

# *Green Power* Carbon Capture Technology

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Fortbildungstag 2011 des ZV München der DMG

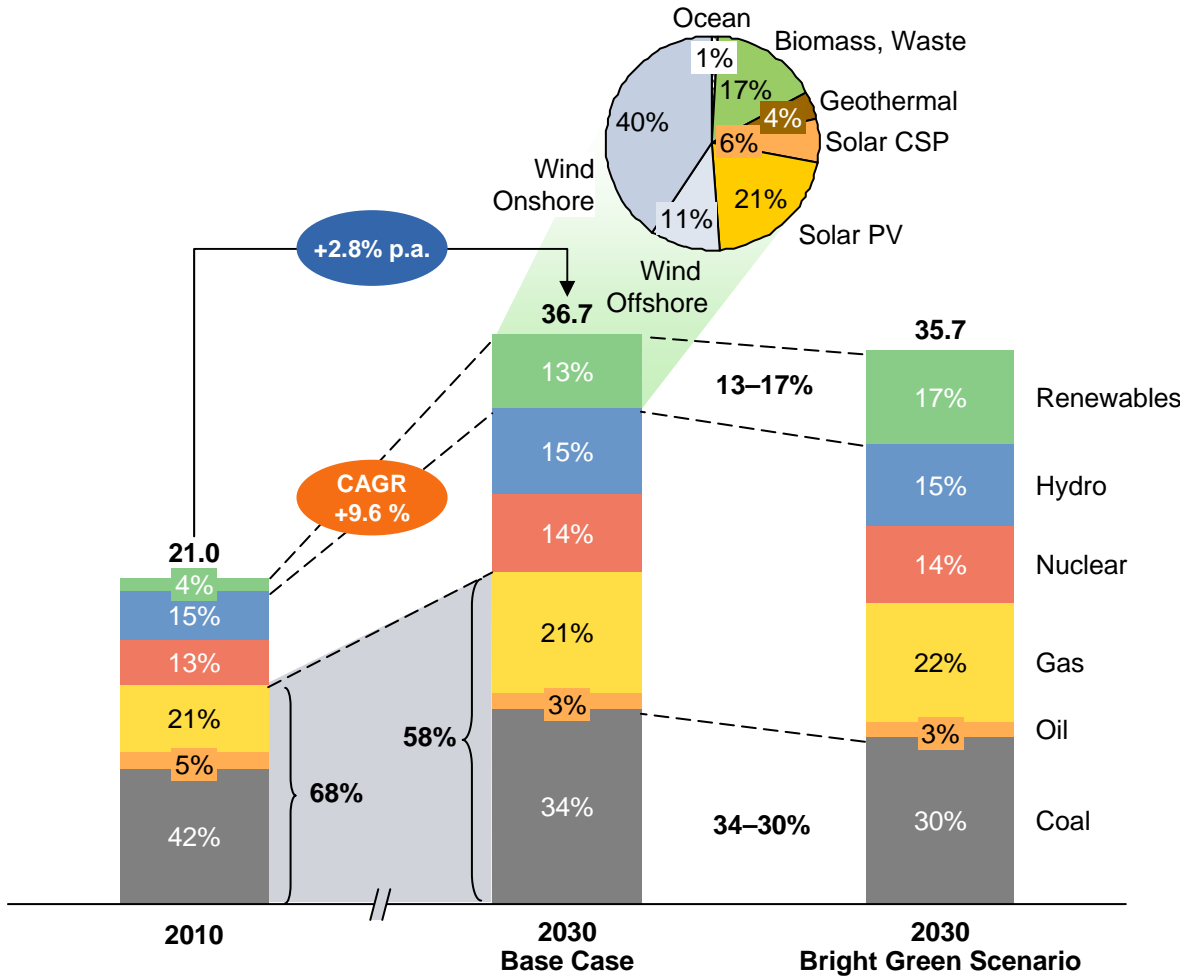
DLR Oberpfaffenhofen, 11. November 2011

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Siemens Energy Sector / Fossil Division /  
New Technologies / CCS

