CO_2 Capture Project

NorCap Seminar

Hydrogen Membrane Reformer Technology

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Outline

- **Part one:**
  - Project overview
  - Project activities
  - Process and reactor system development
- **Part two:**
  - Materials development and testing

Project overview

Vendors: Norsk Hydro, Sintef and UiO

Partly based on Norsk Hydro IPR covering:

- **Ceramic Conducting Materials**
- **Reactor design**
- **Process design**

Target:

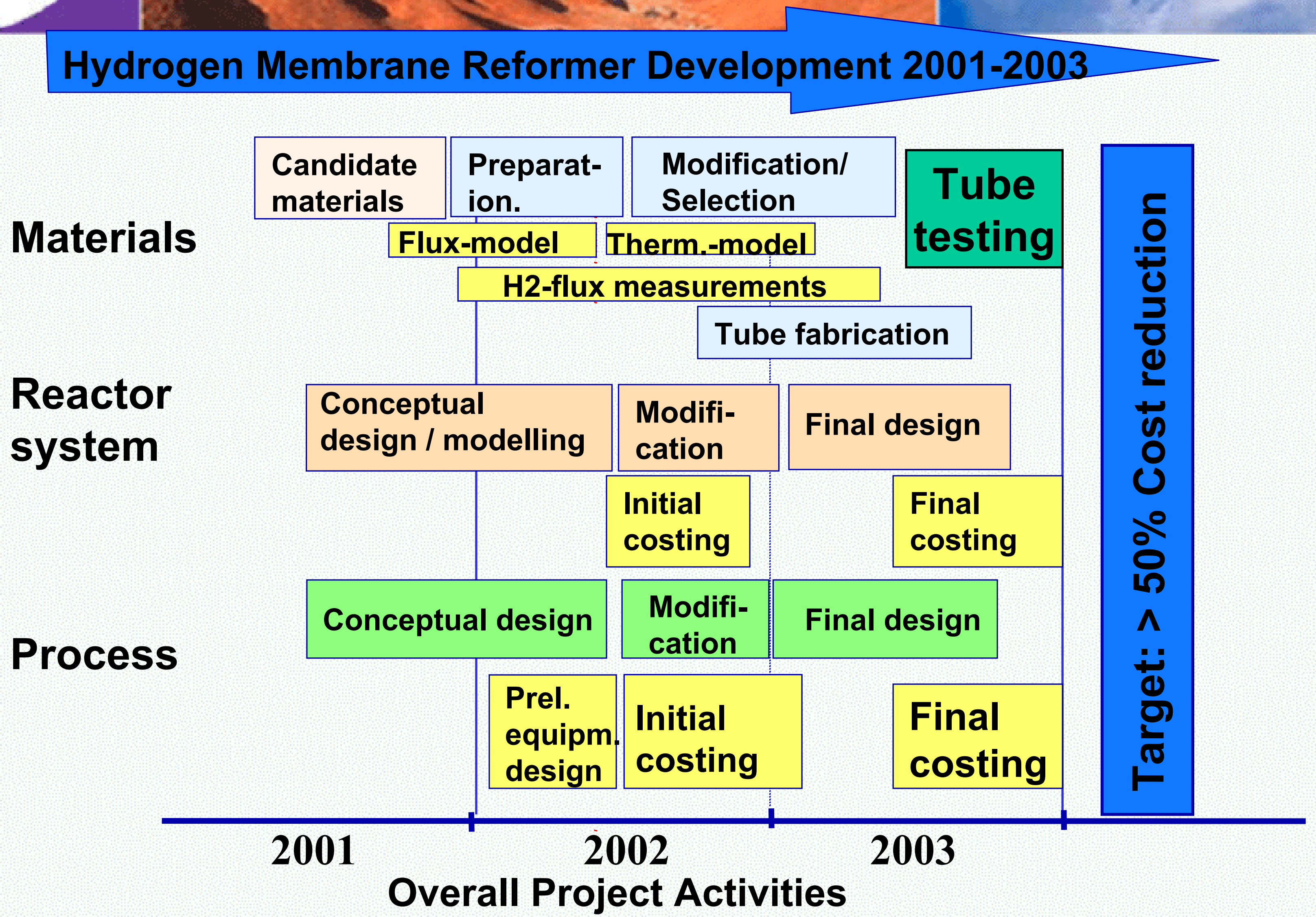
Develop Mixed Conducting Membrane (MCM) with sufficient H_2 transport rates and stability under selected process conditions. Develop a techno- economically viable PCDC process including said materials.

Tasks

- Develop and test membrane materials for a membrane reformer
- Design a membrane reactor/reformer system
- Design a pre-combustion process incorporating a membrane reformer reactor system

Main challenges

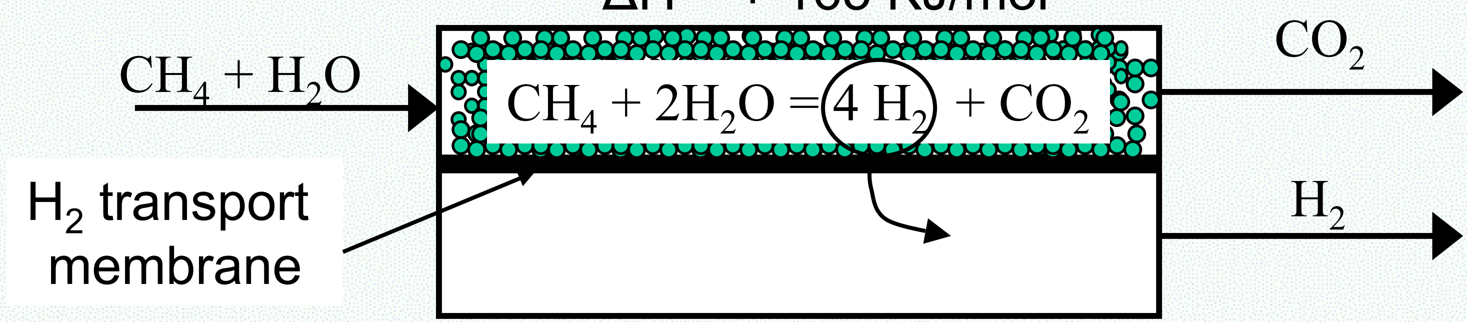
- Sufficient H_2-flux at process conditions
- Material stability
- Membrane fabrication
- Sealing and manifolding
- Reactor design
- Integration with CCGT


Hydrogen Membrane Reformer Development 2001-2003
Materials
Candidate materials
Preparat-ion.
Modification/ Selection
Tube testing
Flux-model
Therm.-model
H2-flux measurements
Tube fabrication
Reactor system
Conceptual design / modelling
Modifi-cation
Final design
Initial costing
Final costing
Process
Conceptual design
Modifi-cation
Final design
Prel. equipm. design
Initial costing
Final costing
Target: > 50% Cost reduction
2001
2002
2003
Overall Project Activities

