CO_2 free Fossil Power Plant – From Vision to Reality

Deutsche Physichalische Gesellshaft

Arbeitskreis Energi

March 26, 2007, Regensburg

Lars Strömberg

Vattenfall AB

Berlin/Stockholm

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The Vattenfall Group

- Vattenfall is one of the major Energy companies in Europe

- Vattenfall sells almost 200 TWh electricity
  - The main part is produced by hydropower, nuclear power, coal and natural gas.
  - A smaller part is produced by biofuels and wind power
  - About 20 TWh is produced in combined heat and power plants

- Vattenfall also sell about 40 TWh heat
  - The main part is produced by biofuels, coal and gas in cogeneration plants

- Vattenfall emits about 90 million tons of CO_2 per annum

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The Climate Change

- European Council and the “Energy package” has recently declared that we have to reduce the emissions to maintain a reasonable CO_2 concentration in atmosphere (+2^{o}C)
  - 30 % until 2020
  - 60 – 80 % until 2050

- Vattenfall has declared in the “3C initiative” that it can be done, and at a reasonable cost. (Reducing the emission from the European energy sector to half, costs the same as the cost for catalytic cleaning of car exhaust)

- A radical solution is necessary. We cannot wait

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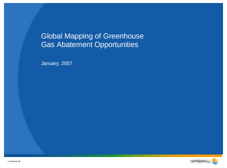
CO_2 free power plant

The CO_2 roadmap to realization

www.vattenfall.com/climatemap



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The Problem

- Fossil fuels are needed
  - Analysis show that fossil fuels will remain as major energy source in 2030
- The top priority is to introduce renewable energy sources in the energy system
  - All analysis show that renewable energy sources will play a large role, but not large enough and soon enough
- In several countries nuclear power is decommissioned
- No renewable energy source not known today can play a significant role in 25 years from now, i.e. 2030

→ Emissions from fossil fuels must be reduced

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Capture and storage

One solution is the CCS

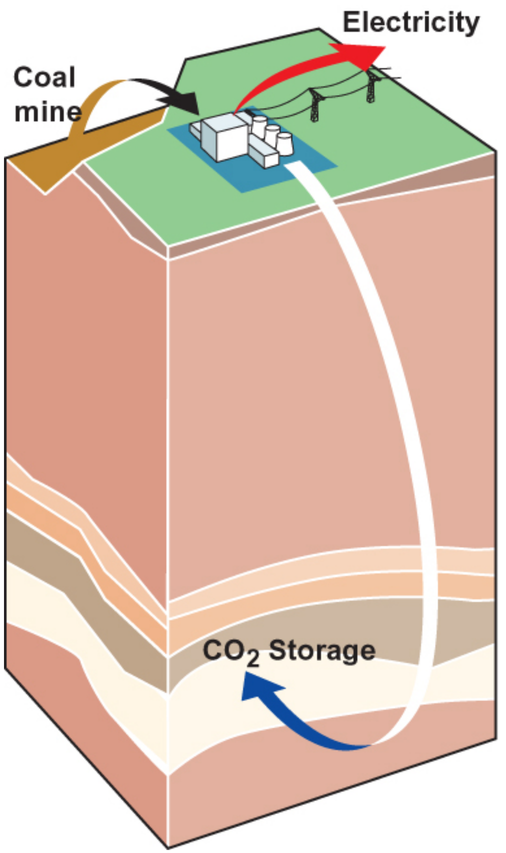
- Carbon Capture and Storage, CCS can offer one solution with the largest potential so far.
- CCS can give an almost zero emission technology
- CCS is less expensive than most renewable energies today
- CCS is not the ultimate solution, it is a bridging technology to the sustainable solutions which have to be found

The CO_2 free Power Plant principle

The principle of capture and storage of the CO_2 under ground

The CO_2 can be captured either from the flue gases, or is the carbon captured from the fuel before the combustion process.

The CO2 is cleaned and compressed. Then it is pumped as a liquid down into a porous rock formation for permanent storage.



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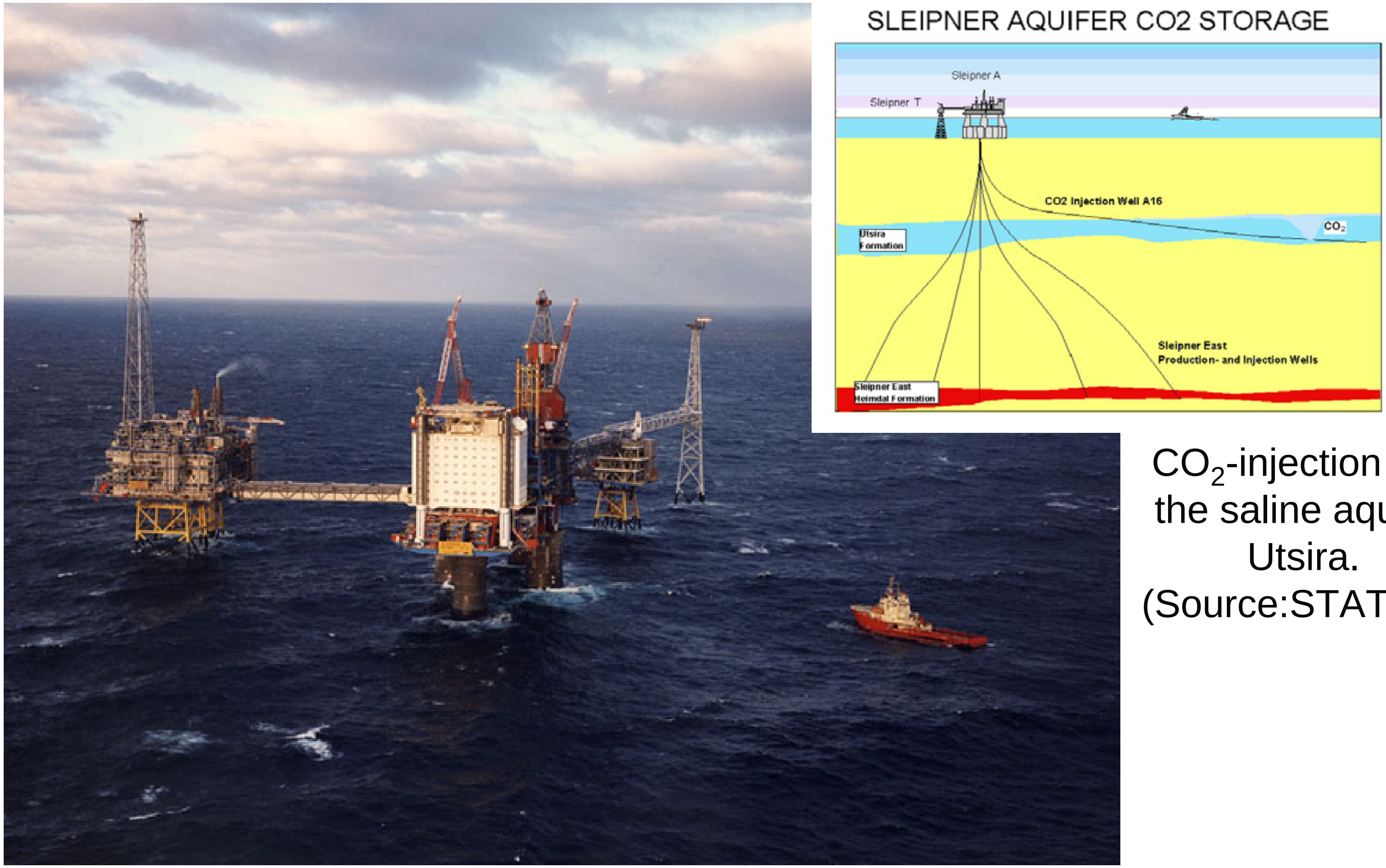
Storage and transport

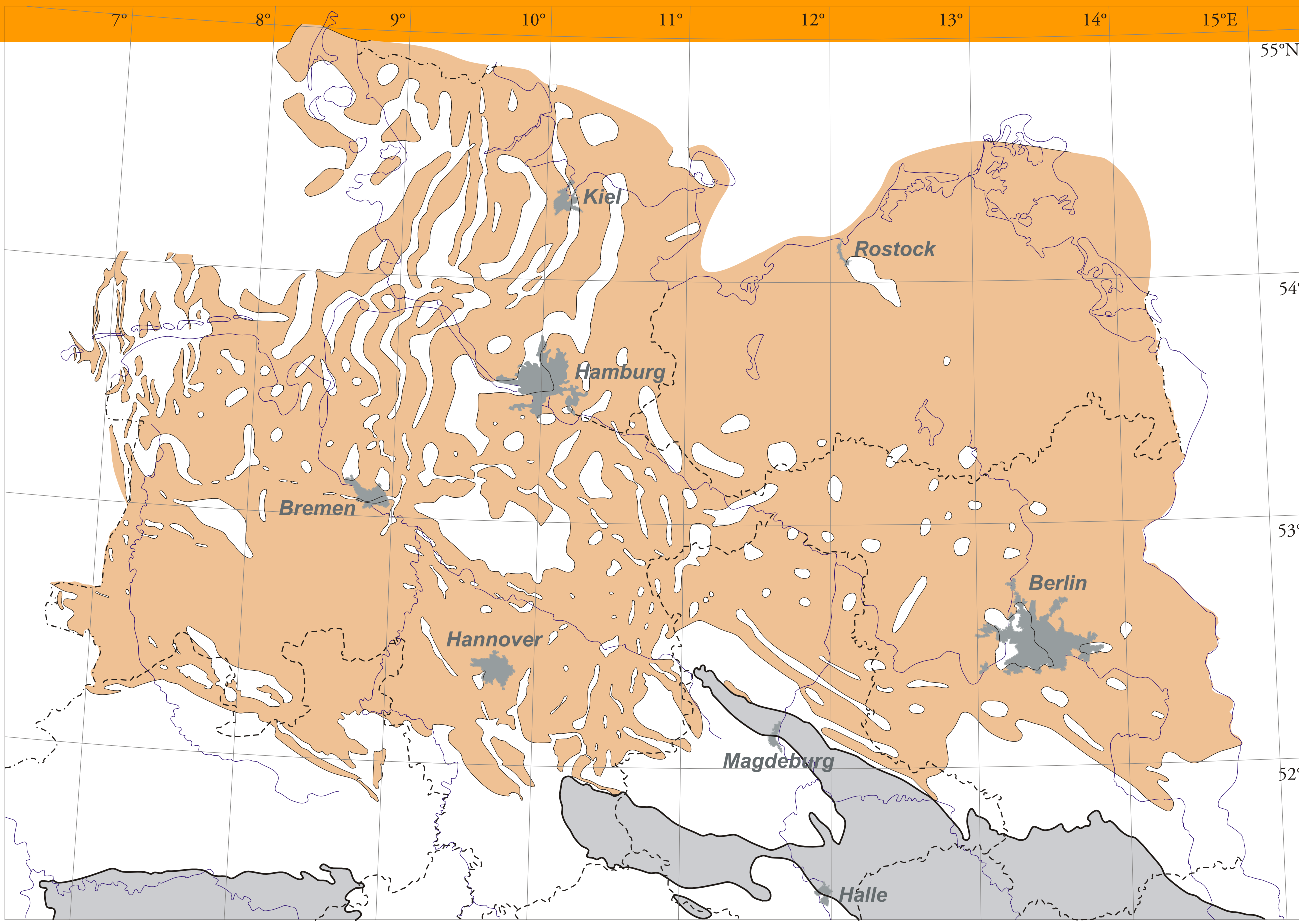
Storage of CO_2 in a Saline Aquifer under the North Sea



CO_2-injection into the saline aquifer Utsira. (Source:STATOIL)

The Sleipner field. Oil and gas production facilities. (Source: STATOIL)

Storage Capacity, saline aquifers



Distribution of Rhetian   Basement below Cenozoic cover

Present day distribution of the Rhetian - aquifers (a. DIENER et al. 1984, FRISCH & KOCKEL 1998)

There exists more storage capacity within Eorope (and in the world) than the remaining fossil fuels

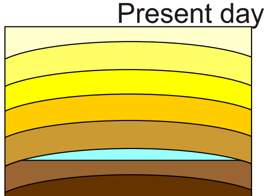
Source:

Franz May,

Peter Gerling,

Paul Krull

Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover



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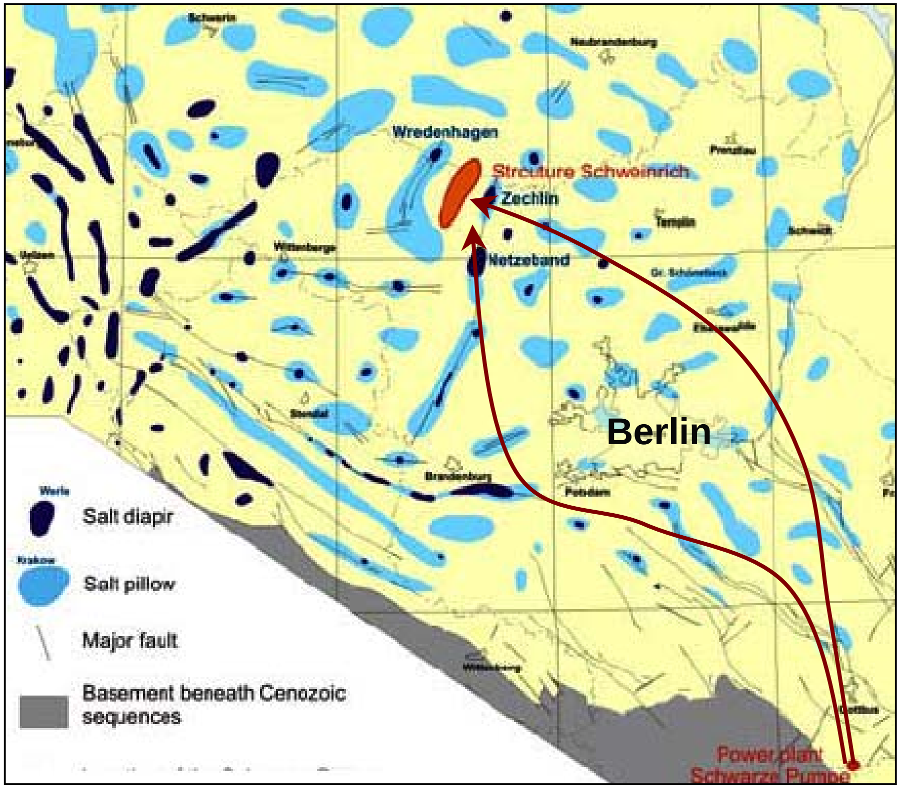
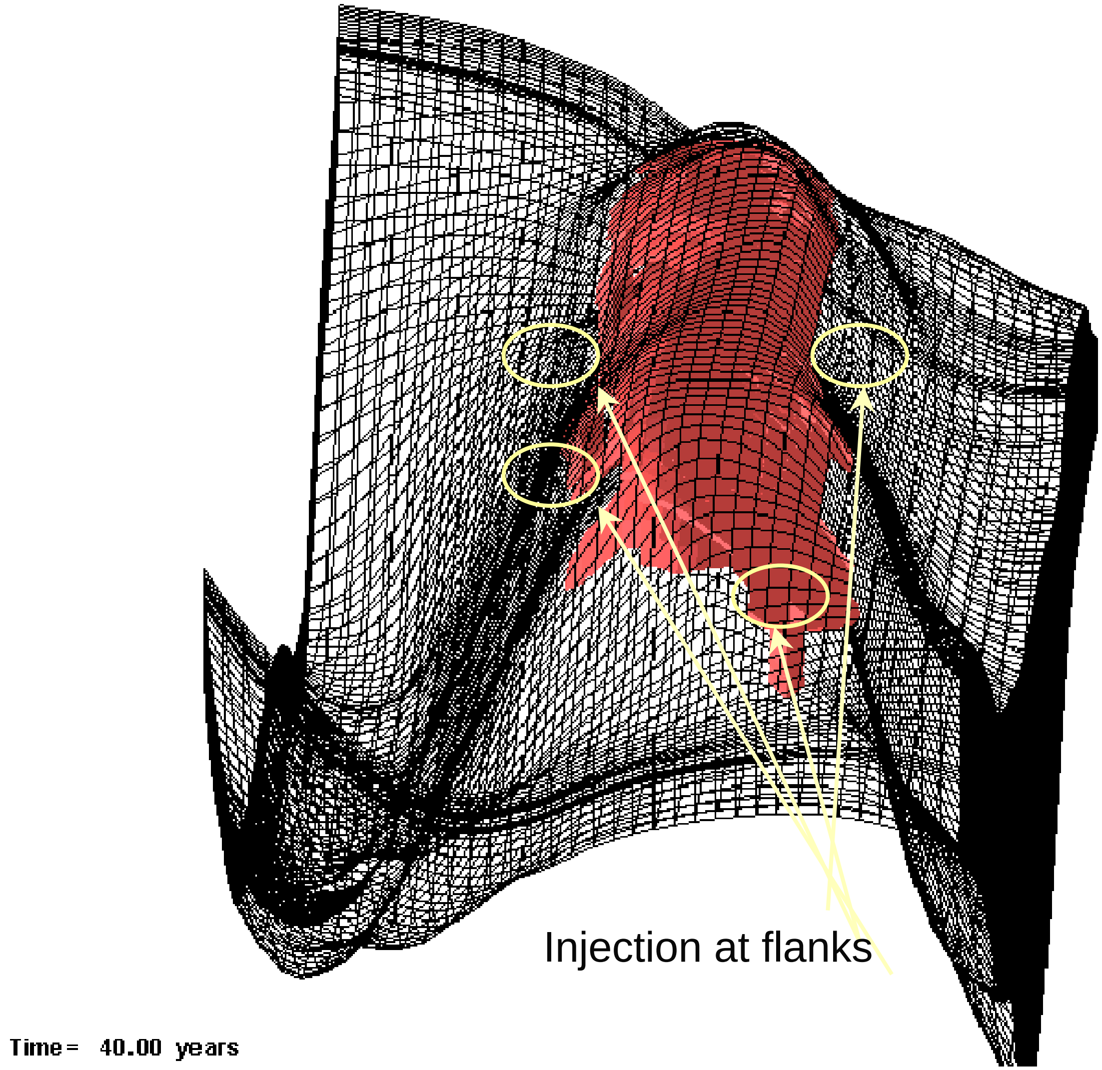
CO_2 Transport and storage Schweinrich structure



