Overview

— Linde Engineering’s Key Plant Types
— Hydrogen Market
— Feedstocks
— Technology: Syngas Generation, Product Recovery
— Summary
Linde Engineering  
Key Plant Types  

**Olefin Plants**  
Products:  
- Ethylene  
- Propylene  
- Butadiene  
- Aromatics  
- Polymers

**Natural Gas Plants**  
- Products:  
  - LNG  
  - NGL  
  - LPG  
  - Helium

**Hydrogen and Synthesis Gas Plants**  
- Products:  
  - H₂/CO/Syngas  
  - Ammonia  
  - Gas removal  
  - Gas purification

**Air Separation Plants**  
- Products:  
  - Oxygen  
  - Nitrogen  
  - Rare gases
Industrial Hydrogen Market

**Installed capacity worldwide:** 600 Billion Nm³/year

**Hydrogen Consumers:**

- Ammonia: 54%
- Chemical Industry / Refineries: 35%
- Electronic Industry: 6%
- Metal- / Glass Industry: 3%
- Food Industry: 2%

**Trends shaping future Hydrogen demand:**

- Increase of World Oil Consumption
- Decline of Overall Crude Oil Quality
- More Stringent Environmental Standards
- New Applications (Automotive fuel, Fuel cell)
Feedstocks

**Light Hydrocarbons**
- Refinery Gases
- LPG (Propane, Butane)
- Natural Gas (48 %)
- Naphtha

**Process**
- Steam Reforming
- Partial Oxidation

**Heavy Hydrocarbons**
- Fuel Oil (30 %)
- Vacuum Tar
- Asphalt
- Petroleum Coke
- Coal (18 %)

**Process**
- Partial Oxidation
Synthesis Gas Generation Principles

- Steam Reforming (SR)
  - Catalytic
- Autothermal Reforming (ATR)
  - Catalytic
- Partial Oxidation (POX)
  - Non-Catalytic
- Pyrolysis

![Graph showing different synthesis gas generation principles](image-url)
Reactions

Non Oxygen Consuming:

- **Steam Methane Reforming (SMR)**
  \[
  \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3 \text{H}_2 \quad \text{endothermal}
  \]

- **Carbon Monoxide Conversion (CO-Shift)**
  \[
  \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \quad \text{exothermal}
  \]

Oxygen Consuming

- **Hydrocarbon Conversion**
  \[
  \text{C}_n\text{H}_m + \frac{n}{2}\text{O}_2 \rightarrow n\text{CO} + \frac{m}{2}\text{H}_2 \quad \text{exothermal}
  \]

- **H2 Oxidation**
  \[
  2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \quad \text{exothermal}
  \]

- **Carbon Monoxide Oxidation**
  \[
  2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2 \quad \text{exothermal}
  \]

- **Synthesis Gas contains H2, CO, H2O, CO2, unreacted Hydrocarbons, Impurities**
- **Requested Products are H2, CO, CO+H2**
- **H2 Separation + Purification required**
Typical Basic Block Diagrams for H₂ Production

**Light Hydrocarbons**

- **Feed Pre-treatment**
  - Steam
  - Feed
- **Steam Reforming**
  - Heat Recovery
- **CO-Shift**
  - Pressure Swing Adsorption
  - Export Steam
  - Hydrogen
  - Fuel Gas
  - Fuel

**Heavy Hydrocarbons**

- **Feed Preparation**
  - Partial Oxidation
  - CO-Shift/Heat Recovery
  - CO₂,H₂S,COS Removal
  - Pressure Swing Adsorption
  - Fuel Gas
  - CO₂-Byproduct
  - Sulphur
  - Export Steam
  - Hydrogen
  - Fuelgas
Steam Reformer

Hydrocarbon + Steam

Burners

Reformer Tubes

Flue Gas

Syngas ~850°C, 20 - 30 bar, ~70 % H₂ in dry gas
Partial Oxidation/Autothermal Reforming Reactors

**ATR (Natural Gas)**
- Feedstock + steam
- Catalyst bed
- Combustion chamber
- ~35 bar
- ~1000 °C
- Synthesis gas: $\text{H}_2$ in dry gas ~ 65%

**POX (All Feedstocks)**
- Feedstock
- Oxygen
- Combustion chamber
- 30 – 70 bar
- ~1400 °C
- Synthesis gas: $\text{H}_2$ in dry gas ~ 61%
CO-Shift Reactor

- Shifts undesired CO to H₂
  \[ \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \]  exothermal

- Simple catalytic reactor

- CO conversion depends on Temperature
  High Temperature Shift: ~ 75 %
  Low Temperature Shift: ~ 90%

- H₂ in dry gas ~ 75 %
Rectisol® Wash Unit for POX Synthesis Gas

- e.g. for Syngas from Coal Gasification
- Methanol as washing solvent
- Rectisol® process separates CO₂, H₂S, COS
- H₂ Purity ~ 98 %
H₂ Purification: Pressure Swing Adsorption

- **Pressure Swing Adsorption** for high purity H₂
  - based on selective adsorption using different kinds of adsorption materials (e.g. molecular sieves)
- **H₂ Purity up to 99.9999 %**
- **H₂ Recovery up to 90 %**
Summary

- Major Hydrogen Market is Chemical Industry
- Feedstocks are Hydrocarbons from Methane to Coal
- Syngas Generation by Steam Reforming, Partial Oxidation, Autothermal Reforming, and CO-Shift Conversion
- \( \text{H}_2 \) Separation from Syngas and Purification depend on Demand and Syngas Process
Thank you for your attention

Linde Engineering