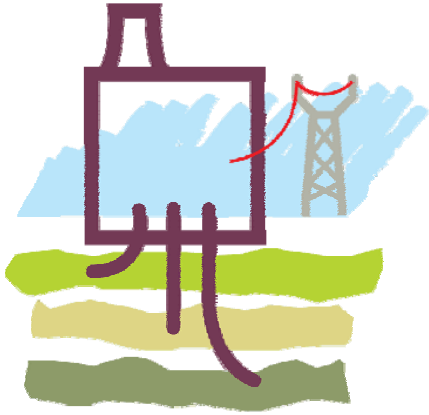


Z E P
Technology Platform
Zero Emission Fossil Fuel Power Plants

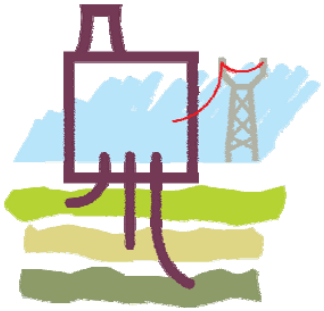
ZEP
The Zero Emission Power Plant Technolgy Platform

MIT, Cambridge, 1st of November 2006

Lars Strömberg

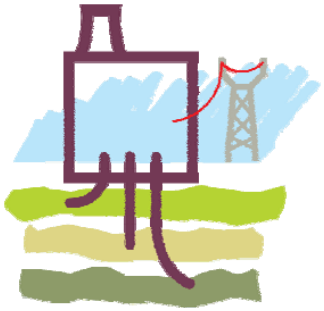
Vattenfall AB

Stockholm/Berlin



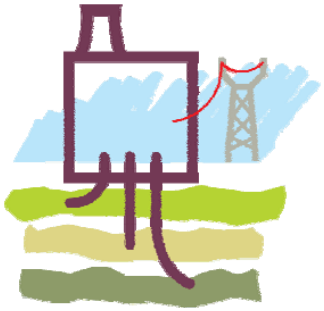
The ZEP

What is the ZEP



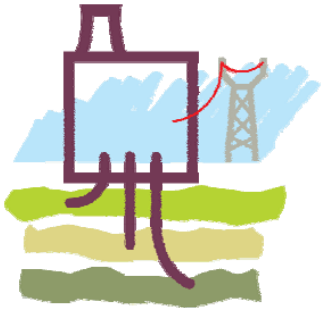
What is the ZEP ?

- The Zero Emission Platform is an initiative within the European Union to get a common view on
  - Present status of the CCS technology
  - Examine the GAPs and hinders to develop CCS to a commercially available option in 2020 and beyond
  - Create a strategic research agenda
  - Define a deployment route
- The work has been performed by more than 100 persons nominated from different parts of society
- The result is presented in form of
  - Reports from five different working groups
  - A Strategic Research Agenda
  - A Strategic Deployment Document



The Working Groups

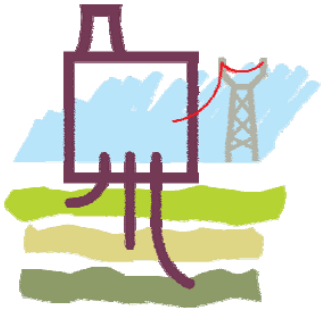
	Working Group	Leads
1	Capture and Power Plant Technology	Lars Stromberg, Vattenfall Johannes Heithoff, RWE Anderas Pistauer, Siemens
2	CO_2 Capture and Use	Tore Torp, Statoil Niels-Peter Christenssen, GEUS
3	Infrastructure and Environment	Graeme Sweeney, Shell Paul Friswold, Bellona
4	Market Regulation and Policies	Fransoise Gigier, EdF Pietro Di Zanno, Air Liquide
5	Communication and Public Acceptance	Philippe Lacour-Gayet, Schlumberger Gabriela von Goerne, Greenpeace



The Groups

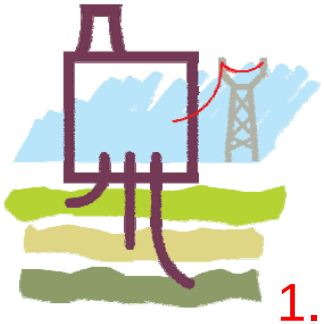
The working groups have worked with the perspectives of different stakeholders. In all 105 stakeholders from:

- The research community
- NGOs
- Equipment manufacturers
- Oil and gas industry
- Power industry



