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## Post-Combustion Carbon Capture – Leading Mature Technology for Decarbonization of Fossil Power Generation

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# Cooperations

## TNO Cooperation



### Exclusive Agreement

Agreement signed June 2009

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



## Masdar Cooperation



### Long-term strategic partnership

Agreement signed March 3rd 2011



Siemens is co-operating together with...

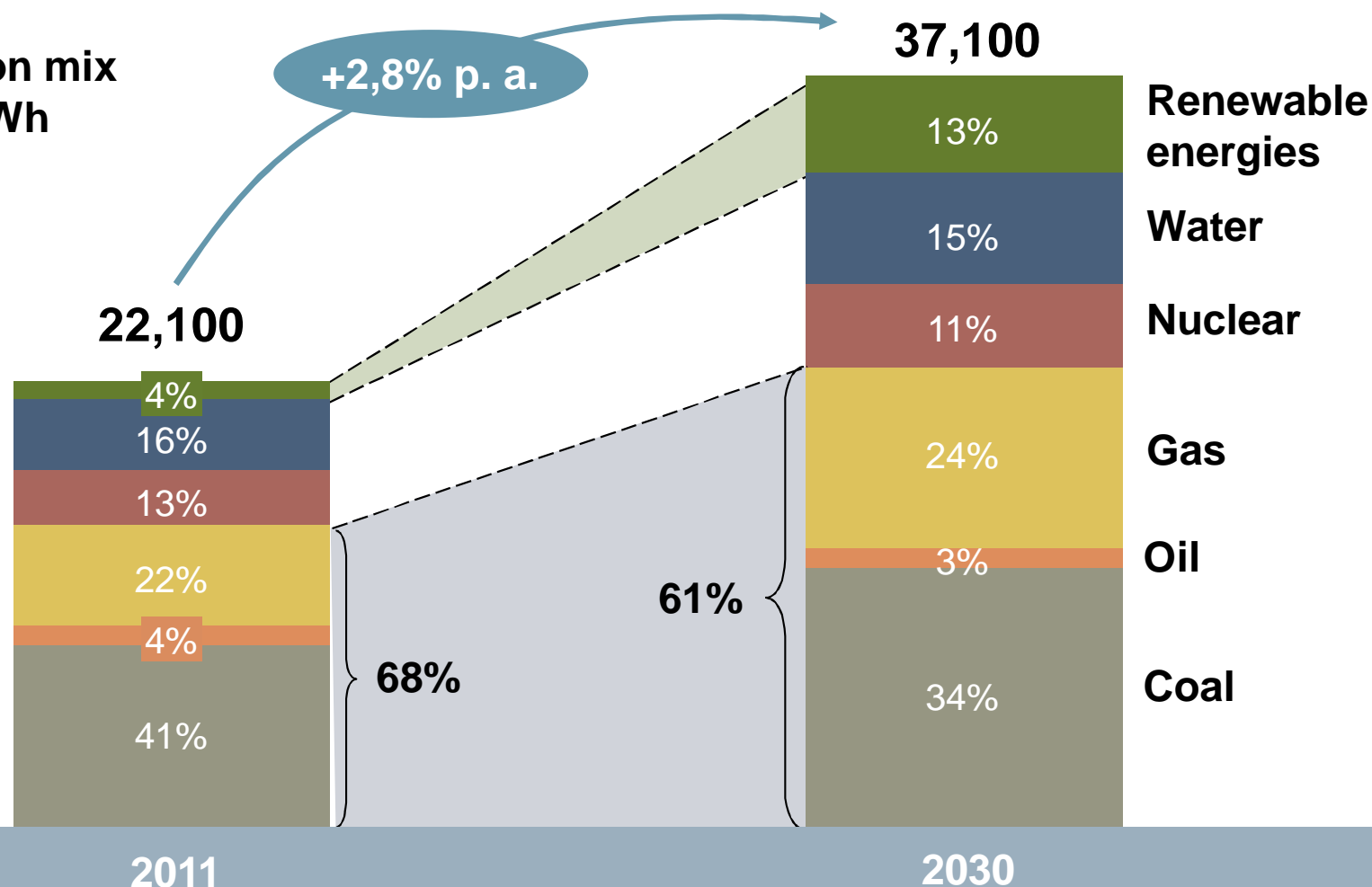
- **Masdar City**
- **Masdar Institute**
- **Masdar Clean Energy**

in the field of  
**Carbon Capture Utilization and Sequestration (CCUS)**  
for improved application of CCUS technology in the Middle East region.

