Post Combustion CO_2 Capture Technology: Current Status and Future Directions

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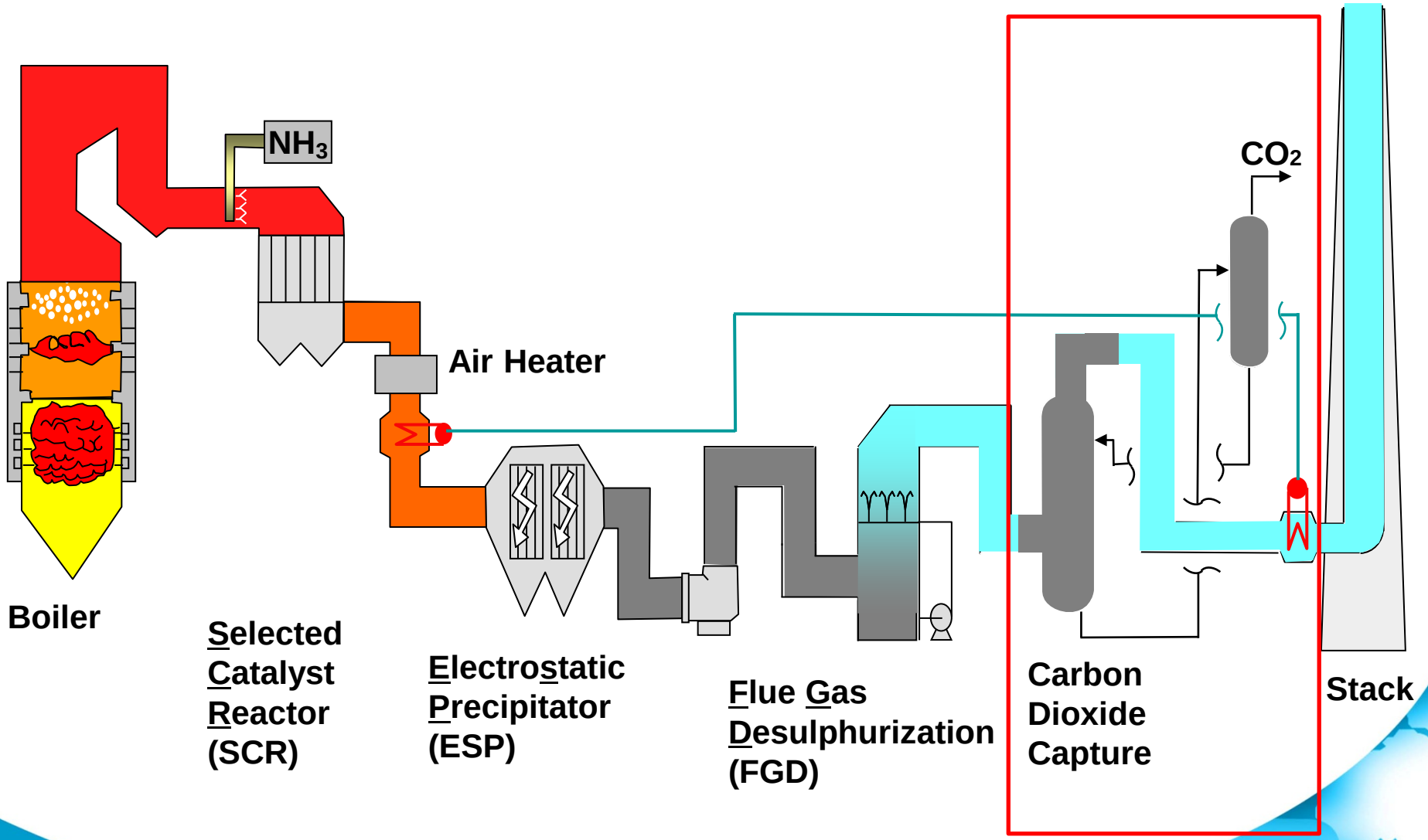
Conference on Clean Coal and Carbon Capture and Storage Technologies

3rd December 2013, Trichy, India

Outline

- Introduction to Post Combustion Capture Technology
- Post Combustion Capture Pilot & Demonstration Plants
- Improvements for solvent based Post Combustion Capture Process
- 2nd & 3rd Generation Post Combustion Capture Technologies

Post Combustion Capture (PCC) Process



Source: Mitsubishi Heavy Industries

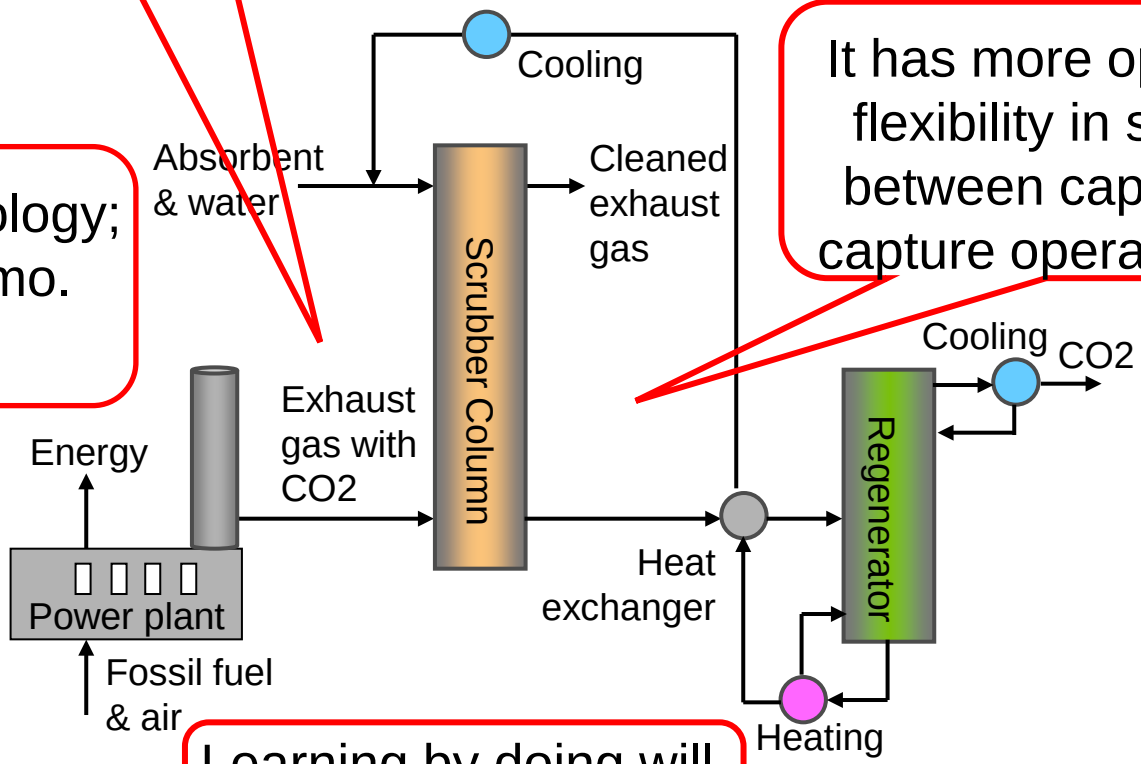
Why Post Combustion Capture (PCC)?

Capture readiness makes relatively easy to incorporate into power plants

Can be easily Retrofitted

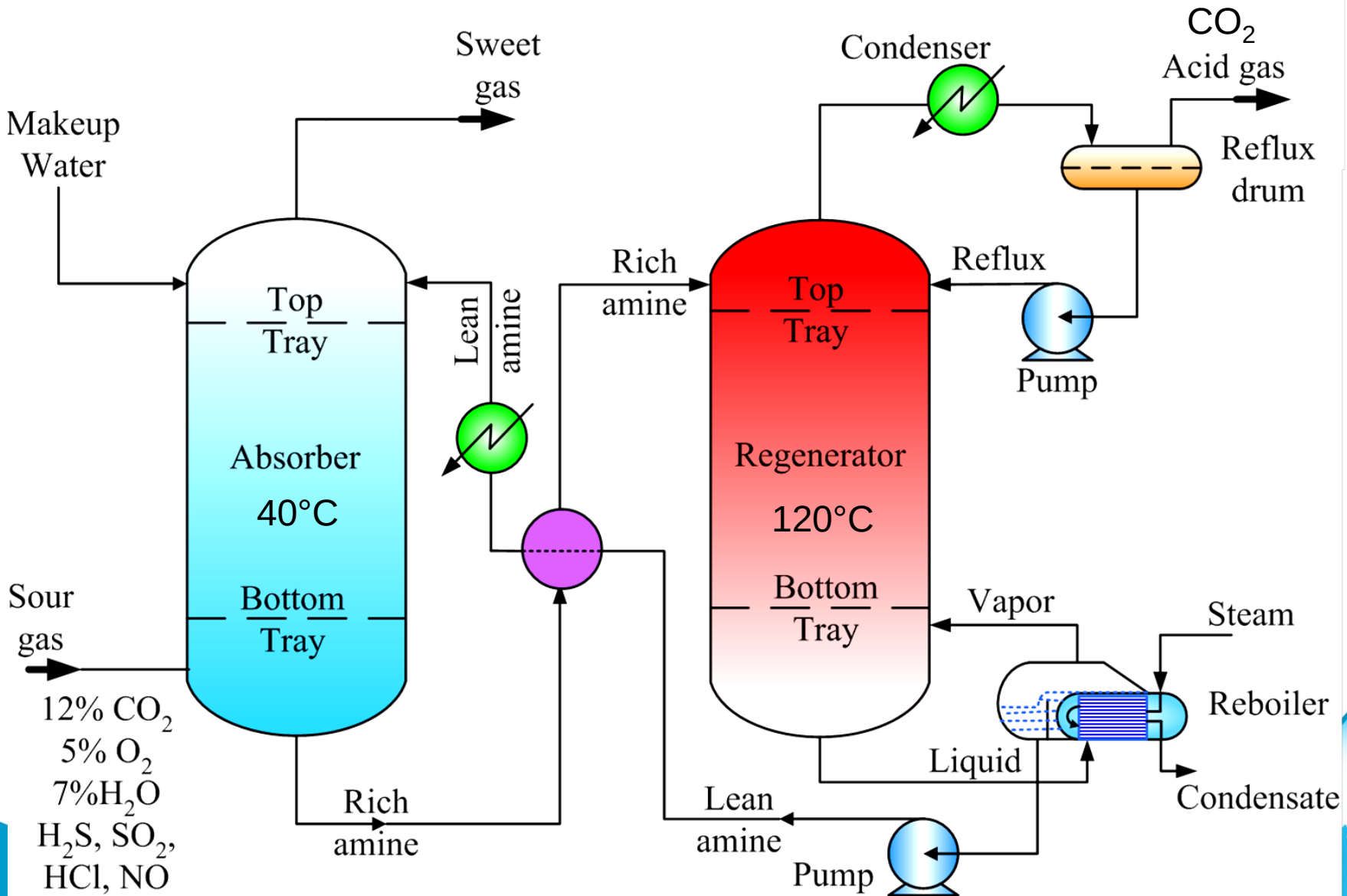
It has more operational flexibility in switching between capture – no capture operation mode

