HiPerCap - High Performance Capture

FP7 Grant agreement n° 608555

Assessment and Benchmarking of Post-combustion Technologies developed in the HiPerCap Project

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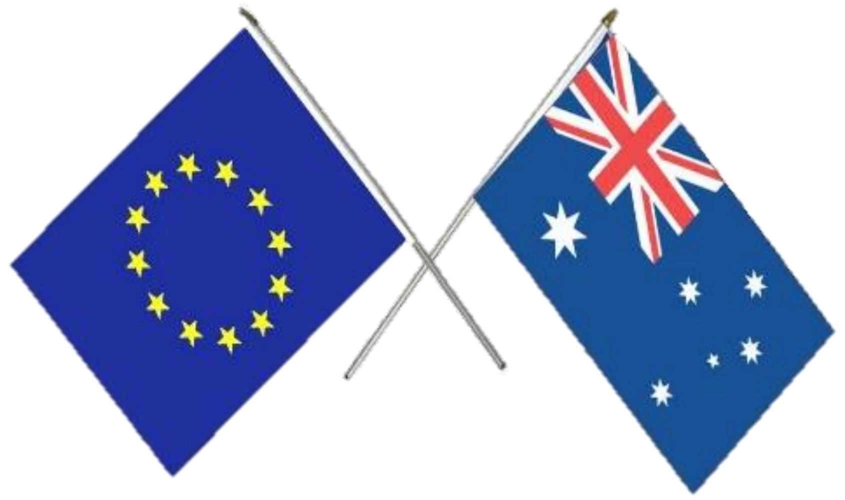
Outline

- Project overview
- Technology assessment and benchmarking
- Assessment KPIs
- Evaluation of the concepts
- Benchmark in HiPerCap

EU project HiPerCap

- ❑ EU-Australia twinning project
- ❑ Coordinator: SINTEF MC (Dr. Hanne Kvamsdal)
- ❑ Partners:
  - ✓ 12 EU partners
  - ✓ 1 from Australia
  - ✓ 1 from Russia
- ❑ Duration:
  - ✓ 4 years, Jan 2014 - Dec 2017
- ❑ Budget:
  - ✓ 7.7 M€ (4.9 M€ from EU)



http://www.sintef.no/projectweb/hipercap/

Project objectives

- ❑ Develop environmentally benign energy- and cost-efficient technologies for post-combustion capture
- ❑ Develop a methodology for fair comparison and benchmarking of the technologies
- ❑ Develop technology roadmap for the two most promising technologies

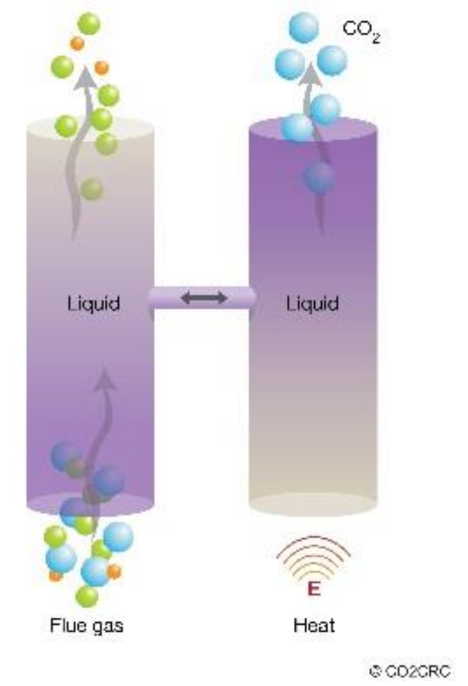
Key focus on potential of the capture technologies

Specific objectives

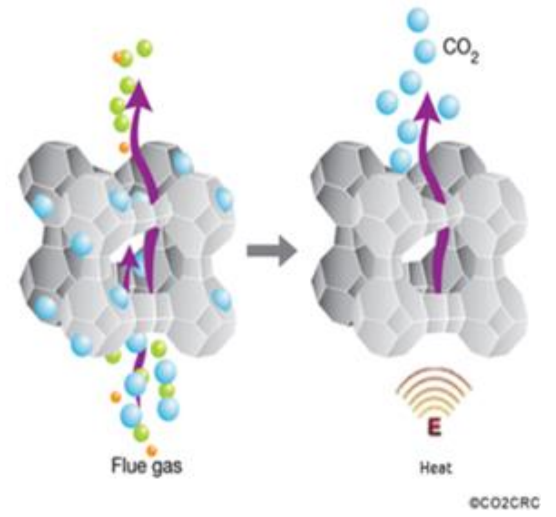
- ✓ Reduction of 25% energy penalty compared to the State-of-the-Art

Post-Combustion capture technologies in HiPerCap

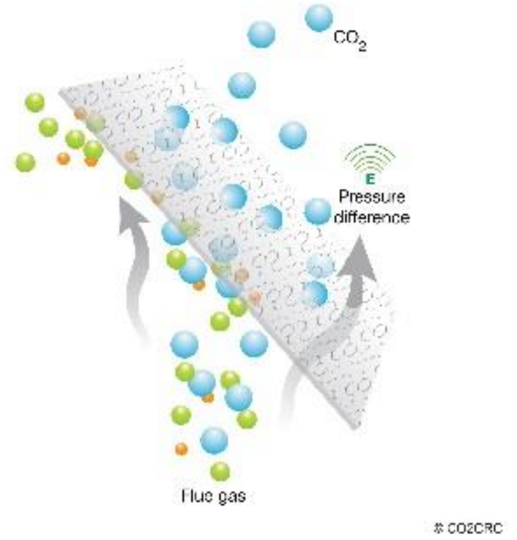
- ❑Absorption
  - ✓Proof-of-concept of 4 solvent concepts
    - ➢DMMEA+enzyme, precipitating solvents, strong bicarbonate solvent systems, absorption combined with algea growth (utilization concept)
  - ✓Feasibility study of bio-mimicking concepts



