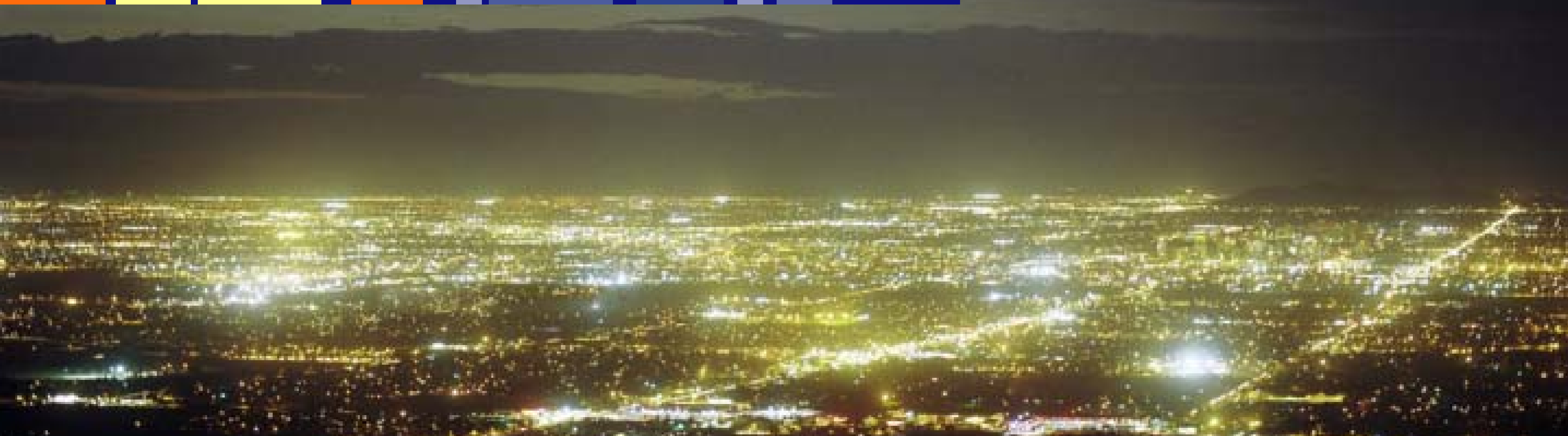
Progress in post-combustion CO_2 capture

Reduction of emissions and geological storage of CO_2
Paris, 15-16 September 2005

TNO | Knowledge for business



Paul H.M. Feron

Presentation Overview

- CO_2 capture introduction
- Post-combustion capture: State of the art
  - Solvent technologies
  - Performances
- Post-combustion capture: Advanced processes
- Conclusions

What are challenges for CO_2 capture?

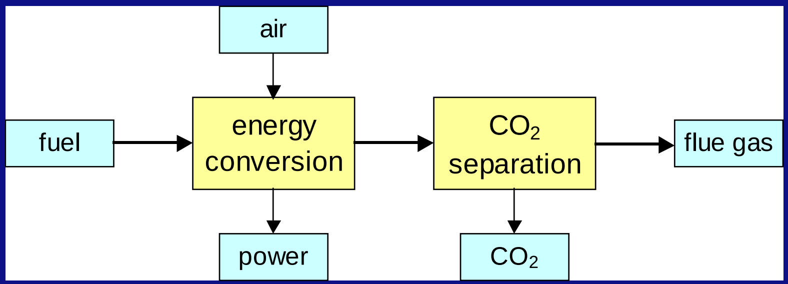
Capture of CO_2 can be done with technologies presently available but:

- Power generation costs will increase
- More fossil fuel needed for same power generation capacity
- Increased reliance on fossil fuels on top of the existing upward trend; increasing the supply security concerns
- There is no experience with CO_2 capture at the power plant scale

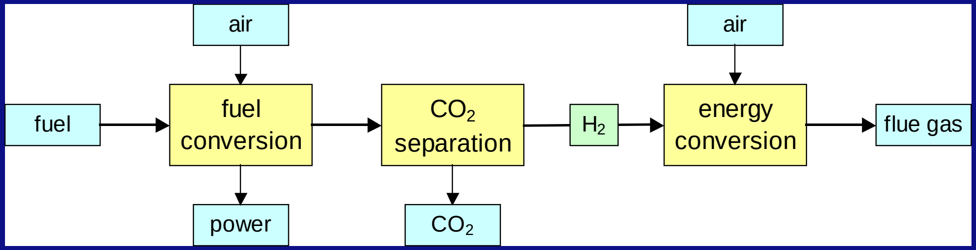
Therefore the following questions need to be addressed:

- How to reduce the additional power consumption as a result of the capture process?
- How to reduce the costs of the capture?

