# Electrochemical purification and compression of Hydrogen using polybenzimidazole (PBI) fuel cell technology

Magnus Thomassen, Edel Sheridan,
Jannicke Kvello
SINTEF Materials and Chemistry
Sem Saelandsvei 12, NO-7495, Trondheim, Norway.

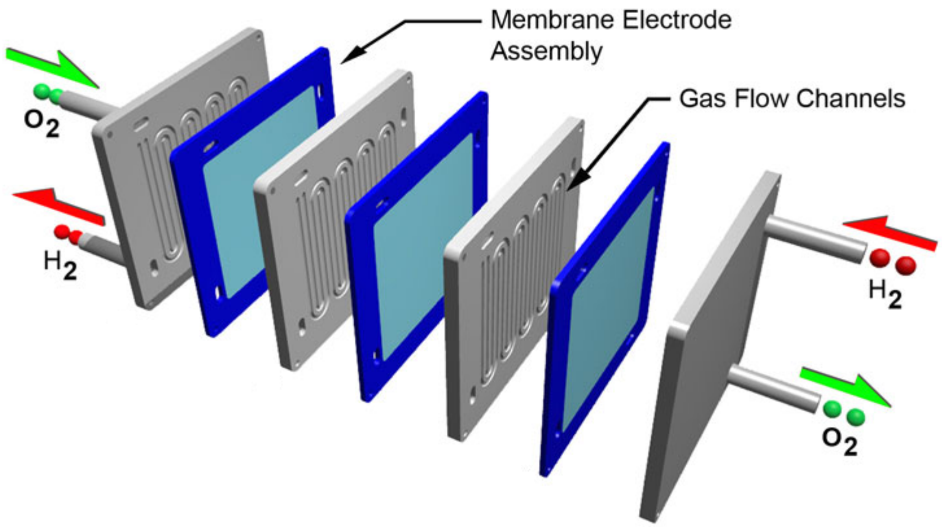
**1st Trondheim Gas Technology Conference, 21-22nd October 2009**

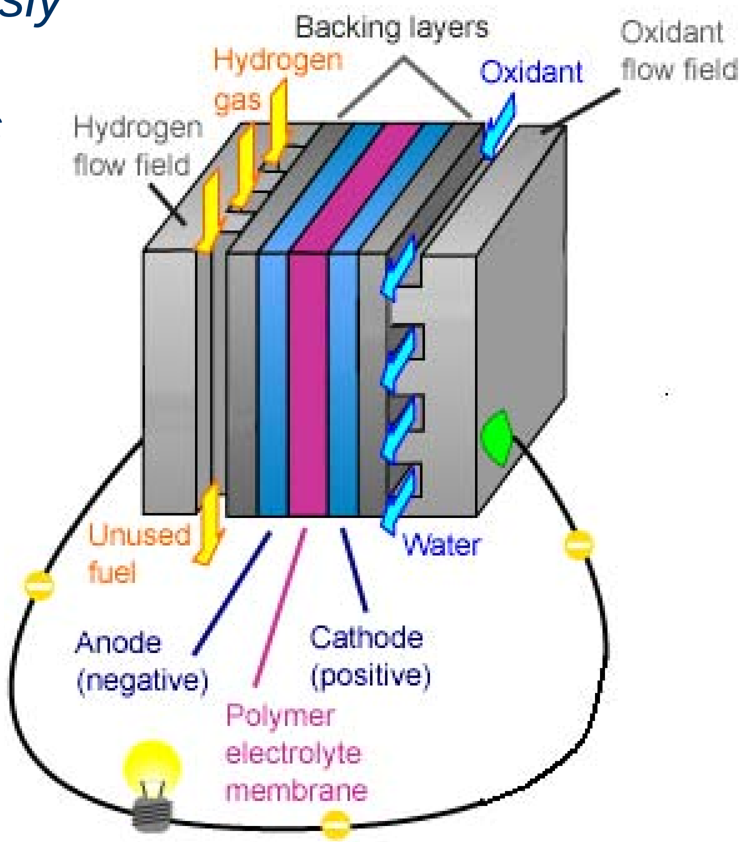
# Outline

- Brief introduction to PBI PEM fuel cell technology
- Working principle of electrochemical hydrogen separation and compression
- Experimental / Methodology
- Results
- Summary and Conclusions

# PEM Fuel Cells – working principal

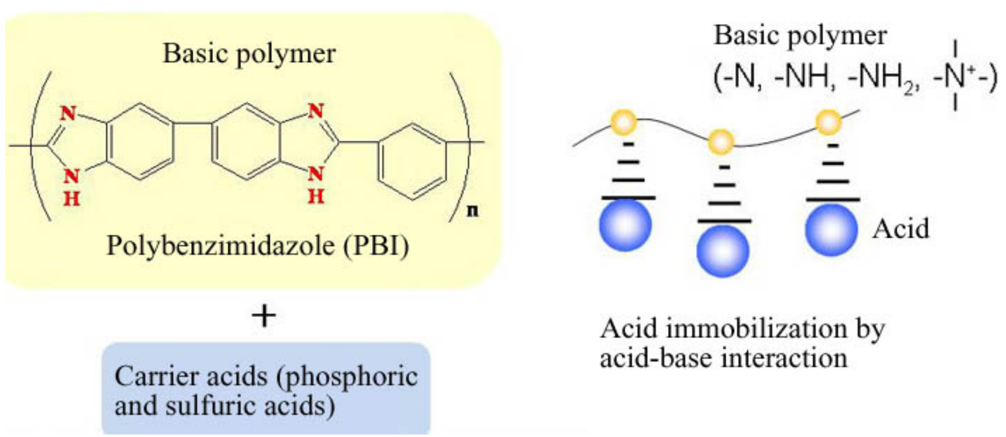
*Electrochemical device that continuously converts chemical energy to electrical energy (and some heat) for as long as fuel and oxidant are supplied*