ZEP

The results



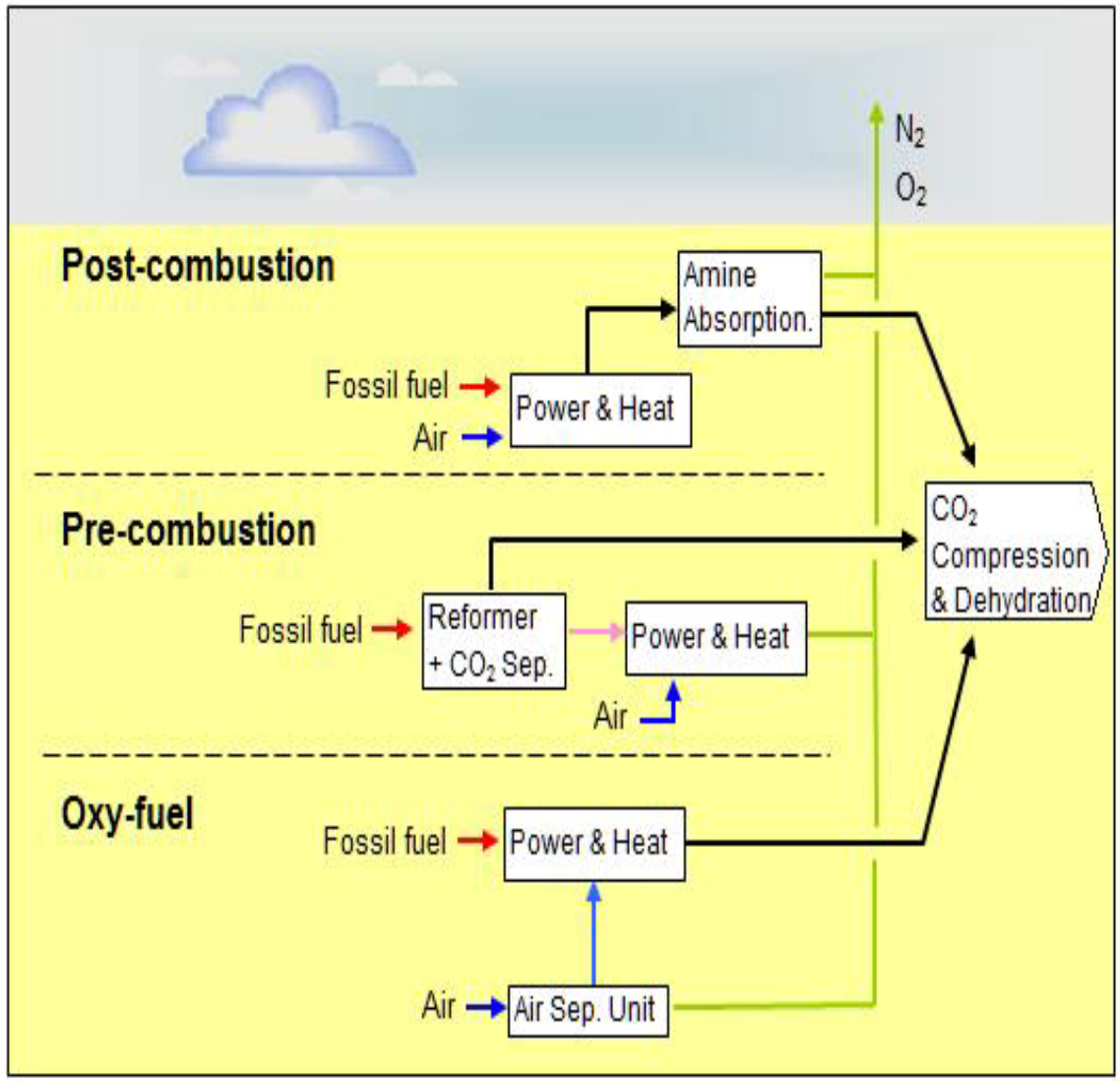
Content of the WG1 report

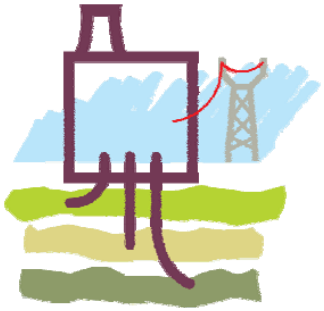
1. Capture and Power plant technology overview
2. Benchmarking the technologies
3. Market potential for different technologies
4. Overall development goals by 2020 and after 2020
5. The R&D Gaps
    1. Power plant efficiency increase
    2. Post combustion capture
    3. Pre combustion capture
    4. Oxyfuel combustion
    5. Emerging and new capture technologies
6. The way forward. Route Map and time frame
7. Barriers for deployment and actions to remove them
8. Conclusions and recommendations for action

Key points - Technology Options

Three technologies seems capable to fulfil the primary target to 2020

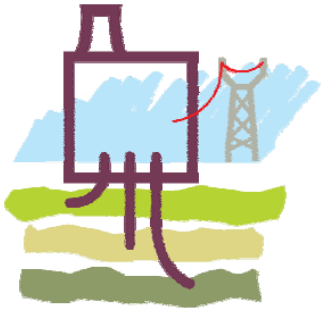
- All largely contain known technology and components
- All need optimization, scale up and process integration
- Power process efficiency increase is always a supporting activity





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.

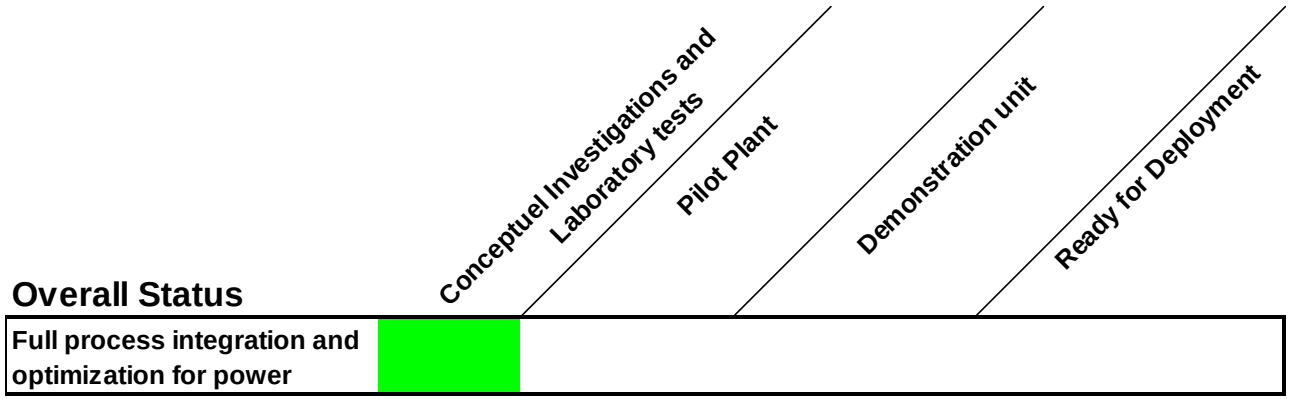


Key Points – Development need

- Generally known technology and components
- Process integration, optimization and scale-up
- The last steps in the development process are long, very expensive and need support

Key Points – Development need

Post-combustion



Overall Status

Full process integration and optimization for power	

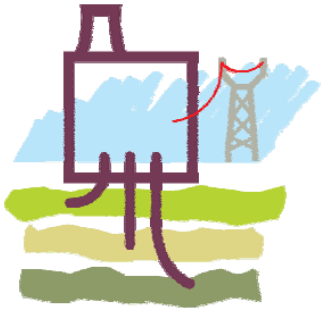
Component Status

Boiler and power process				
Extended desulphurization				
DeNOx process				
CO2 capture process				
Capture process optimization incl. new solvents and scale-up				
CO2 processing				

Key Points – Development need

Pre-combustion

	Conceptuel Investigations and Laboratory tests	Pilot Plant	Demonstration unit	Ready for Deployment
Overall Status				
Full process integration and optimization for power				
Component Status				
Air separation unit				
Coal Gasification				
Natural gas reforming				
Syngas processing				
CO2 capture process				
CO2 processing				
High efficiency, low emission H2 Gas Turbine				

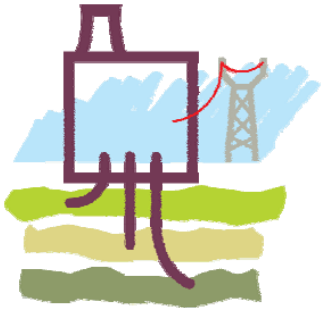


Key Points – Development need

Oxy-fuel

Overall Status	Conceptuel Investigations and Laboratory tests	Pilot Plant	Demonstration unit	Ready for Deployment
Full process integration and optimization for power				

Component Status				
Air separation unit				
Combustion process and boiler				
Water/steam cycle, particle removal				
Desulphurization				
Flue gas condensation				
CO2 processing				