# Trends in power generation – Two possible scenarios



## World power generation (in 1000 TWh)

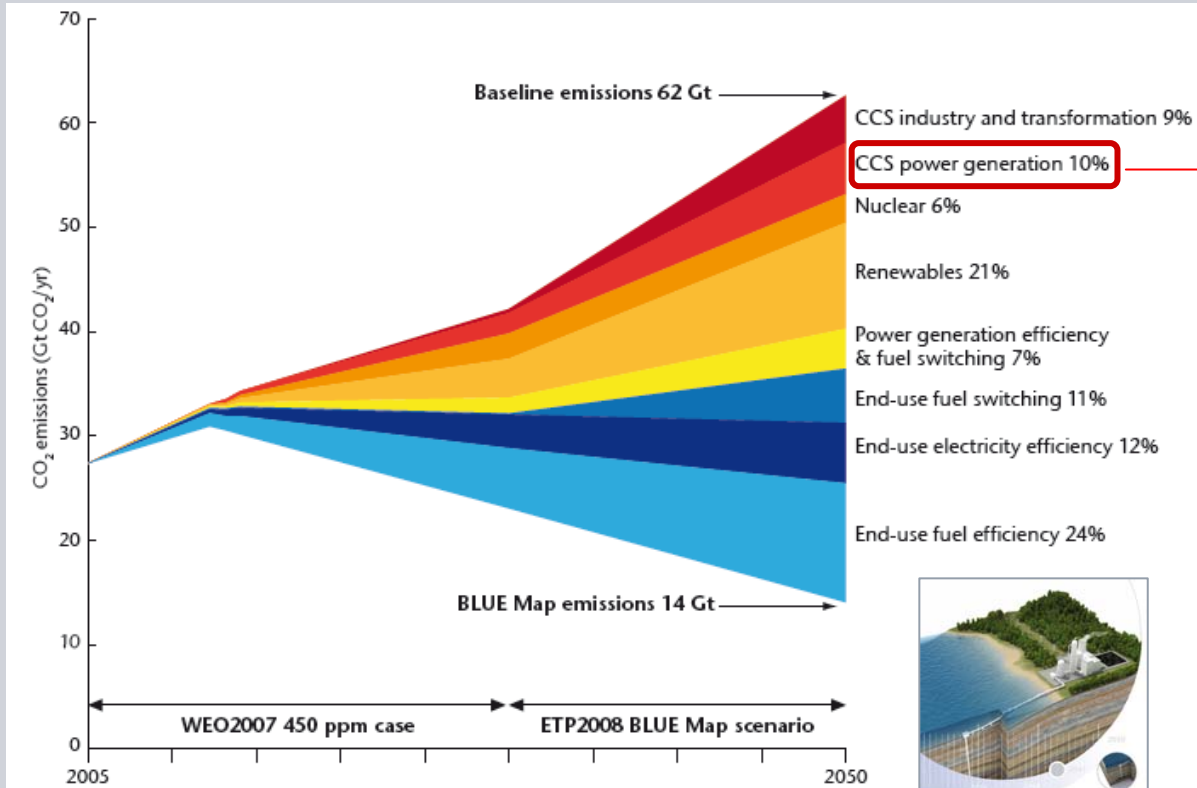
### Bright Green Scenario assumptions:

- Cost-cuts in renewables
- Energy storage available
- Expansion of transmission grids
- Gas to compensate for intermittency of renewables

Source: Siemens

# CCS market scenarios

IEA Blue Map



## Assumption:

- Power Generation: 4.8 Gt CO<sub>2</sub> captured in 2050

## Example:

- Coal: 800MW gross, 40% net eff., 7,000 h/a ; capture rate 90%
- Result => 4 Mt/a captured
- Theoret. Market: ca. => 1.400 PS



In all scenarios: CCS in power and industry play an important role

# Siemens competencies for fossil power generation with carbon capture

**SIEMENS**

**Gasifiers**



**Gas Turbine Generators**



**Steam Turbine Generators**



**Chemical Engineering**



**Air Quality Control**



**Air / N<sub>2</sub> / O<sub>2</sub> / CO<sub>2</sub> / Syngas Compressor Trains**



**Instrumentation & Control Systems**



**Reference Power Plants**



**O & M Services**



Siemens provides key components, complete systems and proprietary post-combustion CO<sub>2</sub> capture process

# R&D Collaboration with the Netherlands Organization for Applied Scientific Research (TNO)

**SIEMENS**

## Exclusive Agreement Signed

- Aimed at further advancement of amino acid salt based carbon capture technology
- Targets faster time to market and implementation of full-scale demo plant by 2014
- Leverage synergies and optimize resources

## Extensive Development at TNO

- Performing research in the field since 1990's
- Coordinates €90 million CATO-2 national CCS program

