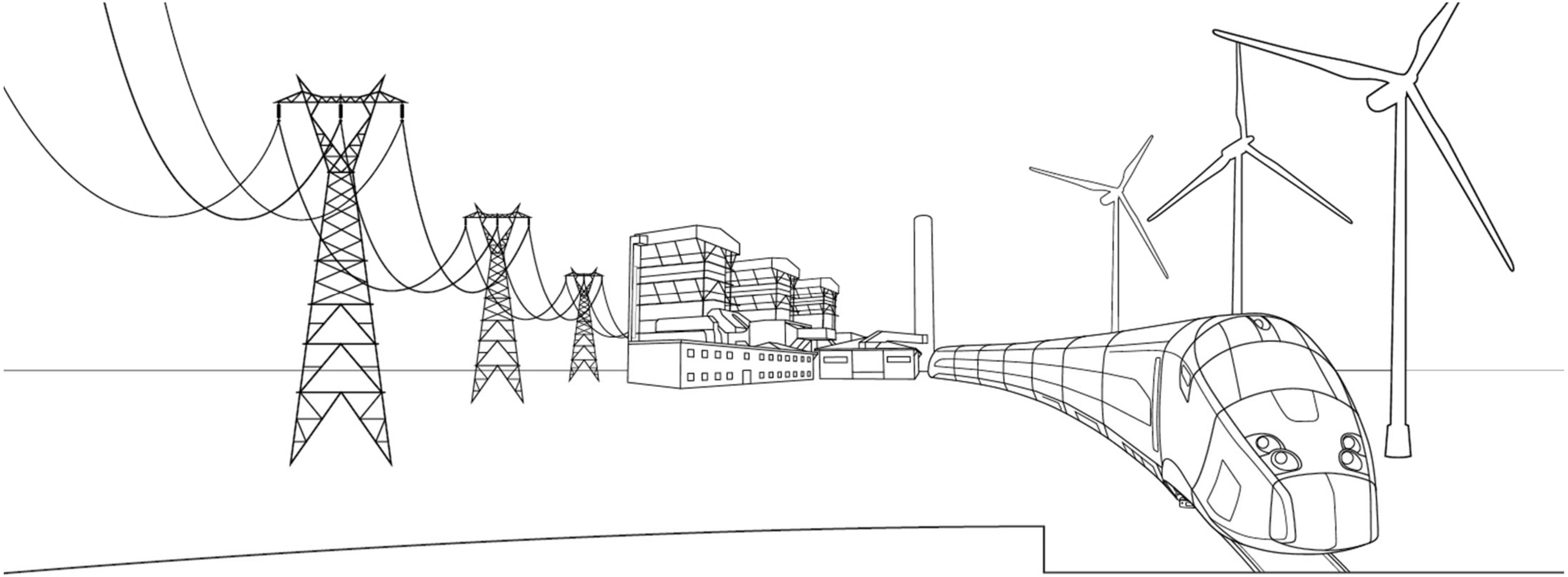

CCS Cost Workshop

Jean-François Léandri

IEA Paris

6-7/11/2013

CLEAN POWER
CLEAR SOLUTIONS™

ALSTOM
Shaping the future

Alstom : three main activities in four sectors

Equipment & services for power generation

Alstom Thermal Power

Equipment & services for power transmission

Alstom Grid

Alstom Renewable Power

Equipment & services for rail transport

Alstom Transport

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Portfolio of power technologies

GAS

COAL

OIL

HYDRO

NUCLEAR (conventional island)

WIND (offshore and

SOLAR

GEOTHERMAL

BIOMASS

TIDAL

...for new plants or installed base

Carbon Capture and Storage

TESTS COMPLETE

AEP Mountaineer
USA – 58 MWth
Chilled Ammonia, Coal

EoN Karlshamn
Sweden - 5 MWth
Chilled Ammonia, Fuel

WE - Energie
USA WI - 5 MWth
Chilled Ammonia, Coal

DOW Chemical Co.
USA, WV
Adv. Amines - Coal

OPERATING

Vattenfall Schwarze Pumpe,
Germany
30 MWth, Oxy - Lignite

TCM Mongstad Norway
40 MWth, Chilled Ammonia, CHP
& Refinery Offgas (RCC)

Total Lacq
France - 30 MWth
Oxy - Gas

Alstom GPU Pilot (Mobile)
0.3 MWth

Alstom BSF Windsor
US - 15 MWth
Oxy - Coals

Alstom Labs Växjö
Sweden – 0.25 MWth
Post C.-multi purpose

DOE/Alstom Windsor
US - 3 MWth
Chemical Looping, Coal

RFCS EU - Darmstadt
Germany - 1 MWth
Chemical Looping - Coal

OPERATING

EDF Le Havre
France - 5 MWth Adv.
Adv. Amines - Coal

LARGE-SCALE PROJECTS (under development)