- ❑Adsorption
  - ✓Testing of various sorbents including "green" sorbents
  - ✓Studying two reactor systems (fixed-bed and moving-bed)



- ❑Membrane
  - ✓Hybrid (polymer + nanoparticles) membranes
  - ✓Supported ionic liquid membranes



Images: www.co2crc.com.au

ASSESSMENT AND BENCHMARKING IN HIPERCAP (2)

Develop and apply an assessment methodology for emerging technologies on different TRL-level

Idea

- Develop a KPI based methodology with a consistent way of scaling up to a representative scale of application.

Work in the project

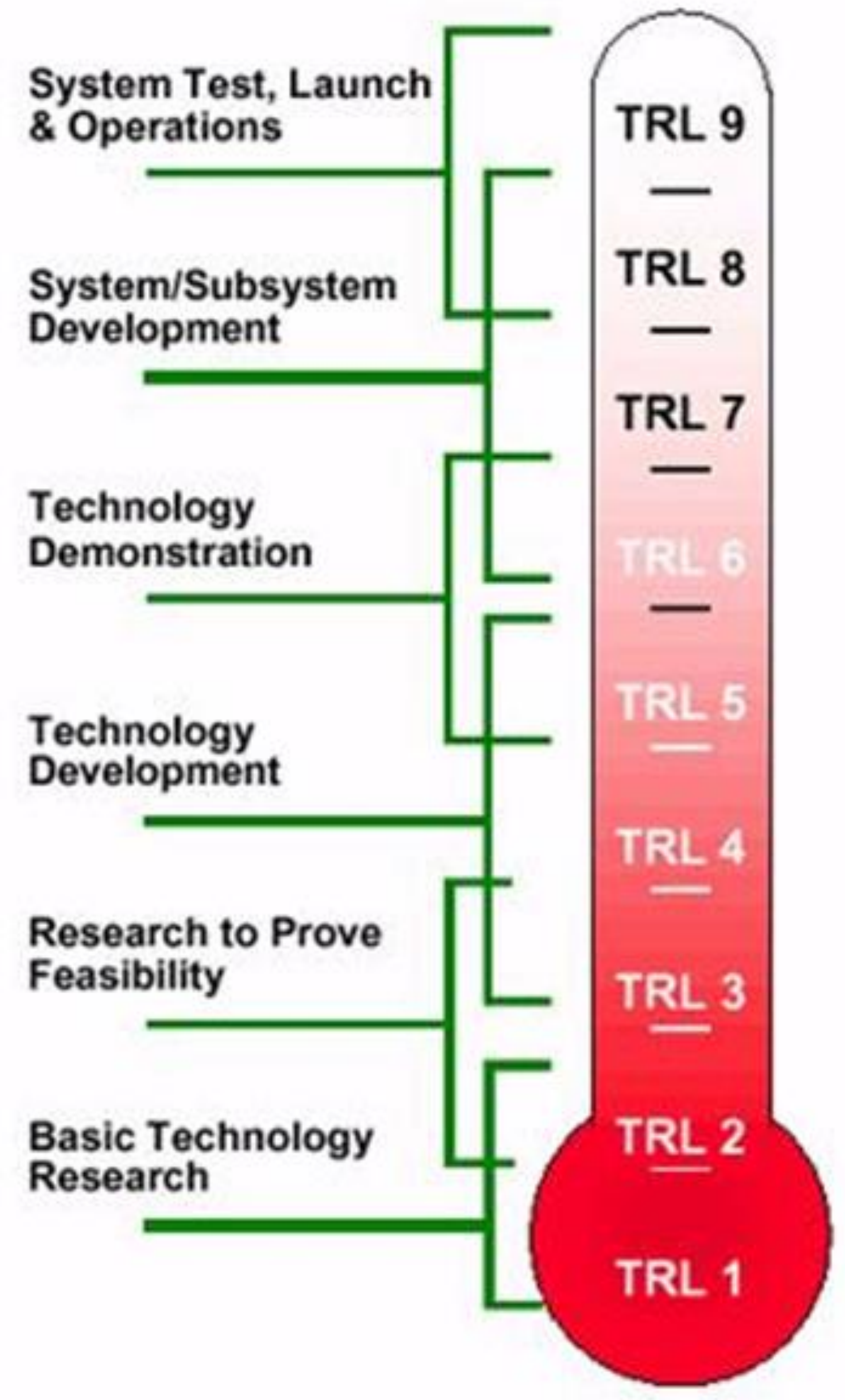
- Define a clear base case, use defined system boundaries, modeling approach and comparison criteria. Select the two most promising technologies for further studies.

Challenges

- Develop a fair methodology for comparison of immature technologies at different TRL levels.