# Polybenzimidazole - PBI Fuel Cell

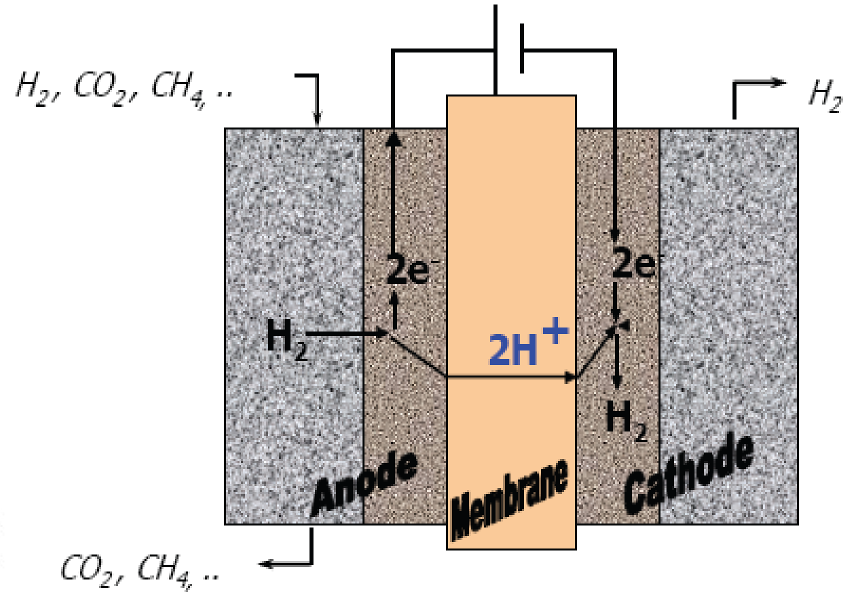
- High thermal resistance $T_g$ = 420°C
- High conductivity when doped with phosphoric acid (~6 x $10^{-2}$ $Scm^{-1}$)
- Not reliant on liquid water for proton conduction
- Low rate of gas crossover
- Fuel cell operating temperature ~ 180°C
- Better CO tolerance than PEM Nafion fuel cell (3% CO)
- More than 20 000 h operation with reformate demonstrated

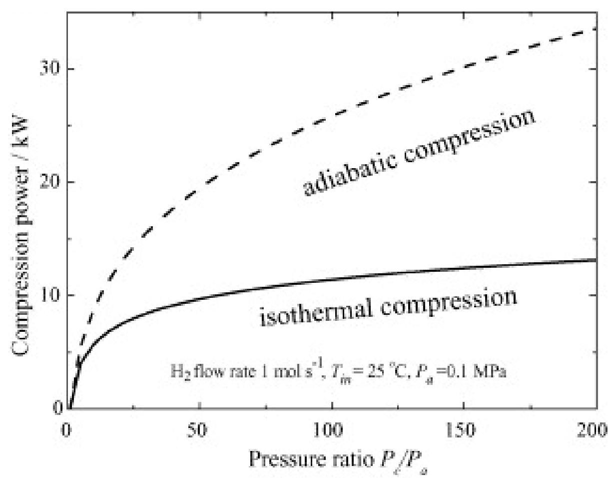


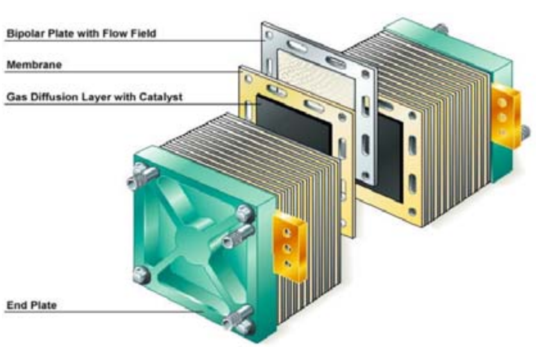
# Concept of PBI $H_2$ pump

Upon application of a voltage the PBI fuel cell separates Hydrogen from a gas mixture through a proton exchange membrane

- Separation and compression of Hydrogen gas in one step
- Modular and Scalable
- Operation temperature: 150-200° C
- Membrane 100% proton selective
- CO-tolerance of at least 3% expected