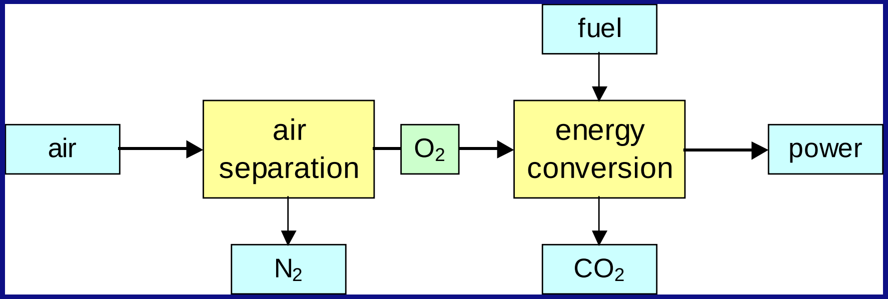
Decarbonisation routes for power plants



Post-combustion



Pre-combustion



Denitrogenation

CO_2-capture classification

By process:

- Post-combustion decarbonisation
  (conventional power plants)
- Pre-combustion decarbonisation
  (new power plants)
- Denitrogenation
  (new power plants)

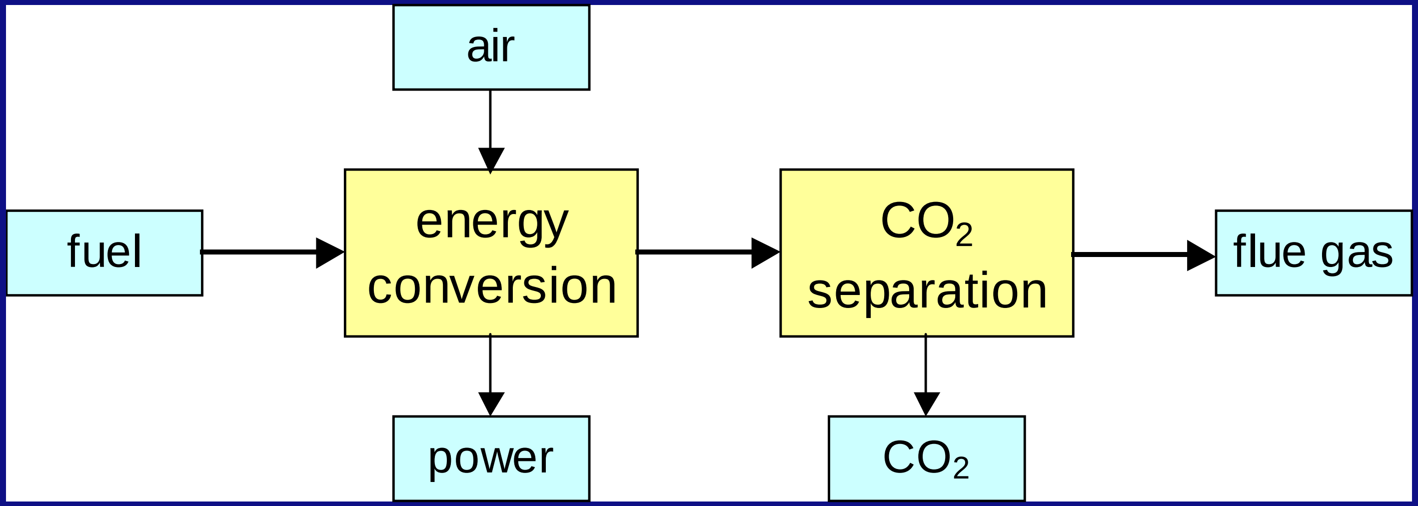
By technology platform/component:

- Membranes
- Absorption
- Adsorption
- Cryogenics
- Carbon extraction
- Biotechnology
- Energy conversion

The CO_2 Capture toolkit: A portfolio approach

Capture method	Post-combustion processes	Pre-combustion processes	Denitrogenation
Solvents	New solvents Contactors Process design	New solvents Contactors Process design	O_2/N_2 absorbent
Membranes	Membrane absorption, polymeric, ceramic, FT, carbon membranes	CO_2/H_2-separation: Ceramic, polymeric, palladium, membrane absorption	O_2-conducting membranes
Sorbents	Lime carbonation	Dolomite Zirconates	O_2/N_2 adsorbents High T adsorbents
Cryogenic	Liquefaction	CO_2/H_2 separations	Distillation for air separation
Carbon extraction	n.a.	Direct decarbonisation	n.a.
Biotechnology	Algae production Biomimetic approaches	High pressure applications	Biomimetic approaches
E-Conversion	Novel power cycles	Hydrogen combustion	Combustion in $O_2/CO_2/H_2O$ atmosphere

