CFB boiler optimized for CO_2 capture-ready for demonstration

Reijo Kuivalainen, Amec Foster Wheeler Energia Oy

CCSP Final results seminar,

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Outline

1. Introduction
2. R&D activities in CCSP
3. Utilization of results
4. Achieved technology readiness
5. Factors hindering the deployment
6. CCS status in Europe
7. What is needed to enhance the CCS deployment?
8. Conclusions

Introduction

Overview of major activities on oxy-CFB development by AmecFW

First generation oxyfuel CFB (Flexi-Burn® CFB)

- R&D support –Testing at VTT´s 100 kWth Oxy-CFB pilot plant
- R&D support –Testing at Canmet Energy´s 0.8 MWth Oxy-CFB pilot plant in 2009-2010.
- R&D support - EU FP7 project "FLEXI BURN CFB" 2009 – 2013
- R&D support – EU PF7 project ”MACPLUS” 2011-2016 (materials)
- **Boiler design - Oxy-CFB-300 Compostilla project 2009 – 2013 (EU/EEPR)**
- Boiler concept – Oxy-fuel fired CFB for a multifuel CHP-plant study (CCSP)

CLEEN (CLIC) Oy´s CCSP program

- Continuation of Oxy-CFB development
- Major focus on filling caps and improvements in modelling and design tools development
- Case studies

Second generation oxyfuel CFB

- High-O2 designs (2nd gen.) – EU FP7 project ”O2GEN” 2012-2015

Partnering with Finnish R&D organizations

- VTT and LUT have participated in all projects listed above
- VTT: testing, modeling and simulation
- LUT: modeling

*) *"Flexi-Burn" is a trademark of Foster Wheeler AG, registered in the U.S., EU, Finland*

Experimental facilities for Oxy-CFB

Test facilities for oxygen-fired combustion in circulating fluidized beds.

Operator and location[a]	Size[b]	FGR[c]	Fuels[d]	Reference[e]
CIUDEN, Ponferrada, ESP	30 MWth	Both	Anthr, Petcoke	Lupion et al. (2013)
Valmet, Tampere, FIN	4 MWth	Both	Bit	Varonen (2011)
Alstom, Windsor, CT, USA	3 MWth	No	Bit, Petcoke	Nsakala et al. (2004)
IET-CAS, Beijing, CHN	1 MWth	Dry	Bit	Li et al. (2014)
IET-CAS, Beijing, CHN	100 kWth	Dry	Bit, Lig	Li (2012)
IET-CAS, Beijing, CHN	30 kWth	No	Lig	Lu (2012)
CanmetENERGY, Ottawa, CAN	800 kWth	Dry	Anthr, Bit, Subbit, Lig, Petcoke, Wood	Jia et al. (2012a)
CanmetENERGY, Ottawa, CAN	100 kWth	Dry	Bit, Subbit	Jia et al. (2010)
University of Utah, UT, USA	330 kWth	Wet	Bit	Eddings et al. (2009)
Cranfield University, GBR	300 kWth	Both	Coals, Biomasses (planned)	Anthony (2013)
University of Stuttgart, DEU	150 kWth	Wet	Bit	Hofbauer et al. (2014)
VTT, Jyväskylä, FIN	140 kWth	Wet	Anthr, Bit, Lig, Petcoke, Wood, Straw	Eriksson et al. (2007)
Czestochowa Univ. of Tech., POL	100 kWth	No	Bit	Czakiert et al. (2009)
Czestochowa Univ. of Tech., POL	Batch/single part.	No	Bit	Luckos et al. (2011)
Czestochowa Univ. of Tech., POL	Batch	No	Lig	Czakiert et al. (2005)
Vienna Univ. of Tech., AUT	100 kWth	Wet	Sewage sludge	Höltl et al. (2009)
Tallinn Univ. of Tech., EST	60 kWth	No	Oil shale (planned)	Loo et al. (2014)
Southeast Univ., Nanjing, CHN	50 kWth	Wet	Anthr, Bit, Petcoke	Duan et al. (2011)
Yonsei Univ., Wonju, KOR	30 kWth	No	Wood pellet, Sewage sludge	Jang et al. (2014b)
Zhejiang Univ., Hangzhou, CHN	30 kWth	No	Bit	Mao et al. (2003)