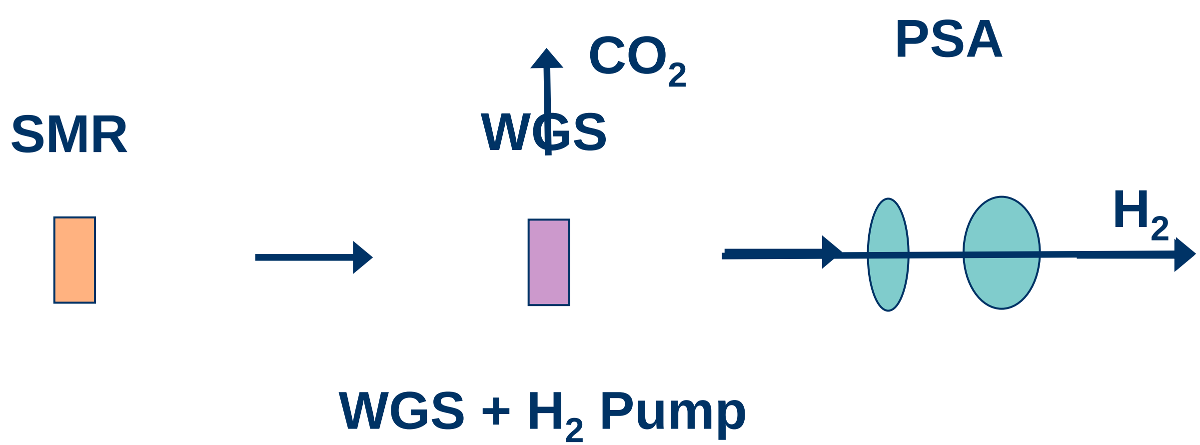


# Potential applications

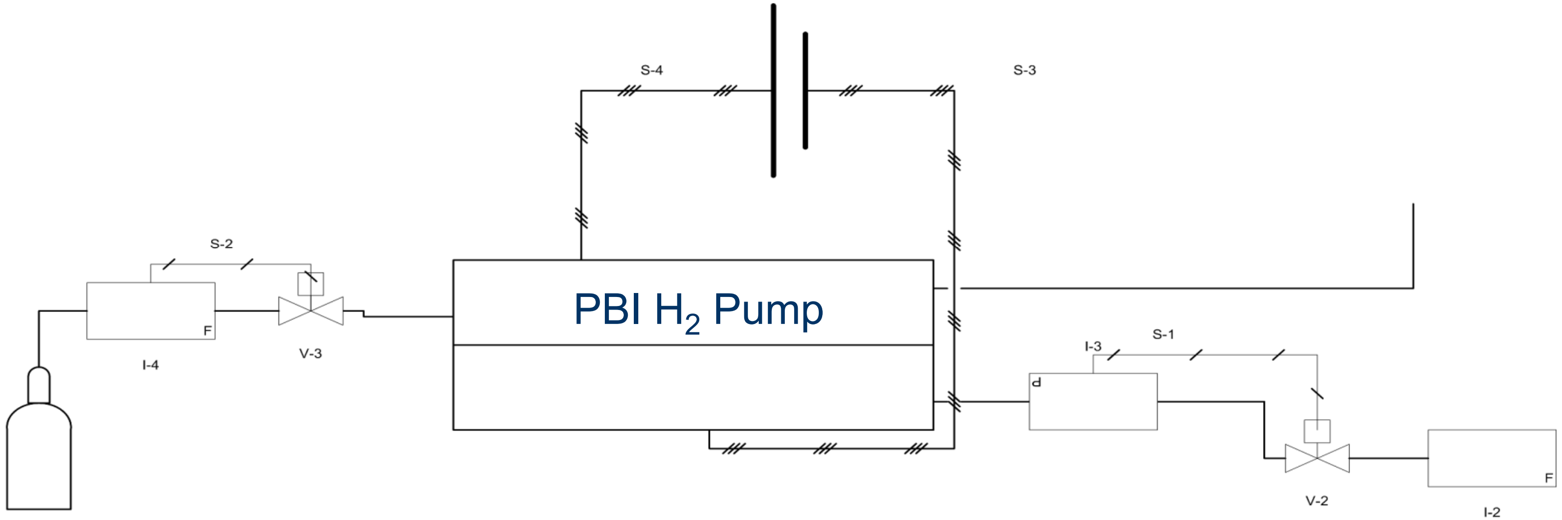
- Increase $H_2$ yield and efficiency, reduced process complexity
  - No need for auxilliaries (e.g compressors and humidifiers)
- Reforming of natural gas methanol, biogas, landfill gas




