CO_2 Capture Project

Pre-Combustion Technology Overview

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Outline

- CCP objectives
  - Scenarios
- Capture routes
- Pre-combustion decarbonization (PCDC) work scope
  - Review and evaluation studies
  - Engineering studies
  - Research and development projects
- Key findings and conclusions

US Department of Energy

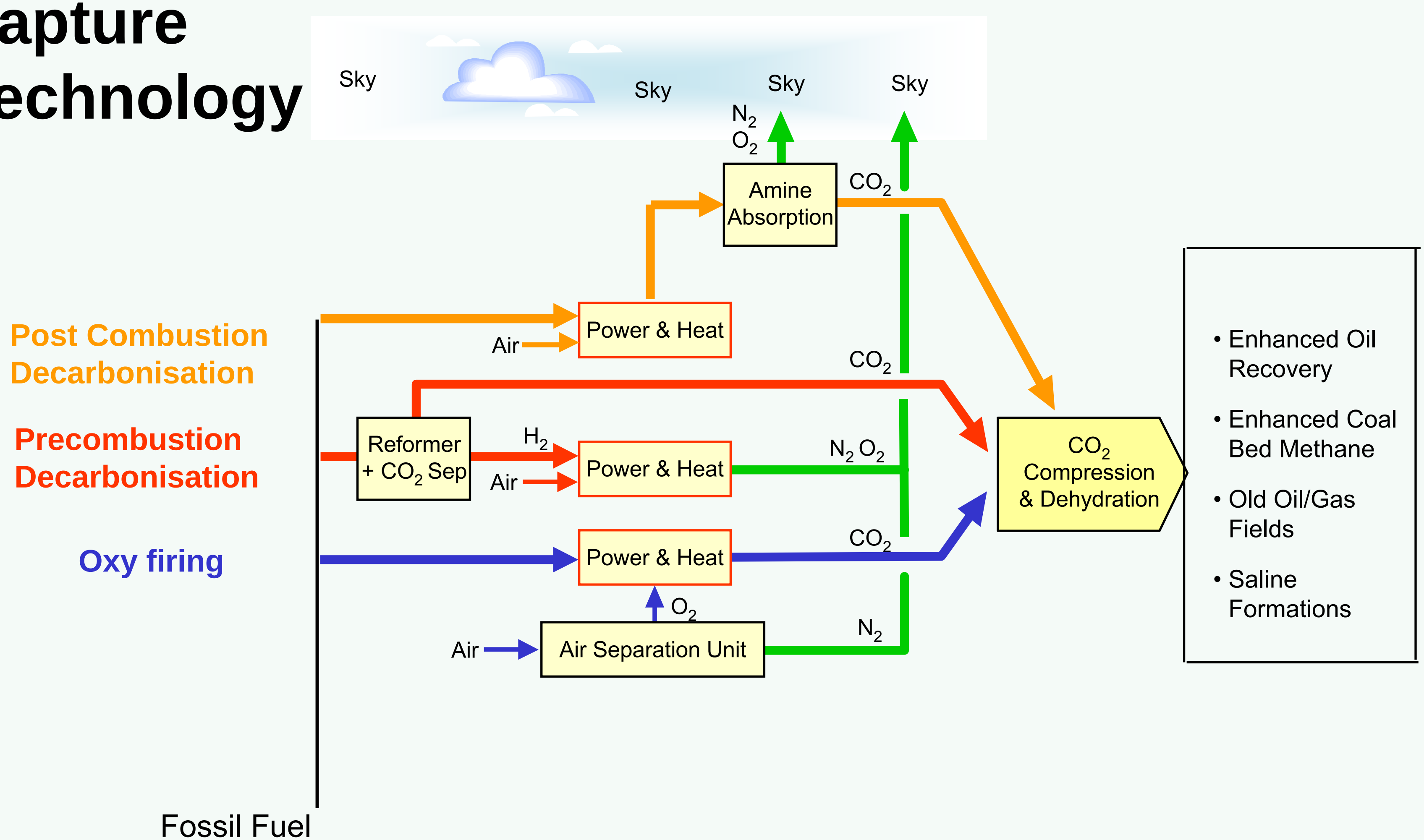
European Union

Klimatek NorCap

CO_2 Capture Project Objectives

- Achieve major reductions in the cost of CO_2 Capture and Storage:
  - 50% reduction when applied to a retrofit application.
  - 75% reduction when applied to a new build application.
- Demonstrate to external stakeholders that CO_2 storage is safe, measurable, and verifiable.
- Progress technologies to:
  - ‘Proof of concept’ stage by 2003/4.

