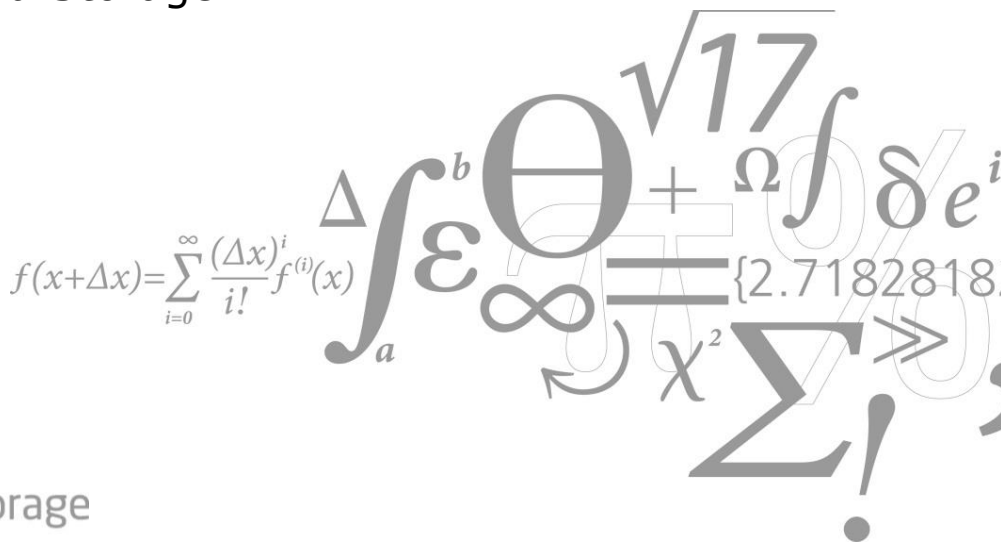
Feeding CO_2 from air into solid oxide electrolyzer cells

Søren Lyng Ebbehøj
M.Sc. Sustainable energy
slebb@dtu.dk

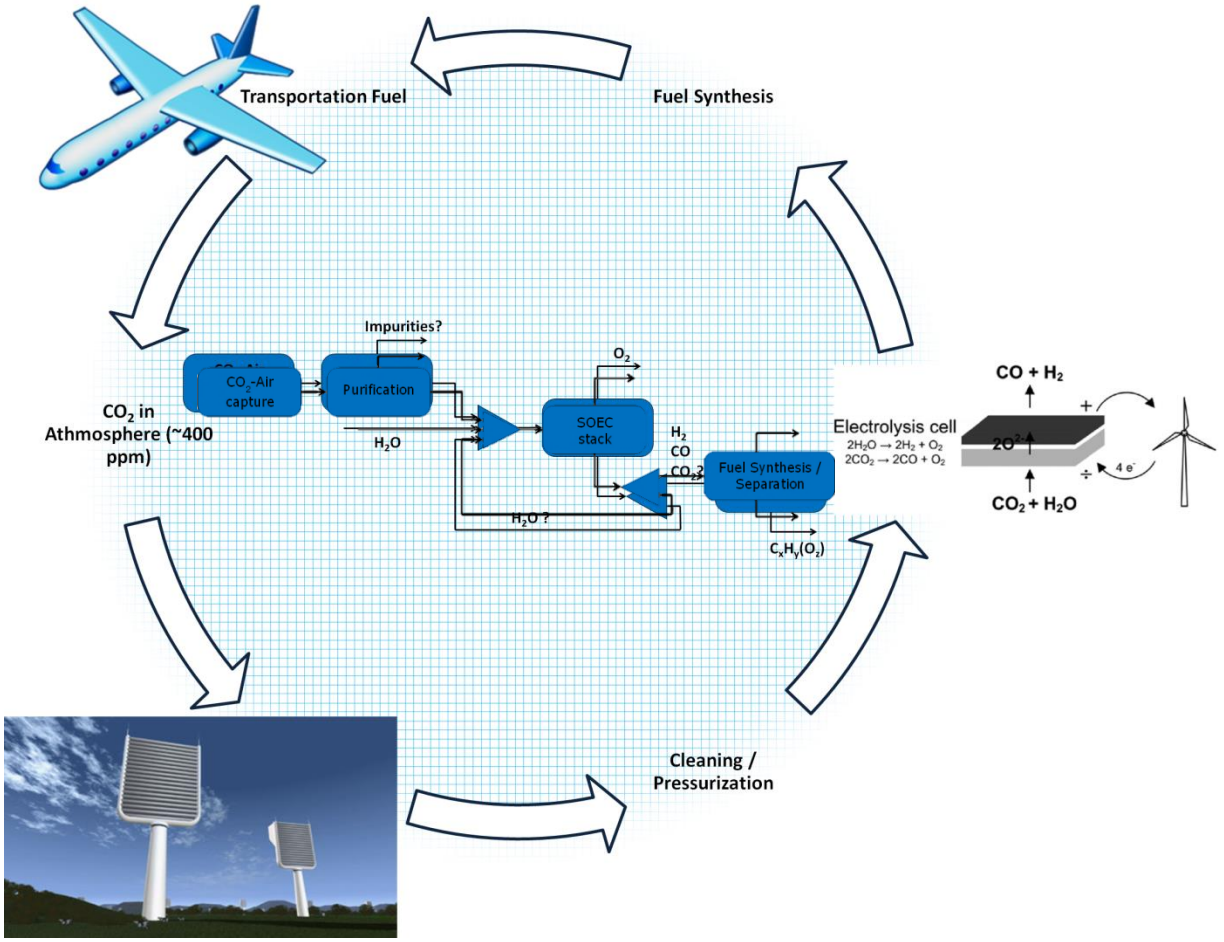
Department of Energy Conversion and Storage
Technical University of Denmark
Risø Campus