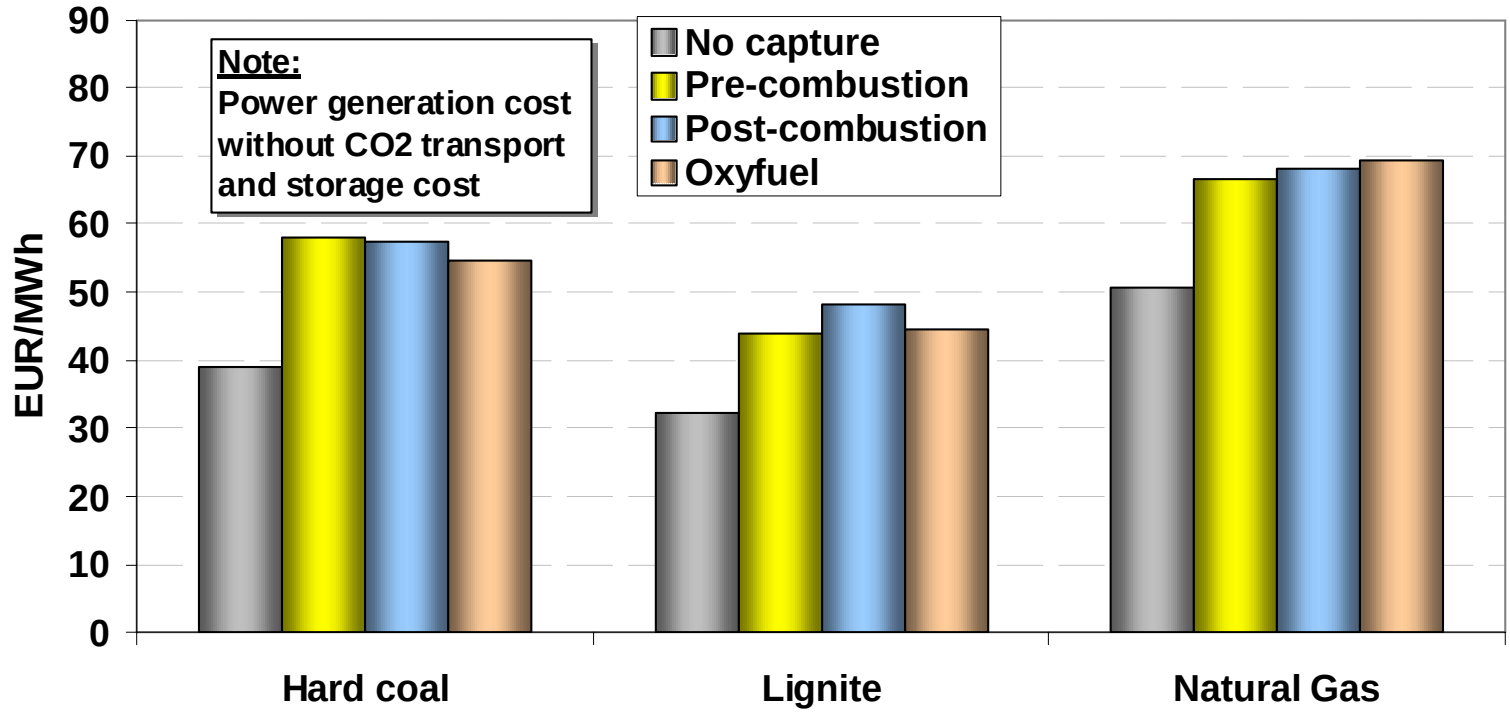


Benchmark

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		

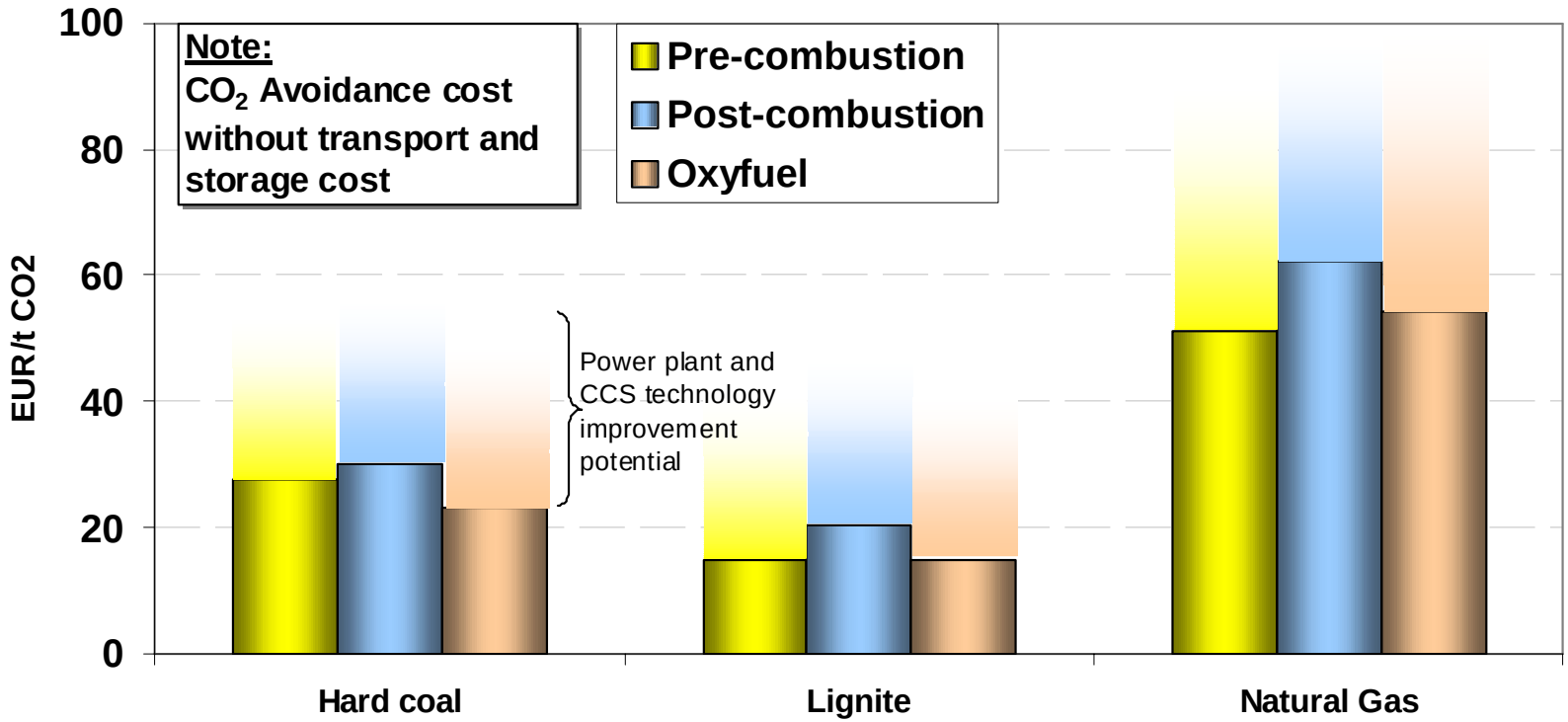
Benchmark

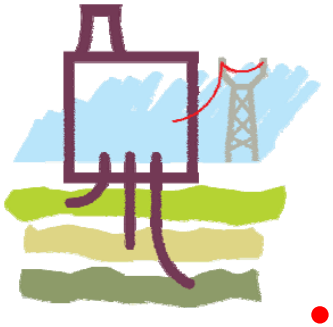
Electricity generation cost for large power plants in operation by 2020 (ZEP WG1)



Benchmark

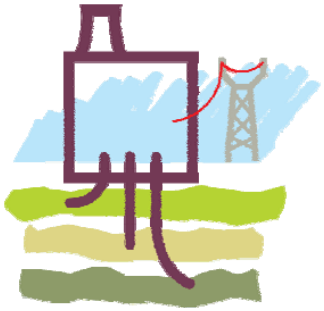
Avoidance cost for large power plants in operation by 2020 (ZEP WG1)