[a] AUT – Austria, CAN – Canada, CHN – China, DEU – Germany, ESP – Spain, EST – Estonia, FIN – Finland, GBR – United Kingdom, KOR – Rebublic of Korea, POL – Poland, USA – United States

[b] Thermal capacity of the unit specified by the operator.

[c] Flue gas recycle mode: wet, dry, or both (wet and dry).

[d] Anhtr – anthracite, Petcoke – petroleum coke, Bit – bituminous coal, Subbit – subbituminous coal, Lig – lignite.

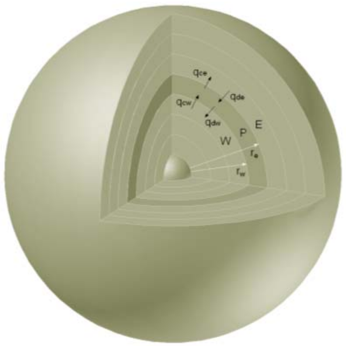
[e] Only one (first) reference is mentioned for finding more information of the unit.

Reference: *Rohan Stanger, Terry Wall, Reinhold Spörl, Manoj Paneru, Simon Grathwohl,Max Weidmann, Günter Scheffknecht, Denny McDonald, Kari Myöhänen, Jouni Ritvanen, Sirpa Rahiala, Timo Hyppänen, Jan Mletzkoe, Alfons Kather, Stanley Santos;* "Oxyfuel combustion for CO2 capture in power plants", 2015,

CCSP: Modelling of sulphur capture and heat transfer in CFB hot loop (LUT)

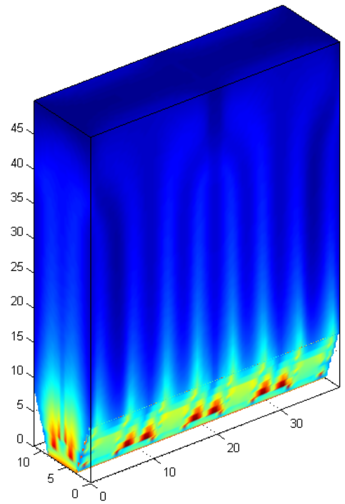
- The effects on combustion have already been accounted for in the models developed in EU FP7 projects.
- The objective during CCSP-project was to improve the modelling capability of limestone reactions and radiative heat in oxygen-fired conditions.

Particle model for limestone



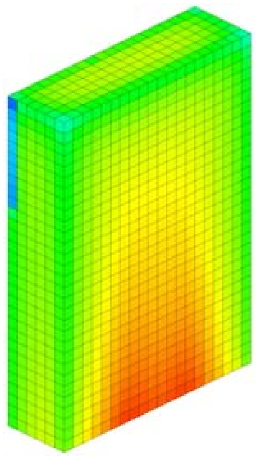
- Detailed transient particle scale model ($CaCO_3$/CaO/$CaSO_4$)