White Rose CCS Project
UK - 426 MWe
Oxy Hardcoal

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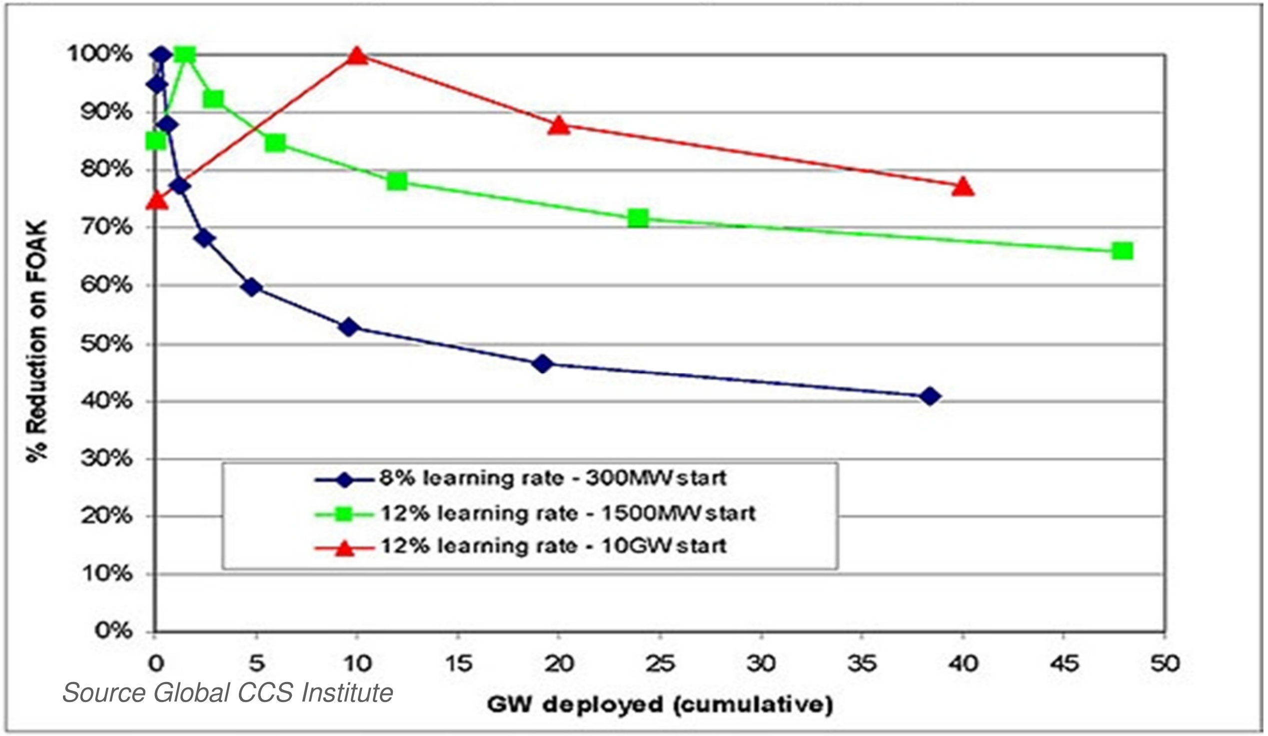
Learning curve or not learning curve ?

Limitation of the learning curves

- To what extend are the historical empirical data valid for CCS technologies?
- Where to start on the curve when zero commercial units sold?



Source Global CCS Institute

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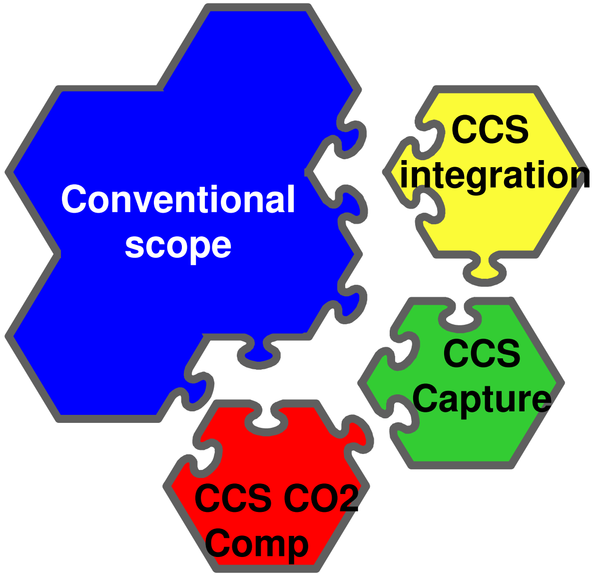
Alstom approach to estimate cost of CCS technologies

Many factors involved in cost reductions:

- technological advances, patchwork of technical fields
- rapid changes in policies & regulations
- economies of scale, process improvements,
- …..