Barriers

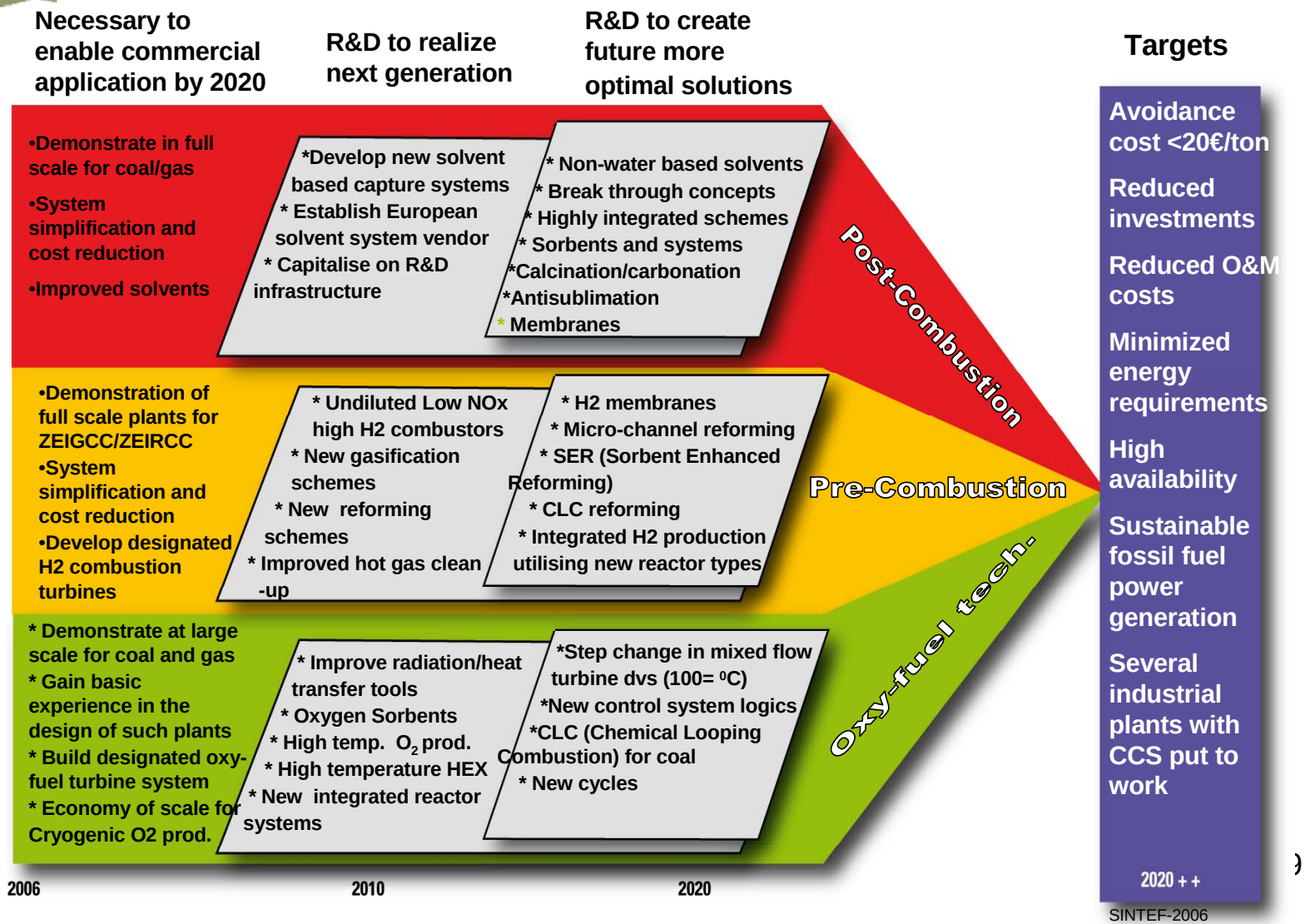
- General barriers
  - Create a worldwide market for CCS
  - Commercial availability to storage facilities
  - Availability of educated people, in universities, administration and industry
- Technical barriers
- Infrastructural barriers
- Institutional and organizational barriers
- Regulatory and legal barriers
  - Permissions and acceptability
  - ETS

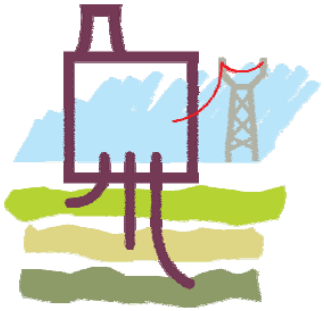


Action to remove the barriers

- Facilitate research and development work in identified areas.
  - Concentrated efforts on prospective technologies, both on an integrated level and basic R&D for support
- Create a level playground concerning market, and commercial framework for the industry
- Create a unified legislation, update regulations, standards, guidelines and permission processes to include CCS
- Make the individuals involved in legislative activities, permission processes, and the public, knowledgeable about the technology.

WG1 Roadmap


Necessary to enable commercial application by 2020
R&D to realize next generation
R&D to create future more optimal solutions
Targets
•Demonstrate in full scale for coal/gas
•System simplification and cost reduction
•Improved solvents
*Develop new solvent based capture systems
* Establish European solvent system vendor
* Capitalise on R&D infrastructure
* Non-water based solvents
* Break through concepts
* Highly integrated schemes
* Sorbents and systems
*Calcination/carbonation
*Antisublimation
* Membranes
Post-Combustion
•Demonstration of full scale plants for ZEIGCC/ZEIRCC
•System simplification and cost reduction
•Develop designated H2 combustion turbines
* Undiluted Low NOx high H2 combustors
* New gasification schemes
* New reforming schemes
* Improved hot gas clean -up
* H2 membranes
* Micro-channel reforming
* SER (Sorbent Enhanced Reforming)
* CLC reforming
* Integrated H2 production utilising new reactor types
Pre-Combustion
* Demonstrate at large scale for coal and gas
* Gain basic experience in the design of such plants
* Build designated oxy-fuel turbine system
* Economy of scale for Cryogenic O2 prod.
* Improve radiation/heat transfer tools
* Oxygen Sorbents
* High temp. O_2 prod.
* High temperature HEX
* New integrated reactor systems
*Step change in mixed flow turbine dvs (100= ^{0}C)
*New control system logics
*CLC (Chemical Looping Combustion) for coal
* New cycles
Oxy-fuel tech.
2006
2010
2020
Avoidance cost <20€/ton
Reduced investments
Reduced O&M costs
Minimized energy requirements
High availability
Sustainable fossil fuel power generation
Several industrial plants with CCS put to work
2020 + +



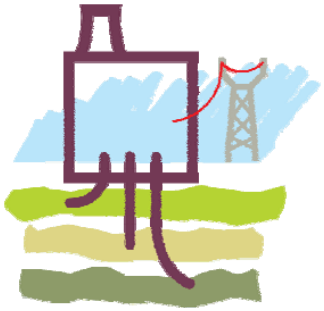
Working group 1

SRA

(Charles Soothill, Alstom)

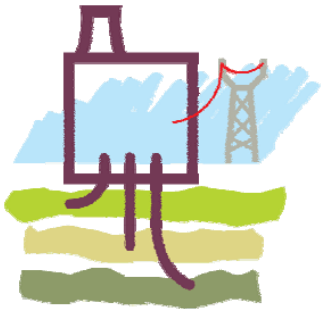
SDD

(Gardiner Hill, BP)



Strategic Research Agenda

- CO_2-The Global Challenge
- The Key Questions
- SRA-key points
  - Technology Options
  - Storage & Transport
  - Environment and the Public
- The R&D Roadmap
- Key Recommendations
- The Way forward