- Hydrogen separation for chemical processes, food production,etc

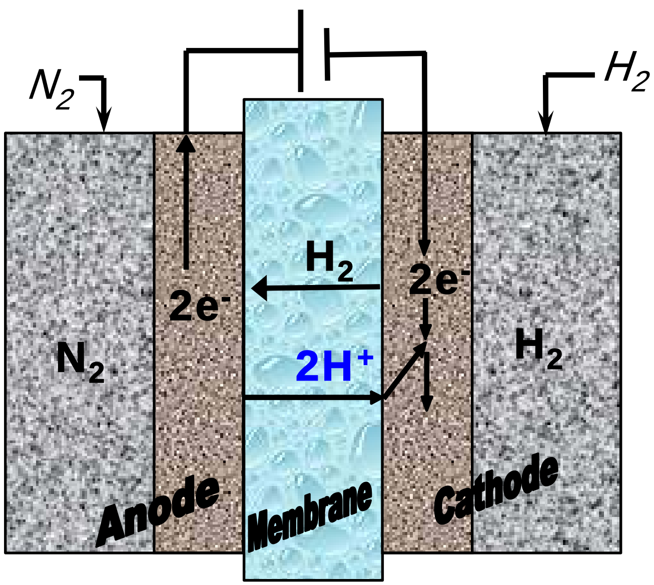
# Experimental

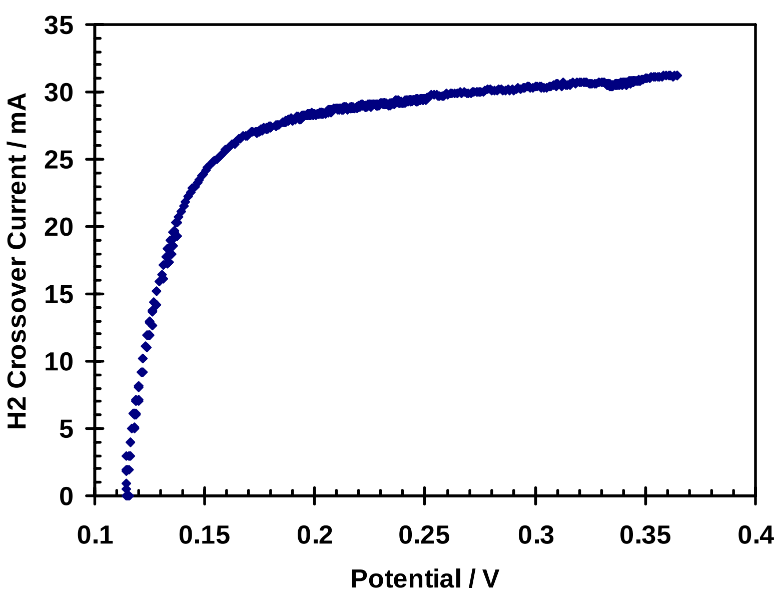
- Operating temperatures
  - Tcell: 160°-200° C
- 2 Stoichiometric gas flow (50% hydrogen utilization)
- Feed gases:
  - Hydrogen in Nitrogen (40-100% $H_2$)
  - 75% $H_2$, 23.5% $CO_2$, 1.36 % CO, 0.36 % $CH_4$
  - 44% $H_2$, 35% $N_2$, 21% $CO_2$, 100ppm CO



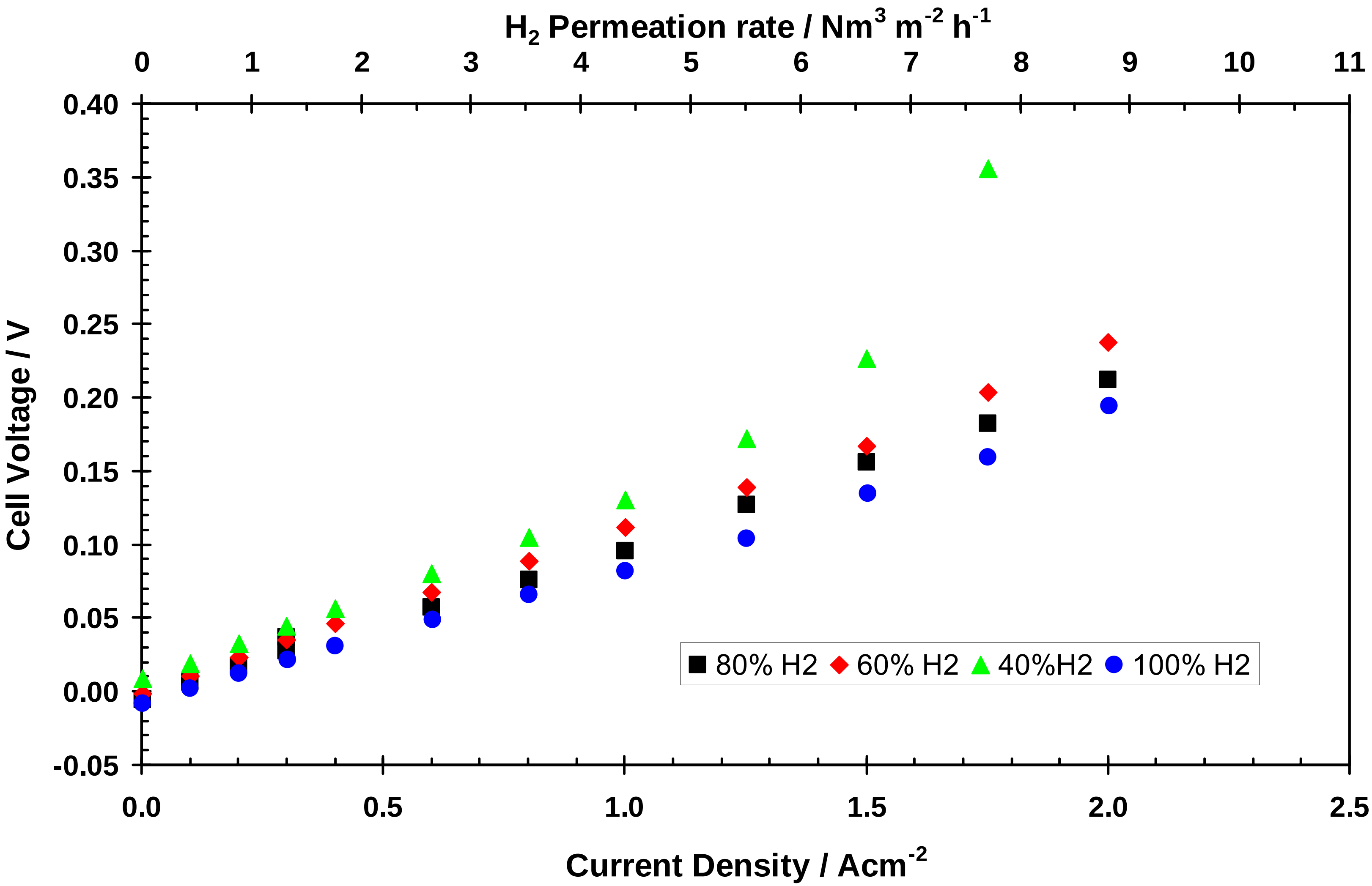
# Experimental

- Polarisation (Current vs Potential) curves
  - Separation rate and energy consumption
- On line current interrupt measurements (membrane resistance)
- GC analysis of permeate gases
- Hydrogen cross over (back diffusion)

