Telemark University College

Norcem CO_2 capture project: International CCS Conference, Langesund, 20-21 May 2015

Benchmark Study – Commercial Scale Perspective

Preliminary results from WP7 Benchmark Study

Lars-André Tokheim[1], Nils Eldrup[2] and Anette Mathisen[2]

[1] Telemark University College & Tel-Tek
[2] Tel-Tek

Outline

1. Purpose of the benchmark study
2. Approach
3. Selected benchmarking results
4. Sensitivity analysis
5. Key points

Purpose of the benchmark study

- Compare technologies with regard to technical, economical and environmental impacts
- Technology providers (TP's):

TP	Technology
Aker	Amine absorption
RTI	Low-temperature capture using a solid sorbent
MC	Membrane separation
Alstom	High-temperature capture using a solid sorbent («Regenerative Carbonate Cycling» (RCC), *i.e.* Calcium Looping)

Alstom not considered today

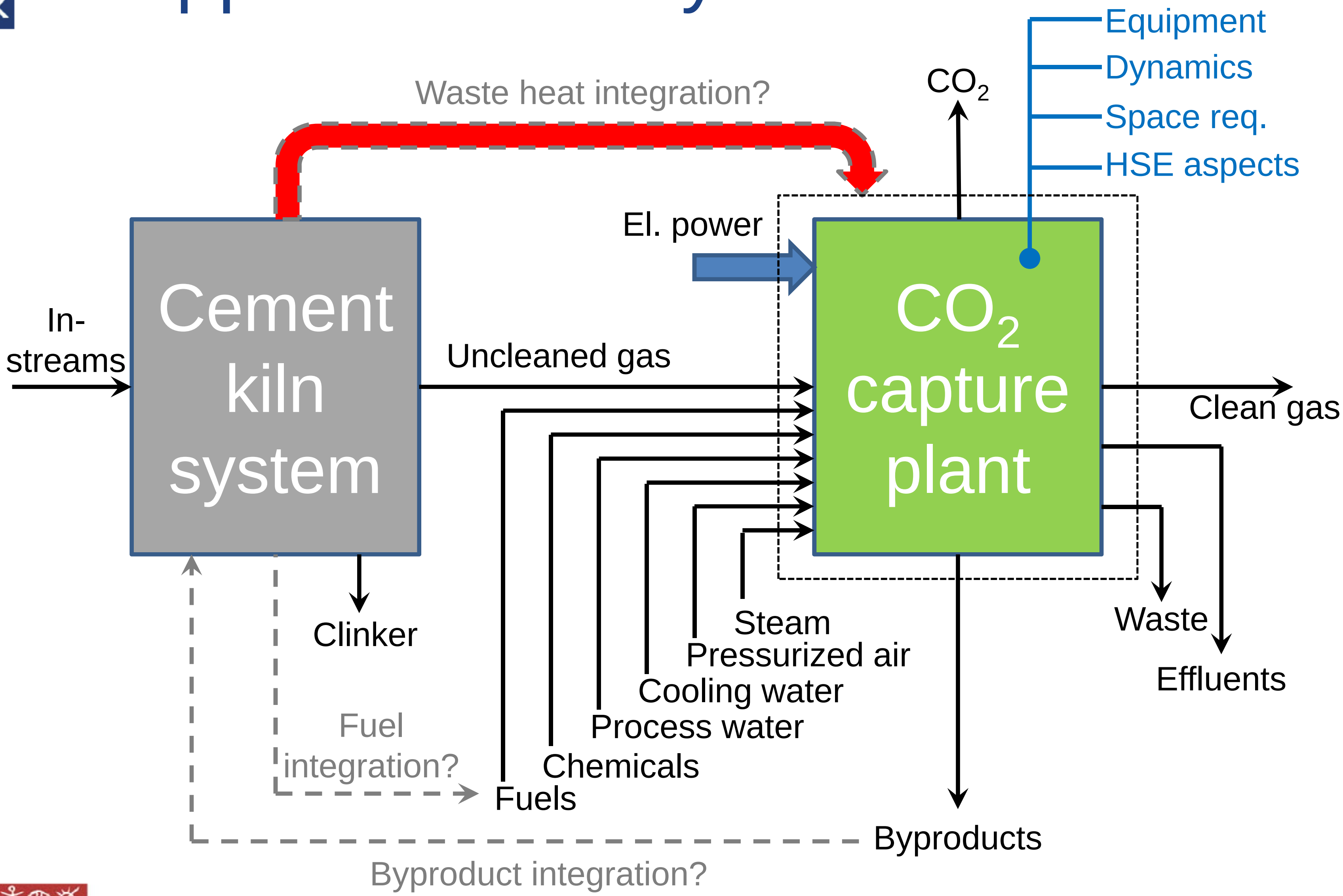
MC = Membrane consortium: NTNU, DNV-GL and Yodfat