- Two pipeline transport routes are possible
- Both routes can be designed to follow existing pipeline corridors >90%
- Structure can contain 1,4 billion ton of CO2, equivalent to about emissions from 6000 MW their whole lifetime

Reservoir simulation – 40 year model

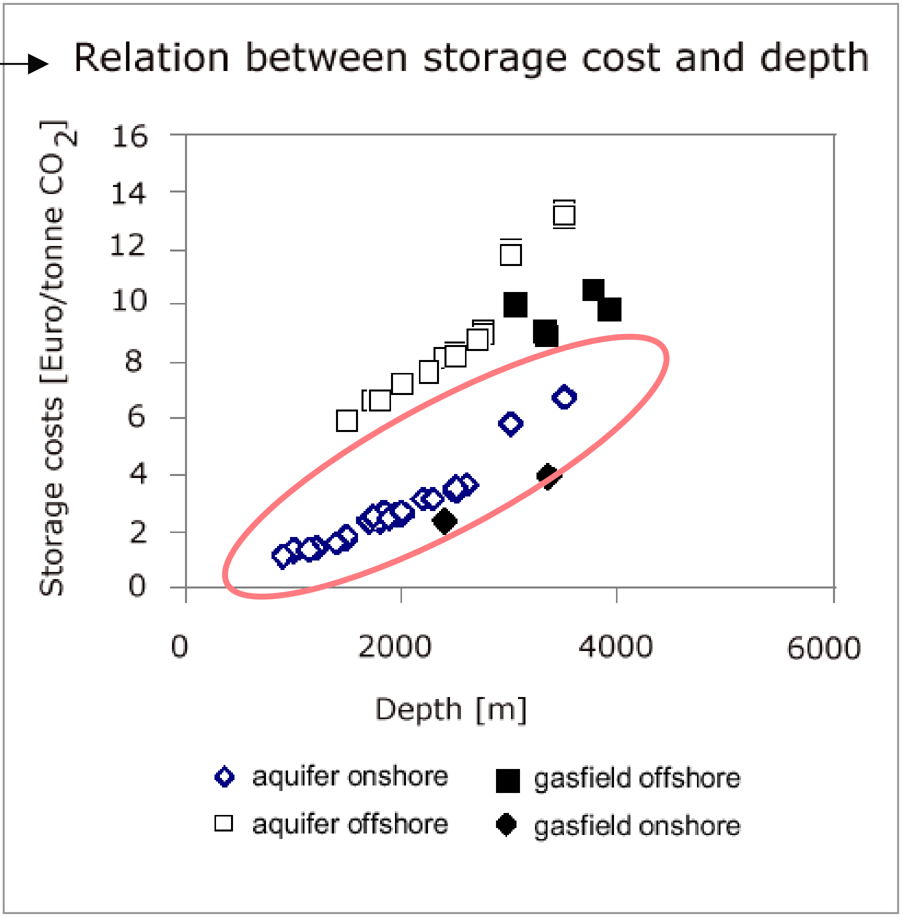


- Due to buoyancy, the CO_2 strive against the top of the formation
- The CO_2 spreads in the whole reservoir
- Conclusion: It is possible to inject 400 Mt CO_2

Storage cost estimates

Storage in aquifer traps (GESTCO Figures)

- **Costs depend strongly on the depth of subsurface layers used for storage**
- **The strongest subsurface uncertainty in storage costs lies in the time it takes to fill the trap**
- **The second important uncertainty parameter is the exploration success ratio of finding a suitable trap**
- **Dutch case: CO_2 source of 5.7 Mton/year stored in one megatrap or a conglomerate of traps. Total sequestration cost: 17-20 Euro/ton CO_2 av.**



Källa: Christian Bernestone Vattenfall Utveckling

CO_2 pipelines in operation in the USA

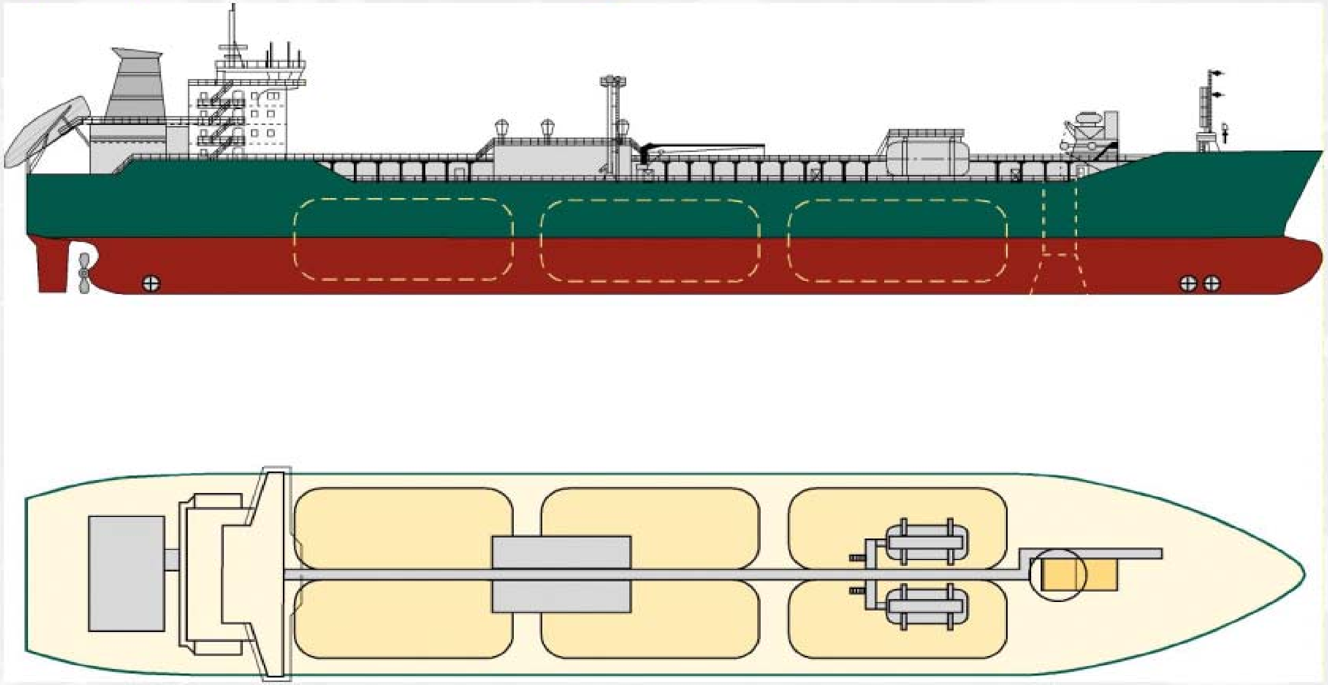
Transportation with water carriers

Transportation of CO_2 in Semi-Cooled Ships.

STATOIL

Illustrated ship has a carrying capacity of 20 000 m3

Project participants: Navion, SINTEF, Vigor and Statoil



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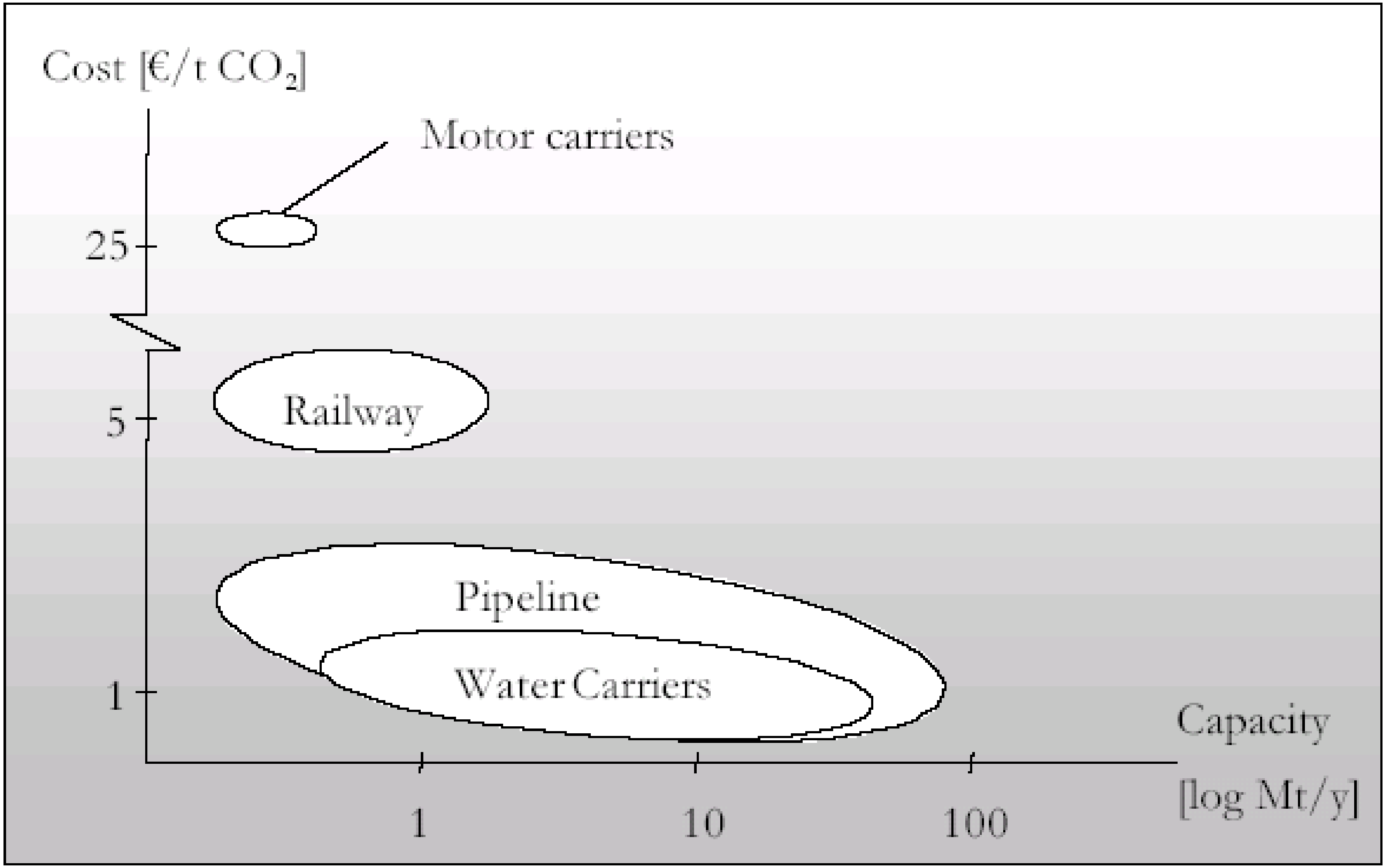
Transport costs for CO2
Cost and capacity ranges



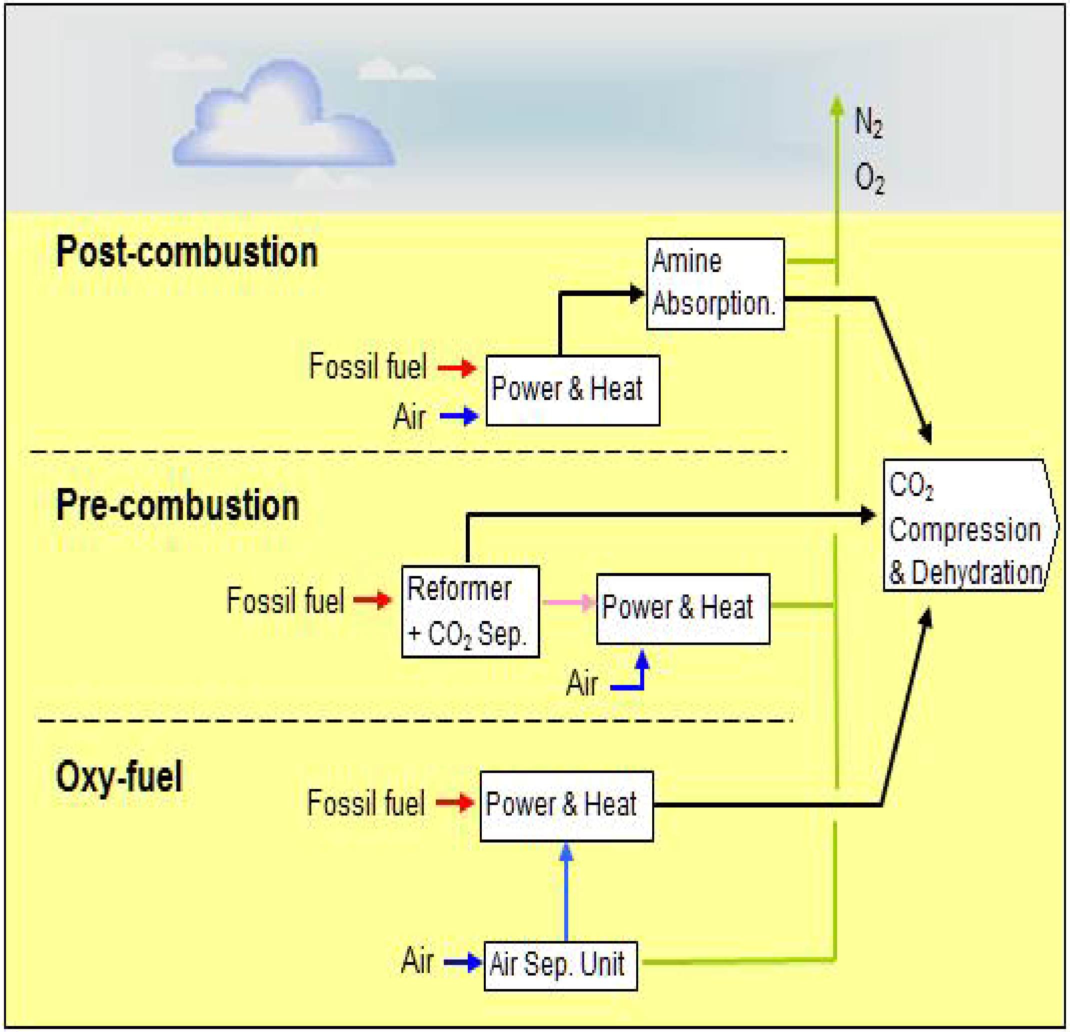
Source: Odenberger M, Svensson R, Analysis of Transportation Systems for CO2, Chalmers, 2003

Capture technologies

Key points - Technology Options

Three technologies seems capable to fulfil the primary target to 2020. No “new” technology can do that.

