Post-Combustion Capture Development Programme of RWE

A Group-wide Approach to Implementing Technological Breakthroughs

The energy to lead

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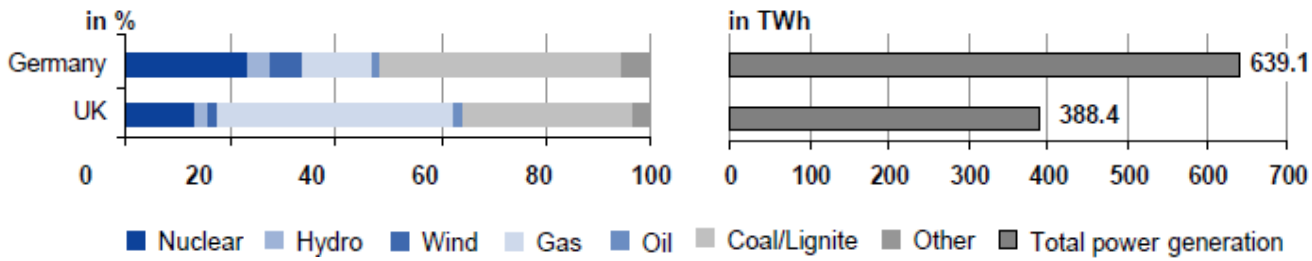
12th Meeting of the International Post-Combustion CO_2 Capture Network
29th September - 1st October 2009, Regina, Canada

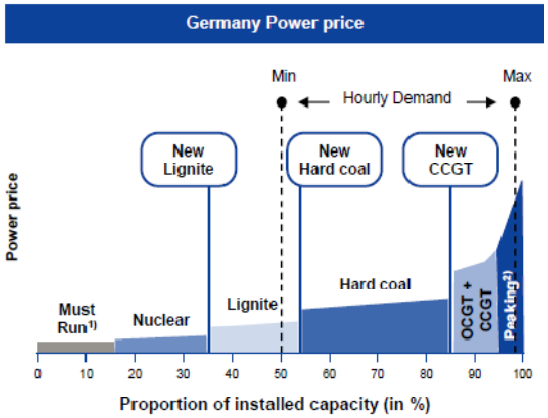
Boundary Conditions in Germany and UK (2008) Fuel Mix and Domestic Electricity Market

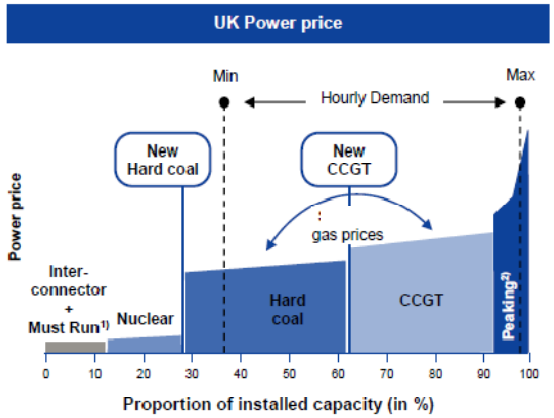
Shares of Primary Energy Sources in Total Electricity Generation Germany/UK



Source: Cambridge Energy Research Associates, 2009.

Attractiveness of Coal/Lignite and Gas differs in Germany and the UK.
In the UK, the sample curves below change month-to-month





1) Including renewables and CHP.
2) Oil, OCGT, hydro, etc.

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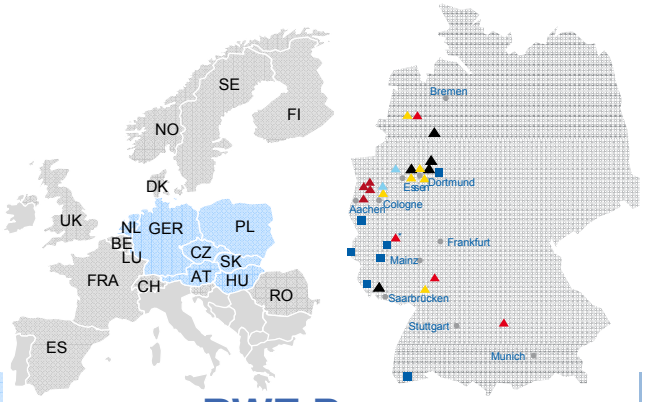
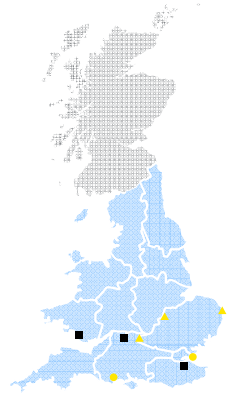
Electricity Production and Power Plant Fleet 2008