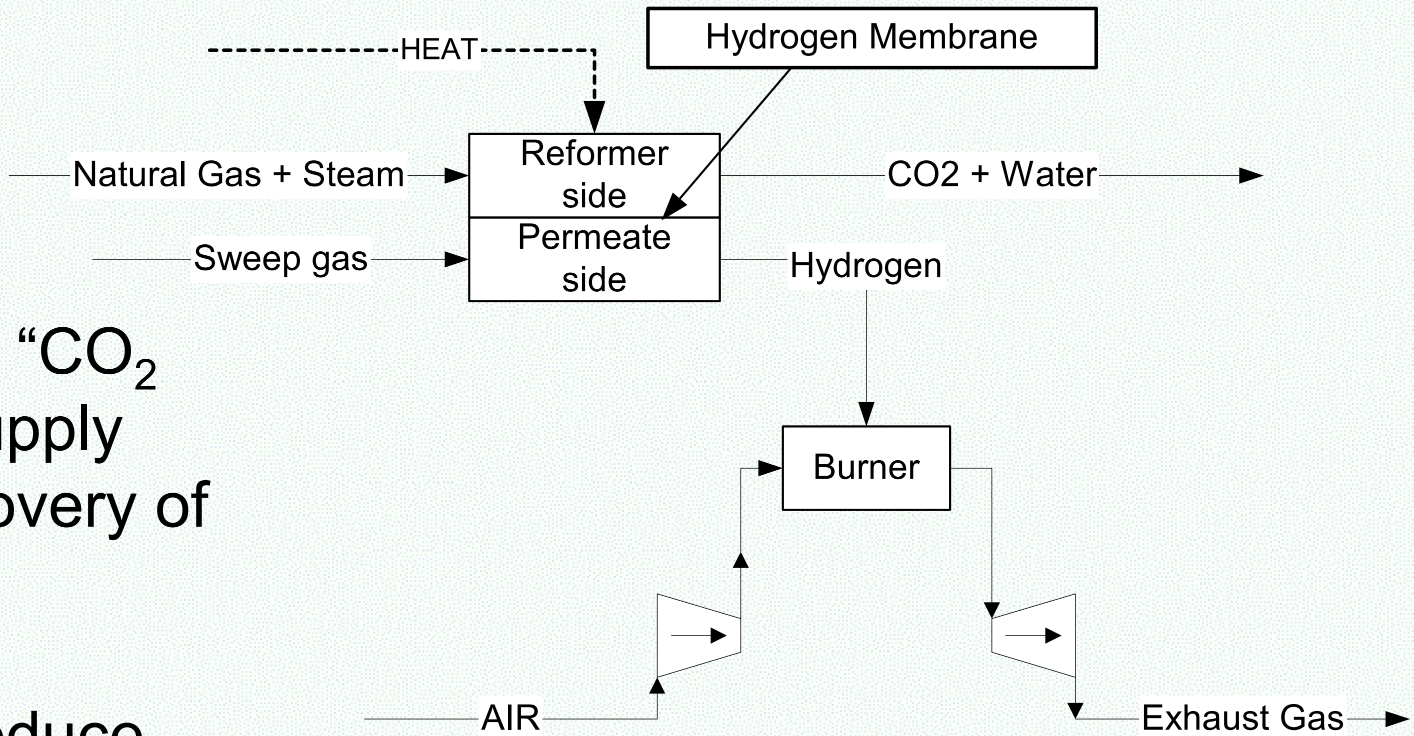
Hydrogen Membrane Reformer

- extract product gas (H_2) from reactor
- drive equilibrium limited reactions towards completion
- expand allowed range of temperatures and pressures

$\Delta H = + 165$ KJ/mol



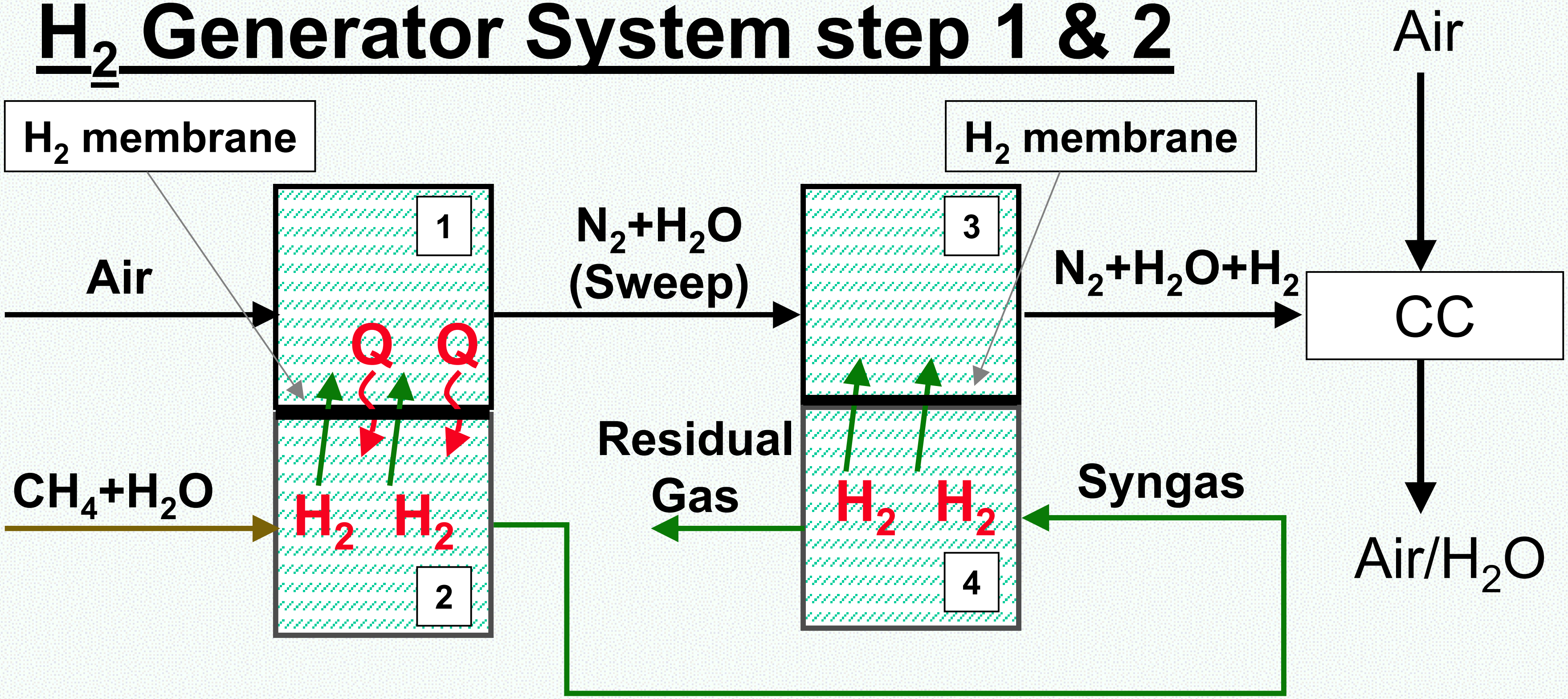
Power Plant Integration



Challenges:

- Efficient and "CO_2 free" heat supply
- Efficient recovery of hydrogen
- Diluted H_2 is needed to reduce NOx emission