## Further Solvent Development Focus

- Reduce Power Demand
- Reduce Costs

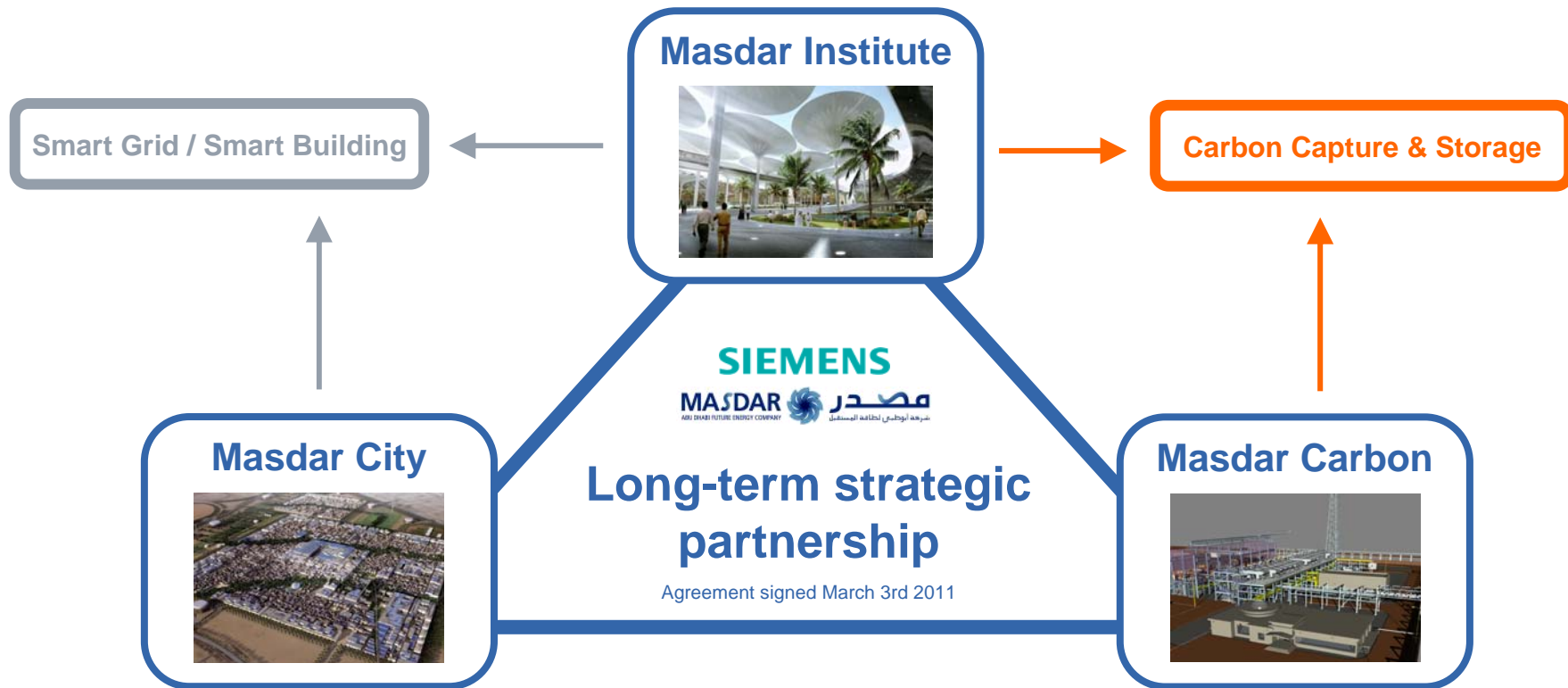
## June 2009 Agreement Signing



# Masdar / Abu Dhabi Fields of co-operation



## ▪ R&D Cooperation



# Siemens Post-Combustion Carbon Capture for Fossil Fuel fired Power Plants

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CO<sub>2</sub> Absorption, Desorption  
is a proven technology  
in chemical processing and oil & gas  
industry



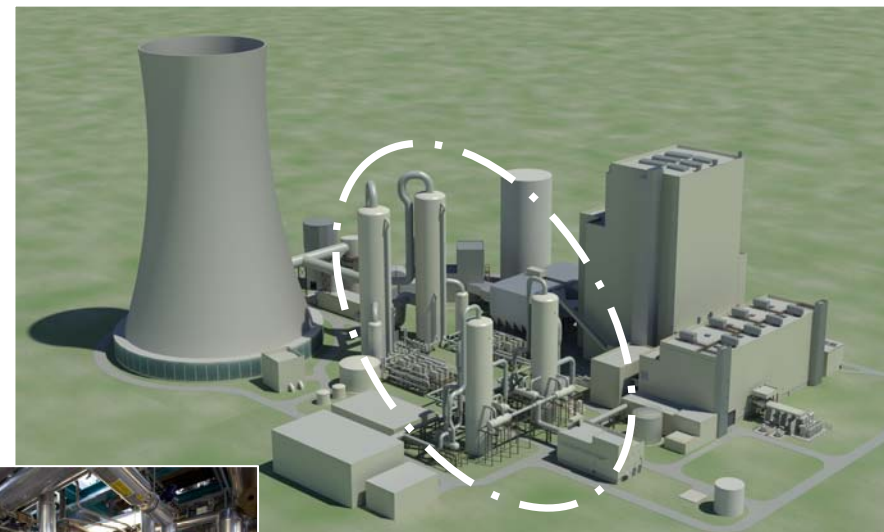
“Scalable” market introduction ,  
retrofitable to existing power plants

Preferred solution for CCS  
demonstration projects

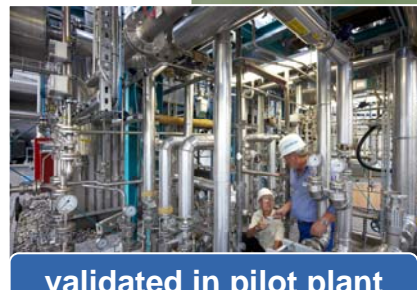
Task: Mastering scale-up from pilot to  
demonstration plant.