Capture Technology

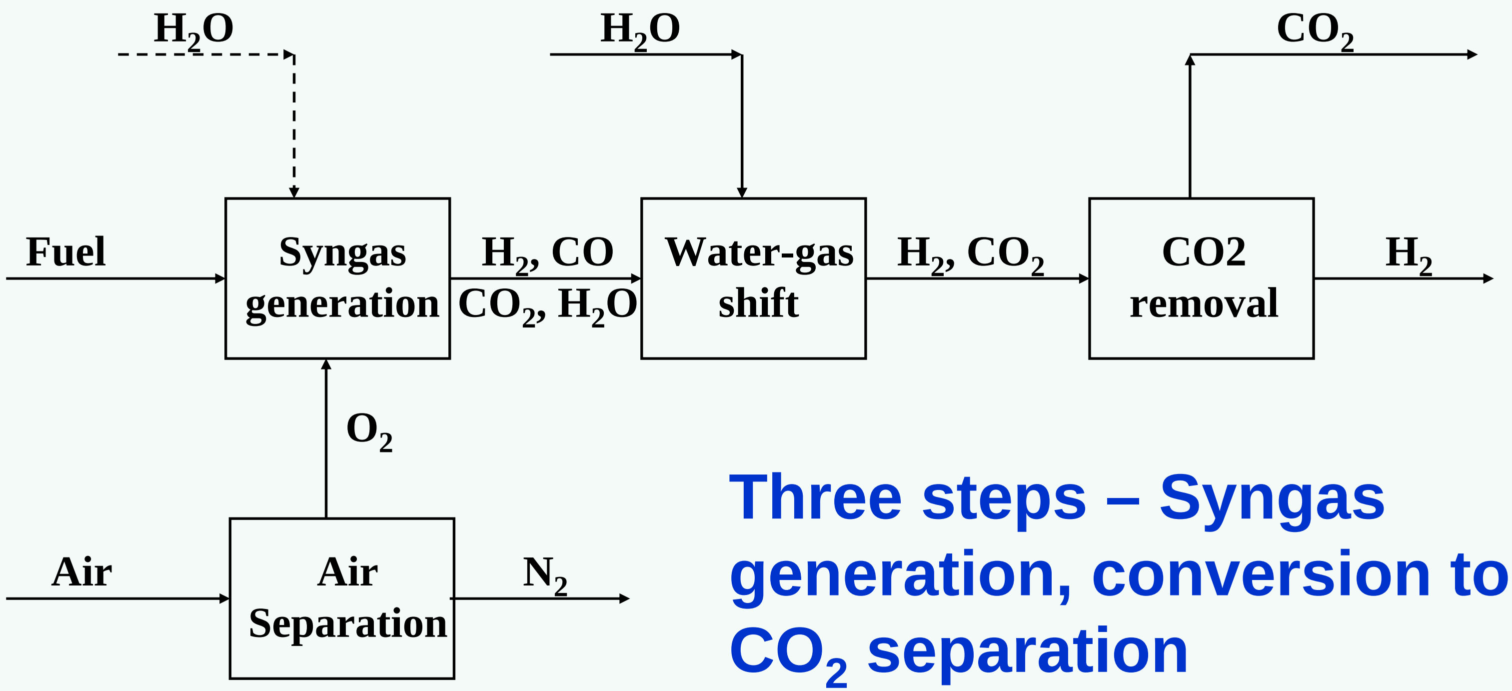


CCP Baseline Scenarios

Scenario	Fuel	CO_2 Source	CO_2 Sink	Capture Target (MM tonne/yr)
Grangemouth Refinery in Scotland	Gas and Fuel Oil	Flue gas from heaters and boilers	Offshore EOR	2.0
Norway 385-MW power plant in Karsto, Norway	Gas	Flue gas from turbine outlet	Offshore EOR	1.1
Alaska Eleven 30-MW single cycle gas turbines.	Gas	Flue gas from distributed turbines	Onshore EOR	1.8
Canada Gasification plant	Pet Coke	Syngas from gasifier	Onshore EOR	6.8

Each technology was evaluated in one or more scenarios.

Basic Pre-Combustion Process Scheme



Three steps – Syngas generation, conversion to H_2, CO_2 separation

PCDC advantages

- CO_2 removal via solvent absorption is proven
  - Elevated pressures and high CO_2 concentrations aid removal
- Applicable to new-build or retrofit
  - Can be designed as stand-alone – minimum integration
- Possible production of CO_2 at moderate pressures (lower compression costs)
- Produces hydrogen
- Low SOx, NOx
- Flexible fuel sources (gas, oil, coke, coal, etc.)

PCDC disadvantages

- Must convert fuel to syngas first
- Requires major modifications to existing plants
- Gas turbines, heaters, boilers, must be modified for hydrogen firing

Precombustion Work Scope

- Review and Evaluation studies
  - Verified economic benefits and determined performance targets
- Engineering studies
  - Evaluated several alternative process schemes
    - IFE power concept, Fluor CO2LDSEP, APCI Gemini
  - Evaluated enabling technologies (e.g. gas turbine firing with H_2)
  - Evaluated impact of standardization and large capacity plants