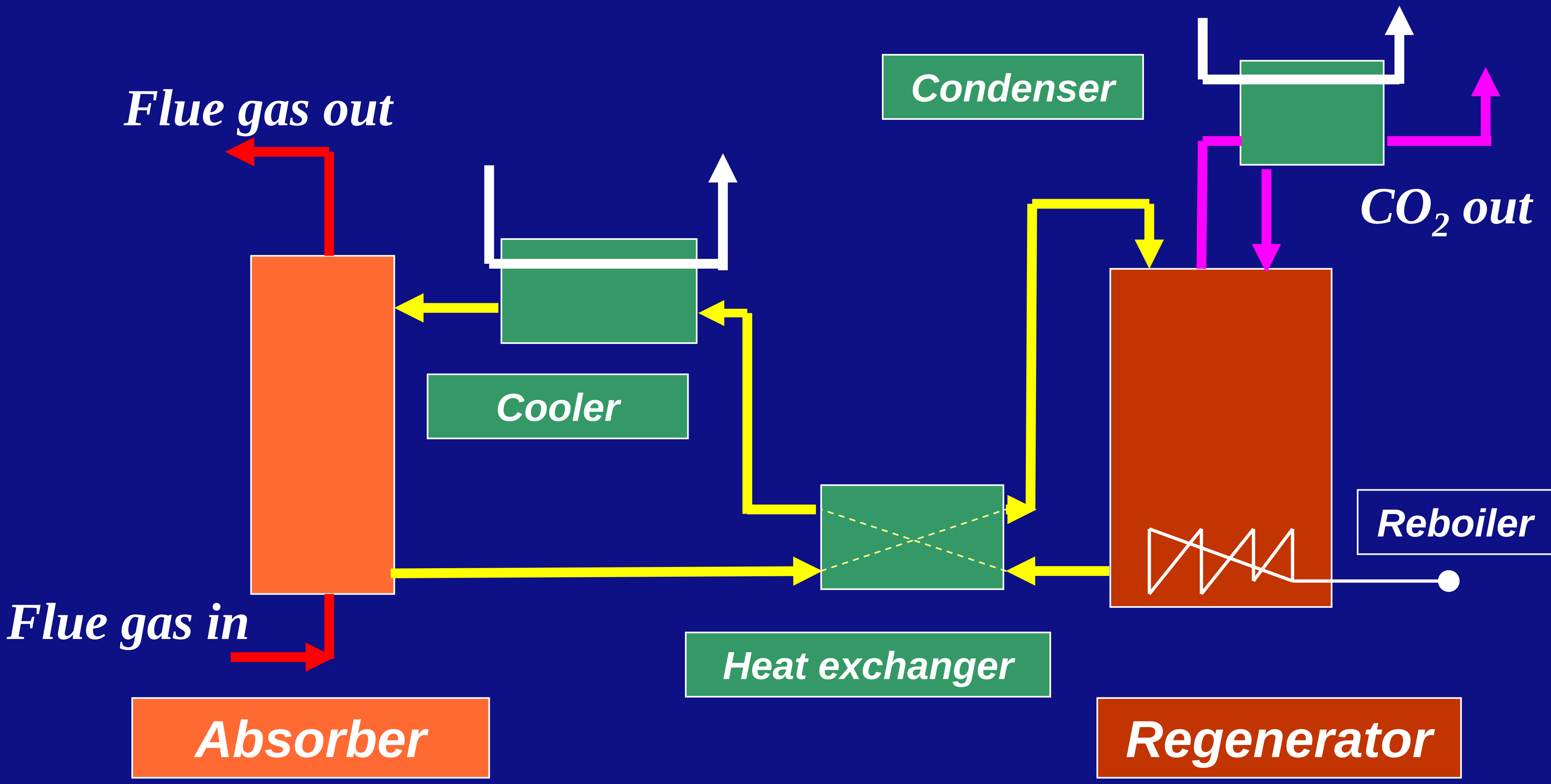
Post-combustion CO_2 capture
CO_2-removal from flue gases



Why post-combustion capture?

