Benchmarking in other twinning projects: lesson learned

Matteo C. Romano
Politecnico di Milano, Department of Energy
Group of Energy Conversion Systems (GECoS)

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SUMMARY

- Why am I presenting about benchmarking?
- Main experiences in benchmarking:
  - EBTF experience
  - Cemcap experience
- Lesson learned
- Conclusions

Why am I presenting about benchmarking?

- Part of the Group of Energy Conversion Systems (GECoS) of Politecnico di Milano, which contributed to two benchmarking works:
  - European Benchmarking Task Force (EBTF), 2008-2011.
  - Cemcap Framework, 2016-2018 (ongoing).

- I was mildly involved in EBTF, but I used it in several EU projects

- I am actively committed to Cemcap techno-economic Framework

EBTF - MOTIVATIONS

1. Consistent and transparent comparison of CO_2 capture technologies is **important**
   - Discrepancies in assumptions and parameters may lead to significant differences in performances and costs, often higher than the real differences between the technologies
   - The qualities of a new technology can be enhanced by the bad qualities of the reference adopted for comparison
   - Inconsistent comparisons and evaluations can have important commercial implications and, if persistent, can lead to the adoption of inferior solutions with losses for companies, governments and society
2. Consistent and transparent comparison of CO_2 capture technologies is **difficult**
   - Widely recognized, well documented, consistent and accepted references are not available

EBTF - OBJECTIVES

A team was created with representatives from three FP7 projects – CAESAR, CESAR and DECARBit – with the following objectives:

– Collect the experience gained in previous projects on the definition of standard references and procedures – ENCAP, DYNAMIS, CASTOR, CACHET

– Elaborate a Common Framework Definition Document (CFDD), containing a set of assumptions and parameters to be adopted in techno-economic evaluations

– Define and analyse a set of test cases, as typical examples of application of the definitions given in the CFDD

The results of the work are public and easily accessible, e.g.:
www.gecos.polimi.it/research/EBTF_best_practice_guide.pdf
caesar.ecn.nl/fileadmin/caesar/user/documents/D_4.9_best_practice_guide.pdf

EBTF – THE TEAM

The team:

Participants	Institution	Project
R. Anantharaman, O. Bolland	NTNU	DECARBit
E. van Dorst, D. Nikolic, M. Prins	Shell	DECARBit
A. Pfeffer, F. Franco	Alstom UK	DECARBit
S. Rezvani	U. Of Ulster	DECARBit
G. Manzolini, E. Macchi	Politecnico di Milano	CAESAR
N. Booth, L. Robinson	E.ON	CESAR
C. Ekstrom	Vattenfall	CESAR
E. Sanchez Fernandes	TNO	CESAR

– Contributions also from Siemens and Doosan Babcock

EBTF – THE COMMON FRAMEWORK

The common framework:

- The purpose is **NOT** to recommend any values as the best or the right ones for future power plants
- The purpose **IS** to define a set of parameters to ensure that technical and economic comparison of novel cycles involving novel technologies is done in a consistent and fair way
- The choice of parameters is justified and the source acknowledged, for example IEA, DOE, EU, specialized publications, other projects, expert opinion and others are identified