- About «commercial scale»:
  - Different technologies applied to a medium size cement plant
  - Not necessarily 85 or 90 % capture, could be for example 30 og 40 % capture – if this makes more sense from an economic, environmental and technical point of view
  - Maturity ➔ Technology readiness level

tel·tek

Telemark University College

Approach: The system



Approach: Preconditions

- Characteristics of uncleaned gas same as for Kiln #6 at Norcem Brevik
- CO_2 stream:
  - > 95 % CO_2
  - Compression to 100 bar and ambient temperature
  - Guidance values for concentrations of other species
- CO_2 capture ratio – three cases:
  1. 85 % without waste heat utilization
  2. 85 % with Norcem waste heat utilization
  3. x %, with Norcem waste heat as the only regeneration energy, x defined by TP

  Basis for comparing technologies
- Tel-Tek cost estimation
  - Basis: Equipment units from TP's
  - Adjust scope / equipment size when necessary
  - Same cost estimation method applied to all technologies

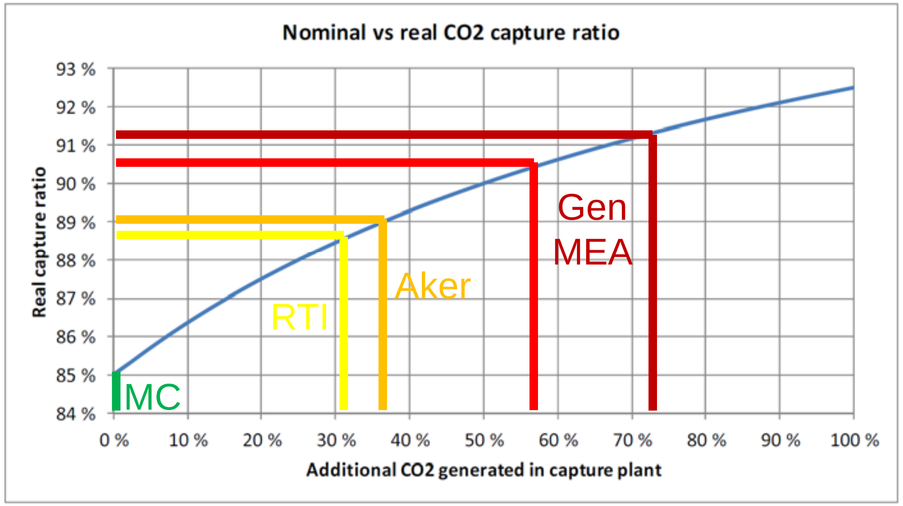
Scope adjustment

Two cases calculated by Tel-Tek to compare with «standard technology»

- Thermal energy ➔ Coal-fired steam generation plant
  - Capture of additional CO_2
  - Equipment size adjustment when required
  - Potential change in pollutant concentrations not considered in the scale-up
- Same CO_2 compression unit for all technologies