LUT-CFB3D



- Comprehensive steady-state 3D-model of CFB furnace

Radiative zone model

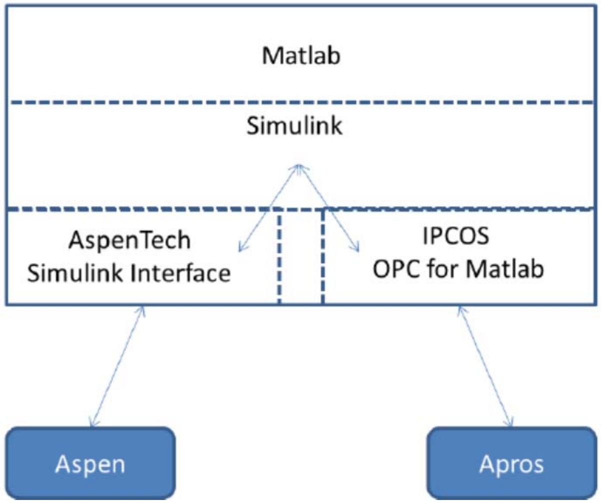


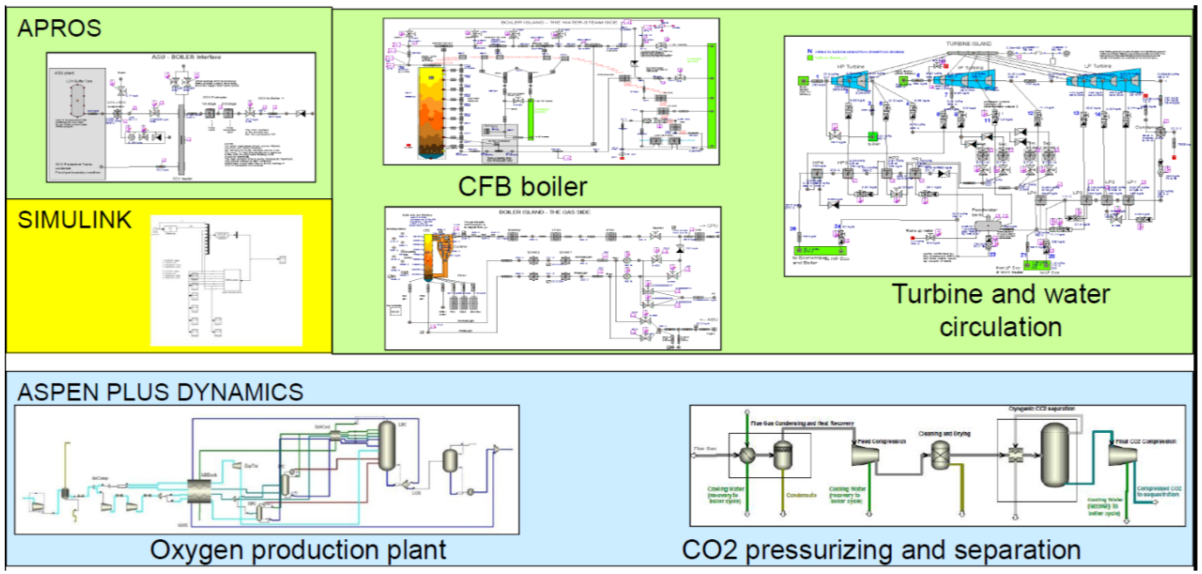
- Radiative heat exchange in suspension and to surfaces

CCSP: Combination of Apros and Aspen models

Simulation of the1st generation oxy firing (VTT)

- **Integration of two dynamic simulation tools (APROS & Aspen Plus Dynamics) for optimization of overal power plant process**
- **APROS: CFB boiler and turbine/generator**
- **Aspen Plus Dynamics: ASU and CPU**
- **Several connection methods evaluated: Direct OPC, Excel, Matlab**
- **Chosen method: Combination of OPC and Matlab**





