Small Scale Distributed Ammonia Production

Less than 100 tons per day

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Overview

- Nitrogen Generation
- Hydrogen Generation
- Hydrogen Purification
- Reaction Gas Blending
- Reaction Gas Storage
- Reaction Overview
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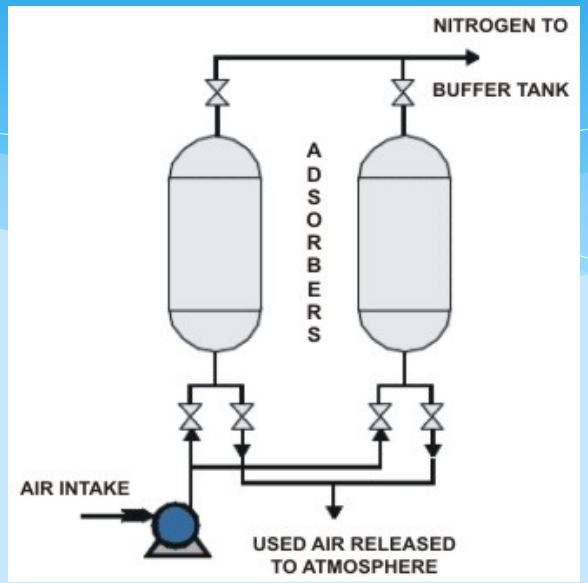
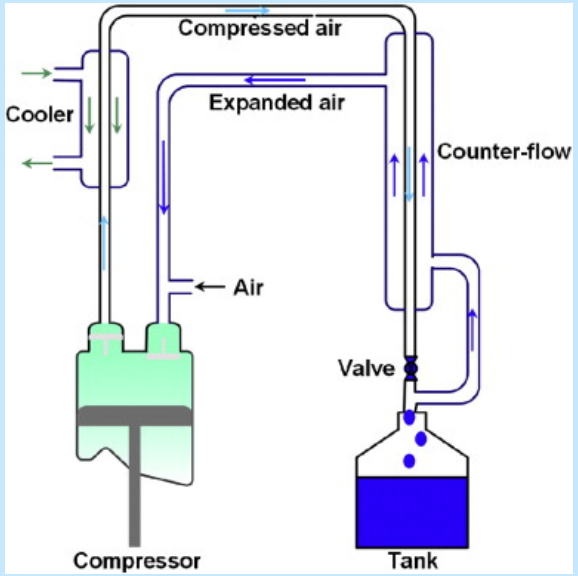
- Residual Gas Stream
- FAQ

Nitrogen Generation

- Nitrogen from Air (79% Nitrogen)
  - Pressure Swing Adsorption (PSA)
    - Gas compression, adsorption on carbon media, depressurization, nitrogen desorption
    - Repeat until desired purity (>99.99%)
  - Cryogenic Liquefaction
    - High Cost
    - High Volume
    - Very High Purity (>99.999%)
  - LN_2 Delivery





Hydrogen Generation

- Traditional Catalytic Steam Reforming of Methane and Water-Gas Shift Reaction

  $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

- Capture CO_2 for Urea Production
- Chloralkali Process

  $2NaCl + 2H_2O \rightarrow Cl_2 + H_2 + 2NaOH$

- Electrolysis of Water

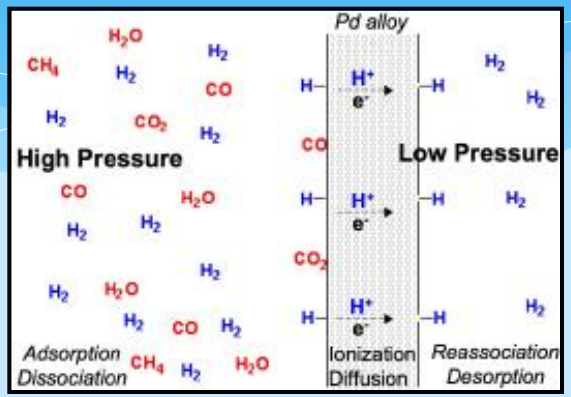
  $2H_2O \rightarrow 2H_2 + O_2$

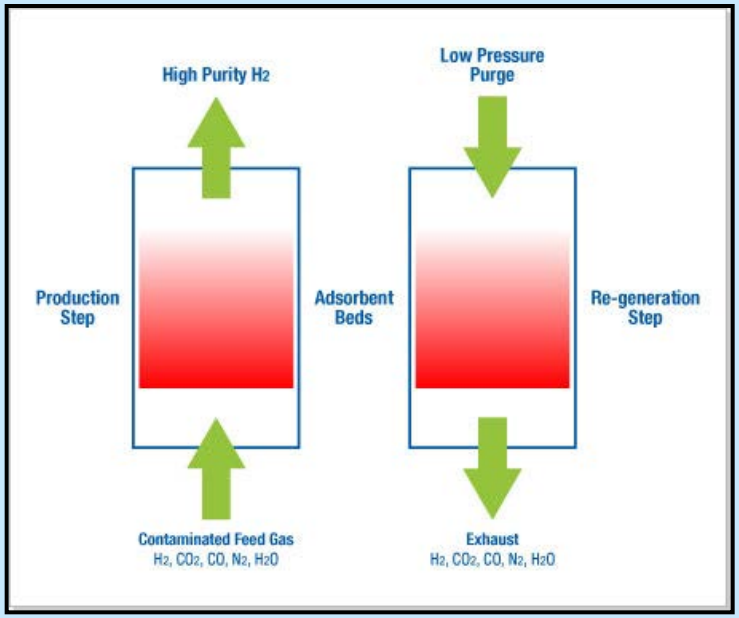
- Pyrolysis (Gasification) of Biomass

  $C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2$

Hydrogen Purification

- High Purity Hydrogen Required to Prevent Catalyst Degradation
  - Low H_2O
  - Low Sulfur
  - Low CO_2 and CO
- Traditional Chemical Methods
  - Diethylene glycol water removal
  - Methyldiethanolamine for CO_2
  - ZnO, FeO remove H_2S chemically
  - N-Formylmorpholine also for H_2S
- Palladium Membrane Separation
- Pressure Swing Adsorption