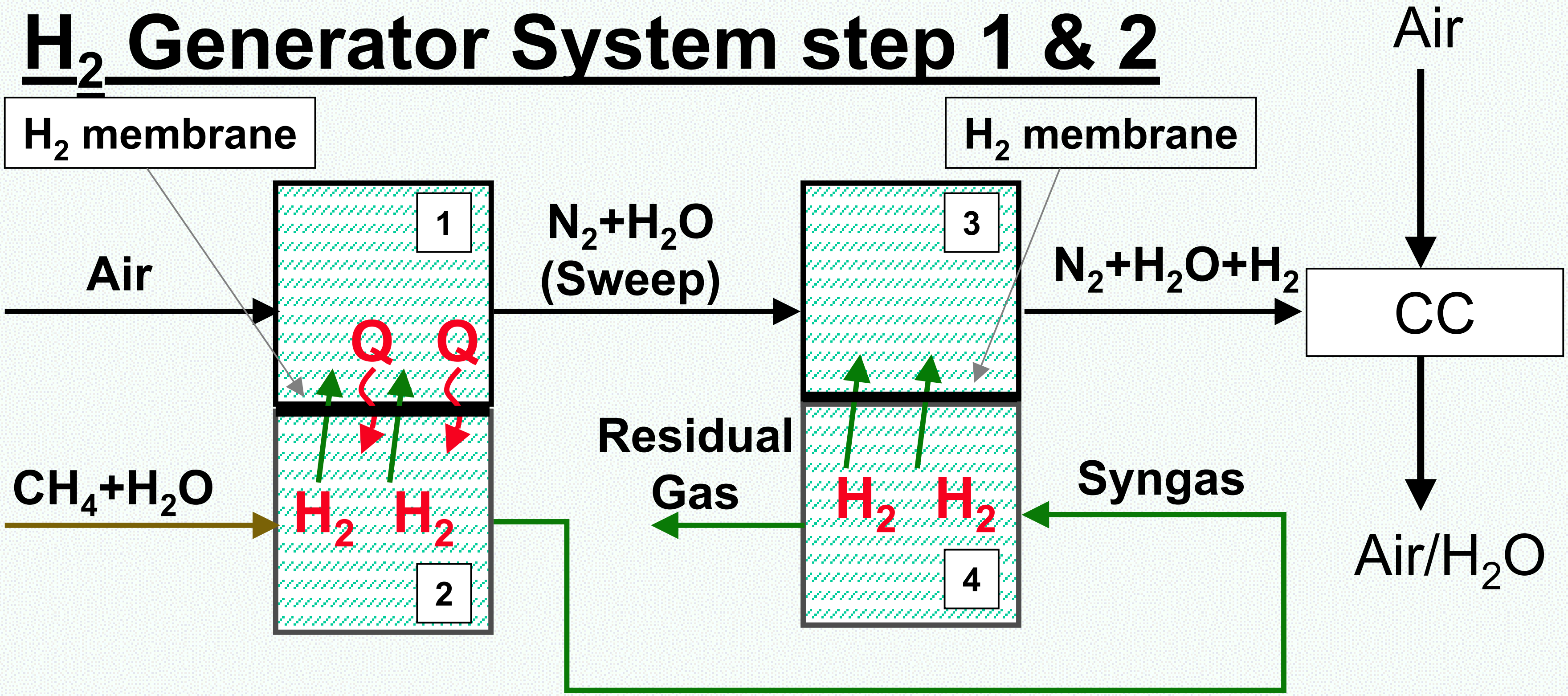
H_2 Generator System step 1 & 2



Oxidation Membrane Section

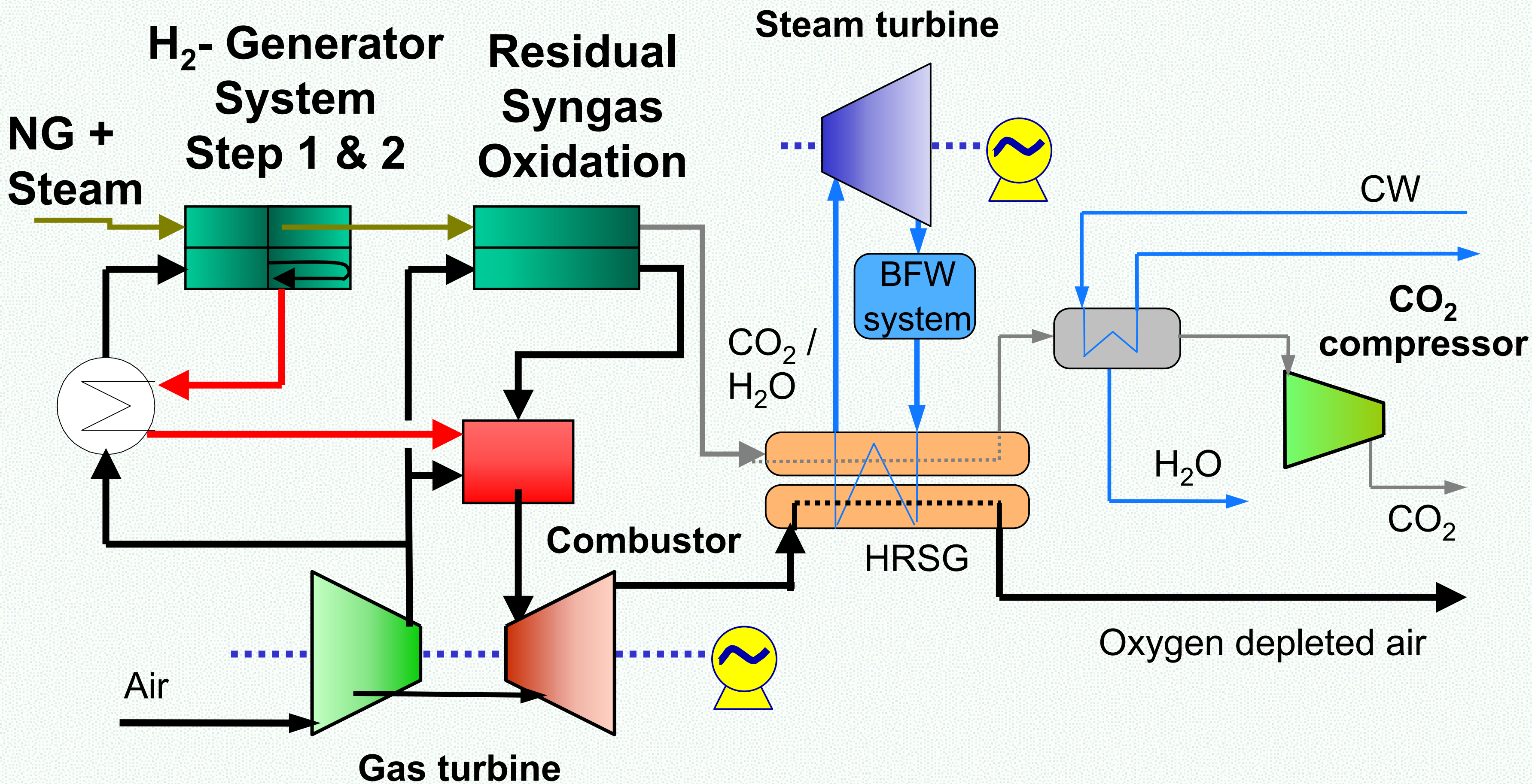
Membrane Steam Reformer Sweep Section