TP	SRD* [GJ/t_{CO2}]
Generic MEA	4.2 and 3.7
Aker	2.7
RTI	2.4
MC	0

* SRD: Specific Regenerator Duty



Cases

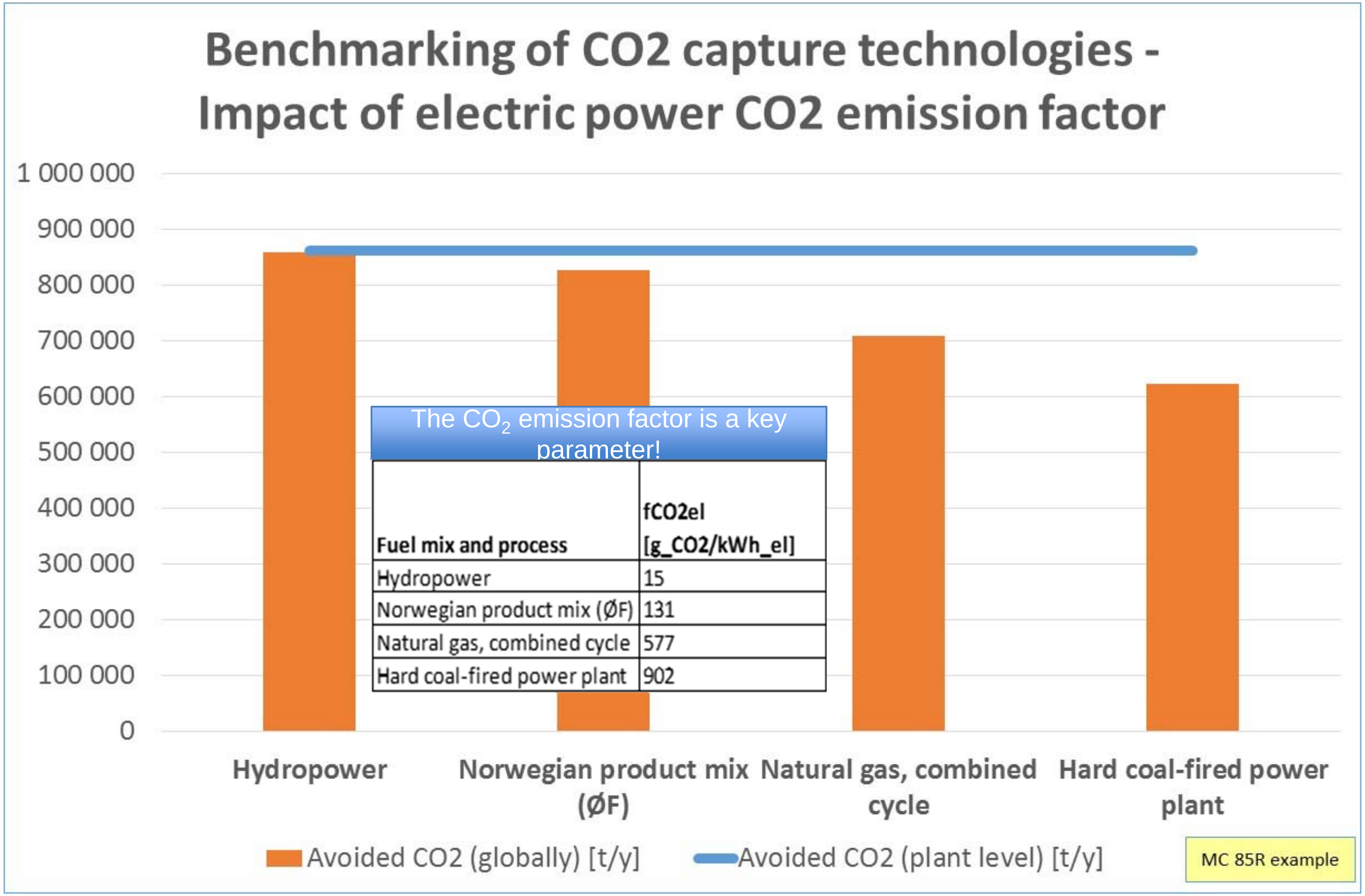
Today: Focus on reference case comparison