State of Art Technology; Several Pilot demo. projects



Learning by doing will lead to cost reductions

Leading PCC Technology is Solvent Based Absorption process

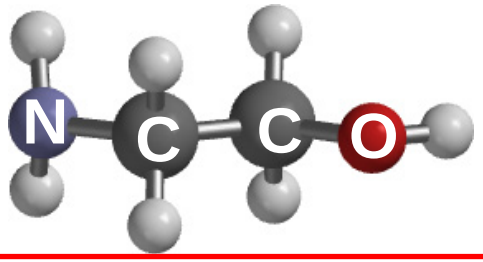


CO_2 and Amine based Solvent Reaction

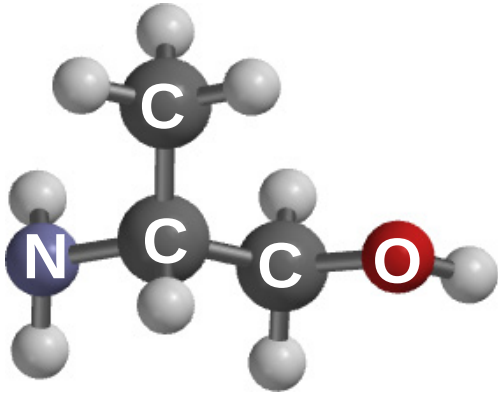
Acid Base, Temperature Dependent, Reversible Reaction

$$2R_2NH + CO_2 \underset{\text{Fast reaction}}{\overset{\textit{Low Temp.}}{\rightleftharpoons}} R_2NCOO^- + R_2NH_2^+$$

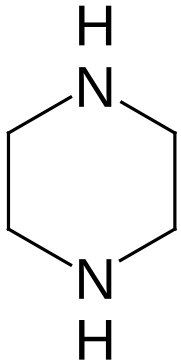
Carbamate



Monoethanolamine (MEA)



Sterically Hindered



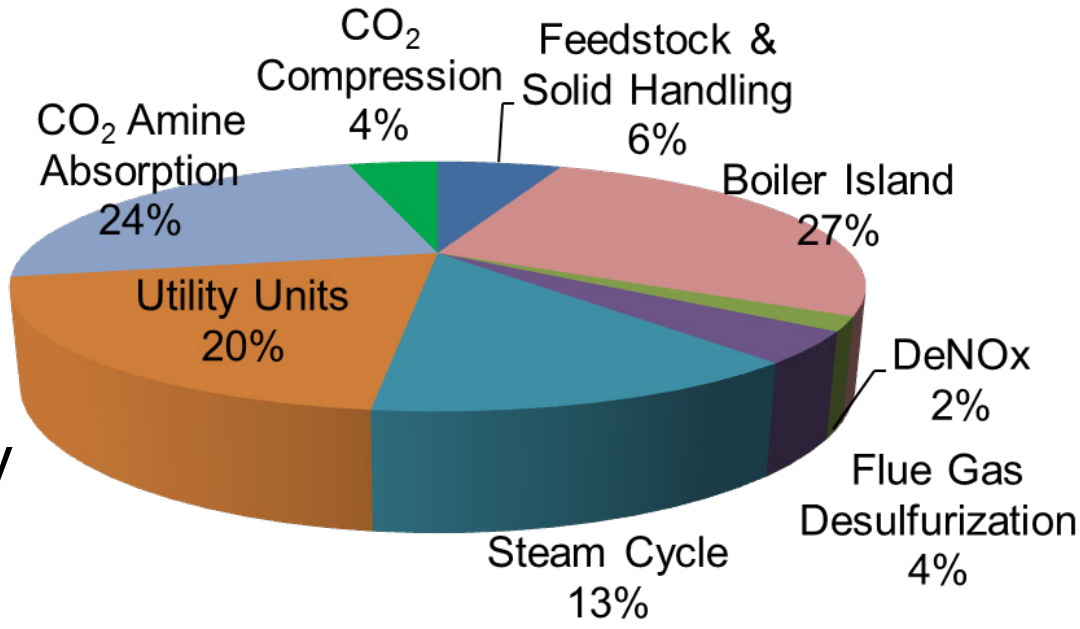
Piperazine (Pz)

Commercially Available Solvents

Solvents	Process Name	Developers
Conventional MEA	Econamine $^{+}$	Fluor, ABB
Ammonia	Chilled Ammonia	Alstom
Hindered Amines	KS-1, AMP, …	MHI, EXXON
Tertiary Amines	MDEA	BASF, DOW
Amino Acid Salts	CORAL	TNO, Siemens, BASF
Piperazine		Uni. Texas at Austin
HiCapt, DMX^{TM}	Mixture	IFP, France
Integrated SO_2/CO_2	Amines	Shell/Cansolv
Amine		Aker Clean Carbon
Chemical solvents	DEAB, KoSol, Calcium based,	HTC, Uni Regina, KEPRI, NTNU, SINTEF, CSIRO, KEPRI, EnBW

Process Economics

- New IEAGHG Base line study for Supercritical Pulverized Coal Power Plant with 90% CO_2 Capture, The Netherlands
- Based on Shell/Cansolv Amine based Post combustion capture process
- 15% Increase in Annual Operational Cost (same coal feed rate)



Capital Cost

Post Combustion Capture Pilot & Demonstration Plants

Ferrybridge CCPilot100+, UK

- PCC demonstration plant using Doosan Power Systems' technology
- 100 t/day slip stream from a 500MWe unit on SSE's Ferrybridge Power Station, making it the largest PCC demonstration in the UK
- Two year test programme, fast-tracked build, operating March 2012
- Funded by all project partners
- Lessons learned to be incorporated into future designs

SSE

DOOSAN

VATTENFALL

Technology Strategy Board
Driving Innovation

DEPARTMENT OF ENERGY & CLIMATE CHANGE

Moving Forward: The Northern Way

one NORTH EAST

Northwest

http://www.sse.com/Ferrybridge/TheCarbonCaptureProject/ProjectInformation/

RWE CO_2 Capture Pilot Plant Niederaussem, Germany

- Flue gas from lignite fired power plant: 1,550 m^3_N/hr
- CO_2 product: 7.2 t_{CO2}/day; capture rate 90%
- Absorber / regenerator packing type and height corresponds to full scale
- Commissioning and start-up 2009, availability of 97%
- Budget of RWE for phases I/II: 15 M€
- 40% funding by German Federal Ministry of Economics and Technology (0327793 A-F)
- Phase III being planned

http://www.rwe.com/web/cms/en/2734/rwe/innovation/projects-technologies/power-generation/fossil-fired-power-plants/co2-scrubbing/

American Electric Power (AEP): Mountaineer CCS Demo., USA

- Alstom Chilled Ammonia Process (CAP) process for 90% of the carbon dioxide capture from a 235 megawatt electric (MWe) slipstream of 1300MWe Mountaineer coal-fired power plant located near New Haven, West Virginia
- Capture and sequester approximately 1.5 million tons per year of CO_2
- The project is comprised of American Electric Power, Alstom, RWE, NETL, and Battelle Memorial Institute
- Between September 2009 and May 2011, validated successfully the capture and storage technologies

http://www.aep.com/environment/climatechange/carboncapture.aspx

Boundary Dam Integrated CCS Demo. Project, Canada

- $1.24-billion partnership involving the Government of Canada, the Government of Saskatchewan, SaskPower, and private industry
- In construction and scheduled to begin operation in 2014
- 1 million tonne CO_2/year captured at 90% emission reduction
- Upgrading the unit's output to help meet the additional power demands of the CCS operation

http://www.saskpower.com/our-power-future/work-currently-underway/boundary-dam-integrated-carbon-capture-and-storage-demonstration-project/

Rotterdam Opslag en Afvang Demonstratie project (ROAD), The Netherlands

- This project is a component of the new E.ON Maasvlakte Power Plant 3 (MPP3), a 1070 MW (gross) coal- and biomass-based power plant
- A 250MWe post-combustion capture unit will be installed at the plant
- Approximately 1.1 million tonnes per annum of carbon dioxide (CO_2) would be captured for storage in offshore depleted oil and gas reservoirs
- Maasvlakte CCS Project C.V., a joint venture of E.ON Benelux and Electrabel; Project currently is under planning

e·on

Electrabel
GDF SUEZ

GLOBAL CCS INSTITUTE

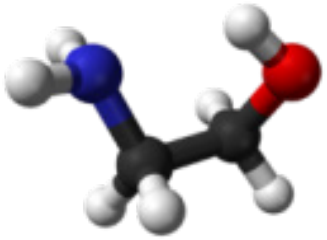
Government of the Netherlands

Co-financed by the European Union
European Energy Programme for Recovery

http://road2020.nl/en

Improvements in Amine based Post Combustion Capture Process

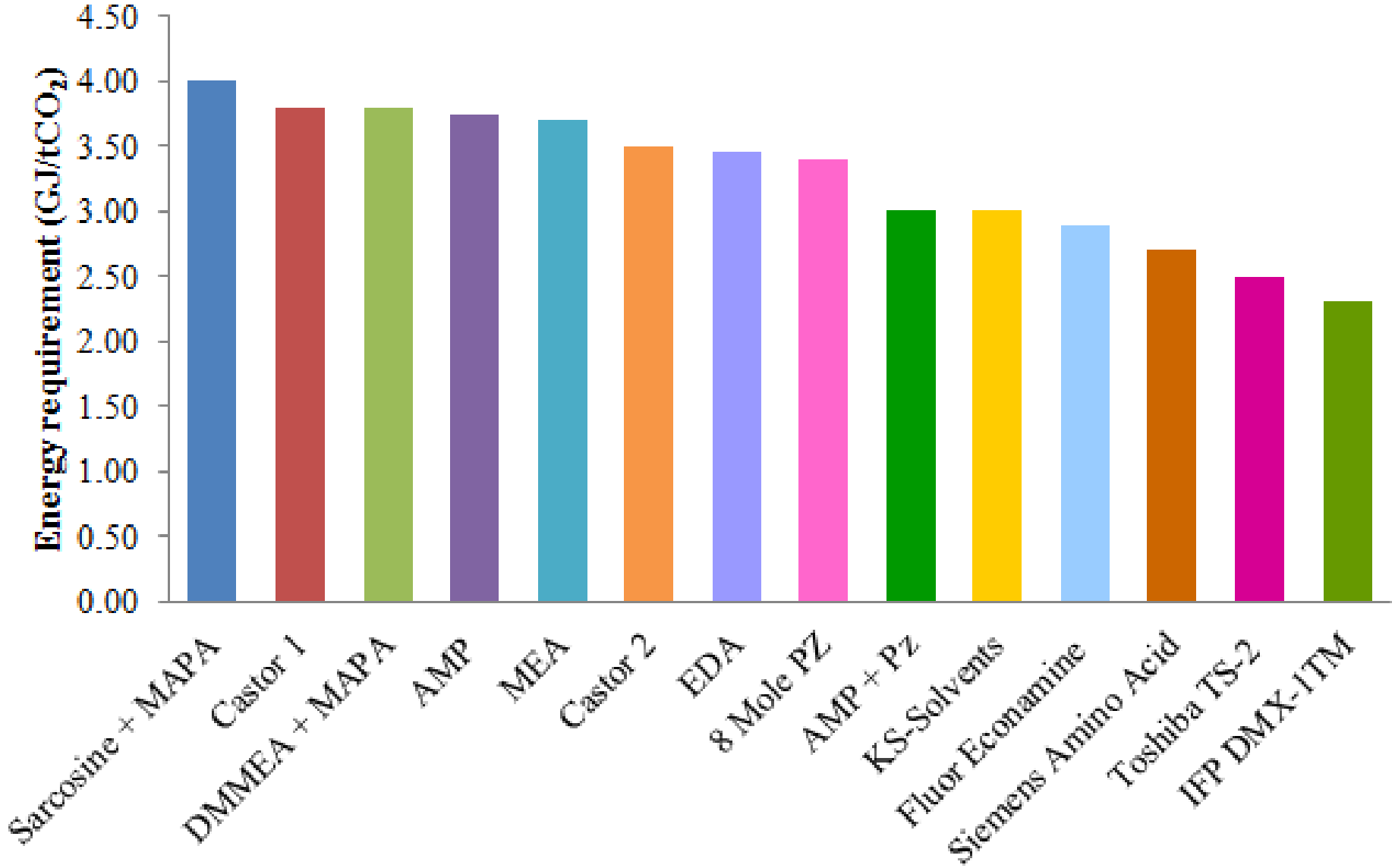
Ideal Liquid Solvent for PCC



- Not only:
  - ✓ High cyclic CO_2 absorption capacity
  - ✓ High rates of CO_2 absorption
  - ✓ Low CO_2 desorption energy requirement