EBTF – THE COMMON FRAMEWORK

- Ambient conditions
- Unit systems
- Fuel characteristics

Operating & cost parameters of components based on novel technologies

New air separation technologies

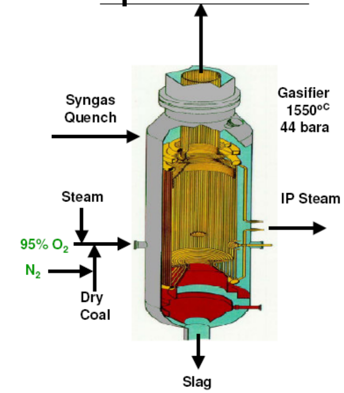
New CO_2 separation technologies

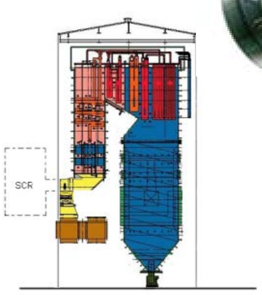
Cycle 1

Cycle 2

Cycle n

Operating & cost parameters of standard components





Consistent comparison of new technologies and cycles

EBTF – THE COMMON FRAMEWORK

- Common Framework Definition Document
  - General definitions and conditions
  - Fuel
  - Air separation
  - Coal gasification
  - Shift reactor
  - Gas turbine
  - Steam cycle
  - Heat exchangers
  - Efficiency calculations
  - CO_2 stream
  - Emission limits
  - Economic assessment criteria

EBTF – THE COMMON FRAMEWORK

Examples of topics and sources

- General definitions and conditions – ISO values, SI units
- Fuels: Bituminous Douglas Premium, lignite and natural gas – from ENCAP, DYNAMIS AND CAESAR
- Coal gasification - Shell technology
  - Base case and alternative case
  - Conditions and composition of syngas
  - Conditions of O_2 for process and N_2 or CO_2 as carrier gases
- Shift reactor
  - Base case and alternative case – defined in DECARBit to fit gasification
  - Conditions and compositions of gases at outlet
- Gas turbine
  - inlet and outlet conditions and performance – Politecnico di Milano
- Heat exchangers – adapted from ENCAP
  - Pressure drop

EBTF – THE COMMON FRAMEWORK

Examples of topics and sources

- Steam cycles – adapted from ENCAP and DYNAMIS
  - Fired boilers and HRSG
  - Steam turbines
  - Condenser
- Efficiency calculations – adapted from several sources
  - Mechanical efficiency
  - Generator efficiency
- CO_2 quality requirements – adapted from ENCAP and DYNAMIS
- Emission limits from solid fuels – adapted by E.ON from EU directives
- Economic assessment criteria – based on data of 2008 (also CASTOR data)
  - Basic assumptions – costs of fuel, plant lifetime, capacity factors, cost indices, interest rates, variations for sensitivity analysis and others
  - Costs of operation and maintenance
  - Costs of engineering and procurement

EBTF – THE TEST CASES

Three cases without and with CO_2 capture

- Integrated Gasification Combined Cycle
- Natural Gas Combined Cycle
- Ultra Super Critical Pulverized Coal

The purpose is **NOT** to compare power generation technologies, for example PF with IGCC

The purpose **IS** to propose references for comparisons within the same power generation technology – PF, IGCC, NGCC