Case	(Generic MEA)	Aker	RTI	MC	Alstom
1: 85 % capture, no waste heat utilization	(Yes)	Yes	Yes	Yes	NA
2: 85 % capture, utilizing waste heat for regeneration		Yes	Yes	NA	Yes
3: Capture using only waste heat for regeneration, if possible		Yes (48 %)	Yes (30 %)	NA	
(Additional case reported)				70 % capture	

NA: Not applicable according to TP

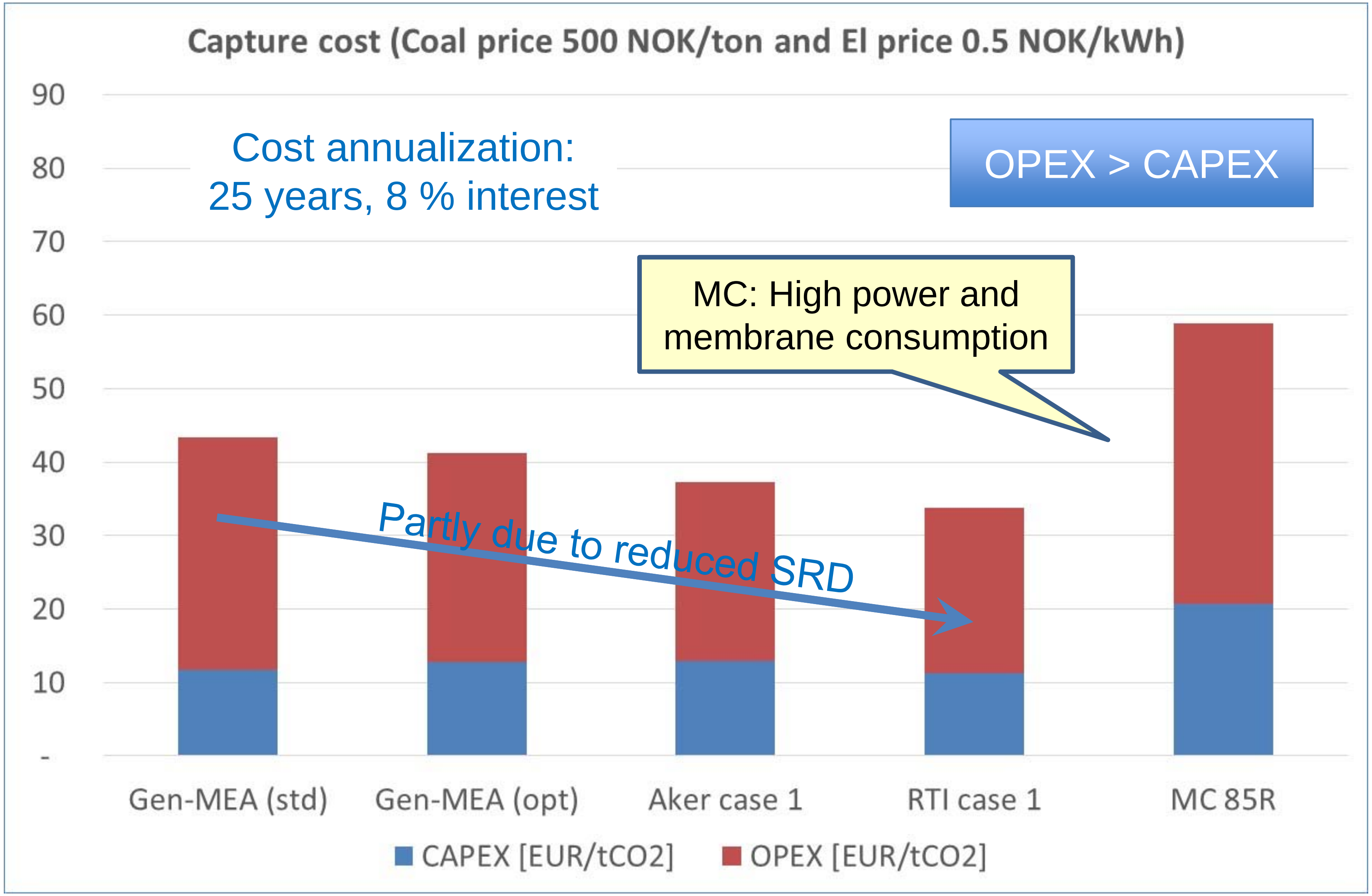
- Comparison:
  - Horizontal (different TP's)
  - Vertical (different cases for a given TP)