Results so far

- Methodology developed based on two stage selection process
- Reference case established and the integrated process simulated
- Energy assessment finished for all chosen concepts
- Cost KPI method developed, but needs further refinements



Assessment and Benchmark methodology (1)

- Two stage selection approach due to various TRL levels:
  1. Screening stage to check if enough data available and to check if no environmental showstoppers
  2. Evaluation stage involves: integration with a power plant, compare to a reference capture technology and ranking based on energy, emission and cost KPIs
- Focus here: energy KPI
  - ✓ Specific Energy Penalty of Avoided CO_2 (SEPAC):
    - Description:
      The specific loss in power output of the power plant, with and without the CO_2 capture process
    - Math:
      $SEPAC=(P_{ref} - P)/(\varphi_{CO2ref} - \varphi_{CO2})$
      where:
      P = net electric output of the power plant in MW_e
      φ_{CO2} = the emitted flow of CO_2 in kg/s
      subscript ref means the power plant without capture

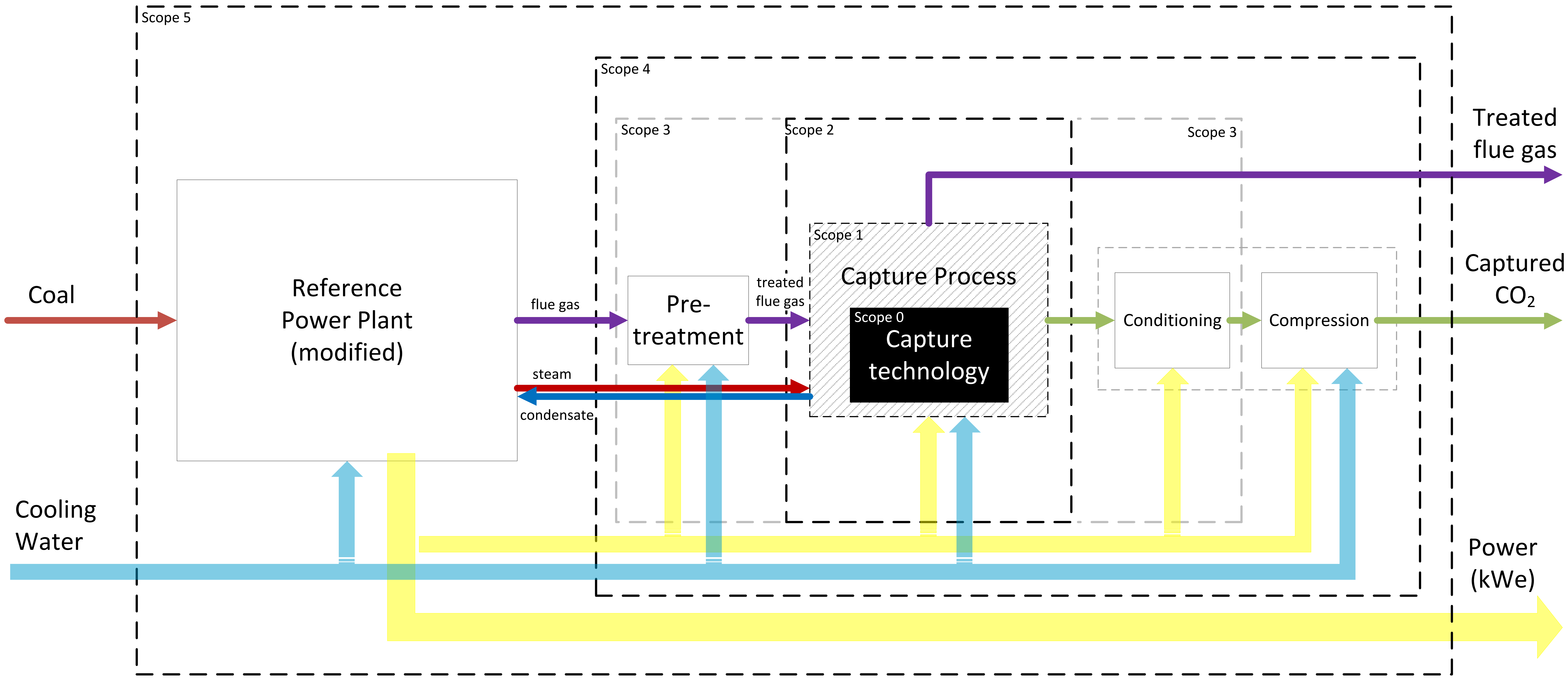
Assessment and Benchmark methodology (2)

- Power-plant: Advanced-supercritical pulverized single unit coal boiler (ASC) from EBTF*
- Benchmark capture system: absorption based with CESAR1 as solvent system** and conventional absorber/stripper process (simulated in Aspen Plus)
- All capture processes integrated with the ASC process
  - Specifications:
    - At least 85% capture rate and 95% purity (CO_2 product stream)
  - Six absorption, two adsorption, and four membrane based processes

**N. Booth et al., (2013), European Best Practice Guidelines for Assessment of CO_2 Capture Technologies, CESAR Deliverable D2.4.3, March, available at http://www.co2cesar.eu*

**Knudsen, J., Andersen, J., Jensen, J.N., and Biede, O. Evaluation of process upgrades and novel solvents for the post combustion CO_2 capture process in pilot-scale, presented at the GHGT-10 conference in Amsterdam 2010