# Need for CCS

## Power generation mix worldwide, in TWh

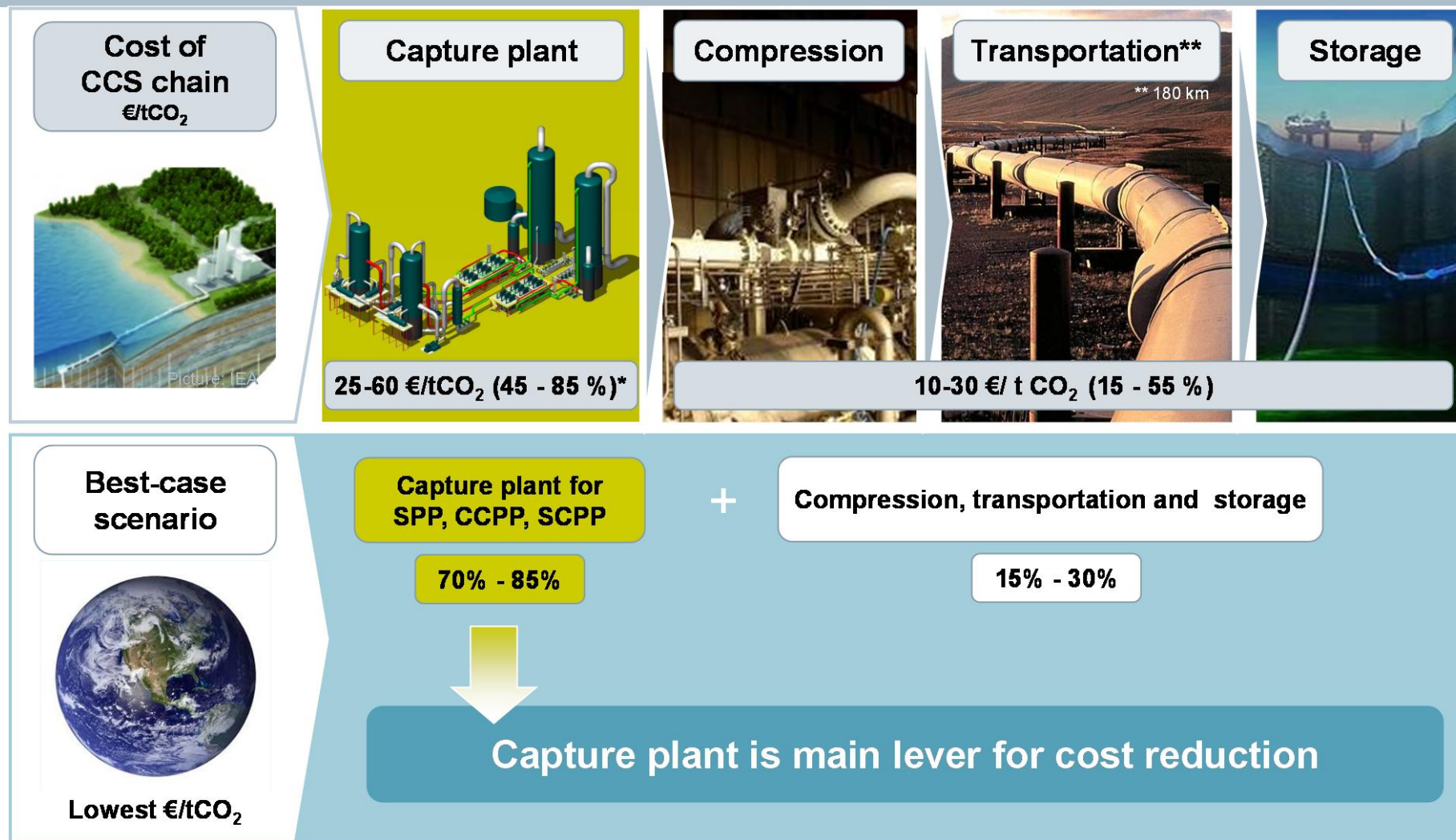
Source: Siemens



In spite of % percentage of fossil decreasing (68% - 61%) CO<sub>2</sub> emissions increase every year in the coming decade.