H_2 Generator System step 1 & 2



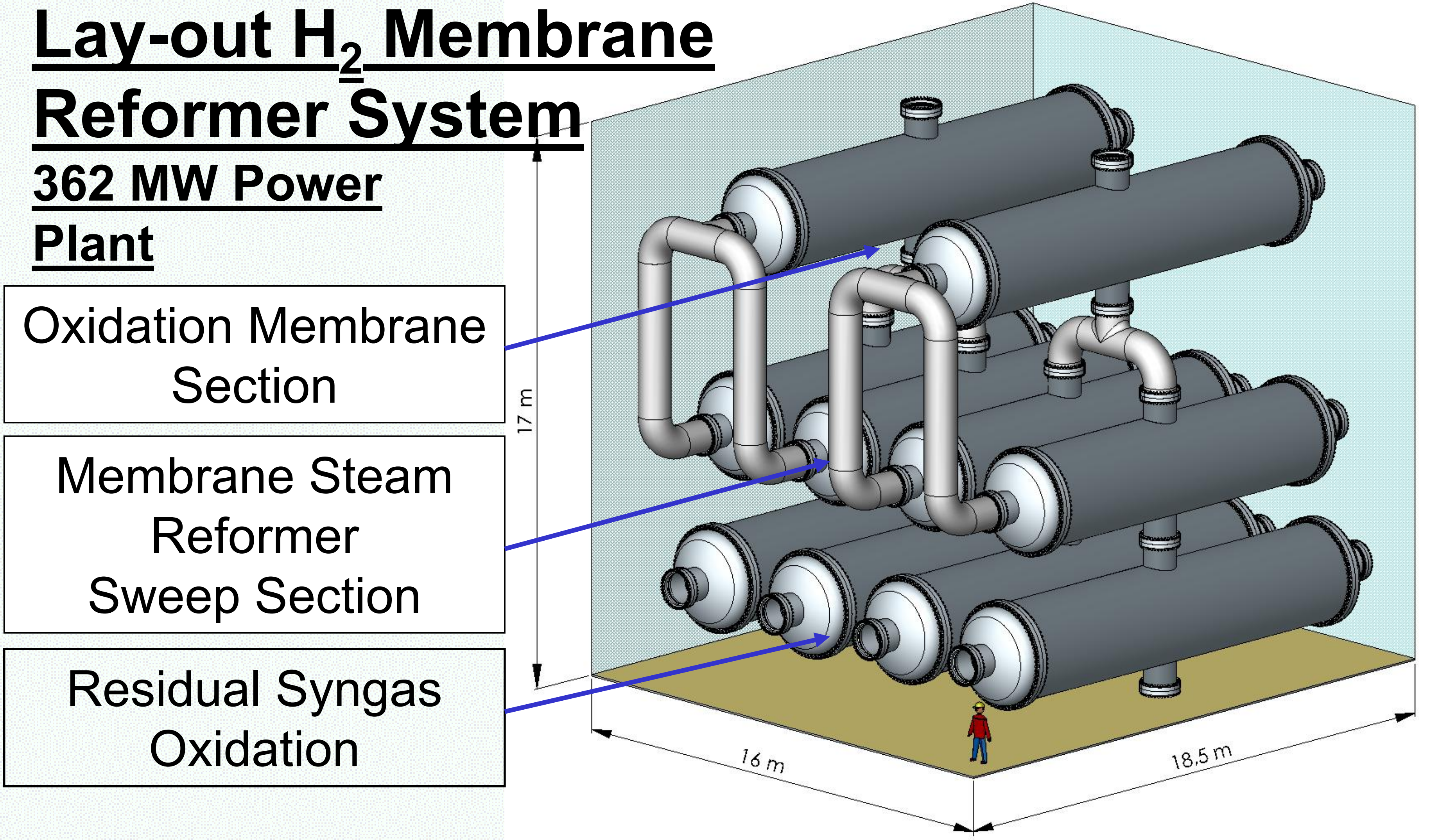
1	$\frac{1}{2} O_2+H_2 = H_2O$	3	Sweep
2	$CH_4+H_2O = CO+3H_2$ $CO +H_2O = CO_2+H_2$	4	$CH_4+H_2O = CO+3H_2$ $CO +H_2O = CO_2+H_2$