General flow diagram for capture plant integration



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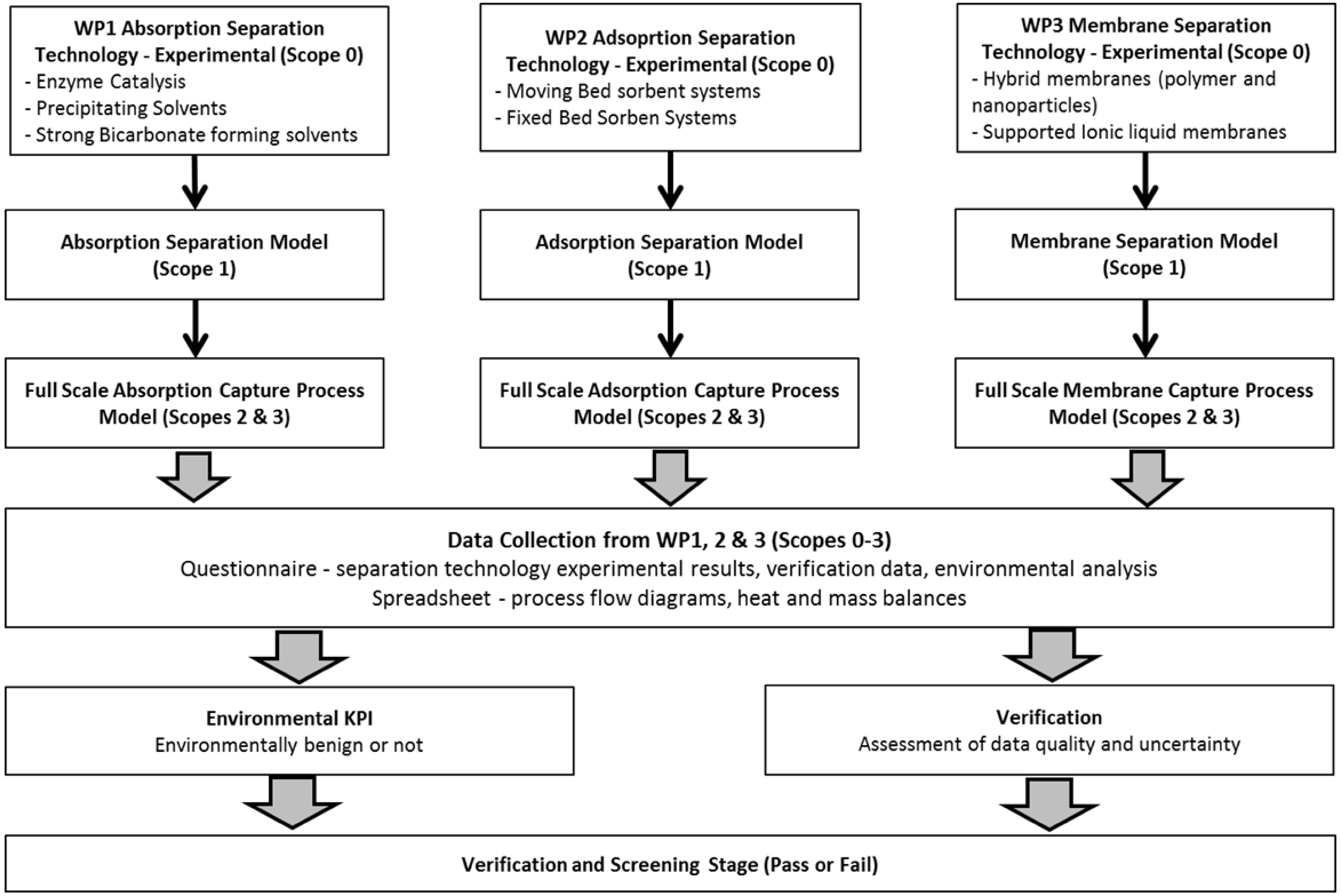
Work flow up to first stage evaluation



Work flow second stage evaluation and final benchmark

Energy KPI
Comparison of SEPAC value compared to Caesar 1. Improved technologies move to next stage

↓

Cost KPI
CAPEX and OPEX assessment. Initial ranking with qualitative assessment of cost drivers. Technologies that outperforms CESAR 1 on the qualitative assessment, will proceed into the quantitative approach

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Technology Evaluation
Ranking of technologies based on Energy and Cost KPI.
Memo summarising the evaluation and the recommendations to the General Assembly

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TWO BREAKTHROUGH TECHNOLOGIES (GA Decision)

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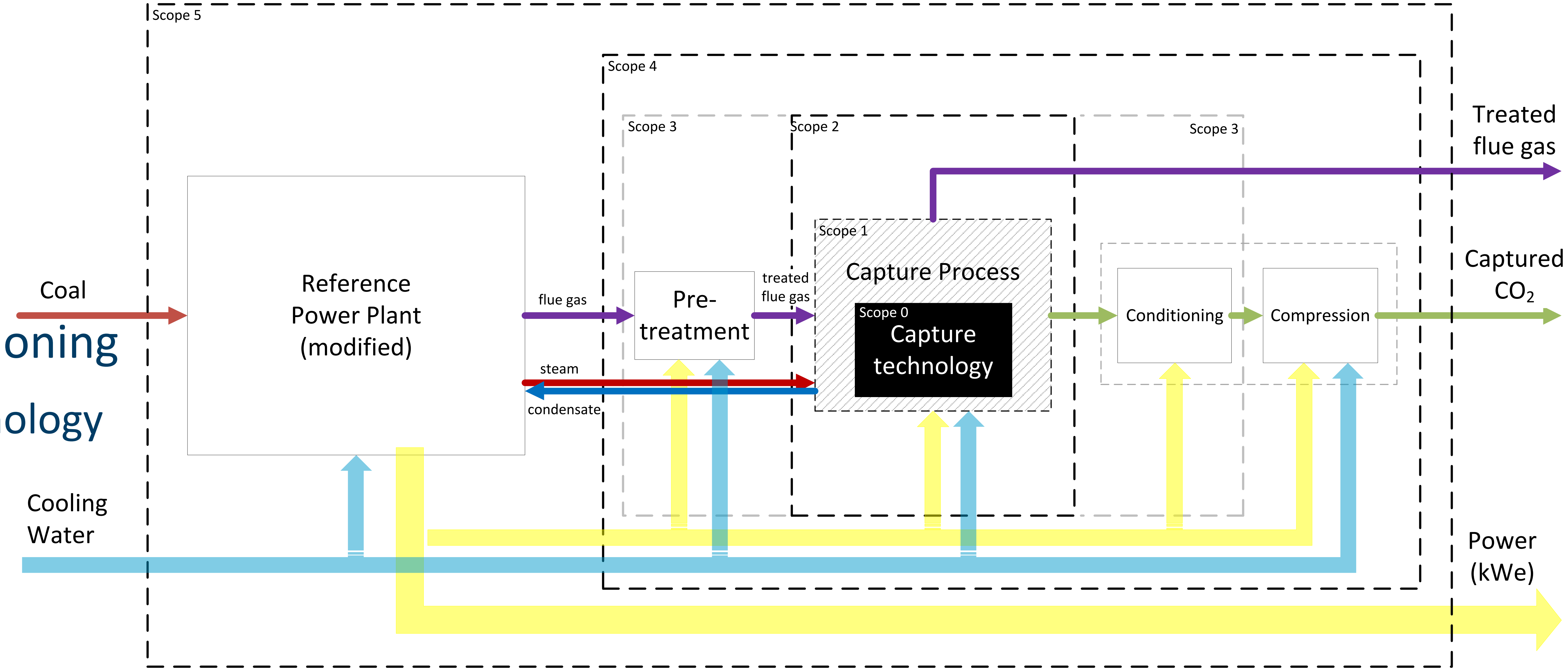
WP5 Road mapping of Breakthrough Technologies
More detailed energy benchmark and analysis