- Add-on to existing power plants and plant concepts
- Capture technologies available, i.e. solvent technologies, which are proven on a smaller scale
- Similarities with cogeneration plant lead to proven methods for integration
- Capture readiness easy to incorporate into power plant tackling issue with infrastructure inertia
- Flexibility in switching between capture – no capture
- Learning by doing will lead to cost reductions similar to experience with SO_2 capture process development
- Learning by searching will lead to better solvents and processes

Solvent process flow sheet
Aqueous ethanolamine solutions



State of the art post-combustion CO_2-capture

- Fluor Daniel Econamine FG[SM]
  - 30% MEA solution incorporating additives to control corrosion
  - > 20 commercial plants in sizes between 0.2 and 15 tonnes CO_2/h
- ABB-Lummus
  - 15-20% MEA solution
  - 4 commercial plants in size between 6 and 32 tonnes CO_2/h
- Mitsubishi Heavy Industries
  - KS-1 – sterically hindered amines
  - 1 commercial plant: 9 tonne CO_2/h
- More to come…..

Energy impacts for post-combustion CO_2 capture using solvent processes

- Thermal energy
  - Regeneration of solvents; Extracted from steam cycle in power plant:
    - Sum of solvent heating, desorption enthalpy and reflux ratio
    - Energy impact determined by solvent properties, process design and integration into power plant
- Electricity
  - Flue gas fans:
    - Higher CO_2-content in flue gas reduces specific power consumption
  - Solvent pumps, cooling water pumps:
    - Higher CO_2-loading of solvent reduces specific power consumption
  - CO_2 compressor:
    - Specific power consumption determined by pressure ratio

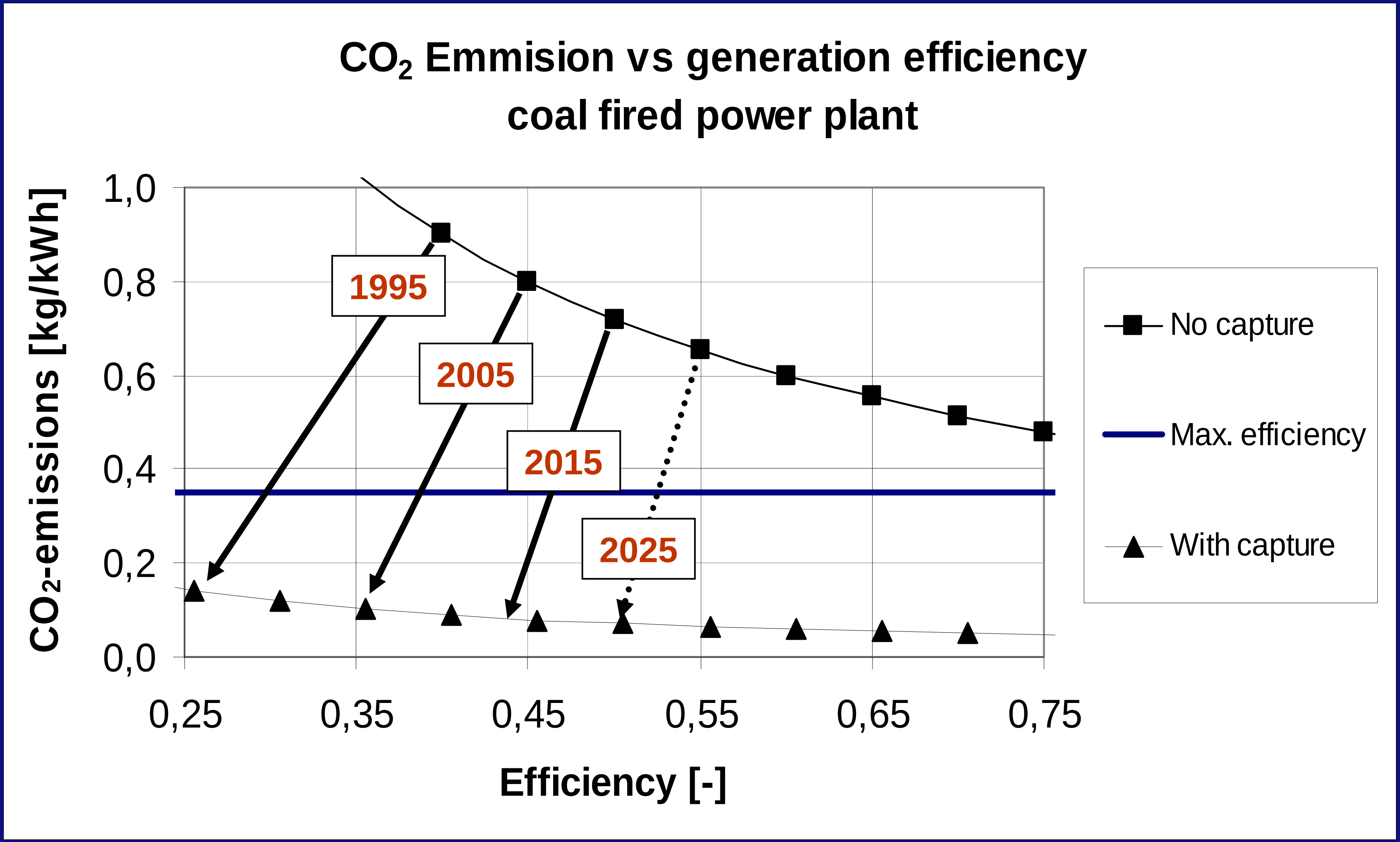
Post-combustion capture process performances: Past, present and future