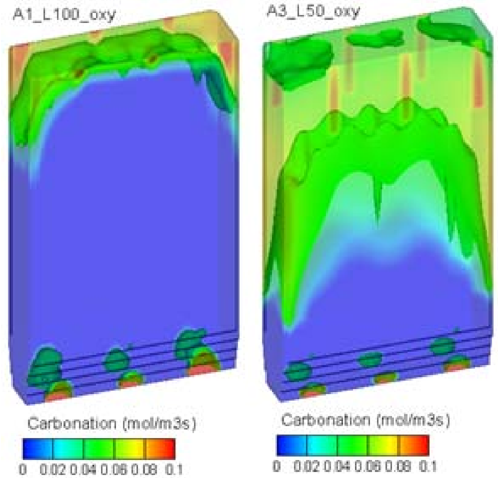
Utilization of results

Modeling and scale up of 2nd generation oxyfuel power plant

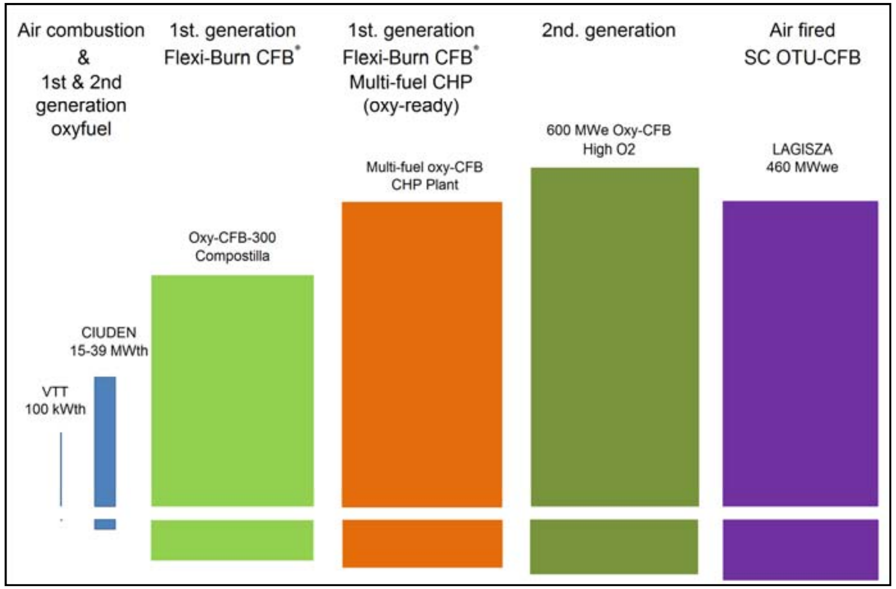
R&D results were utilized in 3D modeling of the CFB furnace and hot loop in the 2nd generation oxy-CFB boiler concept (O2GEN (FP7) project):

- Checking of furnace profiles (heat transfer, temperature, emissions) with the selected heat surface configuration
- SO_2 capture and limestone reaction profiles

Oxyfuel plant dynamics was simulated with VTT´s integrated APROS and Aspen Plus dynamics simulatior