Large scale modelling in HiPerCap

- Scope 5 - Reference Power plant
  - ✓ PROATES
- Scope 4 - Compression train
  - ✓ Aspen Plus
- Scope 3 – Pre-treatment and conditioning
  - ✓ Optional, dependent on capture technology
  - ✓ E.g. NO_X/SO_X removal
- Scope 2 -Capture process
  - ✓ Aspen adsorption
  - ✓ Aspen Plus RateSep
  - ✓ CO2SIM
  - ✓ Matlab and others
- Scope 1 - Small scale modelling
  - ✓ Experiment modelling and validation



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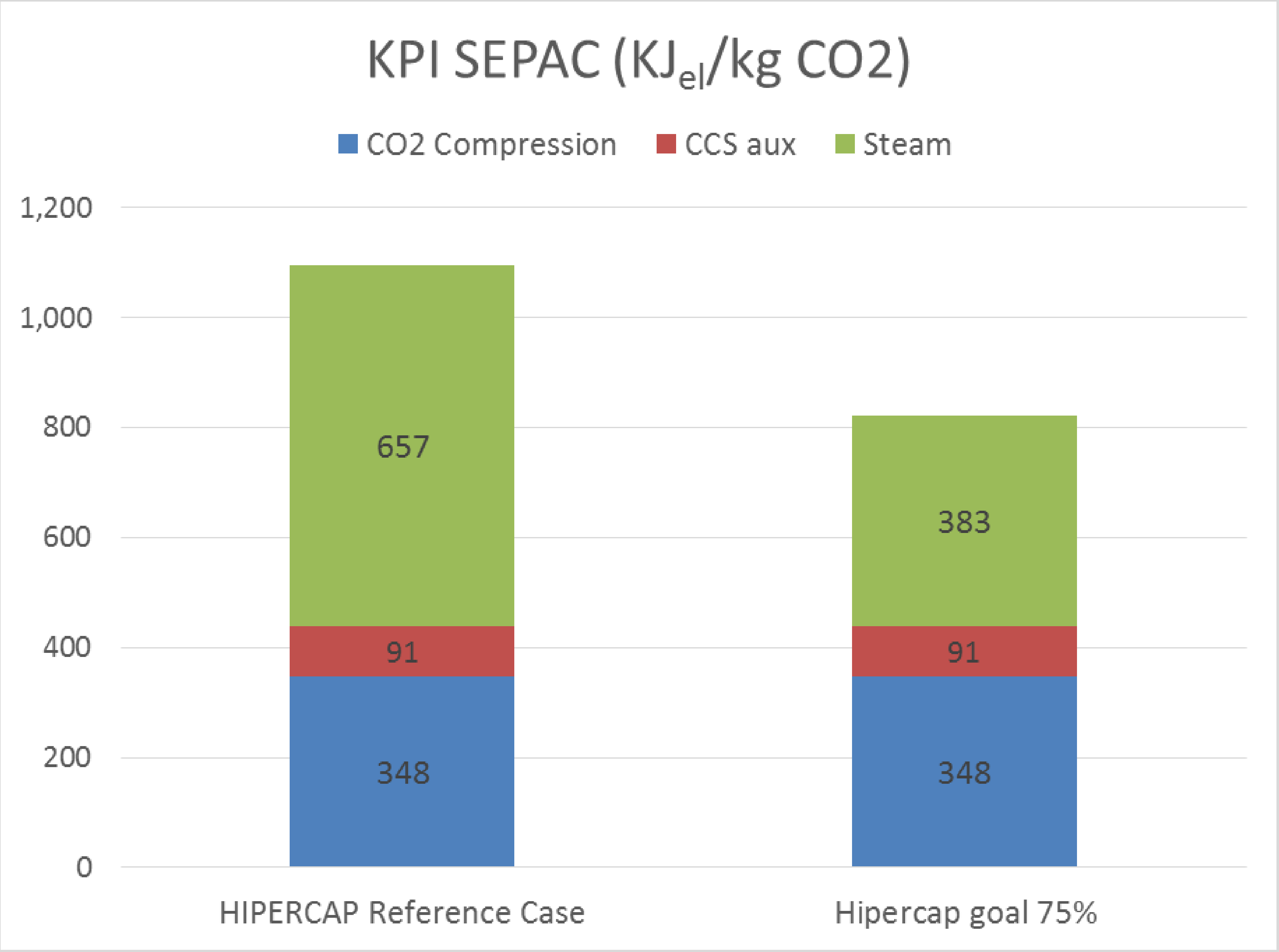
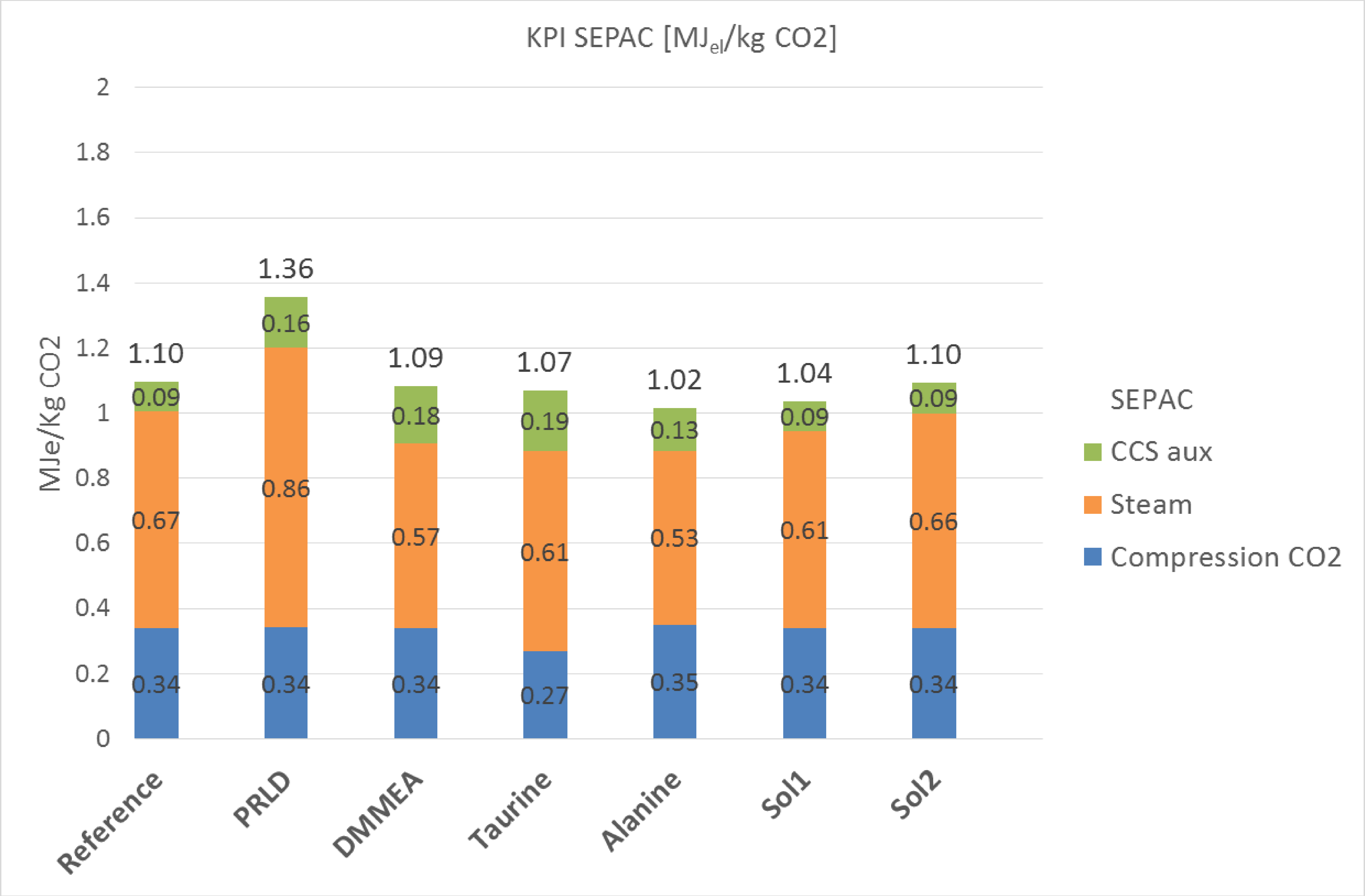
Reference Capture plant modelling and SEPAC value

- One Capture train with 90% CO_2 Capture
  - Aspen Plus Ratesep
  - No Intercooler or Lean Vapour Compression
- Solvent
  - Cesar 1 Solvent
- Columns (One Capture train)
  - 70% Flooding/Capacity
  - Absorber section D=18.2m, L=16.5 m (Mellapak 2x)
  - Desorber section D=10.4m, L=10 m (Mellapak 2x)
- Utilities (scope 2+3+4)
  - SRD=3.02 GJ/tonne CO_2 (443.4 MW_{th})
  - Steam (S1)=1.23 tonne/tonne CO_2
  - Electric power consumption =0.44 GJ_{el}/tonne CO_2 (120 KWh_{el} /tonne CO_2)
  - Cooling water=105 tonne/tonne CO_2