Avoided CO_2: Plant level vs globally



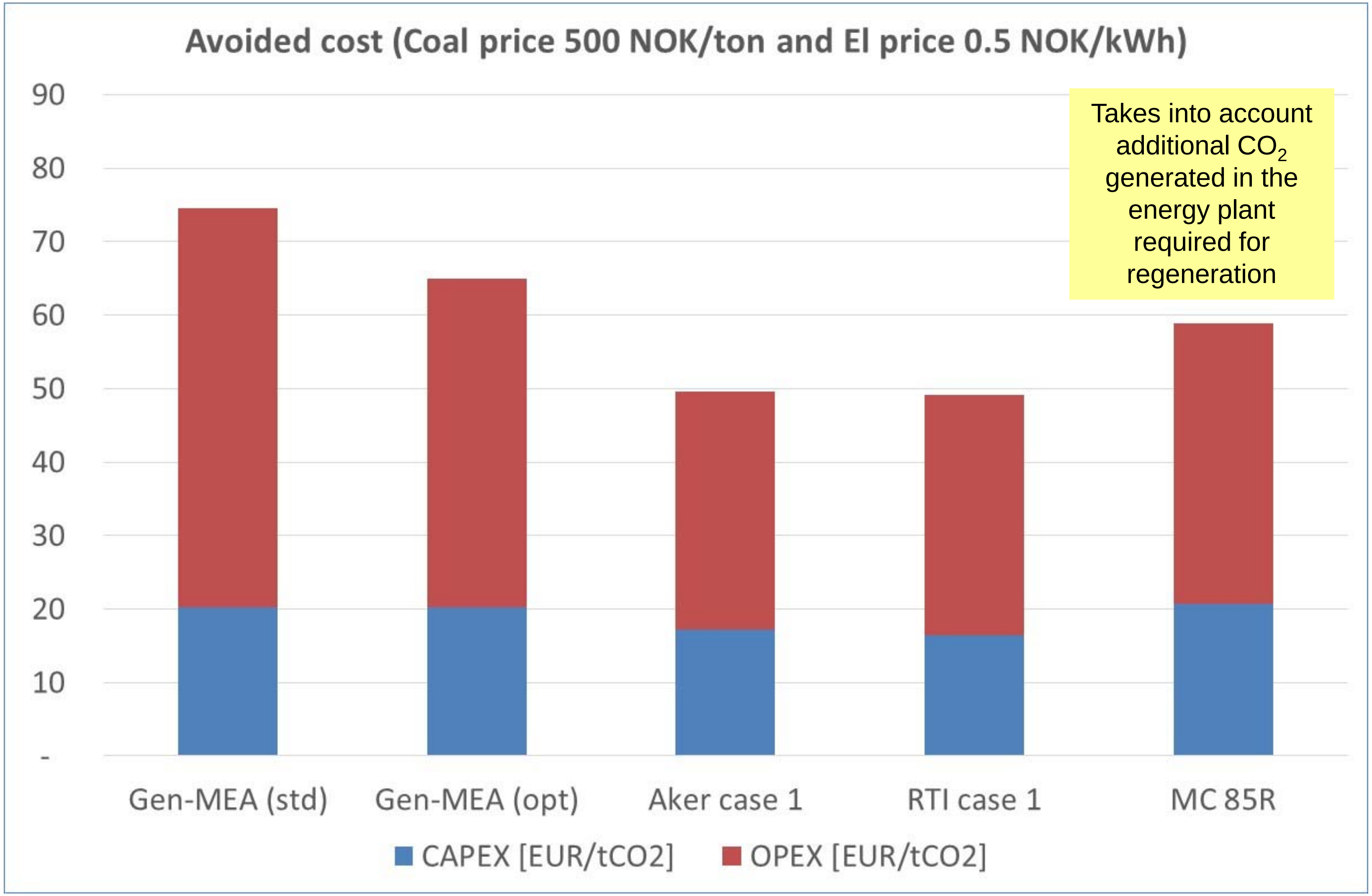
Fuel mix and process	fCO2el [g_CO2/kWh_el]
Hydropower	15
Norwegian product mix (ØF)	131
Natural gas, combined cycle	577
Hard coal-fired power plant	902