## SIEMENS PostCap Process

based on: **AMINO ACID SALT** Formulations

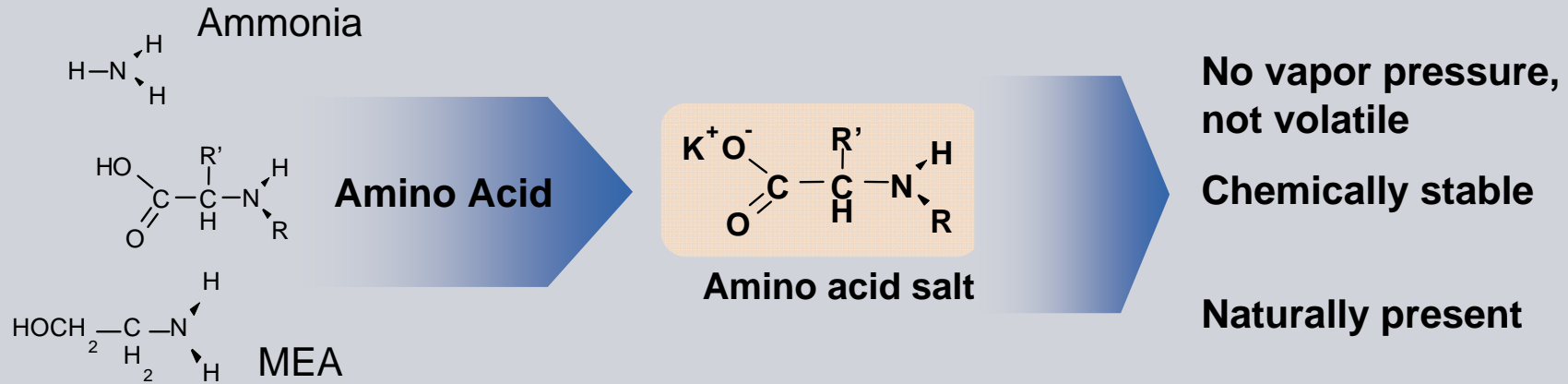


SPP w/ PostCap™ Process




validated in pilot plant

# Amino acid salt is the basis of our solvent



**Salts have no vapor pressure**

- No thermodynamic solvent emissions
- Not inflammable
- Not explosive
- Odorless
- No inhalation risk




**Negative ion is less sensitive to O<sub>2</sub>**

- Low degradation

**Amino acids are naturally present**

- Biodegradable
- Nontoxic
- Environmentally friendly



Solvents based on amino acid salts are economic, have low environmental impact and are easy to handle.

