Industrial Hydrogen Production & Technology

Linde Engineering

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Overview

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

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Key Plant Types

Olefin Plants

Products:
- Ethylene
- Propylene
- Butadiene
- Aromatics
- Polymers

Natural Gas Plants

- Products:
- LNG
- NGL
- LPG
- Helium

Hydrogen and Synthesis Gas Plants

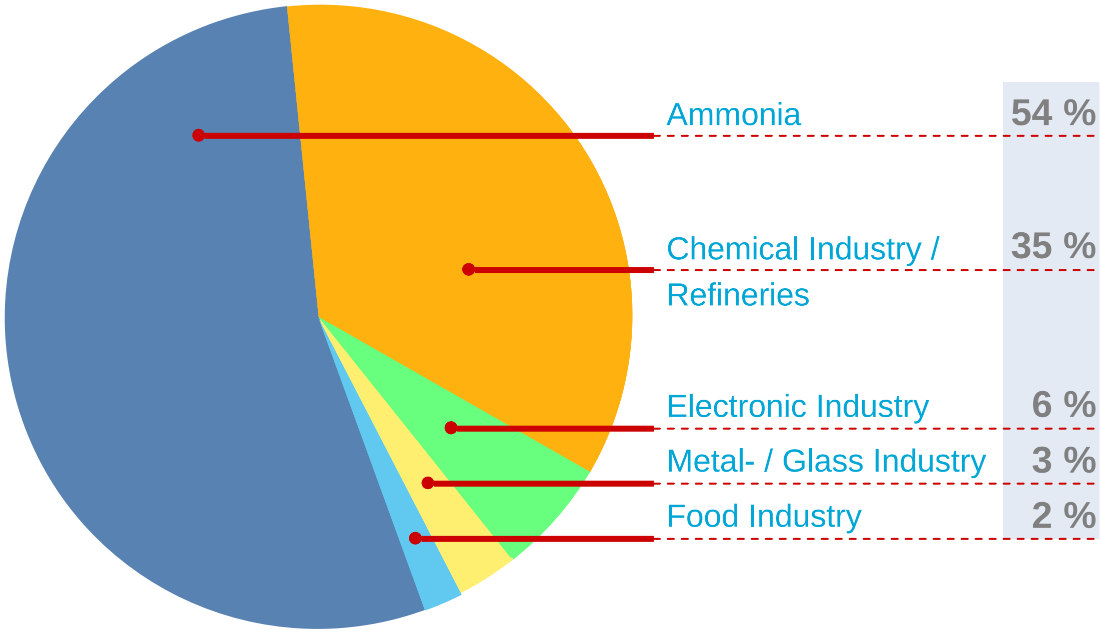
- Products:
- H_2/CO/Syngas
- Ammonia
- Gas removal
- Gas purification

Air Separation Plants

- Products:
- Oxygen
- Nitrogen
- Rare gases

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

Hydrogen Consumers:



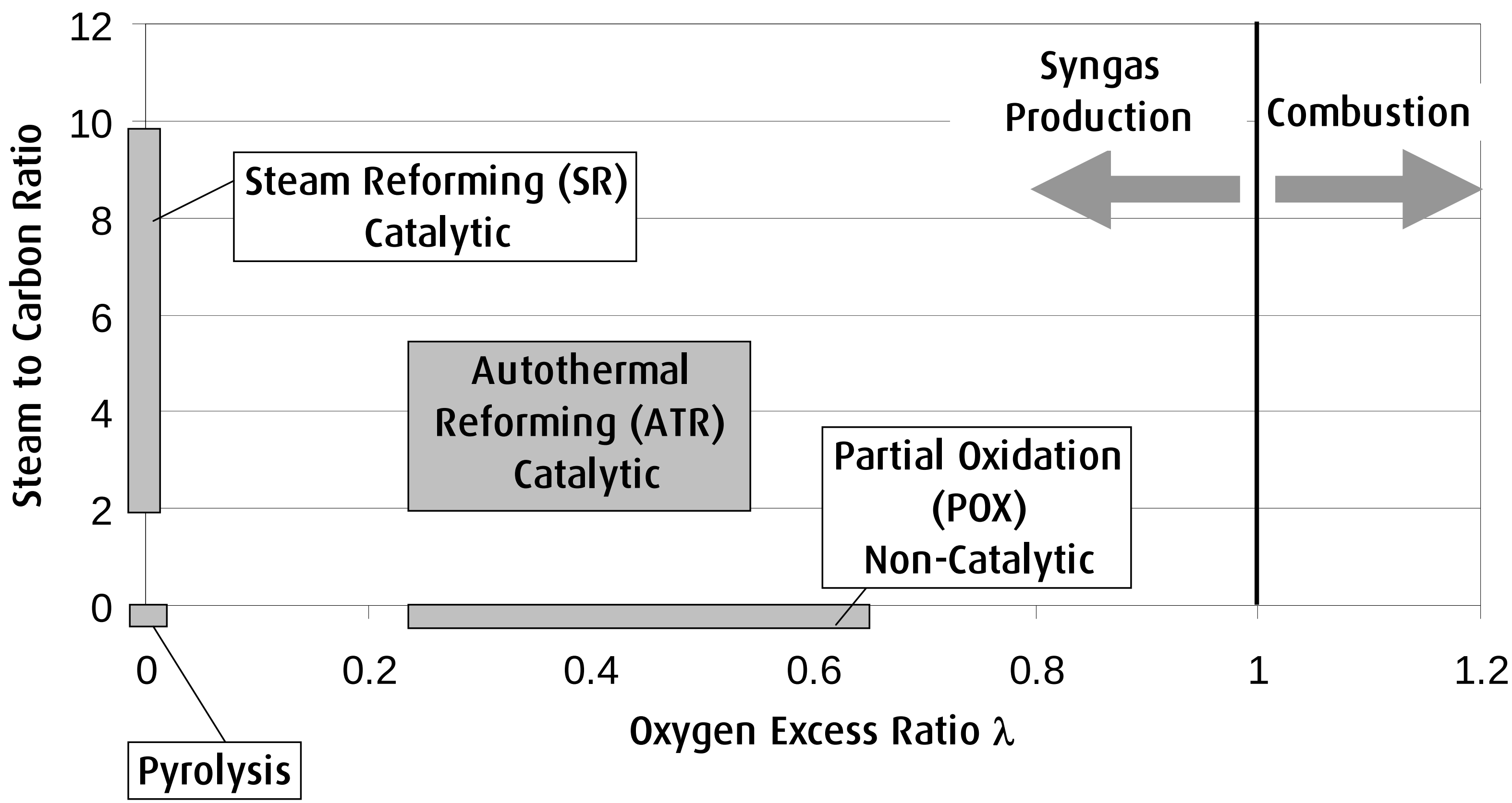
Trends shaping future Hydrogen demand:

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

Feedstocks

Light Hydrocarbons	Heavy Hydrocarbons
▪ Refinery Gases ▪ LPG (Propane, Butane) ▪ Natural Gas (48 %) ▪ Naphtha	▪ Fuel Oil (30 %) ▪ Vacuum Tar ▪ Asphalt ▪ Petroleum Coke ▪ Coal (18 %)
Process	**Process**
▪ Steam Reforming ▪ Partial Oxidation	▪ Partial Oxidation

Synthesis Gas Generation Principles



Non Oxygen Consuming:

- Steam Methane Reforming (SMR)
  $CH_4 + H_2O \rightarrow CO + 3\ H_2$ endothermal
- Carbon Monoxide Conversion (CO-Shift)
  $CO + H_2O \rightarrow CO_2 + H_2$ exothermal

(Steam Reforming)

Oxygen Consuming

- Hydrocarbon Conversion
  $C_nH_m + n/2\ O_2 \rightarrow nCO + m/2\ H_2$ exothermal
- H_2 Oxidation
  $2\ H_2 + O_2 \rightarrow 2\ H_2O$ exothermal
- Carbon Monoxide Oxidation
  $2\ CO + O_2 \rightarrow 2\ CO_2$ exothermal

(Partial Oxidation, Autothermal Reforming)

- **Synthesis Gas contains H_2, CO, H_2O, CO_2, unreacted Hydrocarbons, Impurities**
- **Requested Products are H_2, CO, CO+H_2**
- **H_2 Separation + Purification required**