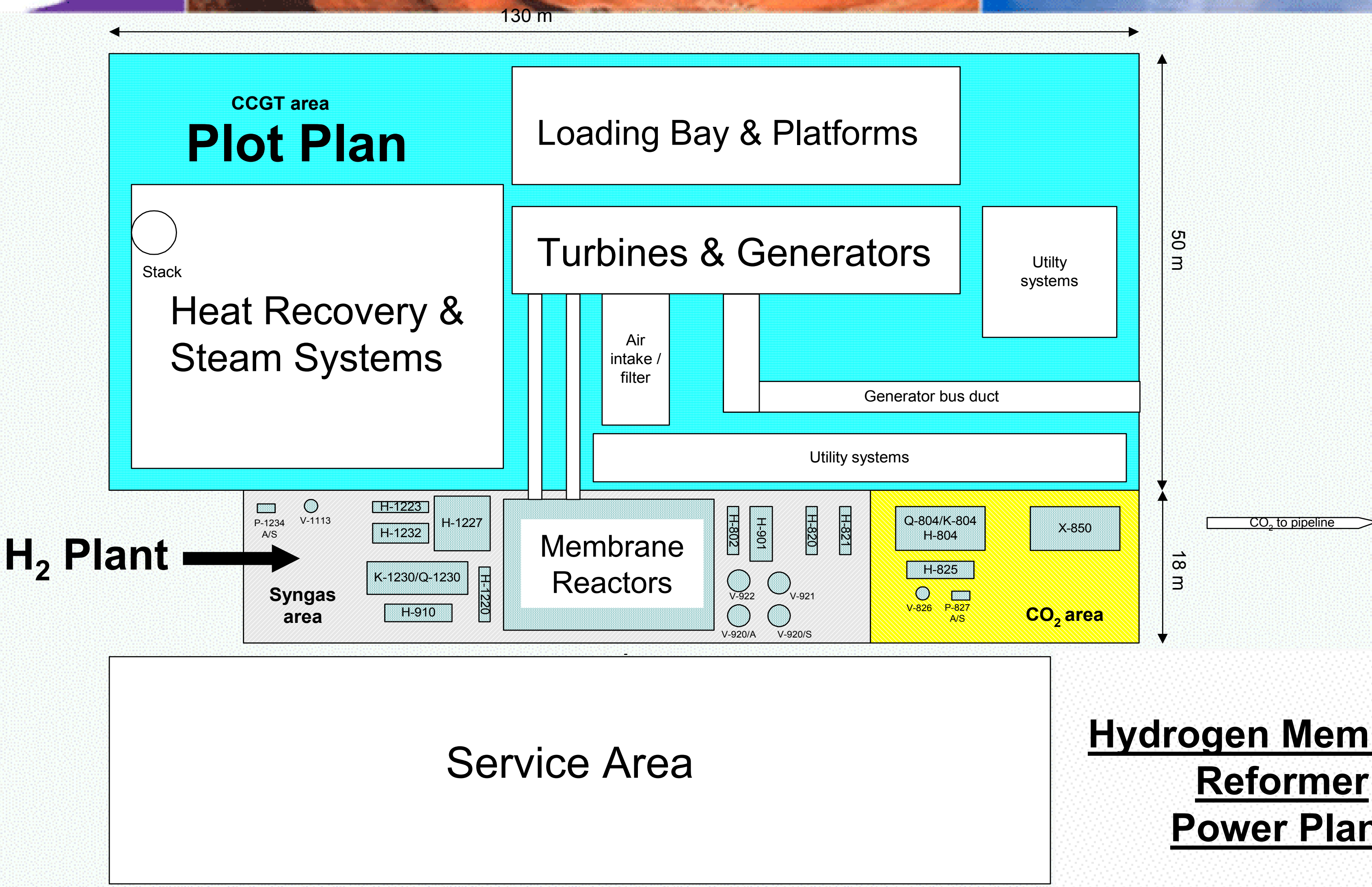
H_2 Membrane Reformer - Power Plant



Lay-out H_2 Membrane Reformer System

362 MW Power Plant





Hydrogen Membrane Reformer Power Plant

Fuel gas NOx - emission

	Ref. gas tested at GE	Actual gas
H_2	45.5 mol%	42.4 mol%
N_2 + Ar	26.7 mol%	37.4 mol%
H_2O	27.8 mol%	20.2 mol%
NOx@15% O_2	4.7 ppmvd	5 ppmvd OK!

Comparison with CCGT

	H2 Membrane CCGT	Base case (conventional CCGT)
Total fuel consumption, MW:	681.0	681
Net power output, MW	362	395
Thermal efficiency, inclusive CO_2 compression:	53.1 %	58.0 %
CO_2 emission, t/h	Close to zero	144.1

CO_2 gas leaves the product purifying at 27 bar and is compressed to 150 bar.

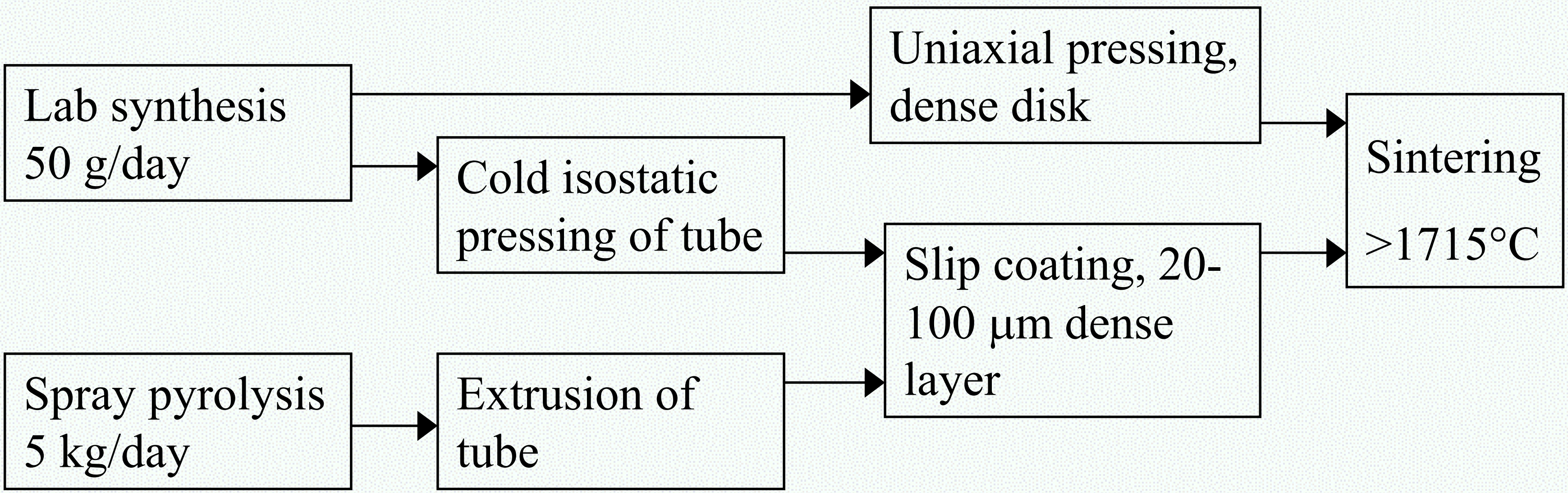
Process development summary

- **Initial estimates shows that the *high temperature* Hydrogen Membrane Reformer concept has the potential to reduce the CO_2 capture cost in power plant compared with conventional amine scrubbing (assuming target H_2 flux).**
- **5 ppm NOx emission can be achieved without catalytic NOx reduction.**
- **Loss in efficiency only 5%-points.**
- **CO_2 emission close to zero**
- **Compact Hydrogen Plant: Only 20 x 80 m (plot plan)**

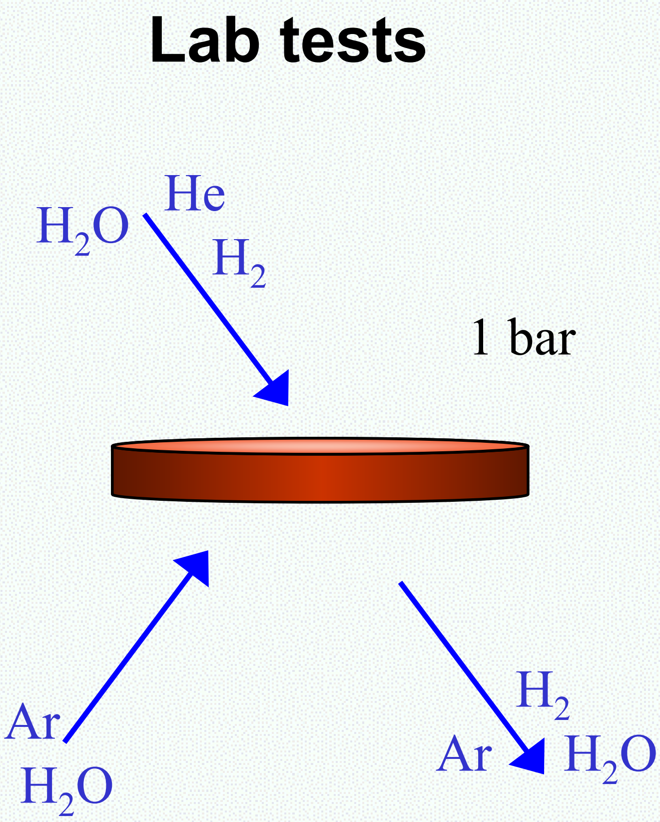
Hydrogen Membrane Reformer Technology – Part II