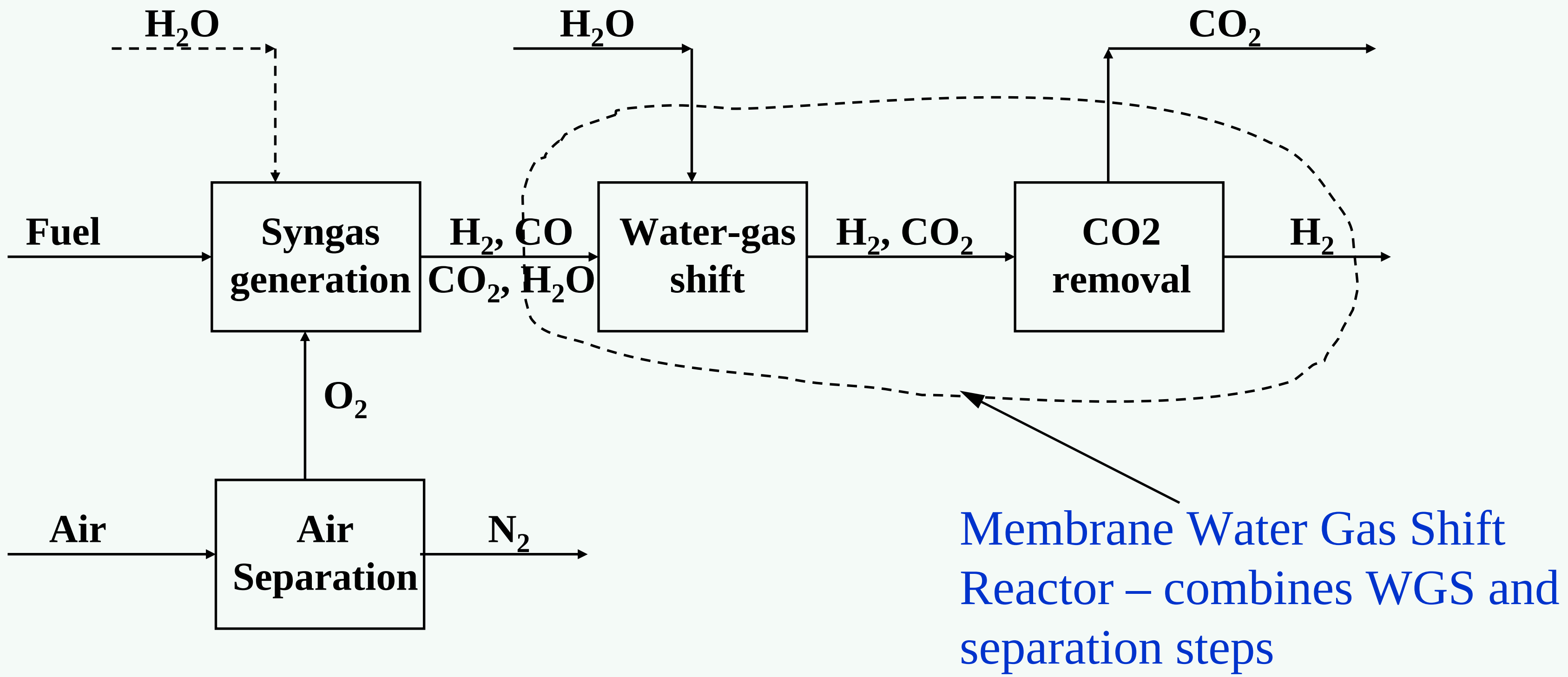
Advanced Gasification Technology

- Canadian scenario (IGCC concept w/ H2, steam)
- Two Baseline cases (uncontrolled & controlled)
- Multiple capture technologies considered
  - Membranes, adsorbents, etc.
- Fluor's CO_2LDSEP process chosen

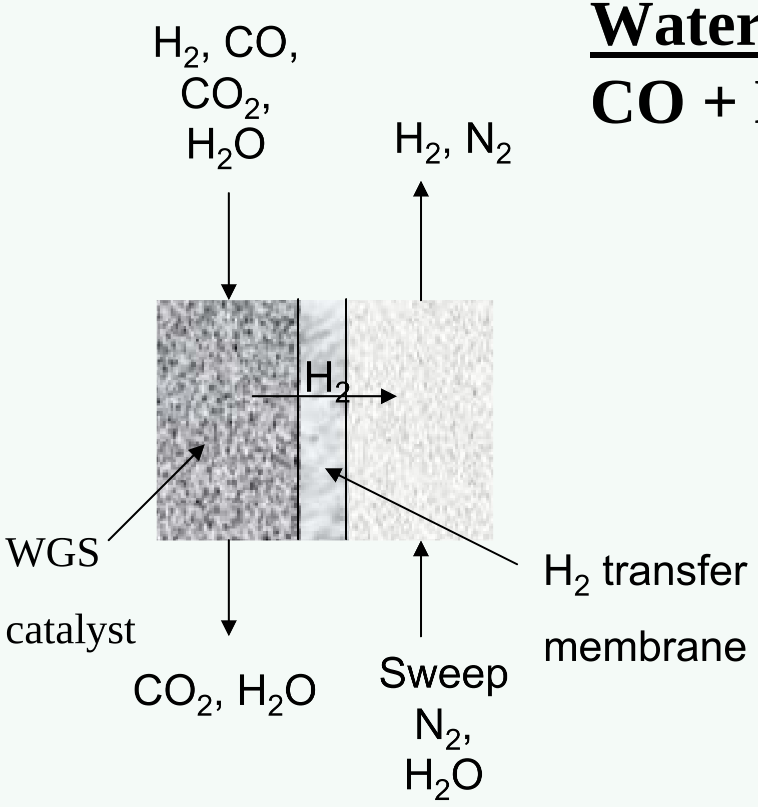
Precombustion Work Scope (Cont'd)

- Technology R&D projects
  - Membrane Water Gas Shift – Eltron - DOE
  - Membrane Water Gas Shift – Sintef – EU Grace
  - Membrane Reformer – Norsk Hydro – Klimatek
  - Sorption Enhanced Water Gas Shift – APCI - DOE

