Florian Ausfelder

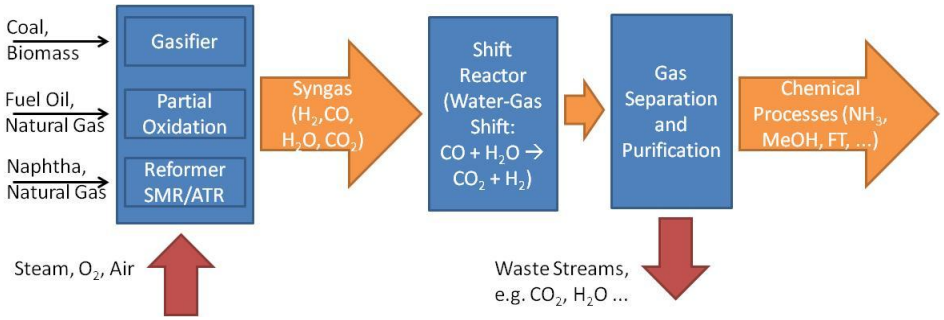
Hydrogen in the Chemical Industry

Market options and challenges

10.7.2013 IEA Hydrogen Roadmap Europe Workshop, Paris

Current production pathways of hydrogen in the (petro-) chemical industry

- Via syngas processes



- Refinery processes:

  e. g. catalytic reforming

  n-heptane → methylcyclohexane + H_2 → Toluol + 4 H_2

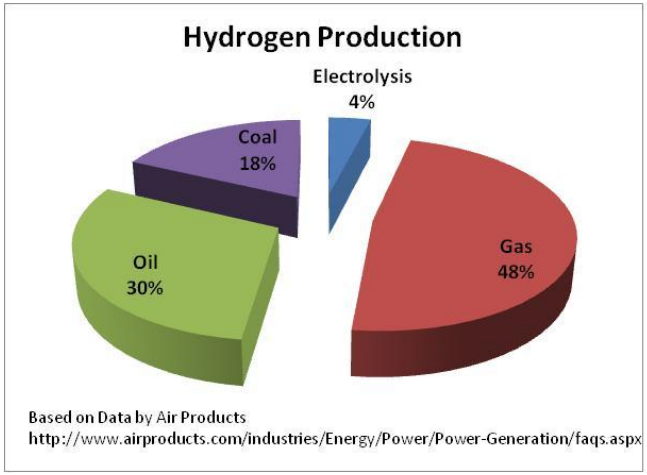
- As part of waste streams

- Water electrolysis

  $H_2O \rightarrow H_2 + O_2$

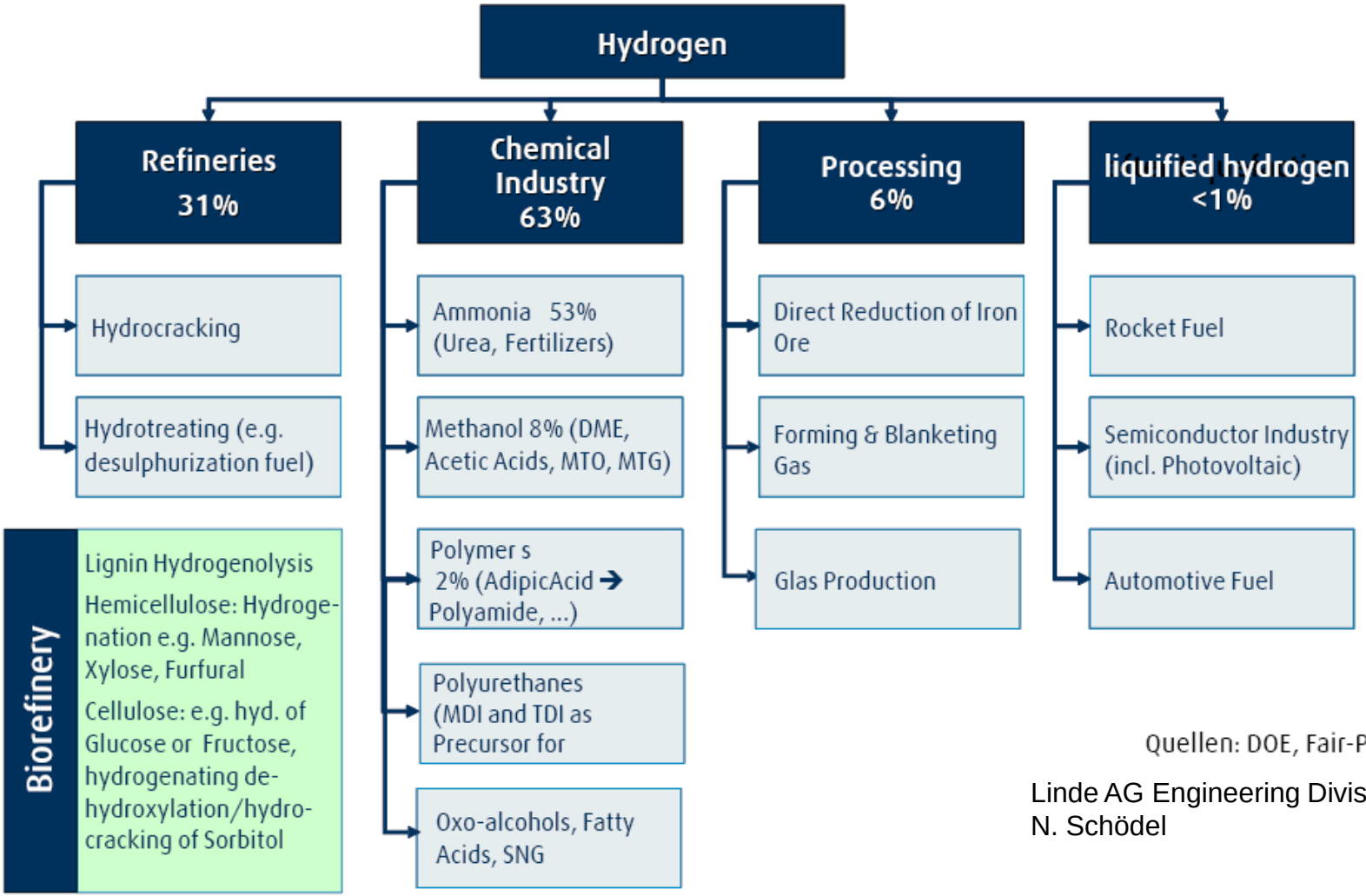
- Alkaline-based electrolysis (state-of-the-art)
- Proton Exchange Membrane electrolysers (PEM) (demonstration)
- High Temperature Solid Oxide Electrolysers (research and development)
- Chlor-alkaline process (by-product)

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



Current hydrogen markets and applications

Overall hydrogen market ≈ 50 +/-5 Mill. t H_2/yr ≈ 500 G Nm^3 H_2/yr ≈ 1500 TWh/yr



Quellen: DOE, Fair-PR

Linde AG Engineering Division
N. Schödel

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Potential future production pathways for hydrogen

- Thermal processes:
  - Thermal water splitting (T> 2500°C)
  - Thermochemical cycles (T≈1000-1500°C)

- Biomass-based hydrogen production
  - Gasification
  - Pyrolysis (e.g. pyroreforming of glycerol)
  - Anaerobic fermentation
  - Microbiological hydrogen production (algae, bacteria, ...)
  - ...

- Photocatalysis
  - Photocatalytic water splitting

- Photoelectrolysis
  - Semiconductors

Potential future use of hydrogen in the (petro-)chemical industry

- Biomass / Biorefineries
  - Deoxygenation
  - HVO (Hydrotreated vegetable oils → renewable diesel)
  - ...
- „Green“ fuels (in combination with a renewable carbon source)
  - Methanisation (with biogas CO_2)
  - Fischer-Tropsch
  - Methanol production
  - ...
- „Green“ substition of fossil raw materials (in combination with biomass)
  - Lower GHG emissions
  - Reduced dependence on fossil fuel imports
  - ...
- Abundant precursor for reduction processes