- But also:
  - ✓ Resistance to oxidation
  - ✓ Resistance to other routes for degradation
  - ✓ No impact of O_2, SO_x, NO_x and fly ash
  - ✓ No corrosion issues
  - ✓ No concerns around health, safety and environment

Solvent Regeneration Energy



Source: IEAGHG 2013/TR5Incorporating Future Technological Improvements in Existing CO2 Post Combustion Capture Plants: Technical Review

Solvent Regeneration Energy

Increase

Negative Effect

Increase steam consumption for reboiler, require larger LP steam to produce extra steam.

Regeneration Energy

- Heat of absorption
- Sensible heat (Heat capacity)
- Heat for water vaporization

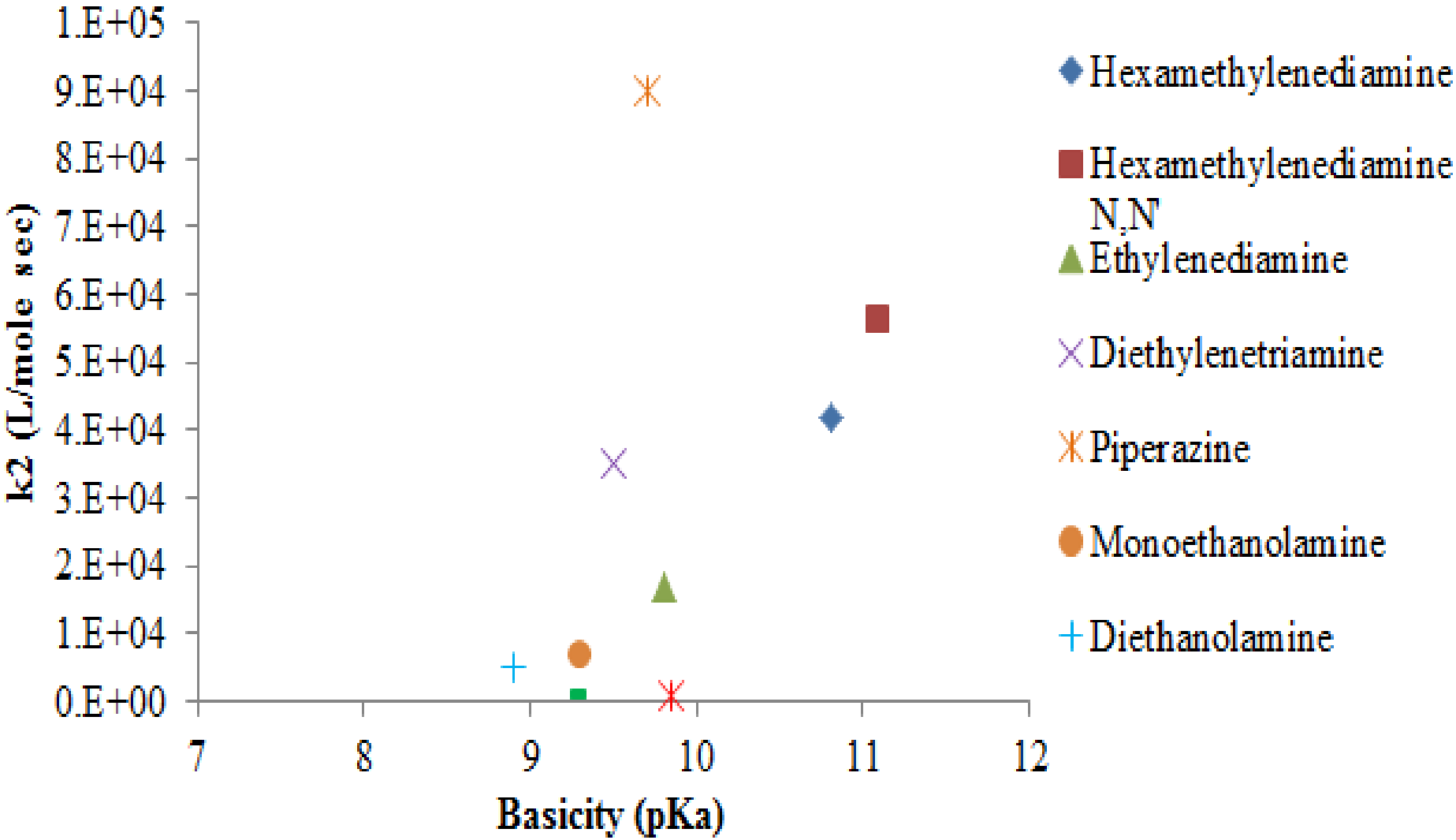
Direct impact on fuel consumption and affects OPEX

Decrease

Positive Effect

Require LP steam turbine to generate electricity from extra steam; Low quality steam is required; require additional energy for compression due to lower regeneration pressure.

Solvent Absorption Kinetics



Source: IEAGHG 2013/TR5Incorporating Future Technological Improvements in Existing CO2 Post Combustion Capture Plants: Technical Review

Solvent Absorption Kinetics

Increase

Positive Effect

Absorption Kinetics/ Mass transfer

Determine the height of absorber, also impact the power consumption by blower, affects CAPEX and OPEX

Require larger LP steam turbine capacity for reduction in steam demand from the capture unit;

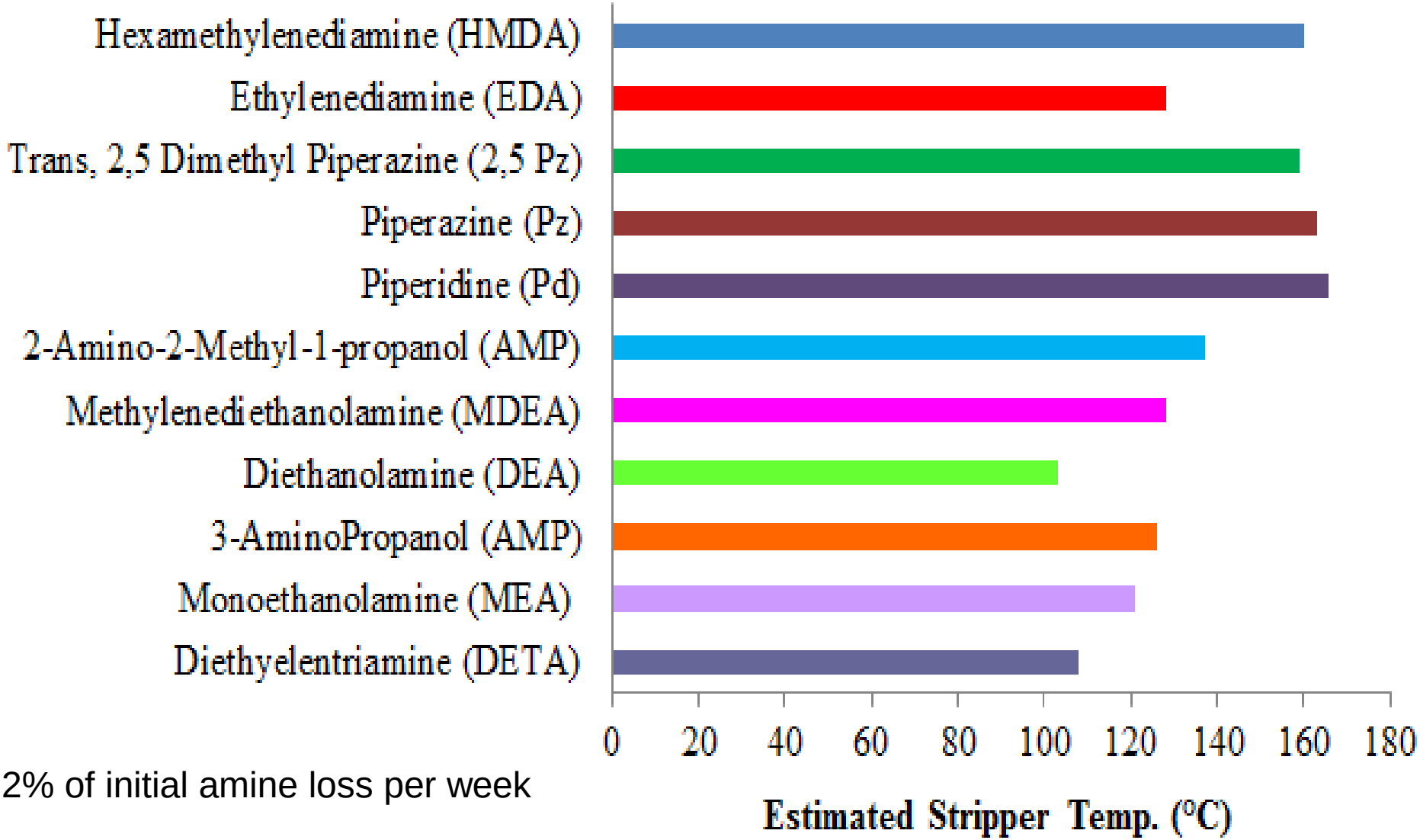
•Absorption Capacity Depends on:
•Base strength (pKa)
•Molecular weight (per NH functionality)
•Viscosity

Decrease

Negative Effect

Require higher electricity due to increase in blower power consumption;
Require increase in absorber height

Solvent Loss: Degradation



2% of initial amine loss per week

Source: IEAGHG 2013/TR5Incorporating Future Technological Improvements in Existing CO2 Post Combustion Capture Plants: Technical Review

Solvent Loss: Degradation

Increase

Negative Effect

Increase solvent make-up rate, fouling of system, corrosion rate, reclaimer waste; will also require deeper SOx and NOx removal, require addition pre-treatment column and utilities

Degradation

•Presence of Impurity in Flue gas

Affect solvent characteristics, ,affect solvent makeup cost, OPEX. Thermal degradation affect stripper temperature and pressure

Decrease

Positive Effect

Reduce solvent makeup cost, reclaimer waste, regeneration at higher stripper pressure and temperature