# Competitive Environment

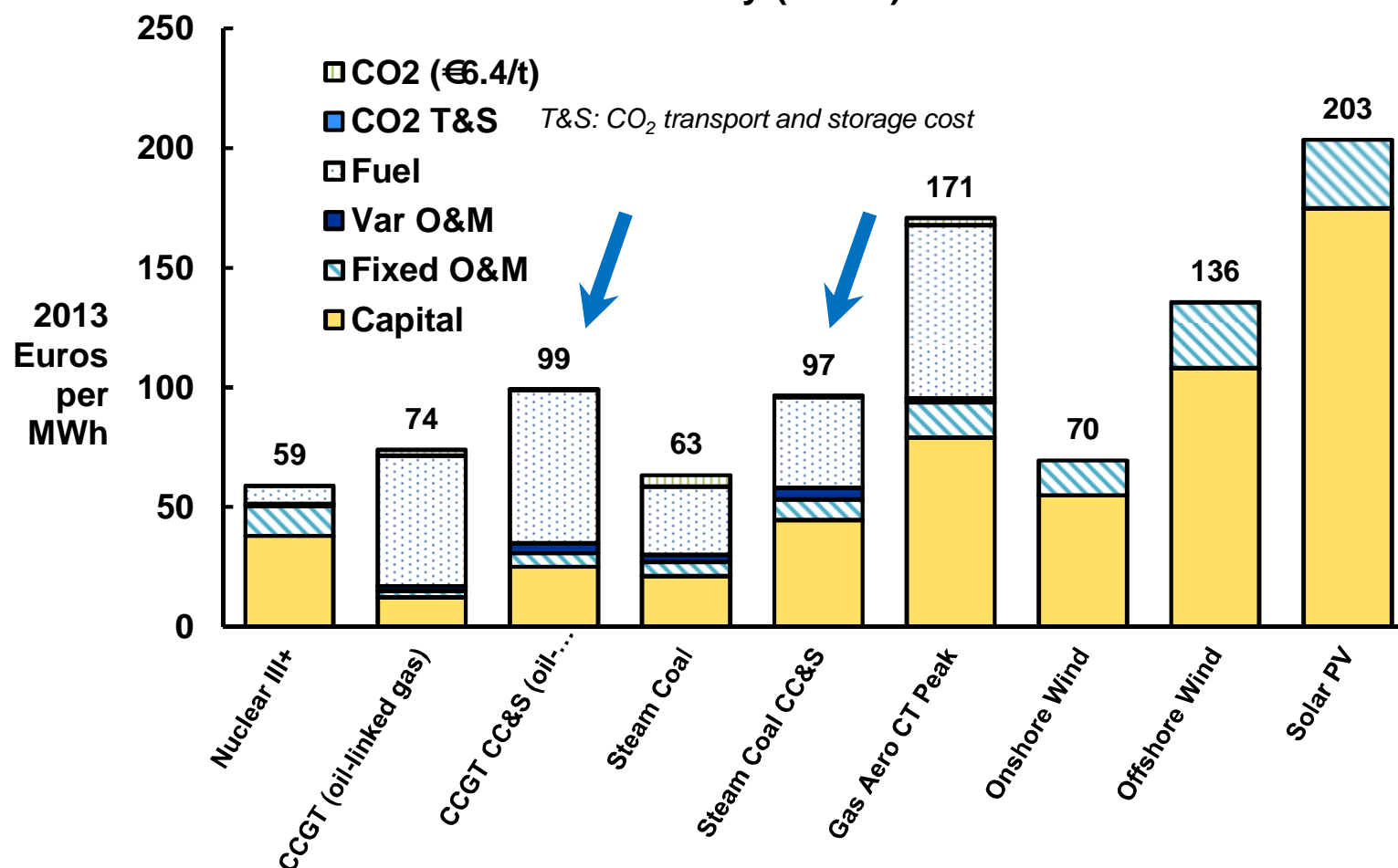


Compensation mechanisms mostly not in place to compensate power plant operation for higher OPEX and CAPEX.

# Competitive Environment

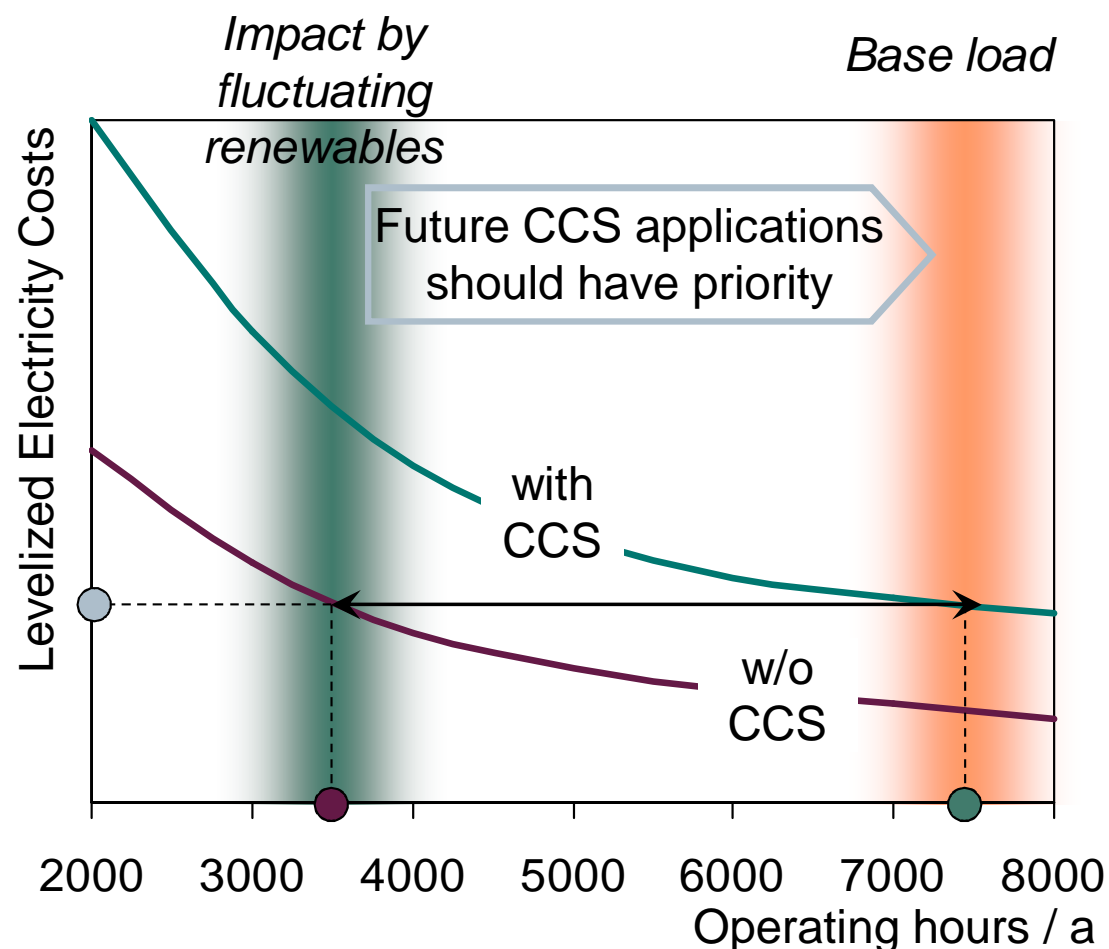
## Levelized Cost of Electricity (LCOE)

Source: IHS CERA - Levelized cost of electricity 2013 (All Europe)



CCS is a fully dispatchable, base load capable, low carbon technology with electricity cost comparable to many renewable technologies.