Alstom approach:

- Learning disaggregated into:
  - ✓ conventional and CCS plants
  - ✓ then into performance and volume
  - ✓ then into CCS sub-systems
- Estimations based on technical analysis and expert judgment

Detailed performance and cost analysis of each CCS sub-items

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Conventional reference plant
Setting the stage for future evolutions

"Increasing intermittent Power "

- Will reduce thermal capacity factor
- Efficiency at part load, emissions

"Unaffordable Fuel bill , too low elec. prices"

- Increase efficiency
- Fuel characteristics (carbon %, FHV)

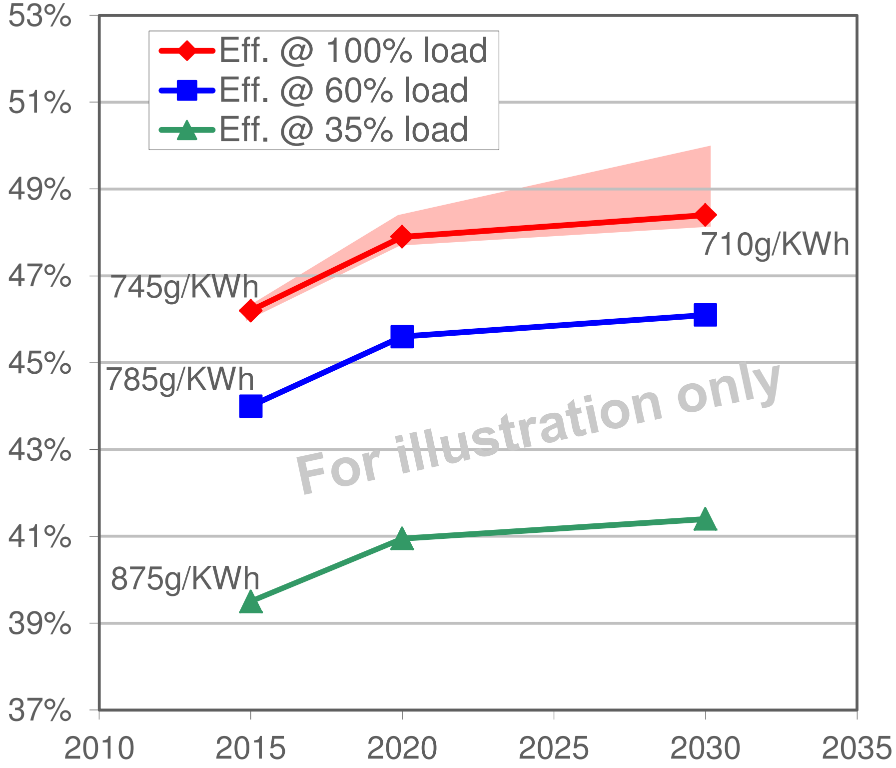
"increasing water scarcity & cost of water"

- Cooling temperature (ACC, hybrid CT)

"Budget squeeze & tougher access to capital"

- Scaling-up size
- Standardization & Modularization

Improvement net efficiency LHV vs load
(conventional hardcoal plant – Europe)



Fossil plant operation and performance could change several times over its lifetime

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Conventional reference plant
Capex estimation

- Cost of efficiency and flexibility performance improvements
- Volume effect (could also be negative: e.g. less coal PP w/o CCS sold)
- Cost reduction through shorter lead time (design & manufacturing) and size increase (exponential scaling factor)

Flexibility will have a cost

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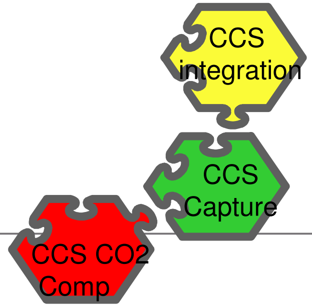
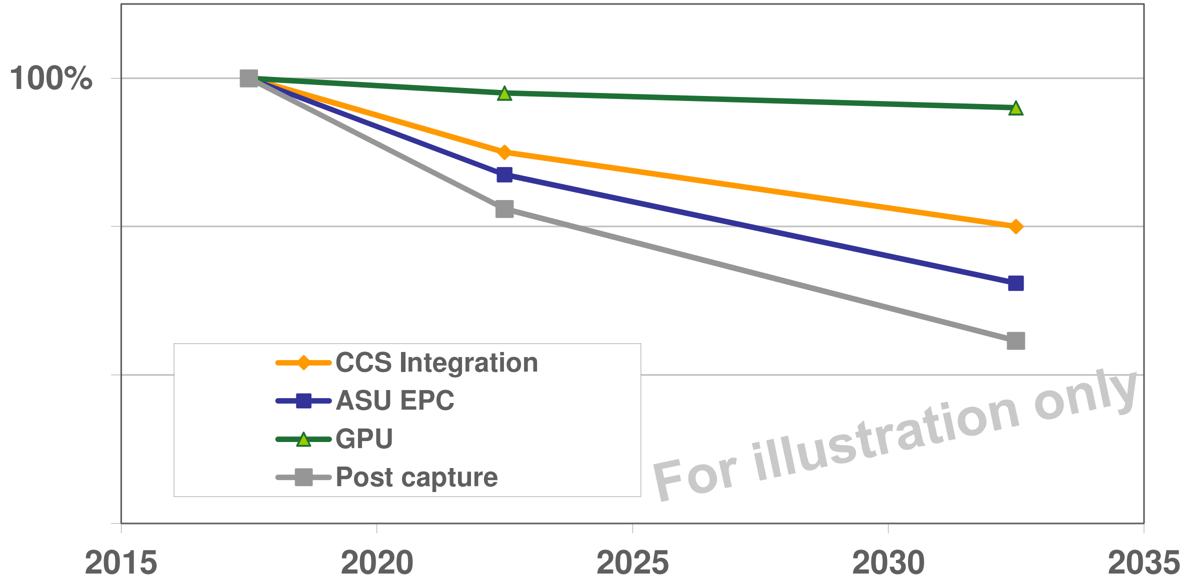
Capture system
Performance improvements - Auxiliary consumption