Year	1995	2005	2015
Thermal energy	4.2 GJ/tonne CO_2	3.2 GJ/tonne CO_2	2.0 GJ/tonne CO_2
Power equivalent (Factor used)	0.292 kWh/kg CO_2 (0.25)	0.178 kWh/kg CO_2 (0.20)	0.083 kWh/kg CO_2 (0.15)
Power for capture	0.040 kWh/kg CO_2	0.020 kWh/kg CO_2	0.010 kWh/kg CO_2
CO_2 compressor	0.114 kWh/kg CO_2	0.108 kWh/kg CO_2	0.103 kWh/kg CO_2
Total	0.446 kWh/kg CO_2	0.306 kWh/kg CO_2	0.196 kWh/kg CO_2

Post-combustion capture in a coal fired power plant (Emission factor: 0.1 tonne CO_2/GJ)

Year	1995	2005	2015
Base plant efficiency	40 %	45 %	50 %
Base plant emission	900 kg CO_2/MWh	800 kg CO_2/MWh	720 kg CO_2/MWh
Power loss due to capture	0.446 kWh/kg CO_2	0.306 kWh/kg CO_2	0.196 kWh/kg CO_2
Plant efficiency with 90% capture	25.5 %	35.1 %	43.6 %
Emission with 90% capture	141 kg CO_2/MWh	103 kg CO_2/MWh	82 kg CO_2/MWh

Development of capture technology hand in hand with generation efficiency improvements