RWE Group **Employees:** 65,908 **External Revenues:** Euro 48.9 billion **Customers Electricity:** 20 million





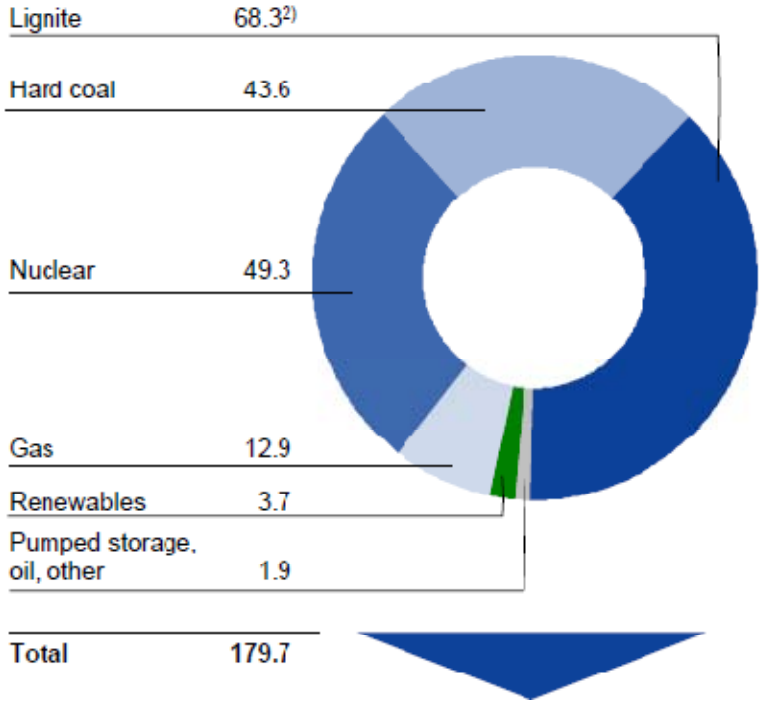
Renewables are bundled at **RWE Innogy**

Capacity 1.3 GW

	RWE Power		RWE npower	
	Electricity producer in the RWE Group in Continental Europe		**Electricity producer and supplier in the RWE Group in the UK**	
	Employees: 17,505		**Employees:** 12,747	
	Power plant capacity in MW	**Power Produced in TWh**	**Power plant capacity in MW**	**Power Produced in TWh**
Lignite	10,828	73.9	-	-
Bituminous coal	9,513	43.1	4,575	18.0
Nuclear	6,295	49.3	-	-
Gas	3,994	11.5	2,913	18.2
Renewables	55	0.6	-	-
Pumped storage, oil, other	2,348	1.9	2,657	0.5
Total	**33,033**	**180.3**	**10,145**	**36.7**

RWE´s Generation Mix in Germany/UK (2008)

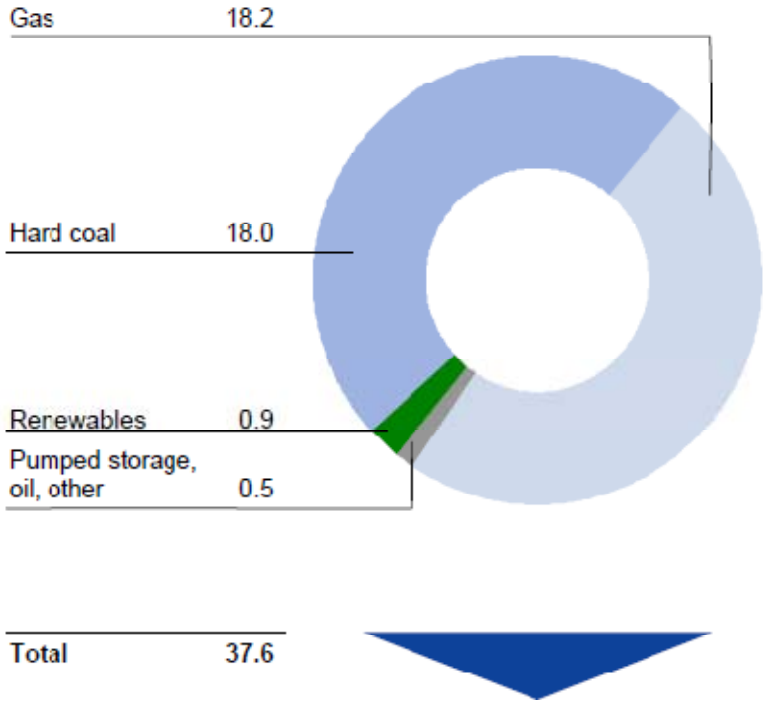
Germany: power produced in 2008 in TWh[1)]



CO_2 emissions in 2008

141 million tons

UK: power produced in 2008 in TWh



CO_2 emissions in 2008

25 million tons

1) Including electricity procured from power plants not owned by RWE that we can deploy at our own discretion on the basis of long-term agreements, totalling 28.6 TWh (hard coal), 0.6 TWh (renewables) and 1.4 TWh (pumped storage, oil, other).