Basic PCDC/MWGS Process Scheme



MWGS Reactor Concept



Water gas shift

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

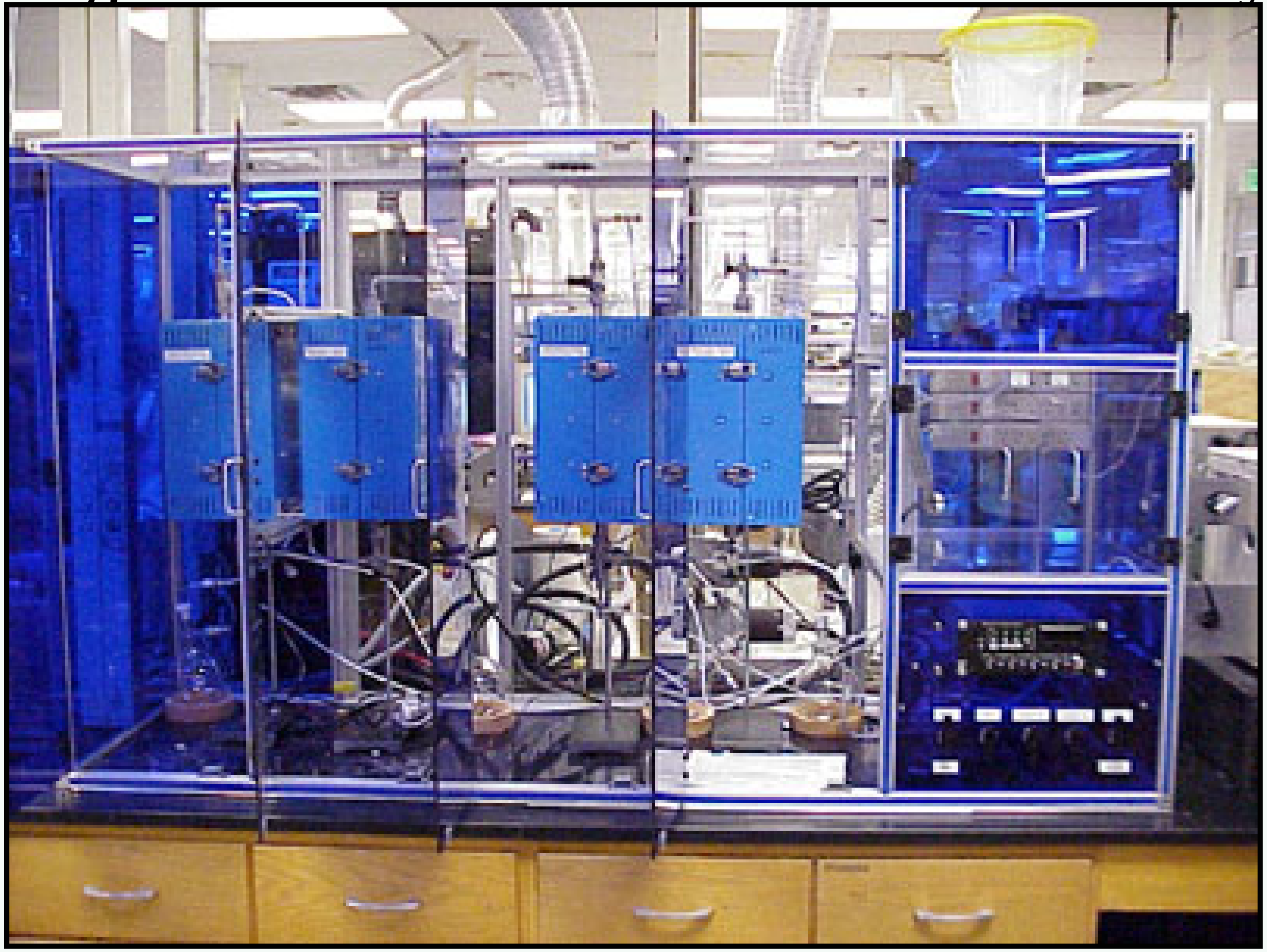
DOE MWGS Overview

- Objective
  - Develop a sulfur tolerant, highly selective hydrogen membrane for a water gas shift reactor
- Four sulfur tolerant membrane development programs
  - Silica, ECN
  - Zeolite, University of Cinncinnati
  - Palladium alloy, CSM/TDA
  - Ceramic metal composite, Eltron
- Failure to develop sulfur tolerant membrane
  - Either inadequate H_2/CO_2 selectivity or intolerance to H_2S