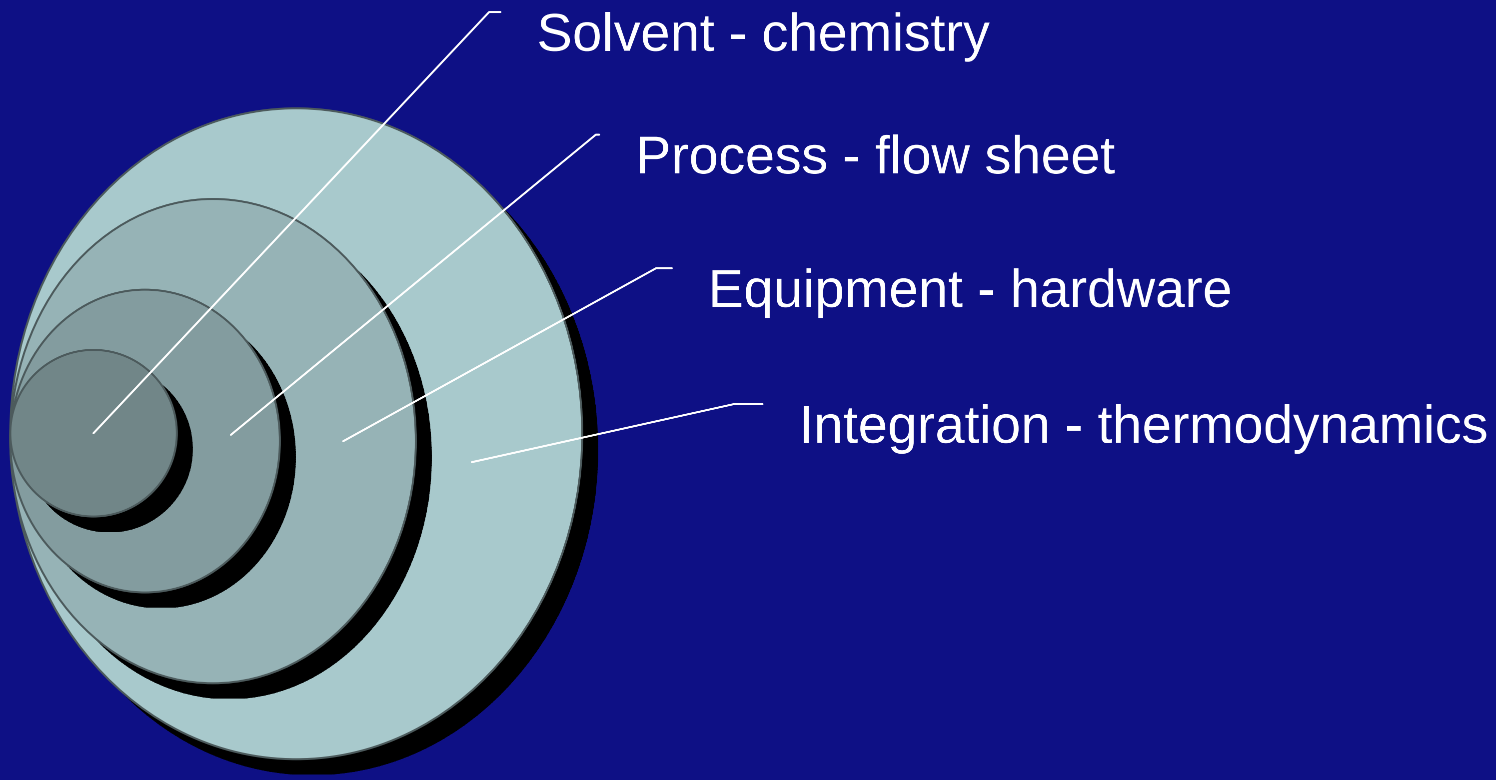
Issues for post-combustion CO_2-capture

- Solvent technologies are leading option but currently:
  - Power cost increases >50%
  - Generation efficiency decreases by 15 – 25%

- Solvent process break-throughs required
  - Energy requirements
  - Reaction rates
  - Contactor improvements
  - Liquid capacities
  - Chemical stability/corrosion
  - Desorption process improvements
  - Hence cost reductions

- Integration with power plant
  - Heat integration with other process plant, particularly in relation to desorption process
  - Concepts for “capture readiness”

Integrated approach in solvent process development for post-combustion capture



CO_2 post-combustion capture: R&D objectives

- Development of absorption liquids with a thermal energy consumption of 2.0 GJ/tonne CO_2 at 90% recovery rates
- Development of an integrated process with a conversion efficiency loss of less than 5%, at 90% recovery rates
- Resulting costs per tonne CO_2 avoided not higher than 20 to 30 €/tonne CO_2, depending on the type of fuel
- Pilot plant tests showing the reliability and efficiency of the post-combustion capture process

CASTOR

CO_2, from Capture to Storage

a European Integrated Project
(IFP – Project Coordinator)

Consortium participants

R&D

- IFP (FR)
- TNO (NL)
- SINTEF (NO)
- NTNU (NO)
- BGS (UK)
- BGR (DE)
- BRGM (FR)
- GEUS (DK)
- IMPERIAL (UK)
- OGS (IT)
- TWENTE U. (NL)
- STUTTGARTT U. (DE)

Oil & Gas

- STATOIL (NO)
- GDF (FR)
- REPSOL (SP)
- ENITecnologie (IT)
- ROHOEL (AT)

Power Companies

- VATTENFALL (SE)
- ELSAM (DK)
- ENERGI E2 (DK)
- RWE (DE)
- PPC (GR)
- E.ON-UK (UK)

Manufacturers

- ALSTOM POWER (FR)
- MITSUI BABCOCK (UK)
- SIEMENS (DE)
- BASF (DE)
- GVS (IT)

Co-ordinator: IFP

Chair of the Executive Board: Statoil

CASTOR main components

SP1 Strategy for CO_2 Reduction

WP1.1 Development of CO_2 reduction strategies

WP1.2 Geological storage options for CO_2 reduction strategy

Budget: 0,9 M€

Management Dissemination

WP0.1 Project Management

WP0.2 Dissemination & Training

Budget: 0,75 M€

SP2 CO_2 Post-Combustion Capture

WP2.1 Evaluation, optimisation & integration of post-combustion capture processes

WP2.2 Solvent development

WP2.3 Development of membrane based solvent processes

WP2.4 Advanced processes

WP2.5 Process validation in pilot plant

Budget: 10,3 M€

SP3 CO_2 storage performance & risk assessment studies

WP3.1 Field case "Casablanca"

WP3.2 Field case "Lindach"

WP3.3 Field case "K13b"