2) Including plant consumption by RWE opencast mines

Post Combustion Capture as Part of RWE´s CO_2 Mitigation Strategy for Power Plants

Horizon 1: Modernisation to increase efficiency

Under construction:
5,160 MW capacity
Coal-fired

Power plant portfolio: continuous renewal

Efficiency >50%

Nearly CO_2-free

Horizon 2: Further efficiency increase

WTA lignite pre-drying prototype

700 °C test plants

First dry lignite-fired power plant

700 °C demo plant

IGCC demo plant

PCC demo plant

Horizon 3: Nearly CO_2-free

450 MW low-CO_2
IGCC power plant incl. storage

CO_2 scrubbing incl. storage
for conventional power plants

CCS Acts and National and EU Funding influences PCC-CCS Development Approach

Germany is not supporting large scale-demonstration projects

- State sees his task of establishing clear legal provisions for the environmentally sound use of CCS, but not more
- No PCC demonstration plant on the short list of EU´s Recovery Plan

UK identified lack of PCC demonstration as barrier for CCS deployment

- “UK Competition” to actively support technology demonstration
- Coal demonstration projects on the short list of EU´s Recovery Plan
- “No new coal without CCS demonstration”

Timelines and Frameworks of the different funding programmes require different approaches and determine widely the content of the projects:

- minimum size of the PCC plant (250 MW or less?)
- availability of the PCC technology (commercial process or under development)
- schedule (off-the-shelf technology or time for development and optimisation)

Key Factors for RWE Power´s and RWE npower´s Definition of RWE´s PCC Development

RWE´s group-wide approach focuses on:

> techno-economical evaluation and optimisation of PCC technology

> testing of most promising PCC technology on pilot plant-scale

> large-scale PCC-CCS demonstration project

> access to best available technology for commercial full-scale application from 2020

> competition between PCC suppliers

Key factors that define the approach and timeline:

> specific boundary conditions in the countries

market and investment strategy, technical norms, legal and political aspects, public acceptance, funding conditions

> fuel mix (bituminous coal, raw lignite, pre-dried lignite, natural gas)

> target size of PCC plant
(~800 MW bituminous coal, ~1100 MW pre-dried lignite)

RWE Power and RWE npower defined a Complementary PCC Development Programme

Split of work in the current phase:

> RWE npower is focusing on PCC for bituminous coal-fired power plant

> RWE Power investigates PCC especially for the next generation of lignite fired power plants

Approach guarantees:

> Close examination of fuel related questions

> trace elements in the flue gas, fly ash particles, aerosols and their impact on solvent degradation, corrosion and material selection

> specific power plant related integration concepts, waste heat usage and PCC scale-up issues

> **RWE npower and RWE Power entered in this first stage of the development programme with different amine-based solvents, processes and equipment.**

PCC Pilot Plant Projects on Amine-Based Processes - Preparing for Demonstration Projects

1. **Cooperation of RWE Power, BASF, Linde to develop an advanced amine-based CO_2-Scrubbing-Process:**

2. **RWE npower realized the generic test facility at Didcot**

> Assessment of the performance of competitive PCC technologies is not sufficient.

> Pilot plant projects, the optimisation programmes and collaboration with process suppliers is providing knowledge and operational experience for the RWE Group.

> Cooperation and “hands on” experience provide develops a wider knowledge base than simply buying and independently testing “off-the-shelf” plants.

