Carbon-Footprint Based Merit Analysis of Ammonia as Hydrogen Carrier and for Energy Storage

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Investing Existing *Finite* Carbon-Based

Energy & Material Sources on Future

***Sustained* Energy Supplies**

Presentation Outline

- ➢ **Today's NH3 Market and Production**

- ➢ **Energy Consumption in Commercial Process**

- ➢ **Energy Consumption using Renewable Energy**

- ➢ **C-Footprint Profile of NH3 Production**

- ➢ **C-Footprint Frame Work of NH3 End Use**
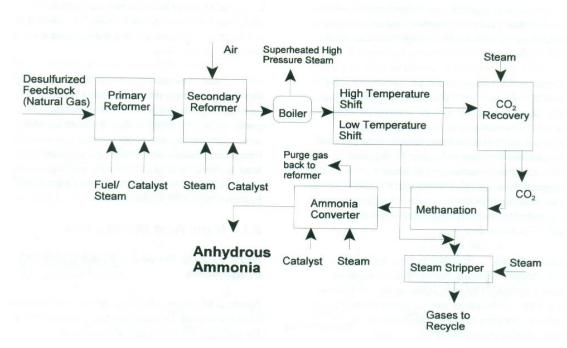
- ➢ **Summary & Recommendations**

Today's NH3 Market & Production

- **Global Production** **~ 156 Million Metric Ton/y (MMTA)**

- **Global production based on NG, Petroleum Product & Coal**

- **US Consumption** **~ 16 MMTA**

  Production **~ 9.6 MMTA (NG feed stock)**

- **Average 2015 price in Midwest** **$500 to $650/T**

Commercial NH3 Production Based on NG SynGas Process

Energy Consumption:
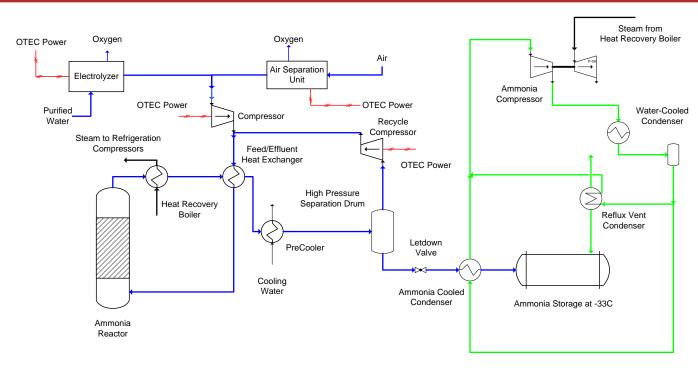
Process Heat	7,250 kWh/T NH3
Electricity (Primary energy)	1,825 kWh/T NH3
Total	9,075 kWh/T NH3

Ref: Energy & Environment Profile of the US Chemical Industry, DOE Report, 2000

NH3 Production Using Renewable Energy

Energy Consumption for OTEC Plantship:

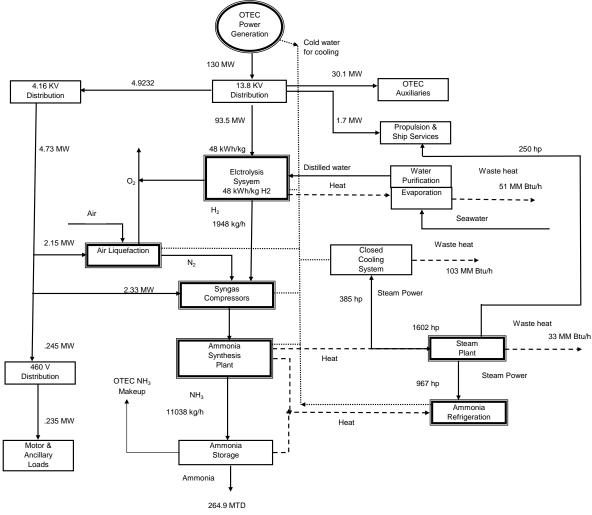Electricity (Haber-Bosch Process)   8,917 kWh/T NH3

Electricity (NHThree™ Solid State Process)   7,000 kWh/T NH3

Ref: OTEC Plantships for Production of Ammonia as Hydrogen Carrier, ANL Report, 2009
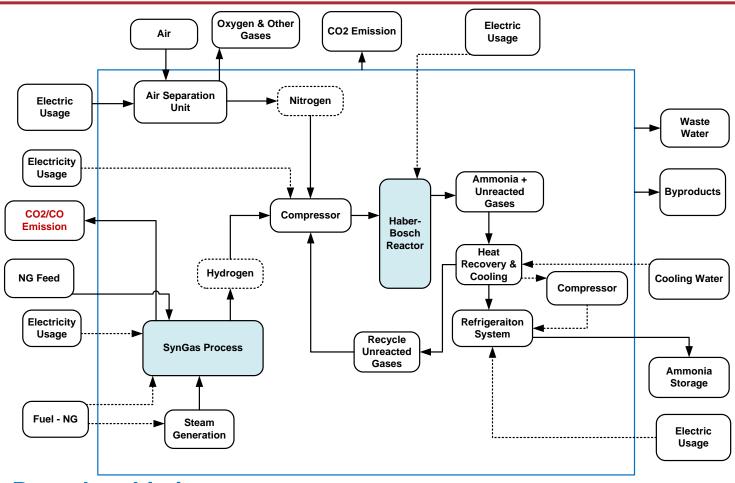
Significance of C-Footprint Analysis