Cost comparison: Capture cost

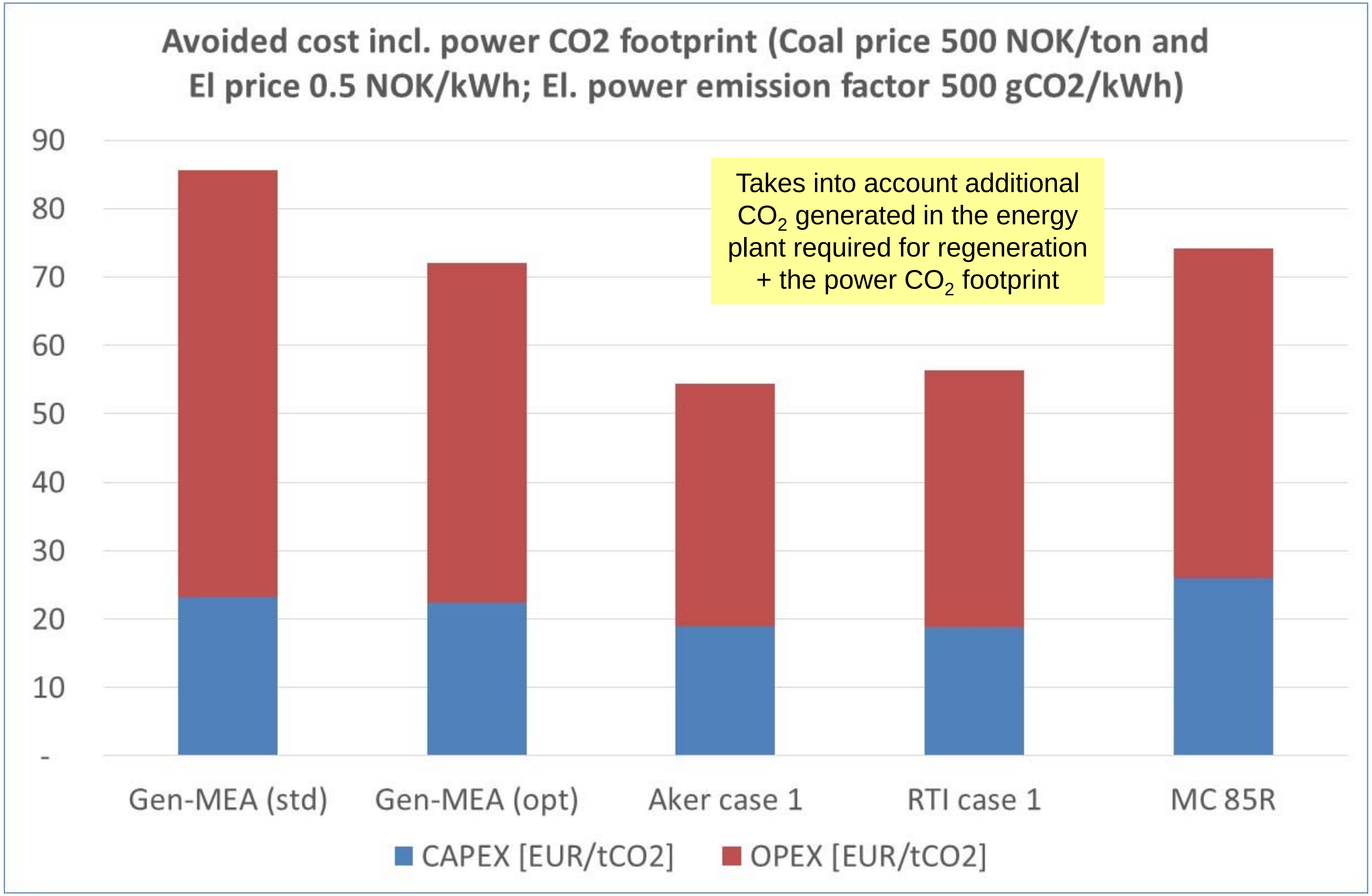


Telemark University College

Cost comparison: Avoided cost



Cost comparison: Avoided cost, including effect of power CO_2 footprint



Telemark University College

Main cost drivers

CAPEX

TP (Case 1)	Main CAPEX drivers
Generic MEA	• Absorber (14-15 %) • CO_2 compressors (13-14 %) • Reboiler (9-10 %)
Aker	• CO_2 compressors (13 %) • Reboiler (11 %) • Desorber (11 %)
RTI	• CO_2 compressors (16 %) • Adsorber (9 %) • Acid gas scrubber (9 %)
MC	• Membrane stage 2 (48 %) • Membrane stage 1 (13 %) • CO_2 compressors (10 %)

OPEX

TP (case 1)	Main OPEX drivers
Aker, RTI and Generic MEA	• Coal-fired energy plant (36-50 %) • CO_2 compression unit (22-32 %)
MC	• Membrane unit compressors (59 %) • CO_2 compression unit (20 %)