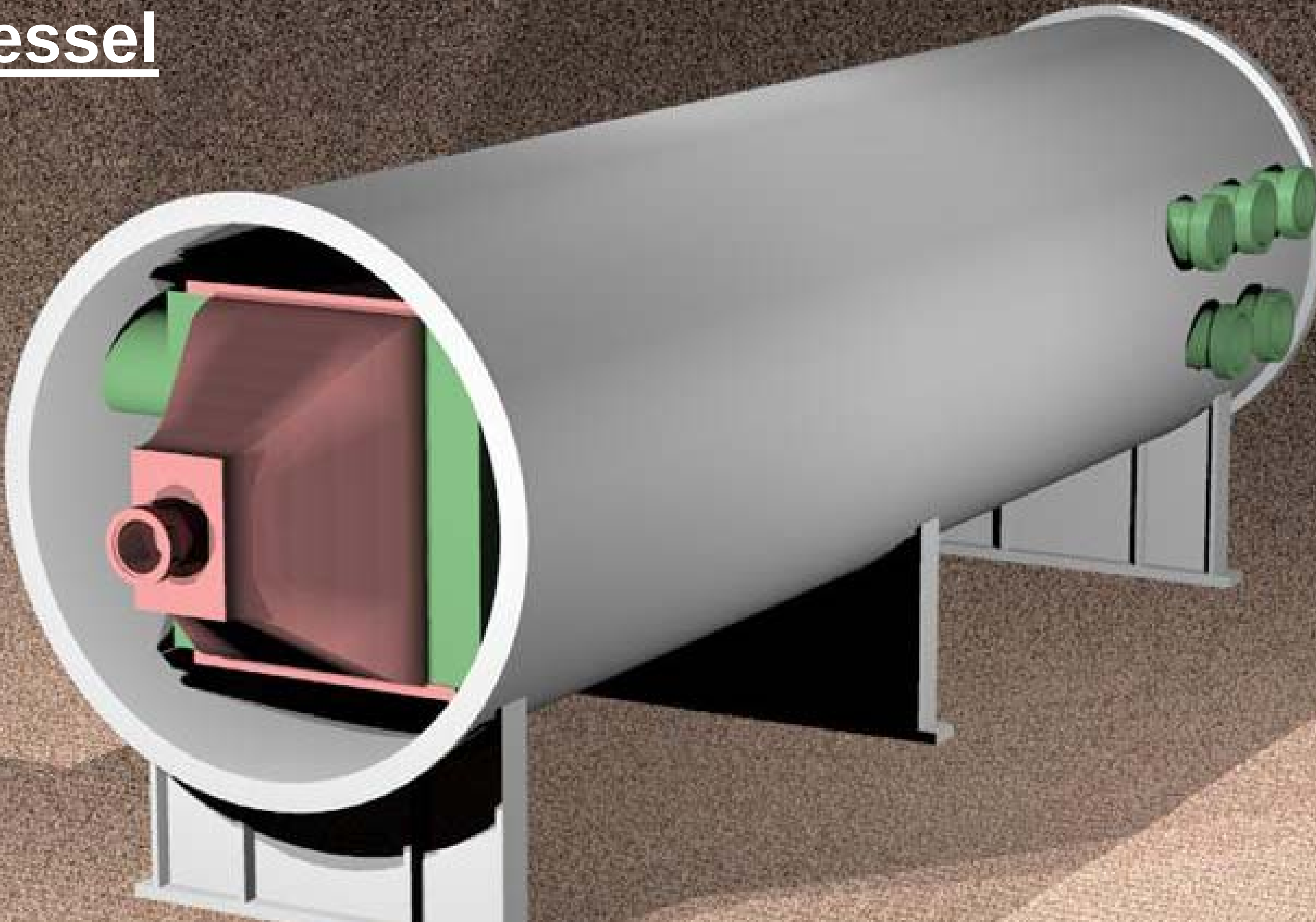
DOE MWGS Overview – Phase II

- Eltron membrane development program
  - Focus on metal alloy membrane for sweet syngas
  - Significant improvement in flux/permeance
    - Two orders of magnitude improvement in flux over current state of the art (25 micron Pd)
  - Proof of concept testing successfully completed at ambient pressures
- SOFCo commercial MWGS reactor design

New Ambient Pressure Reactors for Testing Membranes Integrated with Beds of Water-Gas Shift Catalyst



Vessel



EU Grace MWGS Overview

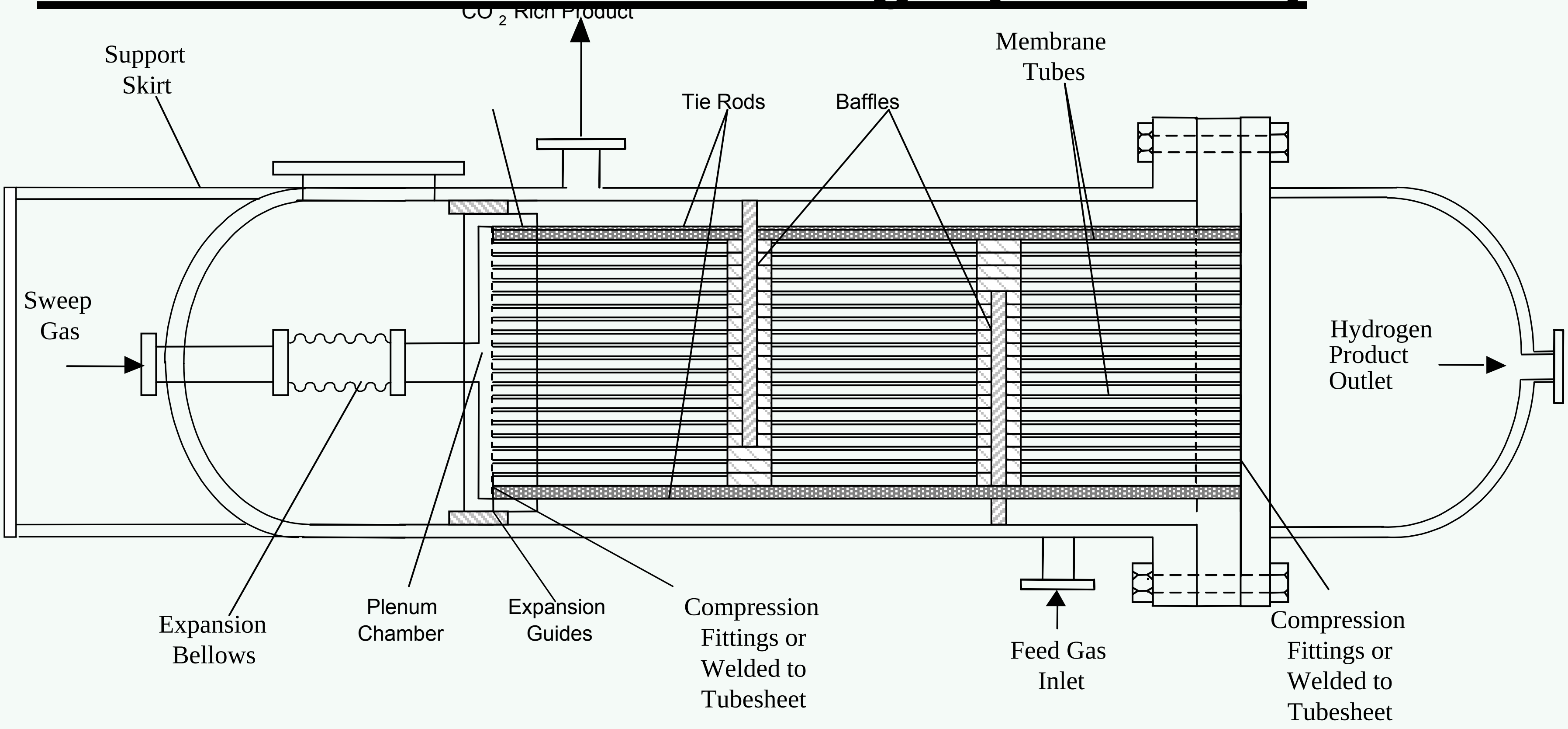
- Objective
  - Develop a highly selective hydrogen membrane for a water gas shift reactor