Analysis for each sub-systems

(Hardcoal illustration)



- **Starting Point**: system performance as at starting year
- **Rates**: potential level of improvement from system experts: ex: analysis of post capture GJ/tO2 achievable and requirements (roadmap, IB, risks…)
- Rates applied in addition to efficiency improvement of the reference plant
- Rates could be customised by region/coal type

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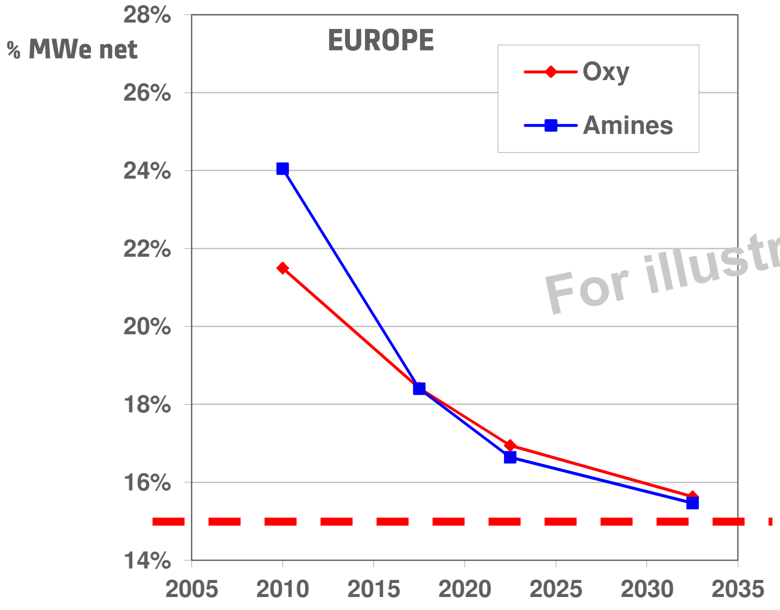
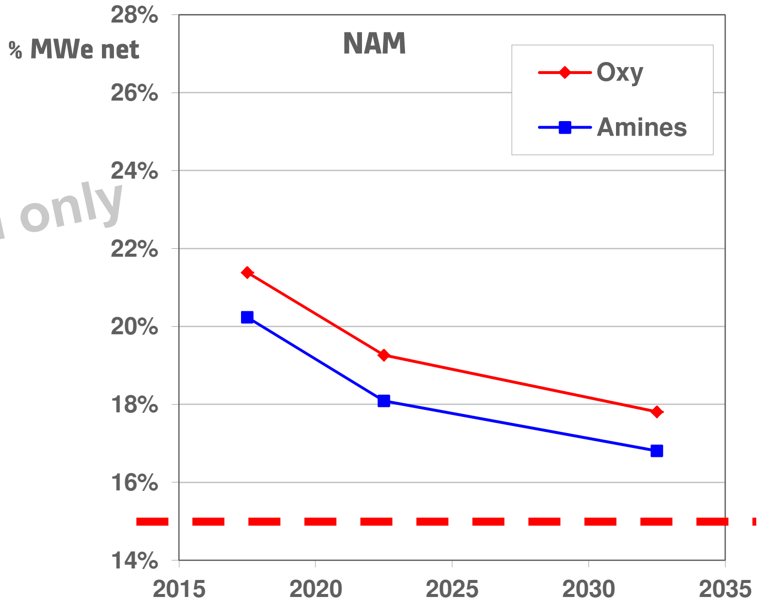
Capture system
Consolidated energy penalty (Hardcoal PP)





- Amine: high starting point (3,5 GJ/tCO2)

- Impact of higher cooling temperature
- Coal characteristics not as good as EUR

Note: Energy penalty = (Net Output Ref PP – Net Output CCS PP)/ Net Output Ref PP