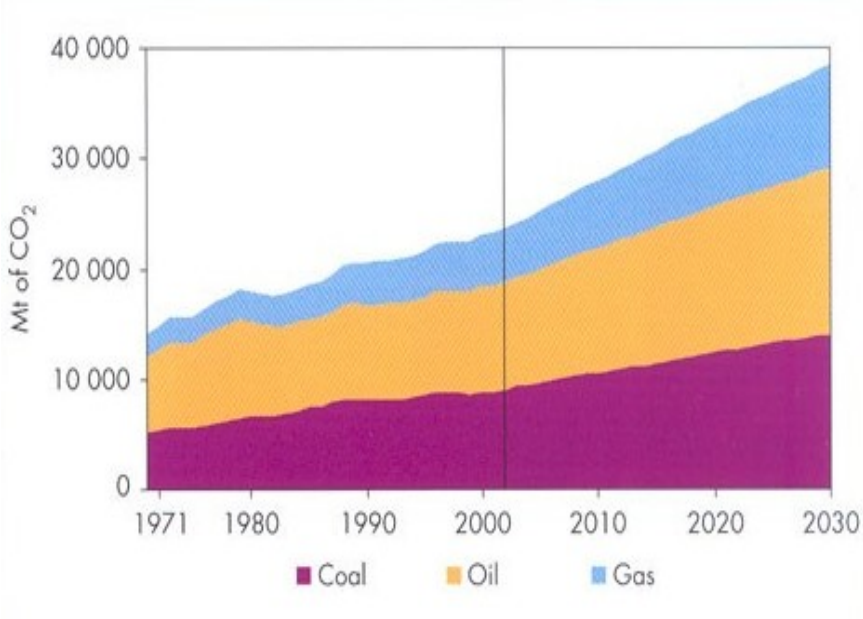


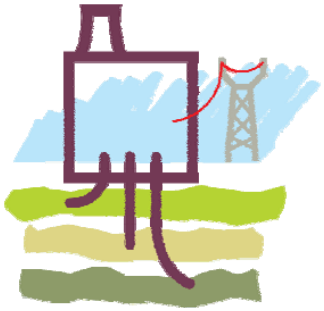
The Global Challenge

CCS, together with improved energy conversion efficiency, is a near-term solution to reducing CO_2 emissions on a massive scale. Its rapid deployment will help avoid the catastrophic consequences of climate change.

But:- we must demonstrate:-

- Reduced CO2 capture and plant costs
- The safety of CO2 geological storage





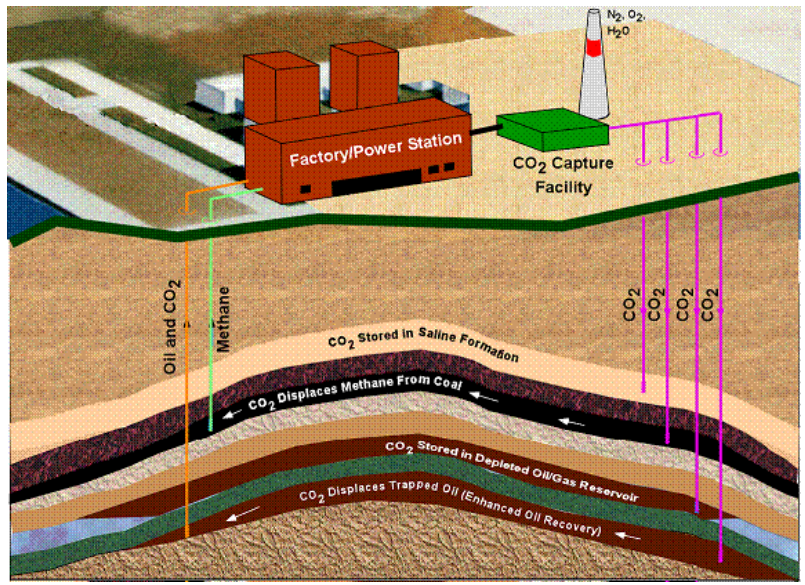
The Key questions

1. Can CO2 from fossil plant be captured effectively?
2. How can captured CO2 be safely transported?
3. Can the capture and long term storage of CO2 be achieved at reasonable cost?
4. Is CO2 storage safe?

The SRA proposes RD & D priorities
and a technology roadmap to address these issues

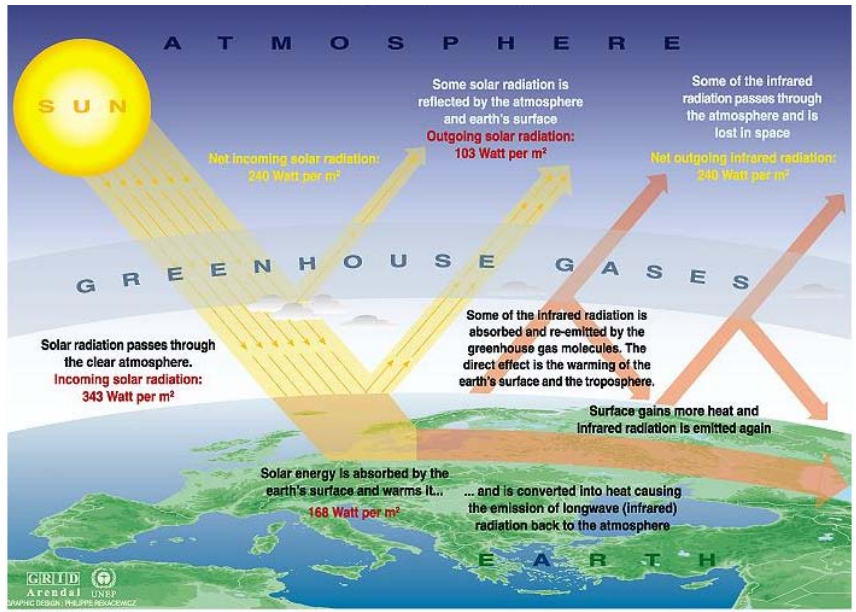
Storage & transport -key points

1. Demonstration of long term safety and monitoring is vital for CO2 storage.
2. Numerous storage options exist - but room for more innovation and better mapping of capacity in EU.
3. Optimise the benefits & use of CO2 (EOR,NGPS)
4. Transport options are well understood, but safe, efficient & cost effective routes must be identified