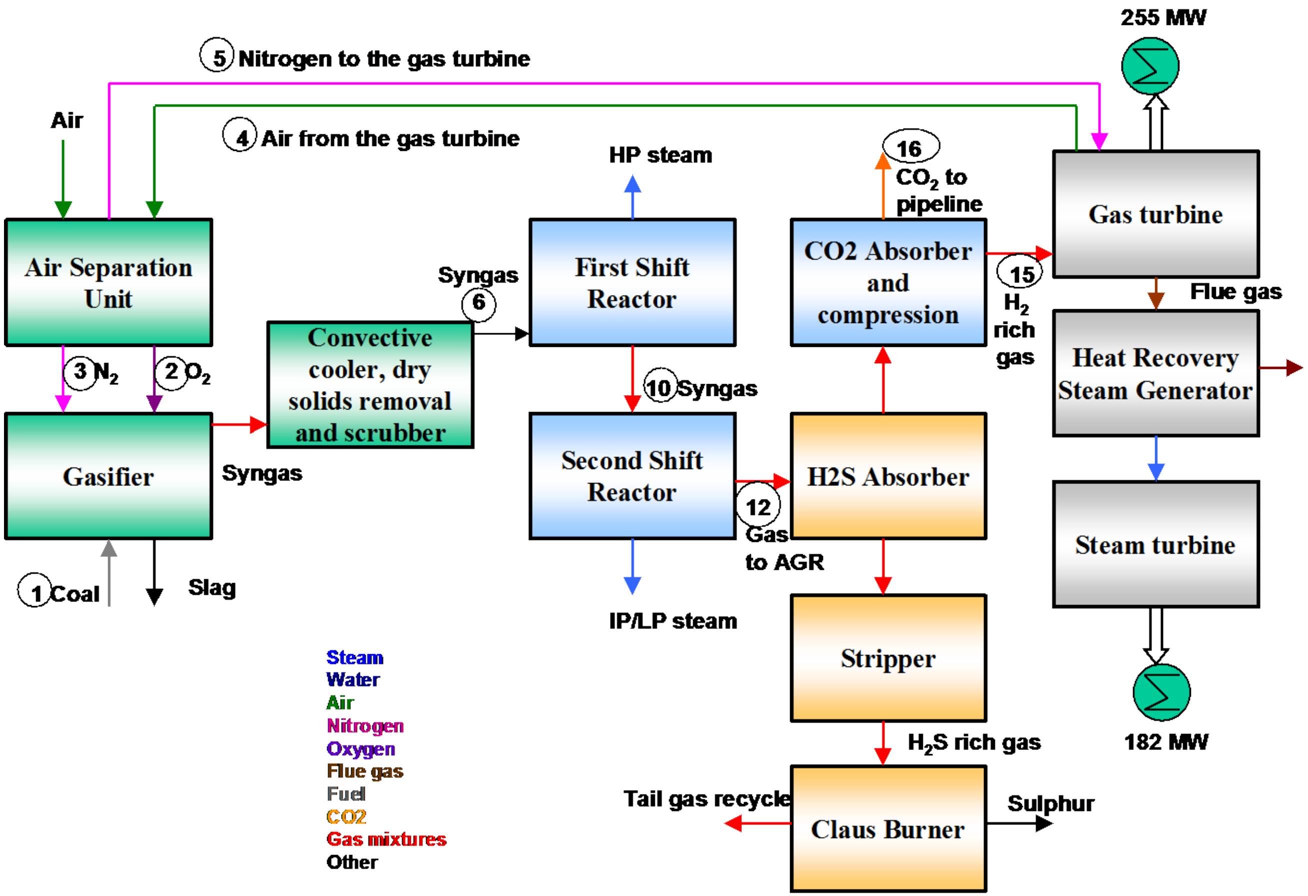
Contents of the report, for each case

- Cycle description
- Heat and mass balance
- Operational characteristics
- Operational performance
- Comparison of results independently produced by two of the three projects

EBTF – TEST CASE EXAMPLE: IGCC WITH CAPTURE

Integrated Gasification Combined Cycle with capture

DECARBit
and
CAESAR



EBTF – TEST CASE EXAMPLE: IGCC WITH CAPTURE

Comparison of H&M balance and performance

	DECARBit MWe	CAESAR MWe
GT output	282.87	304.97
ST output	168.46	175.95
Gross elec. power output	457.17	491.09
Total aux. power consumption	104.43	107.61
Net electric power out.	352.74	383.48
Efficiency	36.66	36.40
Specific emissions, kg/MWh	85.28	97.54
SPECCA, MJ_{LHV}/kg_{CO2}	3.30	3.67

Specific primary energy consumption for CO_2 avoided:

$$SPECCA = \frac{HR - HR_{REF}}{E_{CO2,REF} - E_{CO2}} = \frac{3600 \cdot \left(\frac{1}{\eta} - \frac{1}{\eta_{REF}} \right)}{E_{CO2,REF} - E_{CO2}}$$

EBTF – ECONOMIC FRAMEWORK

- Breakeven electricity selling price (BESP) and CO_2 avoidance cost are the main economic performance characteristics;
- BESP is composed of capital investement costs, fixed O&M costs (e.g. Labour), variable O&M costs (consumables) and fuel costs;
- A sensitivity analysis on main assumptions (e.g. specific investment costs, fuels, etc.) is suggested;
- Capital investement cost calculated with bottom-up and top-down approaches;