Reaction Gas Blending

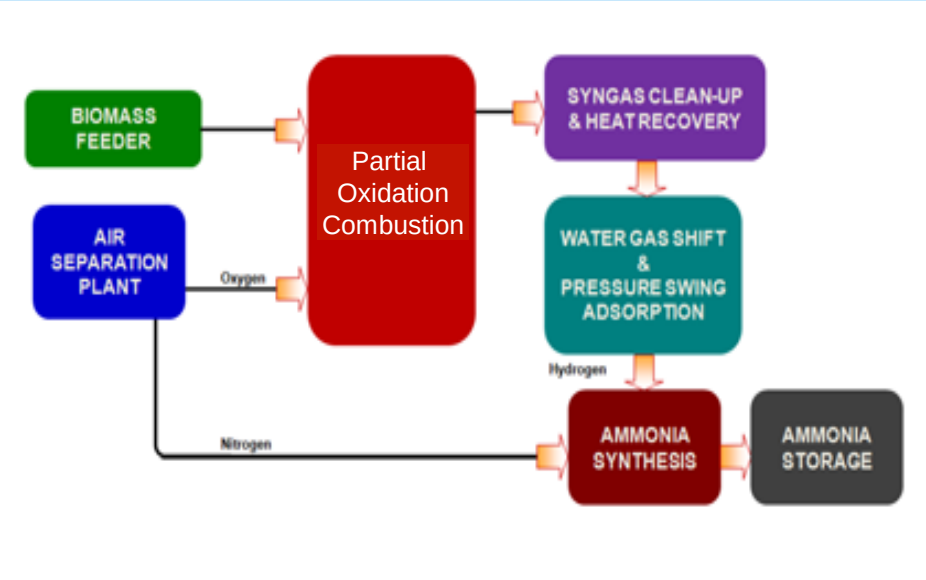
- Low pressure hydrogen and nitrogen are blended using mass flow controllers then compressed to 3000 psi

Reaction Gas Storage

- Renewable Sources (Solar, Wind) Require Large Buffer Storage: for carryover when sun and wind are absent
  - Fixed Tanks
  - Tube Trailers
  - Pressurized to 3,000 psi

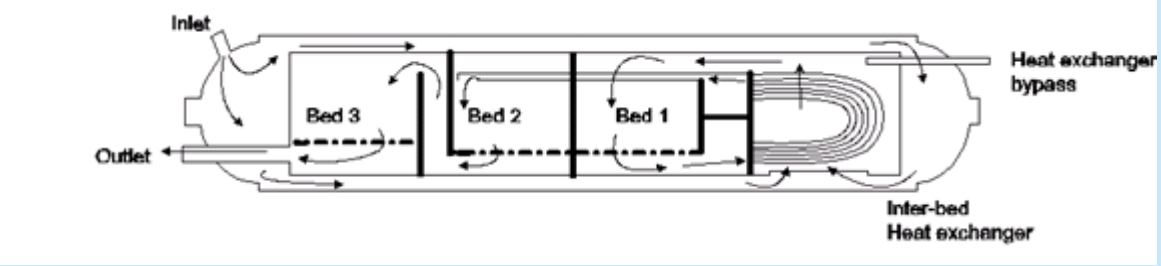
Reaction Overview

- High Pressure (10,000 psi)
- No Gas Recirculation Loop (Once through)
- 95% Conversion of Hydrogen



Reactor

- Catalyst Optimized for High Pressure
  - Catalyst is pre-reduced and sealed in reactor
- Internal Heat Exchanger
- Cooled by Low Pressure Steam
- Rapid Start-up and Stabilization
- Automated Control of Operation
- Remotely Monitored



Ammonia Separation

- Internal Heat Exchanger to Reduce Temperature of Product Gases
- Let-down Turbine Further Reduces Temperature and Pressure
- Refrigeration of Product Gases
  - Cryogenic cooling using LN_2
    $LN_2 \rightarrow N_2$ (gas)
  - Electrical Refrigeration
- Ammonia Captured
  - 97% condensed and removed to liquid storage tank
  - 3% non-condensed

Residual Gas Stream

$$N_2 + H_2 \rightarrow NH_3 + N_2 + H_2$$

- Unreacted Hydrogen (5% of feedstock)
- Non-condensed Ammonia (3% of product)
- Residual Nitrogen
- Add Oxygen From Nitrogen Pressure Swing Adsorber
- Pressure is 200 psi

FAQ

- How Much Does It Cost?
  - For a 5 Ton Per Day (TPD) Unit; Excluding Hydrogen Generation - $500k
- How Soon Can I Get It?
  - System Delivery - 18 months
- How Long Does It Take To Get Permits?
  - If “Bugs and Bunnies Report” is required - up to 2 years
- Recent Projects
  - 5 lbs. (1 gallon) per day – completed and demonstrated
  - 5 Tons/day - under construction
  - 50 Tons/day - permitting in process (Aurora Renewable Energy)