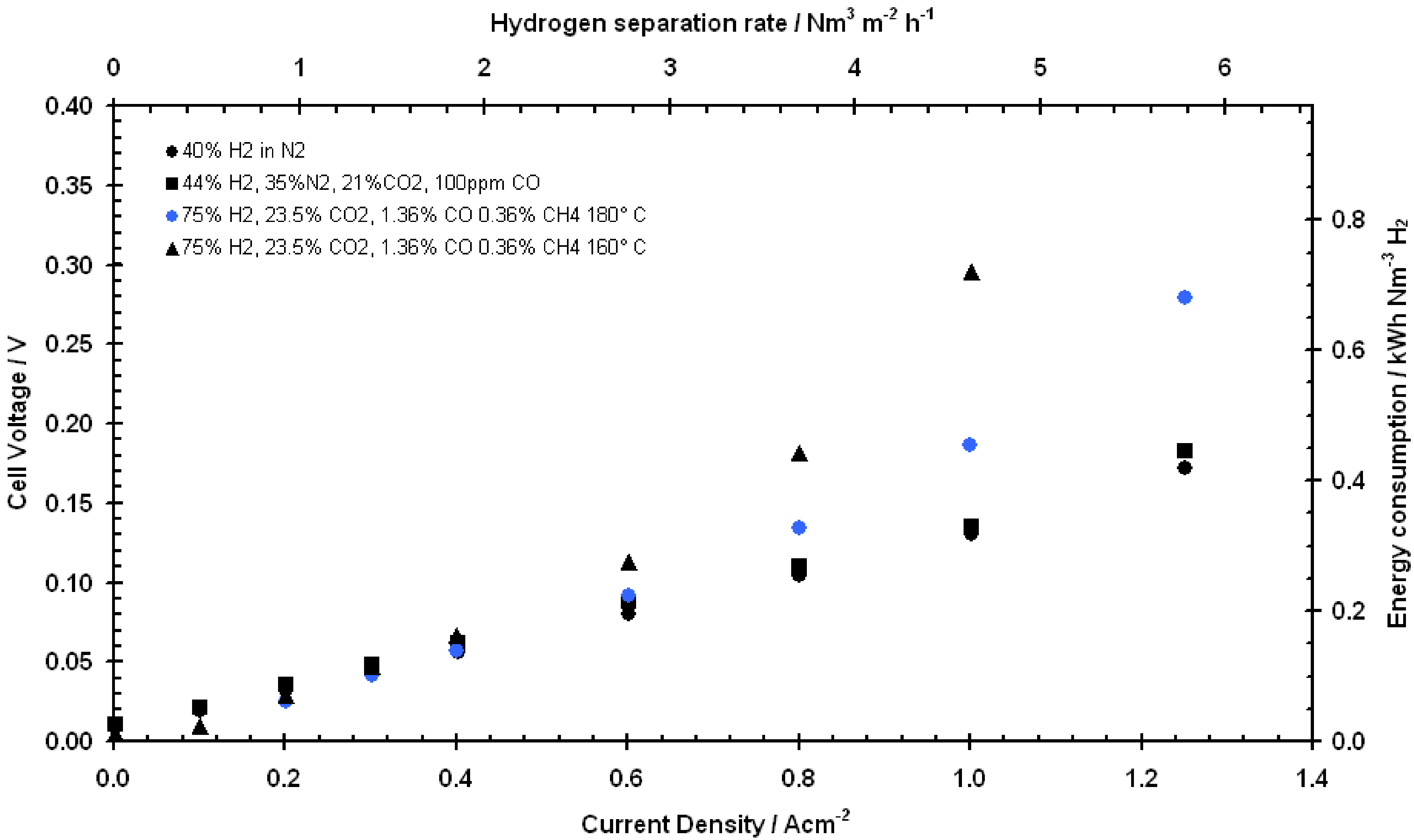


# Results $H_2$ in Nitrogen

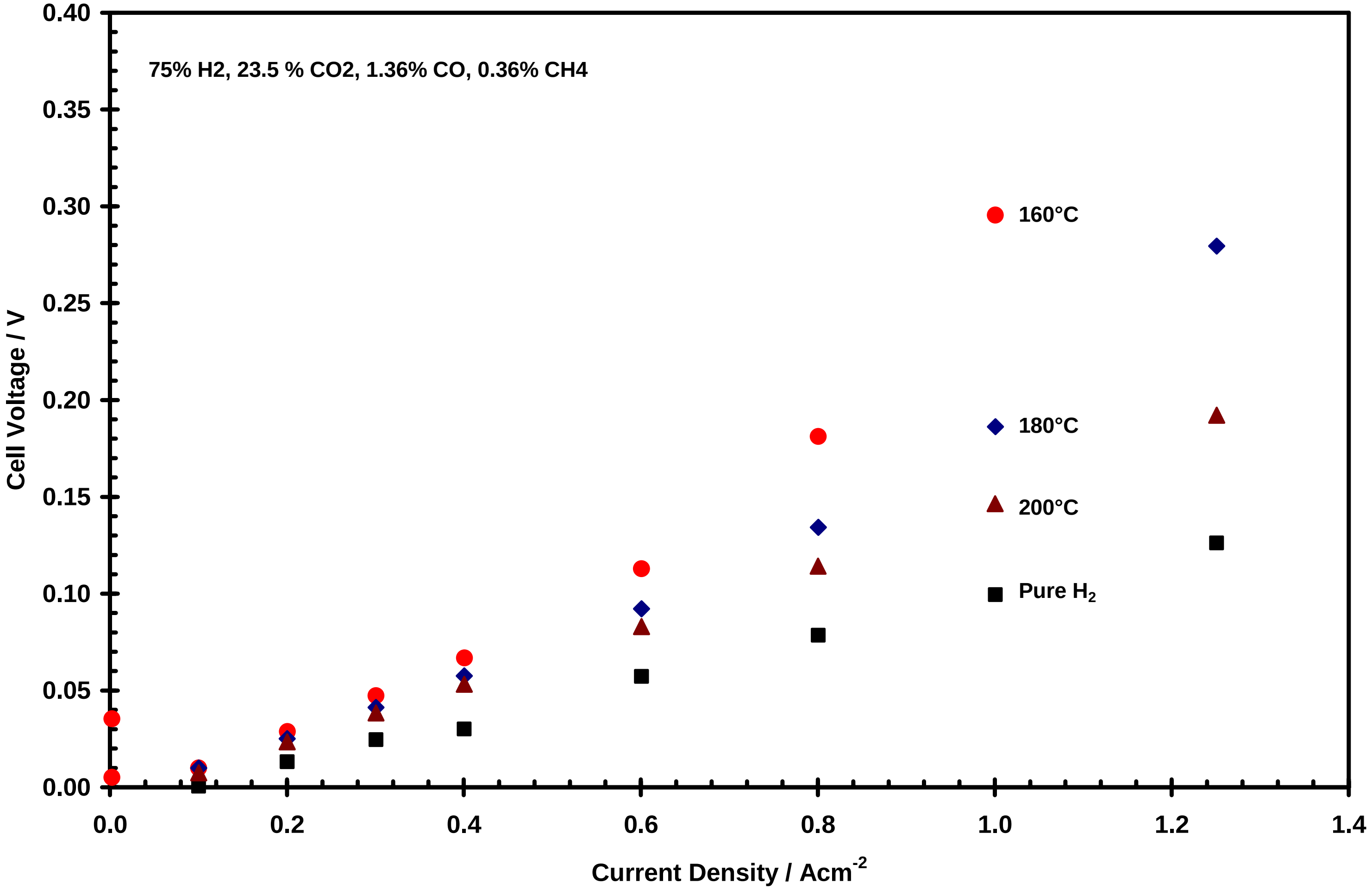


# Results – Reformate gases




($1 Acm^{-2}$ / 0.05 mol $H_2$ $m^{-2}$ $s^{-1}$)

# Results - Effect of Temperature

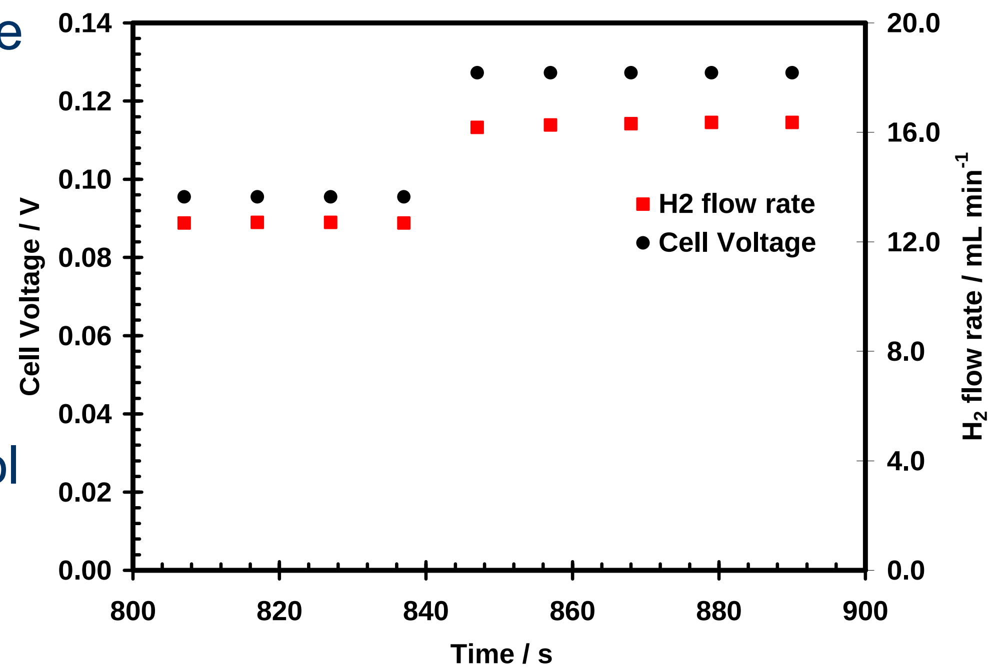



- Maximum operational temperature 200°C
- Optimal temperature 180°C

# Results – Transient behaviour

- Hydrogen separation is directly related to the applied current
- The hydrogen flux will stabilise at new level within seconds after applying a current step