## Competitive Environment

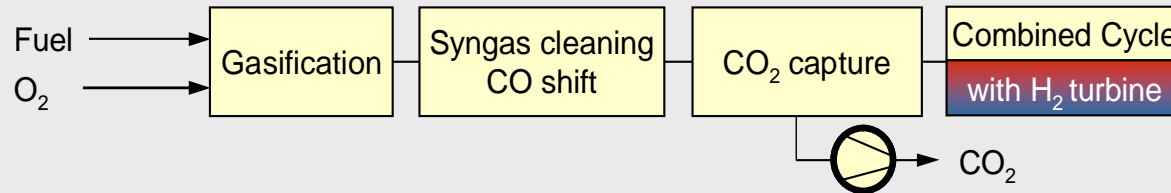


Fossil Power Plant w/ CCS in optimal operating regime can be more economically than Fossil Power Plant w/o CCS

Low-CO<sub>2</sub> power plants are required to be operated on mid- to base-load, CO<sub>2</sub> certificate price assumed at current, moderate levels.

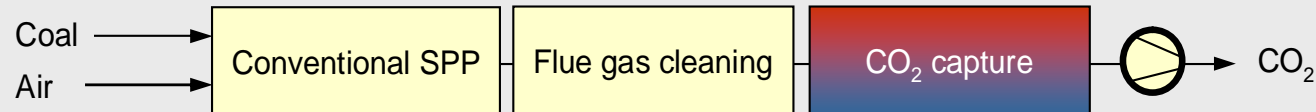
# Post Combustion Capture

## CO<sub>2</sub> Capture before Combustion (Pre-Combustion)

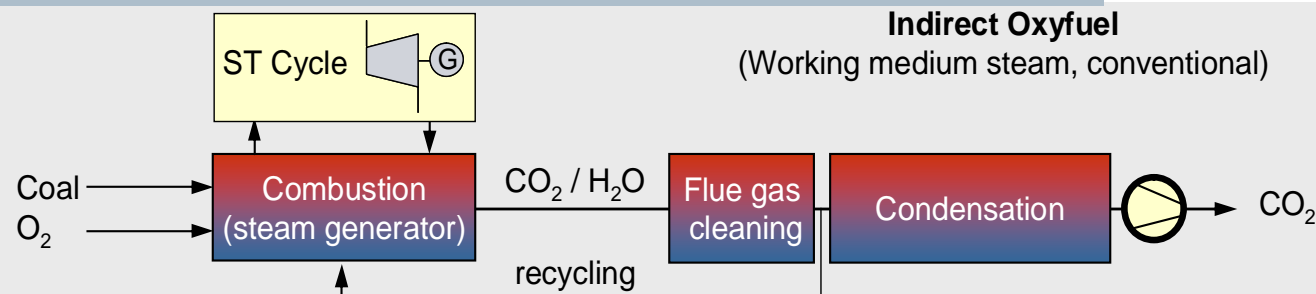


## CO<sub>2</sub> Capture after Combustion (Post-Combustion)

### Conventional PP with CO<sub>2</sub> scrubbing



## Integrated CO<sub>2</sub> Capture after Combustion (Indirect Oxyfuel)



After many years there are still three main options for CCS:

### Pre-Combustion

- New build, no retrofit possible
- Main application in polygeneration (→ mature technology)
- large global GT gasifier fleet

### Post Combustion

- Large reference base for absorption processes in chemical industry
- Retrofittable !!!
- Mature technology

### Oxyfuel

- No large reference base in global industry
- No proven applicability to high-temp gas turbines

In addition many new ideas.....but need more time, not available before 2020.



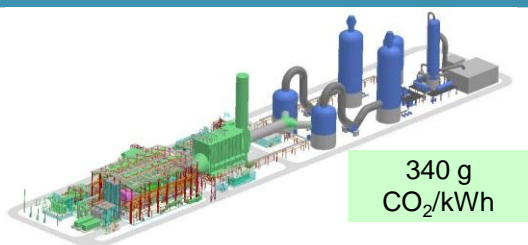
# Post Combustion Capture

## PostCap™ Technology



Validated in unit 5  
of E.ON Staudinger  
steam power plant  
in Germany

### 700 MW CCPP in O&G Business



approx. **1,8 Mio** tons of CO<sub>2</sub>  
reduction per year

✓ 40\* g CO<sub>2</sub>/kWh

### 800 MW Steam Power Plant



approx. **4,0 Mio** tons of CO<sub>2</sub>  
reduction per year

✓ 80\* g CO<sub>2</sub>/kWh

### Other Industrial Processes



CO<sub>2</sub> concentrations higher,  
CO<sub>2</sub> quantities lower than in  
power generation