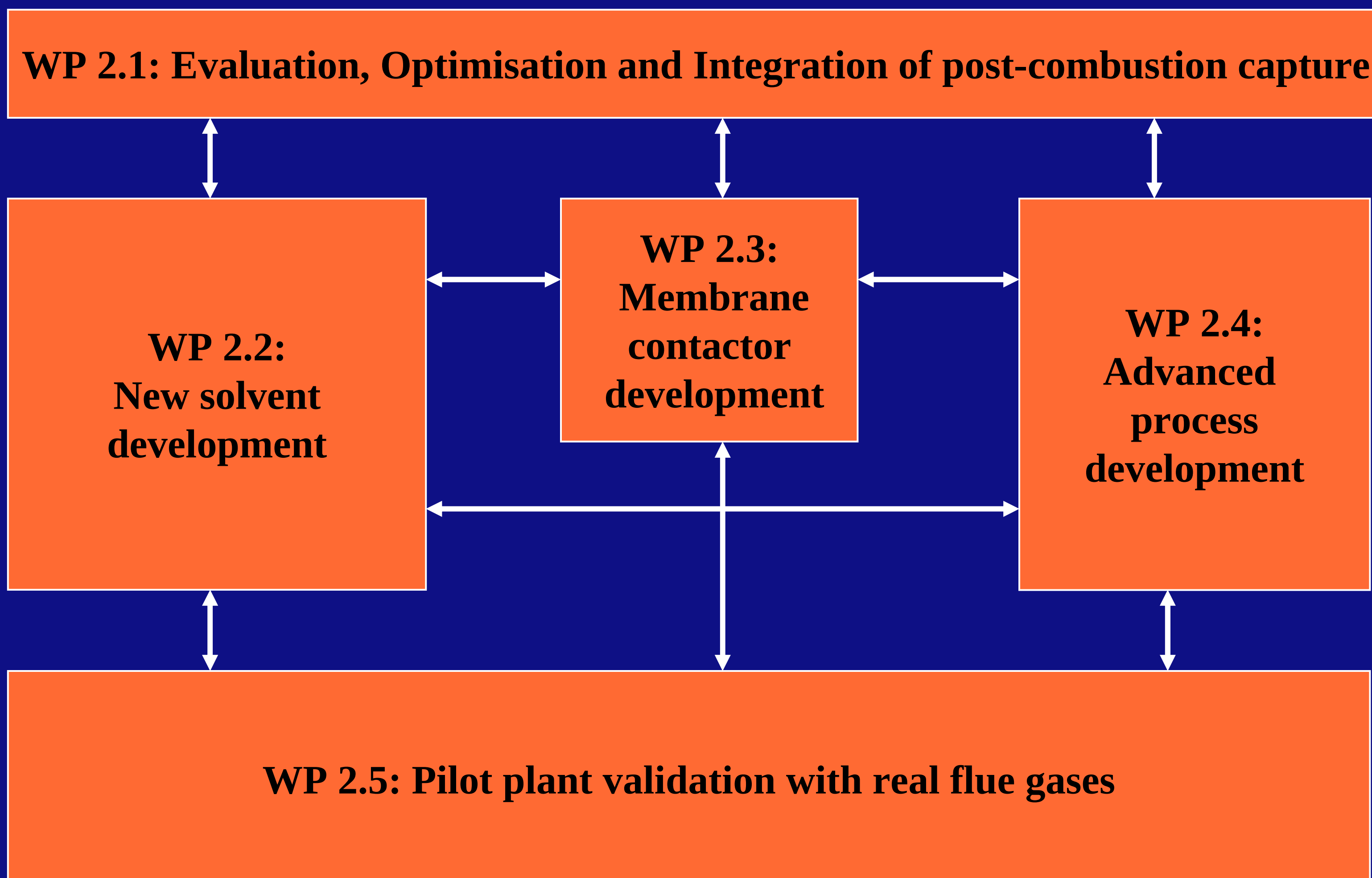
WP3.4 Field case "Snohvit"

