Clean Coal Technologies for a Sustainable Coal Industry in SA

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Presentation Outline

1. Background Information and Introduction
2. GHG Emissions and Environmental Impacts
3. Technologies to Improve the Image of Coal
4. Applications and References

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2. GHG Emissions and Environmental Impacts

3. Technologies to Improve the Image of Coal

4. Applications and Reference Plants

INTRODUCTION

THE IMPORTANCE OF COAL

- Coal is an indigenous resource of SA and is a significant contributor towards the economy.
- Despite coal's importance, the role of coal in the economy is being disrupted by policy and regulatory changes, such as:
    - policy shifts to reduce the contribution of coal in South Africa's energy mix
    - climate change commitments to reduce greenhouse gas emissions under the Paris Agreement
- Coal is uniquely capable of providing the most stable electricity, with a scale and cost profile that is unmatched compared with other power generation.
- Coal provides the lowest priced per kJ energy source compared to other fuels

BACKGROUND

- Coal is a complex chemical latticework of carbon, hydrogen, and various elements such as sulfur, nitrogen, mercury and other trace metals. When combusted these elements are converted to chemical forms that create pollutants which are harmful to the environment, if not addressed.

- Extensive research suggests that Coal is still crucial for the world and cannot disappear from the energy mix despite being portrayed as a polluting energy source.

- Energy and mining companies have been under increasing pressure to curb their emissions

- The survival of the coal industry is dependent on promoting the idea of "clean coal" technology (CCT) as an energy generation option.

So what is CCT????

BACKGROUND

CCT (Clean Coal Technology) is an umbrella term, encompassing a wide array of new generation and advanced technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use

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POINT OF COMBUSTION POLLUTANT LIMITS

Range of Pollutant Limits						
Pollutant (mg/Nm3 at 6% O_2)	RSA National Environmental Management (at 10% O_2)	World Bank Guidelines 2008		European Commission Industrial Emissions Directive	BREF* Existing Units	BREF* New Units
		Non-Degraded Airshed	Degraded Airshed			
SO_2	500	200 – 850	200	200	130	75
NO_x	750	510	200	150	150	85
PM	50	50	30	10	10	5
Hg µg	Not defined	Not defined	Not defined	5 to 10	4	2

*BREF = Best available techniques reference documents

BASIC DEFINITIONS OF TERMINOLOGY

- Reading emissions data can be very confusing. Different terms such as "**Greenhouse Gases**", "**CO_2**", "**CO_2eq**", **and** "**Carbon**" get used in reporting and at times interchangeably

- **Carbon dioxide:** is the by-product of the combustion of fossil fuels and living cellular respiration.

- **Carbon dioxide equivalent "CO_2eq"** is a measure used to compare the emissions from various GHG's based upon their global warming potential reduced to a common base. For any of the defined GHG's, CO_2eq signifies the amount of CO_2 which would have the equivalent global warming impact.

- **Carbon** is a chemical element which is present in many gases and compounds.

- **CO_2** is not equal to **CO_2eq** is not equal to **Carbon**

GLOBAL WARMING POTENTIAL

100-year Global Warming Potential (GWP) values as defined in IPCC Assessment Reports for the most important GHGs as defined by the Kyoto Protocol

Greenhouse gas	Average lifetime in the atmosphere	100-year Global Warming Potential
Carbon dioxide	thousands of years	1
Methane	12.4 years	25
Nitrous oxide	121 years	265–298
Fluorinated gases Hydro-Fluoro-Carbons (HFCs) Per-Fluoro-Carbons (PFCs) Sulphur Hexafluoride (SF_6) Nitrogen Trifluoride (NF_3)	A few weeks to thousands of years	 124 – 14,800 7,390 – 12,200 22,800 17,200

The 20 yr Greenhouse Gas Global Warming Potential of Methane is 85.

This implies that one ton of methane emission is equivalent to emissions of 85 tons of carbon dioxide in the short term. (ie. 1 t CH_4 = 85 t CO_{2eq})

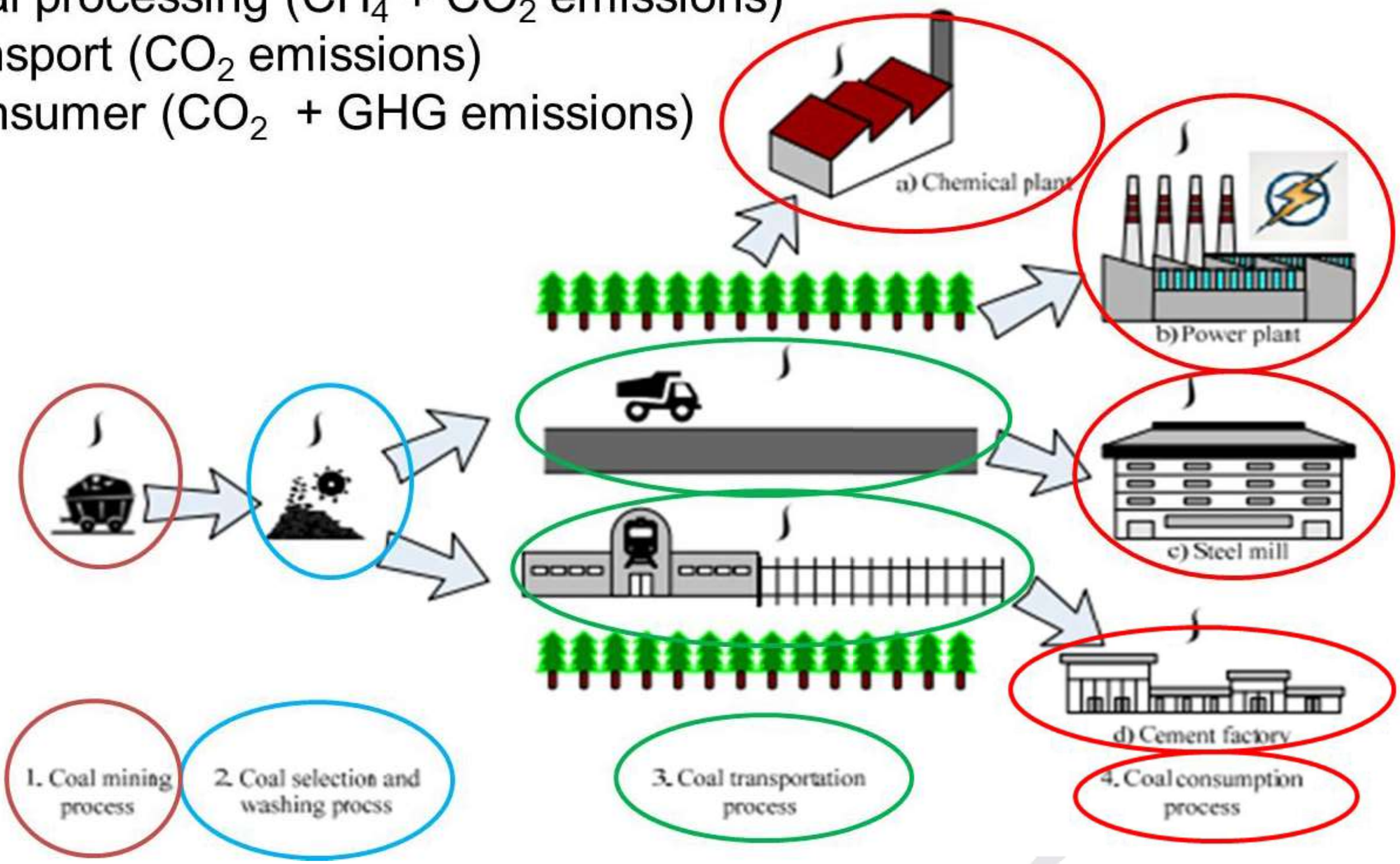
VALUE CHAIN EMISSIONS

- Natural gas is widely considered a viable replacement for coal as the emission from gas combustion is lower than emissions from coal combustion.
- The draw-back with this evaluation is emissions are compared at point of combustion and only CO_2 emissions are taken into consideration. Emissions from smokestacks do not tell the full story
- Concentrating only at the point of use emissions will not effectively address climate change as GHG emissions takes places at the different stages in the Value Chain which cumulatively contributes to the Global Climate Impact
- Each fossil fuel has a different life cycle and each fuel contributes greenhouse gases at different stages of its life cycle.

COAL VALUE CHAIN

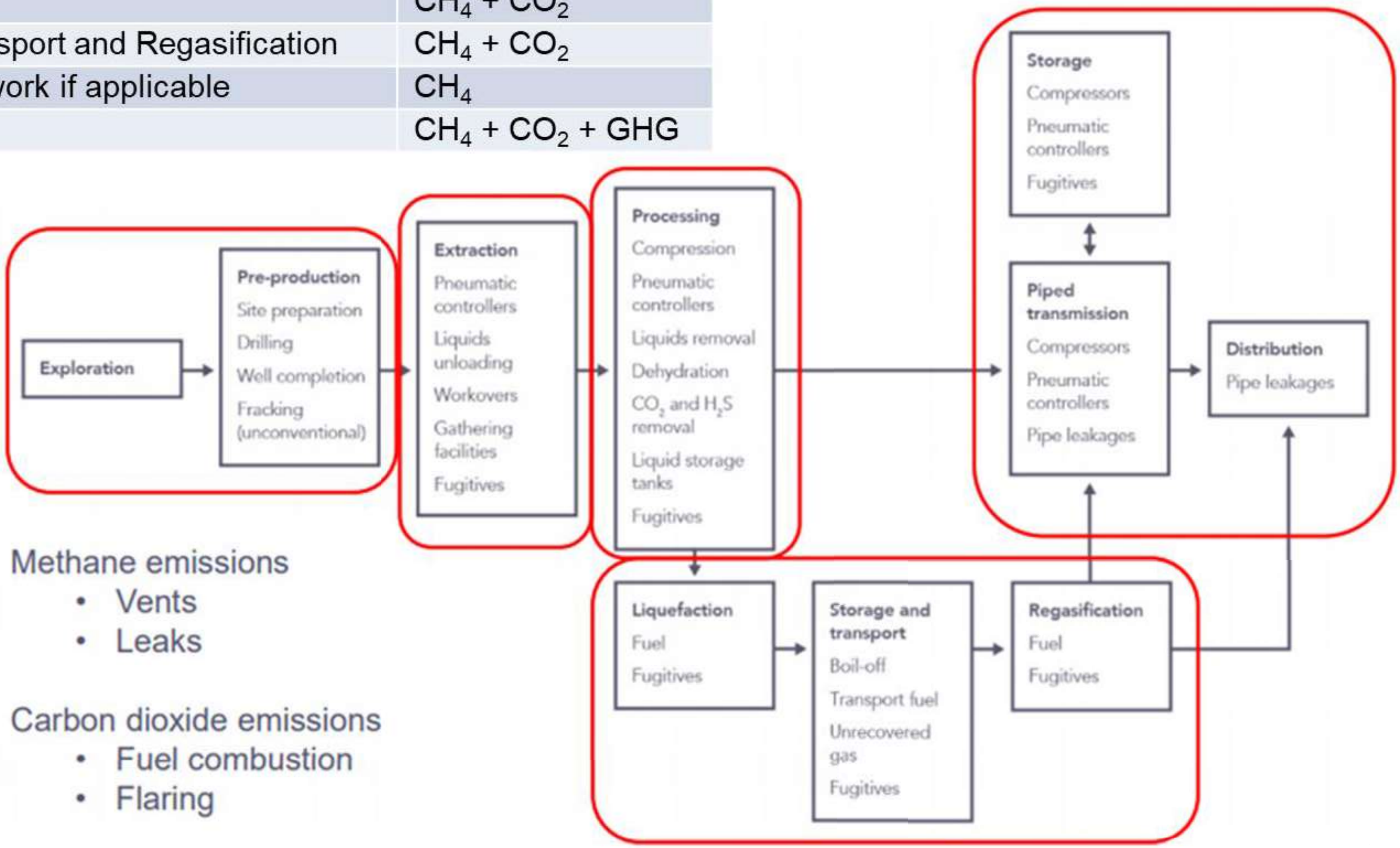
Emissions occur during;

- Mining (CH_4 + CO_2 emissions)
- Coal processing (CH_4 + CO_2 emissions)
- transport (CO_2 emissions)
- Consumer (CO_2 + GHG emissions)



LNG VALUE CHAIN

Stage	Emission
Exploration and pre-production	$CH_4 + CO_2$
Extraction and Processing	$CH_4 + CO_2$
Liquefaction	$CH_4 + CO_2$
Storage, Transport and Regasification	$CH_4 + CO_2$
Pipe-line Network if applicable	CH_4
End User	$CH_4 + CO_2$ + GHG