Typical Basic Block Diagrams for H_2 Production

FuncHy functional materials for mobile hydrogen storage

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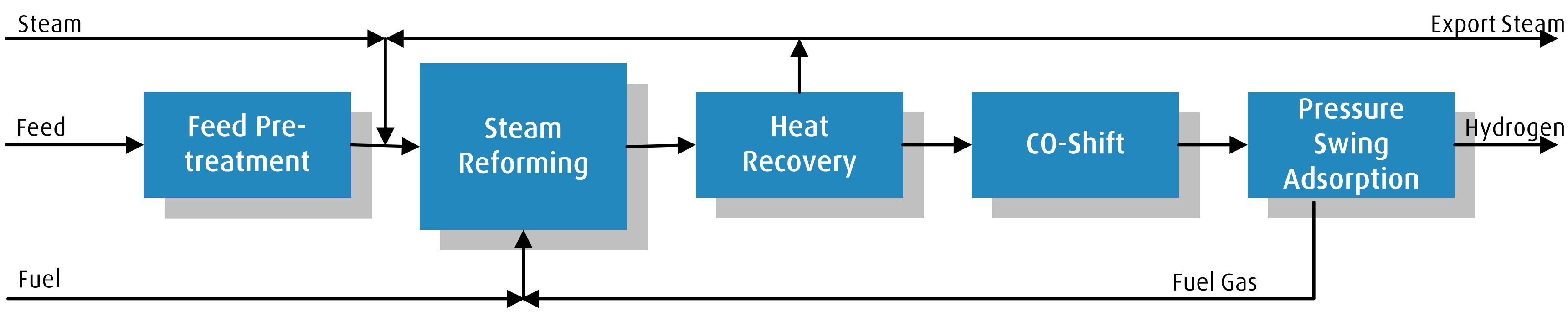
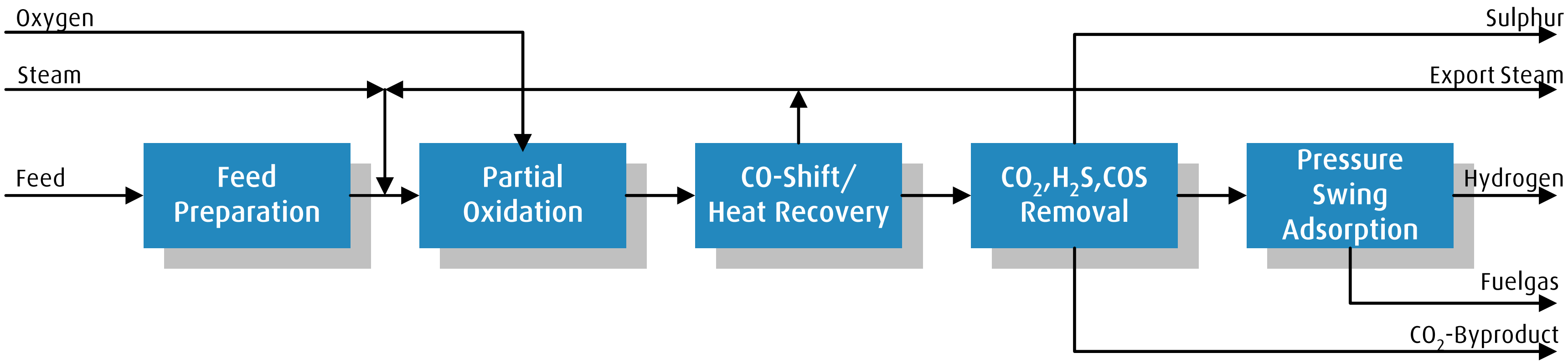
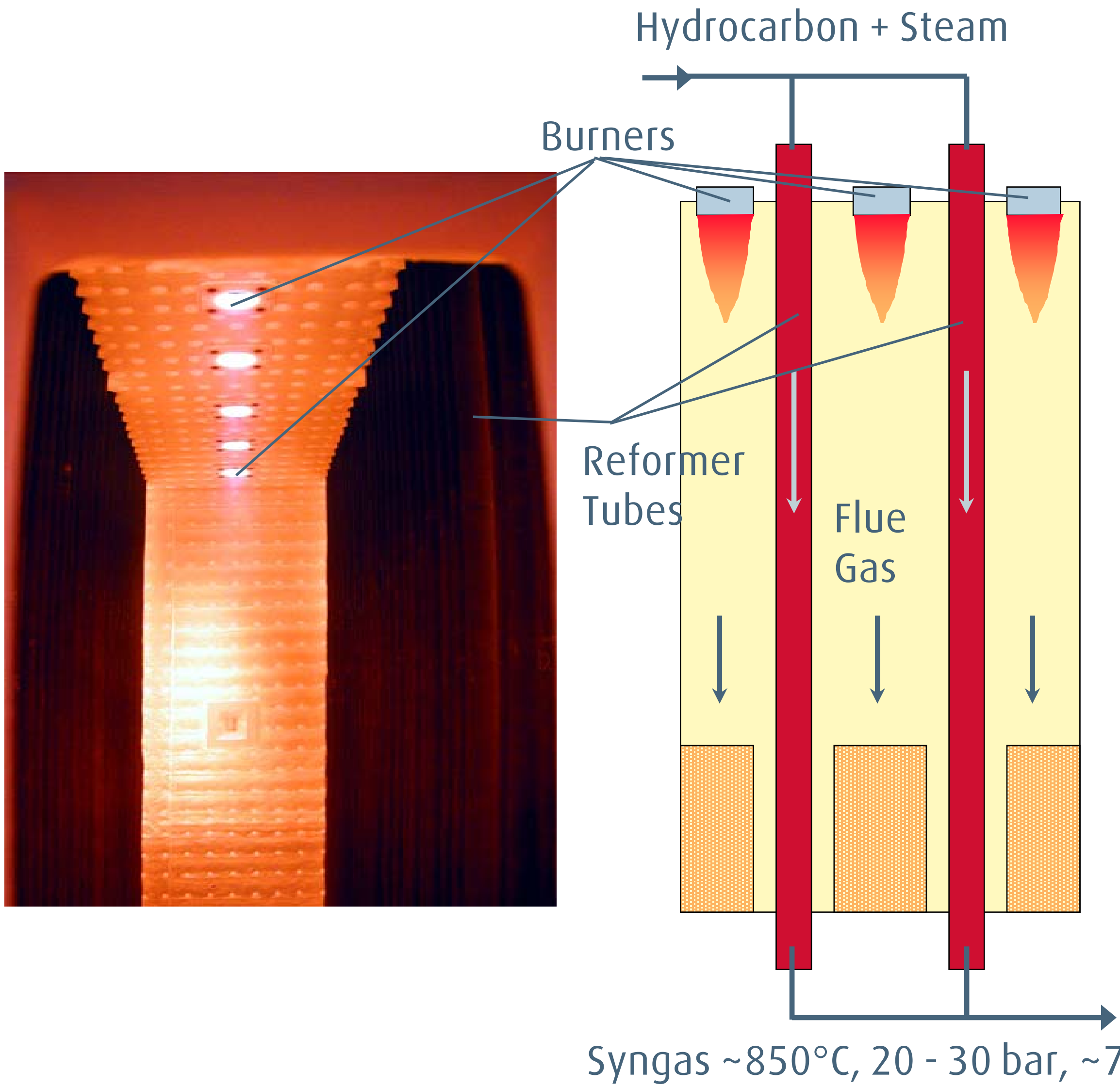
Light Hydrocarbons