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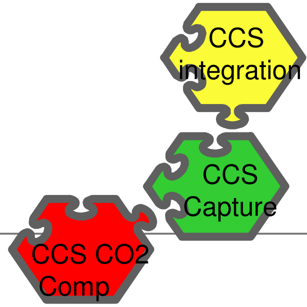
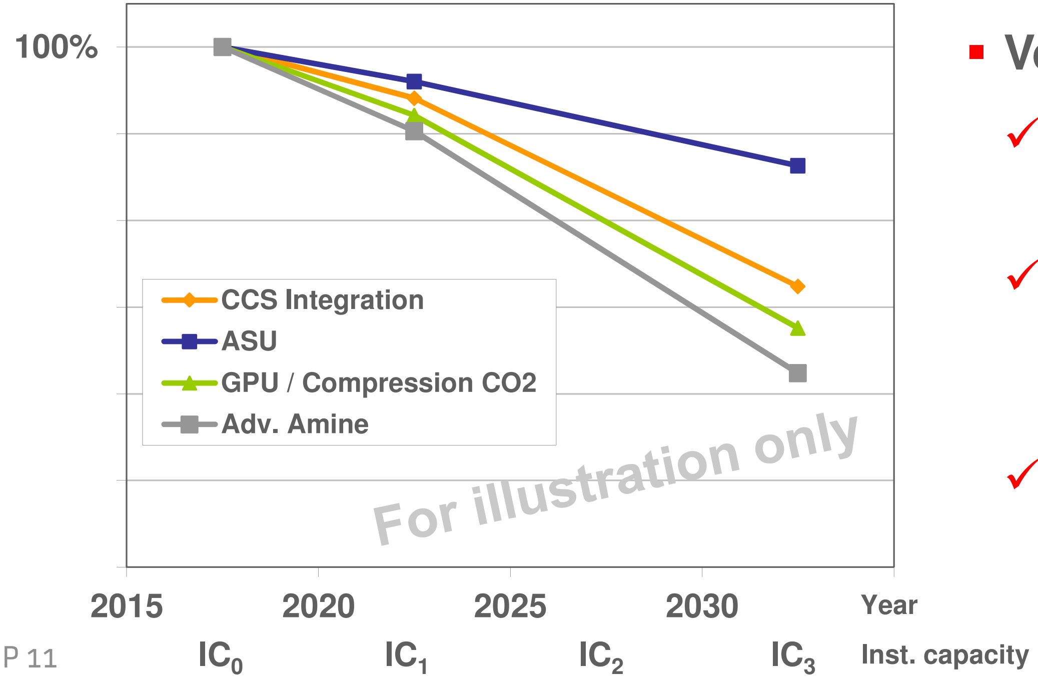
Capture system
Capex improvement



- **CCS plant drivers**
  - ✓ Volume effect applies differently on conventional scope and on capture scope
  - ✓ Starting point for the Capture scope: large scale demo or FoaK commercial
  - ✓ Optimum economical size for capture train and number of trains
  - ✓ Risk provisions on first of a kind technology



- **Volume effect**
  - ✓ Rate derived from installed base volume forecast (linked to years)
  - ✓ Specific rates considered by capture sub-system (integration, ASU, GPU / Compr. CO2, post capture)
  - ✓ Same rates applied for all regions

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Capture system
O&M cost improvement

- **First method:** disaggregate and estimate of the different cost reductions
  - ✓ Variable O&M:
    - lower solvent cost due to cheaper solvents
    - less solvent consumed with better reclamation and reduced waste cost
  - ✓ Fixed O&M:
    - less manual chemical lab services, less dedicated process operators
    - more automated analysis & process

- **Second method (selected):** apply a full and aggregated O&M learning curve
  - ✓ to all the incremental fix/variable O&M CCS cost (excl. conventional plant)