Solvent Loss: Corrosivity

- Found in the order of MEA > AMP > DEA > MDEA

Corrosivity

•Degradation

Affected by oxidative and thermal degradation, affects CAPEX

Increase

Negative Effect

Increase in degradation and solvent makeup cost; Increase equipment maintenance cost; Require additional coating to the capture equipment

Decrease

Positive Effect

Reduce solvent makeup cost, equipment maintenance cost

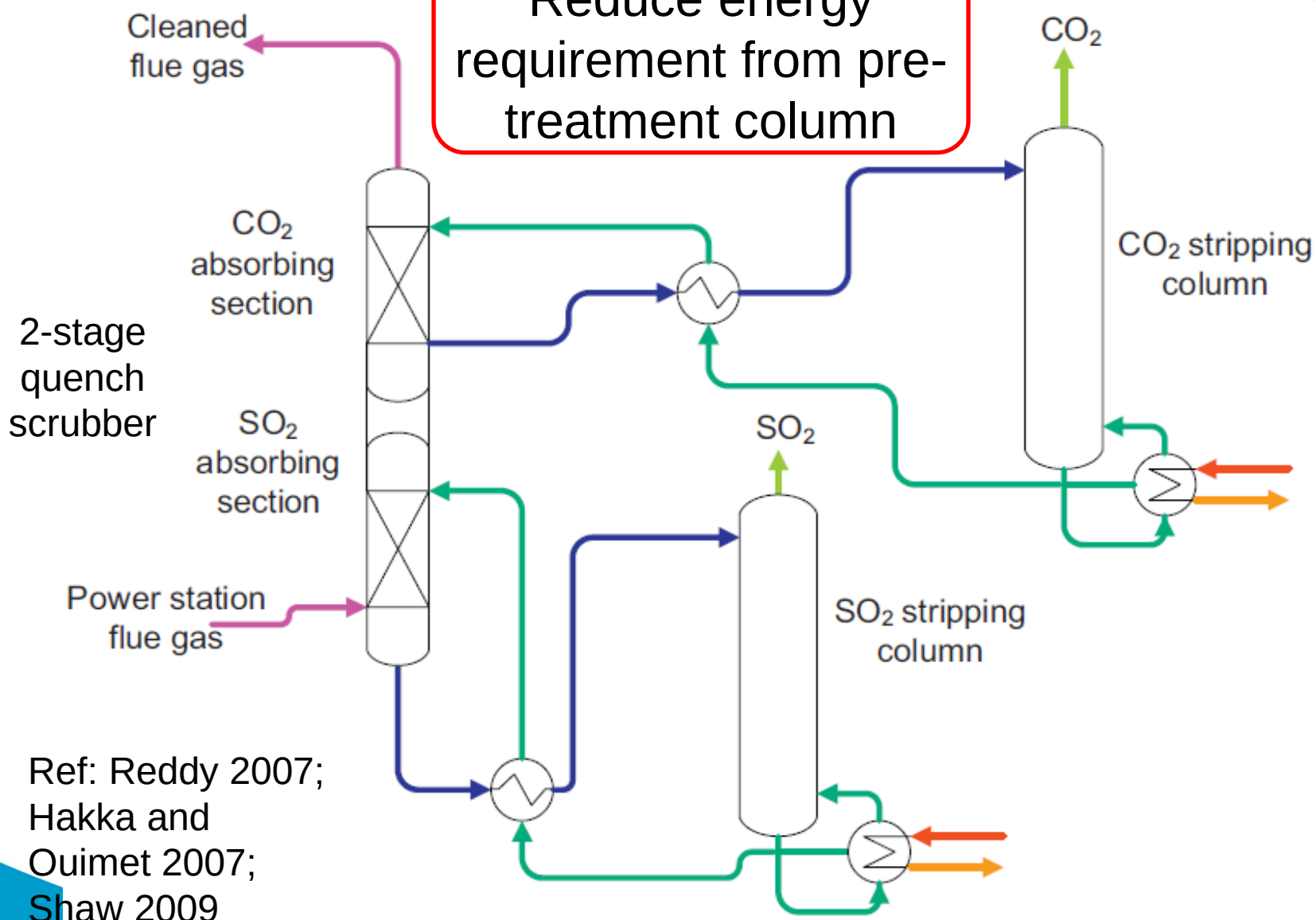
Process Design

Around 15 different process integrations are reported in Open Publications and Patents

- Inter-stage temperature control
- Split flow process
- Matrix stripping
- Heat integration options like
  - Extracting semi-loaded CO_2 solvent from stripper and heat exchanging it with the hot exhaust gas from boiler or steam condensate from the reboiler
  - Inlet feed gas to pre-heat rich solvent before entering the stripper
  - Stripper overhead gas to pre-heat rich solvent entering the stripper

Multi-Component Column

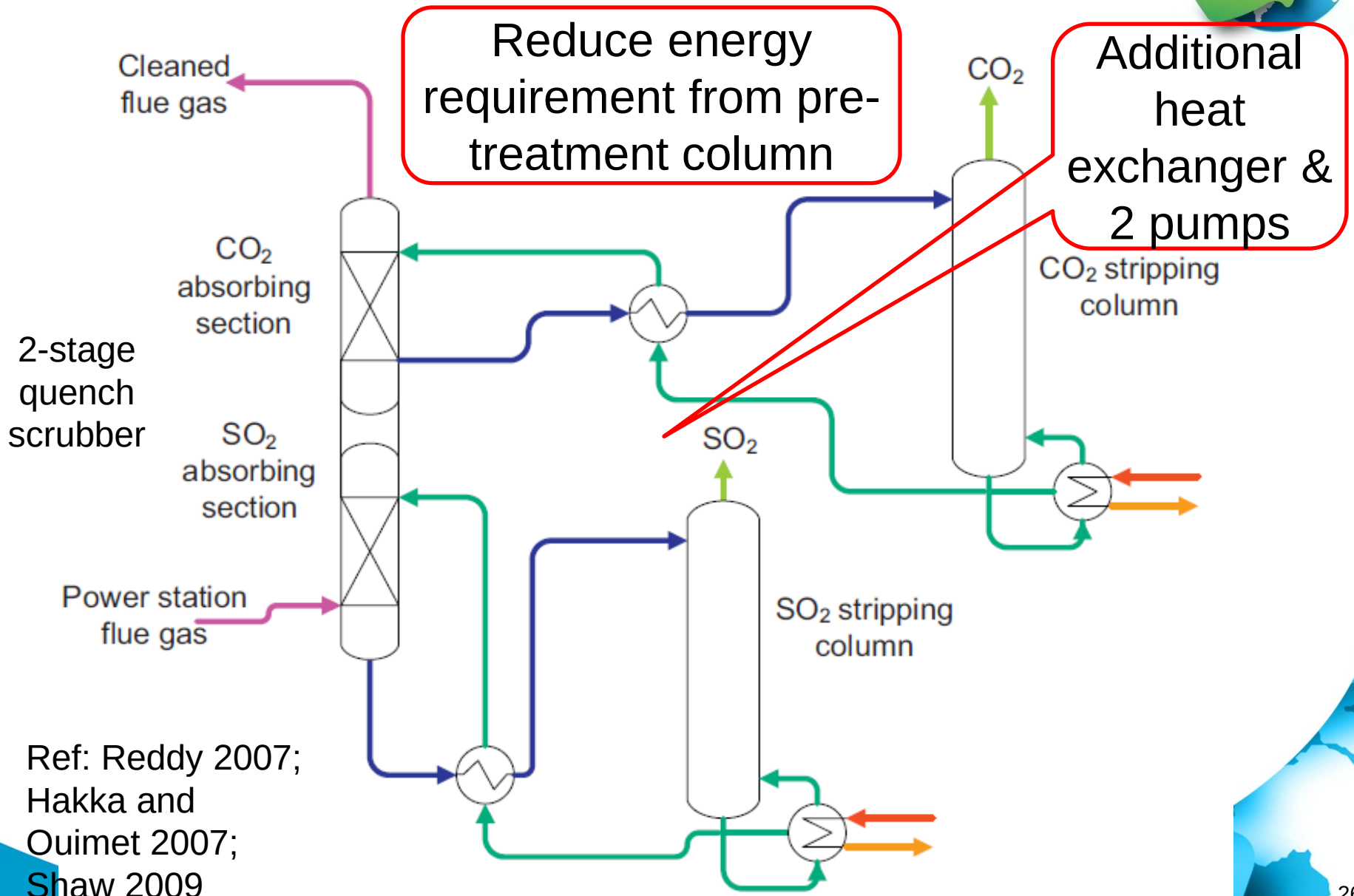
Reduce energy requirement from pre-treatment column



2-stage quench scrubber

Ref: Reddy 2007; Hakka and Ouimet 2007; Shaw 2009

Multi-Component Column



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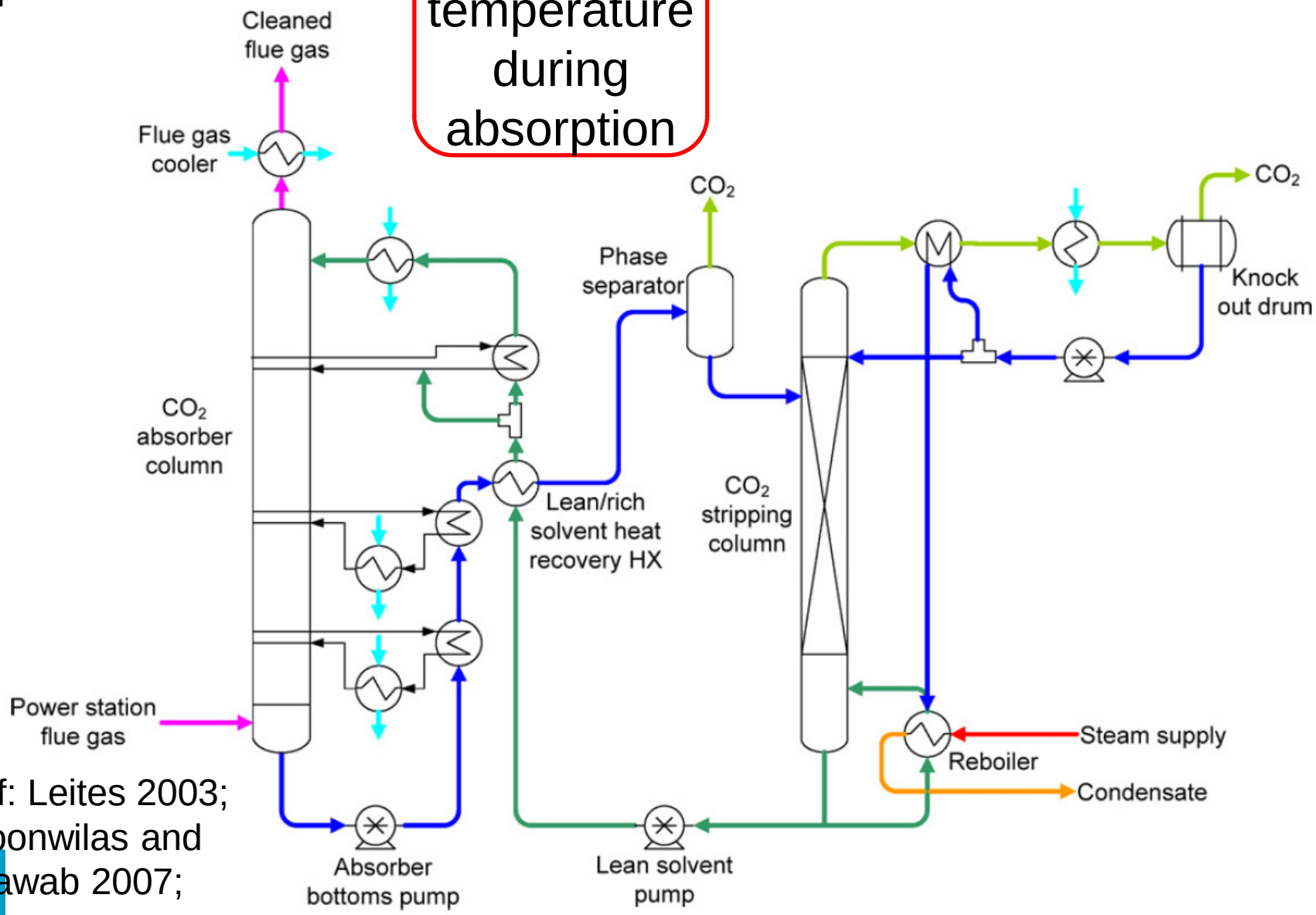
Inter-stage temperature control process