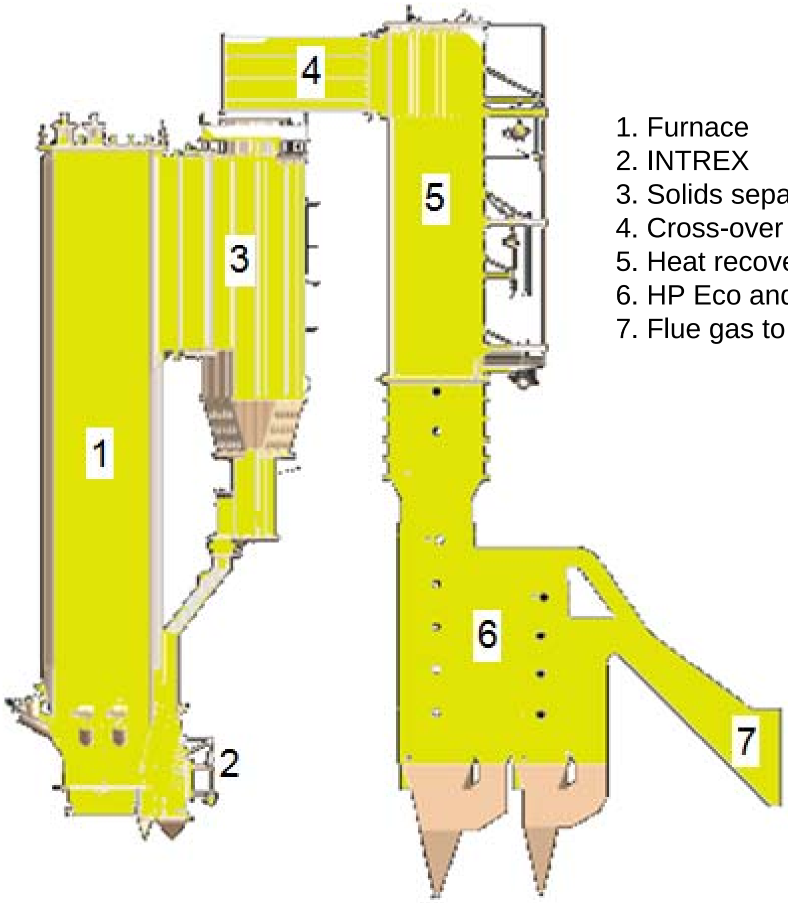


Parameter	Unit	CIUDEN	OXY-CFB-300 Flexi-Burn CFB	Multi-fuel CHP	Lagisza 460 $MW_{e, gr.}$	600-MW_e High-O_2 CFB
Furnace dimensions						
Height	m	20	37	38	48	52
Width	m	2.9	28	17.6	27.6	29.7
Depth	m	1.7	7	8.3	10.6	9.5
Number of separators	-	1	4	2	8	6
Thermal power [1]						
Oxy mode (max.)	MW	30	708	427	--	1439
Air mode	MW	14.5	647	427	966	--
Steam parameters [2]						
SH steam flow	t/h	47.5	845	515	1300	1919
SH steam temperature	°C	250 [3]	600	555	560	600
SH steam pressure	bar	30	279	164	275	257
RH steam flow	t/h	--	745	475	1101	1633
RH steam temperature	°C	--	601	555	580	607
RH steam pressure	bar	--	56.5	43	50.3	52
Feedwater temperature	°C	170	290	257	290	300



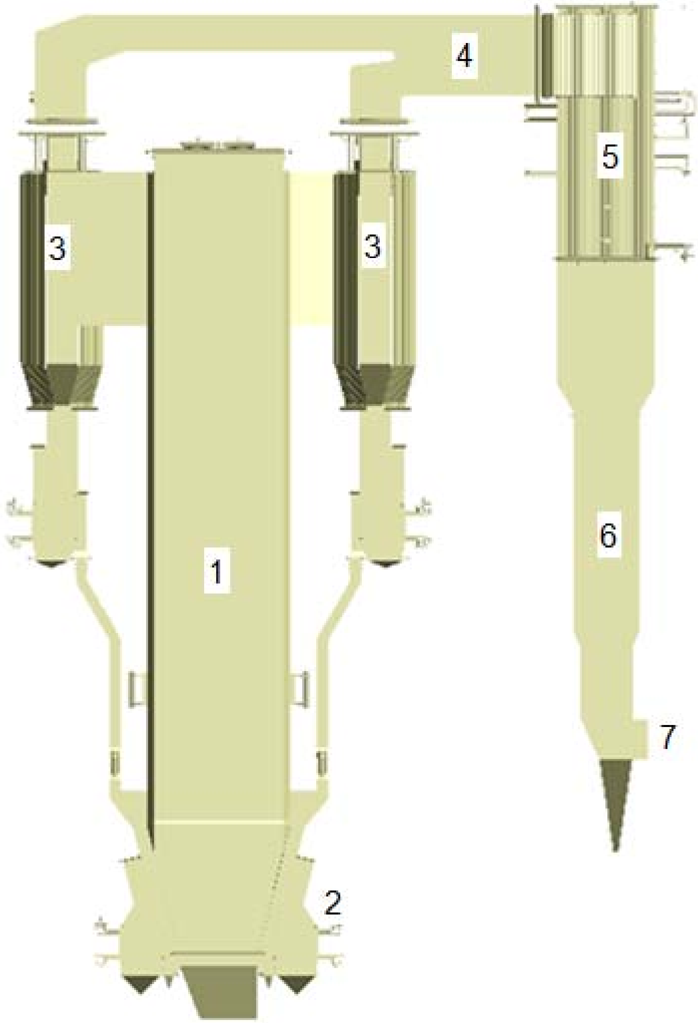
300 MWe Scale Flexi-Burn CFB and 600 MWe High-oxygen Oxy-CFB Designs