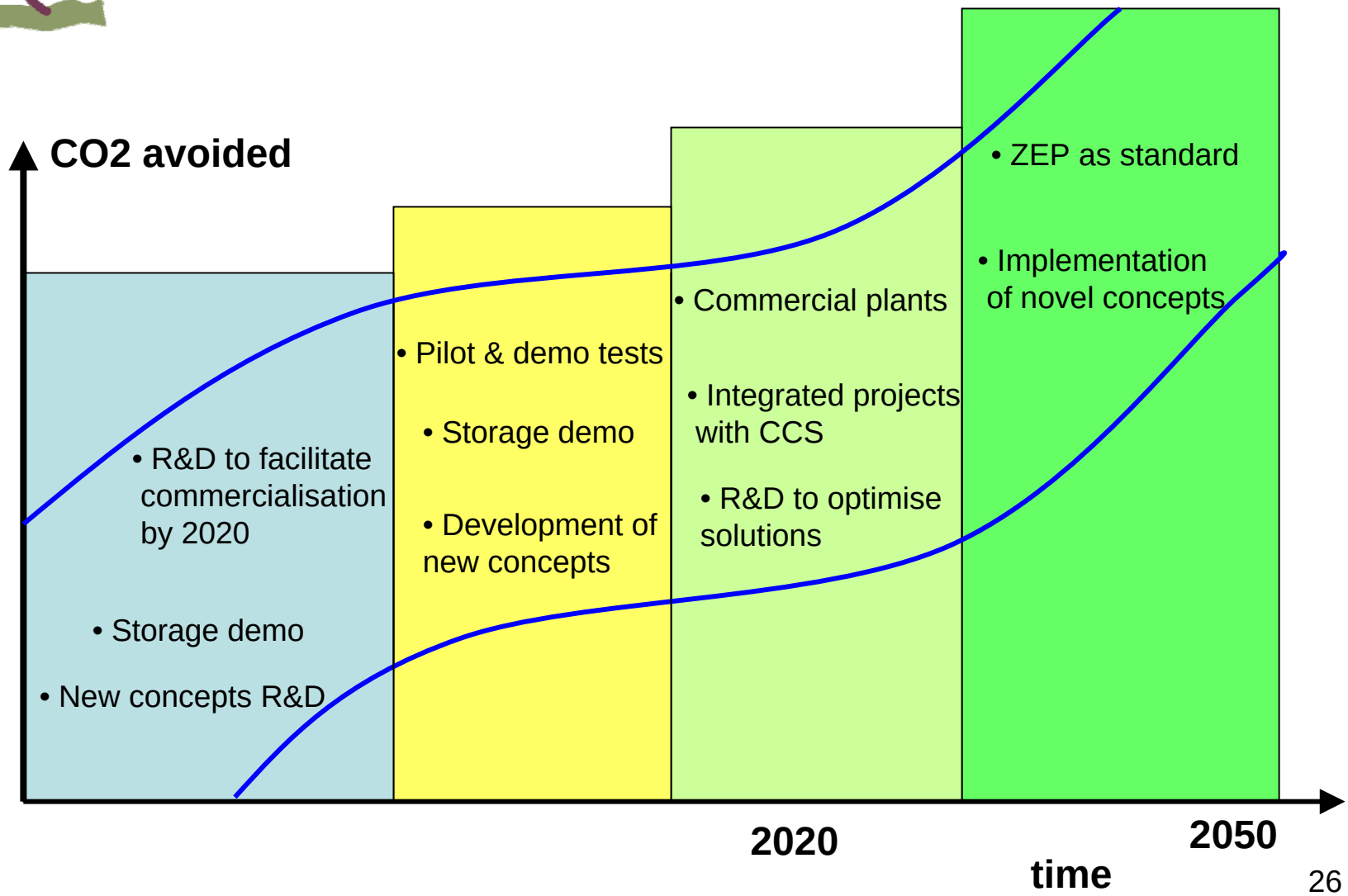


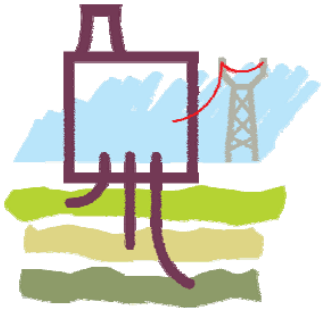
Environment & Public Perception -key points

1. Adopt zero tolerance to major CO2 leaks and establish mitigation plans.
2. Determine impact on the full ecosystem
3. Develop advanced studies & models for CO2 infrastructure.
4. Transport options are well understood, but safe, efficient & cost effective routes must be identified
5. Public acceptance of CCS is prerequisite and will be addressed



Building the Road to Success



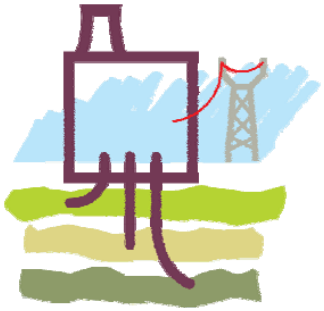


The Key Recommendations

1. Implement 10-12 integrated, large-scale CCS demonstration projects Europe-wide
2. Develop novel underpinning concepts for demonstration by 2010-2015 and implementation beyond 2020.
3. Support long-term exploratory R&D in advanced, innovative concepts for implementation of next-generation technology by 2050
4. Maximising co-operation at national, European and international level
5. Strengthen and accelerate R&D priorities to support the Strategic Deployment