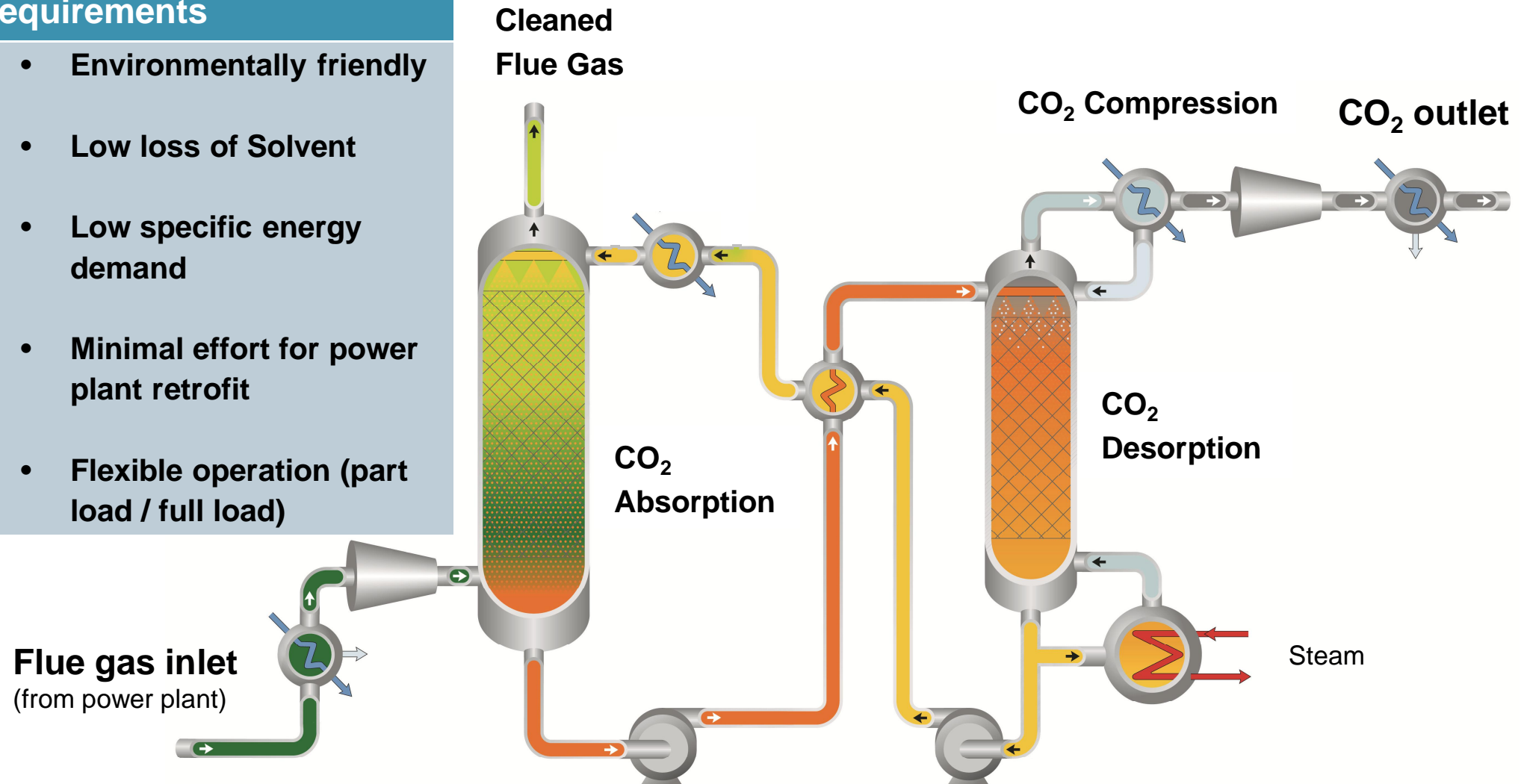
\*90% CO<sub>2</sub> capture rate

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# Post Combustion Capture

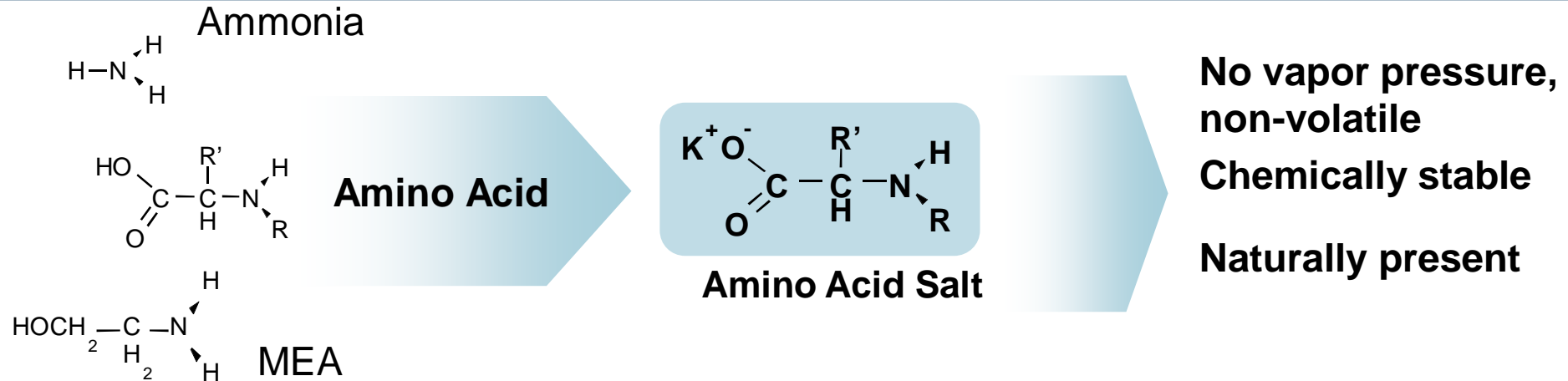
## Post Combustion Process Requirements

- Environmentally friendly
- Low loss of Solvent
- Low specific energy demand
- Minimal effort for power plant retrofit
- Flexible operation (part load / full load)



# Power Plant Competitive Capture Technology

## Siemens Approach for Post Combustion Capture



### Salts have no vapor pressure

- No thermodynamic solvent emissions
- Non-flammable
- Non-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.

# Power Plant Competitive Capture Technology

## PostCap™ Pilot Plant at E.ON Staudinger

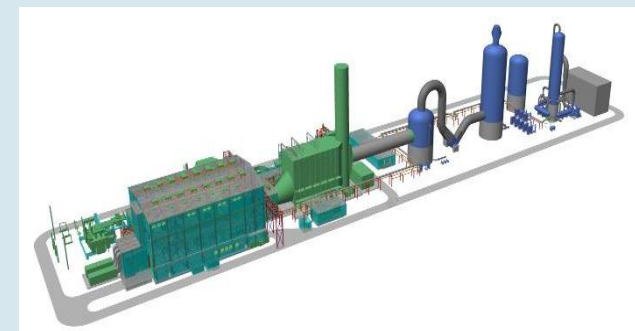


Project	Siemens PostCap™ Pilot Plant
Location	Frankfurt, Germany
Customer	E.ON (coal-fired power station Staudinger)
Commissioning	September 2009
Plant size	Approx. 1 t/d CO <sub>2</sub>
Operating Hours	> 9,000 hours