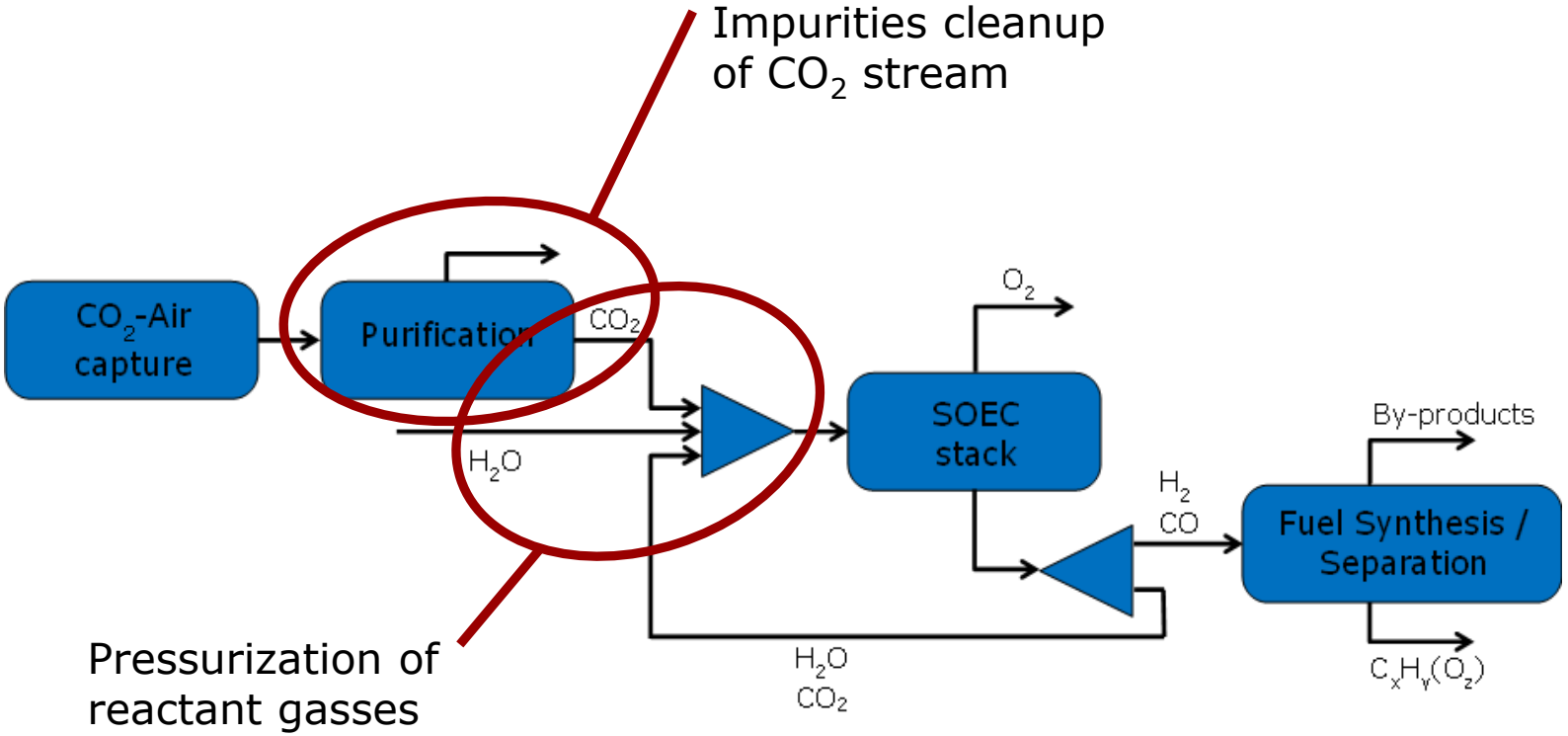
eurostars™ CAPFUEL

DTU Energy Conversion
Department of Energy Conversion and Storage

Project vision



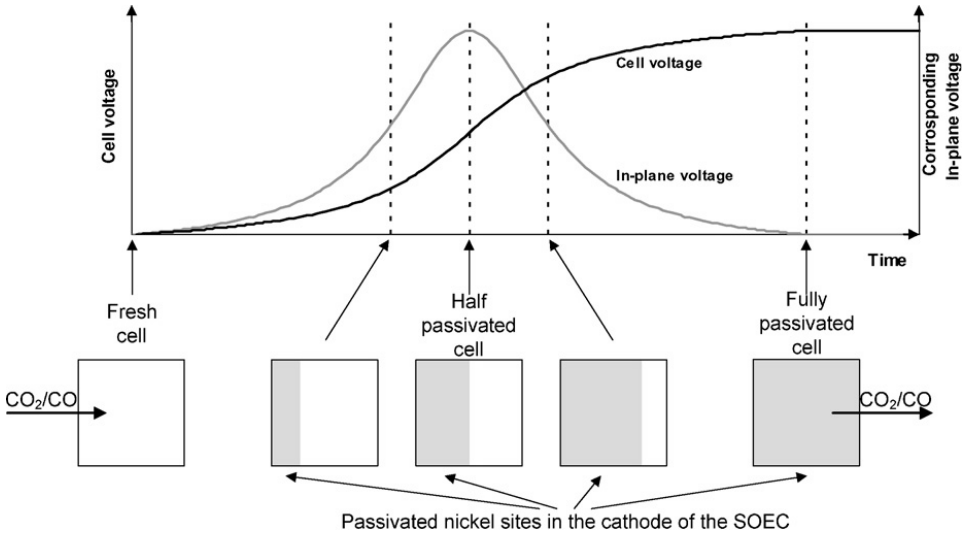
Project vision

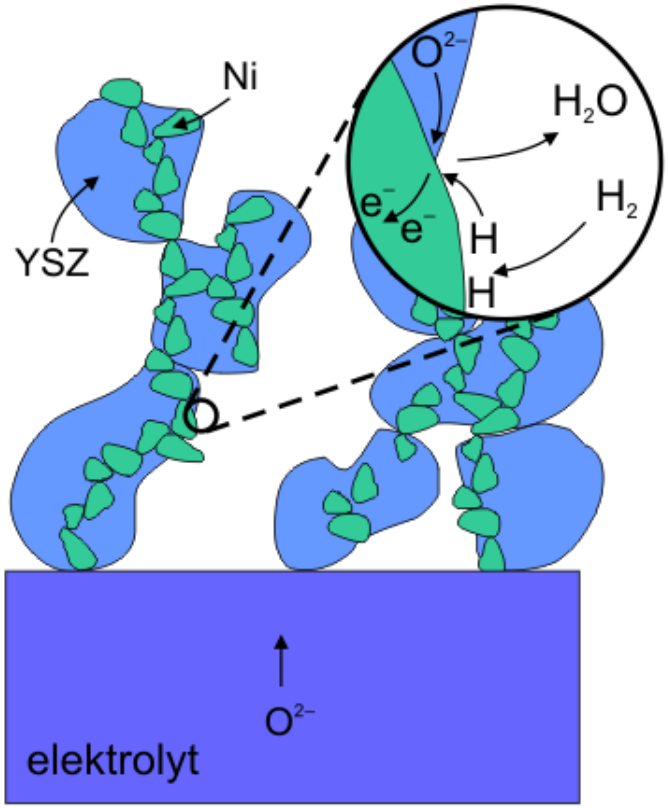


Impurities and SOEC operation

- Glassy Na, Si, Al, etc. Blocks catalytically active sites (TPB)
- Sulfurous compounds etc. block Ni surface sites