ZEP on the web

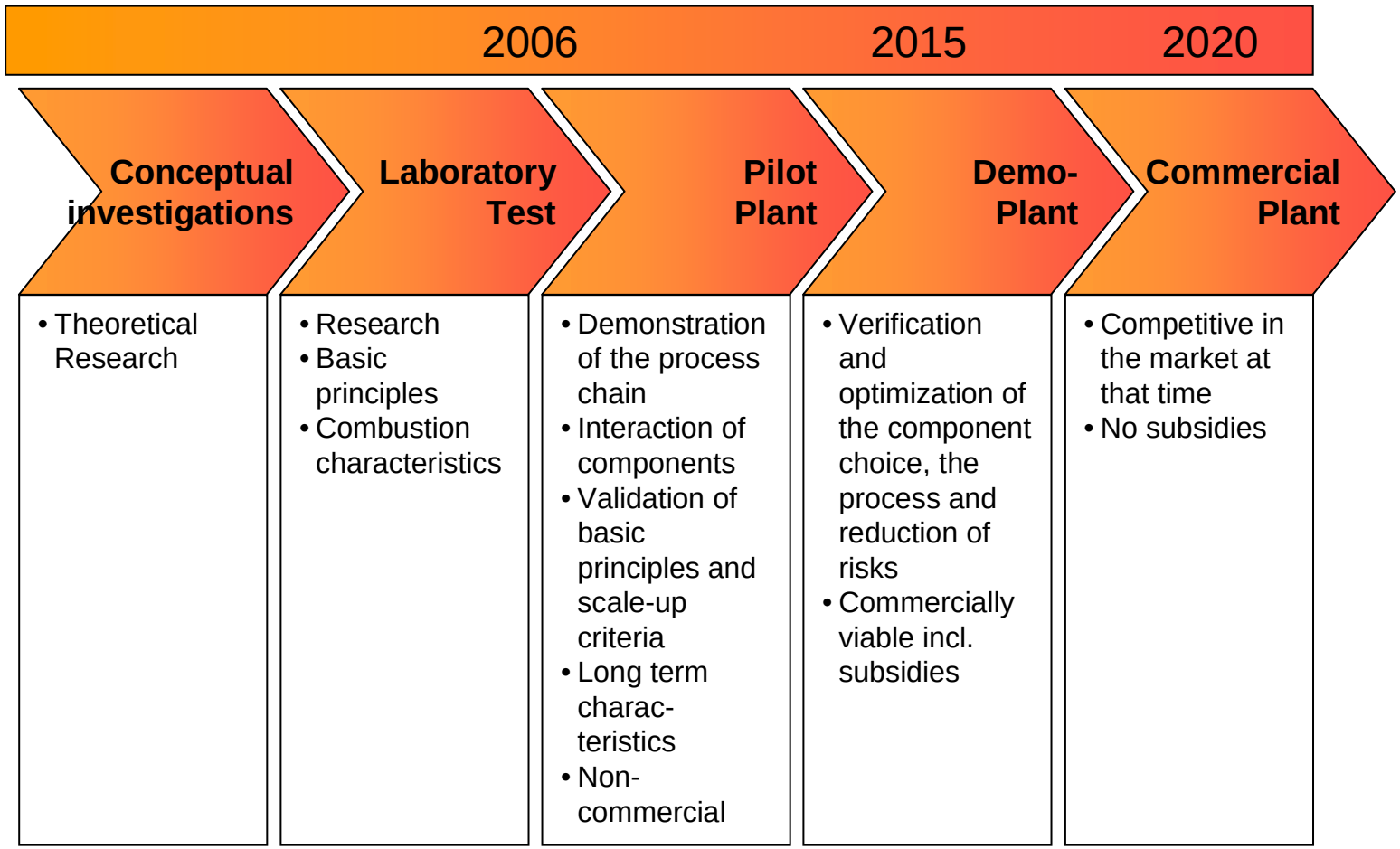
www.zero-emissionplatform.eu



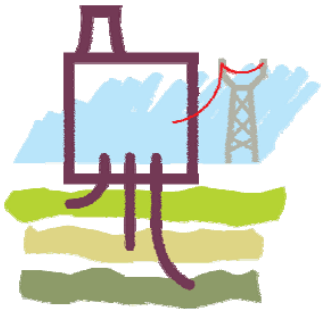
Vattenfalls CO_2 free power plant project

Roadmap to realization - Pilot Plant and Demo Plant

Vattenfall's Roadmap to realization



The demonstration project time line: Capture & Storage



06/2006
03/2007
09/2008
01/2010
06/2010
01/2012

Pre-feasibility study ¾ years
Feasibility study 1 ½ years
Pre-planning 1¼ years
Bidding phase ½ years
Detailed engineering 1½ years
3 years of construction

6 Scenarios
1(3) Scenarios
A,B
C, D
E

Order
Investment decision
Capture plant permit

Approval procedure
3¼ years (pipeline), 4 ½ years probably needed
2 years (storage), Actual time needed uncertain
1½ years (capture)

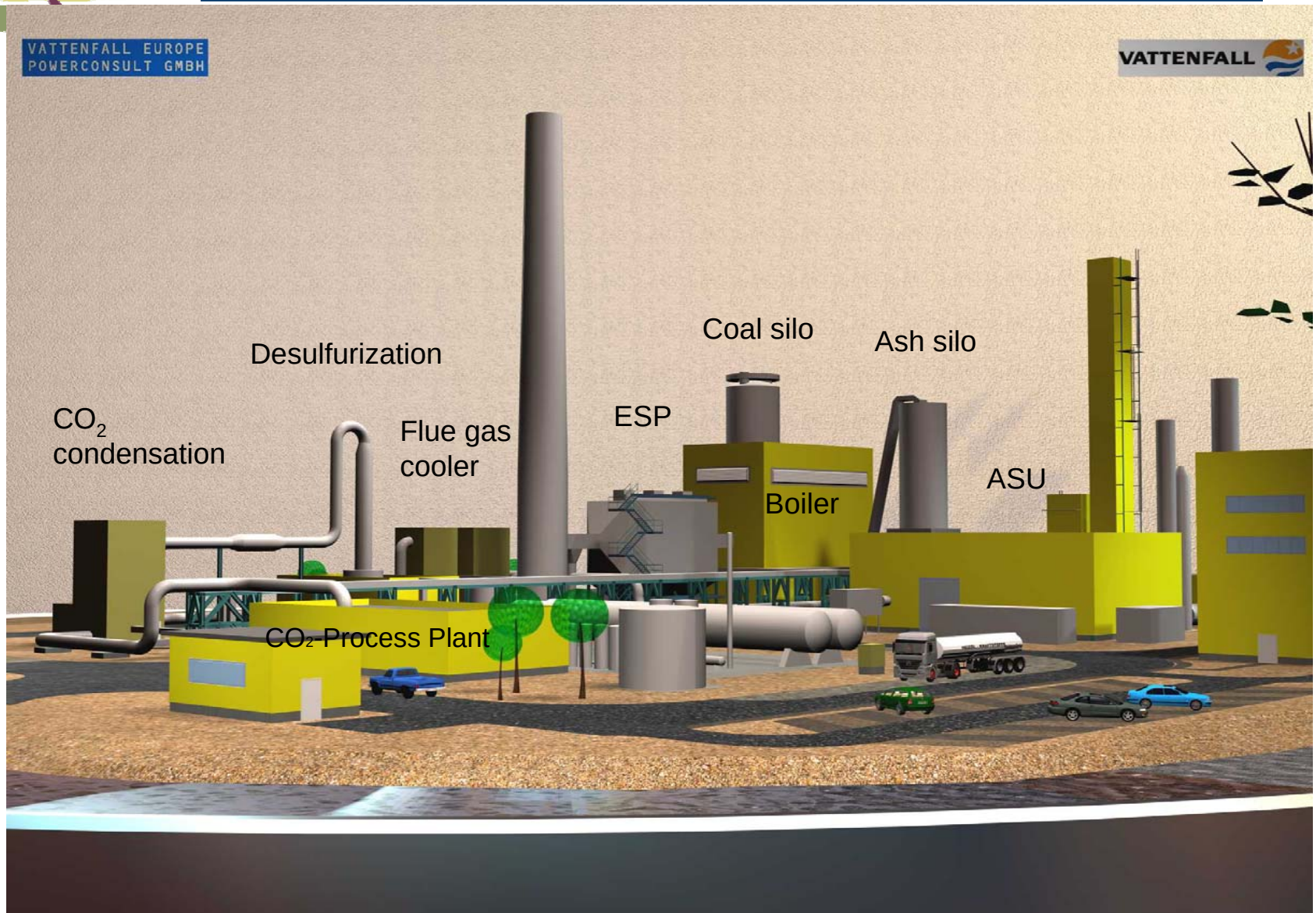
Pre-feasibility phase Site-screening ¾ years
Feasibility phase Initial site charact. 1 ½ years
Investigation phase: Site characterisation Long-term risk ass. Baseline-monitoring 1¾ years
Planning phase Site design & Planning consent 1½ years
Bidding phase

3 years of construction
(production drilling, surface facilities)