WP3.5 Preventive & corrective actions

WP3.6 Criteria for site selection and site management

Budget: 3,8 M€

CASTOR SP2 – Work package structure



European post-combustion test facility

Capacity: 1 t/h CO_2 capture

5.000 Nm^3/h fluegas
(coal combustion)

In operation early 2006

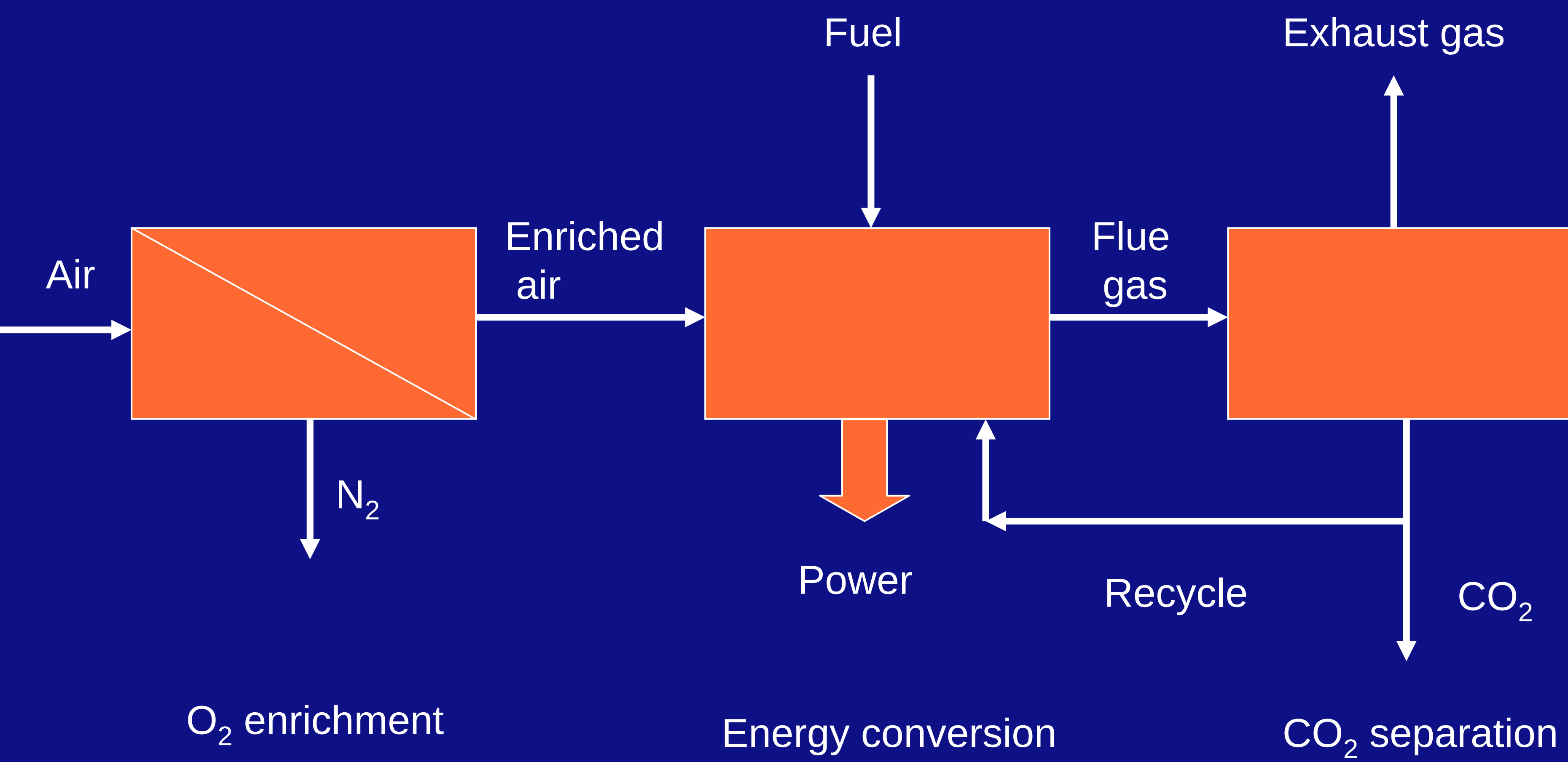
Budget:	**25.4 MEuro**
BSIK support:	**12.7 MEuro**
Coordinator:	**UCE**

Other CO_2 separation technologies

- Adsorption processes
  - Sorbent development (selectivity, high temperature)
  - Scale-up (circulating fluidised bed, rotating wheels)
- Membrane processes
  - Membrane development (selectivity, high temperature)
  - Scale-up (using modularity)
- Refrigeration processes
  - Anti-sublimation process (CO_2 available at high pressure)
  - Scale-up (available process equipment)

Process suitability will benefit from increased CO_2 concentration:
Use of flue gas recirculation and oxygen enrichment

HICLON (High CO_2/Low N_2-capture process)



Conclusions

- Post-combustion capture presents the decarbonisation approach with least impact on power generation processes
- Capture readiness is relatively simple to take into account for post-combustion capture
- Potential for improvement post-combustion capture by “doing” and “searching” is large
- CASTOR IP and CATO programme results provides an integrated approach to post-combustion capture, which is essential for success