- Deposition damages structural integrity (carbon formation)

- Measurable below 5 ppb (H_2S)

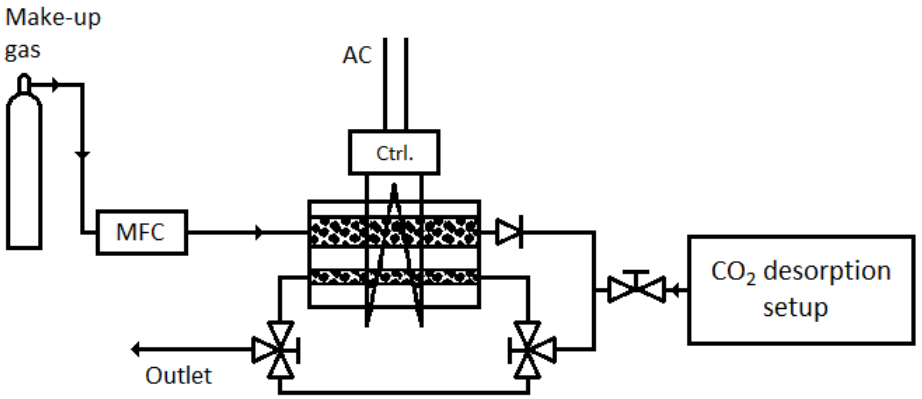




Ebbesen SD, Mogensen M, Journal of Power Sources 193 (2009) 349–358

Impurity collection experiments

- Solid state adsorption of trace impurities
- Crushed cathode material (Ni/YSZ)
- Operated at 1023 K
- Reducing conditions



Climeworks ltd.:

- functionalized amine based
- temperature-vacuum swing
- pre-pilot prototype
- ~99% CO_2 (N_2, O_2, H_2O)

Lenfest Centre for Sustainable Energy:

- an-ion exchange resin based
- carbonate-bicarbonate humidity swing
- simple bench scale setup
- 0.5~5 % CO_2 (N_2, H_2O, H_2)

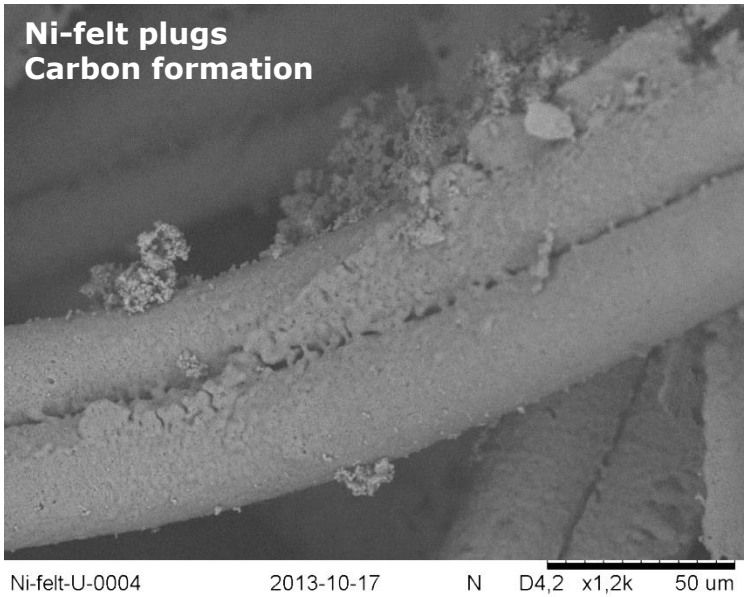
Correction: revised numbers in table
Elemental analysis of impurities