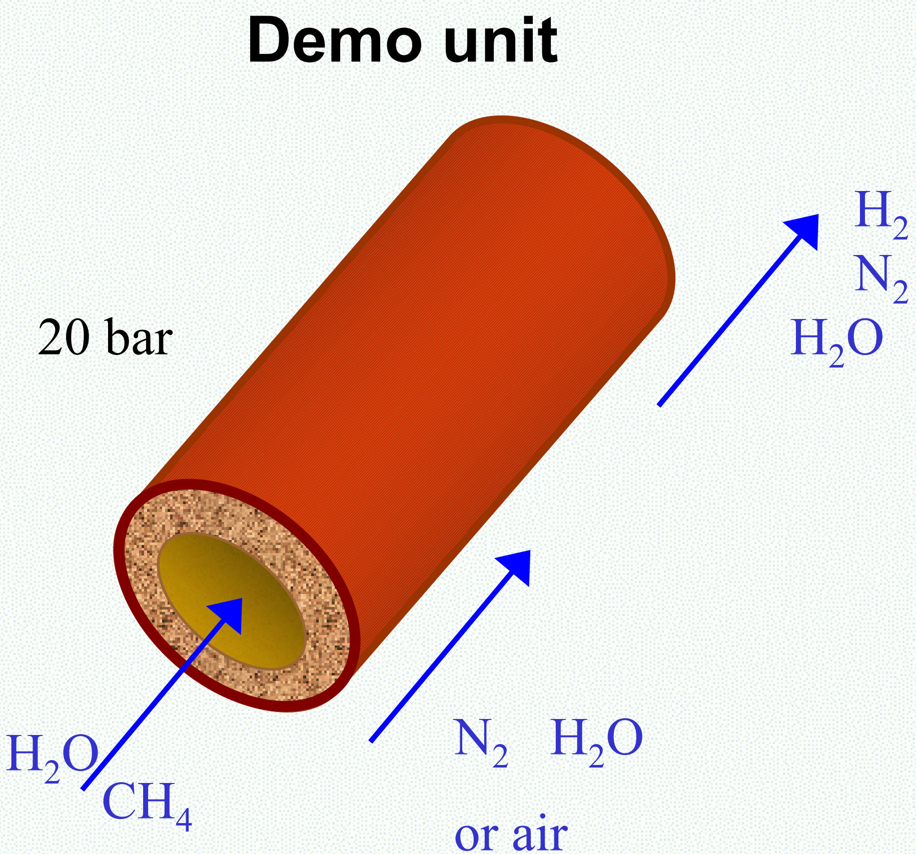
Membrane fabrication

Powder production | **Porous support** | **Dense membrane**

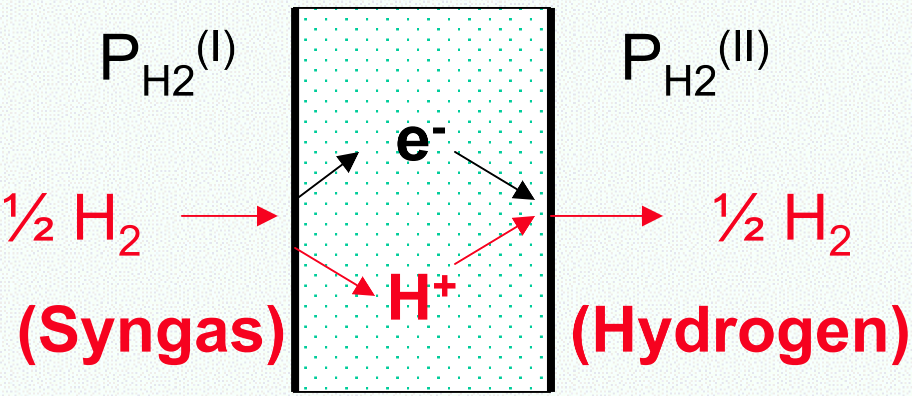


Hydrogen flux measurements





Hydrogen Mixed Conducting Membranes

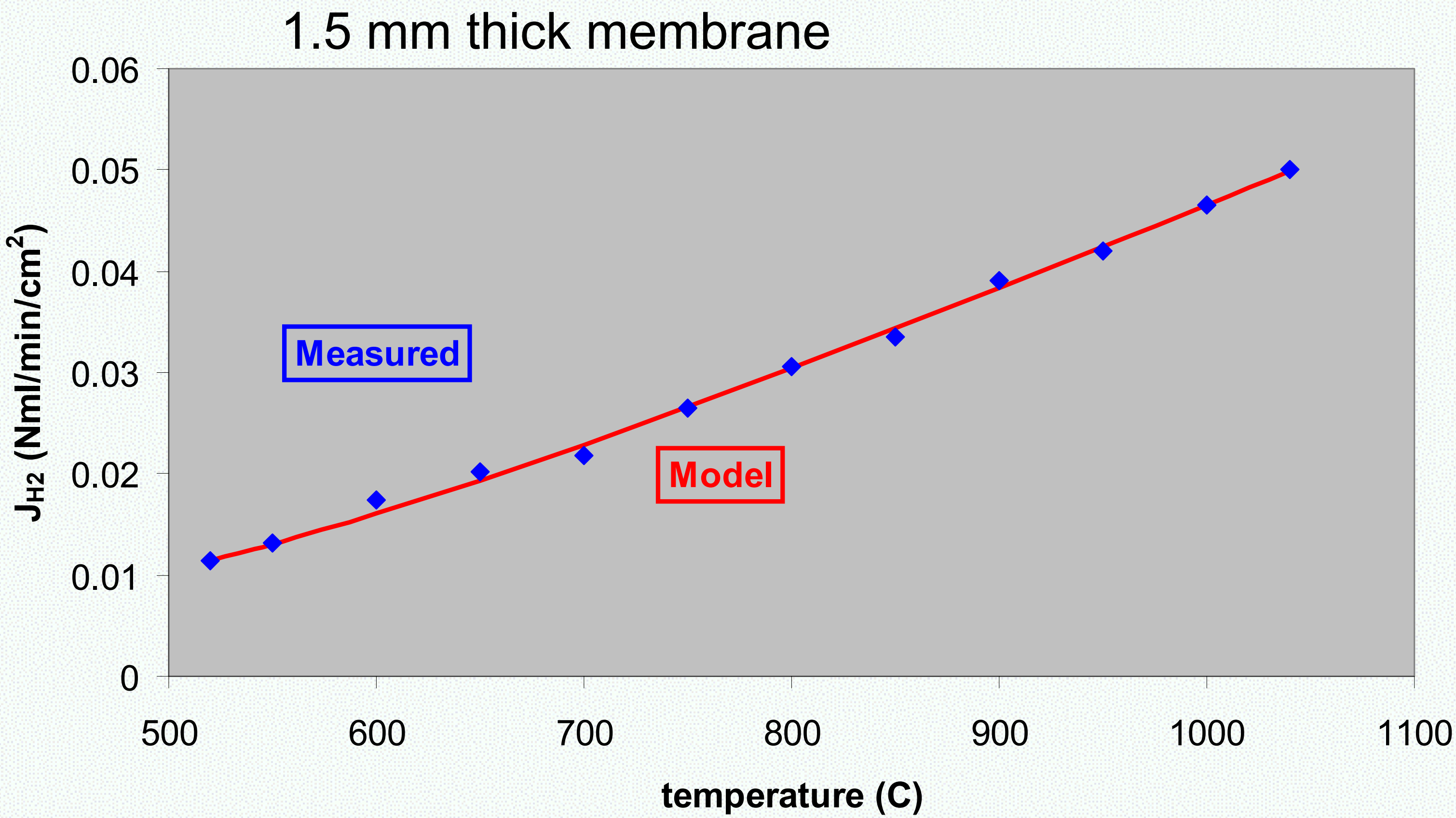


$$\tfrac{1}{2} H_2 \longrightarrow H^+ + e^- \qquad H^+ + e^- \longrightarrow \tfrac{1}{2} H_2$$