RWE Power Pursues Two PCC Routes

> **Goals for commercial full-scale application from 2020:**
  - PCC-CCS efficiency loss < 10%-points of the power plant efficiency
  - Cost of CO_2 capture & storage < CO_2 certificate price

> **Basic results of our worldwide screening of more than 20 potential PCC-processes and 4 feasibility studies:**
  - Focus on amine-based scrubbing and the new “Chilled Ammonia”-Process
  - Joint and integrated technology development is necessary

The interdisciplinary approach – key to success:

> BASF – ”The Chemical Company“: development of new solvents and optimized process design

> Linde – “Engineering company”: engineering and construction of the of the pilot plant, system optimization, scale up

> RWE Power – “Power producer and utility”: plant integration, interface optimization, operation

Pilot Plant Niederaussem - Key Figures

- CO_2-capture rate 90 %
- app. 7.2 t per day
- Height: app. 40 m
- Skid mounted design
- Start testing programme: July 2009
- Budget RWE Power: 9 Mio. €
- 40% Funding by the Federal Ministry of Economics and Technology

RWE Power/BASF/Linde

Development of a highly efficient amine based PCC Process

Feasibility Study "PCC Full-Scale"

> Delineation of the pilot plant design

> **Solvent Development BASF**

> Solvent screening

> Miniplant performance tests

PCC Pilot Plant Niederaussem

> Engineering, procurement

> Construction

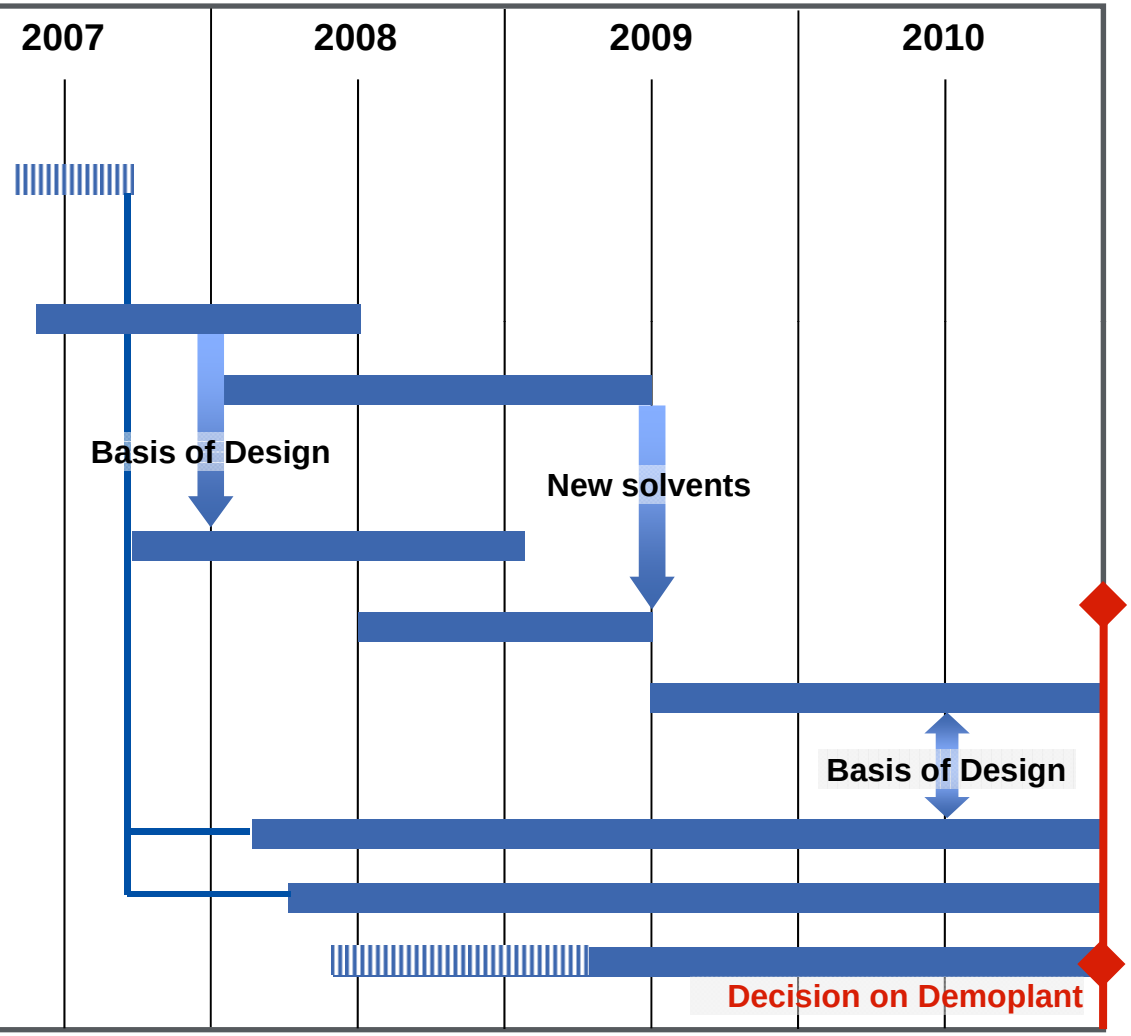
> Operation

Working Group "Full-Scale/Demo"