- Extended opportunities for fuel upgrading and hydrotreating

Production Costs of Hydrogen, Trends

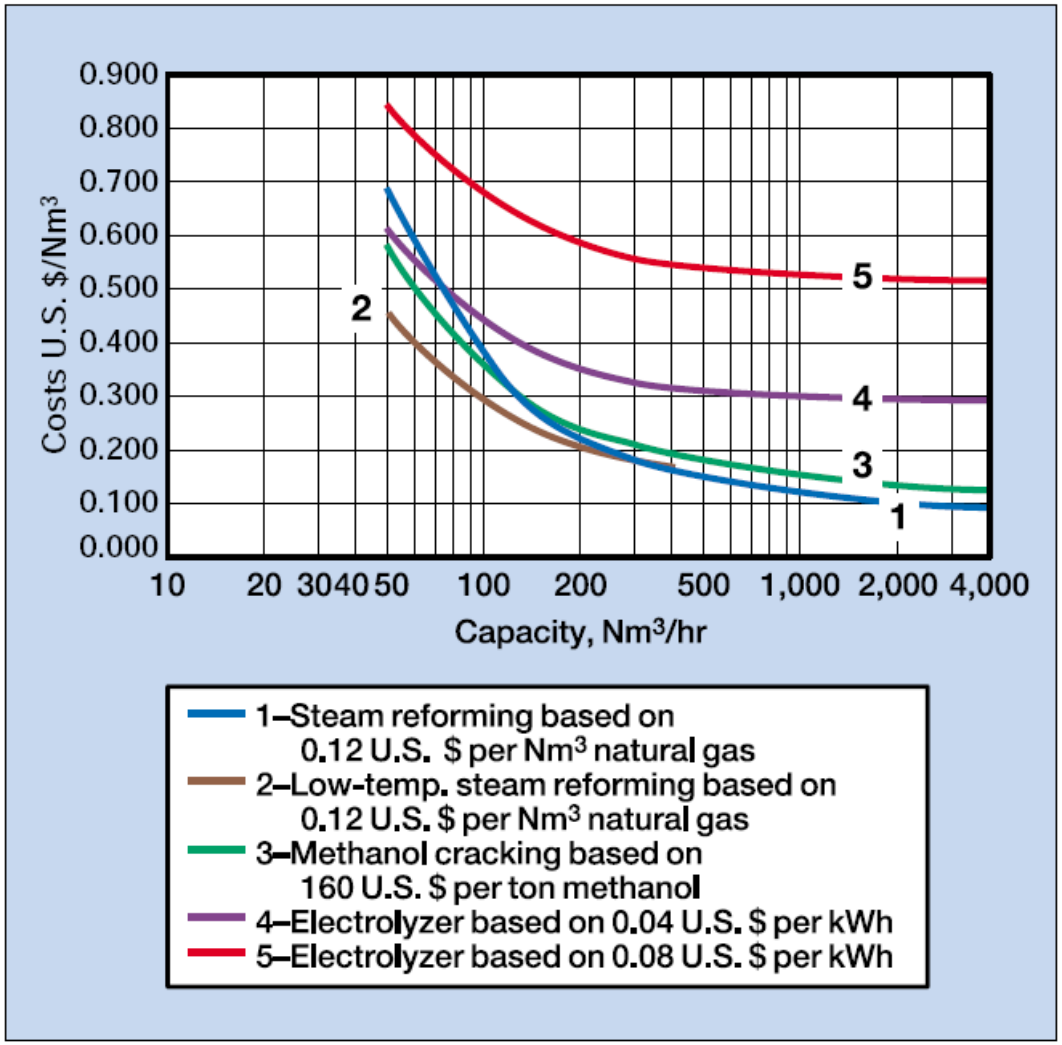

Fig. 6. Production costs per Nm^3 H_2

R.E. Stoll, F. von Linde Hydrogen – What are the costs
Hydrocarbon Processing, December 2000 page 42-46

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OPEX vs. CAPEX Steam Reforming

