CCS Cost Workshop

Jean-François Léandri

IEA Paris

6-7/11/2013
Alstom: three main activities in four sectors

- Equipment & services for power generation
  Alstom Thermal Power

- Equipment & services for power transmission
  Alstom Grid

- Equipment & services for rail transport
  Alstom Transport

- Alstom Renewable Power
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
- **Total Lacq**
  France - 30 MWth
  Oxy - Gas
- **Alstom BSF Windsor**
  US - 15 MWth
  Oxy - Coals
- **DOE/Alstom Windsor**
  US - 3 MWth
  Chemical Looping, Coal

**OPERATING**
- **TCM Mongstad**
  Norway
  40 MWth, Chilled Ammonia, CHP & Refinery Offgas (RCC)
- **Alstom GPU Pilot (Mobile)**
  0.3 MWth
- **Alstom Labs Växjö**
  Sweden – 0.25 MWth
  Post-C - multi purpose
- **RFCS EU - Darmstadt**
  Germany - 1 MWth
  Chemical Looping - Coal

**LARGE-SCALE PROJECTS**
(under development)
- **EDF Le Havre**
  France - 5 MWth Adv.
  Adv. Amines - Coal
- **White Rose CCS Project**
  UK - 426 MWe
  Oxy Hardcoal
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
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
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

Fossil plant operation and performance could change several times over its lifetime
- 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)
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
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
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
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)
CCS Plant
LCoE – illustration hardcoal plant Europe

Cost of CCS plant as a result of a full consolidation

(*) Excluding CO2 Transport & Storage

-15 %

Avoided CO2 cost
90% capture

Incremental
CCS cost *

CAPEX

OPEX

FUEL

CO2 cost
(14 €/t)

Avoided CO2 cost
90% capture

Incremental
CCS cost *

2015 - 2020

2030 - 2035

- 5%

+ 7%

+ 1%

+ 240 %
(50€/t)

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

### CCS Opex
- Re-boiler duty (1,8 GJ/tCO₂)
- CO₂ compression
- CCS Capex
- Capex Storage

### CCS Capex
- Ref plt net efficiency (48,4%)
- Capex Transport (200 km)
- Capture rate (90%)

### WACC w/o inflation (6%)
- Economic life (25 yrs)
- Fuel cost (78,2 €/t)

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

#### Example: CCS PP 2030-35
(w no CO₂ price applied)

Example: 74 €/KWh
Applying CO\textsubscript{2} Price in 2030-35

Plant load (100% load)  

Conventional plant portion

CCS portion

CF @ full load (7446 hrs)  

Conventional plant portion

CCS portion

LCoE CCS PP 2030-35  
Example: 74 €/KWh  
(w no CO2 price applied)

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