- Sorption on Ni/YSZ grannulate (fuel electrode material)
- Operated at 1123 K
- Elemental analysis by XPS, EDS, SEM and Glow Discharge Mass Spectrometry (GDMS)

- Detection limit: ~10±2 ppb (in gas)

	Content in CO_2 [ppm molar]	
Element	**LCSE**	**Climeworks**
B	-6.9 ± 9.7	-8.0 ± 17.3
Na	-13.6 ± 4.6	-10.1 ± 10.7
Mg	5.6 ± 8.2	0.0 ± 8.7
Al	-8.3 ± 13.3	0.5 ± 9.1
Si	4.1 ± 6.5	1.5 ± 9.5
P	-0.1 ± 0.1	-0.1 ± 0.1
S	1.2 ± 0.2	-0.2 ± 0.1
Cl	3.4 ± 1.3	3.6 ± 4.9
Co	1.6 ± 6.9	3.8 ± 11

GDMS elemental analysis



Elemental analysis: Glow Discharge Mass Spectrometry

- Various trace elements present in low concentrations
- Many are expected to be harmful for high purity applications (÷ carbon)

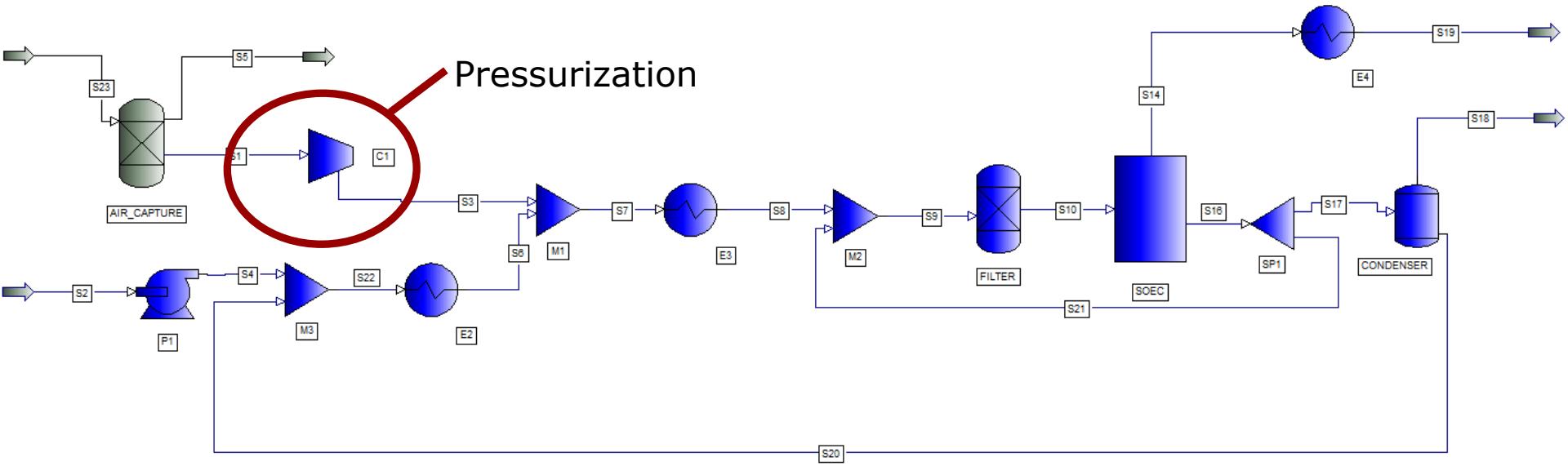
- Expected impurity sources:
  - Machine parts
  - Sorbent and filter material contaminants
  - Adhesives/oils
  - Captured from air (difference in location?)