EBTF – BOTTOM UP APPROACH

Module costs/Equipment costs		
XXXXXXX		A
yyyyyyyyyy		B
TOTAL EQUIPMENT COST [TEC]		A+B+......
Installation costs as percentage of the total equipment costs (TEC)		
Total installation costs [TIC]	**ZZ%**	ZZ% TEC
TOTAL DIRECT PLANT COSTS [TDPC]		TEC + TIC
INDIRECT COSTS (yard improvment, service faciilities,...) [IC]	14%	14% TDPC
ENGINEERING AND PROCUREMENT COSTS [EPC]		**TDPC + IC**
Contingencies and owner’s costs (C&OC)		
Contingencies	10%	10% EPC
Owner’s costs	5%	5% EPC
TOTAL CONTINGENCIES & OC [C&OC]	**15%**	**15% EPC**
TOTAL PLANT COSTS		**EPC + C&OC**

EBTF – TOP-DOWN APPROACH: IGCC

Table 8.3.1 - Indicative cost breakdown of the IGCC test case with CO_2 capture – figures in kEuros

	Equipment cost	Installation cost	Overall cost
Coal handling	23951	29939	53891
Gasifier	108000	72000	180000
Gas turbine	50996	42327	93323
Steam turbine	32000	20000	52000
Heat recovery steam generator	15500	18600	34100
Low temperature heat recovery	5250	5671	10921
Cooling	15000	24000	39000
Air separation unit	45500	27300	72800
Ash handling	7838	9580	17418
Acid gas removal	12023	20729	8706
Gas cleaning	4324	2594	6918
Water treatment	13152	21044	7891
Water gas shift reactor	13200	7920	21120
Claus burner	8000	4800	12800
Selexol plant	28125	16876	45001
CO_2 compression unit	18750	11252	30002

EBTF – TOP-DOWN APPROACH

Module costs/Equipment costs		
XXXXXXX		A
yyyyyyyyy		B
TOTAL EQUIPMENT COST [TEC]		A+B+......
Installation costs as percentage of the total equipment costs (TEC)		
Total installation costs [TIC]	ZZ%	ZZ% TEC
T		
IN		PC

Adopting Top-Down approach, the table becomes:

ENGINEERING AND PROCUREMENT COSTS [EPC]		**TDPC + IC**
Contingencies and owner's costs (C&OC)		
Contingencies	10%	10% EPC
Owner's costs	5%	5% EPC
TOTAL CONTINGENCIES & OC [C&OC]	**15%**	**15% EPC**
TOTAL PLANT COSTS		**EPC + C&OC**

EBTF – Top-down approach: USC plant

Table 7.5 – Overall costs for ASC without and with capture for top down and bottom up approaches – 800 MW					
		CESAR		DECARBIT/CAESAR	
Parameter	Unit	Without capture	With capture	Without capture	With capture
Gross electricity output	MW	819	684.6	819	684.6
Net electricity output	MW	754.3	549.6	754.3	549.6
Efficiency	%	45.5	33.4	45.5	33.4
CO_2 emitted	kg/MWh	763	104.7	763	104.7
CO_2 produced	Mton/yr	-	3.90	-	3.90
Power plant EPC	M€	1266	1266	1013	1013
Capture plant EPC	M€		173	0	226
Total plant cost (EPC+OC+Cont.)	M€	1456	1655	1165	1439
Specific investment (gross)	€/kW gross	1777	2417	1423	2102
Specific investment (net)	€/kWe net	1930	3011	1545	2618
Fuel	M€/yr	133	133	133	133
Fixed operating and maintenance costs	M€/yr	27	45	27	31
Variable operating costs	M€/yr	9	20	9	26
Operating costs	M€/yr	169	198	166	185
Cost of CO2 avoided	€/tonne	N/A	51.62	N/A	50.07