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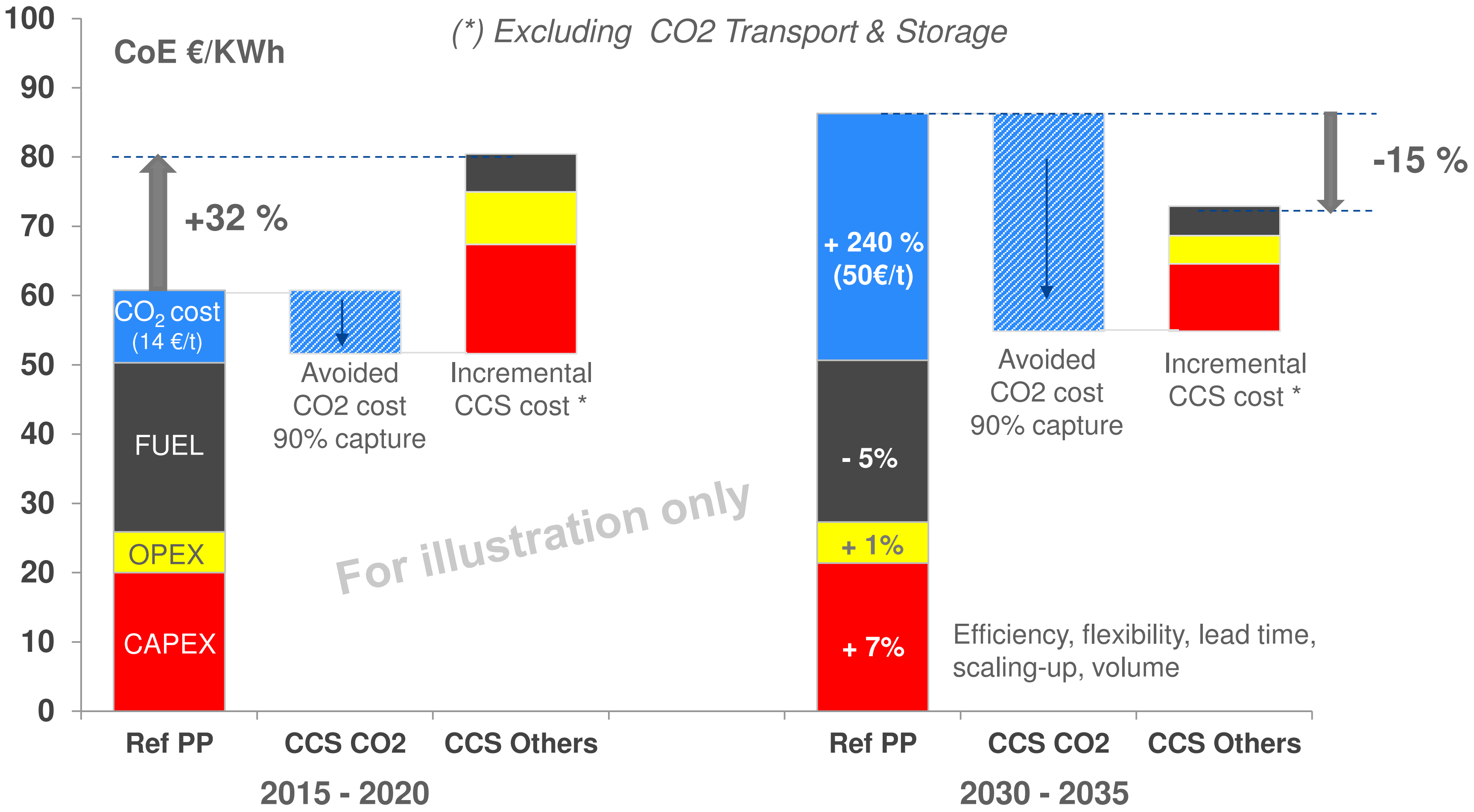
CCS Plant
LCoE – illustration hardcoal plant Europe