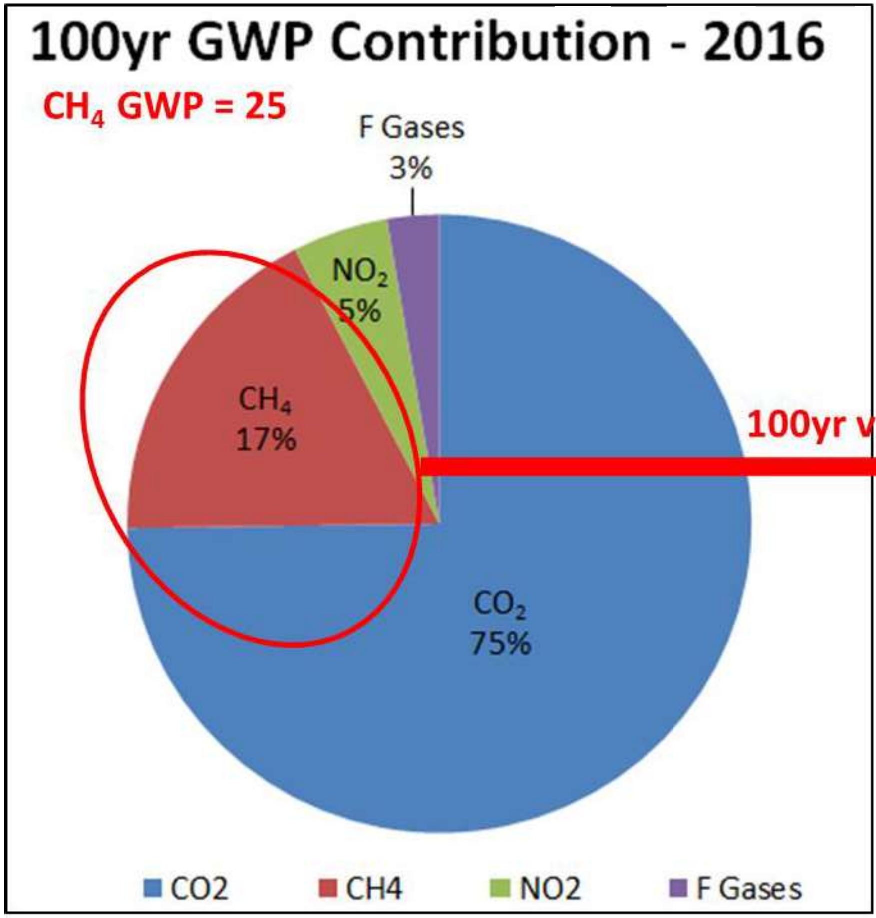
Methane emissions

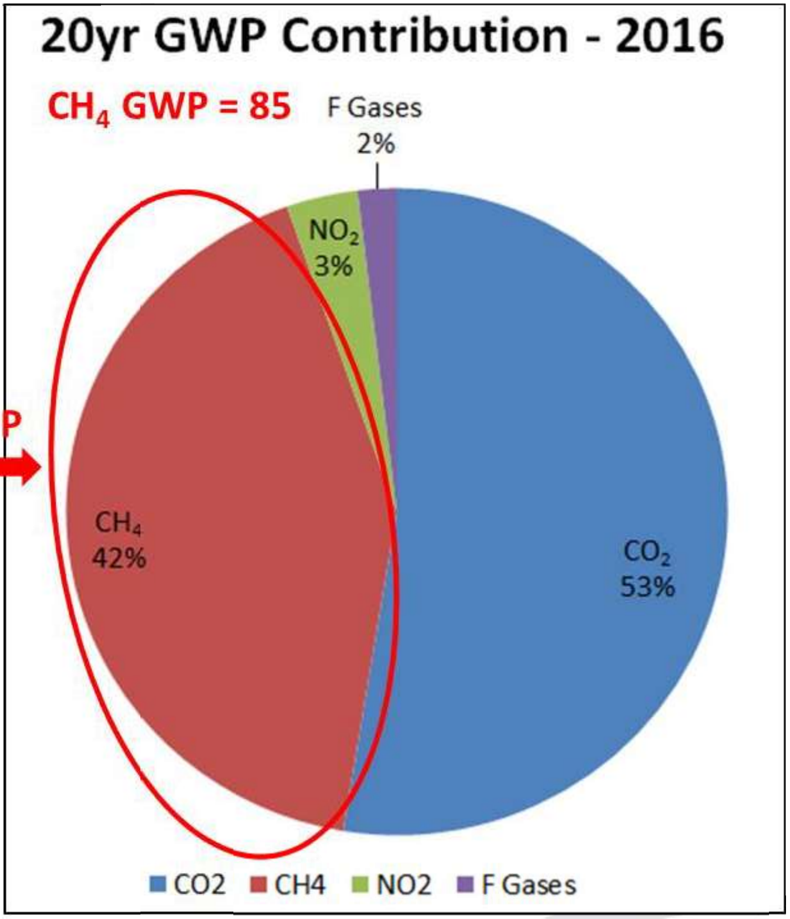
- Vents
- Leaks

Carbon dioxide emissions

- Fuel combustion
- Flaring

IMPACT of NON-CO_2 GAS LIFE-TIME





Super-pollutant greenhouse gases such as methane, nitrous oxide and fluorinated compounds have an outsize negative impact and collectively contribute contribute ~47% (@ CH_4 GWP of 85) to the current the global warming trend.

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CHALLENGES FOR CCT

- Climate mitigation interventions pose unique challenges due to the major factors influencing the selection of energy sources which are: energy availability, economics or affordability and lastly environmental considerations

- GHG's are not emitted only at the point of use

- Lack of understanding of what contributes to GHG emissions and the lack of awareness of the technology available for addressing emissions in the Coal value chain

- CCTs are perceived to be costly and energy intensive, and hence advocates of renewables believe that fossil fuels should be removed from the energy mix.

- Coal is competing against gas and renewables for survival and therefore will "require a different way of thinking" to enhance its productivity and address climate concerns simultaneously

CCT PROCESSES FOR COAL LIFE CYCLE STAGES

MINING

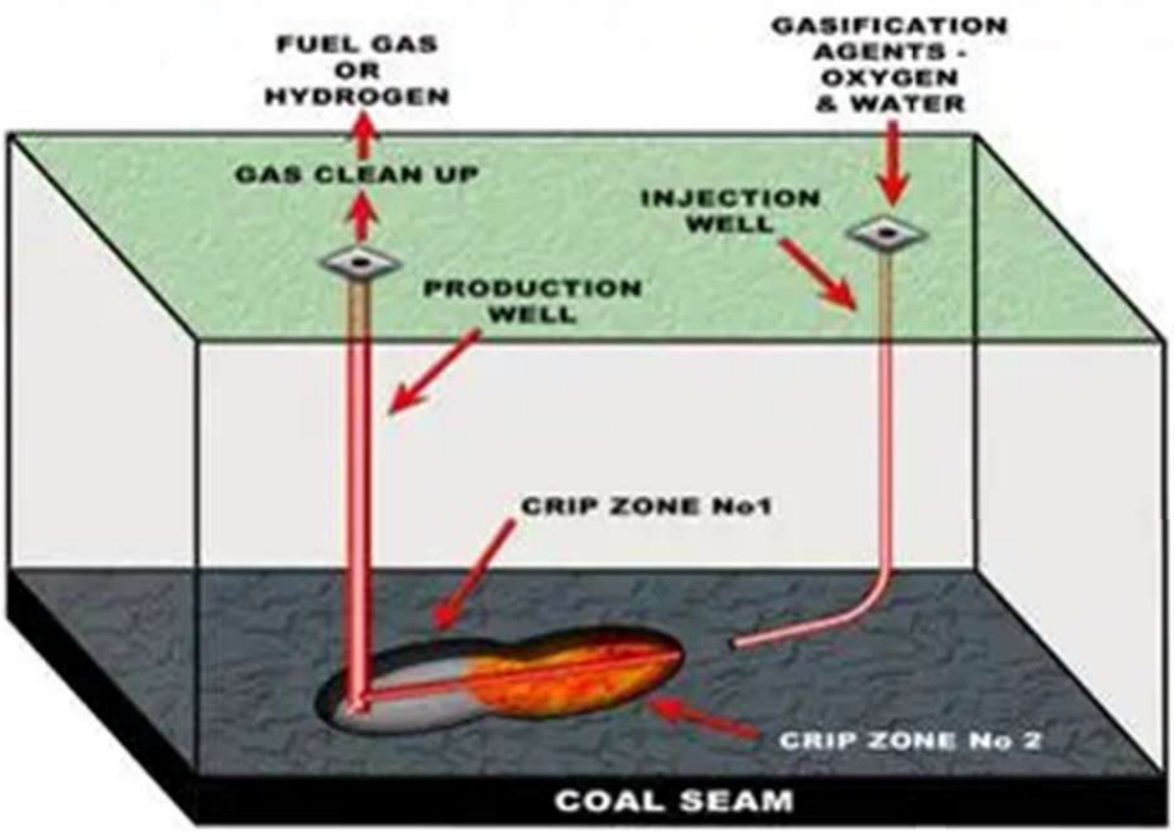
Coal is normally associated with ash-forming minerals including sand, rock and chemical material for example organic sulfur, nitrogen and some mineral salts. Some materials are intermixed through the coal seam, some bound organically to the coal, and some are introduced by the mining process.

➢ **Cleaner Coal Technology in Coal Mining**

- Operational efficiencies through enhanced mining methods
- Optimal reserve recovery using advanced extraction methods
- Methane Gas Capture
- Underground Coal Gasification (UCG)

UCG – UNDERGROUND COAL GASIFICATION CONCEPT

Underground coal gasification (UCG) is an industrial process which converts coal into product gas. UCG is an in-situ gasification process, carried out in non-mined coal seams using injection of oxidants and steam. The predominant product gases are methane, hydrogen, carbon monoxide and carbon dioxide.



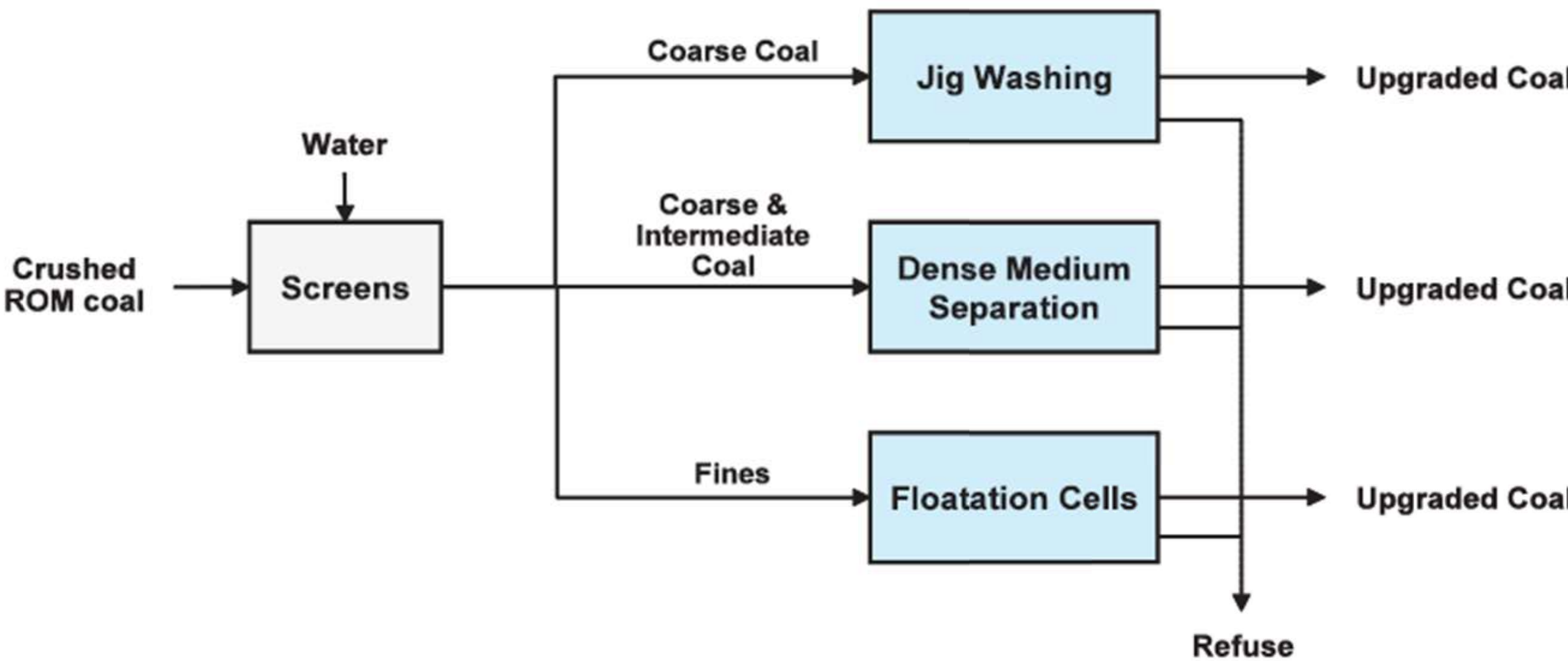
CCT PROCESSES FOR COAL LIFE CYCLE STAGES

➢ Cleaner Coal Technology in Coal Preparation

- Coal Washing and Beneficiation
- Ultra-clean coal (UCC)
- Dry / Waterless Cleaning Technologies
- Coal dehydration technology

COAL PREPARATION – WET PROCESS

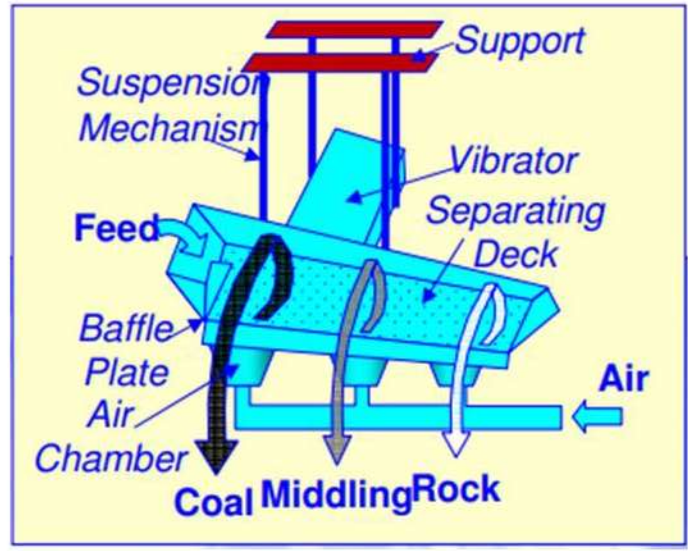
The system used in physical cleaning varies among coal cleaning plants but broadly involves the following stages: initial preparation, fine coal processing and coarse coal processing, and final preparation.