300 MWe Scale Flexi-Burn CFB



1. Furnace
2. INTREX
3. Solids separators
4. Cross-over duct
5. Heat recovery area
6. HP Eco and LP Eco
7. Flue gas to filter unit

600 MWe Scale Oxy-CFB



Achieved technology readiness

- **Development the Oxy-CFB models, boiler design tools and plant simulators for better accuracy and effectiveness**
- **Detailed engineering of 300 MWe scale Flexi-Burn CFB boiler and power plant (EU/EEPR)**
- **Design of a 600 MWe scale 2nd generation Oxy-CFB boiler with optimized heat integration.**
- **Case study to evaluate suitability of Oxy-CFB for CHP plant (CCSP/Fortum)**

→ AmecFW has readiness to design and demonstrate the technology in commercial scale plant

Technology readiness level of oxyfuel power plants
Status of implementation in Europe

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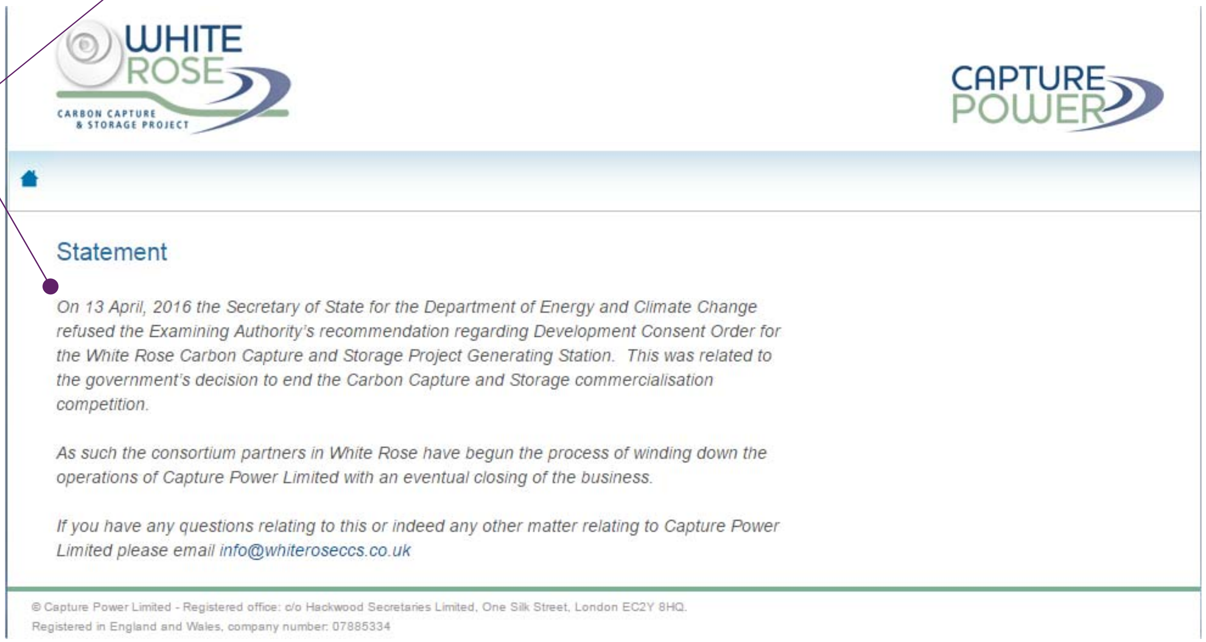
Assessing the technology readiness level of oxyfuel combustion for coal fired power plants with CCS.[1)]