# Siemens PostCap™ Process

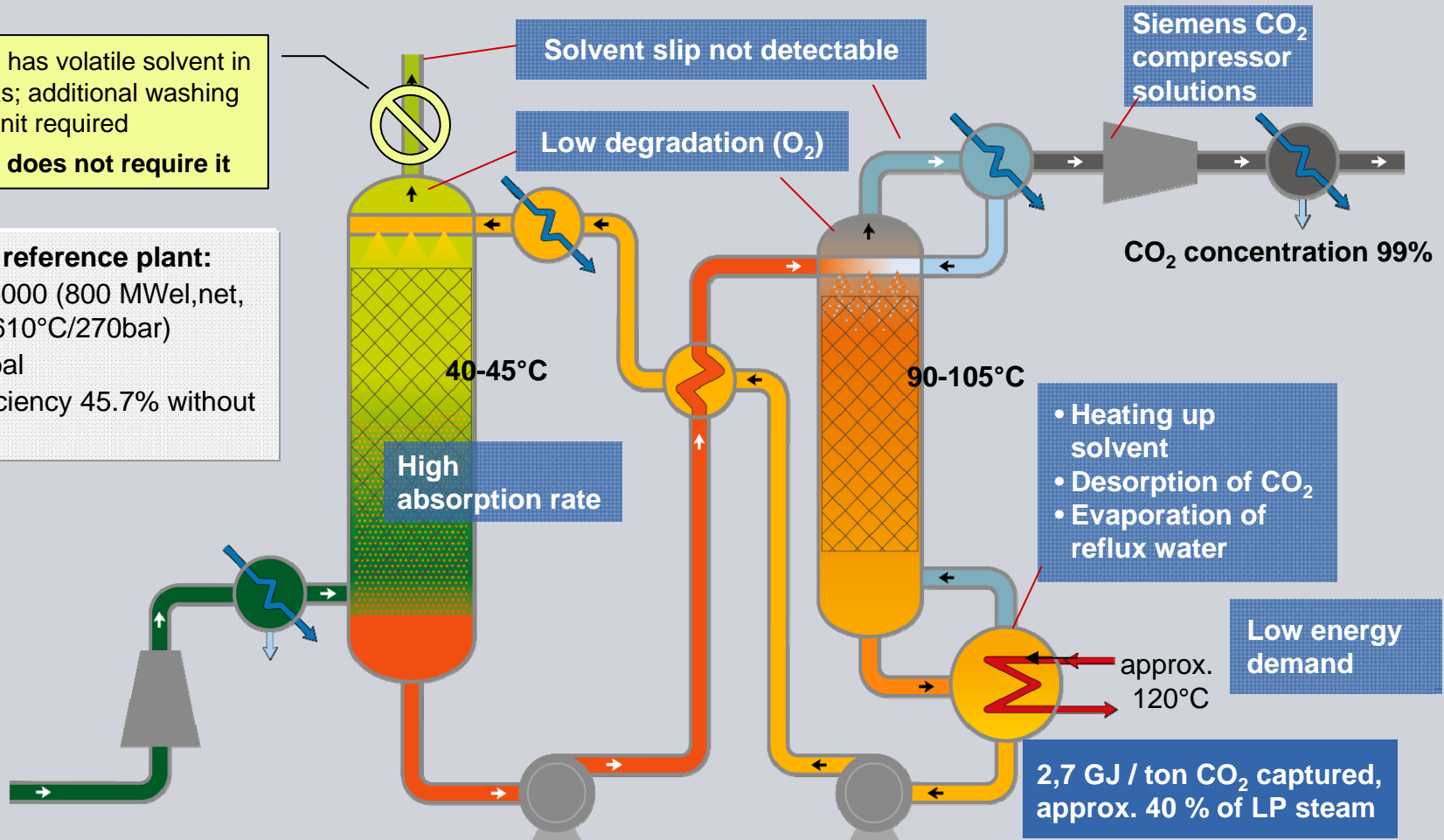
## Current development status

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Competition has volatile solvent in exhaust gas; additional washing unit required  
**SIEMENS does not require it**

**Non-CCS reference plant:**

- SSP5-6000 (800 MWeI,net, 600°C/610°C/270bar)
- Hard coal
- Net efficiency 45.7% without CCS



- Heating up solvent
- Desorption of CO<sub>2</sub>
- Evaporation of reflux water

Low energy demand

approx. 120°C

2,7 GJ / ton CO<sub>2</sub> captured, approx. 40 % of LP steam

The efficiency is < 6 %-pts. lower than the reference hard-coal fired power plant, w/o CO<sub>2</sub> compression.

**Upscaling: From Lab to Demonstration Plant  
Pilot Plant at E.ON SPP „Staudinger“ Germany and in USA**

November 2011:  
~ 5.500  
operating hours

FGD

CO<sub>2</sub>  
Absorber/  
Desorber

Start Operation  
September 2009

Footprint of capture plant for  
800 MW SPP, approx.: 25.000 m<sup>2</sup>

✓ Up-scaling via slip-stream  
Demo-Plants,  
✓ Up-scaling Design Tools  
validated

**Pilot Plant in USA**

- Flue gas from a coal-fired power plant
- Pilot plant size: approx. 2.5 MW<sub>el</sub> slip stream
- Funding by DoE: 15 million US\$
- Start up 2012

# Pilot Plant Operation Results and Conclusions

## After more than 5,500 hours of operation

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### Efficiency

Low energy consumption

- < 6% pts efficiency loss
- 2.7 GJ heat consumption

High capture rate: >90 % proven

- EU prerequisites can be easily met
- Low CO<sub>2</sub> capture cost

### Emissions

- No detectable solvent and nitrosamine salt emissions

- Add'l washing step avoided
- Permission less critical

### Solvent stability

- < 1%/year solvent degradation by O<sub>2</sub>
- High thermal stability
- Smart reclaimer concept