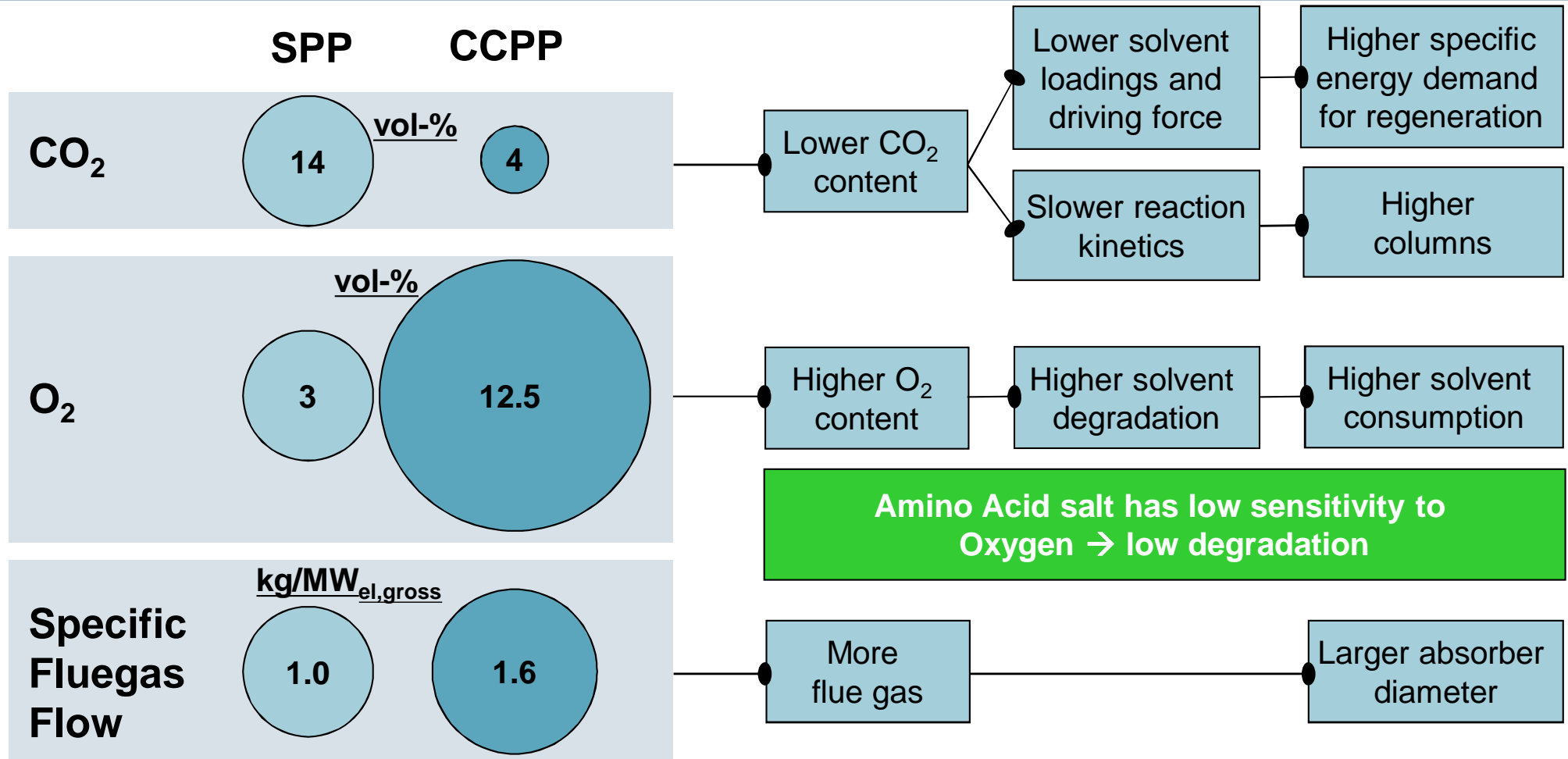


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- Siemens PostCap™-Technology verified
- Simulation tools and scale up-methods validated
- Optimizations and adaptations ongoing



# Carbon Capture at Gas Fired Plants



SPP - Steam Power Plant CCPP - Combined Cycle Power Plant



# Carbon Capture at Gas Fired Plants

## Masdar FEED



Project	Masdar full-scale CO <sub>2</sub> capture project
Location	United Arab Emirates
Customer	Masdar Carbon
Process	Combined Cycle Power Plant
Plant size	1.8 Mio tons of CO <sub>2</sub> per year
Commissioning	tbd



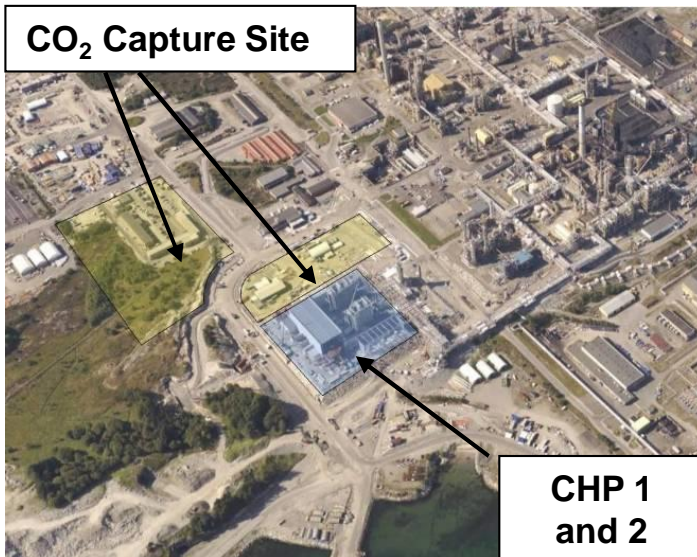
- Overall target for 2030: Capture approx. 30 Mio tons/a for EOR
- Highly advanced CO<sub>2</sub> pipeline network (target 500 km) with excess capacity for growth until 2030