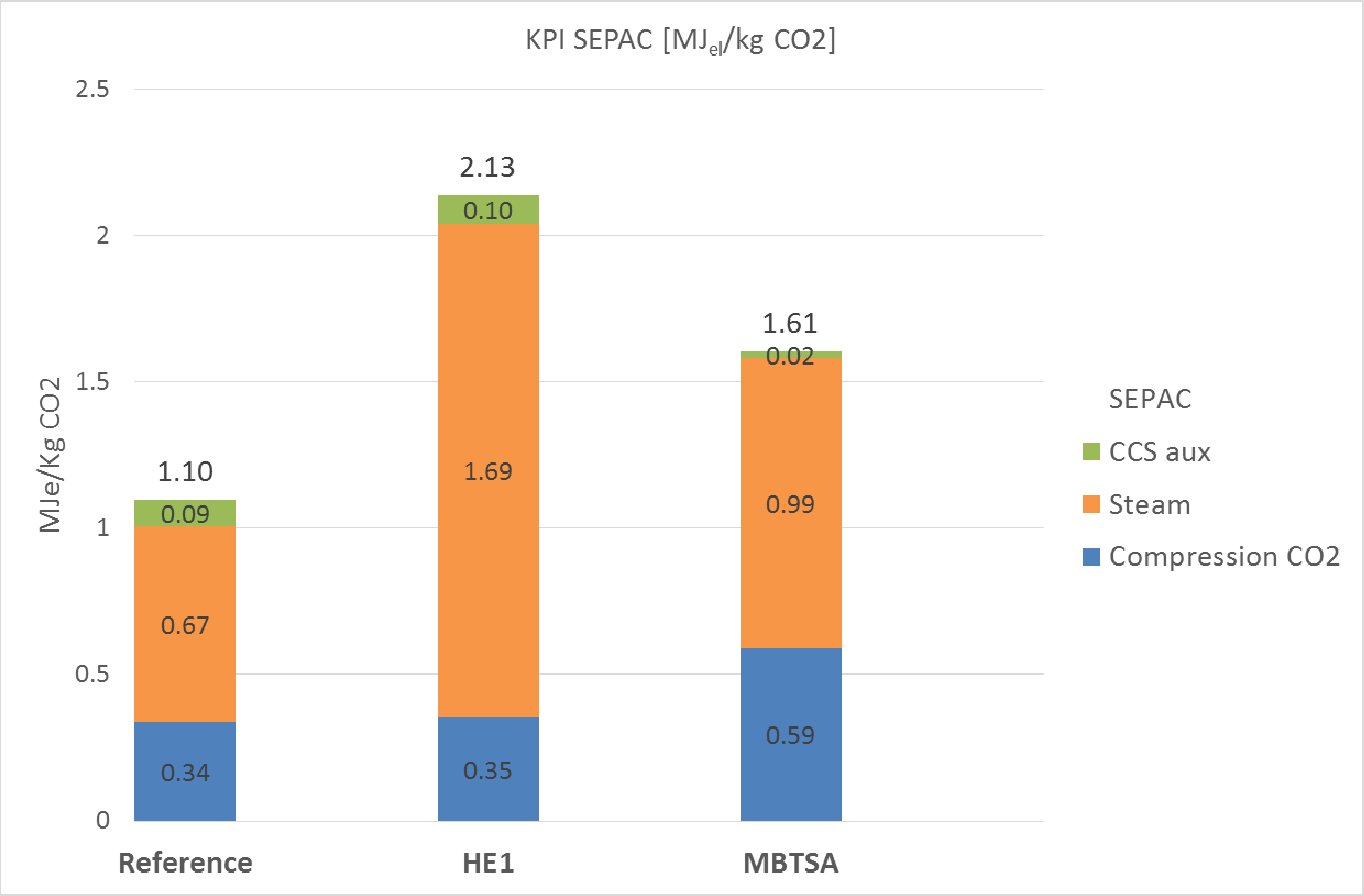


Comparing ENERGY KPI (SEPAC) Absorption systems



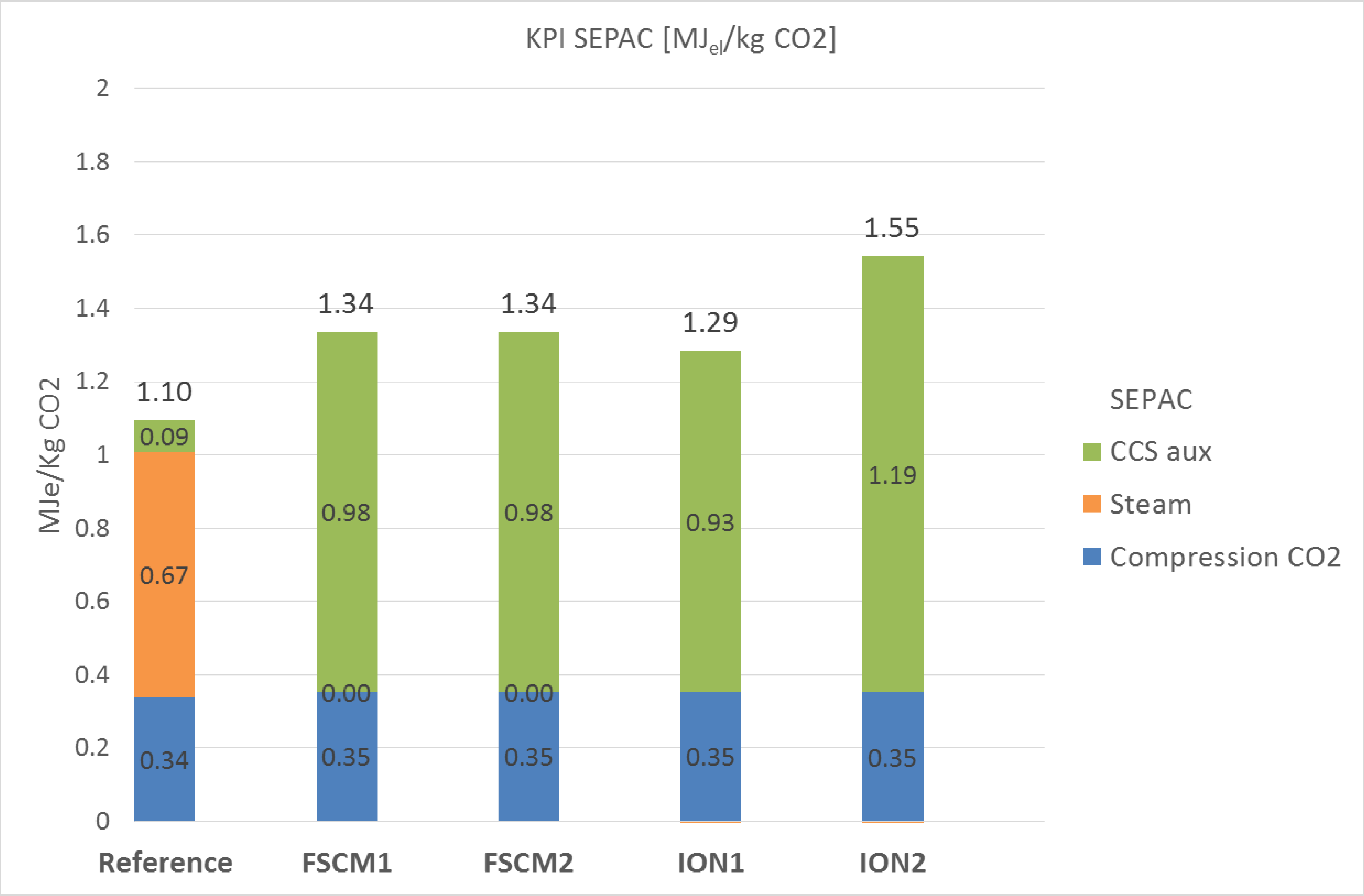
- Cases
  - ✓ Enzyme catalysis of CO_2 absorption (PRLD, DMMEA)
  - ✓ Precipitating solvent systems (Alanine, Taurine)
  - ✓ Strong bicarbonate forming solvent (Sol 1, Sol 2)
- All similar performance as reference
- CO_2 compression equal
  - ✓ Exception Taurine (stripper pressure 4 bar)
- CCS aux
  - ✓ Fan
  - ✓ Solvent pumps
- Steam consumption
  - ✓ ~3 $MJ_{th}/kg\ CO_2$
  - ✓ Steam LP to Electric
    - ➢ Factor of 4-5

Comparing ENERGY KPI (SEPAC) Adsorption systems



- MBTSA (Moving bed)
  - ✓ Final modelling/optimization not finished before the comparison with all technologies
    - ➢ CO2 purity failure
    - ➢ CO2 capture rate failure
  - ✓ More promising results after deadline, but no time for integration with power-plant simulation
- HE1 (Fixed bed)
  - ✓ Final modelling/optimization not finished before the comparison with all technologies
    - ➢ High energy demand
  - ✓ More promising results after deadline, but no time for integration with power-plant simulation

Comparing ENERGY KPI (SEPAC) Membrane systems



- Cases:
  - ✓ 2 Mixed matrix (hybrid) membranes: FSCM 1, FSCM 2
  - ✓ 2 Supported ionic liquid membranes: ION 1, ION 2
- No steam, only mechanical energy
  - ✓ E.g. CCS AUX (ION 1)
    - Fluegas compression: 1.05 MJ_{el}/kg CO2
    - Vacuum pumps: 0.4 MJ_{el}/kg CO2
  - ✓ CO_2 "boosting" 2 bar: 0.08 MJ_{el}/kg CO2
  - ✓ Flue gas Expansion: -0.56 MJ_{el}/kg CO2
- Membranes should be further improved (highly complex)
- Process should be more optimized and possibly more integrated with the power-plant
- Look for application with lower capture rate requirement

Ranking of technologies based on energy KPI

Rank	Case	Capture rate (%)
1	Alanine (abs.)	90