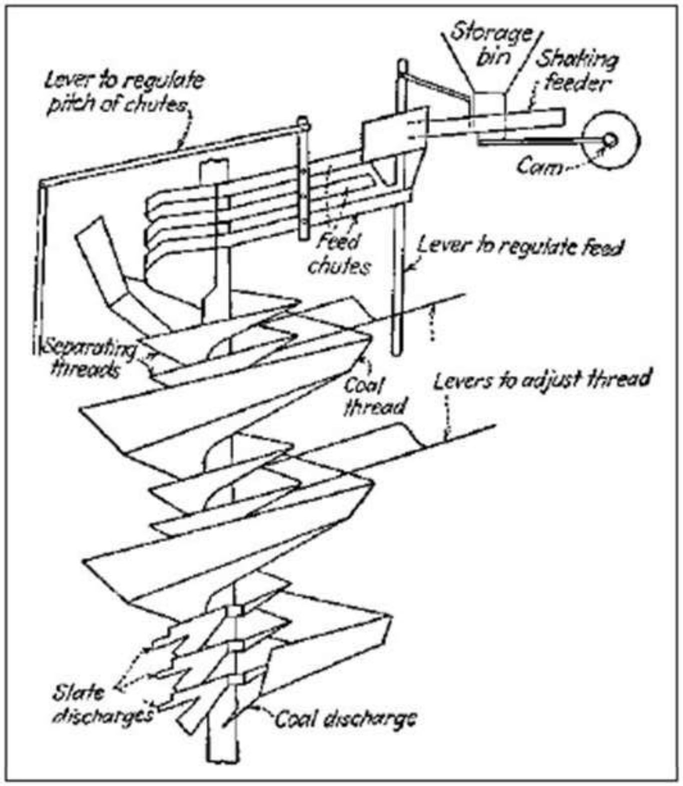
Process flow diagram of a typical coal cleaning plant

COAL PREPARATION – DRY SEPARATION

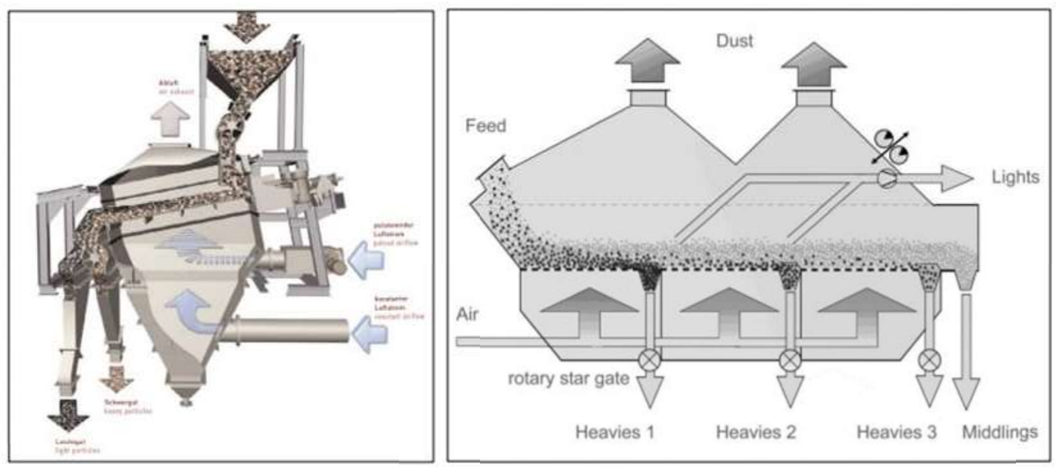
Dry cleaning methods such as Gravity Separators, Air Tables, and Air Jigs can also be used for when wet washing is not suitable or when washing plants are considered not economically feasible



Flow diagram of a typical Air Table



Flow diagram of a typical Spiral Separator



Typical Deshaling plant

COAL PREPARATION – DEHYDRATION

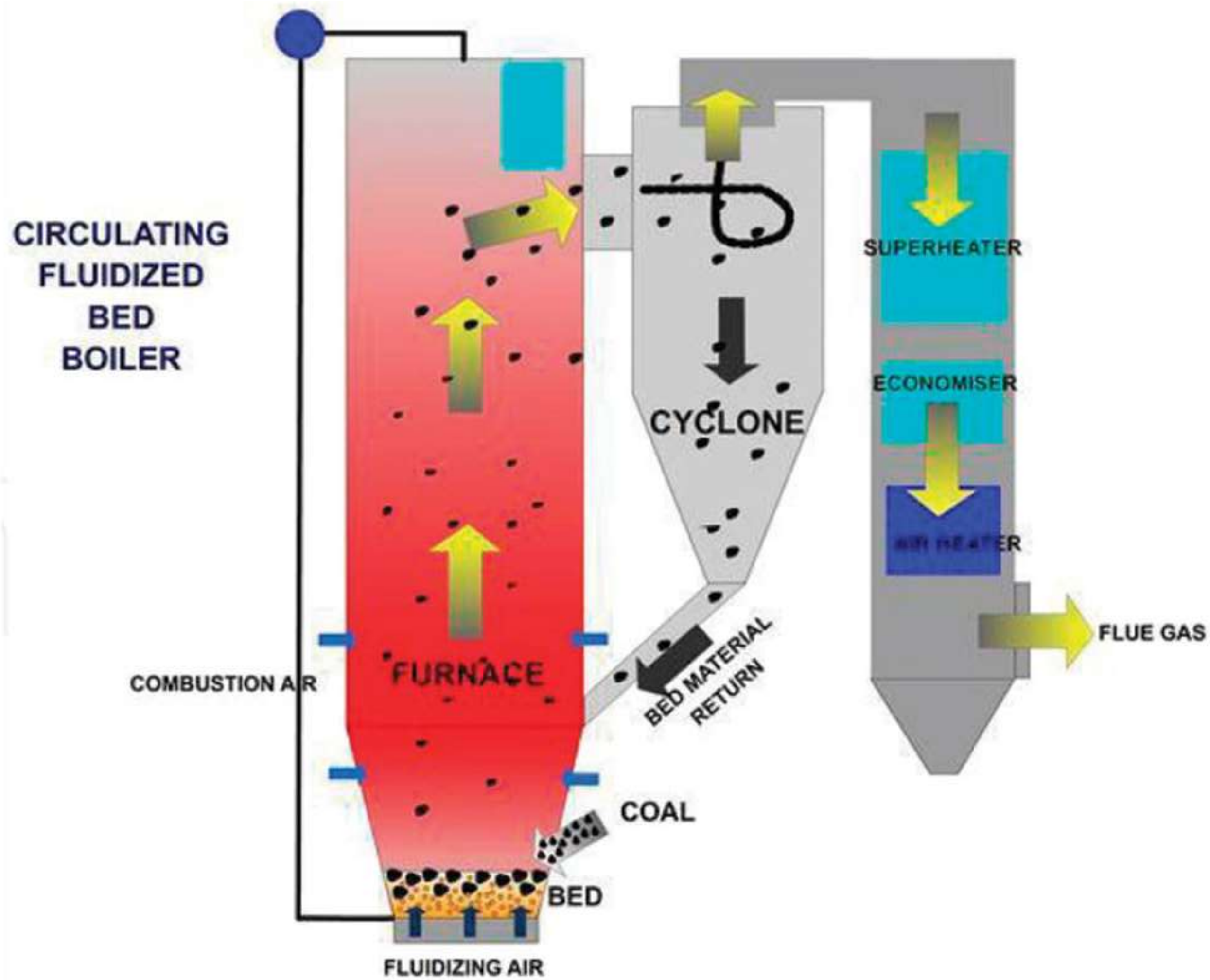
Clean Coal Technologies Inc is developing the world's first commercially viable and scalable coal dehydration technology (Pristine-M) that creates stable, dust-free coal, Removal of water improves combustion efficiency

CCT PROCESSES FOR COAL COMBUSTION

Cleaner Coal Technologies used During Combustion

- HELE technology
- Fluidised-Bed Combustion (FBC)
- Integrated Gasification Combined Cycle (IGCC)
- Pulverised Coal Supercritical and Ultra- Supercritical Boilers
- Oxy-fuel combustion
- Chemical Looping Combustion
- Carbonate Looping Technology
- NOx Control Processes
- Advanced Controls
- Supercritical CO_2 based power generation

BURNING OF COAL - FBC

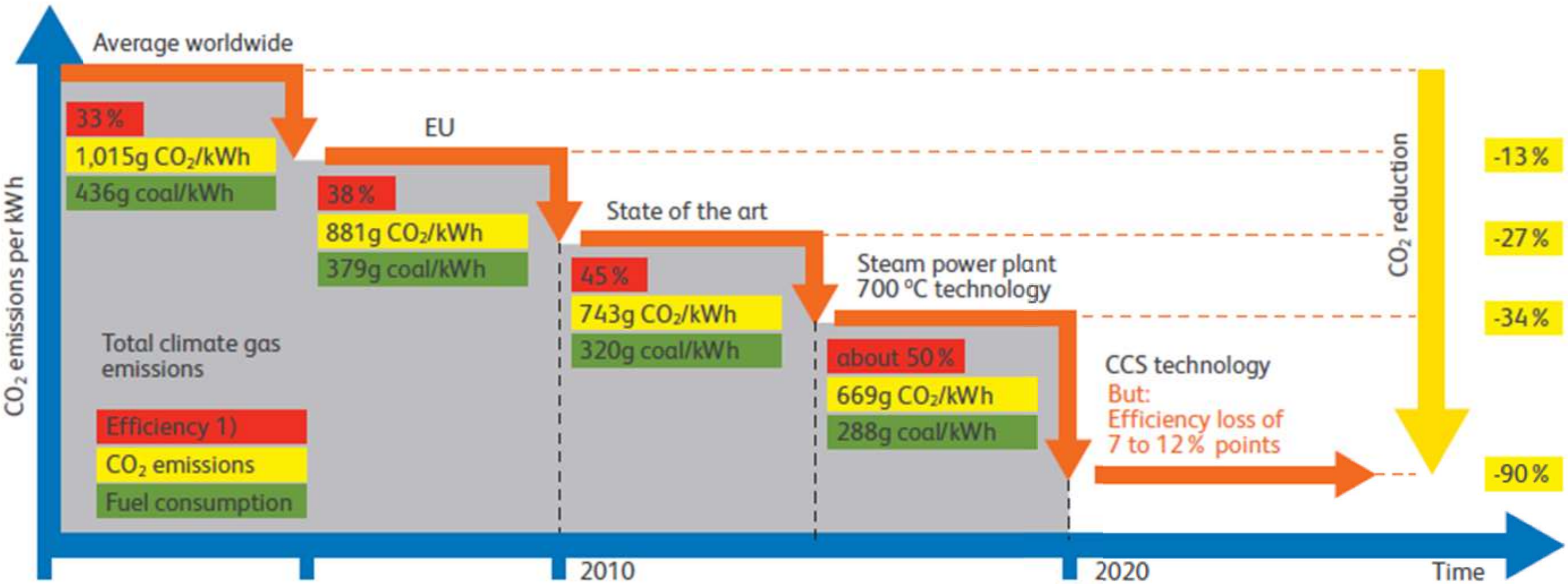


Fluidised bed combustion (FBC). Image: Courtesy of Eskom fact sheet (2016).

ENERGY EFFICIENCY AND CO_2 EMISSION

Impact of the steam conditions of the thermodynamic cycle.