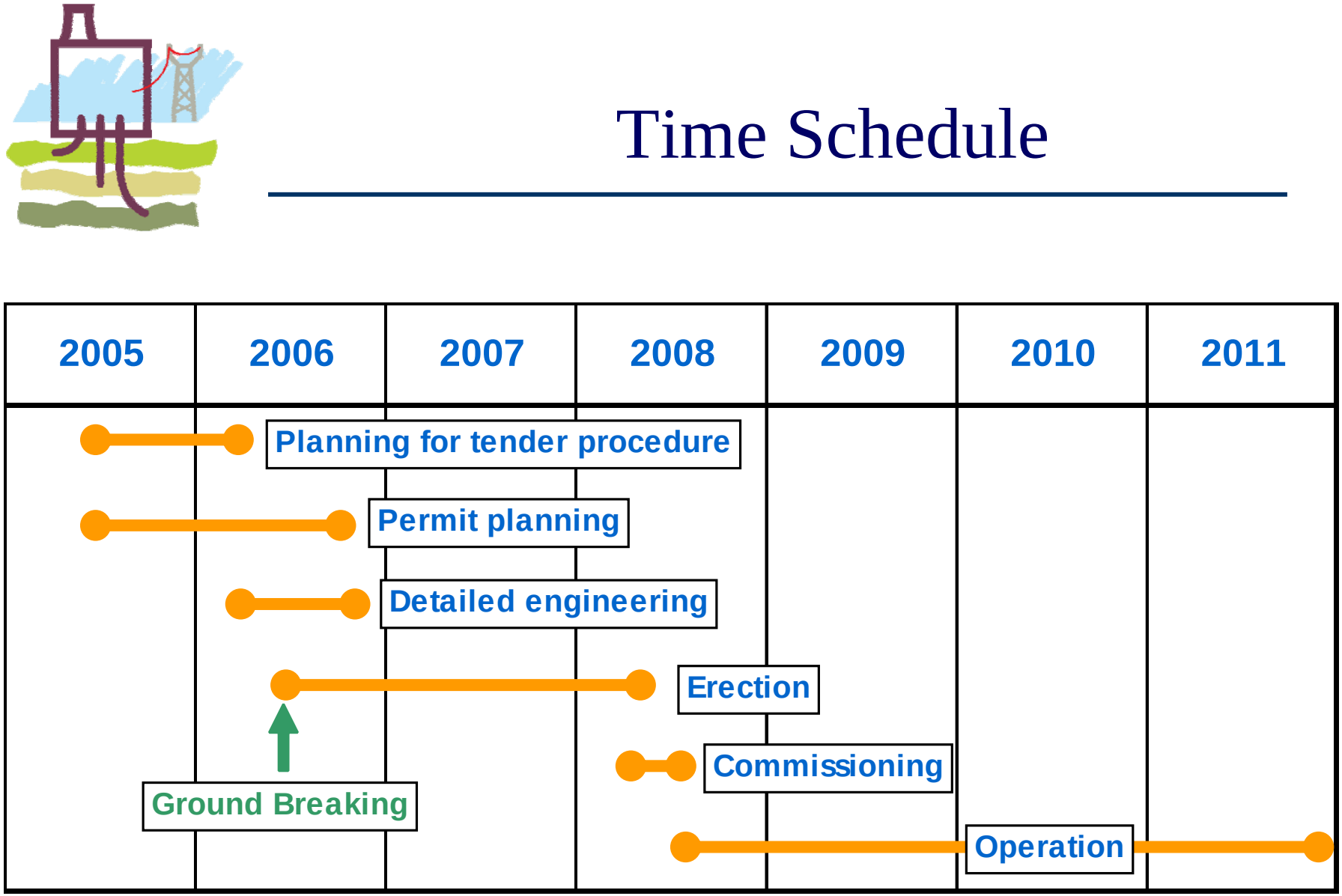
Order
Investment decision
CO2 storage permit

A = Early Consultations
B = Pipeline permit application submitted
C = Capture plant tenders sent out
D = Storage permit application submitted
E = Capture permit application submitted0

Pilot Plant Lay out

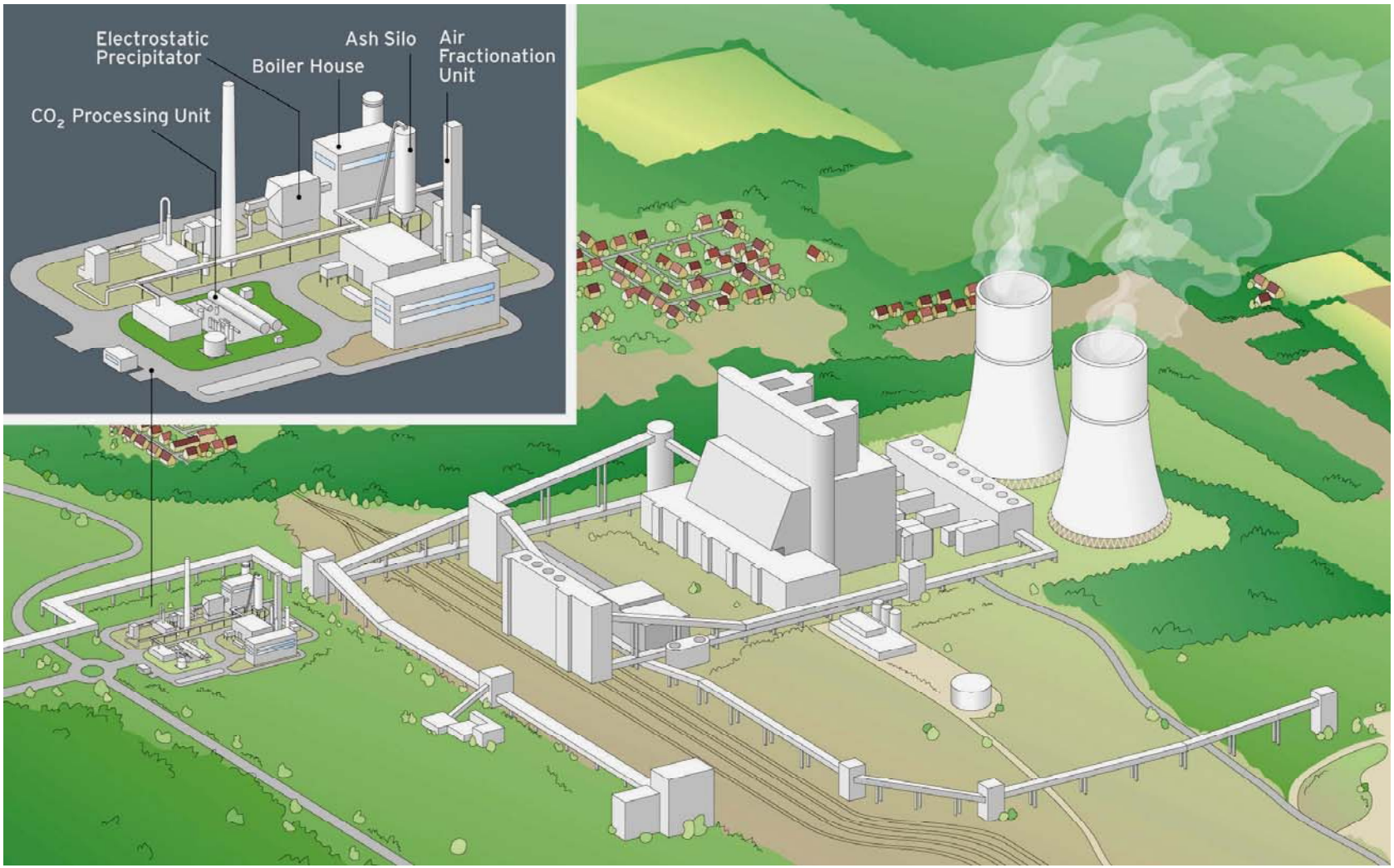


Time Schedule



Schwarze Pumpe power plant

Vattenfall oxyfuel pilot plant at Schwarze Pumpe Power station




Klimaschutz durch Innovation
DAS CO_2-FREIE KRAFTWERK VON VATTENFALL
CO_2-Verflüssigung und -Reinigung
Kesselhaus
E-Filter
Aschesilo
Luft-zerlegungs-anlage
Leistung: 30 MW (thermisch)
Dampfmenge: 40 t/h

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

Computer simulation of Vattenfall‘s new units in Hamburg 2 x 835 MW hard coal