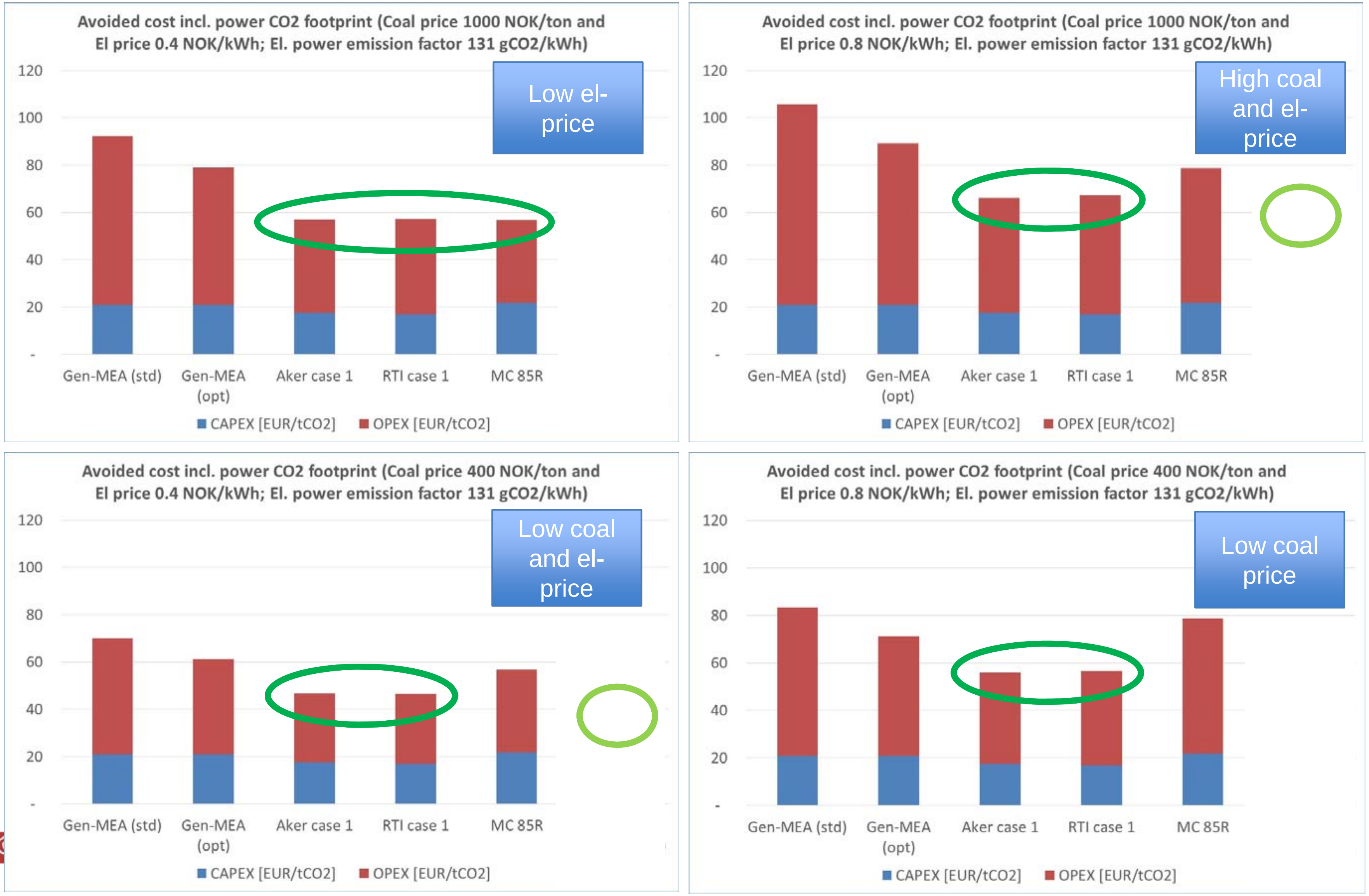
Telemark University College

Sensitivity analysis

Parameter	Low value	High value
El. power price NOK/kWh (€/kWh)	0.4 (0.05)	0.8 (0.10)
Coal price NOK/t (€/t)	400 (50)	1000 (125)

- Power footprint according to Norwegian product mix
- Extra MC case calculated:
  - Membrane permeance increased by a factor of 10 (technology development over the last few years)

Sensitivity analysis: Summary



Technology Readiness Level (TRL)

Table 4.1: Technology readiness level (TRL) as defined by the US DOE [7].

TRL	Description
1	Scientific research begins translation to applied R&D - Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2	Invention begins - Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Active R&D is initiated - Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Basic technological components are integrated - Basic technological components are integrated to establish that the pieces will work together.
5	Fidelity of breadboard technology improves significantly - The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6	Model/prototype is tested in relevant environment - Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
7	Prototype near or at planned operational system - Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.
8	Technology is proven to work - Actual technology completed and qualified through test and demonstration.