- All three largely contain known technology and components
- All need optimization, scale up and process integration



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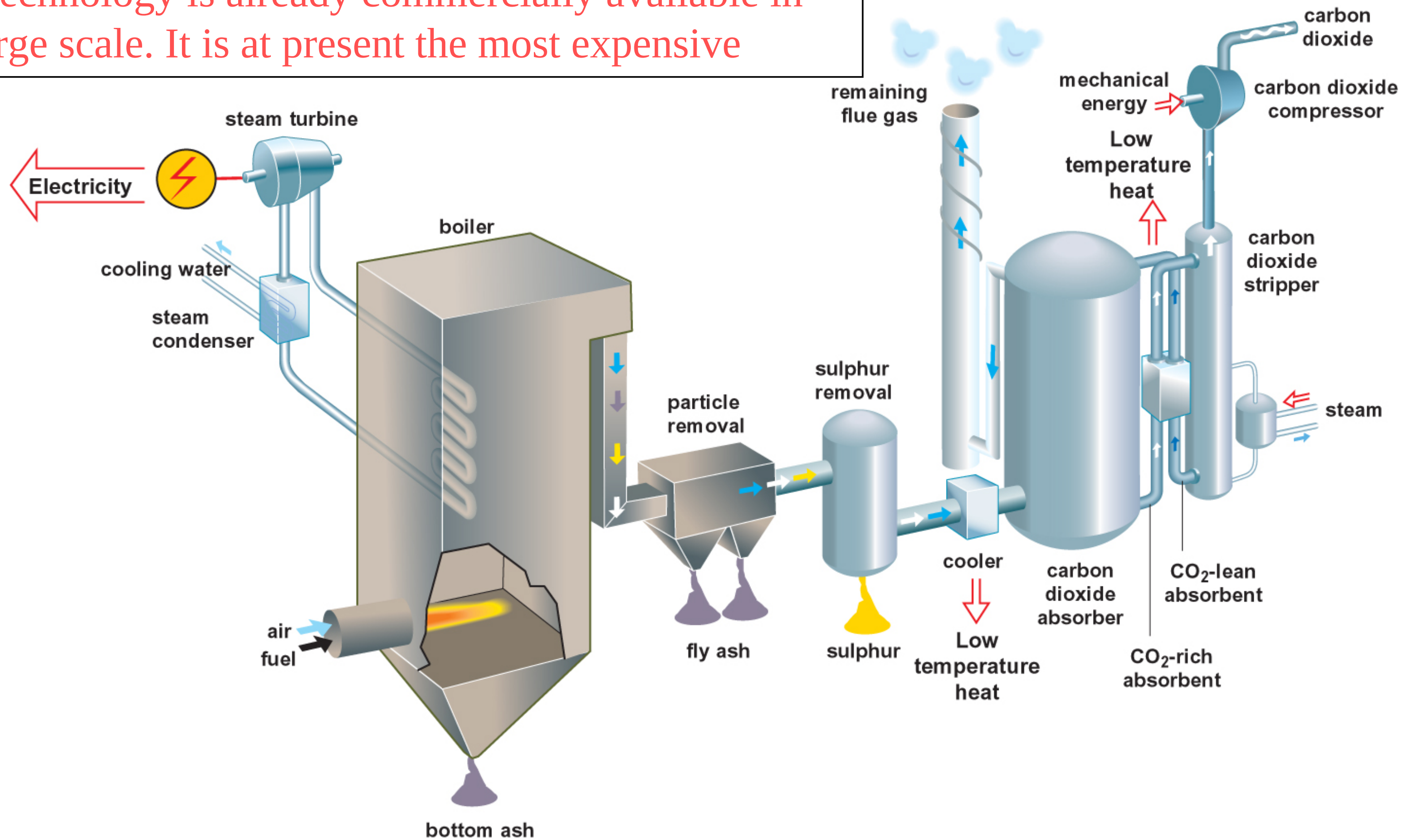
Post-combustion capture

This technology is already commercially available in large scale. It is at present the most expensive



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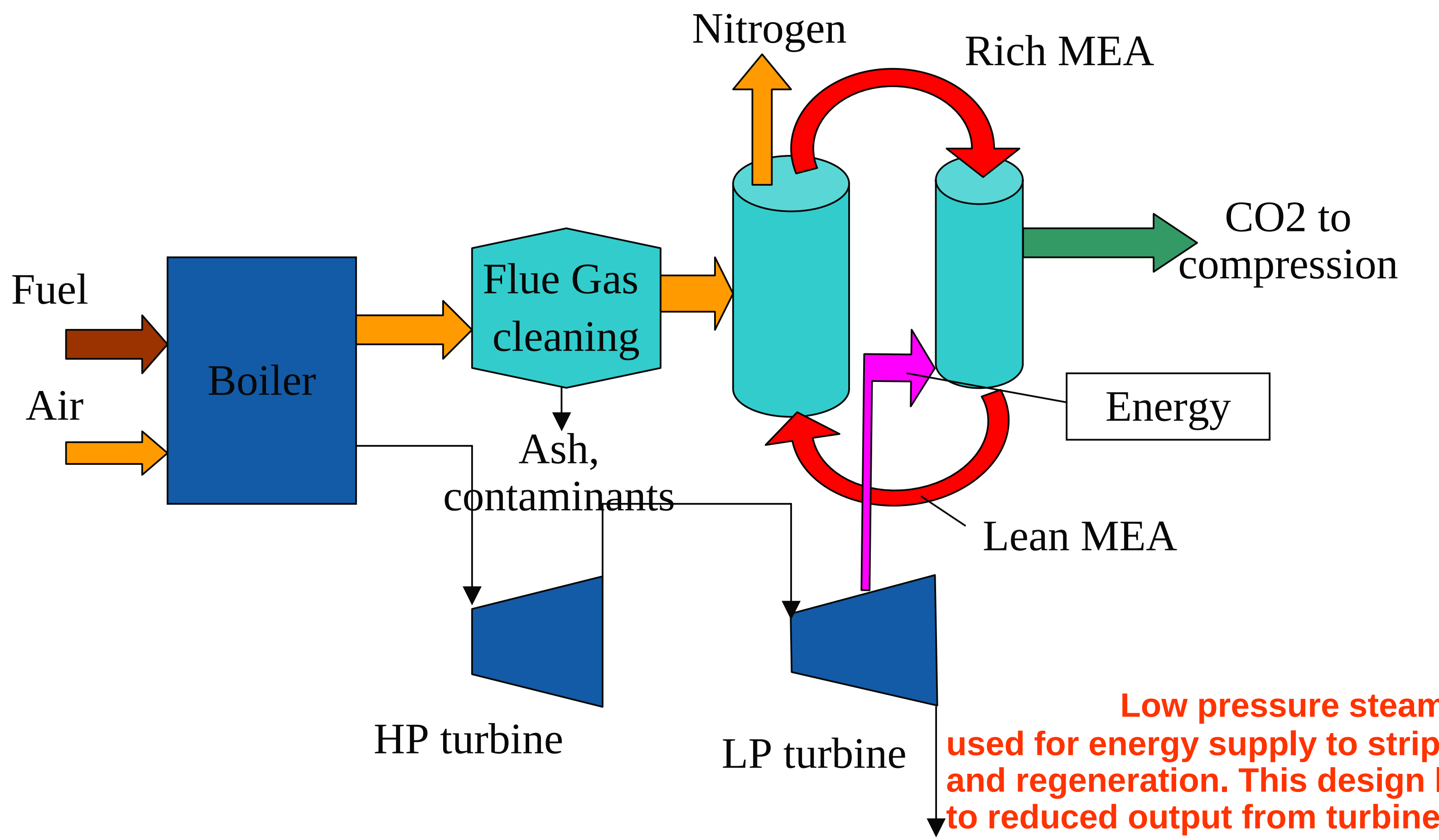
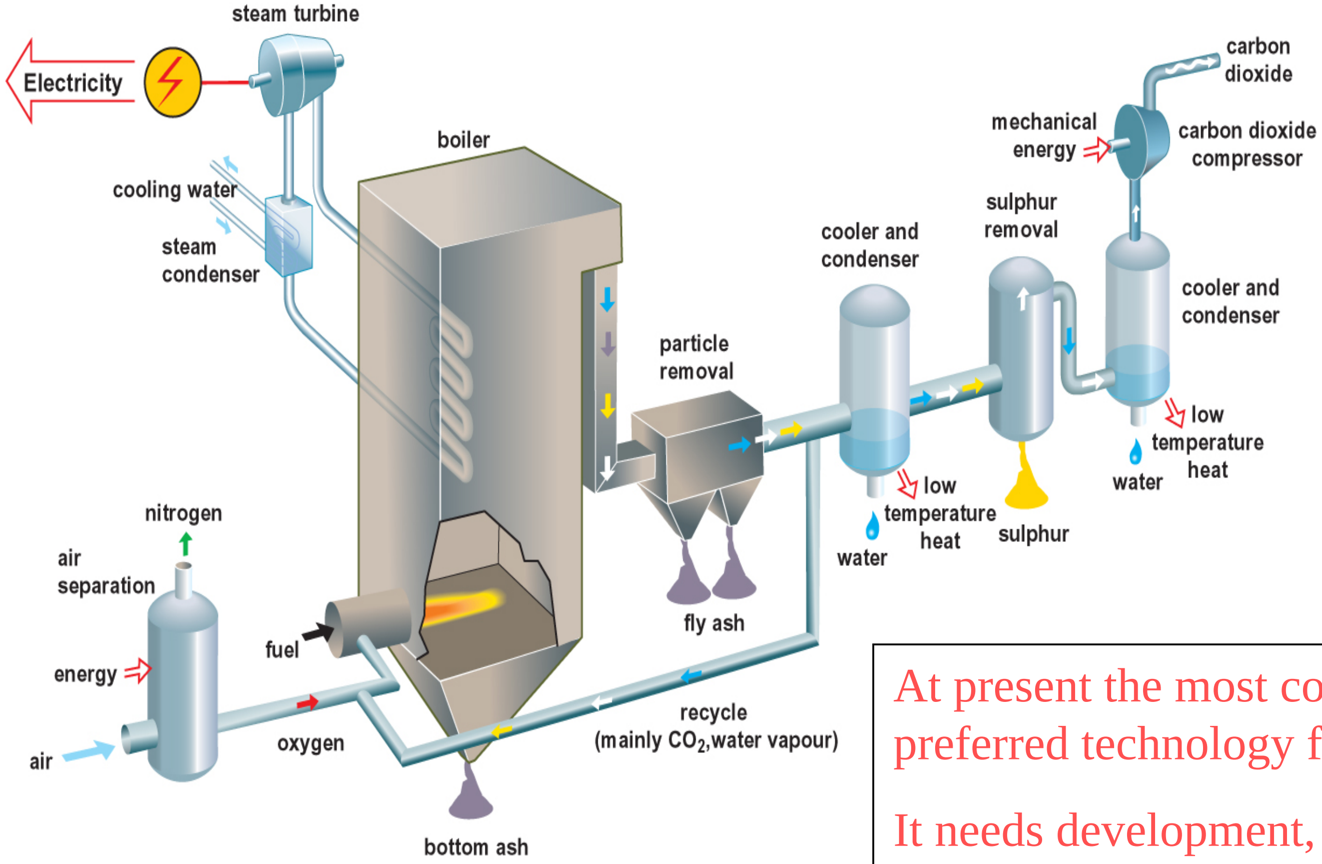
Amine Absorption process principle



Low pressure steam is used for energy supply to stripping and regeneration. This design leads to reduced output from turbine (400 MW instead of 500)

O_2/CO_2 combustion is the preferred option at present



At present the most competitive and preferred technology for coal.

It needs development, pilot and demo plants to get design data

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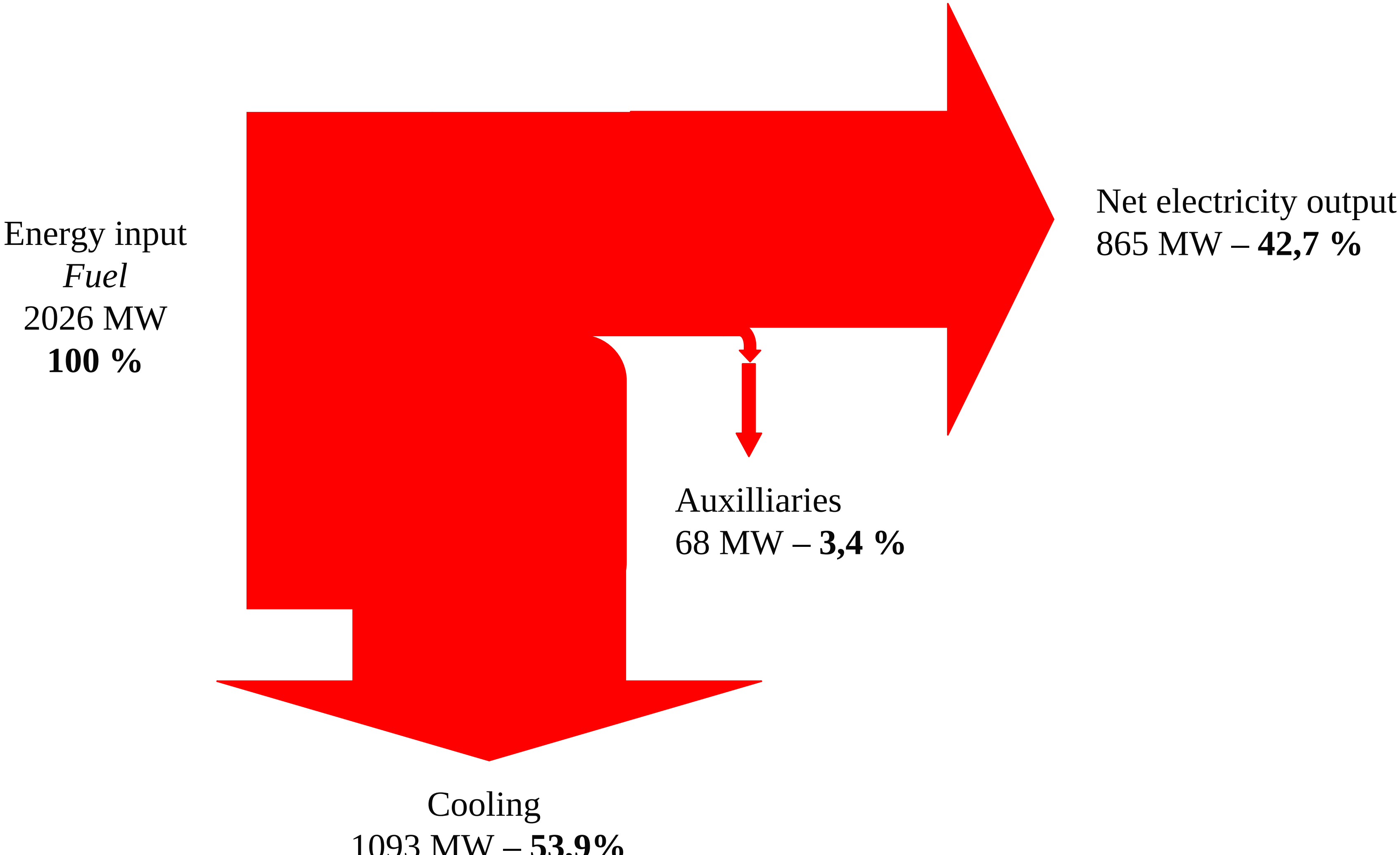
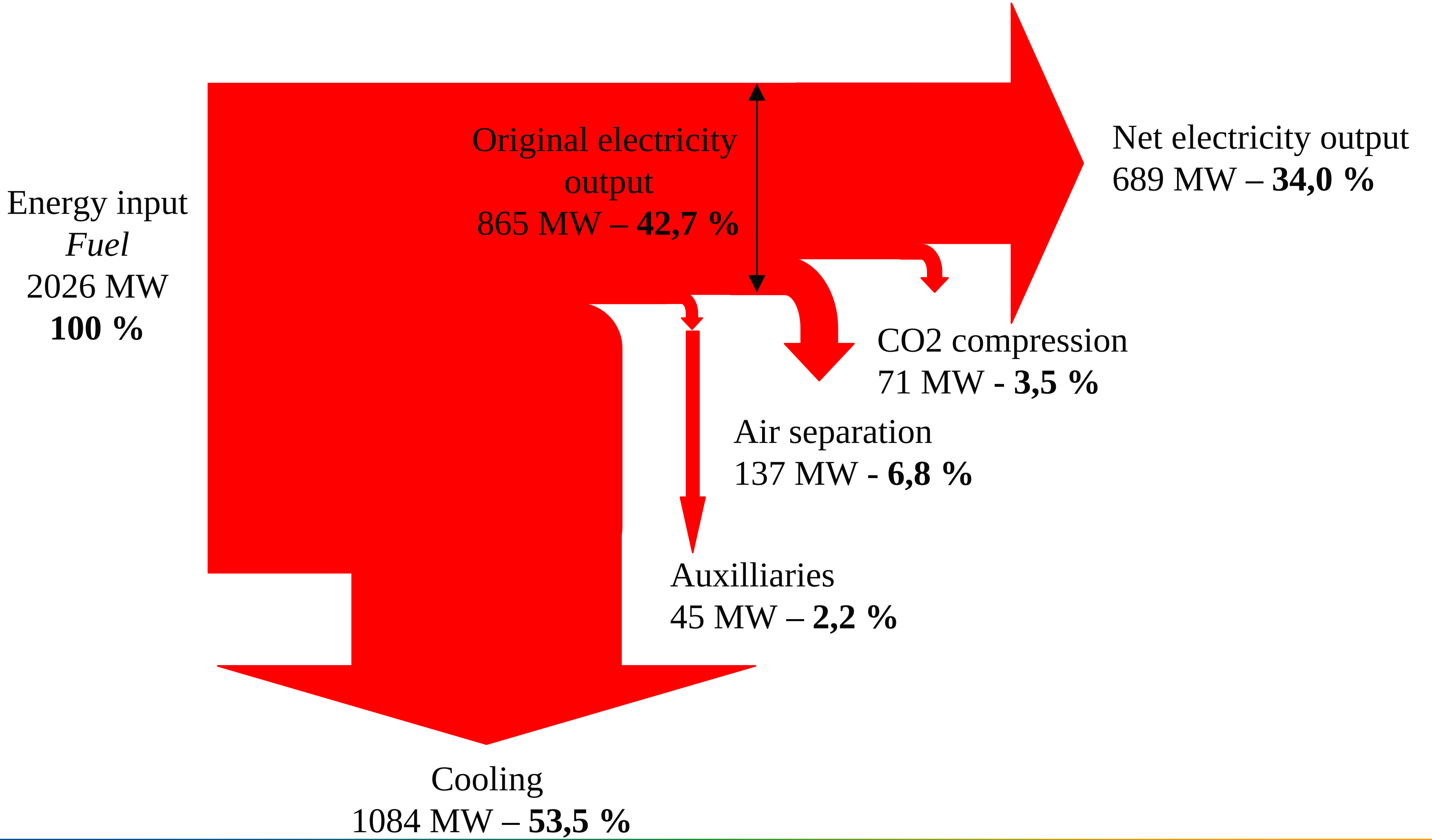
Energy flow diagram for a lignite fired Power Plant