> Optimization of the PCC concept

> Scale up for a full-scale plant

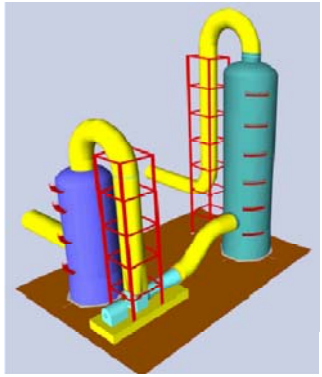
> Demo plant design, e.g. Eemshaven



PCC-CCS Demo Plant as Intermediate Step from Pilot Plant to Commercial Application

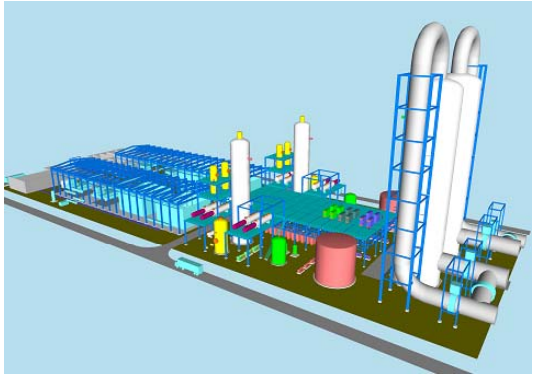
Scale-up factor

280



Scale-up factor

4



Today	2010	2015*	2020*
Operation	Design, Construction, Commissioning	Design, Construction, Commissioning	
Pilot Plant Niederaußem app. 0,5 $MW_{el, equiv.}$ ≈2,500 t/a CO_2	**Demo Plant** e.g. Eemshaven app. 140 $MW_{el, equiv.}$ ≈0.7 million t/a CO_2	**Commercial PCC Plant** 2 trains for a 1,100 MW power plant app. 550 $MW_{el, equiv.}$ per train ≈3 million t/a CO_2 per train	
No CO_2 Storage	**CO_2 Transportation and Storage** - Design, Construction, Commissioning		

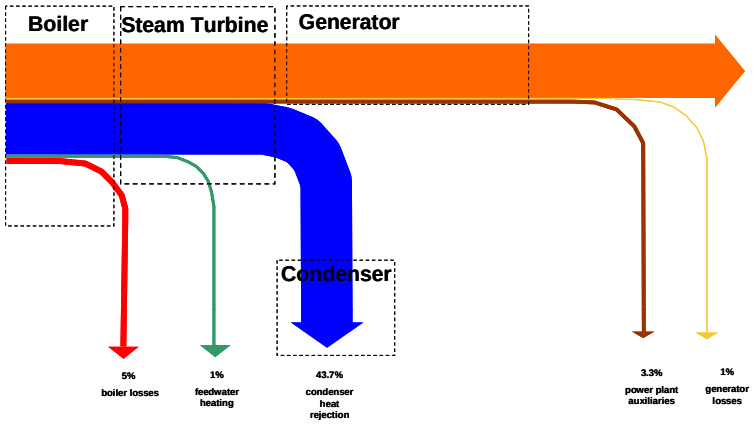
*Timeline depends on development progress and especially project boundary conditions (e.g. permitting).

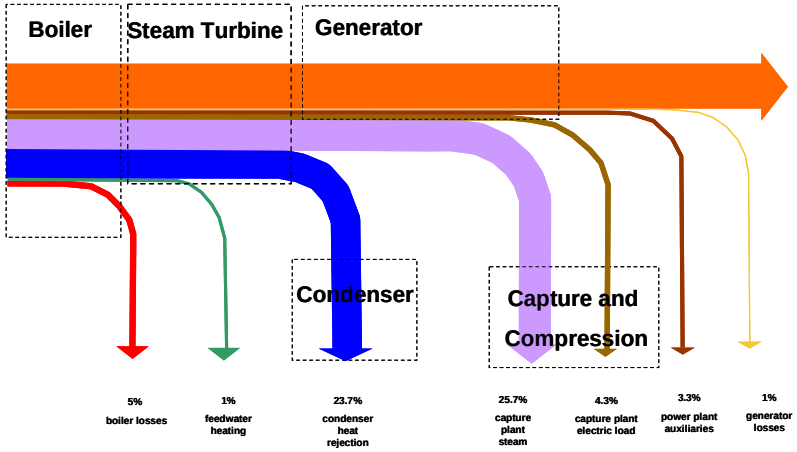
Knowledge Requirements

Understanding and minimising costs and impact on host plant	✓
Understanding environmental issues (emissions, waste streams)	✓
Understanding process chemistry, corrosion, solvent degradation	✓
Process integration and optimisation	✓ Site specific research needed
Gas cleaning requirements	✓
Evaluating technologies	✓
Improvement in process technology / reduction in efficiency penalty	✓
Developing modelling capability	✓
Understanding implications for power plant flexibilty, grid code and commercial	✓
Understanding Engineering issues for retrofit	Limited -site specific
Understanding implications for CCGTs	(✓)
Understanding regulatory and legislative requirements	Limited