EU Grace MWGS Technology Program

- Porous membranes
  - Silica – Univ. of Twente, Holland
  - Zeolite – Univ. of Zaragossa, KTH - Stockholm
  - Both membrane types exhibited inadequate CO_2:H_2 selectivity
  - Unstable in steam atmosphere (silica)
- Dense membrane - SINTEF
  - 1-3 µm Pd/Ag alloy foil (dense) sputtered on single crystal silicon

Membrane development

Membrane Module Design (Rotated)



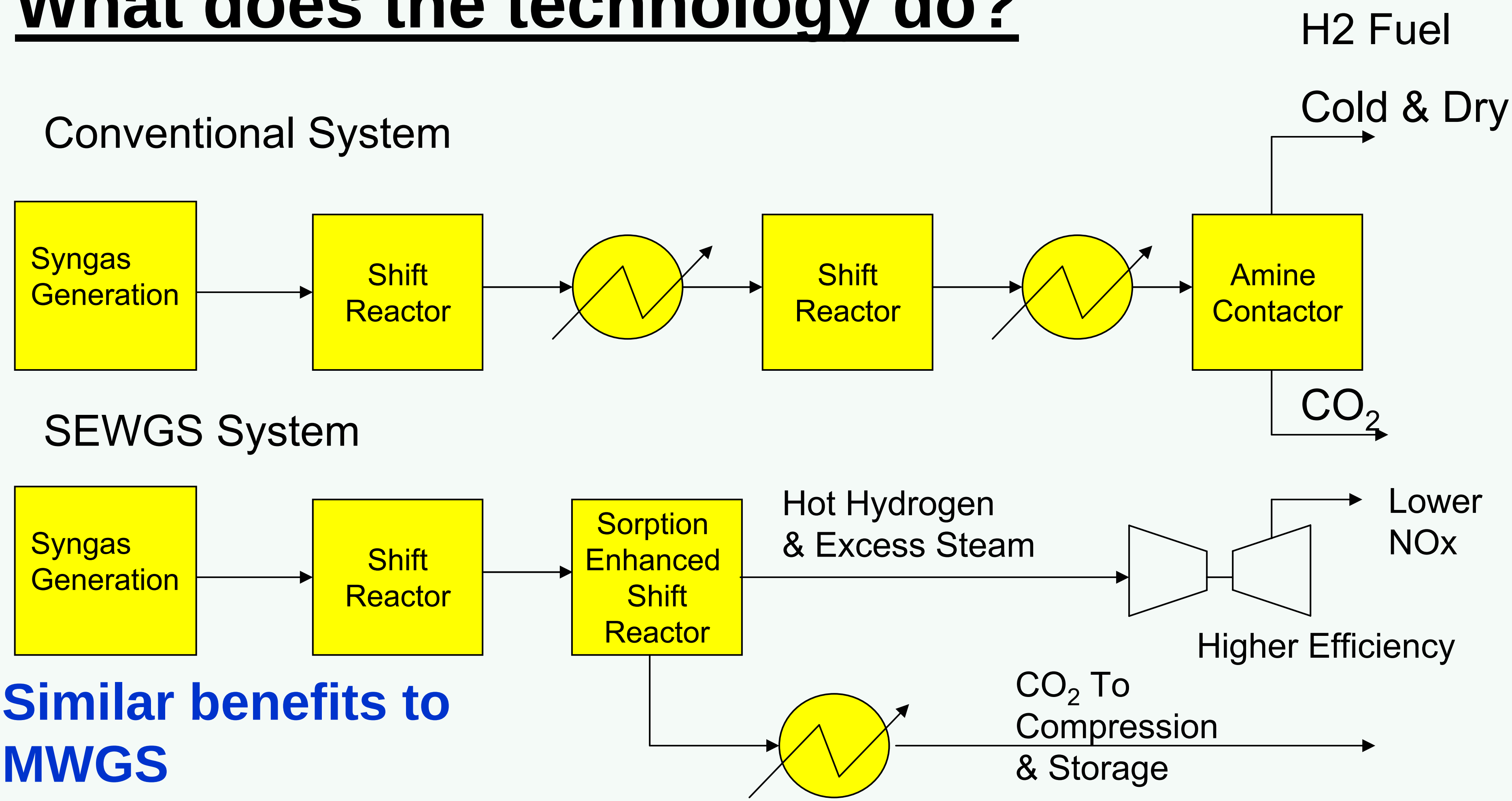
MWGS Conclusions

- Pre-Combustion Decarbonisation by Membrane Shift Reaction is technically feasible
  - Both Eltron and Sintef membranes look promising
- Sequential reaction/separation lower risk
- The efficiency of CO_2 capture for the process is higher then the baseline
- Capital cost significantly lower than baseline.
- Cost of CO_2 avoided significantly lower than baseline (natural or fuel gas feeds)

Sorption Enhanced WGS Overview

- Objective
  - Develop and test an adsorbent for a water gas shift reactor

What does the technology do?