- Most of these are preventable (minimize) in real systems

- Cheap and reliable filtering strategies available and tested
  - Ni/YSZ filter required for S-content <8 ton/1000 ton CO_2
  - Easily regenerated by redox-cycling

Compression: System simulation

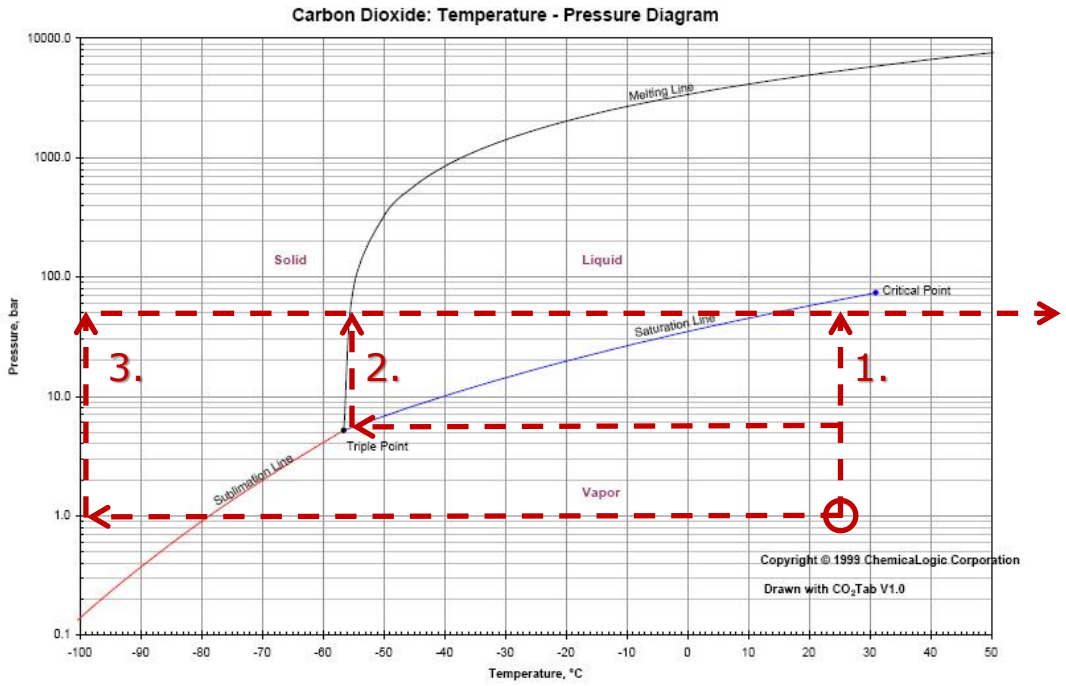
- Steady state, thermodynamic model
- 1000 ton of CO_2 per year Climeworks ltd. plant ~ 530 kW SOEC
- Starting conditions: CO_2 in air, clean H_2O, ambient conditions
- SOEC operating conditions: 1123 K, 50 atm, 1.24 V (> thermo neutral)
- Syngas $H_2/(CO+CO_2) = 3$ ~ methane production (~12% CH_4)
- Outlet conditions: syngas stream at 400 K and 50 atm.



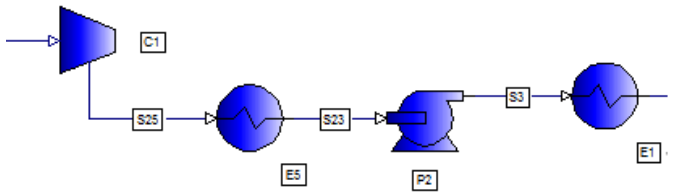
Compression cases

1. Base case: Simple compressor
2. Cryo: Cryogenic compression (5.15 atm, 205 K)
3. Solid Cryo: Cryogenic via solid CO_2 (1 atm, 187 K)

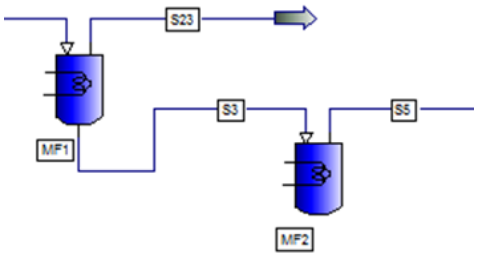
Inlet: ambient, outlet: 50atm, 533 K



2.