Cost of CCS plant as a result of a full consolidation

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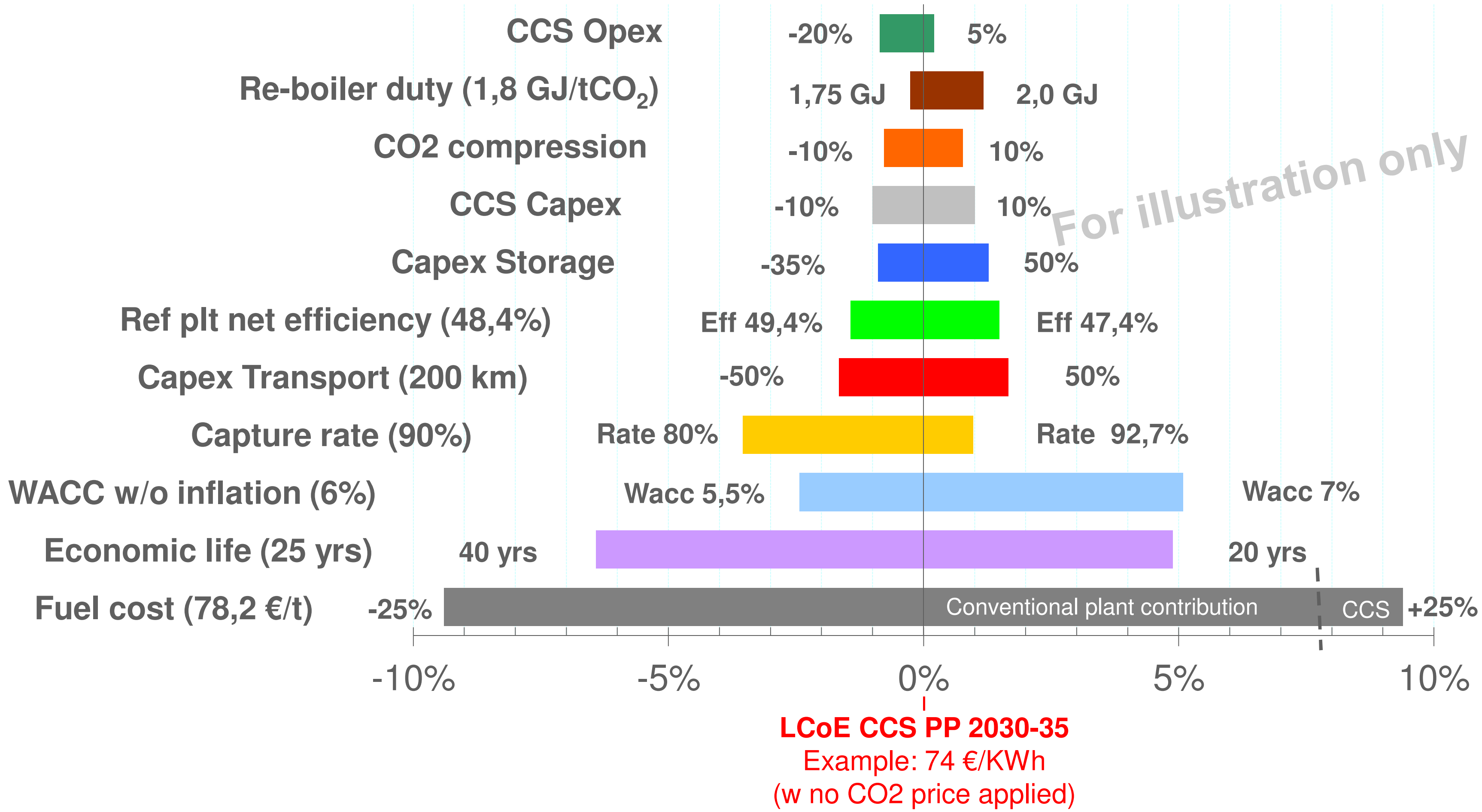
CCS Plant
Sensitivity LCoE – illustration hardcoal plant Europe (1/2)



Performance and cost of CCS Sub-systems to be put in perspective with other dimensions ….

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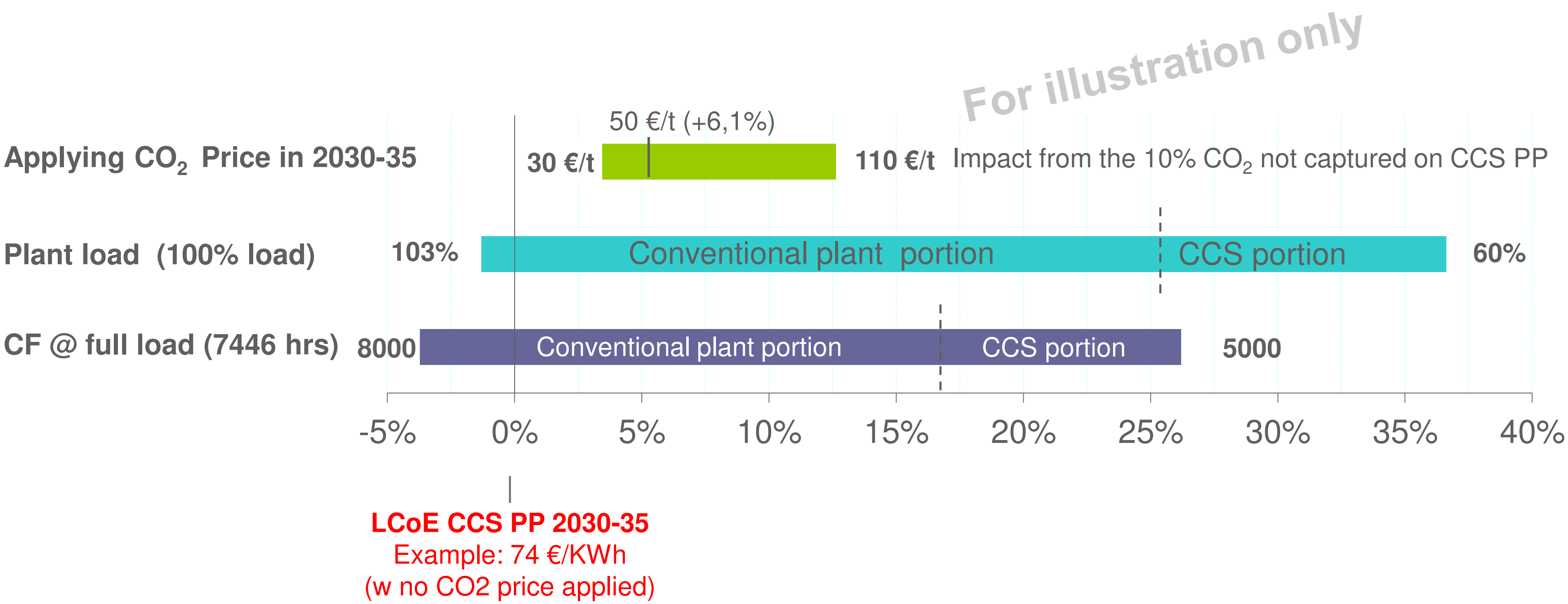
CCS Plant
Sensitivity LCoE – illustration hardcoal plant Europe (2/2)



….in particular with CO2 market price and trend for flexibility.