Increase of temperature during absorption

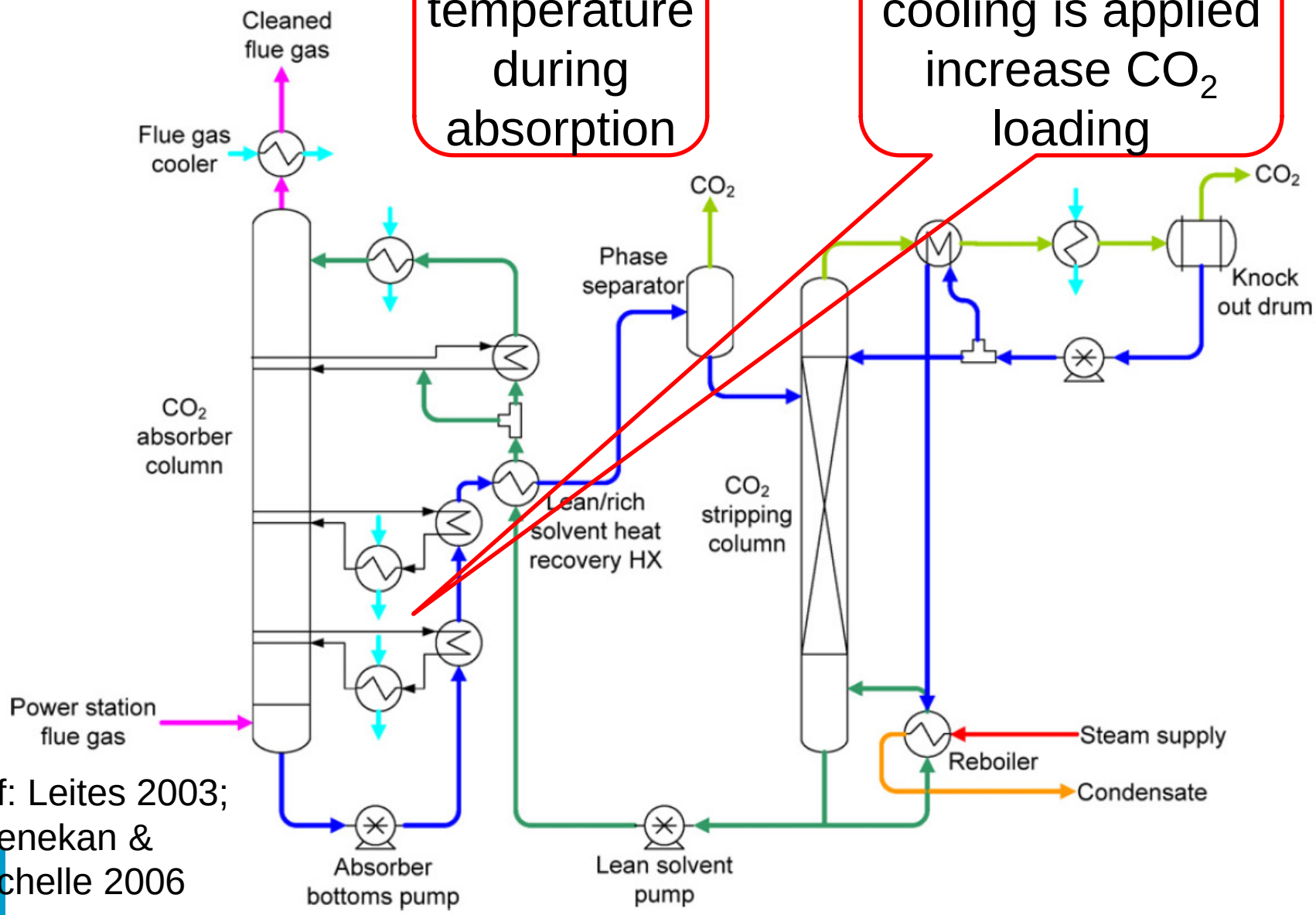


Ref: Leites 2003; Aroonwilas and Veawab 2007;

Inter-stage temperature control process

Increase of temperature during absorption

Inter-stage cooling is applied increase CO_2 loading



Ref: Leites 2003; Oyenekan & Rochelle 2006

Inter-stage temperature control process

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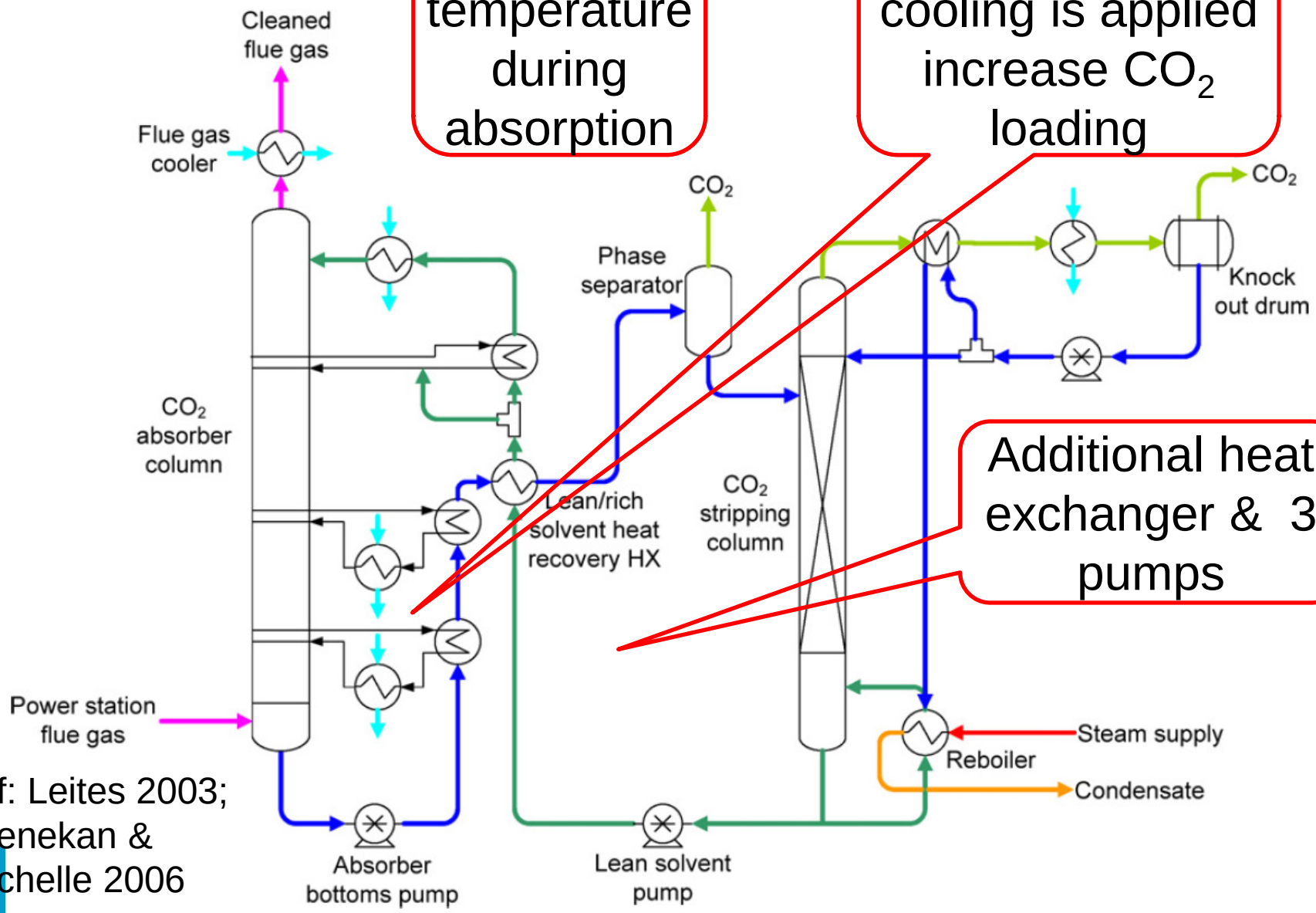
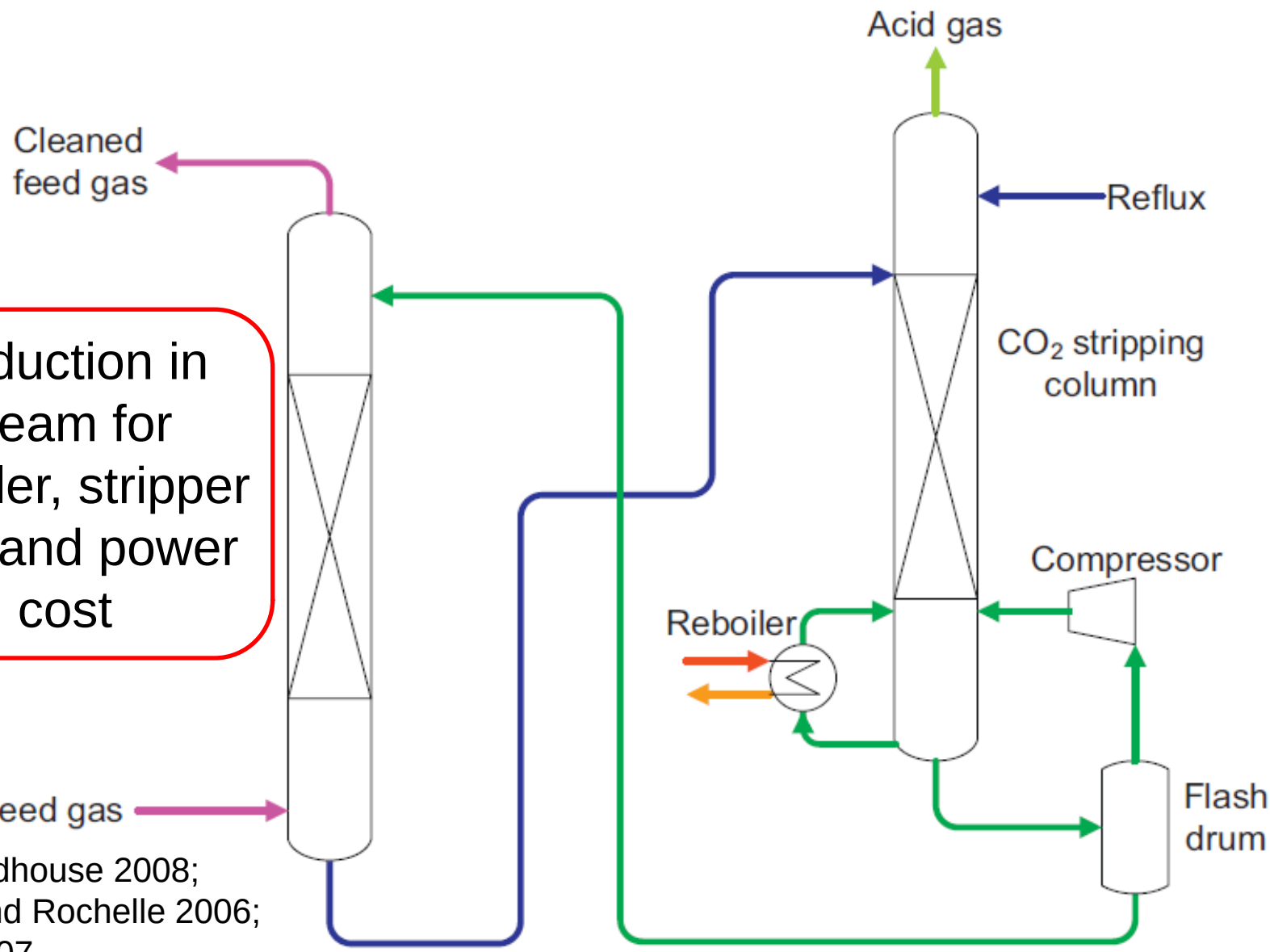