My personal experience as EBTF user

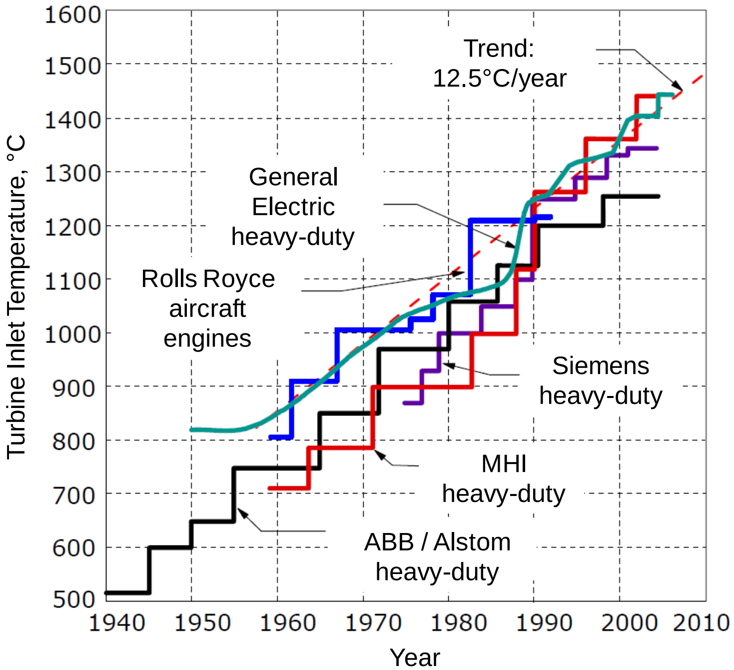
Lesson learned:

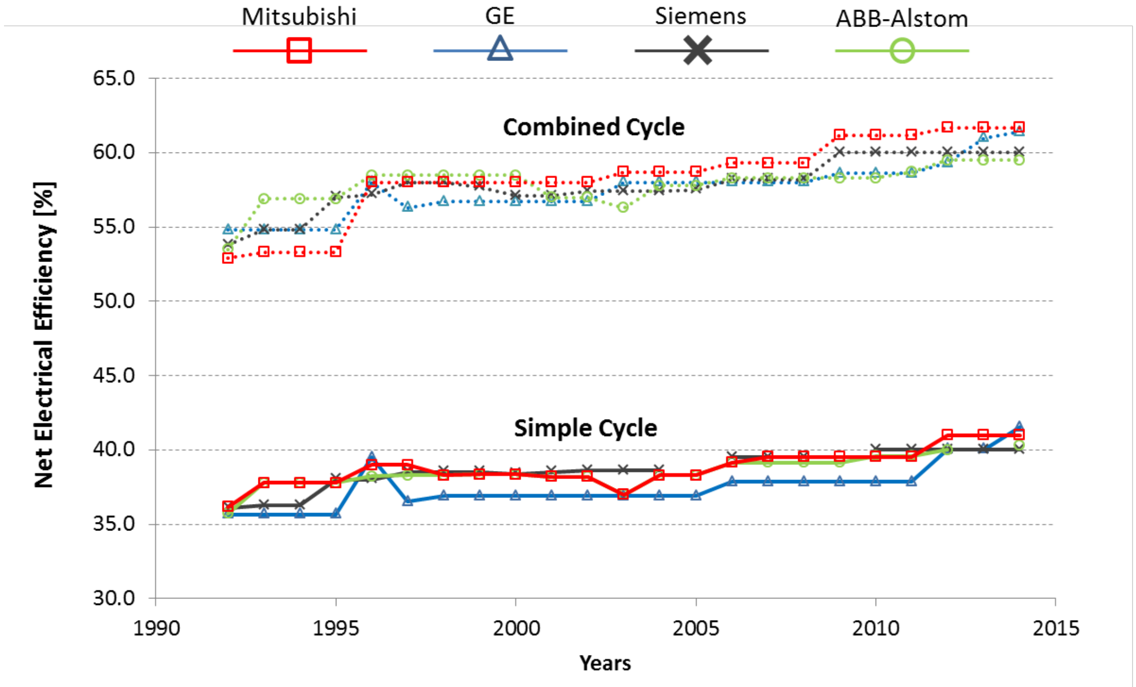
- Excellent initiative, very good outcomes as 1st of kind benchmarking exercise.
- Report maintenance would be needed to:
  - Correct small inevitable mistakes
  - Update performance of evolving components such as gas turbines
  - Change outdated flowsheets, e.g. integrated ASU
  - Add new plants (NG pants with pre-combustion capture).
- Collaborative report maintenance involving different partners is time consuming and unlikely to occur without dedicated funds.
- The lack of capital cost functions for plant components makes the economic benchmarking weaker.