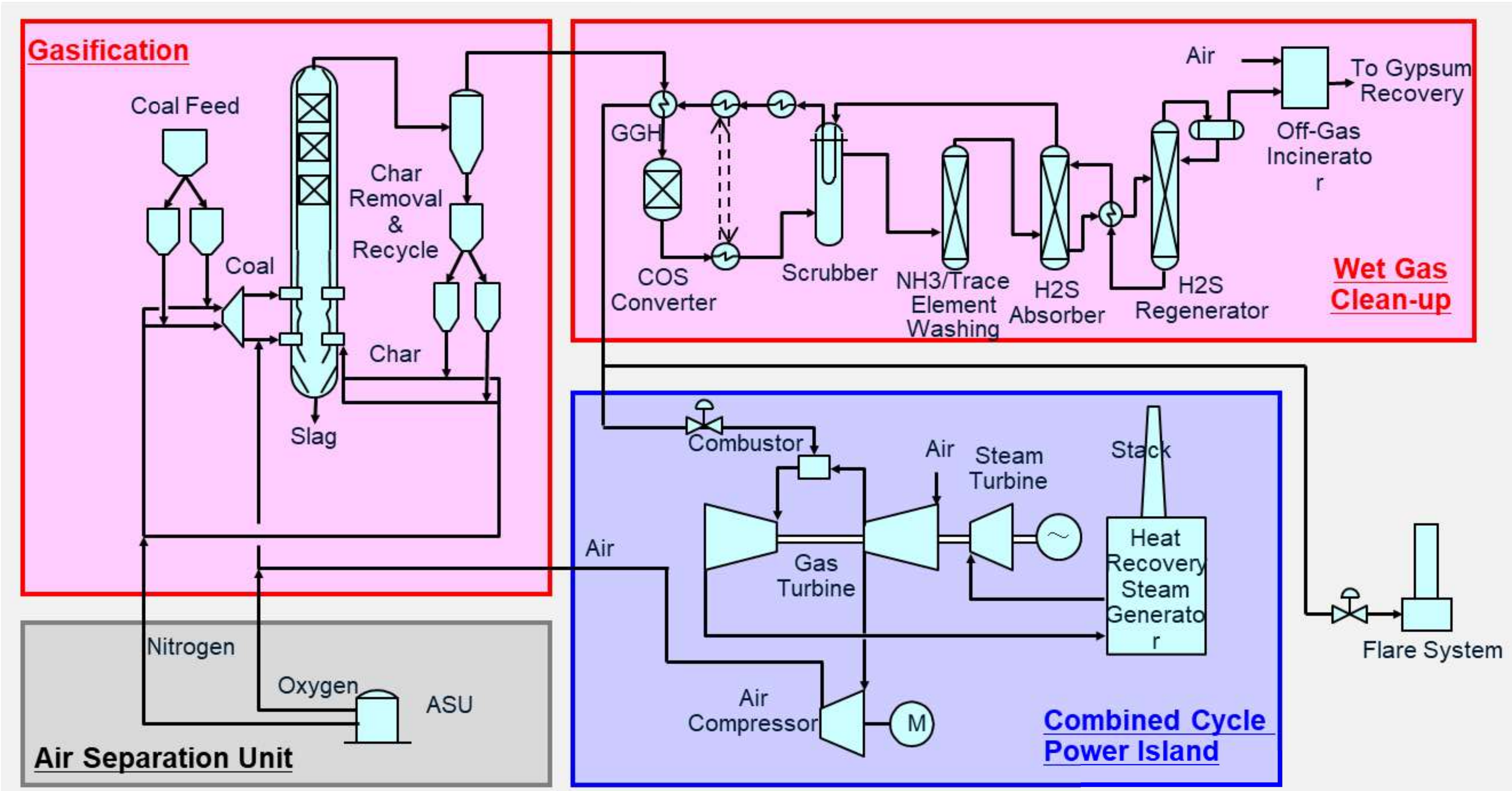
Large potential for lower emissions, through the introduction of advanced coal-fired combustion technologies, which include supercritical (SC) and ultra-supercritical (USC) technologies



Energy efficiency and CO2 emission reduction potential on coal-fired power plants.

(Source: VGB, 2013)

SCHEMATIC of IGCC PLANT

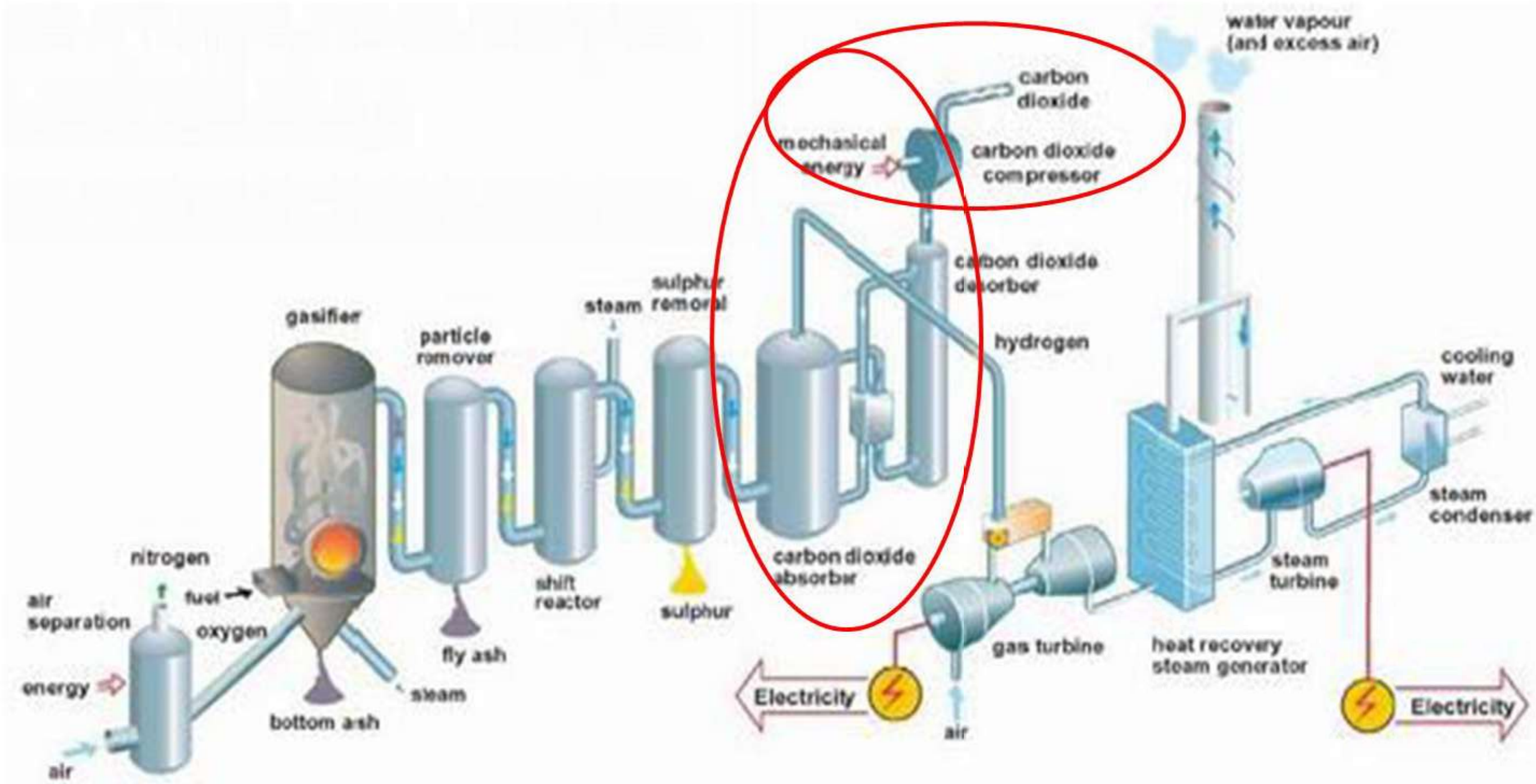


Key Components/Unit Operations in an IGCC Plant are:

- Gasification
- Wet Gas Clean-up
- Combined Cycle Power Island
- Air Separation Unit

IGCC PROCESS and CO_2 CAPTURE

Pre-combustion capture using IGCC to isolate and capture CO_2 before it is released



Source: www.rmcmi.org/education/clean-coal-technology

TECNOLOGY vs CO_2 EMISSIONS

Technology	Average Efficiency	CO_2 intensity factor	Coal consumption
Subcritical	36 %	≥ 880 g CO_2 / kWh	≥ 380 g/kWh
Supercritical	up to 45 %	800-880 g CO_2 / kWh	340-380 g/kWh
Ultra-supercritical	> 45 %	740-800 g CO_2 / kWh	320-340 g/kWh
Advanced ultra-supercritical (700°C class)	45-50 %	670-740 g CO_2 / kWh	290-320 g/kWh
Integrated Gasification Combined Cycle (IGCC)	45-50 %	670-740 g CO_2 / kWh	290-320 g/kWh

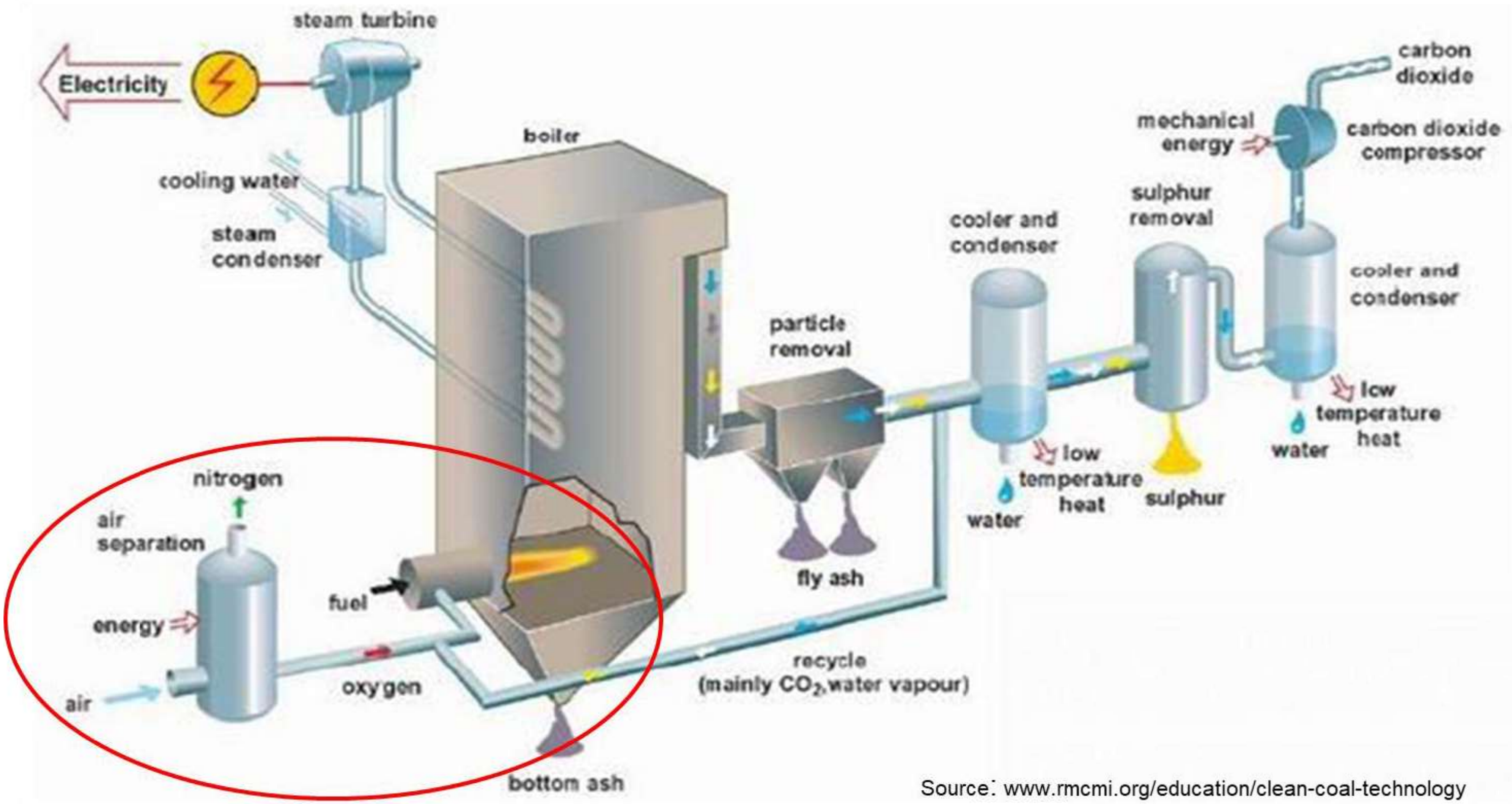
NO_x REDUCTION TECHNOLOGIES

NO_x Reduction techniques include:

- Low excess air (LEA) combustion
- Low NOx Burners (LNB)
- Staged Combustion (SC)
- Flue Gas Recirculation (FGR)
- NO_x Reburning

OXY-COAL COMBUSTION

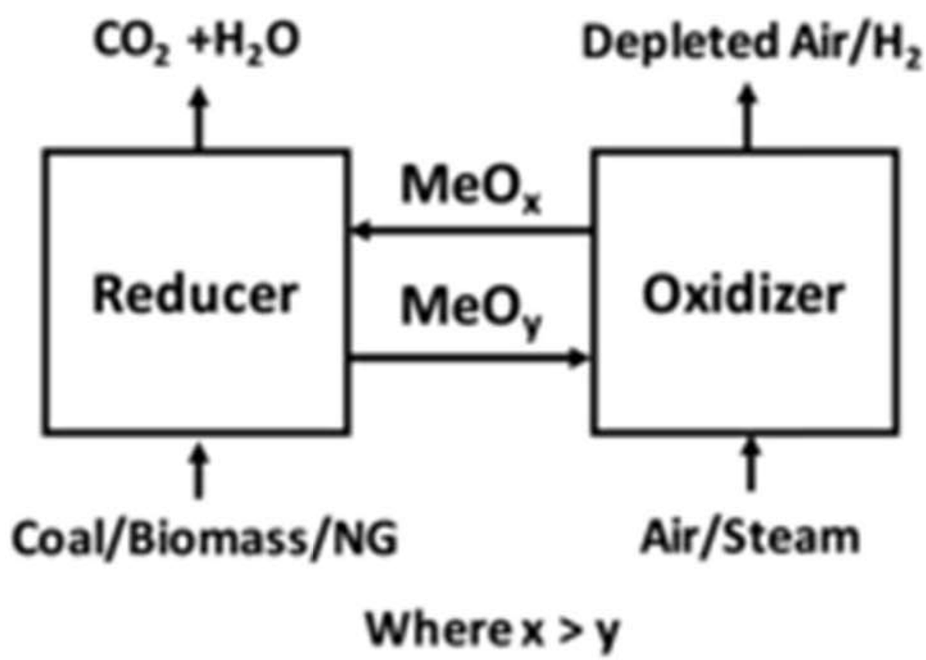
Oxy-Coal combustion using pure oxygen in the boiler to significantly increase the concentration of CO_2 in the exhaust gas stream, that enables easier CO_2 capture