Energy flow diagram for lignite fired plant with O_2/CO_2 combustion



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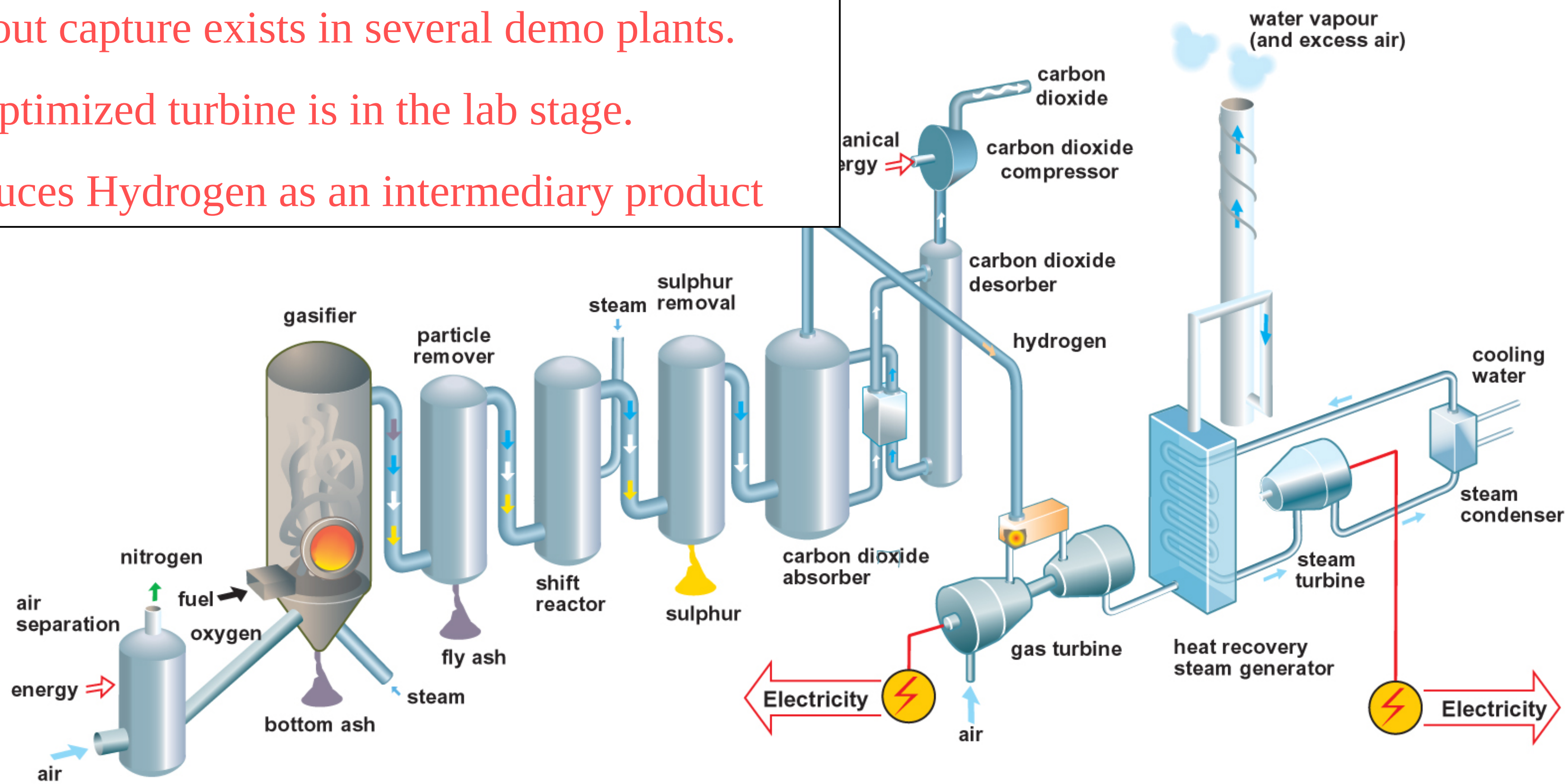
Pre-combustion capture

This technology might be competitive. The IGCC without capture exists in several demo plants.

An optimized turbine is in the lab stage.

Produces Hydrogen as an intermediary product



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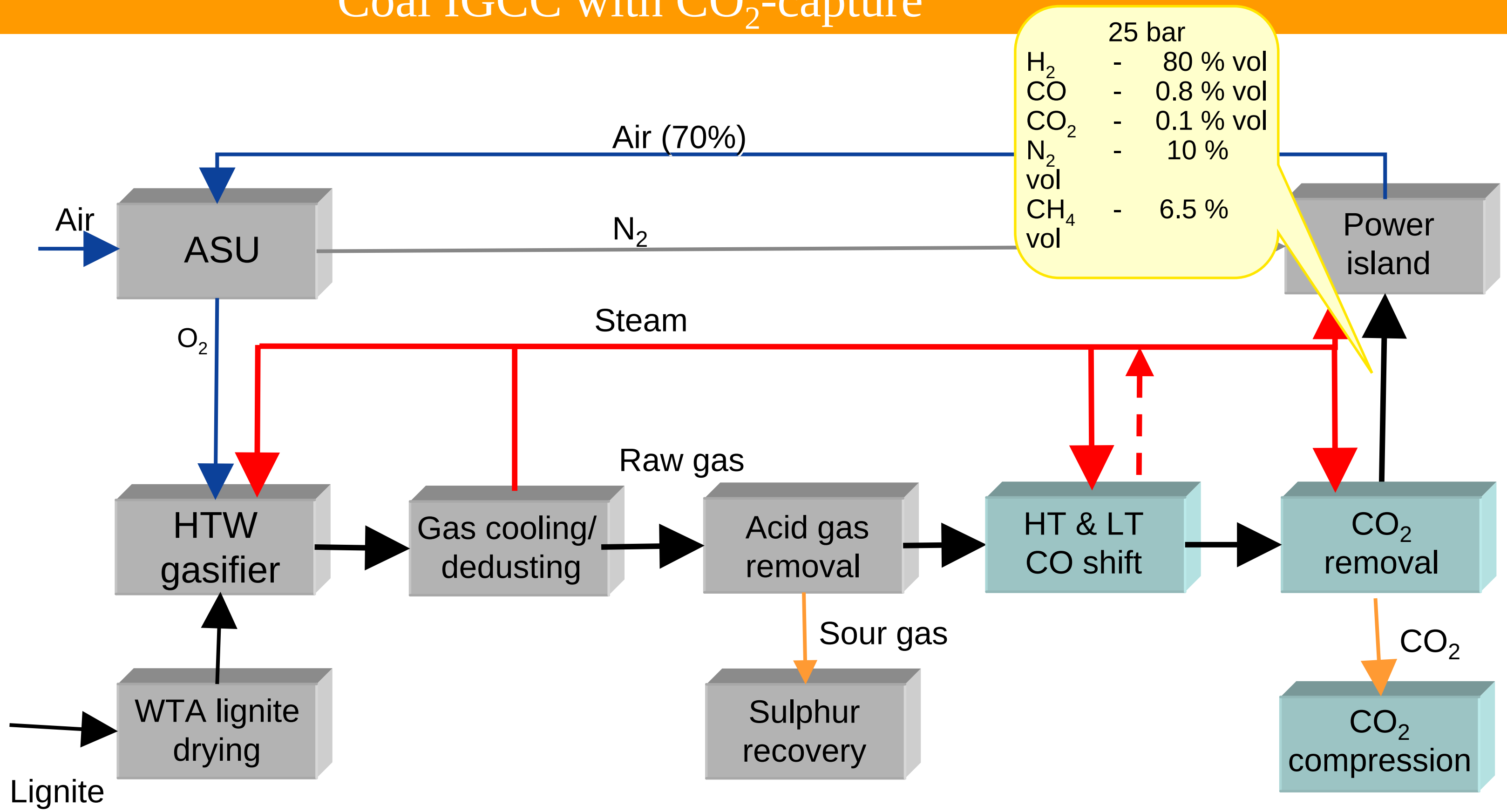
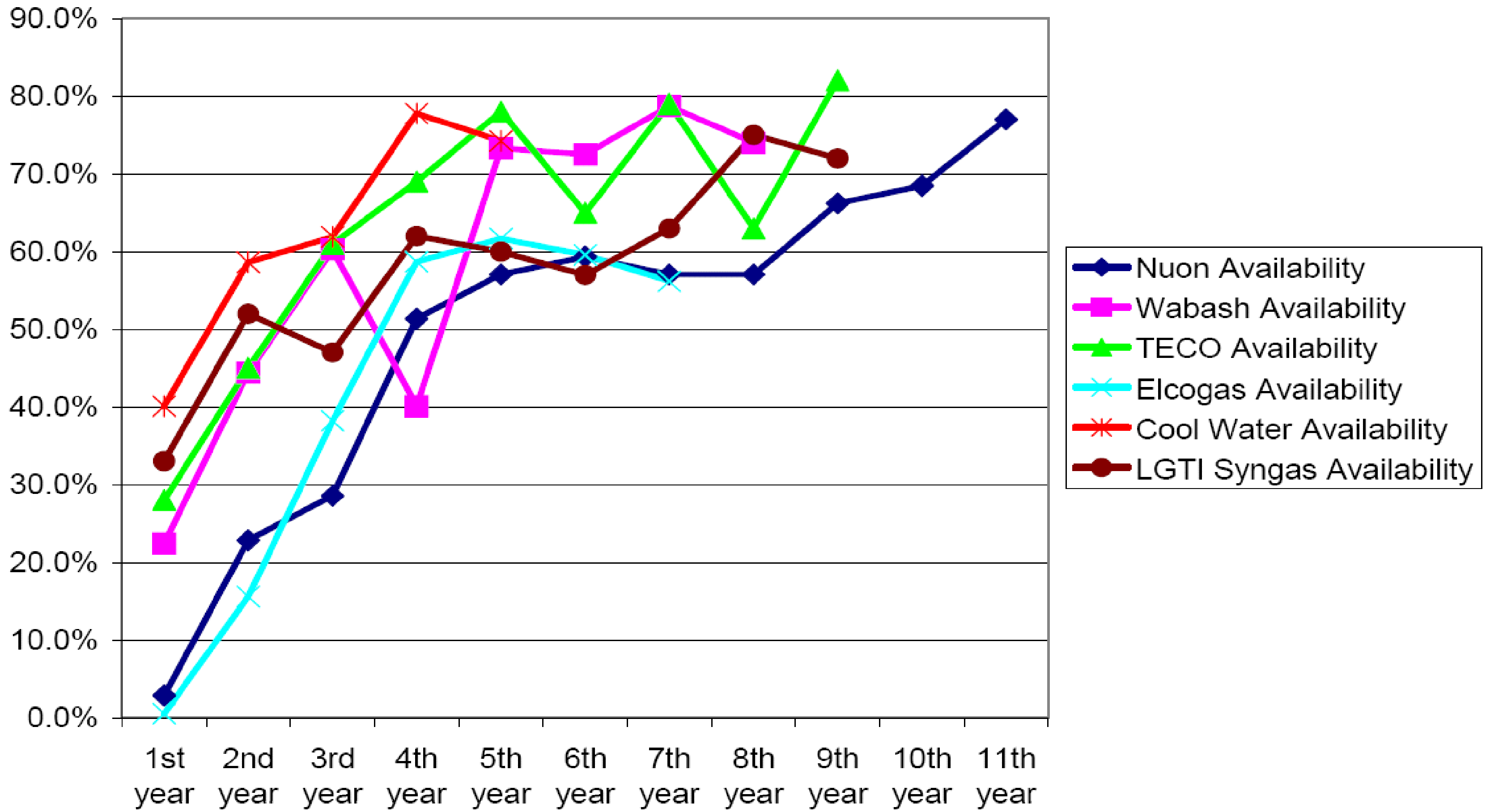
IGCC Process Development

Coal IGCC with CO_2-capture



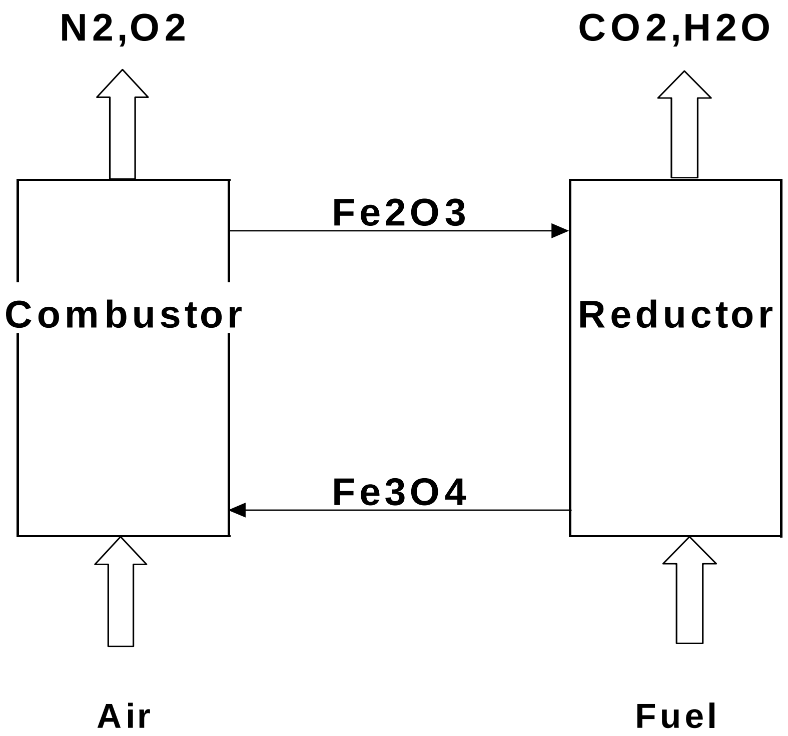
- **LT-Shift necessary for carbon recovery of 85 %**

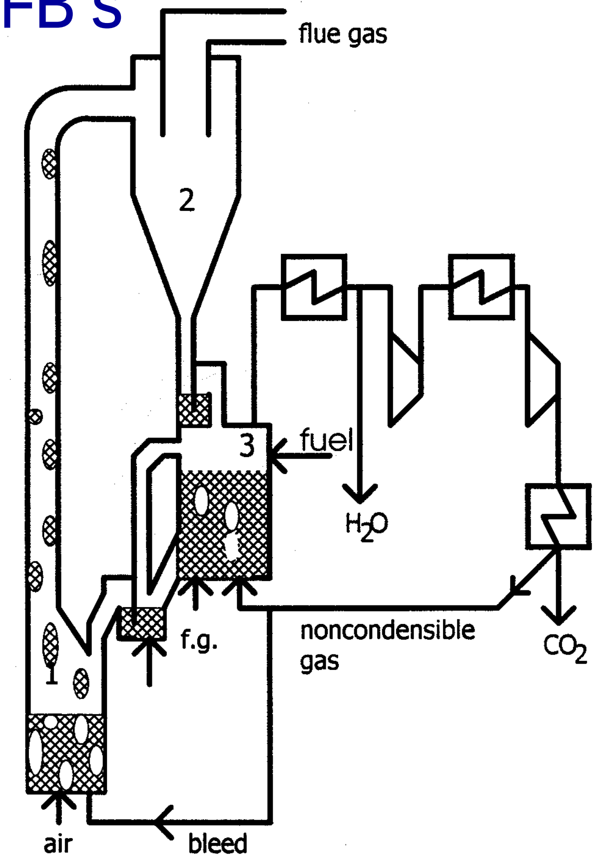
CO_2 free power plant- Pre combustion capture



Chemical Looping

Metal oxides oxygen carriers – a type of oxy-fuel firing – shown here in connected CFB's





Chalmers U., ALSTOM, others

Chemical Looping is a potential breakthrough technology

Benchmarking of the technology options

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Technology Platform Benchmarking