TRL	TRL phase name for R&D initiatives	Phase for facility development	Oxyfuel projects
9	Full-scale commercial deployment	Commercial	
8	Sub-scale commercial demonstration plant	Demonstration	White Rose Project
7	Pilot Plant	Industrial Scale Pilot	Callide Oxyfuel Project
6	Component prototype demonstration	Industrial Scale Pilot	Schwarze Pumpe Pilot Plant, Lacq Pilot Plant, CIUDEN's TDP Pilot Plants
5	Component prototype development	Industrial Scale Pilot	Various large scale burner test facilities(i.e. B&W, Alstom, Doosan Babcock)
4	Laboratory component testing	Bench	
3	Analytical 'proof of concept'	Bench	
2	Application formulation	Bench	
1	Basic principles observed	Bench	

White Rose as the only remaining oxyfuel based CCS project in Europe, is facing headwinds



WHITE ROSE CARBON CAPTURE & STORAGE PROJECT

CAPTURE POWER

Statement

On 13 April, 2016 the Secretary of State for the Department of Energy and Climate Change refused the Examining Authority's recommendation regarding Development Consent Order for the White Rose Carbon Capture and Storage Project Generating Station. This was related to the government's decision to end the Carbon Capture and Storage commercialisation competition.

As such the consortium partners in White Rose have begun the process of winding down the operations of Capture Power Limited with an eventual closing of the business.

If you have any questions relating to this or indeed any other matter relating to Capture Power Limited please email info@whiteroseccs.co.uk

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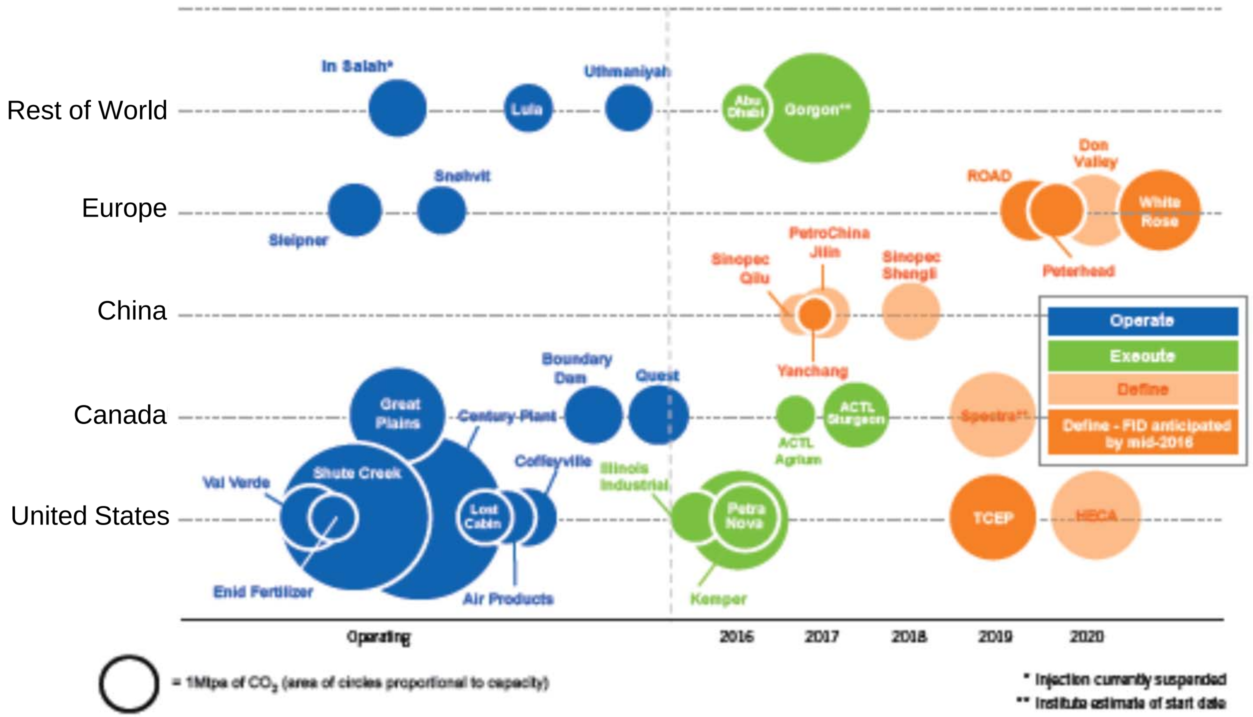
[1)] Reference: *Rohan Stanger, Terry Wall, Reinhold Spörl, Manoj Paneru, Simon Grathwohl,Max Weidmann, Günter Scheffknecht, Denny McDonald, Kari Myöhänen, Jouni Ritvanen, Sirpa Rahiala, Timo Hyppänen, Jan Mletzkoe, Alfons Kather, Stanley Santos;* "Oxyfuel combustion for CO2 capture in power plants", 2015,