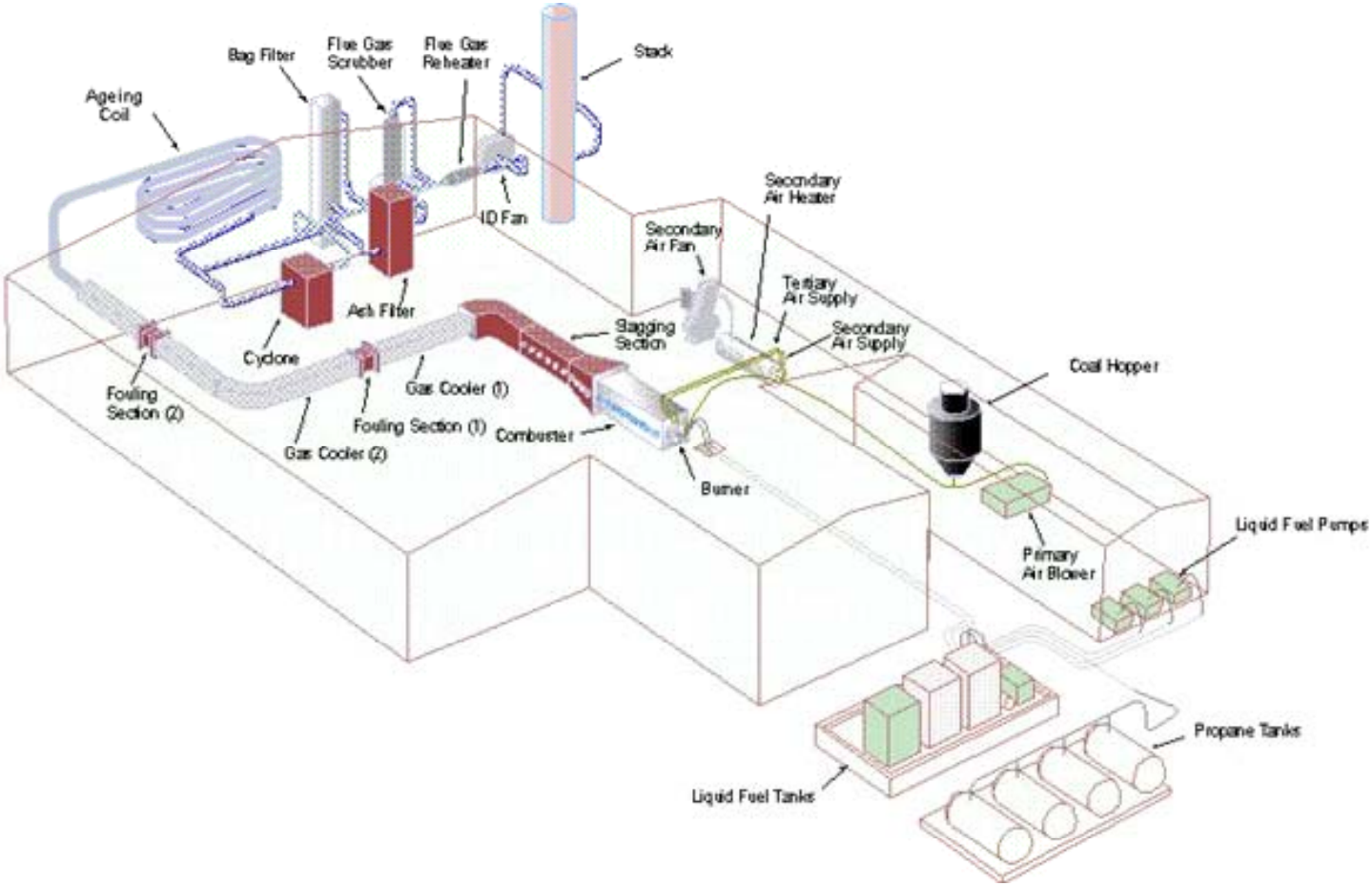
PCC Impact on Host Power Station

- Reduces efficiency from approx. 45% to approx. 35%
- Requires about half steam from LP turbine
- Energy penalty comprises steam for reboiler 45%, pumps and fans 10% and CO2 compression 45%
- Increased capital cost
- Substantial land area
- Impact on flexibility
- High impact means that even incremental improvements can make a big difference