- Precise monitoring and control of hydrogen flow rate



# Results – Selectivity

- Feed gas:
  - 75% $H_2$,
  - 23,5% $CO_2$,
  - 1,36 % CO
  - 0.36 % $CH_4$
- Hydrogen permeability
  - 0.02 $Nm^3\ m^{-2}\ h^{-1}\ bar^{-1}$
  - ~0.5% av sep. capacity

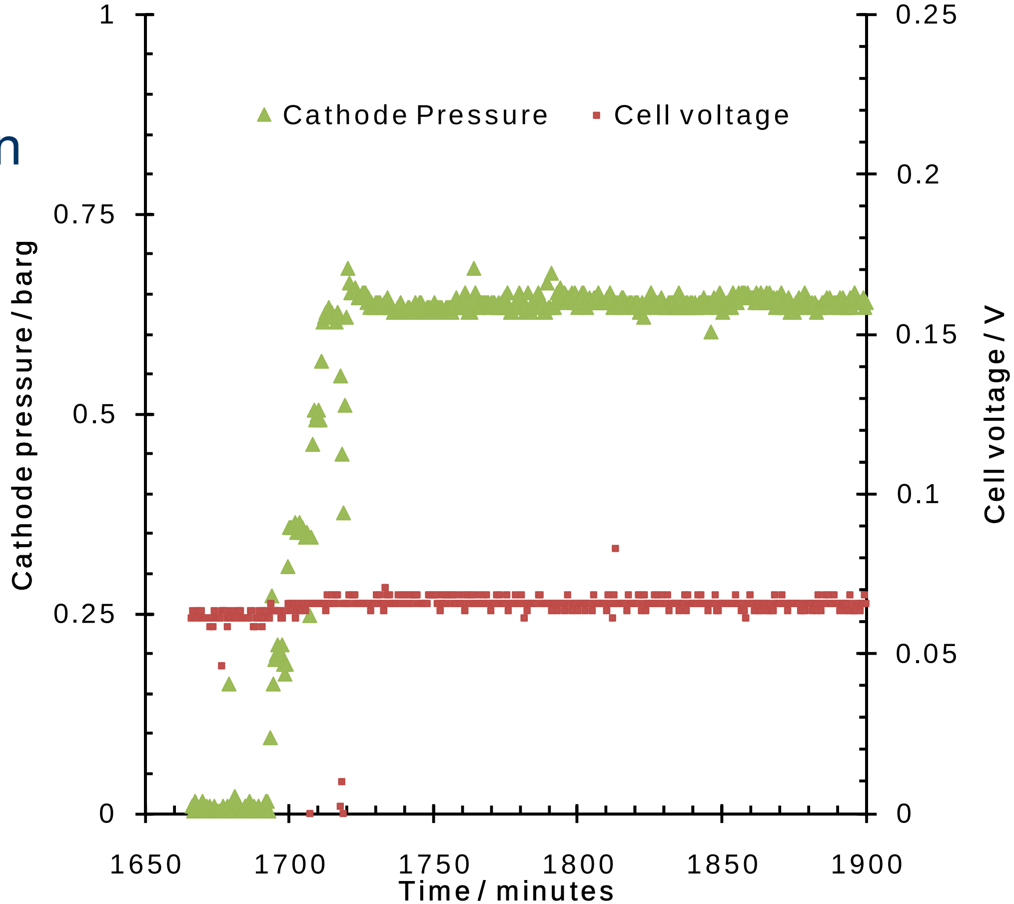
| Current density ($Acm^{-2}$) | Cathode outlet $CO_2$ concentration (%) | Reduction in $CO_2$ concentration (%) |
|---|---|---|
| 0.5 | 0.45 ± 0.05 | 98 |
| 1.0 | 0.23 ± 0.09 | 99 |
| 1.5 | 0.12 ± 0.04 | 99.5 |

| Current density ($Acm^{-2}$) | Cathode outlet CO concentration (%) | Reduction in CO concentration (%) |
|---|---|---|
| 0.5 | 0.025 ± 0.05 | 98 |
| 1.0 | 0.012 ± 0.02 | 99 |
| 1.5 | 0.011 ± 0.02 | 99 |

# Results – Compression

- Hydrogen compression to 0.6 barg results in practically no increase in energy consumption
- Compression up to 2 barg performed.
  - Catastrophic membrane failure in between carbon electrode and gasket
- Alternative membrane support/current collector structure will probably increase compression ability.