Additional heat exchanger & 3 pumps

Ref: Leites 2003; Oyenekan & Rochelle 2006

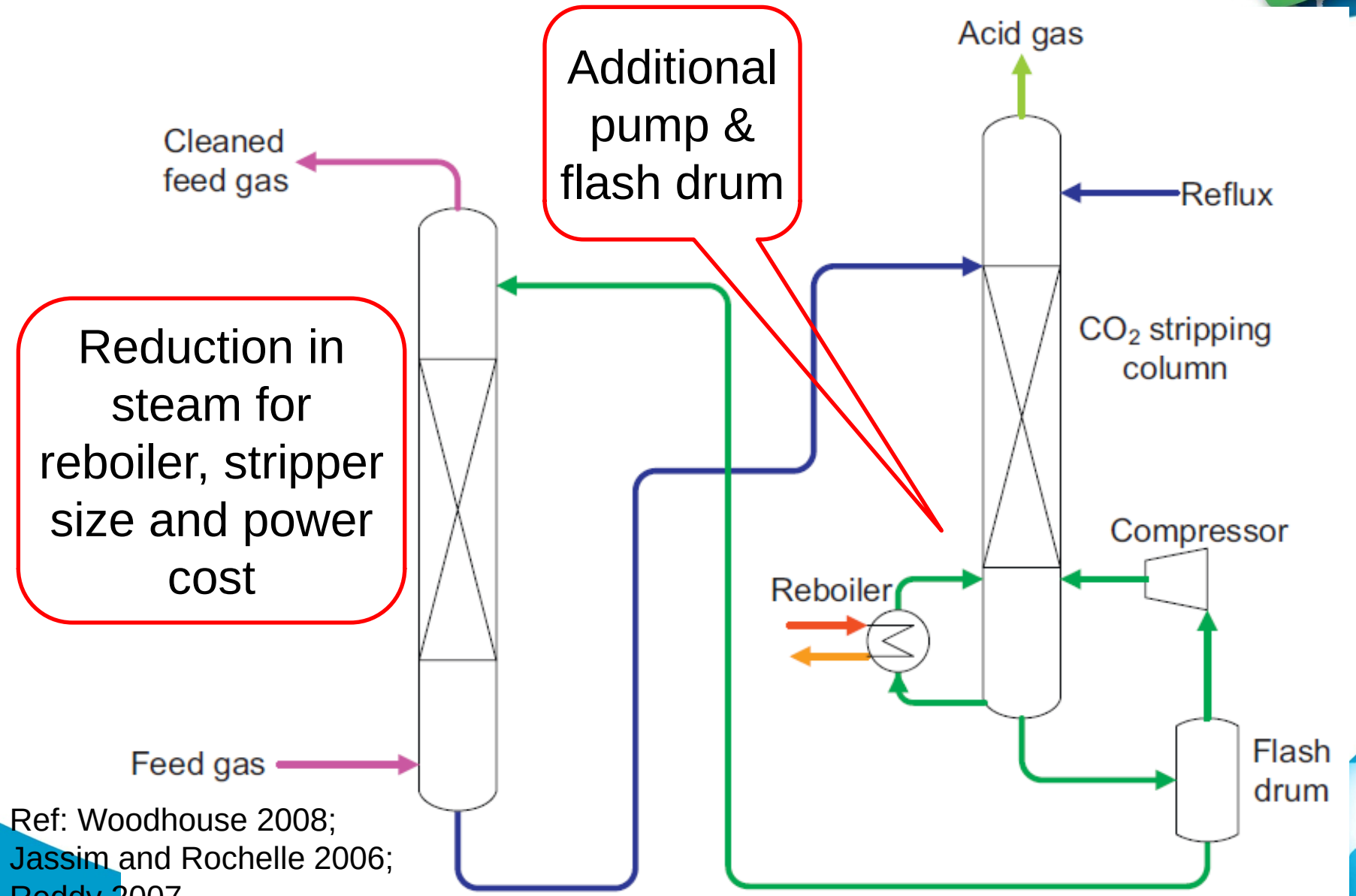
Vapour Recompression



Reduction in steam for reboiler, stripper size and power cost

Ref: Woodhouse 2008; Jassim and Rochelle 2006; Reddy 2007

Vapour Recompression



Ref: Woodhouse 2008; Jassim and Rochelle 2006; Reddy 2007

Process Integration

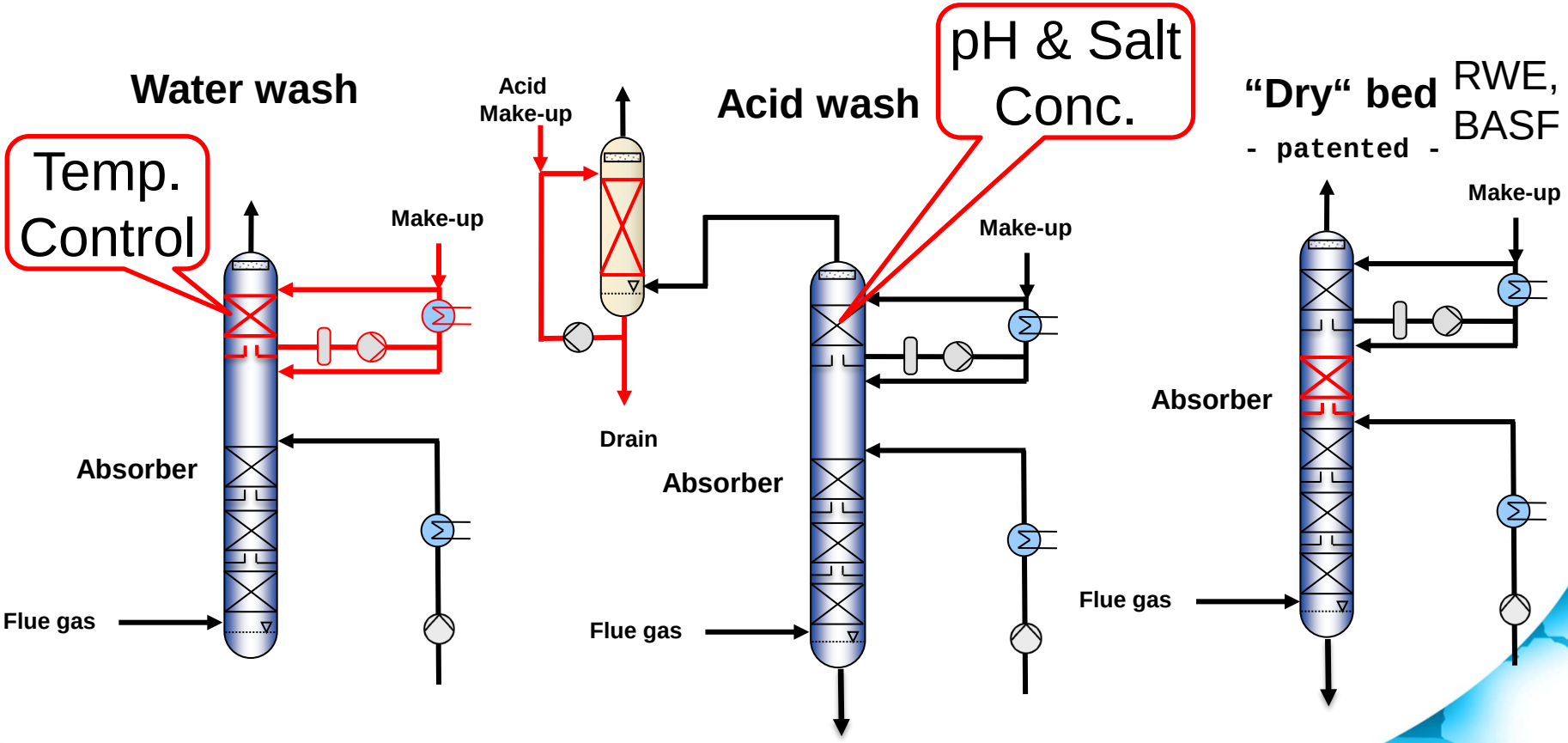
Several process integrations focuses on reducing steam consumption in the reboiler, reducing CO_2 compression energy, reducing solvent circulation rate, reducing water consumption

When considering these processes integration, one should focus on following main issues:

- ✓Effect on the power plant performance related to steam requirement, electricity duty, utilities, operational flexibility
- ✓Incorporation of process integration to an existing CO_2 capture plant
- ✓Site specific issues like available space for additional units and pipe work, water requirement, ambient conditions

Emission Control

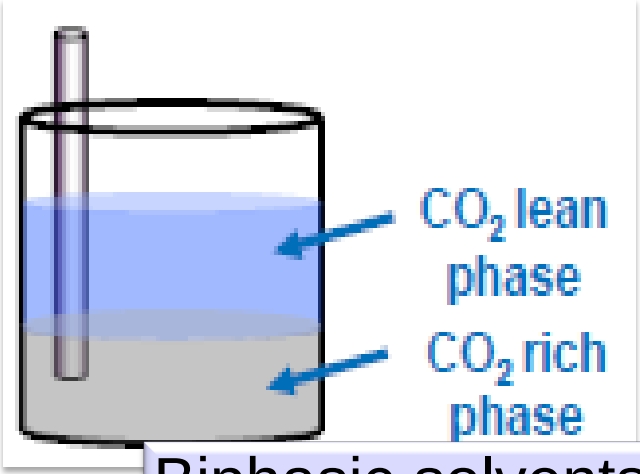
Several options available to reduce emission from amine based PCC process