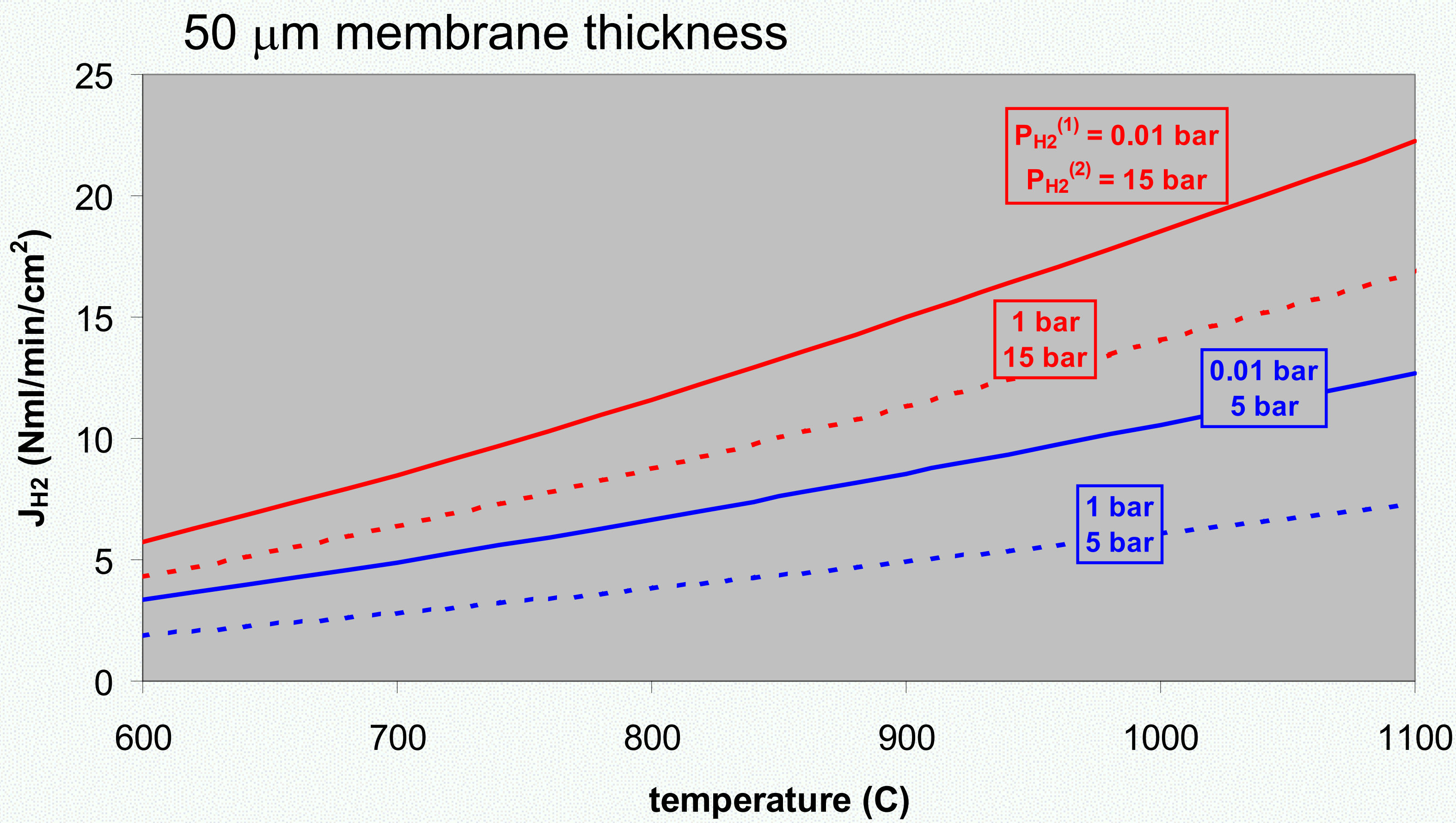
$$P_{H2}^{(I)} > P_{H2}^{(II)}$$

- Driving force for H_2: H_2 flux $\approx \log P_{H2}^{(I)} / P_{H2}^{(II)}$
- Membrane material 100% dense