MY PERSONAL EXPERIENCE AS EBTF USER

About the importance of updating GT performance:

- The novel CO_2 capture technology to be assessed may introduce constrains on the TIT and the GT efficiency with respect to the benchmark without capture, e.g. H_2 turbines, CLC.
- What is the time horizon for the commercial exploitation of the technology?





CEMCAP FRAMEWORK - OBJECTIVES

The common framework:

- To provide a framework for comparative techno-economic analysis in the CEMCAP project, where four CO_2 capture technologies (oxyfuel, chilled ammonia, membrane assisted liquefaction, and calcium looping) are to be evaluated for application in cement plants.
- It defines a reference cement kiln with description of the main unit, and characteristics of raw material and flue gas.
- Specifications are set for process units (e.g. heat exchangers, compressors etc.), for the generation of utilities (e.g. steam, electric power etc.) and for CO_2 capture efficiency and purity.
- Techno-economic KPI are defined and parameters relevant for sensitivity studies are suggested.

Available for download on:

https://www.sintef.no/projectweb/cemcap/results/

D3.2 CEMCAP framework for comparative techno-economic analysis of CO_2 capture from cement plants

CEMCAP FRAMEWORK - METHODOLOGY

Examples of framework specifications: steam and heat recovery steam cycle.

Cost and climate impact for steam

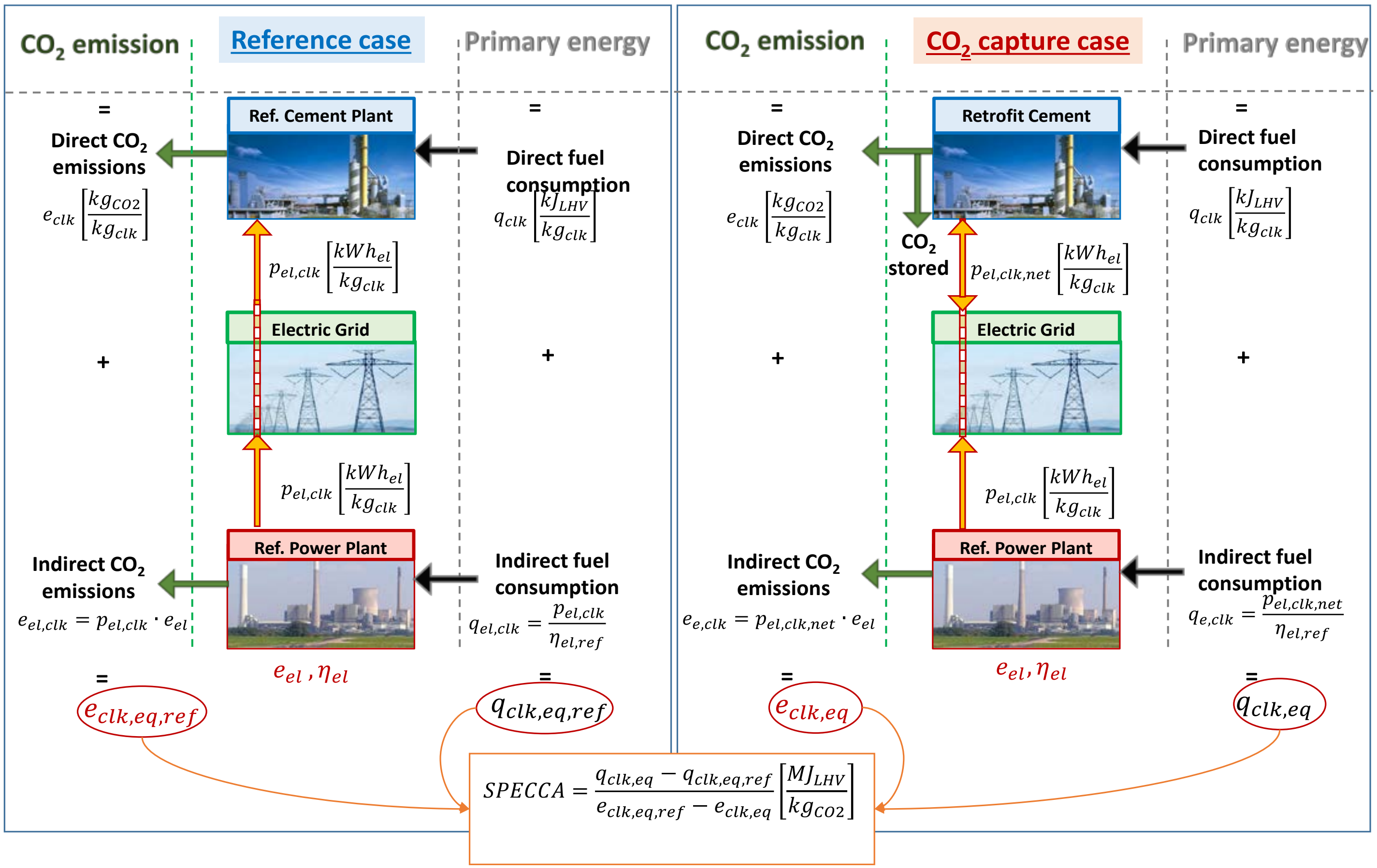
Steam source	Steam cost [€/MWh_{th}]	Steam climate impact [kg_{CO2}/MWh_{th}]
Waste heat available on the plant	8.5	0
External CHP steam plant at 100°C	7.7	101
External CHP steam plant at 120°C	10.3	136
External CHP steam plant at 140°C	13.0	170
Natural gas boiler	25.3	224

Steam cycle parameters as function of thermal input

Nominal thermal input, MW	12.5	25	50	100	200	300
Steam pressure at turbine inlet, bar	30	40	60	80	100	125
Steam temperature at turbine inlet, °C	350	400	460	480	530	565
LP regenerative condensate preheater	No	No	Yes	Yes	Yes	Yes
Feedwater temperature at boiler inlet, °C	120	120	140	140	140	140
Estimated turbine isentropic efficiency, %	70.0	75.0	78.0	80.8	85.6	86.8

CEMCAP FRAMEWORK - METHODOLOGY

Examples of energy and emissions KPIs.