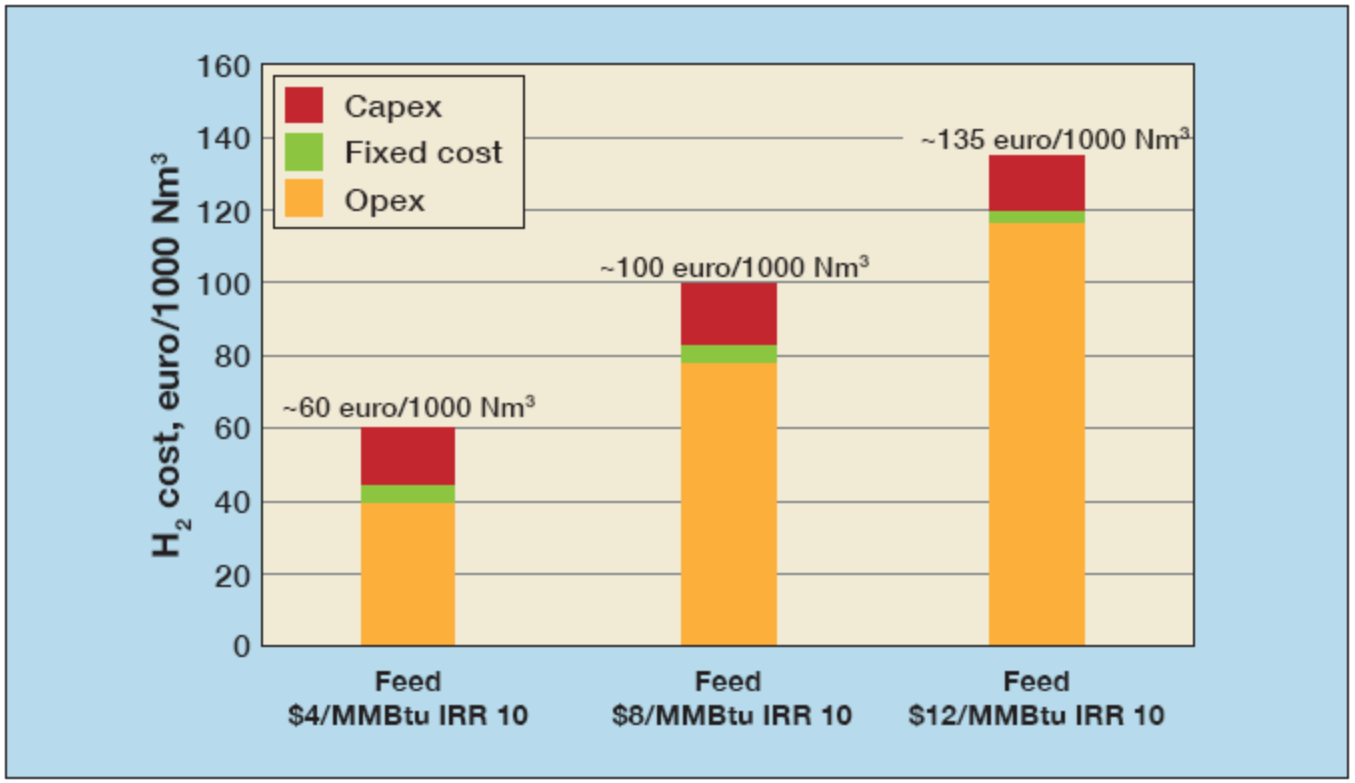
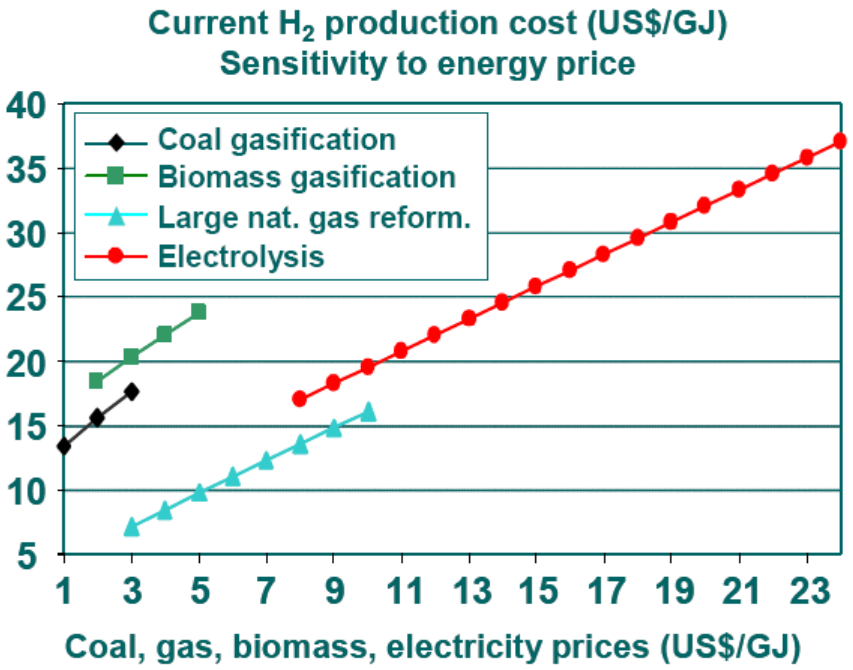
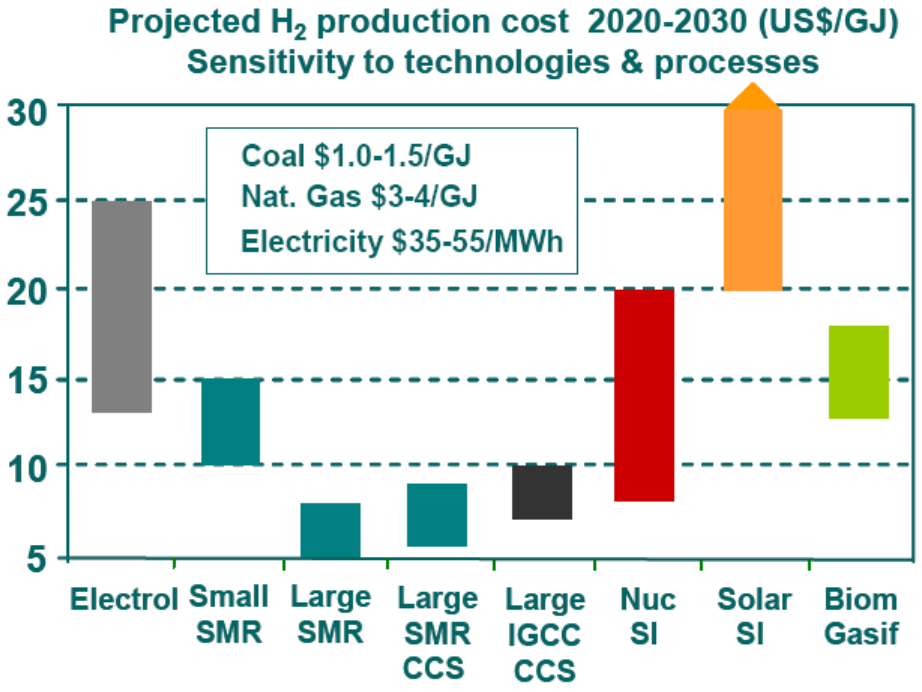