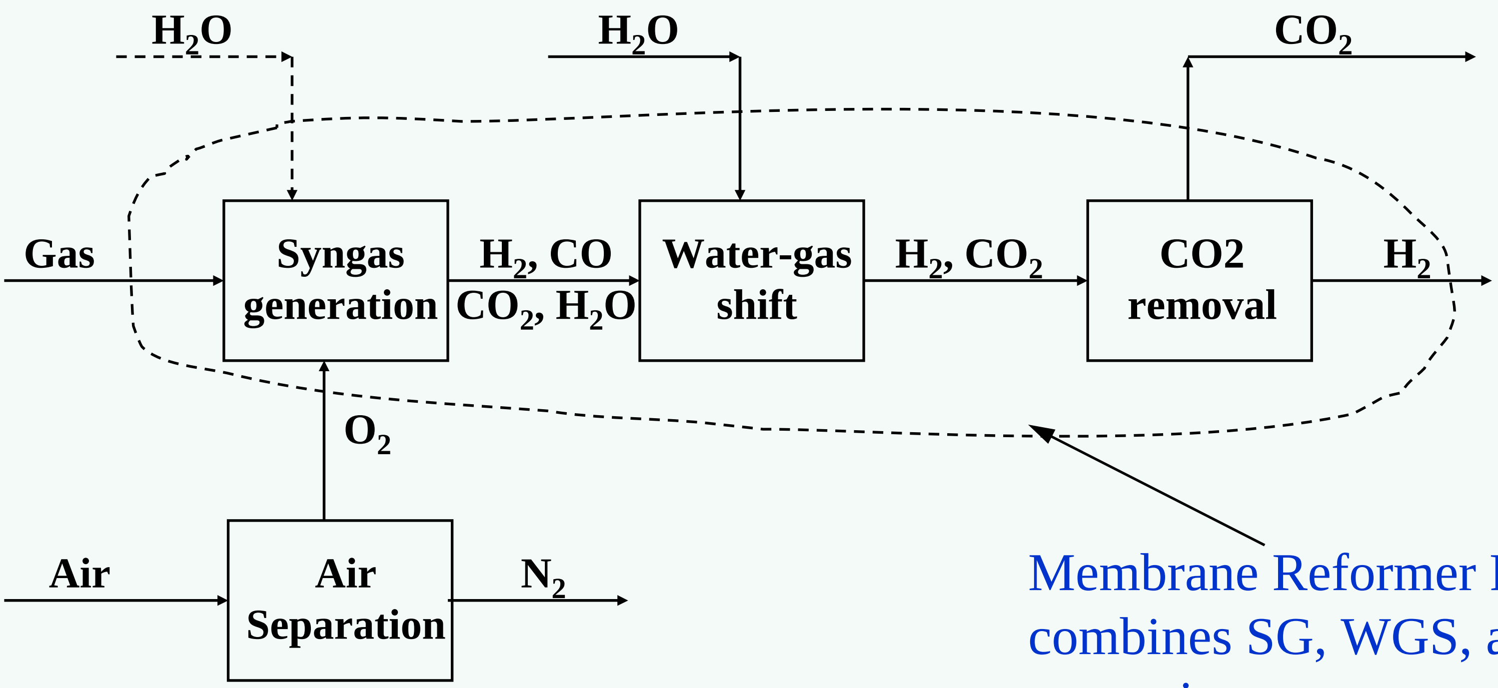
Similar benefits to MWGS

SEWGS conclusions

- SEWGS Concept proved
- Avoided CO_2 Cost reductions in Norcap to 31%
- 26% Capex reduction in Alaska

  But avoided cost reduction only 19% due to gas cost
- Technology relatively low risk & short timescale
- NOx emission reductions possible to <25ppm
- Possible further savings- better adsorbents

Membrane Reformer Process Scheme



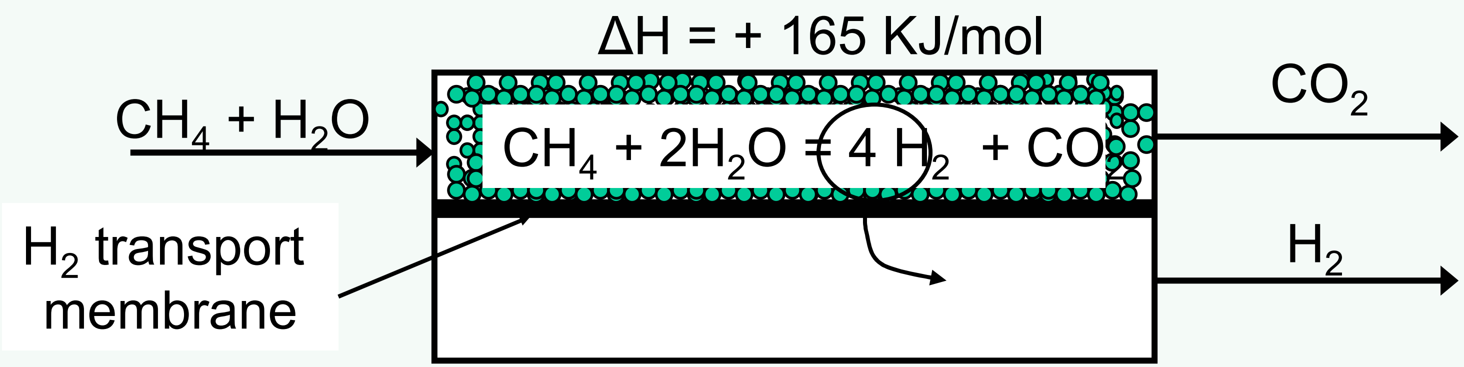
Membrane Reformer Reactor – combines SG, WGS, and separation steps