➢ **Focus on long-term realistic scenario of NH3 as hydrogen carrier and energy storage**

➢ **Realistic C-Footprint analysis without performing an extensive Life Cycle Analysis (LCA)**

➢ **Identifies elements of high C-Footprint that would suggest alternate approach of production and end uses**

➢ **Identifies opportunities of energy efficiency and alternate energy sources – such as combined heat and power or process intensification or renewable energy**

C-Footprint Analysis

Process Block Diagram of NG-Based Commercial Plants

Ammonia Synthesis Process Block Diagram

Mass Flow ——→   Energy Flow ·····►
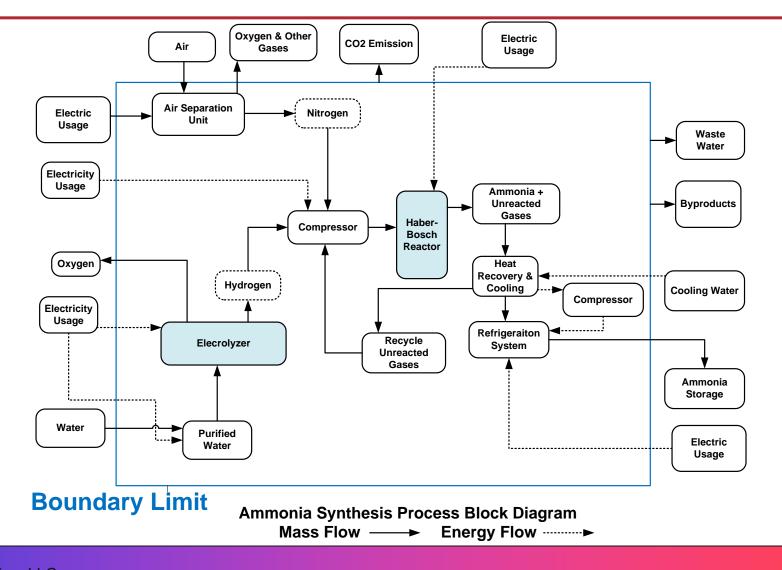
C-Footprint Analysis

Process Block Diagram of NH3 Synthesis using Renewable Energy

Boundary Limit

Ammonia Synthesis Process Block Diagram

Mass Flow ⟶   Energy Flow ┈┈▶

C-Footprint NH3 Production

Initial Target for Global Reduction of CO2 Emission

- **Commercial Haber-Bosch Process**

    - *CO2 Emission (Global scale)*   *2.4 T CO2/T NH3*
    - *CO2 Emission (Energy Efficient)*   *1.7 T CO2/T NH3*

- **Global NH3 Production**   **~ 156 MMTA**

    - *CO2 Emission*   *~ 375 MMTA*

- **Renewable Energy (Electricity from Renewable Energy, such as OTEC)**

    - **Haber-Bosch Process**   **8.9 MWh/T NH3**

    - **Solid State NH3 Synthesis**   **7.0 MWh/T NH3**

Need to perform C-Footprint analysis for renewable energy to determine cross-over period when CO2 emission occurred in manufacturing of renewable energy system is balanced out for net CO2 emission reduction

NH3 End Uses

- ➢ **Fertilizer and Chemicals**
  - ➢ **Replacing commercial C-based production**
- ➢ **Direct Combustion Fuel**
  - ➢ **Replacing petroleum liquid transportation fuel**
- ➢ **Hydrogen Carrier**
  - ➢ **H2 fuel-cell – transportation and distributed power generation**
  - ➢ **Replacing H2 from NG in petroleum and petrochemical industry**
- ➢ **Electric Power**
  - ➢ **Combustion turbine – most likley combined cycle**
  - ➢ **Fuel-cell power**

Need to perform C-Footprint analysis for merit-based justification of NH3 end uses

Summary

➢ **Initial target should be to replace C-based NH3 production for fertilizer and chemical applications**

➢ **NH3 is a promising candidate for effective utilization of renewable energy such as OTEC**

➢ **C-Footprint can be performed for production and end-use of NH3 without full Life-Cycle Analysis (LCA) that would accelerate NH3 as energy and hydrogen carrier**

Last comment is based on on-going two projects of conversion of captured CO2 to value-added alkyl carbonates

Suggestive Recommendations

➢ **Global initiative for green NH3 production with specific targets**

   ➢ **First target to replace NH3 plants using coal and petroleum products**

➢ **C-Footprint analysis for NH3 production and end uses that would justify emerging technologies**

➢ **The island states could be the first target for introducing the NH3-based energy technologies**

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