Figure 5 Operating costs (Opex) as a percentage of overall hydrogen production costs

Source: **LUIGI BRESSAN and CHRIS DAVIS**
***Foster Wheeler in* Processing Shale Feedstocks 2013 27**

Dependence on energy prices





Source: **IEA Energy Technology Essentials, 2007**

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Production Costs of Hydrogen (LHV)

Technology	IEA (2007) $/GJH$_2$	DoE 2012 $/GJH$_2$	EIA (2008) $/GJH$_2$	DoE $/GJH$_2$	DE EERE (2003)
Steam Reforming	6-9 (central.) 50 (decentral.)	12 - 13 (w/o CSD)	12 (central.) 21 (decentralised)		35
Alkaline	30		32 (central. wind) 60 (decentral. wind) 55 (Grid)		36
PEM					
SOFC					
Coal Gasification	7-10		15 (CCS) 10 (no CCS)		
Biomass Gasification			12		17
Thermal water-splitting (nuclear)	10-20 (nuclear) 20-30 (solar)		12 (nuclear)		
Photoelctrolysis				14-86	
Source	IEA Energy Technology Essentials, 2007 http://www.iea.org/techno/essentials5.pdf	DOE Hydrogen and Fuel Cells Program http://www.hydrogen.energy.gov/pdfs/12024_h2_production_cost_natural_gas.pdf	EIA quoted in Timothy Lipman „An overview of hydrogen production and storage systems with renewable hydrogen case studies“ http://www.cleanenergystates.org/assets/2011-Files/Hydrogen-and-Fuel-Cells/CESA-Lipman-H2-prod-storage-050311.pdf	Technoeconomic Analysis of Photoelectrochemical (PEC) Hydrogen Production Final Report (2009) Contract: GS-10F-009J http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pec_technoeconomic_analysis.pdf	DoE, EERE, Hydrogen, Fuel Cells & Infrastructure Technologies Program 2003 http://www.nrel.gov/docs/fy05osti/34289.pdf

Scale?

- NH_3 production (Europe, EU 27): 16,8 Mill. t NH_3 (2011) → 3 Mill. t H_2
- Electrolysis (4,3 kWh / m^3 H_2) → 145 TWh
- Total electricity production (Germany, 2011): 609 TWh
- Electricity by renewables (Germany, 2011): 124 TWh

  (49 TWh Wind, 33 TWh Biomass, 19 TWh PV, 18 TWh Hydro, 5 TWh Waste)
- „unproduced“ renewable electricity (Germany, 2011): 421 GWh

Market Disruption?

- About half of overall hydrogen production is used for the production of ammonia which in turn is the basis of urea and fertilizers.

- What effect would the establishment of a new big market on hydrogen as transportation fuel (with generally higher prices than the current ones for hydrogen) have on the price of fertilizers and agricultural production?