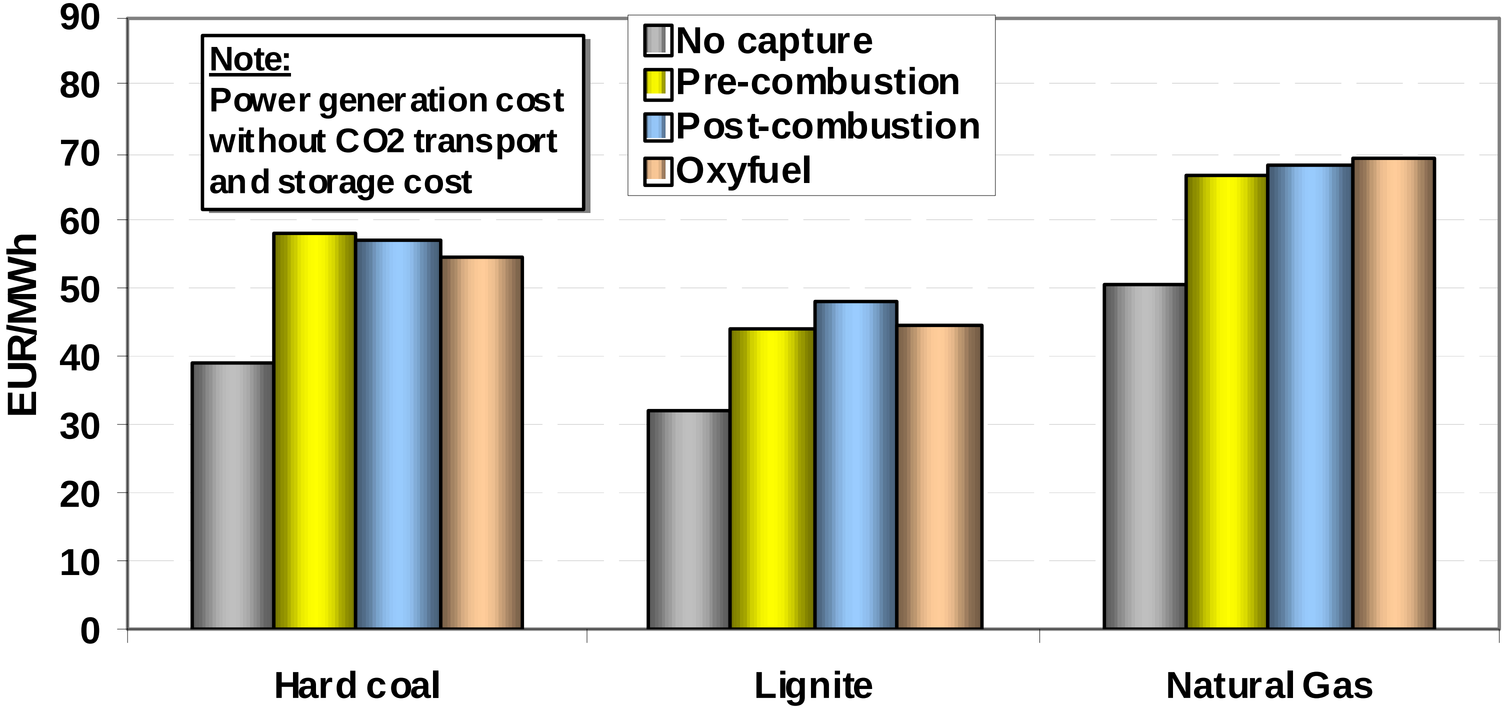
The European Technology Platform for
Zero Emission Fossil Fuel Power Plants (ZEP)

Benchmark

Financial and other boundary conditions		Natural gas	Hard coal	Lignite
Fuel price	€/GJ (LHV)	5,8	2,3	1,1
Plant size	MWe (Ref)	420	556	920
Specific investment	€/MWe (Ref)	471	1058	1278
Common input				
Life time	Years	25		
Wacc	%	8		

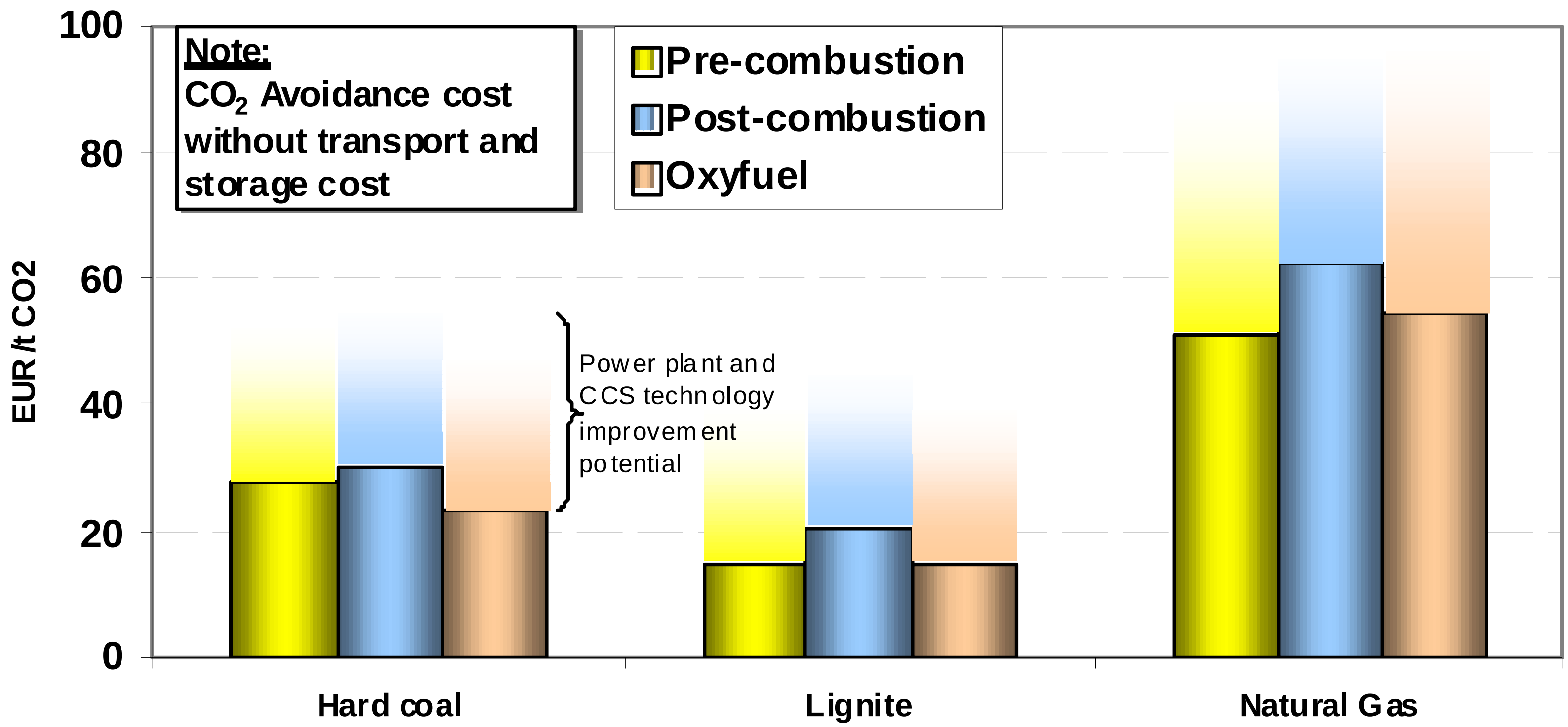
Benchmark

Electricity generation cost for large power plants in operation by 2020 (ZEP WG1)



Benchmark

Avoidance cost for large power plants in operation by 2020 (ZEP WG1)



Technology Platform

Z E P

Zero Emission Fossil Fuel Power Plants

The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP)

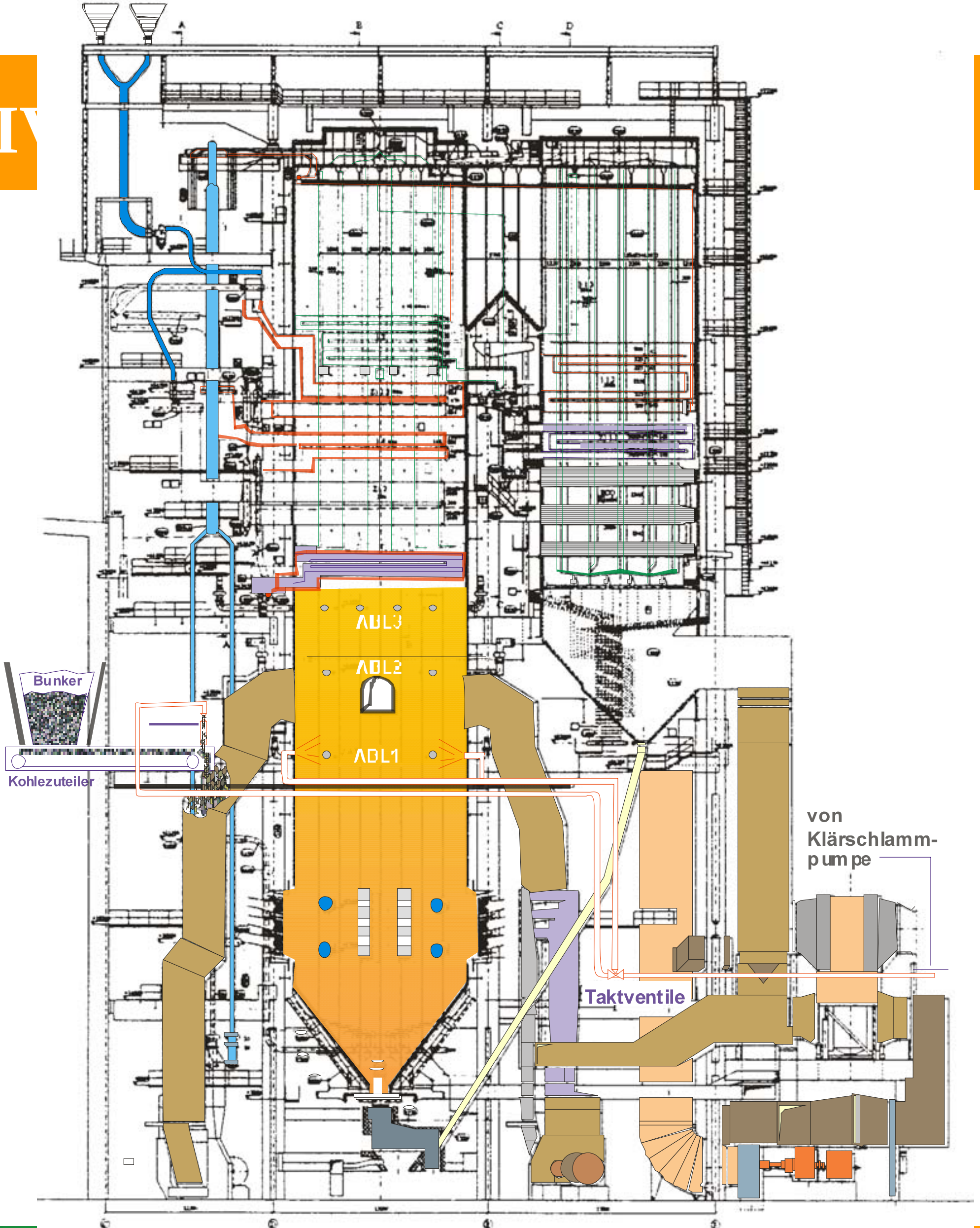
www.zero-emissionplatform.eu

Boxberg IV

Why Oxy-fuel technology ?

We work with all three (four) technologies, but:

- Oxyfuel technology is the technology giving lowest costs at present
- It is suitable for coal and have relatively little development work left
- We can build on our good experience with present PF technology



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The CO_2 free Power Plant project

The Goal

To show that coal can be used in a responsible manner

- It is possible to create a coal fired power plant with “zero emissions”
- There are commercially available primary technology options in 2020
- The cost for carbon dioxide reduction is lower than 20 €/ton of CO_2
- There are even better technologies available after 2020

This will allow us to reduce the carbon emissions with 60 – 80 % within 35 years from our generation portfolio

Parallel R&D routes needed

- Development of the three main technologies for the 2020 target
  - Several large scale pilot and demonstration plants, optimized, with full process integration
  - Supporting R&D to reach lower costs, increase process efficiency and achieve better availability
- R&D for new and emerging technologies for deployment after 2020
  - Many routes to examine
  - Assessment to prioritize the technologies capable to overtake the leading role from any of the three main candidates.

The Logics of the R&D portfolio

R&D path	Technology	Targets	R&D efforts
Basic development for 2020 target	- Post combustion - Pre combustion - Oxyfuel	Ready 2020, 45 €/MWh, 20 €/ton CO_2	++++ + +++++++
Use of process losses	CHP processes	Fuel utilization > 85 % Lower cost	+++
Fuel flexibility and plant versatility	Circulating fluidized beds	Total fuel flexibility, co-combustion, lower cost	+
Post 2020	Chemical looping	No energy losses for separation	++
	IGWC Hybrid technologies	Higher efficiency, lower cost, hydrogen adaptive	+

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Roadmap to realization

2006 | 2015 | 2020

Conceptual investigations
- Theoretical Research

Laboratory Test
- Research
- Basic principles
- Combustion characteristics

Pilot Plant
- Demonstration of the process chain
- Interaction of components
- Validation of basic principles and scale-up criteria
- Long term charac-teristics
- Non-commercial

Demo-Plant
- Verification and optimization of the component choice, the process and reduction of risks
- Commercially viable incl. subsidies

Commercial Plant
- Competitive in the market at that time
- No subsidies

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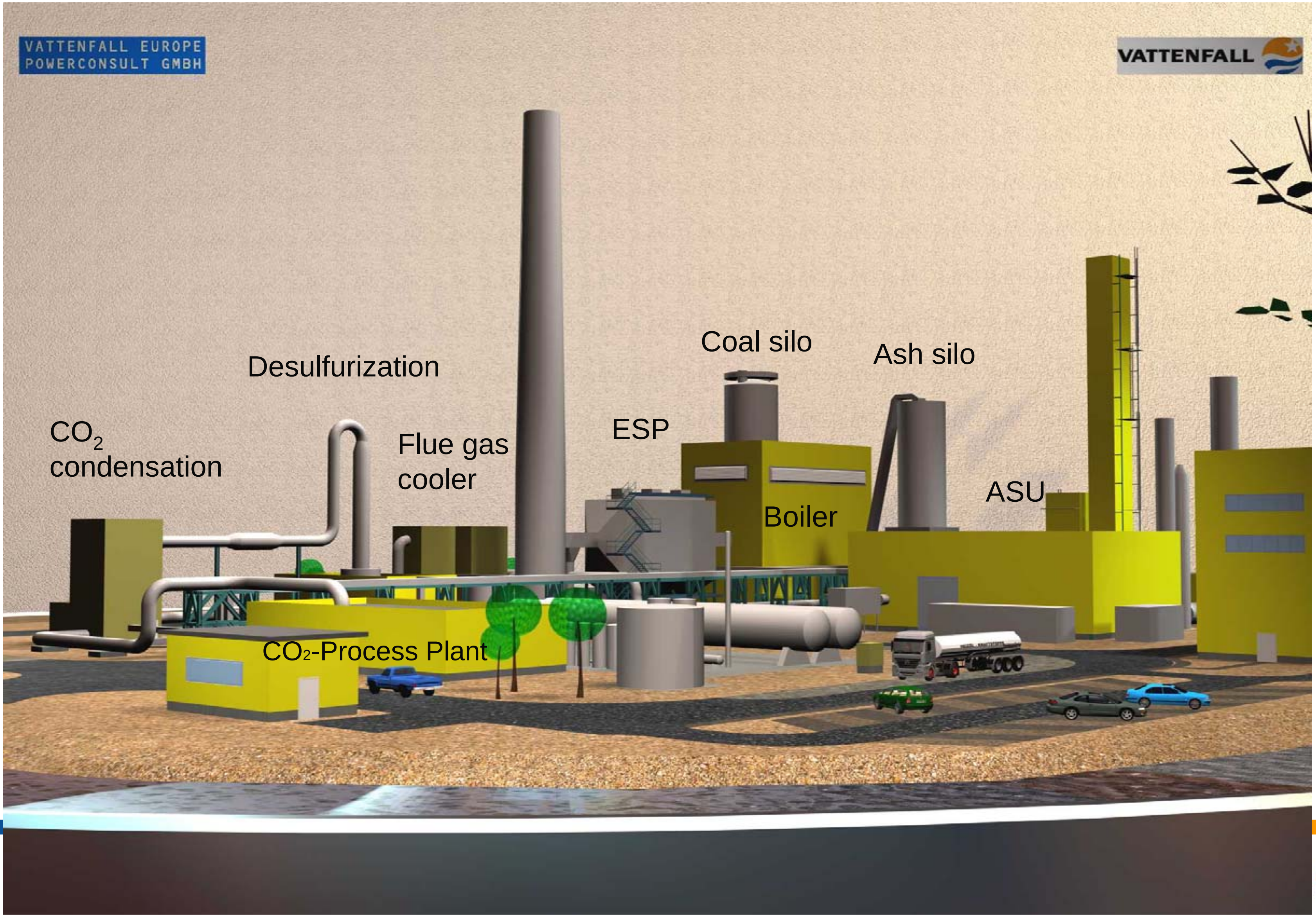
The CO_2 free Power Plant project