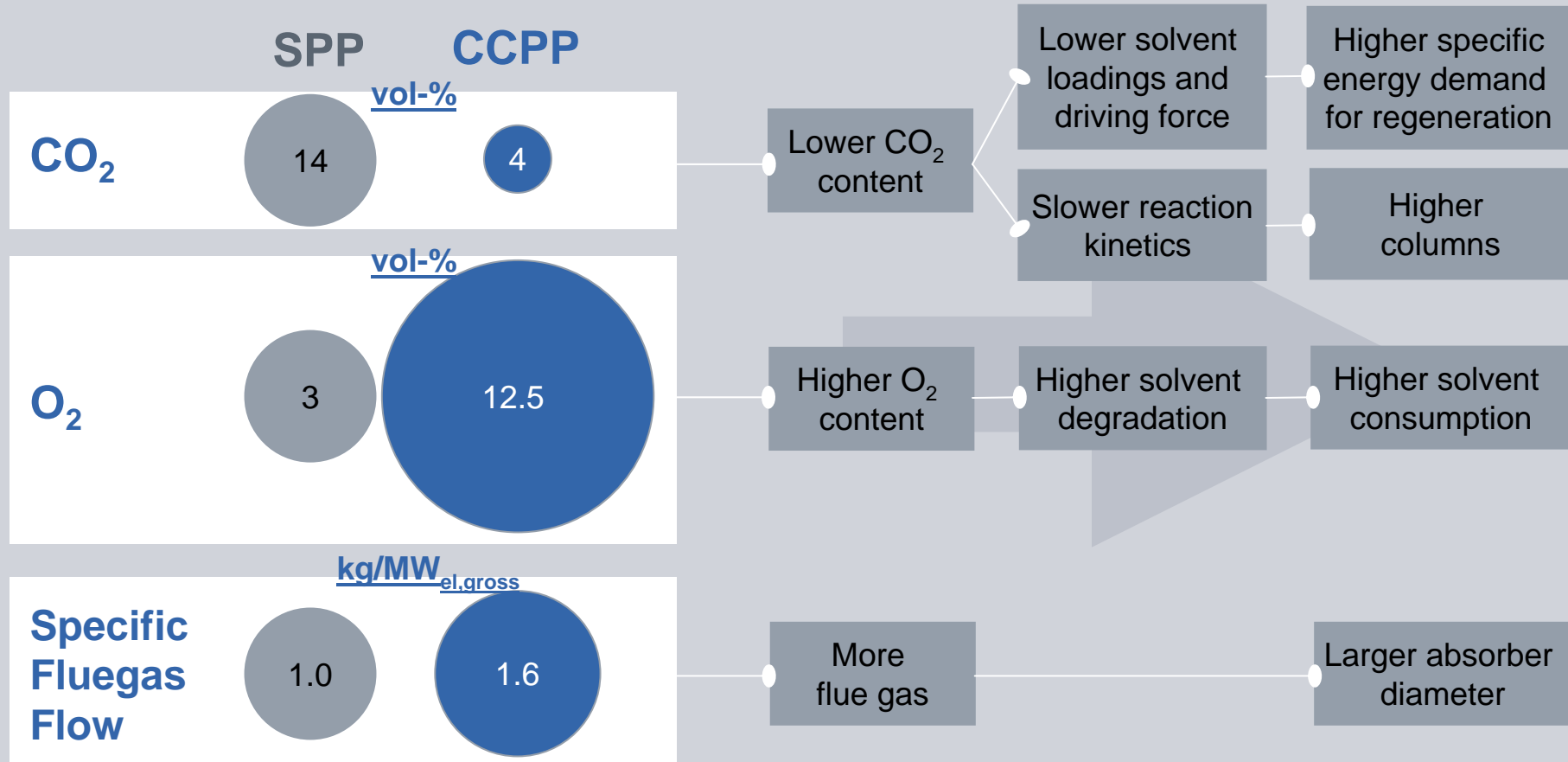
- Low refill requirements
- Low reclaiming costs

### Hardware

- Corrosion tests for construction material in all parts of capture plant

- Standard construction material applicable
- Reduced investment costs

# Solvent and process optimization for CCPP with Post Combustion capture required

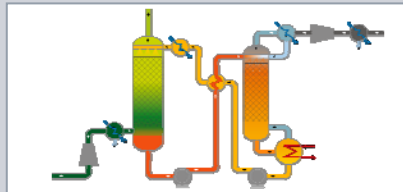


Currently Post-Combustion projects for gasfired power plants in NOR, UK and GCC region under evaluation.

# Targets for Capture Process Development

## Minimum Thermal Energy Demand

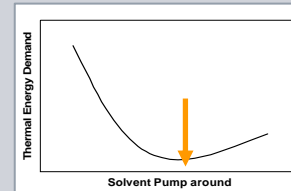
Optimization of Process Configuration



Optimization of Design Parameters

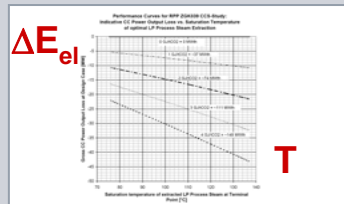
- Column Heights
- Column Diameters
- Feed Points
- Etc.

Optimization of Operating Parameters



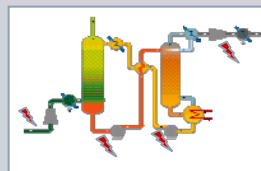
## Maximum Power Plant Efficiency

Influence of Steam Extraction at a Certain Temperature



+

Auxiliary Power Requirements of Capture Plant



=

Power Plant Efficiency Including Capture Plant

$\eta$

## Minimum Separation Cost and LCOE

Process Optimization

Equipment Design

Investment Cost Estimation

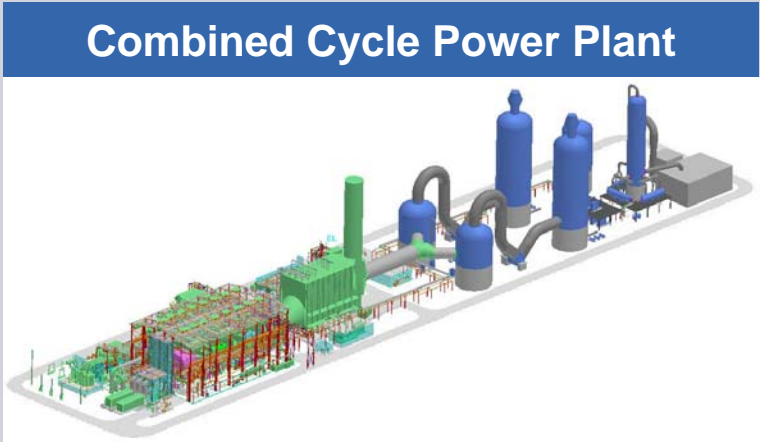
Estimation of Cost of CO2 Avoided / LCOE