However, many reasons have hidered deployment of CCS in Europe and globally

- **High investment costs of CCS**
- **Commercial driver towards CCS is missing due to low CO_2 price.**
- **Since 2008, the economic downturn has continued in Europe.**
- **In many cases, a low public acceptance**
- **Negative emissions (Bio-CCS) is not acknowledged in the ETS or via other mechanisms.**
- **CCS has been opposed because it has been seen as an excuse for continuing the use of fossil fuel based generation.**

Europe is behind in implementation of CCS

- **Globally there are a number of CCS projects in operation, become operational during 2016 and 2017, and projects in development stage. USA and Canada are in front line in the development.**
- **In Europe, only Sleipner and Snøvit are in operation, none is in construction and four under development (2015) with still unsure future.**



Reference: *Global CSS Institute:* “The global Status of CCS, 2015, SUMMARY REPORT”

What does it require?

The countries in the front line of CCS deployment have together implemented a combination of:

- **direct regulation to require power generators to reduce emissions intensity**
- **government funding of large-scale CCS projects and R&D**
- **fiscal and market-based incentives, including carbon pricing and tax credits**
- **supportive legal and regulatory frameworks governing CO_2 storage.**

- **Regardless of the more favourable incentive environment, EOR has been a crusial factor helping USA nd Canada to achieve the leading postion in CCS market.**

As an example, a far reaching strategic approach were outlined by the Parliamentary Advisory Group on CCS for the Secretary of State for Business, Energy and Industrial Strategy in UK (September 2016)

Conclusions

Technology development for Oxyfuel CFB plant

- Extensive R&TD activities has been carried out to develop oxy-fuel CFB power plant technology during the past ten years
- In the CCSP program, the focus has been on improvement of modeling capabilities (Oxy-CFB combustion process and furnace models, dynamic simulator of Oxy-CFB power plant)
- Improved 3D CFB model and dynamic simulator was utilized in development of a 600 MWe scale oxy-CFB boiler concept with high oxygen oxidant.
- Performance estimates for a multi-fuel oxy-CFB boiler was provided for the feasibility study by Fortum.
- **Oxy-CFB technology is ready for commercial scale demonstration.**

Incentives towards CCS commercialisation still required:

- Currently there is insufficient incentive and regulatory framework supporting CCS globally, and especially in Europe, providing long term predictability for investors to invest in CCS.
- Hence, Europe lies behind in deployment of CCS compared e.g with USA and Canada
- New round of CCS deployment is expected after the Paris Agreement gets in force on 4th November 2016, followed by the EU and national legistlation in Europe

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Reijo Kuivalainen
reijo.kuivalainen@amecfw.com
+358-40-511 2104

amec foster wheeler

amecfw.com