www.vattenfall.com/co2free

CO_2 free power plant

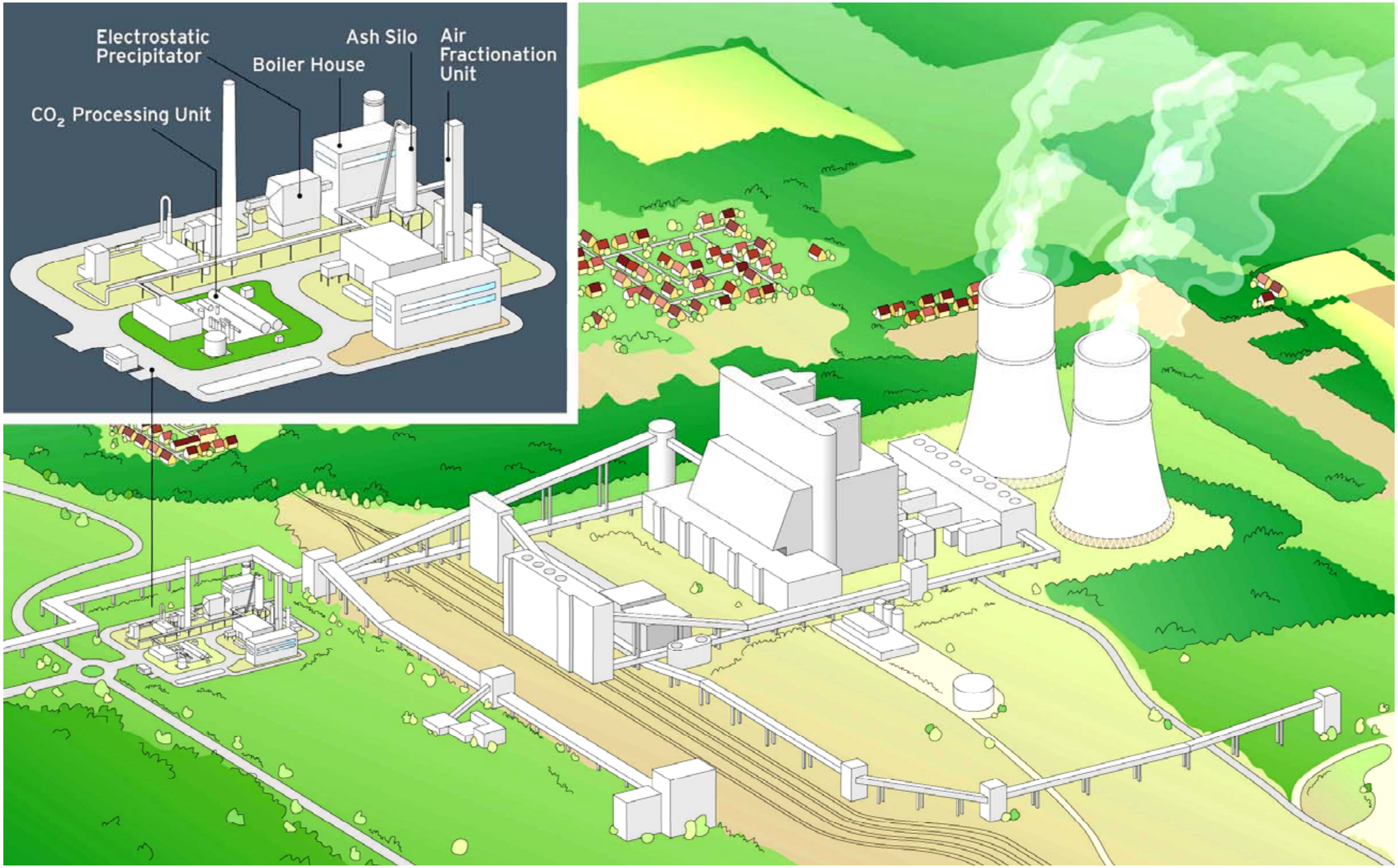
Pilot Plant

Preliminary Pilot Plant layout



Schwarze Pumpe power plant

Location of the pilot plant at Schwarze Pumpe Power station



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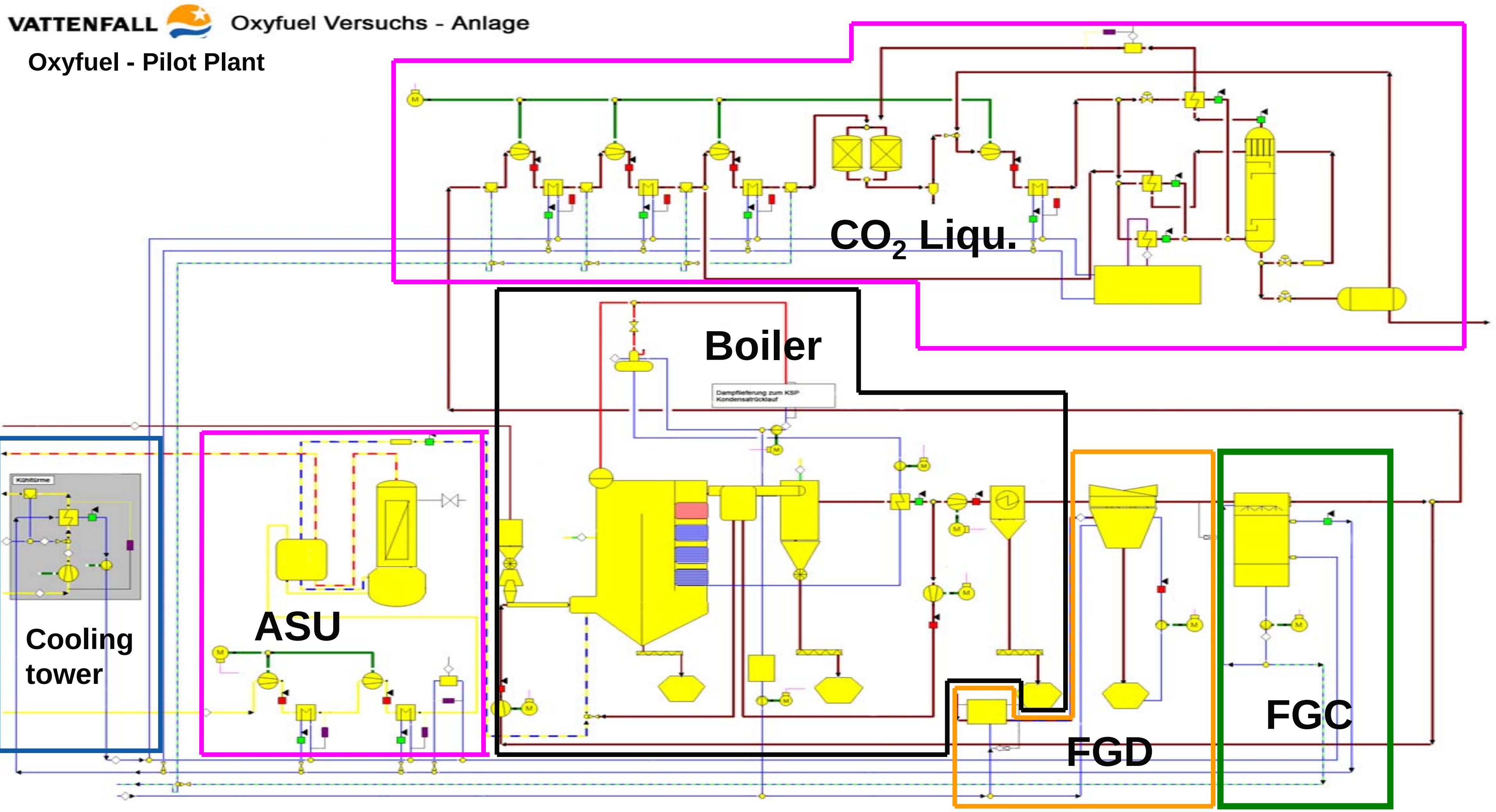
Present status

Pilot Plant component packages



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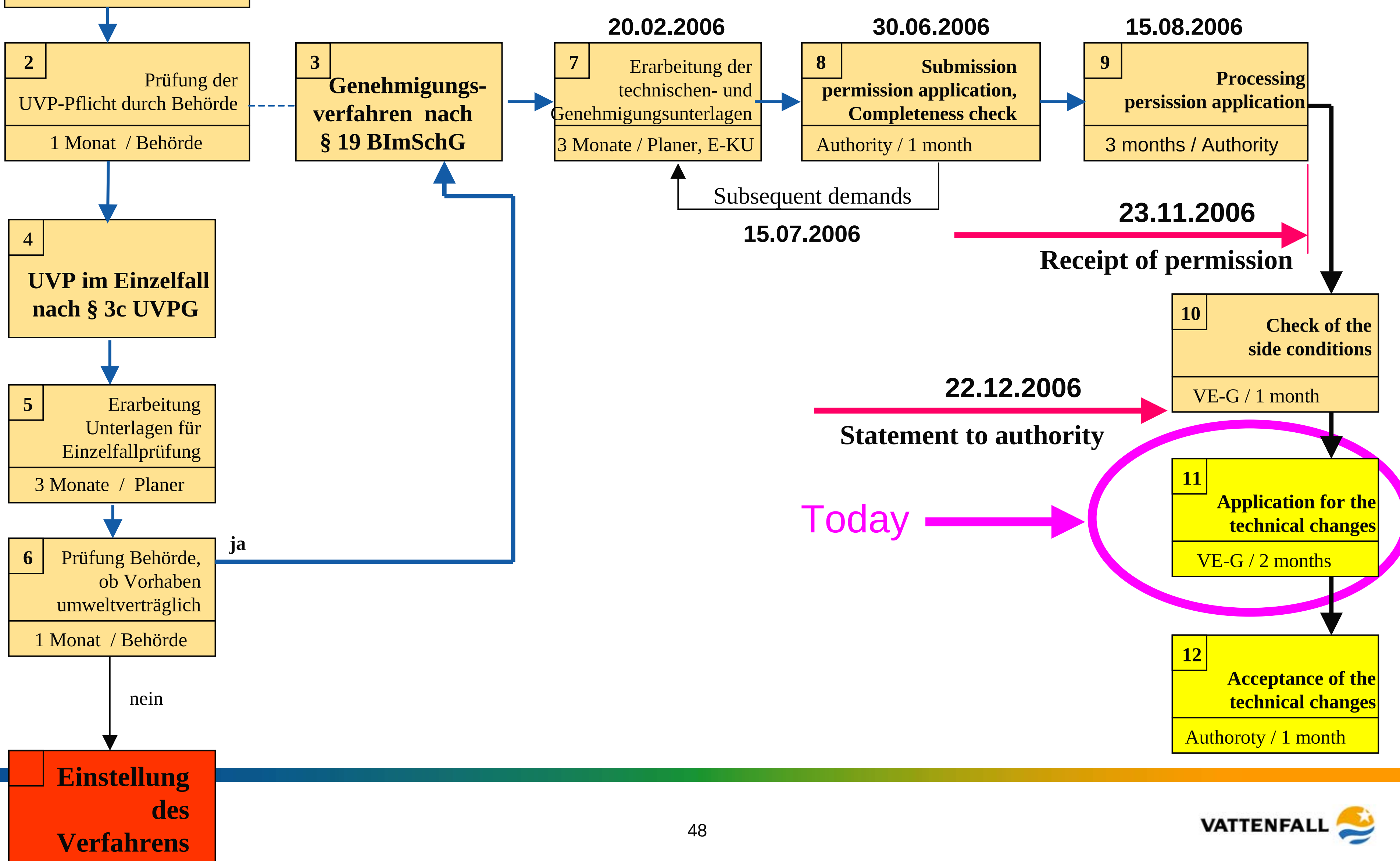
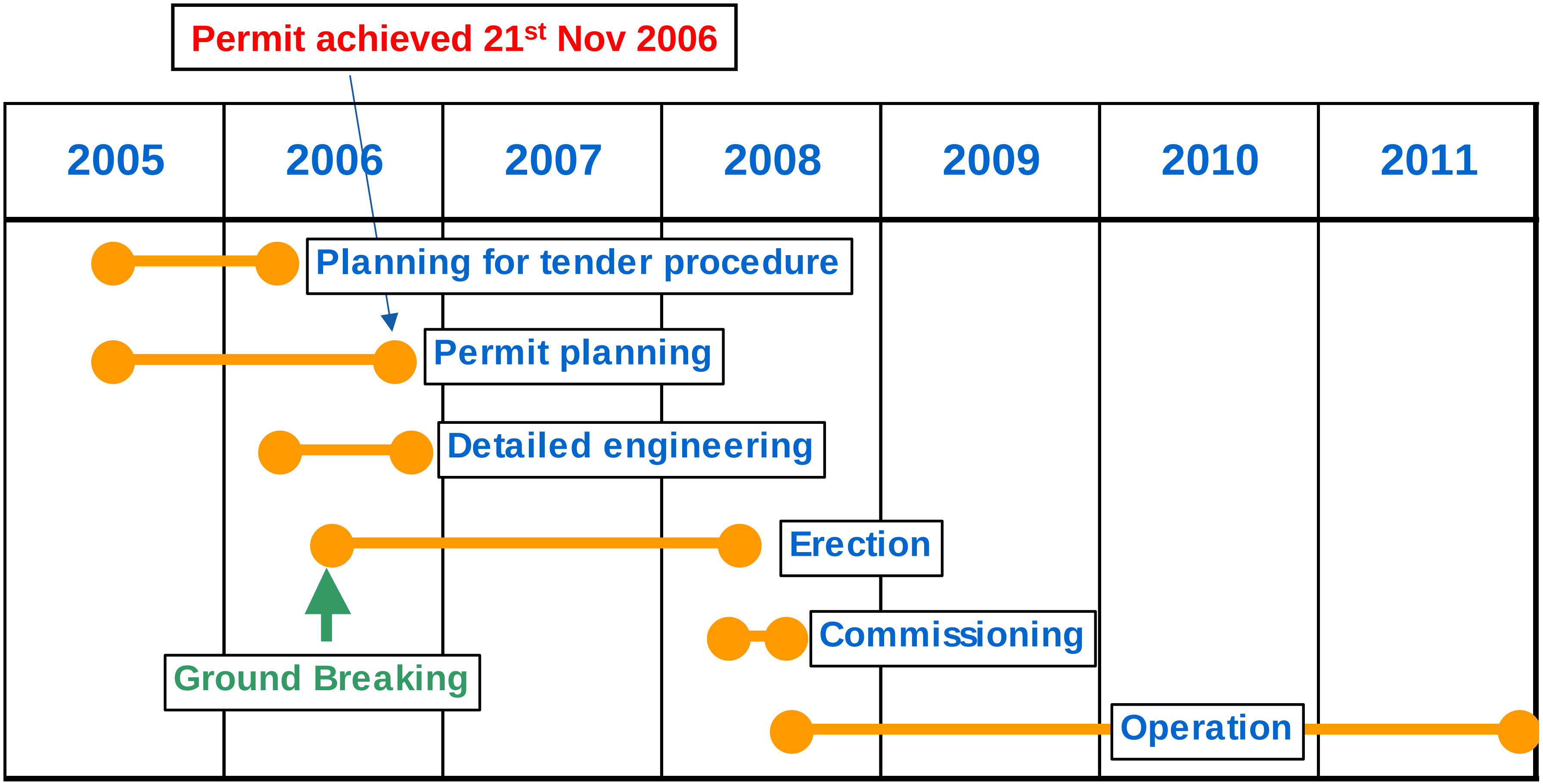
Permission process



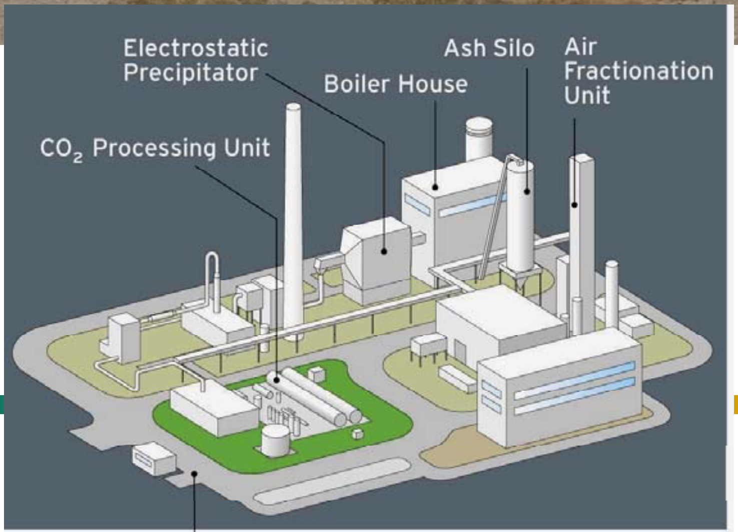
Time Schedule



Pilot Plant

The Pilot Plant's groundbreaking took place in May 2006.