Hydrogen flux, measured and modelled

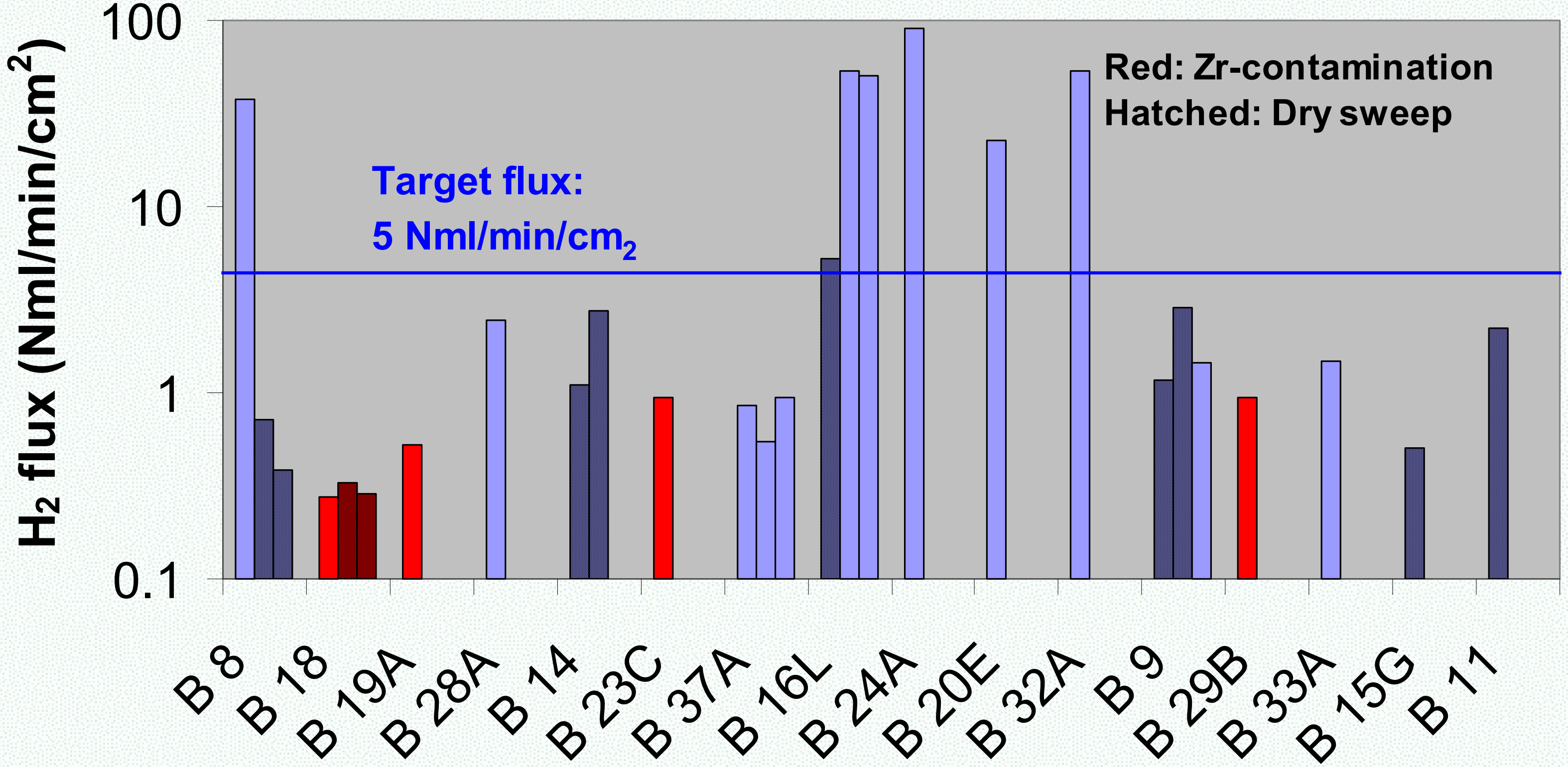


Hydrogen flux, model predictions

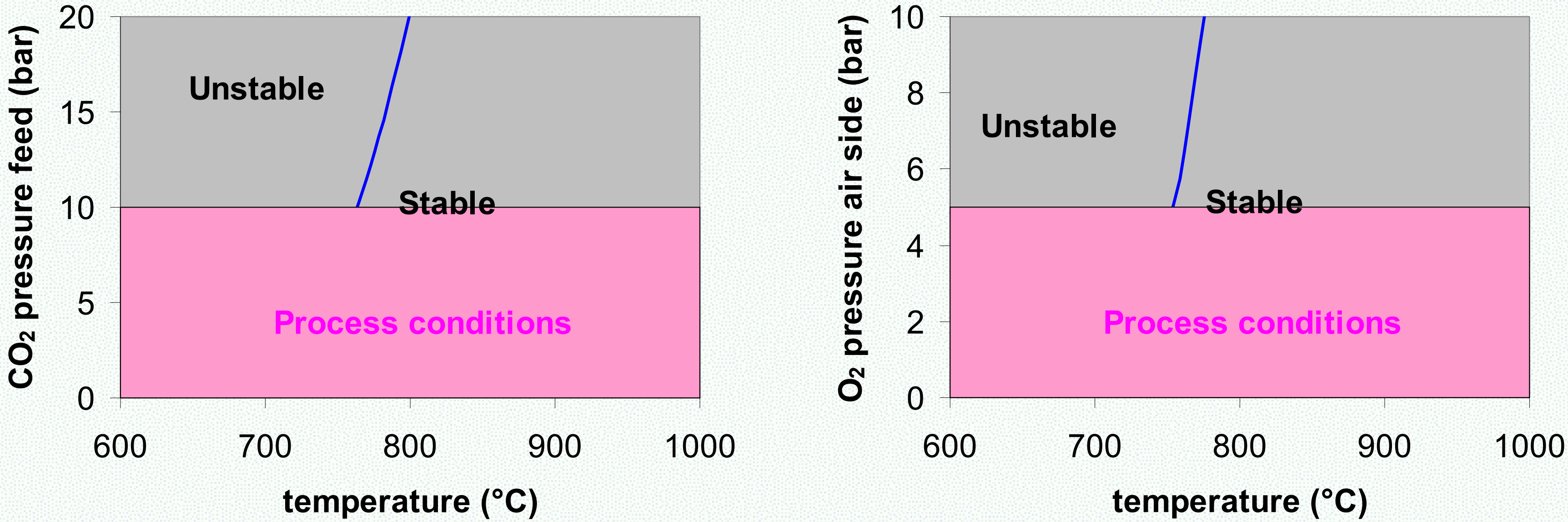


Modelled H_2 flux under process conditions

20μm membrane, 1000°C, P_{tot}=20bar, S/C=2, 20% hydrogen extracted, 0.1 bar H_2 in permeate



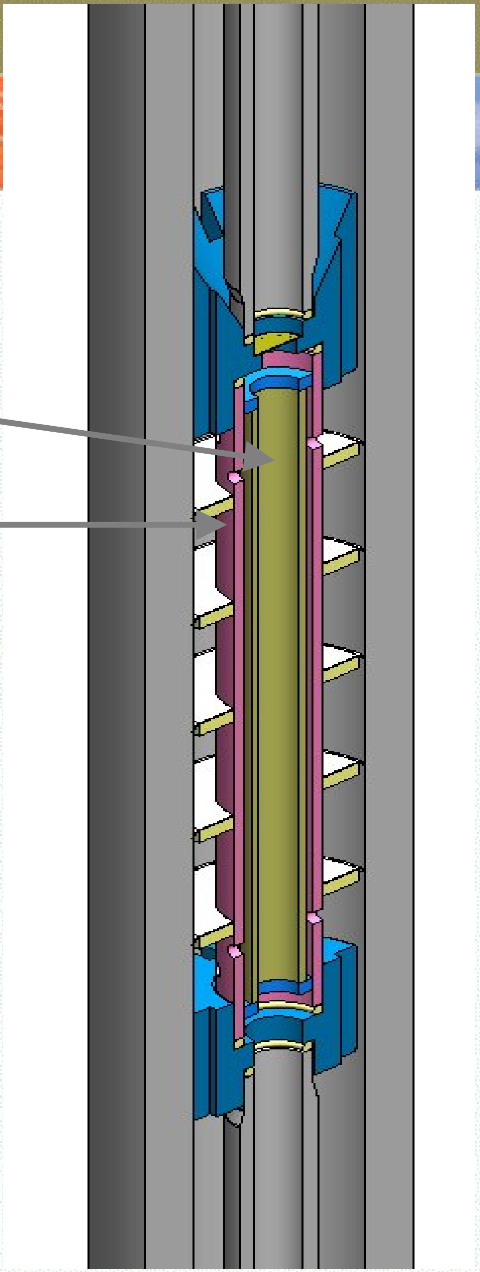
Thermodynamic stability of membrane



- Excellent stability at high temperature
- Limited stability at low temperature
- May be improved by minor changes in membrane composition

Membrane performance overall

- Experiments/model predict hydrogen flux above target
  - ✓ Scatter not fully understood
- Model predicts stability in process above 750°C
  - ✓ May be further improved
- Excellent high temperature stability
  - ✓ melts at around 2000°C, sinters >1700°C
  - ➢ high temperature creep unlikely to limit life time
- Excellent stability at low oxygen partial pressure
  - ✓ in H_2 and natural gas



Start up: October 2003

Bench Scale Testing