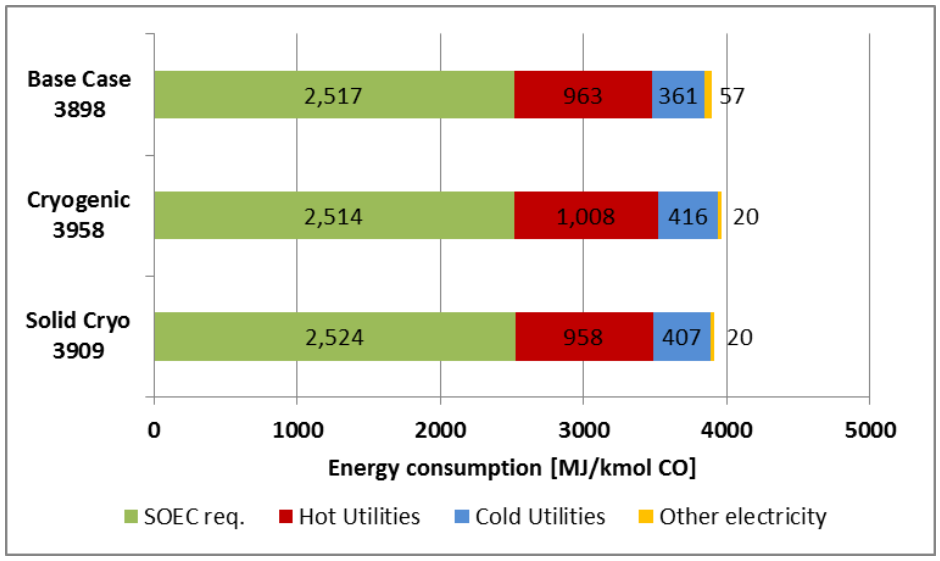
3.

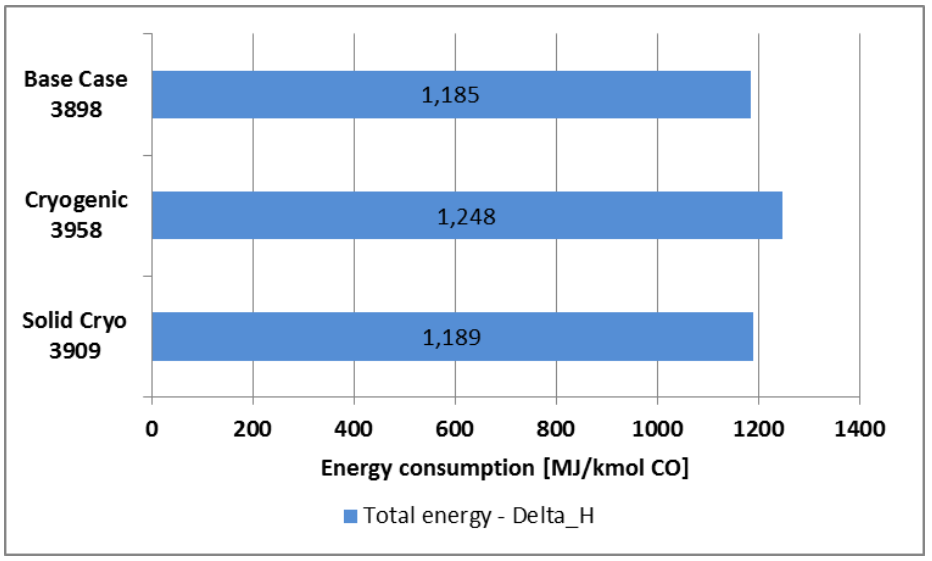


Energy balance

- Energy consumption based on production of CO
  - 1 mol CO
  - ~6 mol H_2
  - 1 mol CH_4
  - $H_2 : (CO+CO_2) = 3 : 1$

- Heat integration pinch analysis:





Conclusion and future work

- Impurities pose a minor problem for SOEC operation and will probably require filtering
- Careful selection of materials will solve some of the problem
- Cheap, efficient filtering strategies exist to take care of the rest

- Alternatives to simple compression of CO_2 exists
- Further heat integration analysis, sizing and costing is needed to evaluate these

- Sorbent based compression is being looked into
- Further system analysis is planned
  - Including matching to various fuel synthesis technologies

Acknowlegements

- Eurostars E! CAPFUEL - CO2 capture from air and conversion into hydrocarbon fuels

- Climeworks Ltd.:
  - Jan Wurzbacher
  - Dr. Nic Piatkowski

- Lenfest Centre for Sustainable Energy:
  - Prof. Klaus Lackner
  - Allen Wright

- DTU Energy Conversion:
  - Prof. Mogens Mogensen
  - Dr. Sune Ebbesen
  - Anders Petersen