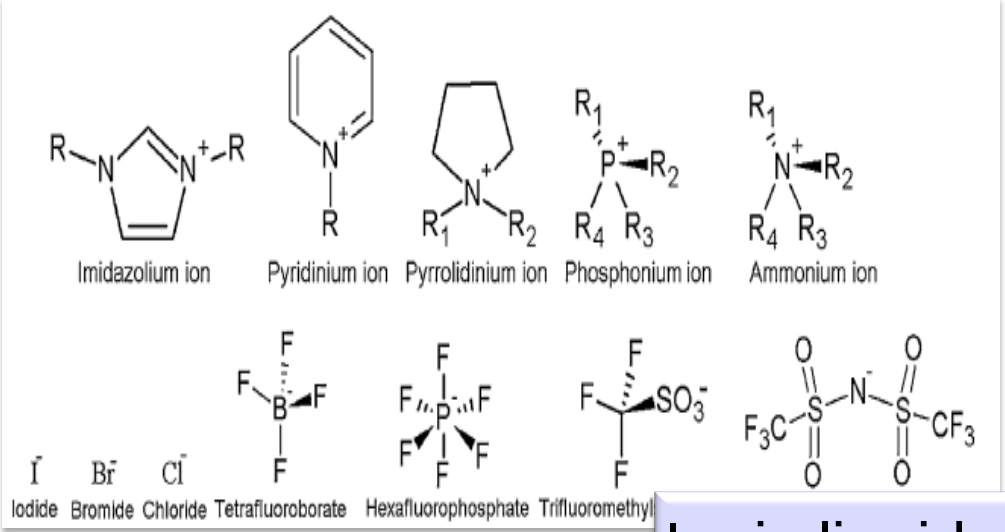
Source: RWE, BASF

2nd & 3rd Generation Post Combustion Capture Technologies

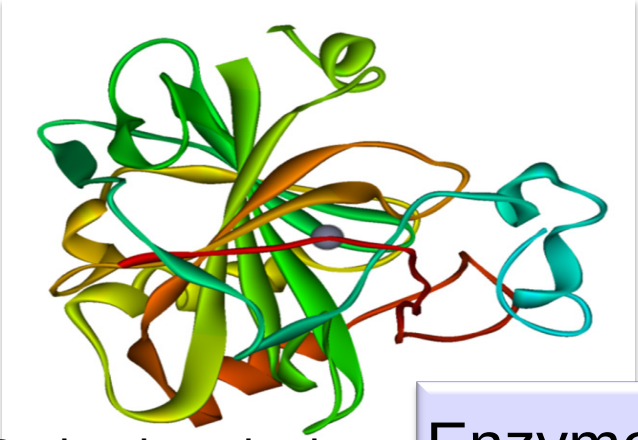
2nd & 3rd Generation PCC Technologies: Solvents



Biphasic solvents



Ionic liquids

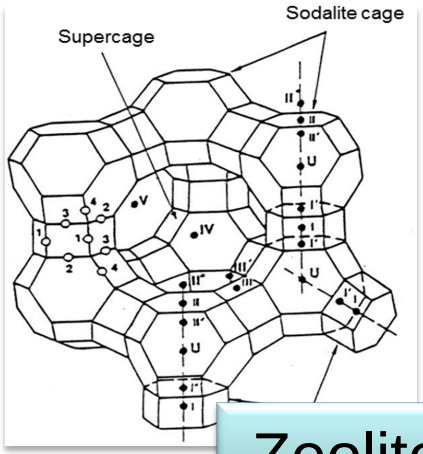


Carbonic Anhydrase

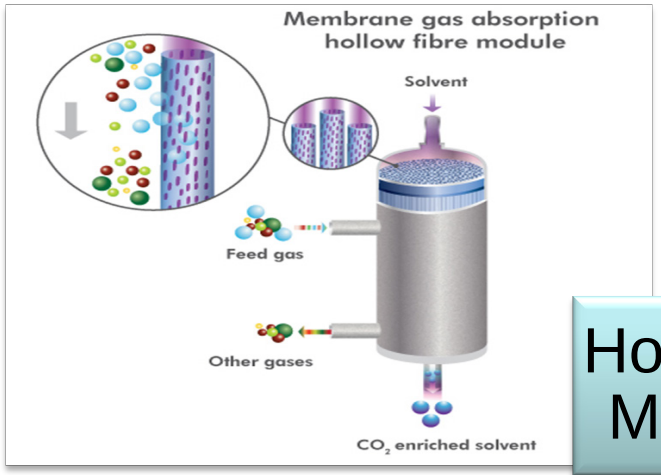
Enzymes

Algae

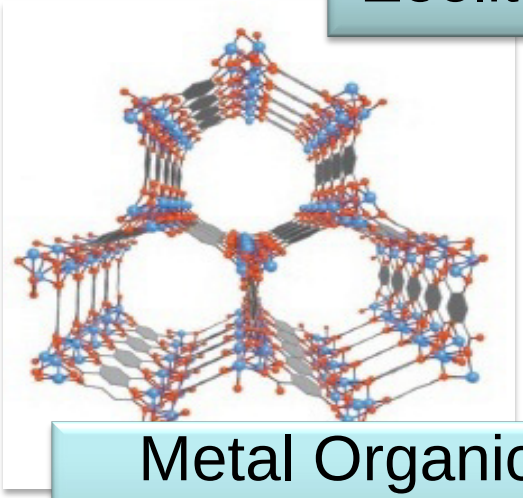
2nd & 3rd Generation PCC Technologies: Solid Sorbents & Membrane



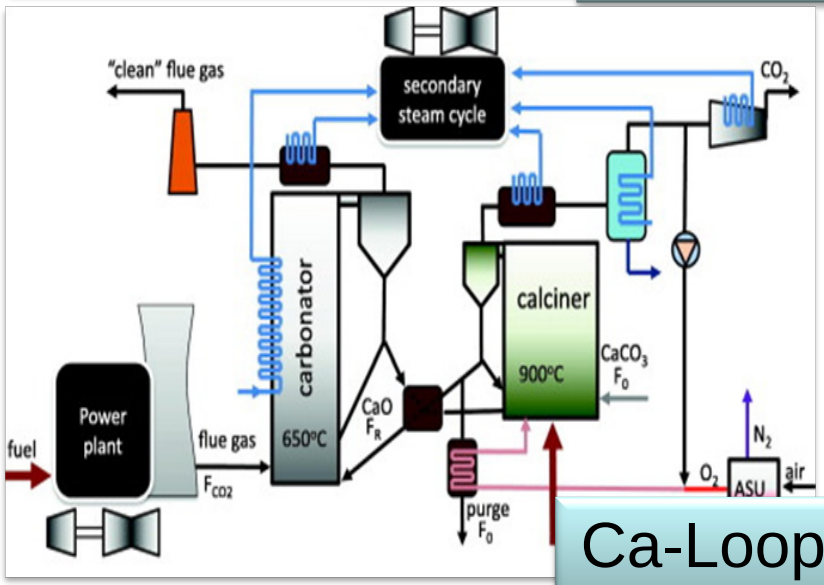
Zeolite



Hollow Fiber Membrane

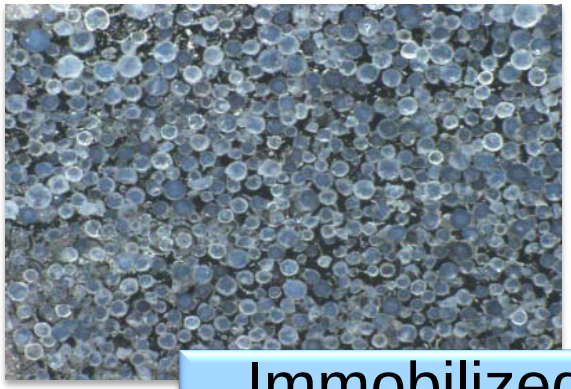


Metal Organic Frameworks (MOF's)

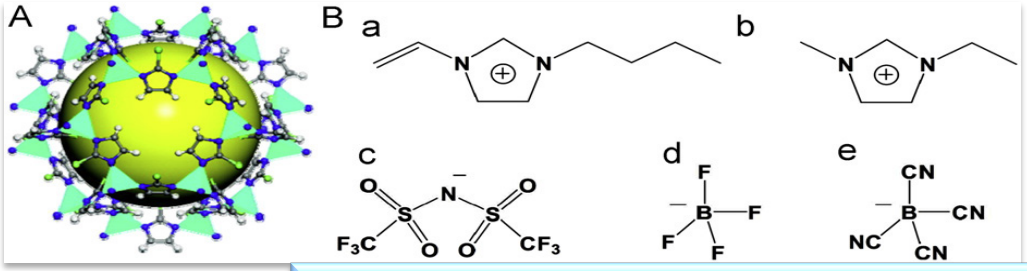


Ca-Looping

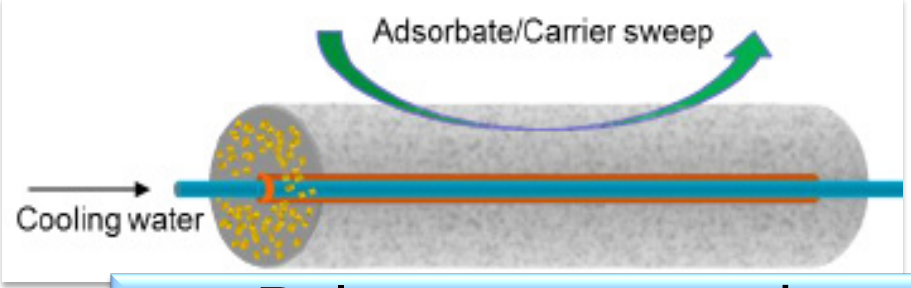
2nd & 3rd Generation PCC Technologies: Hybrid process



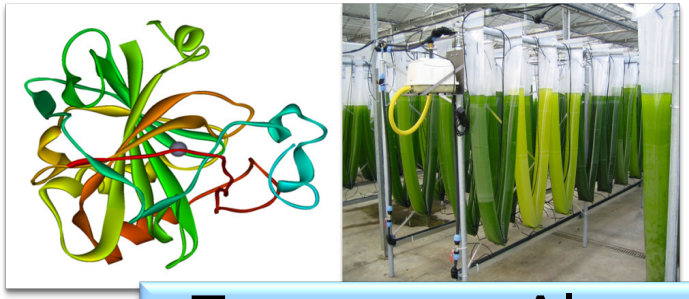
Immobilized amine sorbent



Ionic liquid/ZIF-8 mixed-matrix membranes



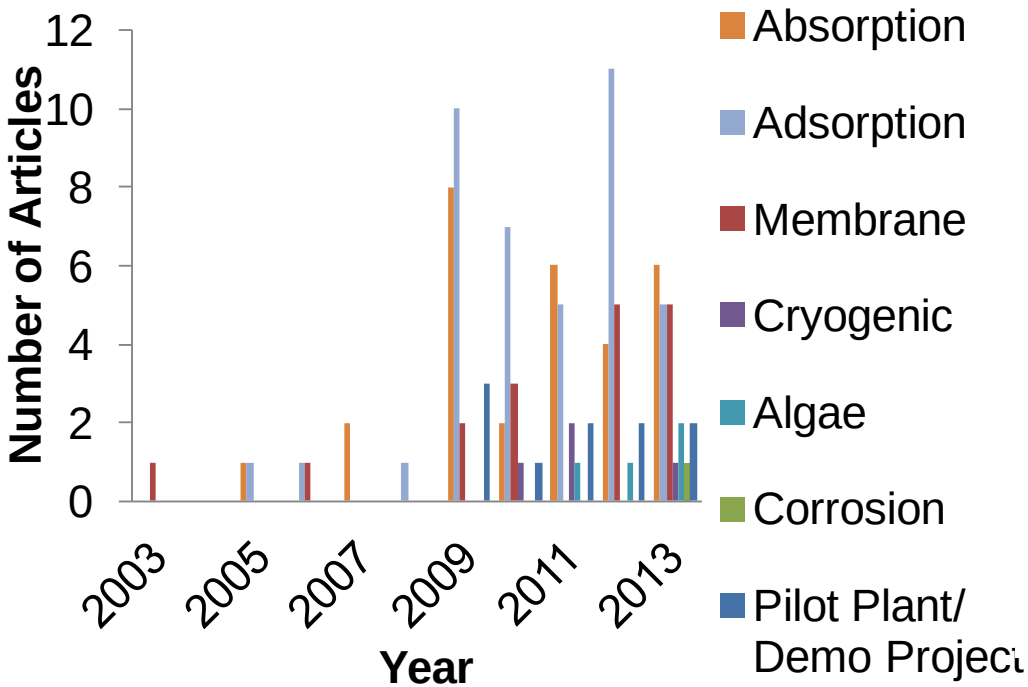
Polymer supported amine/enzymes membrane