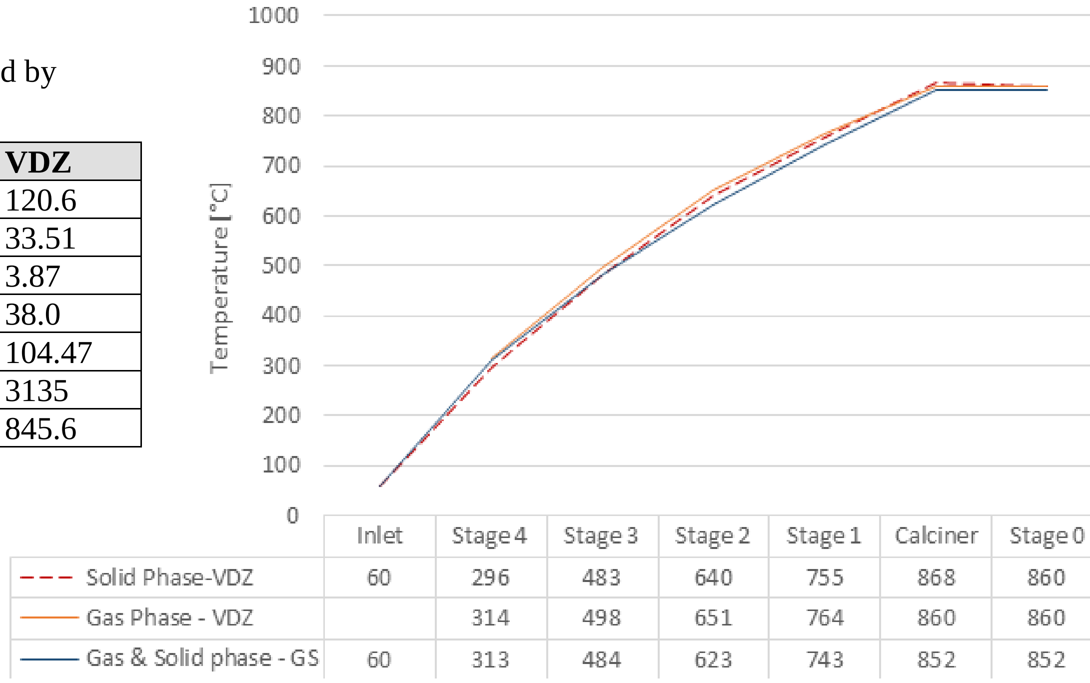
CEMCAP FRAMEWORK - VALIDATION

Validation of benchmark cement plant model on the existing VDZ model.

Overall performances of the cement plant simulated by Polimi and VDZ models.

Cement plant global balance	Polimi	VDZ
Clinker, ton/h	117.6	120.6
Clinker, kg/s	32.68	33.51
Total fuel input, kg/s	3.87	3.87
Fuel to kiln, % of total fuel input	38.0	38.0
Total heat input, MW_{LHV}	104.47	104.47
Specific Heat Input, kJ/kg_{clk}	3197	3135
Specific CO_2 emissions, g_{CO2}/kg_{clk}	863.1	845.6

Temperature profiles along the suspension preheater



Available for download on:

https://www.sintef.no/projectweb/cemcap/results/

D4.1: Design and performance of CEMCAP cement plant without CO_2 capture

CEMCAP FRAMEWORK – METHODOLOGY FOR ECONOMIC ANALYSIS

Preparation of a document for the economic is underway:

- Bottom-up approach adopted for most of the technologies (exception of Chilled ammonia, due to confidentiality.
- Capex cost functions based on scaling factors and/or preliminary design provided.

The report will be available in 2018 for download on:

https://www.sintef.no/projectweb/cemcap/results/

D4.4: Cost of critical components in CO_2 capture processes

MY PERSONAL OPINION ON CEMCAP FRAMEWORK

- Easier job than in EBTF from some points of view:
  - Easier reference plant: consolidated state-of the art technology (differently from IGCC)
  - Minor maintenance is expected to be needed:
    - No need of updating reference plant performance for short-medium term technology evolution
    - No need to update flowsheet (consolidated technology)
- Great committment and high quality contributions by involved companies
- In the end, an excellent piece of work as a 2nd of a kind benchmarking exercise

CONCLUSIONS

A future ideal benchmarking work:

- Should involve collaborative partners from academia/research centers and industry (both technology providers and end users)
- Shoud be funded because it is very time consuming
- Should be subject to continuous update:
    - to follow technology development
    - to follow market evolution: e.g. include part-load calculation methodology for power plants
- Should include sufficiently detailed methodology for economic analysis, with bottom up approach and cost functions for Capex estimation
- Should lead to transparent and shared results of process simulations and economic analyses:
    - detailed stream tables and energy balance (minimum requirement)
    - source files shared as open data (maximum impact)

Thank you

POLITECNICO
MILANO 1863

www.polimi.it

Gecos
Group of Energy
COnversion Systems

www.gecos.polimi.it

Contact: matteo.romano@polimi.it