Source: www.rmcmi.org/education/clean-coal-technology

CHEMICAL LOOPING COMBUSTION

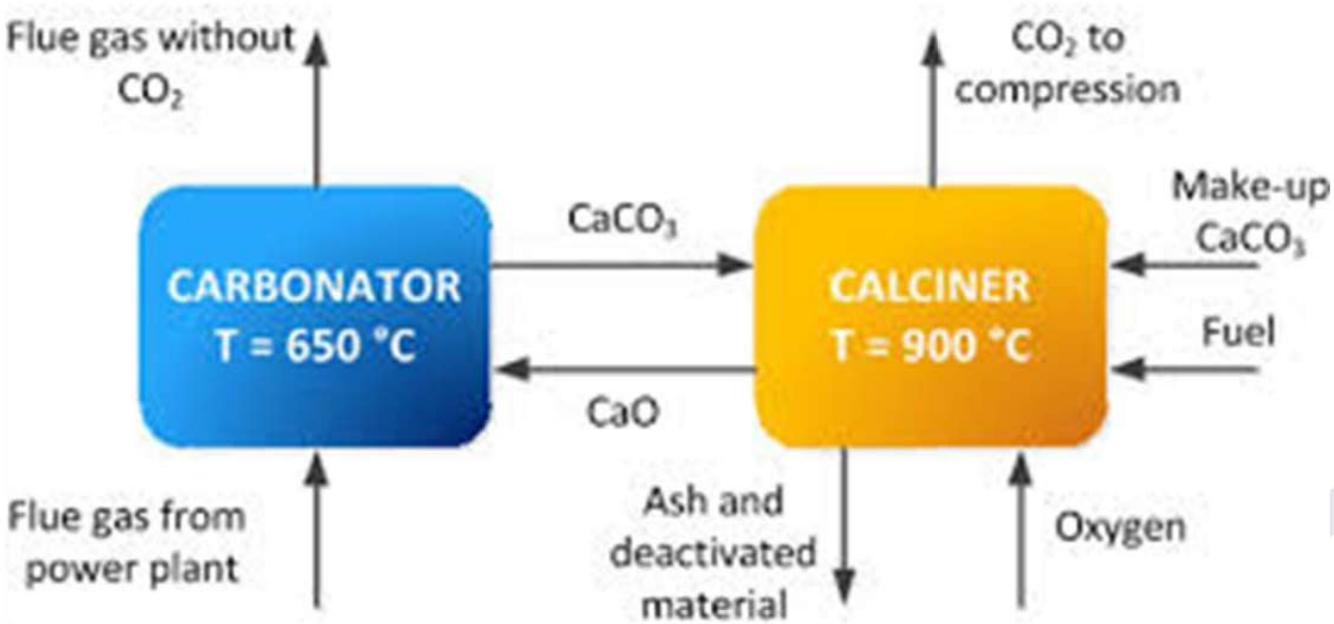
Chemical looping combustion (CLC) is a technological process typically employing a dual fluidized bed system. In CLC, a metal oxide is employed as a bed material providing the oxygen for combustion in the fuel reactor.



Source: www.rmcmi.org/education/clean-coal-technology

CARBONATE LOOPING COMBUSTION

The figure shows the principle of the carbonate looping process. The CO_2 is absorbed and captured by lime (CaO) from the flue gas entering the carbonator. CO_2 depleted flue gas leaves the reactor. The converted limestone ($CaCO_3$) is transferred to a second reactor. In this reactor called calciner $CaCO_3$ is calcined and CO_2 is released.



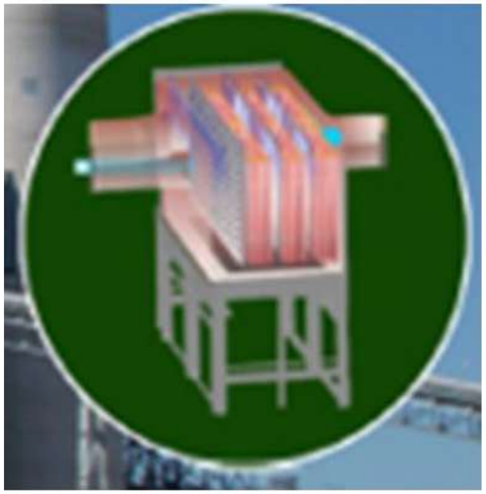
Source: www.rmcmi.org/education/clean-coal-technology

CCT PROCESSES FOR FLUE GAS STREAM

➢ Cleaner Coal Technologies for Flue Gas Streams

- Particulate emissions control technologies
- Flue gas desulfurization
- NOx Reduction (SNCR, SCR)
- Mercury Removal
- Multi-pollutant flue gas treatment with Activated Carbon

CCT FOR CONTROL OF PARTICULATES



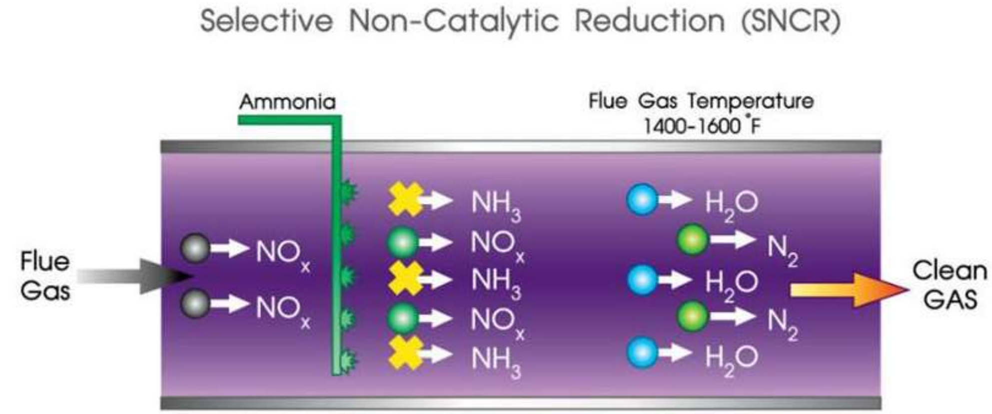
Dry Electrostatic Precipitator (ESP)
The dry ESP uses electrodes to place an electric charge on the particles which are captured on an oppositely charged plate. The particles are then shaken from the plates and collected

Wet Electrostatic Precipitator
The air stream passes through the scrubber into a wet ESP which will remove fine particulates and other constituents.

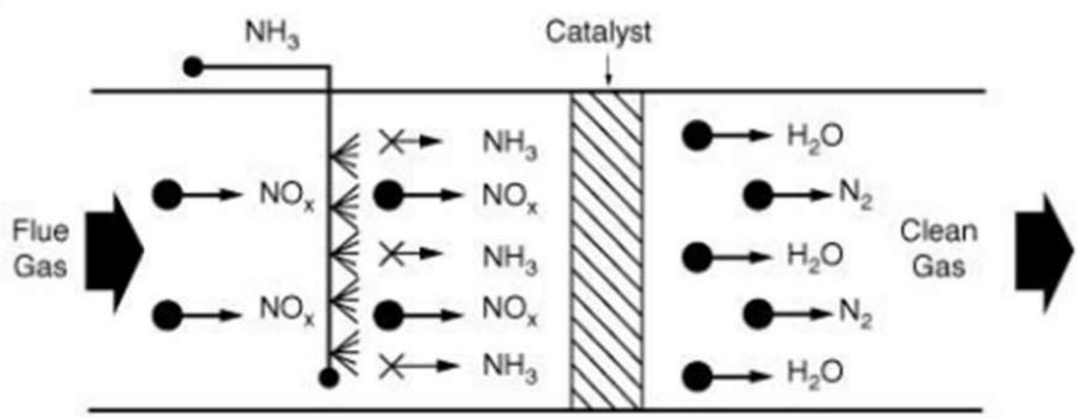
Wet ESP uses multiple high voltage fields to attract the particles to an electrode, which is then washed with water to capture the constituents

CCT FOR CONTROL of NO_x

The two technologies commercially available to convert NO_x to molecular nitrogen or nitrates



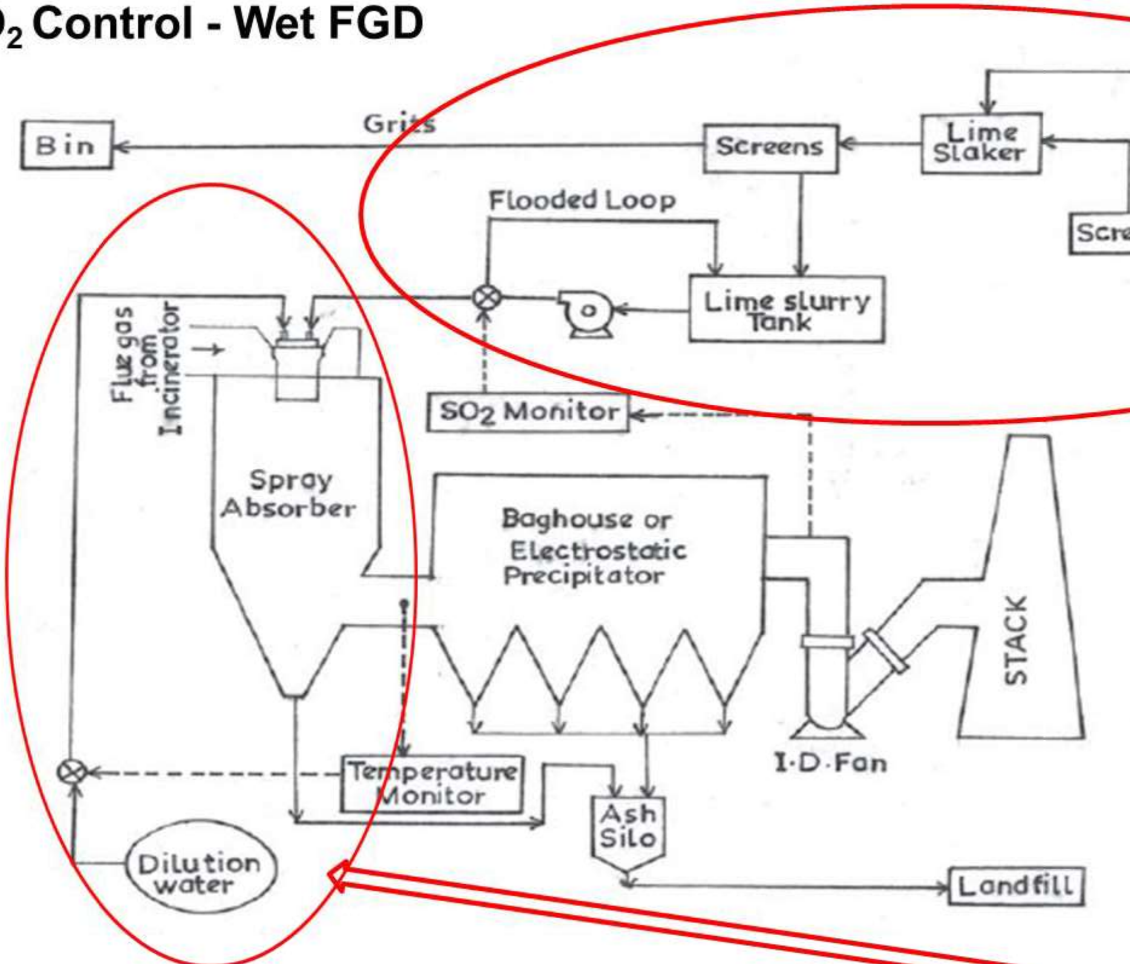
Selective non-catalytic reduction (SNCR)



Selective catalytic reduction (SCR)