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Conclusions

- Capex: Detailed performance and cost analysis of each CCS sub-items
- Opex: O&M learning curve applied
- Benchmark with Learning curve method
- CCS systems evaluated as part of a global gas or coal plant
  - ✓ Key trends in generation anticipated (intermittency, environnement…)
  - ✓ Optimisation of the global performance and cost of the plant
- **CCS plant flexibility and its related cost will be key**

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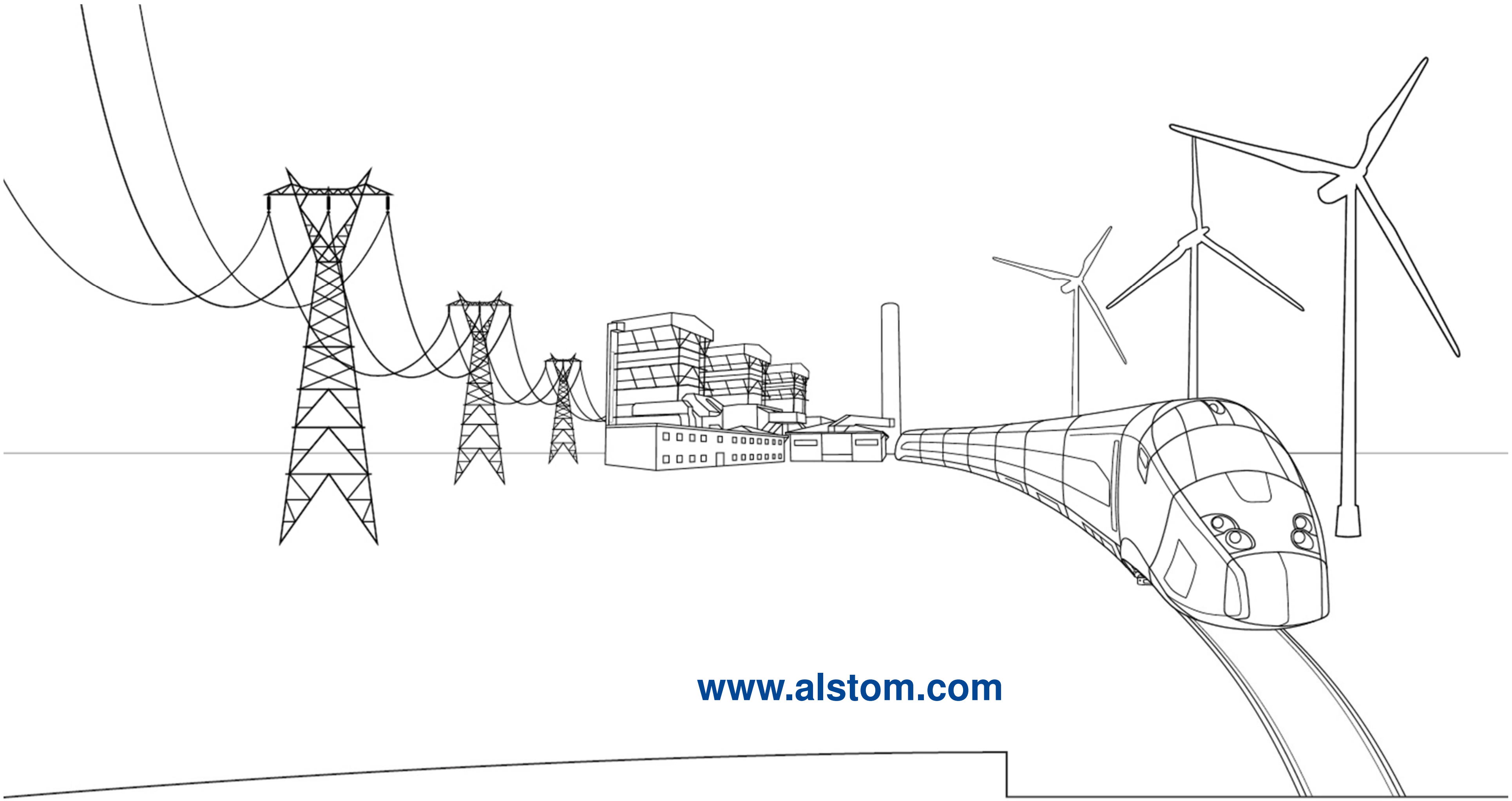

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