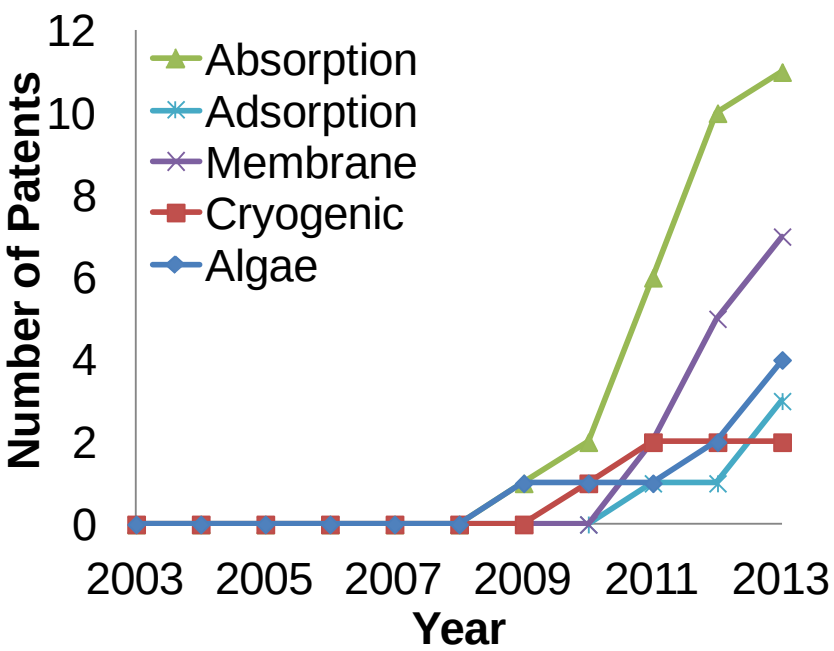


Enzymes + Algae Process

2nd & 3rd Generation PCC Technologies

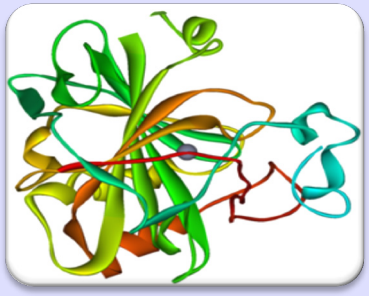
In recent years there has been an increase in publications and patents for 2nd and 3rd generation PCC technologies





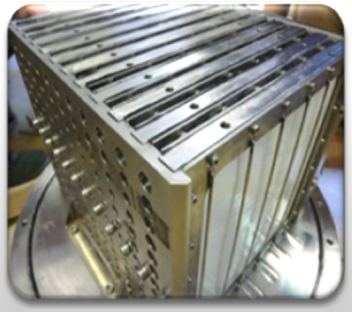
Note: Preliminary survey

2nd & 3rd Generation PCC Technologies Status



Carbonic Anhydrase with Bicarbonate solution is currently tested by AKERMIN at NETL NCCC pilot plant (USA); capture150 kg of CO_2 per day from a coal-based flue gas stream

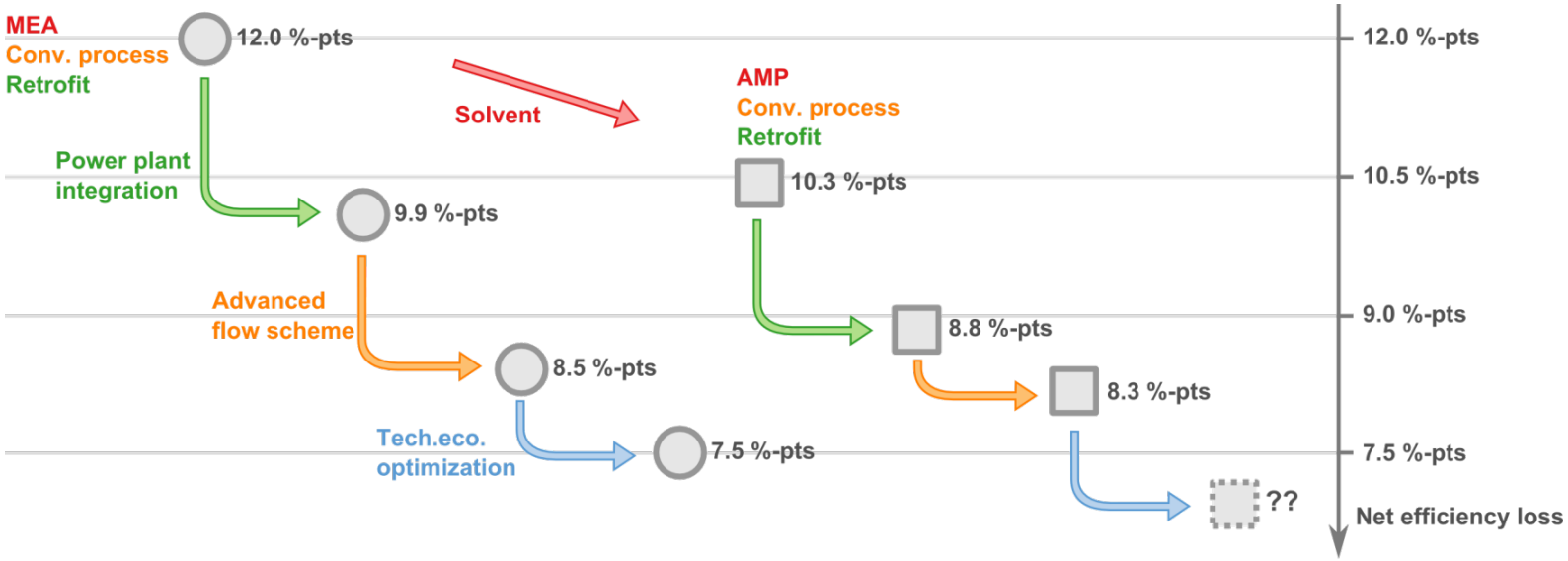
IFP (France) DMX-1 Biphasic solvent process planning tests at Enel's Brindisi industrial CO_2 Pilot (Italy) in 2015-2016 (Decision will be made in Dec 2013)



Polyvinylamine Fixed site carrier Membrane long term pilot testing in EDP Coal Power Plant Sines, Unit 4 (314 MWe) Portugal: show CO_2 permeance and selectivity similar to the lab scale results

Where to Focus?

- Need to consider all → Solvent improvement, Power plant integration, Process flow scheme



- Pilot plant data for operational flexibility and emission control technologies
- 2nd and 3rd generation technologies →techno economics, environmental impact and detailed pilot plant evaluation

Figure Source: EDF, PCCC2

Thank you

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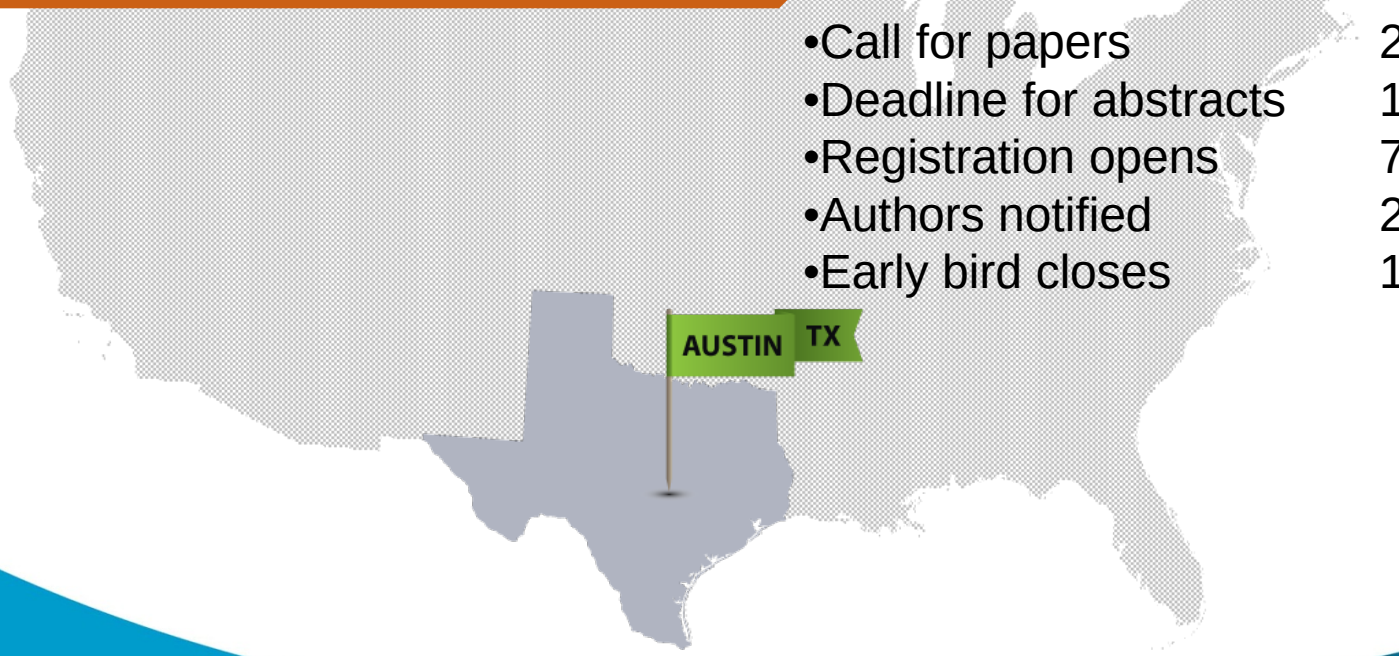

•Call for papers	27th September 2013
•Deadline for abstracts	10th January 2014
•Registration opens	7th March 2014
•Authors notified	2nd May 2014
•Early bird closes	13th June 2014