- 1<sup>st</sup> step being implemented: CO<sub>2</sub> from steel manufacturing, approx. 0.8 Mio tons/a CO<sub>2</sub>
- Possible 2<sup>nd</sup> step:
  - CO<sub>2</sub> from gas fired power plant (target 1.8 Mio tons/a CO<sub>2</sub>): MASDAR-Siemens CCS Collaboration
  - Siemens PostCap™ basis of a FEED executed by Siemens

# Carbon Capture at Gas Fired Plants

## Full-scale Carbon Capture Mongstad Project



Project	Full-Scale Carbon Capture Mongstad (CCM)
Location	Mongstad Refinery, Norway
Customer	Statoil Petroleum AS
Process	Combined Heat and Power Plant
Plant size	1.2 Mio tons of CO <sub>2</sub> per year
Status	TQP finalized -project discontinued by Norw. Gov.

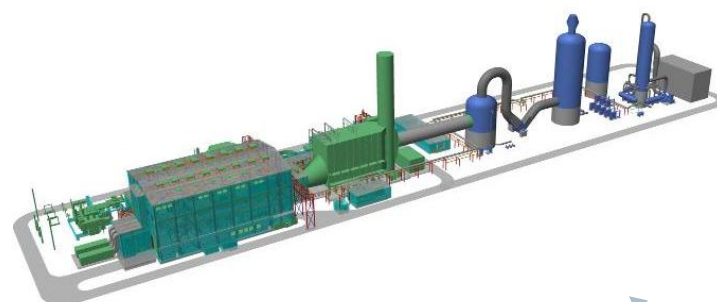
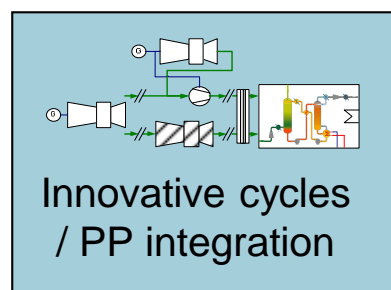
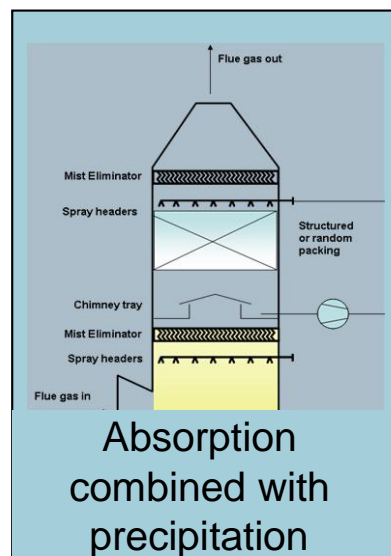