€/t<sub>CO2</sub>

€/MWh

$$\text{cost of CO}_2 \text{ avoided} = \frac{COE_{capture} - COE_{reference}}{CO_2 \text{ emission}_{reference} - CO_2 \text{ emission}_{capture}}$$

# Plant Performance w/ Carbon Capture Comparison for Different Fuels

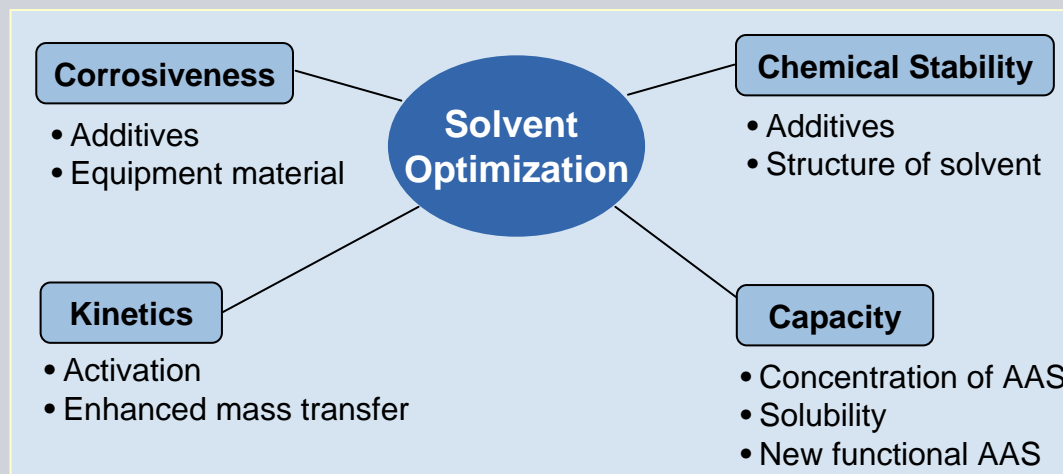
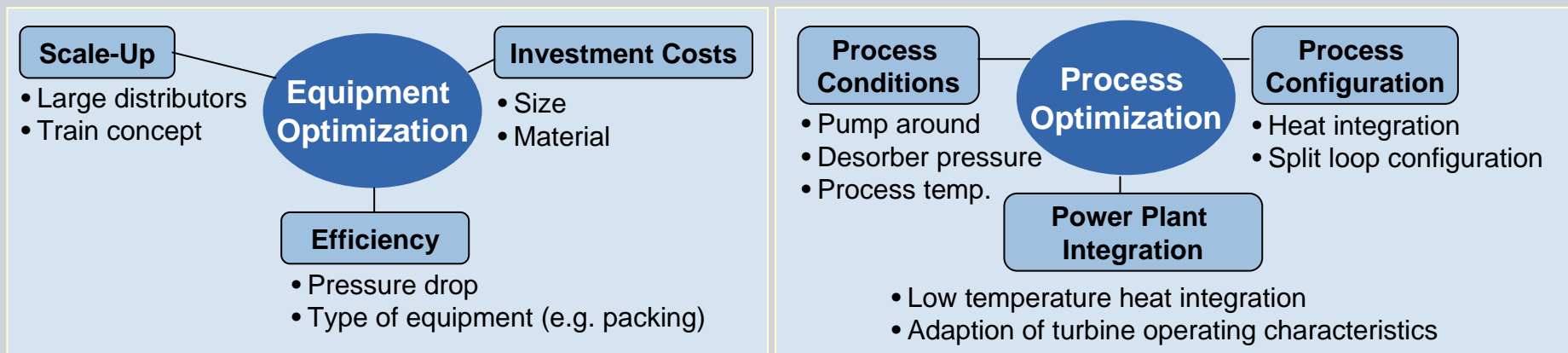


$\Delta\eta_{net}$	Capture Process	$\Delta\eta_{net}$
-8.5 %-pts.	Optimized <sup>1</sup>	-6.9 %-pts.
-6.0 %-pts.	Optimized w/o Compression <sup>2</sup>	-5.6 %-pts.

<sup>1</sup> "Optimized" means capture process configuration and operating conditions are adapted to the specific flue gas conditions of the underlying power plant

<sup>2</sup> "w/o Compression" – the numbers consider the power demand of the capture process, not of the usually subsequent compression of the CO<sub>2</sub> for transport

## Further process improvements in several development fields are ongoing



Risk/contingency adders lead to higher Capex in “First-of-its-kind” demonstration projects.