2	Sol 1 (abs.)	90
3	Taurine (abs.)	90
4	DMMEA (abs.)	90
5	Sol 2 (abs.)	90
6	***CESAR1 BASE***	**90**
7	ION 1 (mem.)	85
8	FSCM 1 (mem.)	85
8	FSCM 2 (mem.)	85
10	PRLD (abs.)	85
11	ION 2 (mem.)	85
12	~~MBTSA (ads)~~[1]	71
13	HE1 (ads)	85

[1] *MBTSA case does not meet the minimum requirements*

Conclusions

- The absorption based alanine case performs the best and has the highest ranking
- All the absorption technologies have the highest ranking
- The assessment of the Energy KPI for the novel capture technologies, shows that none of the technologies outperforms CESAR1 by 25 %.
- The best performing novel capture technology has a 7.2 % lower energy penalty compared to CESAR1.
- Given that the capture technologies are novel and that the focus has been on developing more energy efficient and more environmentally benign processes, this result is not surprising.
- The two chosen technologies for further studies are the Alanine and the SOL1 cases

FURTHER WORK WITHIN HIPERCAP

- The cost KPI will be further refined
- Have identified gaps in knowledge and developed a technological roadmap for the industrial demonstration of the two chosen technologies.
- Improvements of models (based on experimental lab activities) and further optimization of the capture processes for the two chosen technologies are ongoing work.
- New benchmarking with the updated models and information will be done later this fall.
- The results presented here and the major results from the updated benchmarking will be summarized in a journal publication by the end of 2017.
- The major results from the project will be presented at a workshop in Oslo 13.-14. September 2017.

ACKNOWLEDGEMENTS

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Thank you for the attention!

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