
- **Water Electrolyzed per hour**
- **Hydrogen Produced by Electrolyzer**
  - 1.19 lb/hr. H2
  - 10.92 kWh/lb of H2
- **Nitrogen Gas Production**
  - 6.75 lb/hr N2
  - 1.00 kWh/lb of N2
- **Ammonia Production**
  - 6.00 lb/hr NH3
  - 3.00 kWh/lb.

### Efficiency of NH3 Production
- 0.15%

### Catalyst Replacement for Ammonia Skid
- 5 yr

### Other Costs

- **Operator Labor**
- **Maintenance Labor**
- **Depreciation**
- **Interest**
- **Fees, Licenses, Insurance**
- **Real Estate Taxes**

### Production Cost of Anhydrous Ammonia for Facility

- Total: $627,048.09
- Cost per Ton of Anhydrous Ammonia: $23,860
- Cost per lb. of N in product: $14.55

### Net Margin for Facility

- $(608,652.09)
## Ammonia Synthesis and Storage Pro forma

| Capital Cost/Ton of Ann. Cap. | $9,871.40 per Ton | 26.28 T/yr | $259,420 |
| Percent equity | 0.60 |
| Percent debt | 0.40 |
| Interest Rate on Debt | 0.06 |

| NH3 Production | 1.0 | Capacity Factor | Nameplate Cap. | 26.28 Ton/ Yr | 26.28 Tons of Ammonia |
| NH3 Price and Annual Revenue | Price/ lb. N. | $0.427 | Price per Ton | $700.00 | $18,396.00 |

### Operating Expenses

- **Electricity Purchase Price**
  - Water Treatment and Deionization: 22.454 gal/hr. (85 l/hr)
  - Water Electrolyzed per hour: 1.42 gal/hr.
  - Hydrogen Produced by Electrolyzer: 1.19 lb./ hr. (H2)
  - Nitrogen Gas Production: 6.75 lb/ hr (N2)
  - Ammonia Production: 6.00 lb/hr
  - Electricity Purchased: $0.071
  - Efficiency of NH3 Production: 0.15 %
  - Catalyst Replacement for Ammonia Skid: 5 yr

- **Operator Labor**: $120,000
- **Maintenance Labor**: 0.050 % Cap Cost
- **Repairs to Equipment**: 0.050 % Cap Cost
- **Depreciation**: 20 Yr.
- **Interest**: 10 Yr.
- **Fees, Licenses, Insurance**: 0.01
- **Real Estate Taxes**: 0.005

### Financial Calculations

- **Total Production Cost of Anhydrous Ammonia for Facility**: $185,774.01
- **Cost per Ton of Anhydrous Ammonia**: $7,069
- **Cost per lb. of N in product**: $4.31
- **Net Margin for Facility**: $(167,378.01)
IF NON-CONVERTED GAS RECYCLE REPRESENTS 85% OF CAP COST:

<table>
<thead>
<tr>
<th>Ammonia Synthesis and Storage Pro forma</th>
<th>D.G. Tiffany</th>
<th>7/8/2013</th>
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<tr>
<td>Capital Cost/Ton of Ann. Cap.</td>
<td>$1,480.65 per Ton</td>
<td>$26.28 T/yr</td>
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<td>Ammonia Production</td>
<td>6.00 lb/hr NH3</td>
<td>3.00 kWh/lb.</td>
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<td>Electricity Purchased</td>
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<tr>
<td>Maintenance Labor</td>
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<tr>
<td>Total Production Cost of Anhydrous Ammonia for Facility</td>
<td>$144,097.82</td>
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<td>Cost per Ton of Anhydrous Ammonia</td>
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<td>Cost per lb. of N in product</td>
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<tr>
<td>Net Margin for Facility</td>
<td>(125,701.82)</td>
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NEXT STEPS

- Share Conclusions with Research Team
- Validate Conversion Factors
- Apply Catalyst Enhancing Technology
- Improve Assumptions
- Reconsider Scale-up
Thanks!

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