Membrane Reformer - Project overview

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

Hydrogen Membrane Reformer

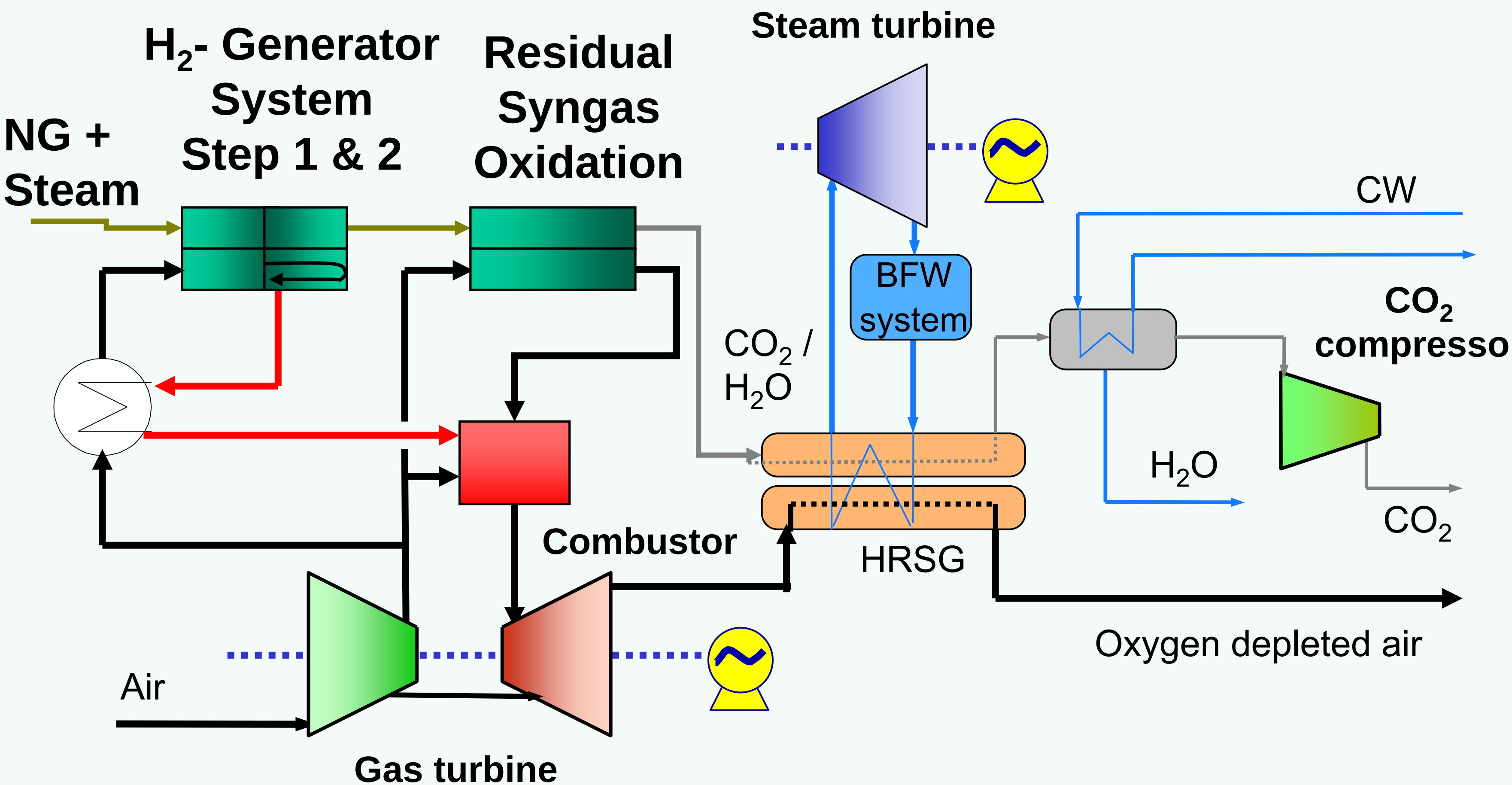
- Combination of reforming reactor and separation
- Extract product gas (H_2) from reactor, no traditional CO_2 removal system required
- Drive equilibrium limited reactions towards completion
- Expand allowed range of temperatures and pressures



Overall membrane performance

- 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

H_2 Membrane Reformer - Power Plant



Key Findings and Conclusions

- Advanced Pre-combustion technology offers significant long-term cost reduction opportunities and the possibility of hydrogen production with minimal associated CO_2 emissions;
  - Cost reductions of 55% over BAT at the start of the CCP
  - For situations where syngas must be produced for reasons other than carbon sequestration (for example to make H_2 or to produce power by IGCC), the incremental cost to capture CO_2 can be as low as $15/t."
  - Process step reduction and H_2 membranes offer significant capital cost reductions and further potential for reducing CO_2 avoided cost