The plant will be in operation in July 2008



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Building site – New year 2007

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Building site – New year 2007

Present status – CO_2 storage

- The plant produces CO_2 of a very high quality
  - It can be stored anywhere, or sold as a commercial product
  - It is a product, not a waste
- Several storage options are examined at present
  - We anticipate to have a storage ready, when considerable amounts of CO_2 start to be produced

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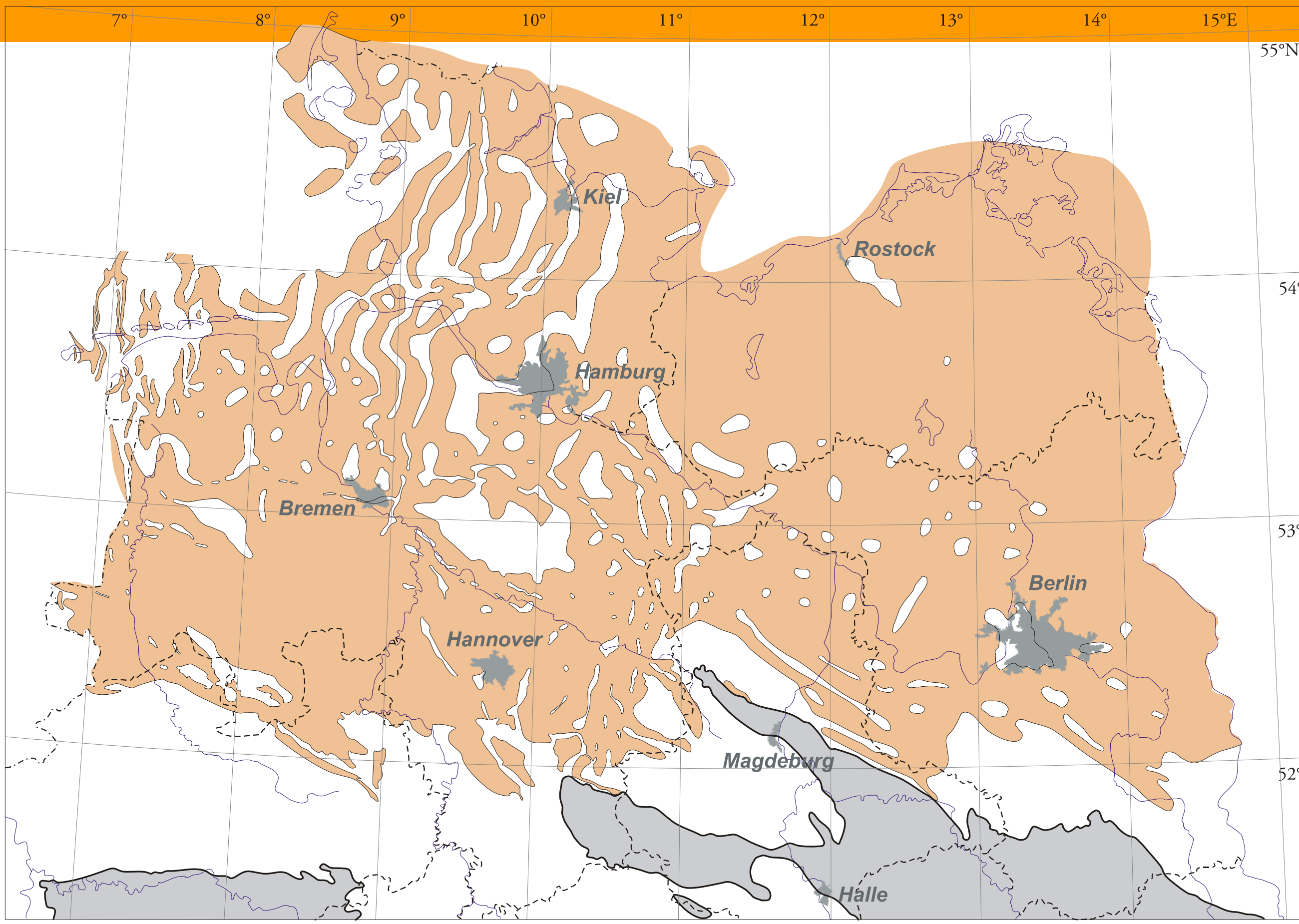
Storage Capacity, saline aquifers



Distribution of Rhetian Basement below Cenozoic cover

Present day distribution of the Rhetian - aquifers (a. DIENER et al. 1984, FRISCH & KOCKEL 1998)

There exists more storage capacity within Eorope (and in the world) than the remaining fossil fuels

Source:

Franz May,

Peter Gerling,

Paul Krull

Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover

Pilot Plant Budget

- Present total budget is estimated at close to 70 million € for the investment in the plant and 23 million € for operating costs during the test period
- Vattenfall has taken decision to finance the Pilot Plant fully. There is presently no public funding at all
- We have invited partners to join us, utilizing the facility and contribute to the funding. Several have indicated participation.
- We seek partners for the storage option

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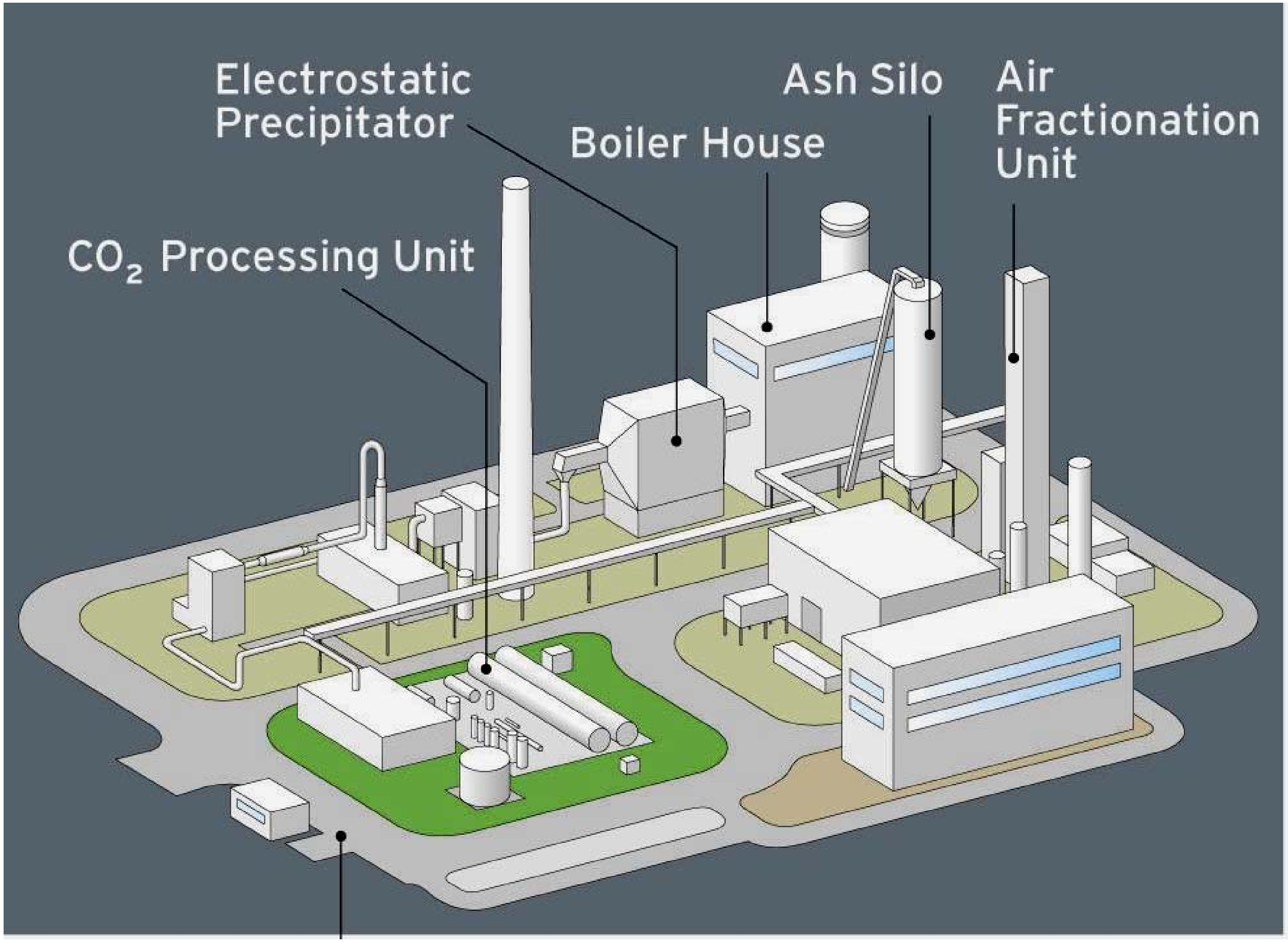
Oxyfuel Pilot Plant



The Demonstration Plant

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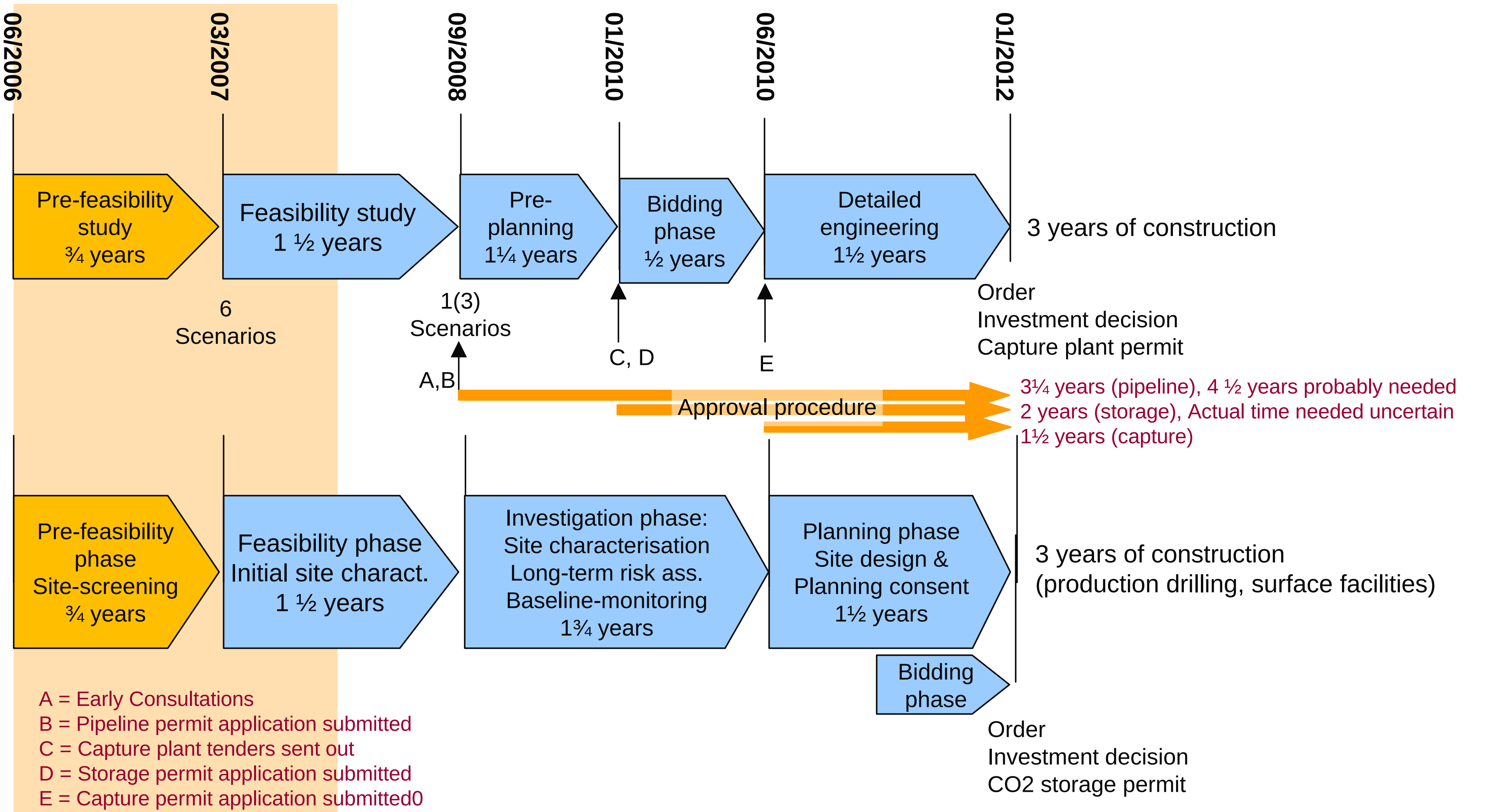
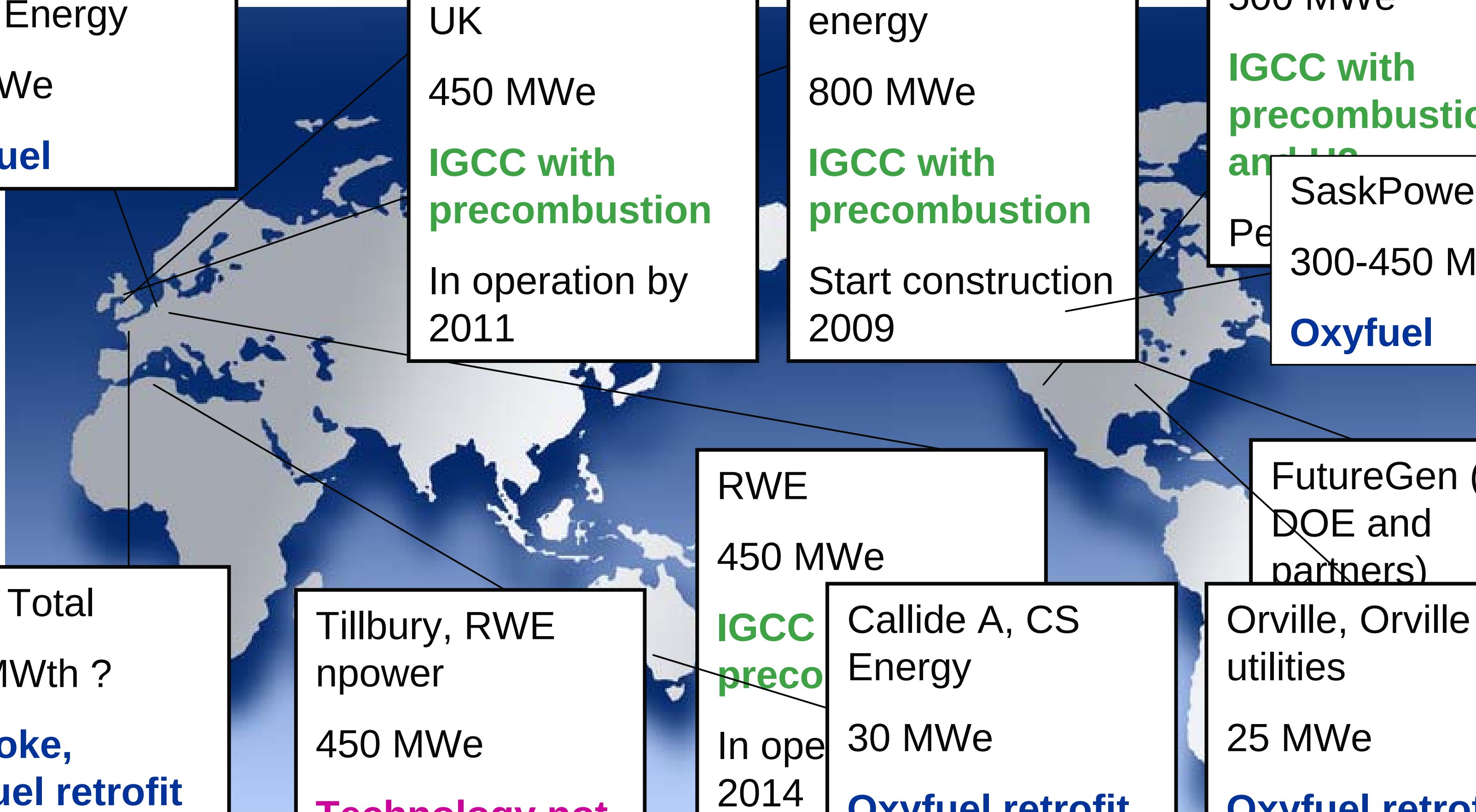
The demonstration project time line: Capture & Storage



Computer simulation of the new units in Hamburg (Moorburg) 2 x 835 MW hard coal

Oxyfuel projects	Characteristics	Pre combustion	Characteristics
Callide, Qld, Australia	30 MW hard coal. 2010	BP, Chevron, Carson Field, Ventura Ca, USA	400 MW. Pet Coke. EOR H2 feed to refinery.2014
Victoria, Australia	350 MW lignite. 2014	Alliance FutureGen, Tx, USA	350 MW hard coal. 2012
Sask power, Canada	350 MW hard coal. 2014	BP, GE, Peterhead, UK	Gas 350 MW, for EOR. 2010
Schwarze Pumpe	30 MWth Pilot. 2008	RWE, Germany	450 MW, Hard coal. 2014
Jupiter Oxygen, Tx, USA	45 MW Demo. 2011	E.on UK, Southern UK	350 MW, Hard Coal. EOR. 2011
Total, Lacq, France	30 MW, heavy oil. 2008	Progressive Energy, Teeside UK	800 MW, hard coal. EOR. 2009
RWE npower, Tilbury, UK	800 MW. Hard coal. 2016	Powerful, Hatfield, UK	900 MW. Hard coal. 2010. Storage ????
SEQ and ONS Energy, Drachten Holland	55 MW Hard coal. EOR. 2011	Nuon, Limburg, Holland	1200 MW, Hard coal. 2014. Storage ???
Post combustion	**Characteristics**		
Shell, Statoil, Tjellbergsodden, Norge	860 MW, Gas for EOR. 2011		
Statoil, Kårstö, Norge	230 MW, Gas for EOR. Pilot 2009. Full 2014		

Examples of planned CO_2 capture plants, coal



SEQ International, ONS Energy
50 MWe
Oxyfuel

Killingholm, E.ON UK
450 MWe
IGCC with precombustion
In operation by 2011

Teeside, Progressive energy
800 MWe
IGCC with precombustion
Start construction 2009

DF2 Carson, BP
500 MWe
IGCC with precombustion an
Pe

SaskPower
300-450 MWe
Oxyfuel

RWE
450 MWe
IGCC preco
In ope
2014

FutureGen (US DOE and partners)
??