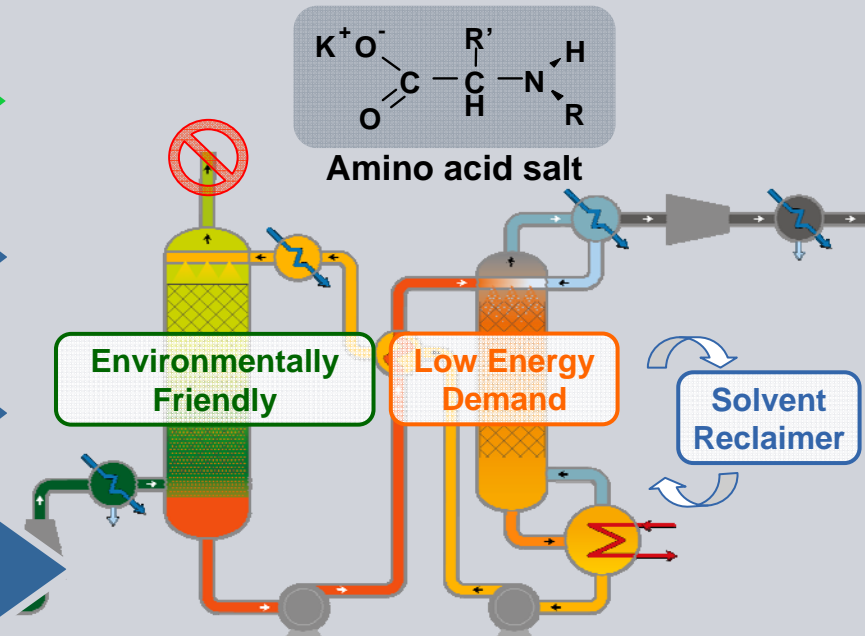
## Siemens PostCap™ technology

No detectable solvent and nitrosamine salt emissions, no additional washing steps required

State of the art reclaiming system with very limited solvent losses, FGD polishing not required

Limited solvent degradation (O<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub>, thermal), "easy to handle" (not inflammable, no inhalation risk)

Energy consumption for regeneration, November 2011: 2,7 GJ/tCO<sub>2</sub> ....target < 2,2 GJ/tCO<sub>2</sub>



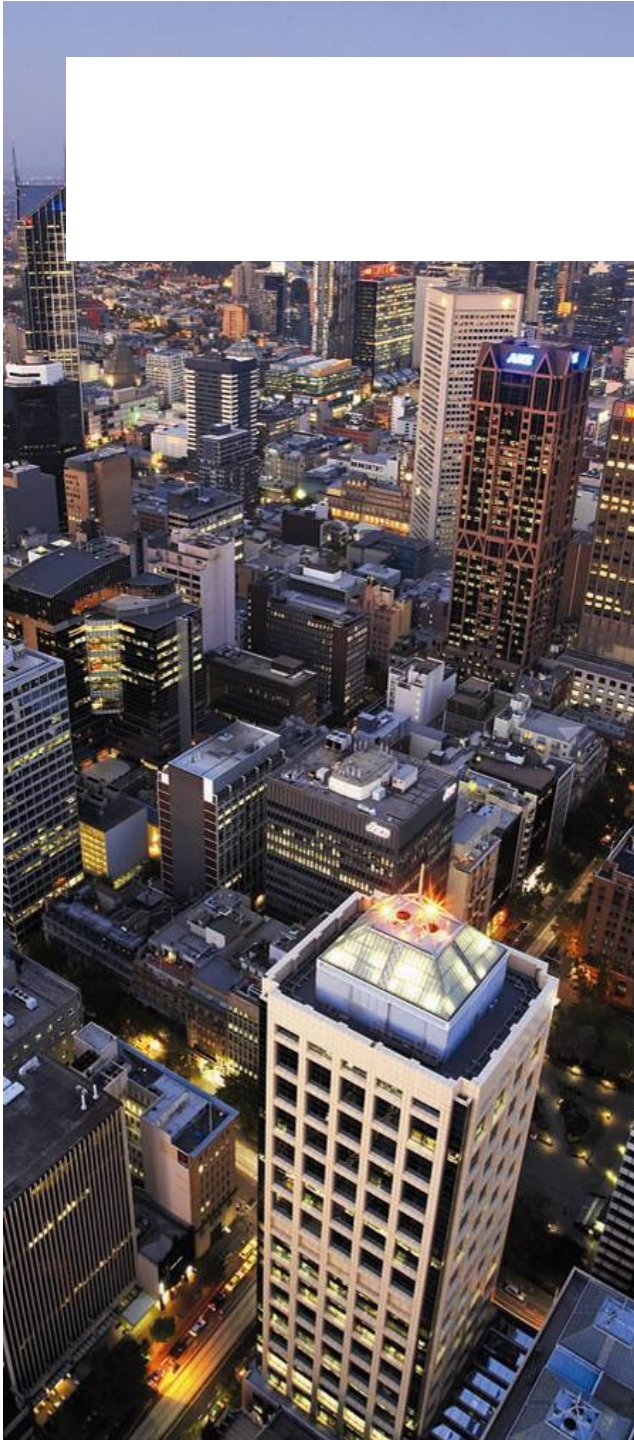
### Optimal integration in power plant

... November 2011: 6% pts. efficiency drop / target < 5 % pts.

... < 30min response time to full capacity

**SIEMENS**

**Vielen Dank für Ihre  
Aufmerksamkeit!**





**SIEMENS**

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