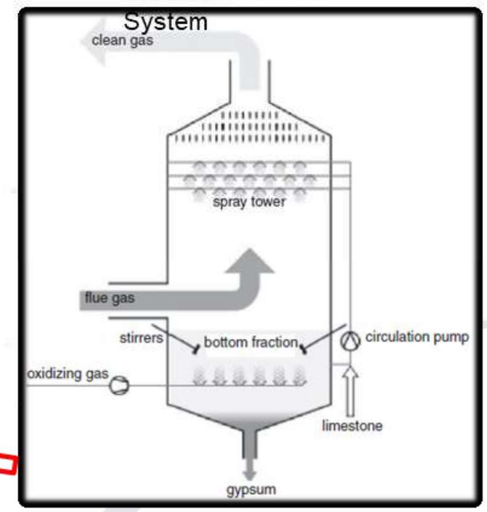
CCT FOR CONTROL of SO_2

SO_2 Control - Wet FGD

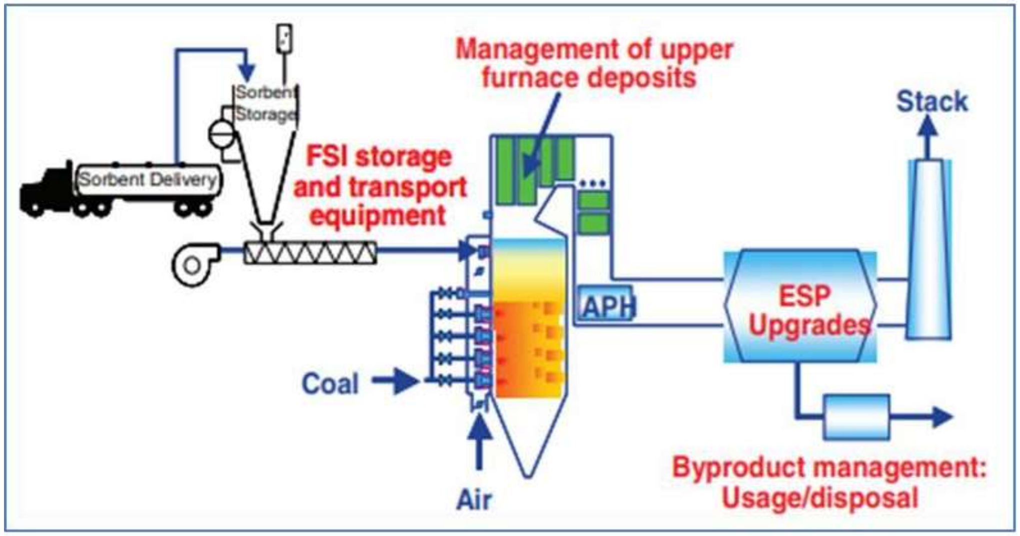


Dry scrubber system using slaked lime slurry

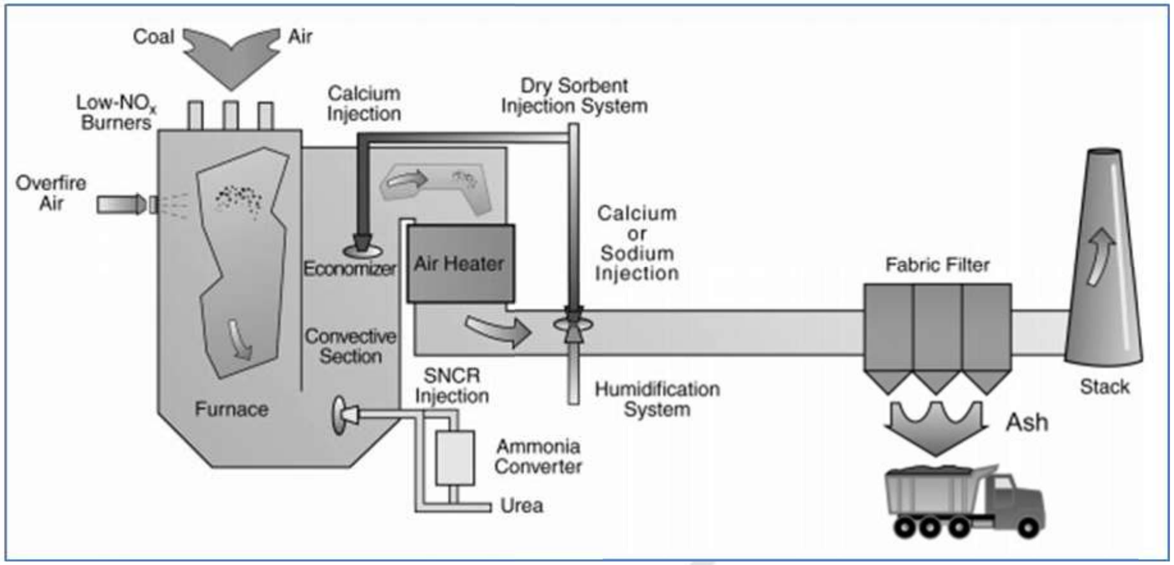
Schematic design of an absorber in a FGD System