Ongoing: Technology Qualification Program (TQP) of CO<sub>2</sub> post-combustion capture technologies, divided into three phases:

1. Feasibility study to show that the technology can be used at Mongstad (completed)
2. Demonstrate process operation and specified emissions level/criteria with test-rig and pilot plant (completed)
3. Concept Phase incl. costing for design of full-scale CO<sub>2</sub> capture (completed)

# Cost Reduction Potential

□ outstanding cost reduction potential achievable with Siemens PostCap™



Short term cost reduction potential

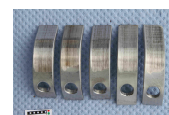


Optimization of reclaiming



Activators

Alternative concepts for direct contact cooling



Material

Target engineering / economy of scale

Short term cost reduction potential: > 20 %, long term > 30 % achievable.

## Conclusion

Fossil fuels will maintain a big share in global electricity production, CCS is urgently needed to cope with climate change.

LCOE of CCS is lower now than with offshore wind or photovoltaic power generation with further cost reduction potential.

Post-combustion technologies comprises a proprietary chemical absorption process that is mature and retrofitable to coal and gas fired power stations.

Siemens PostCap™ process is very efficient, easy to handle; Power Plant remains Power Plant.

Next challenge is to reduce overall costs of CCS chain and gain acceptance for CO<sub>2</sub>-Storage. Siemens has identified first potential measures. Demonstration needed.

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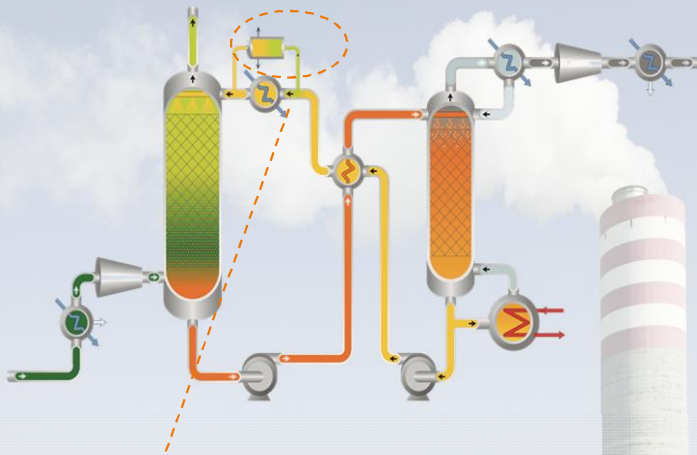
# Backup

# Power Plant Competitive Capture Technology

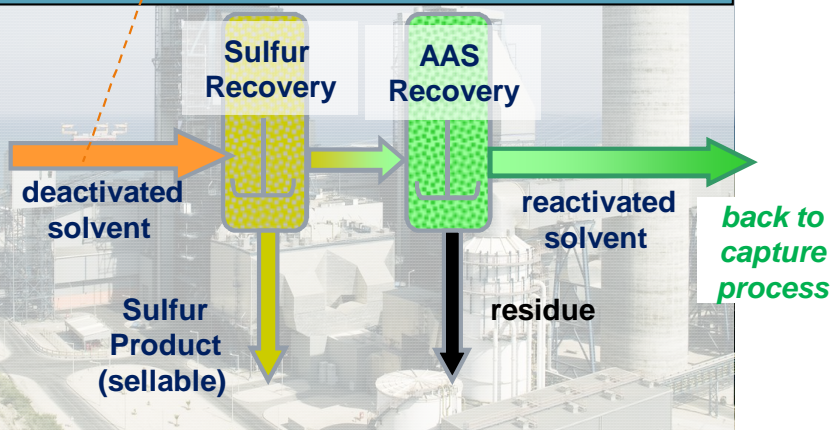
## Siemens Approach for Post Combustion Capture

### Solvent Degradation

Solvent deactivation due to degradation (thermal,  $O_2$ ,  $NO_x$ ,  $SO_x$ , etc...)



### Proprietary PostCap™ Reclaimer



## Siemens PostCap™ Process

based on: **AMINO ACID SALT (AAS)** Formulations

- Siemens AAS Solvent - non volatile :
  - Zero Solvent Slip to atmosphere
  - Easy handling
- Effective combination of a power plant and a capture plant as an end-of-pipe solution

**Power Plant remains Power Plant**

- Chemical reclaiming possible :

- AAS highly  $O_2$  resistant
- Sellable Sulfur product
- FGD retrofit can be avoided
- Small amount of residue

**Proprietary reclaiming process available that complements the Siemens PostCap™ Process**