Lacq, Total
100 MWth ?
Pet coke, Oxyfuel retrofit
In operation by 2008?

Tillbury, RWE npower
450 MWe
Technology not specified,
retrofit?
In operation 2016

Callide A, CS Energy
30 MWe
Oxyfuel retrofit
In operation by 2009

Orville, Orville utilities
25 MWe
Oxyfuel retrofit
In operation by 2008

Computer simulation of the new Boxberg R unit 660 MW- lignite

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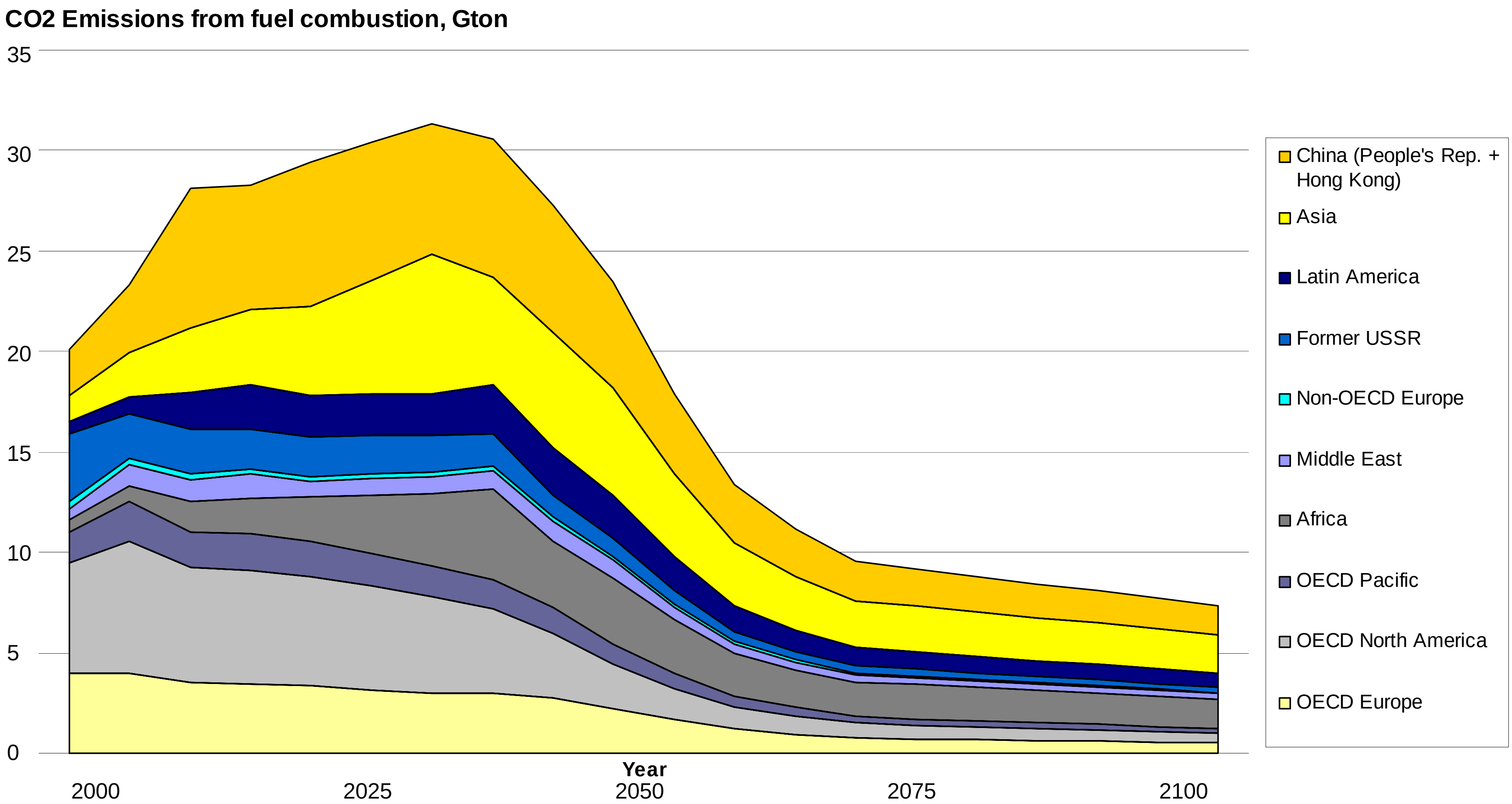
CO_2 free power plant

Back up

In one scenario, the world's emissions peak in 2040, according to the model



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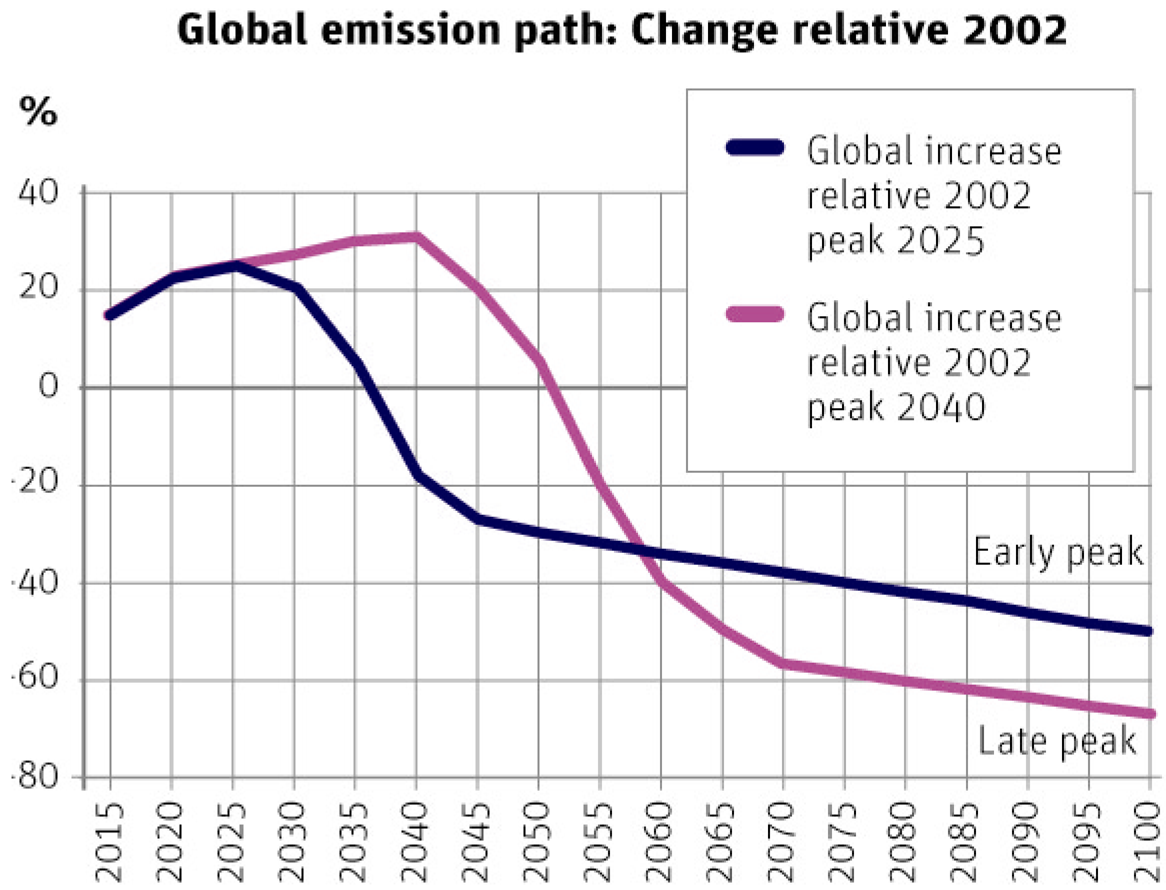
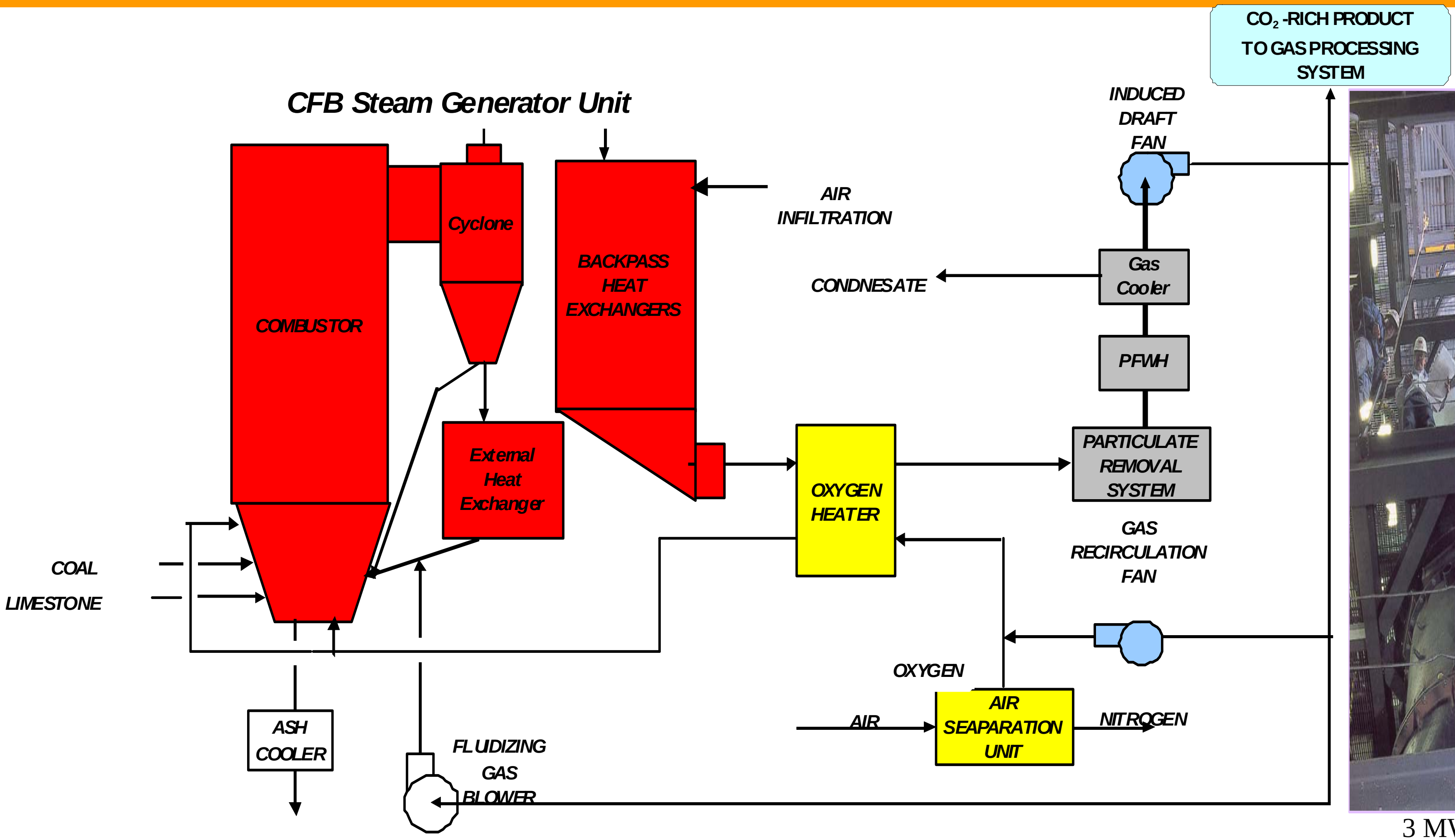
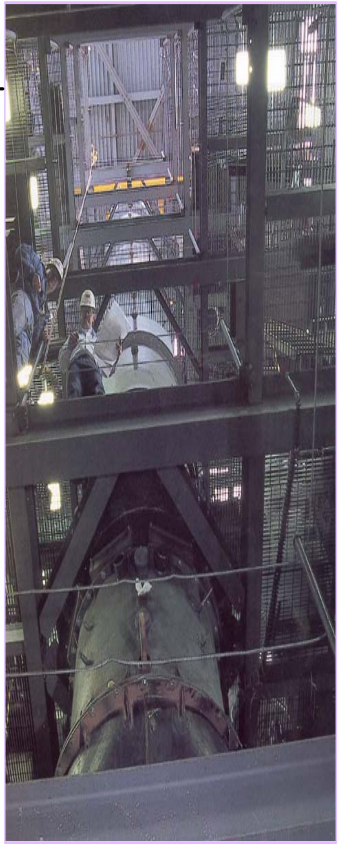
Vattenfall's adaptive global burden-sharing model: Emission path scenarios, % change relative to 2002



Oxy-CFB



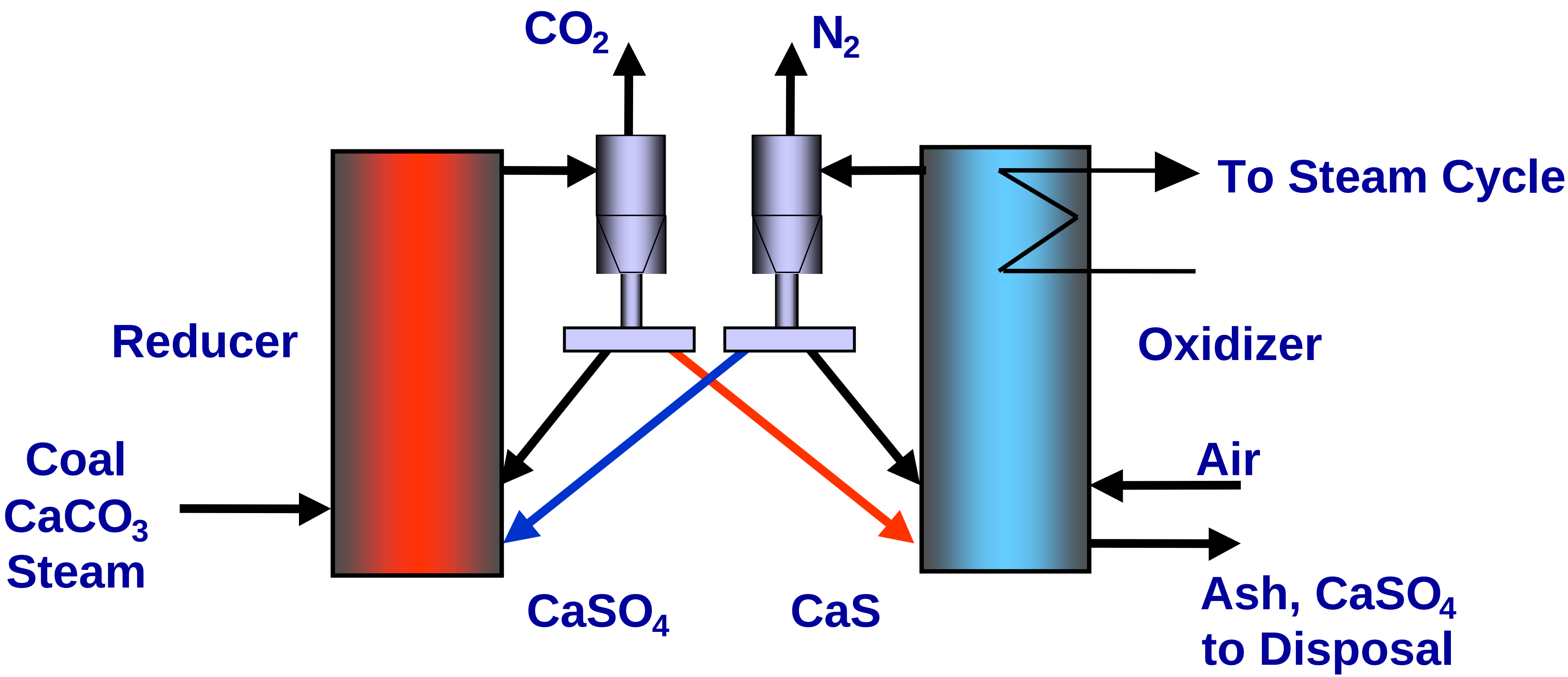


3 MWt pilot CFB

Reduced recycle FGR and resultant smaller boiler & APC

Chemical Looping

CaS - CaSO4 loop in CFB reactors



Combustion with CO2 Capture

Calcium-based oxygen carrier process is suited to coal

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