CCT FOR CONTROL of SO_2



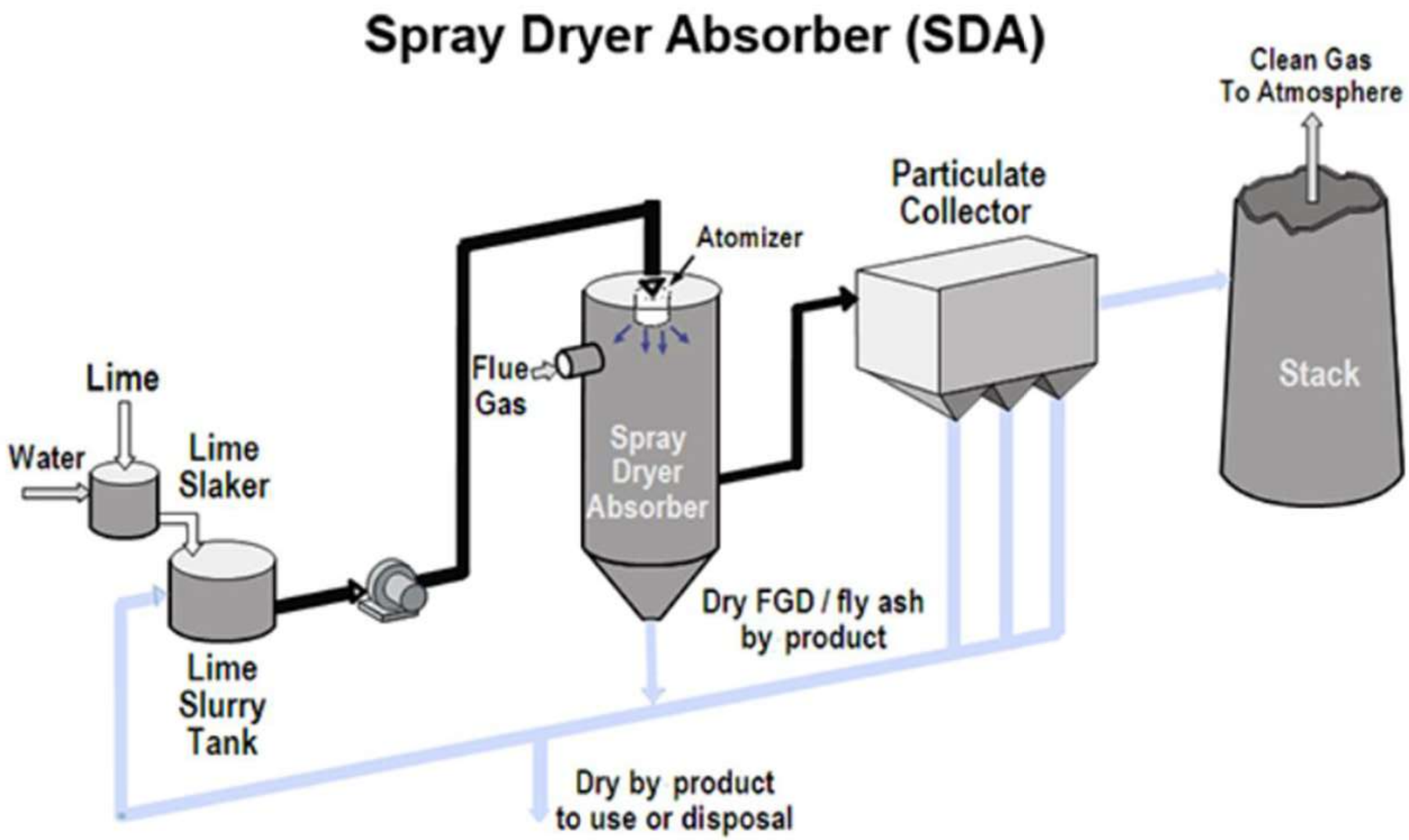
Dry Sorbent Injection During Combustion



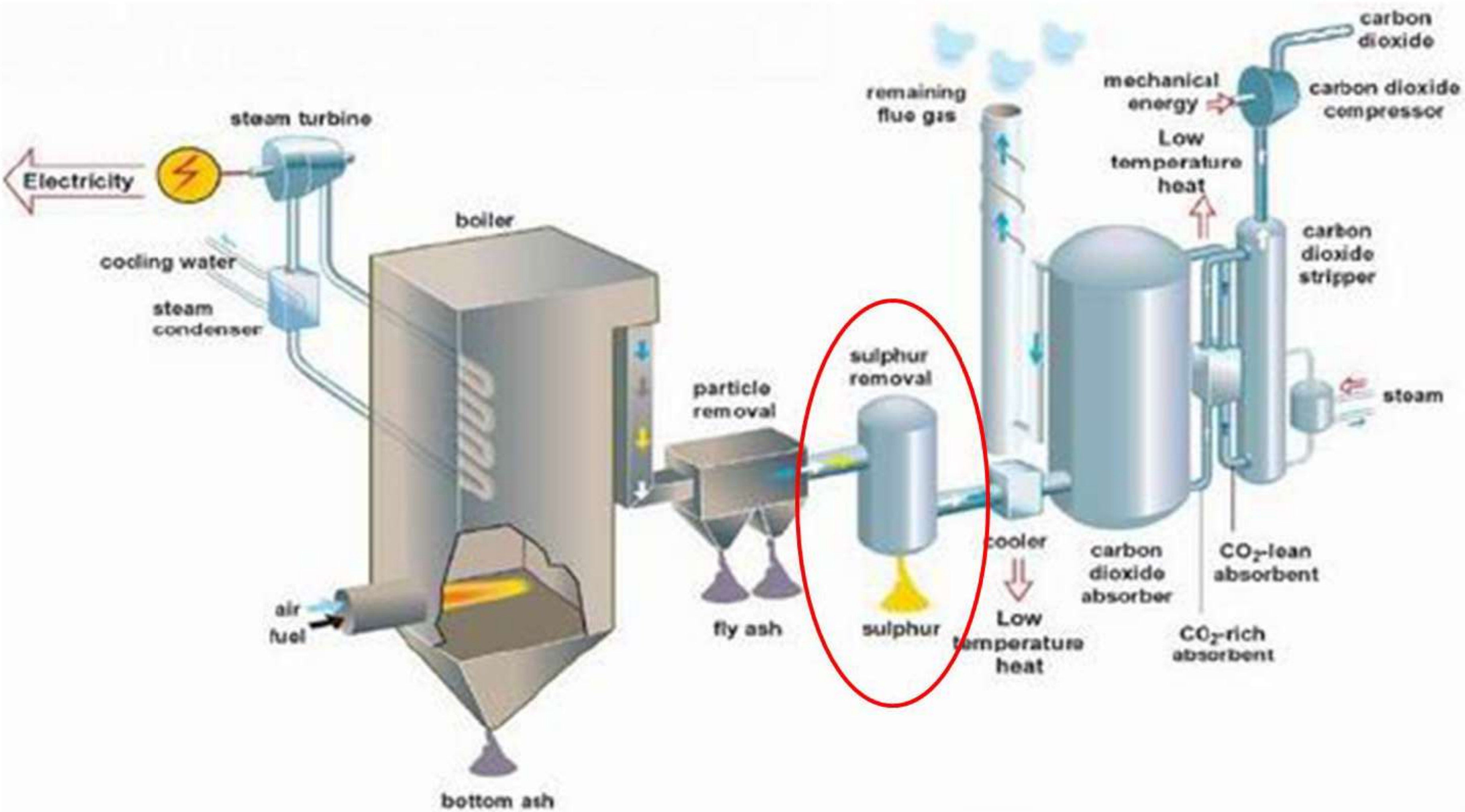
Dry Sorbent Injection Post Combustion

CCT FOR CONTROL of SO_2

Semi- Dry Sorbent Injection

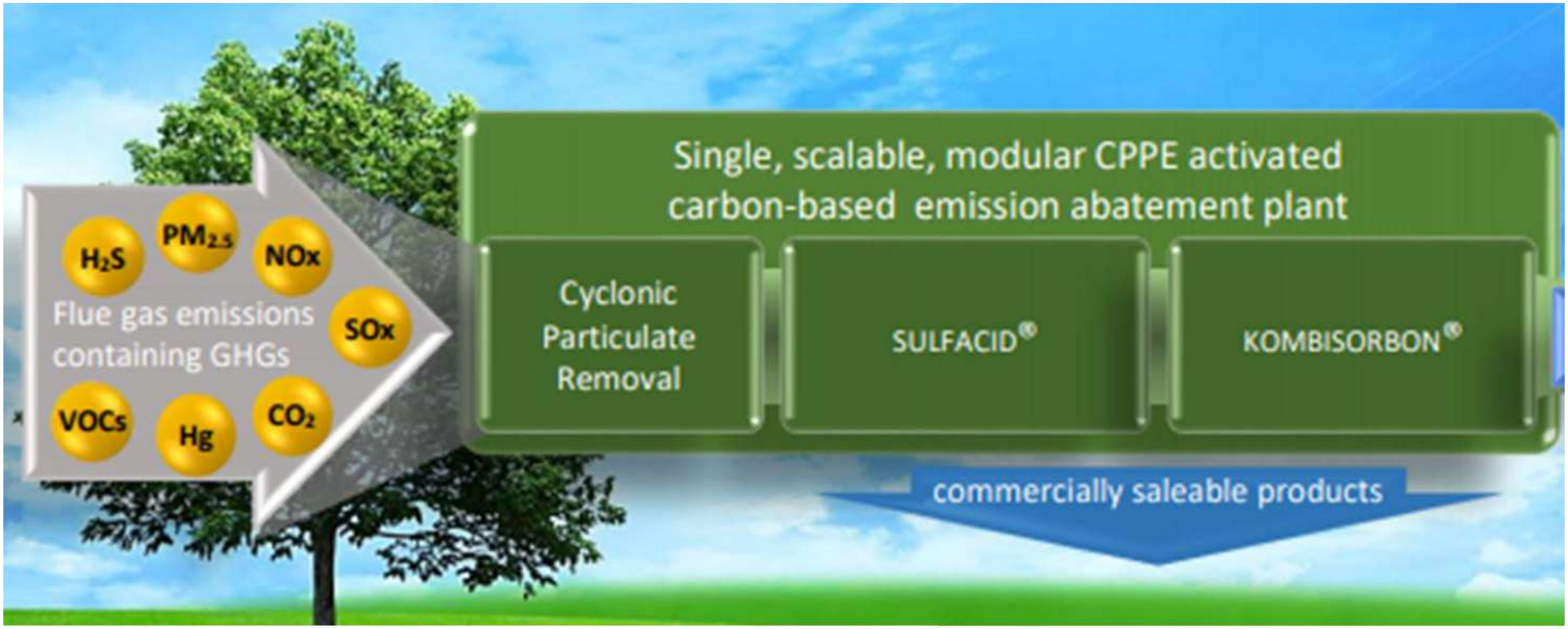


ADVANCED PROCESSES FOR SO_2 CONTROL



Source: www.rmcmi.org/education/clean-coal-technology

MULTI-POLLUTANT CONTROL



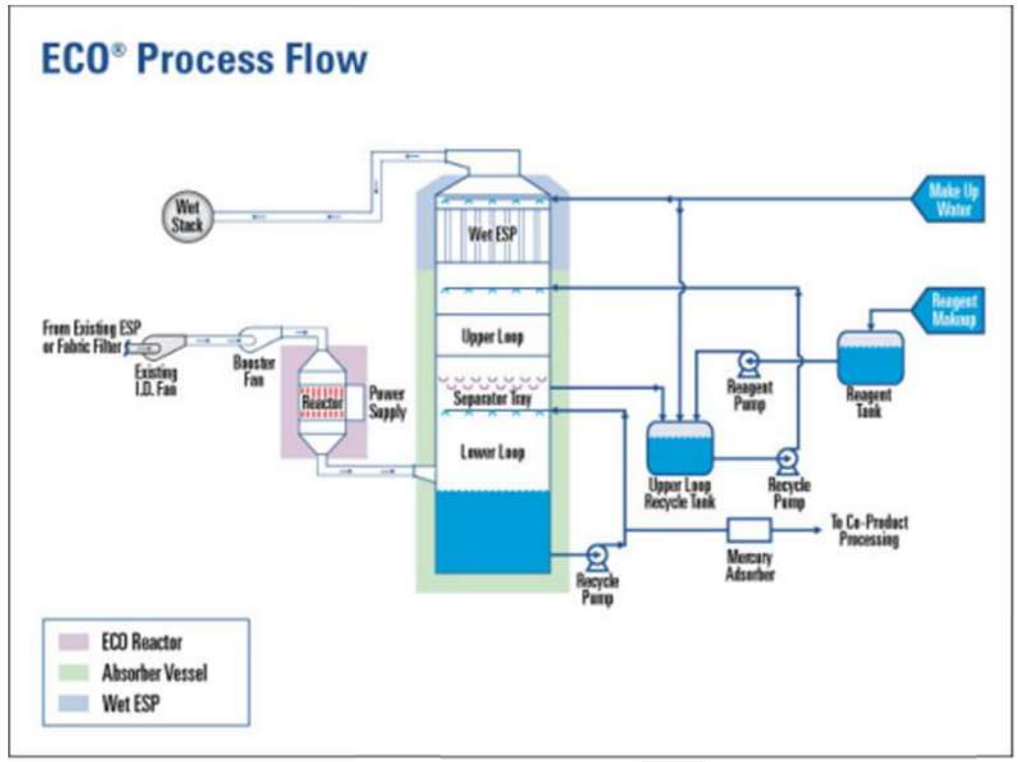
CPPE Carbon Process & Plant Engineering S.A. (Grand-Duchy of Luxembourg)

SULFACID® for the conversion of SO_x into H_2SO_4

KOMBISORBON® removal of Mercury, Cadmium and Dioxins and catalytic CO_2 / NO_x abatement processes for the production of fertilisers.

Electro-catalytic oxidation technology (ECO)

Typical ECO Installation Overview



ECO Process Flow Diagram.

ADVANCED CCT PROCESSES

The need to tackle rising CO_2 emission to address climate change means that CCT now extends to include CCUS, CHP and Hybrid solutions.

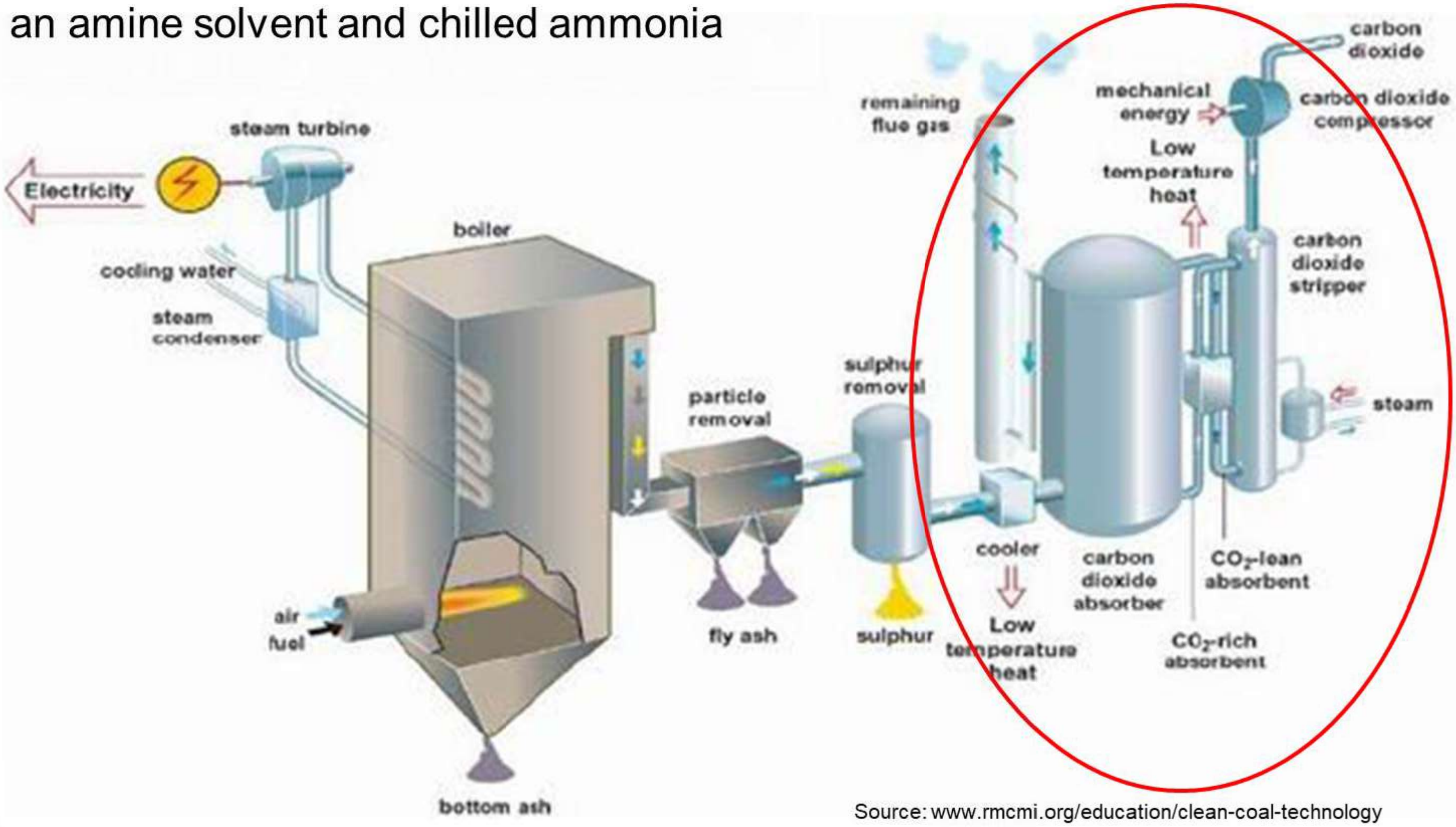
- **Cleaner Coal Technologies On The Horizon**
  - Carbon Capture and Storage
  - Carbon Capture and Utilisation
  - Combined Heat and Power (CHP)
  - Energy capture from waste heat (eg, ORC and chilling)
  - Hybrid Solutions

CCS – CONCEPT for SOUTH AFRICA

- The development and deployment of CCS technology has significant potential to reduce CO_2 emissions in energy systems
- CCS is a combination of different technologies of capturing waste CO_2 usually from large point sources, transporting it to a storage site, and injecting the captured carbon dioxide in a compressed form into a suitable deep geological strata where the CO_2 can be safely stored over a long geological period.
- CCS is being considered as part of South Africa's energy and climate change future.
- Some realities of CCS for South Africa:
  - The general geology of South Africa is not suitable for onshore CO_2 storage.
  - CCS Value chains will be complex and has no economic contribution. ie Capture and storage will be a cost burden
  - South Africa has little opportunity to ultimately store the quantities of CO_2 currently being produced

CO_2 CAPTURE

Post-combustion CO_2 capture from flue gas using an amine solvent and chilled ammonia



Source: www.rmcmi.org/education/clean-coal-technology

CCU – CONCEPTS

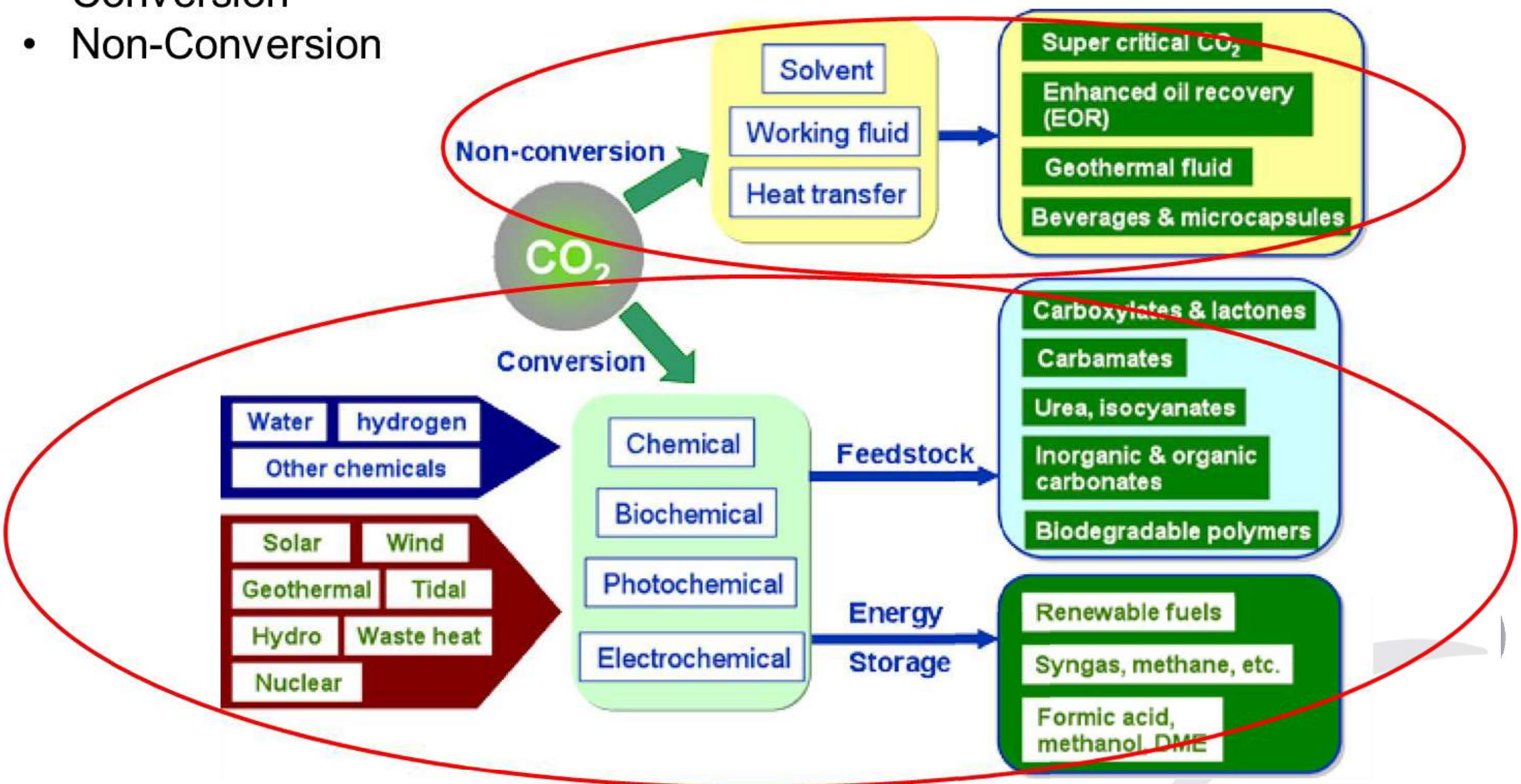
- Energy efficiency and renewables are often positioned as the only solutions needed to meet climate goals in the energy system, but they are not enough.
- However, without carbon capture and utilisation coal power plants cannot achieve the deep reductions that is required to avoid substantial contribution to global warming.
- Carbon is an input chemical and basic component for numerous processes and economic activities which is mainly derived from fossil-based raw materials.
- Globally over 90% of organic chemicals are derived from fossil based carbon which constitutes between 7% of the global demand of crude oil.

  ("The grand challenges in carbon capture, utilization, and storage: Berend Smit; Ah-Hyung Alissa Park and Greeshma Gadikota – Published Nov 2014).
- The carbon capture and utilization (CCU) paradigm advances the view that CO_2 is a valuable source of carbon.