RWE npower
Schematic of Didcot CTF (Combustion Test Facility)



Post-combustion capture at Didcot

Test programme

- Comparison of energy requirements for range of solvents
- Compatibility with bio-mass
- Testing different flue gas compositions.
- Parametric tests of solvent loading and desorption temperature and pressure.
- Alternative solvents e.g. MDEA, hindered amines
- Validation of baseline process economics and assessment of plant flexibility

Specification

- Treat 33% of 0.5 MW CTF flue gas
- Carbon dioxide removal using MEA of 1 tonne per day (>85%)
- SO_2 and NO_X pre-treatment

Didcot Amine Test Rig

- 8m column height
- 0.07 MWe (50 kg/h CO_2)
- SO_2 and NO_X pre-treatment
- Multiple solvent sampling locations
- Provision for corrosion coupons and alternative material test sites
- Trace gas injection
- Continuous analysis

Test programme

- MEA reference tests with heat and material balances and parametric studies
- Alternative solvents e.g. MDEA, hindered amines and blends
- Validation of baseline process economics and assessment of plant flexibility
- Tests on different flue gases and fuels including biomass

ECO-Scrub Concept

- **39 month project funded by EC Research Fund for Coal and Steel, co-ordinated by RWE npower in collaboration with three universities, two research institutes and three utilities from five EU member states**
- Enhanced combustion with oxygen and scrubbing
- no recirculation or partial recirculation of flue gas with replacement of some air by oxygen
  - reduces volume of flue gas
  - enhances CO_2 concentration of flue gas

Output of simulations for a lignite-fired power plant		Reference case	Retrofit Case (post-combustion)	Retrofit Case (oxyfuel)	Retrofit Case (ECOS-Scrub)
Gross electric power	MWe	330.67	299.44	357.44	312.19
Gross electrical efficiency	%	42.45	38.44	45.89	40.08
Net electric power	MWe	304.15	243.43	258.62	248.24
Net electrical efficiency	%	39.05	31.25	33.20	31.87
Pumps (electric)	MWe	18.15	18.87	20.16	19.27
CO2 compressors (electric)	MWe	-	21.24	21.24	21.23
Fans and compressors (electric)	MWe	8.37	15.9	57.42	23.35
Reboiler duty	MWth	-	268	-	256.85
O2 in secondary air	% vol.	21	21	95	30

Data courtesy of CERTH/ISFTA, National Technical University of Athens

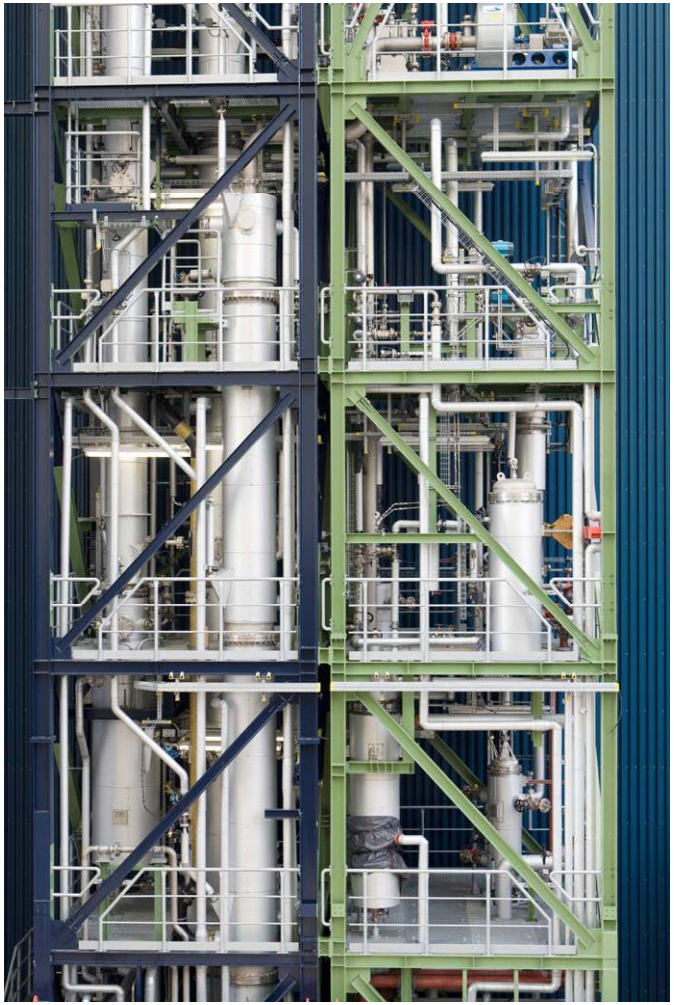
- Several potential benefits
  - potential for net reduction of operating cost due to increased capture efficiency (opex)
  - potential for slight reduction in size of post-combustion capture plant (capex)
  - reduced-cost retrofit option or potential for savings in new plant through advanced combustion optimisation and reduced boiler size
  - may also be able to reduce size of SCR plant
  - no issues with air in-leakage