Heavy Hydrocarbons



Steam Reformer



Partial Oxidation/ Autothermal Reforming Reactors

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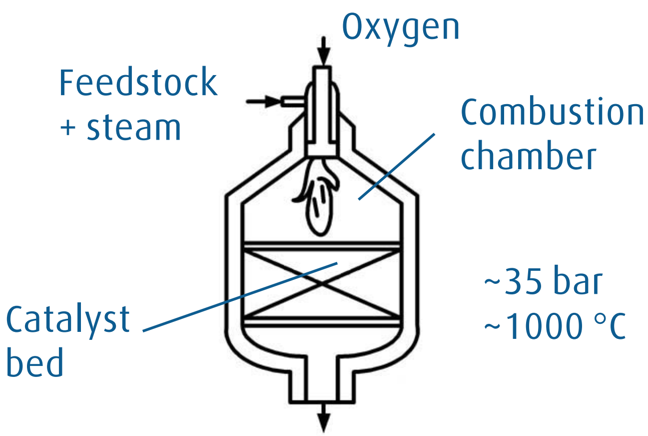
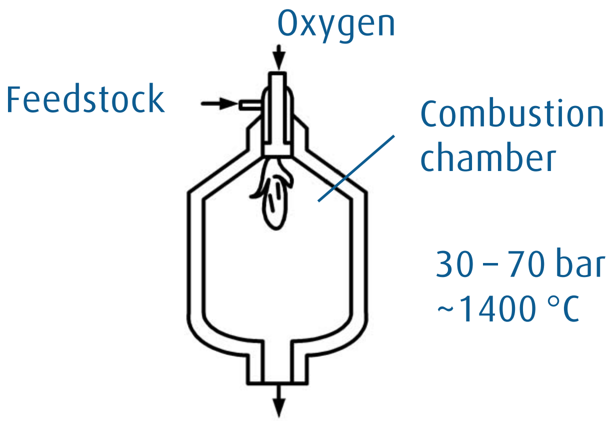
ATR (Natural Gas)



Synthesis gas: H_2 in dry gas ~ 65 %

POX (All Feedstocks)



Synthesis gas: H_2 in dry gas ~ 61 %

CO-Shift Reactor

- Shifts undesired CO to H_2
  $CO + H_2O \rightarrow CO_2 + H_2$ exothermal
- Simple catalytic reactor
- CO conversion depends on Temperature
  High Temperature Shift: ~ 75 %
  Low Temperature Shift: ~ 90%
- H_2 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 CO_2, H_2S, COS
- H_2 Purity ~ 98 %

H_2 Purification:
Pressure Swing Adsorption

- **Pressure Swing Adsorption for high Purity H_2**

  based on selective adsorption using different kinds of adsorption materials (e.g. molecular sieves)

- **H_2 Purity up to 99.9999 %**

- **H_2 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
- H_2 Separation from Syngas and Purification depend on Demand and Syngas Process

Thank you
for your attention

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