9	Actual application of technology is in its final form - Technology proven through successful operations.

MC: 5
RTI: 5

Pilot at Norcem?

Aker: 8

Telemark University College

TP	Key points
Aker	• Thermal energy required for regeneration ➔ Additional CO_2 • Quite low SRD (2.7 GJ/$t_{CO2capt}$) due to solvent characteristics and process integration with CO_2 compression unit • Full utilization of cement kiln waste heat (case 2/3) ➔ additional cost reduction • Mature technology (TRL = 8) • Successful MTU tests at Norcem • Next step full-scale capture in the cement industry?
RTI	• Thermal energy required for regeneration ➔ Additional CO_2 • Quite low SRD (2.4 GJ/$t_{CO2capt}$) due to sorbent characteristics • Utilization of cement kiln waste heat (case 2) ➔ additional cost reduction • Promising results from small-scale tests at Norcem • TRL improvement by next test phase at Norcem?
MC	• SRD = 0 ➔ No thermal energy required for regeneration • But high power consumption ➔ Power CO_2 footprint + suffers at high power prices • No circulating medium ➔ Reduced system complexity and more compact system • Higher membrane permeance ➔ Significant cost reduction potential • Quite promising results from small-scale tests at Norcem, demonstrating improved permeance • TRL improvement by new tests at Norcem?
Alstom	• Potential for energy efficient capture due to high temperature capture • Requires integration with kiln system

tel·tek

www.CO2-lab.com

Telemark University College