Didcot CTF Burner Inlet (Air and ECO-Scrub firing)

Conclusions

- There is currently no obvious best technology. All need development but amine-based PCC technologies are currently favoured for retrofit.
- In the current phase of RWE´s development programme, RWE Power is focussing on PCC for lignite-fired power plants and RWE npower on bituminous coal-fired power plants.
- The combination of pre-selection of the most promising PCC technologies, individual collaborations with appropriate partners from the technology supply industry and a generic test facility boosts the development.
- Ongoing process optimisation and hands-on experience in the pilot plant projects provides valuable understanding of the technologies and how they interact with power plants.
- Other technology options are being investigated in parallel.
- We believe that this is an excellent basis for the RWE Group to decide on the preferred carbon dioxide capture technology for demonstration plants and commercial application from 2020.

Thank you very much for your attention



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RWE Power´s Development of the Demo Plant

Finalization of the preliminary design study of a full scale PCC plant

Continuous optimisation of the integrated PCC concept

Definition of tasks for pilot plant testing to validate the technology and to minimize scale up risks

Up date of the design of a full scale PCC plant on basis of the pilot plant results

Definition of tasks for the demo plant testing to validate the optimized technology and to minimize scale up risks

Demo plant design

Boundary conditions from the power plant and the CO_2 transport and storage infrastructure

Political Framework / Legal Boundary Conditions Influences Power Plant and PCC Design

Large Combustion Plant Directive: Closure of 13 GW by 2015 (or earlier)

> New emission limits from 2008 for power stations to operate more than 20,000 hours / beyond 2015:

Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Large Combustion Plants and Gas Turbine Plants)

> Emission limits for power plants with a thermal input of more than 300 MWe:

- NO_x 200 mg/m^3 (from 2013: 100 mg/m^3)
- total dust 20 mg/m^3; CO 200 mg/m^3; SO_x 200 mg/m^3 and additionally to the limitation of the mass concentration a rate of desulphurisation of at least 85 per cent must be achieved.

Coal Power Plant Modernisation Programme. Candidates for PCC Retrofit

2009

Lingen

Natural gas
875 MW CCGT

2011

Neurath

Lignite
2,100 MW

Hamm
Hard Coal
1,530 MW

2013

Eemshaven

Hard Coal/
Biomass
1,530 MW

Goal of PCC development:
PCC as a retrofit option and for new-built power plants

Minimal Size of the Demo Plant as Result of a Scale-up Risk Analysis for commercial Application

Large Combustion Plant Directive: Closure of 13 GW by 2015 (or earlier)

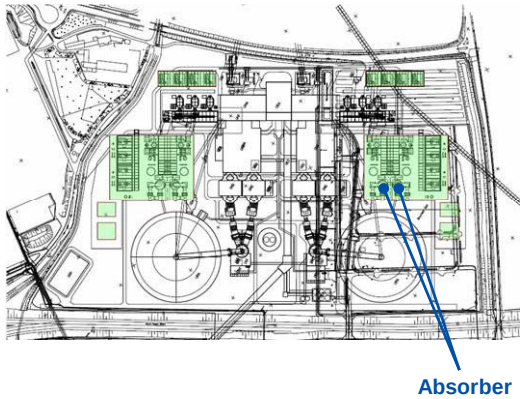
> PCC design study for a 1,100 MWel pre-dried lignite power plant completed

⇒ 2 PCC trains in parallel, each 550 MWel

> Thorough scale-up risk analysis to define minimal size for a PCC demo plant as a reliable and representative validation for the commercial full-scale application:

⇒ Absorber defines necessary minimal size of the demonstration plant (gas-liquid distribution, mechanical concept, internals, packings, advanced materials)

2 x 1,100 MW_{el} power stations



For 1,100 MW_{el}:

- **two trains in parallel**
- **each 550 MW_{el}**

Result:

The minimal size of a reasonable demonstration plant is app. 140 MW_{el}