CARBON UTILISATION PATHWAYS

The utilisation reactions can be differentiated into two main groups:

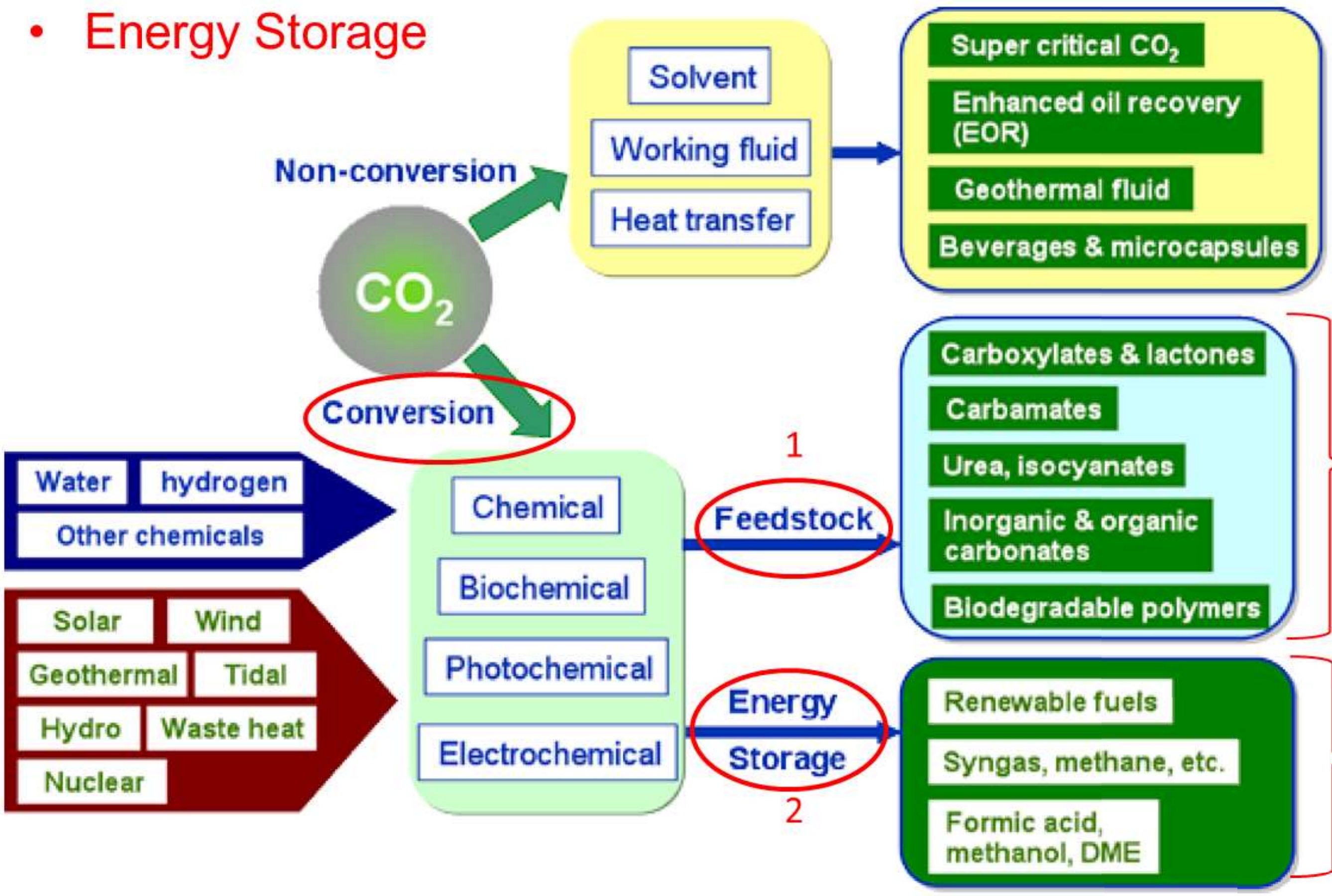
- Conversion
- Non-Conversion



Source: Carbon Dioxide Utilization – Electrochemical Conversion of CO_2 – Opportunities and Challenges, DnV Research and Innovation, Position Paper 07-2011

The Conversion Pathways can be differentiated into two groups:

- Feedstock for Fine Chemicals
- Energy Storage



Conversion Pathways

1. Reaction with other reactants to form fine chemicals.
2. Conversion with hydrogen (synthesis gas) to form hydrocarbons or simple alcohols (methanol)

Source: Carbon Dioxide Utilization – Electrochemical Conversion of CO_2 – Opportunities and Challenges, DnV Research and Innovation, Position Paper 07-2011

4. Applications and References

FACTORS INFLUENCING POWER GENERATION EFFICIENCY

Power Generation Efficiency is influenced by a number of factors and operating parameters that include:

- coal type and quality (e.g., high ash/moisture content),
- steam temperature and pressure (steam cycle severity), supercritical (SC), ultra-supercritical (USC) and advanced ultra-supercritical (AUSC)
- Boiler design and technology and the type of combustion system
- condenser cooling water temperature,
- location (altitude and local climate conditions)
- industrial symbiosis and industrial clustering

CCT – EFFICIENCY IMPROVEMENT

- Operating at Altitude and prevailing Ambient conditions have a negative impact on efficiency.

- Thermal power generation at coastal regions utilizing wet cooling technology will provide electricity more efficiently (between 3 – 5%) when compared to plants at higher altitudes utilizing dry cooling technology for identical power generating technology producing the same net power output.

- Additionally generating power close to the load centres would reduce transmission losses and assist with balancing the power grid.

- The combined effect of a better generating efficiency, lower transmission losses and generation close to the point of consumption will conservatively reduce the net carbon emissions footprint between 120 – 150 kg CO_2 / MWhr for the coastal plant.

- HELE thermal power generation technologies will provide electricity with a comparatively lower emissions profile. The average CO_2 at the point of generation for the ESKOM fleet is 1030 kg / MWhr compared to ~700 kg / MWhr for HELE technology.

OPPORTUNITIES FOR A COASTAL INSTALLATION

Opportunity	Benefit
Can use seawater for FGD	No sorbent or water required reduced capital cost
Can use seawater cooling	Higher efficiency reduced fuel cost, less CO_2
Sea level altitude	Smaller boiler or IGCC plant, Better Plant Efficiency
Construction closer to port	Reduced cost and schedule (reduced Transport and opportunity for preassembled components
No degraded airsheds	Does not add to local emissions inventory
Possibility to sequester CO_2 offshore (CCS)	Major CO_2 reduction possibility
Distributed Baseload	Helps grid stability and reduce Grid Losses

Base figures from EPRI Report 2017 Annex 7.8

THE LAGISZA POWER PLANT (POLAND)

- The world's first supercritical CFB technology
- This plant began commercial operations in late June 2009, and it marked a new era in the evolution of circulating fluidised bed (CFB) technology.
- Since its operation period, the load range, the boiler has been performing as designed, and the plant operation has been stable and easily controllable

WET FGD – KUSILE POWER PLANT

Eskom's Kusile wet flue gas desulphurisation plant (South Africa). *Image: Biznis Africa (2018).*

- The WFGD system at Kusile is the most advanced environmental control technology to significantly reduce SO_2 emissions.
- Kusile's WFGD plant has achieved 93% removal efficiency rate.
- The WFGD plant is expected to be the cleanest coal-fired power plant in Eskom's fleet.

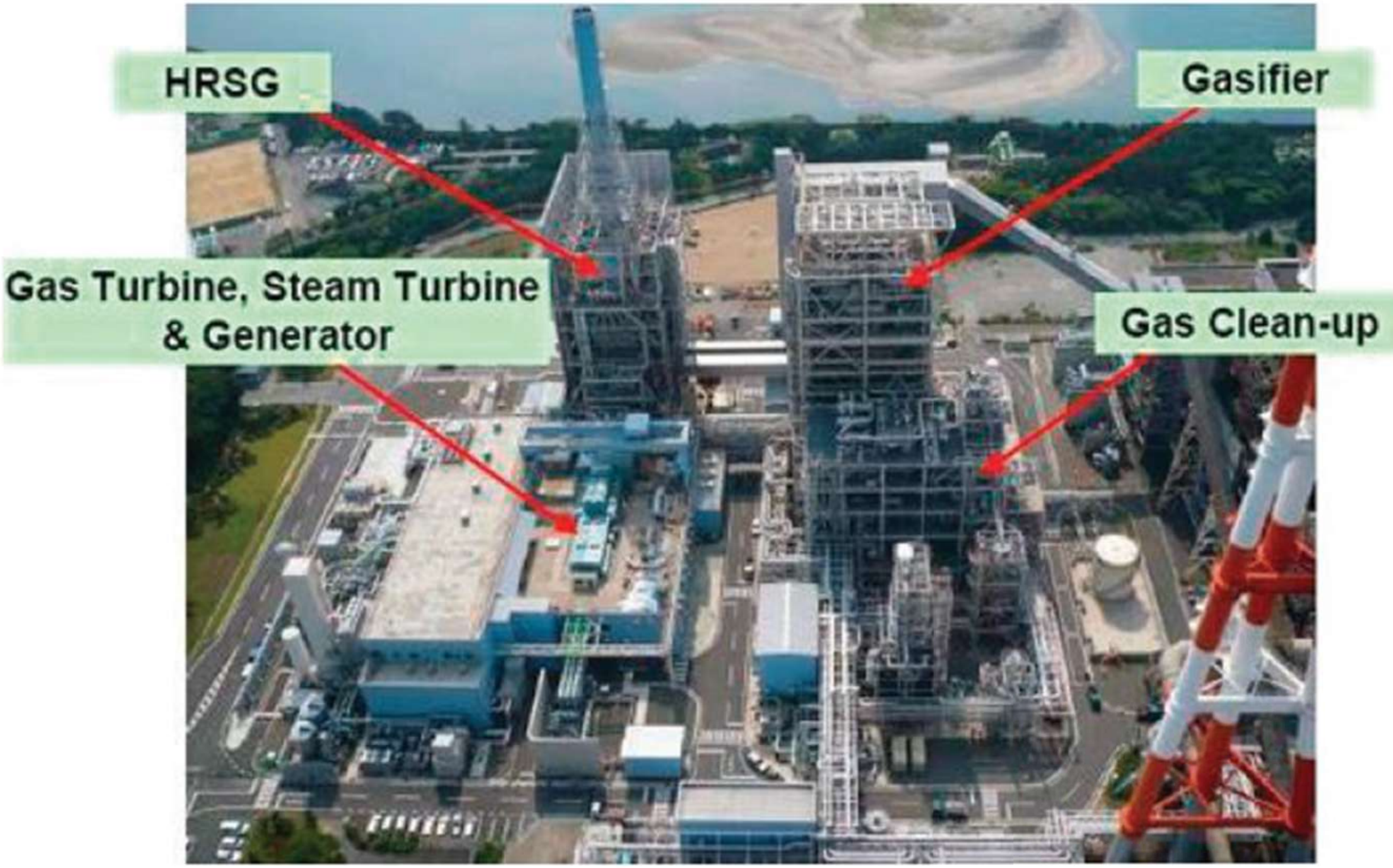
ULTRA-SUPERCRITICAL TECHNOLOGY

Tanjung bin 4 ultra-supercritical technology. *Image: Courtesy of GE POWER*

- The plant operates at a higher temperature and pressure compared to regular coal-fired power plants. The steam parameters improve their efficiency, increasing the amount of power output and decreasing fuel consumption and emissions, particularly CO_2 per unit of fuel burnt.

- This is regarded to be the most efficient coal combustion technology on the market today.

IGCC TECHNOLOGY

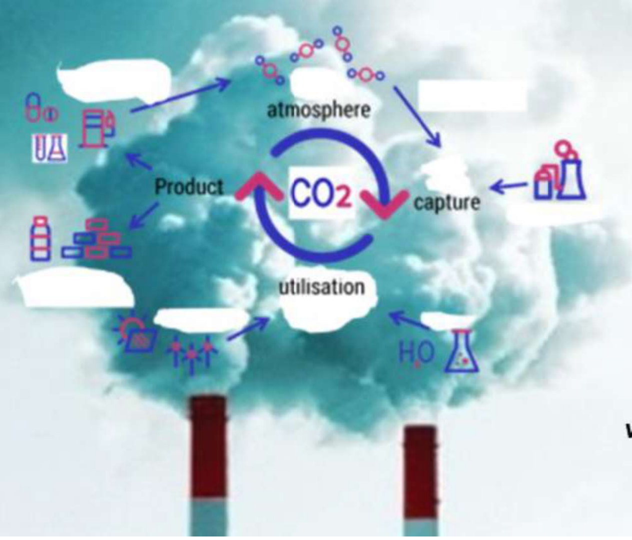


View of the 250 MW IGCC demo plant at Nakoso, Japan. Source: Mitsubishi heavy industries, ltd.

CONCLUDING REMARKS

- Coal has suffered setbacks owing to environmental policies and “market distortions”
- The focus of Cleaner Coal Technologies is on addressing emissions instead of trying to get rid of a fuel. The implementation of clean coal technologies is a solution to the continued use of coal
- HELE technology and Efficiency improvement concepts facilitate the quickest pathway to CO_2 reduction
- Research projects is the best way to determine which technologies are fit for purpose and implementable for the qualities of coal used
- A holistic approach must be used for effective climate mitigation solutions because emission do not occur at the smoke-stack only
- Identify demonstration projects and prove the potential of CCT through government - industry partnerships.

THANK YOU FOR YOUR ATTENTION



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