@ 0.5 A $cm^{-2}$



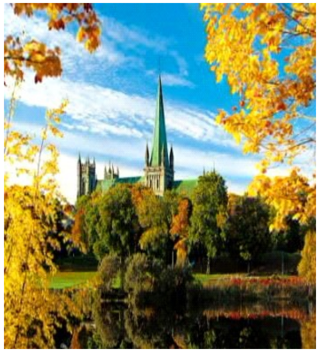
# Summary

- The PBI hydrogen pump can separate and compress hydrogen from different gas mixtures
  - Energy efficiency of 80-90% (LHV)
  - Separation capacity of ~ 5-7 $Nm^3 m^{-2} h^{-1}$
  - High CO tolerance (1.5 % CO demonstrated)
  - Can operate on dry gas

    (increased efficiency with 10-20 vol% water)
  - Compressed to 2 barg upon demonstration, but possible to have higher differential pressure across the membrane with modification
  - Can provide a finely controlled stream of Hydrogen gas at a selected pressure ($\Delta p_{H2}$ 0-10 bar)

# Thank you for your attention



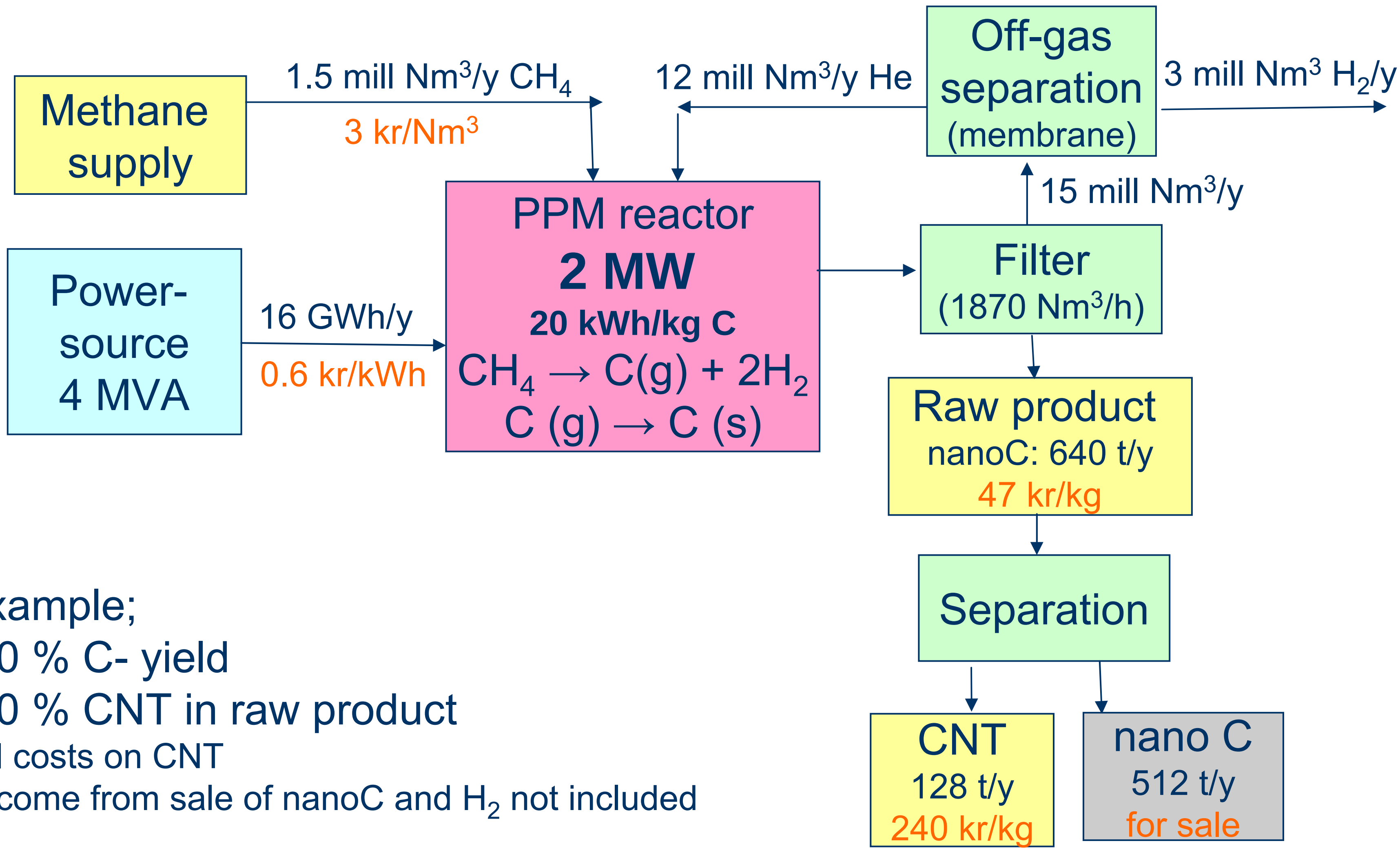



# Resultater - Kostnadsestimat

- Case:
  - Hydrogen fra SINTEFs Nanokarbon plasmaprosess
  - 15 mill $Nm^3$/år, 20% $H_2$ i He
- Elektrisitetsforbruk
  - 0.45 kWh / $Nm^3$ – 0.6kWh / $Nm^3$
- Kapitalkostnader
  - 2500 € / $m^2$ membranareal
  - 50000 h levetid (ca 5 år)
- Separasjonskapasitet:
  - 5 $Nm^3$ $m^{-2}$ $h^{-1}$

# PPM process; CNT-production from $CH_4$

Plasma gas: He




Example;

- 80 % C- yield
- 20 % CNT in raw product
- all costs on CNT
- income from sale of nanoC and $H_2$ not included

# Resultater - Kostnadsestimat