

# Tapping into new technologies to minimise carbon emissions from fossil fuelled power generation

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1. Mitigating fossil fuel power generation carbon emissions with innovative post combustion CCS technology
2. Simplification of CCS with CO<sub>2</sub> capture on the IGCC oxy-fuel process with coal, Vac Res or petcoke gasification
3. The Allam cycle, an oxy-fuel based advanced thermal process with CCS to achieve clean power from coal or natural gas

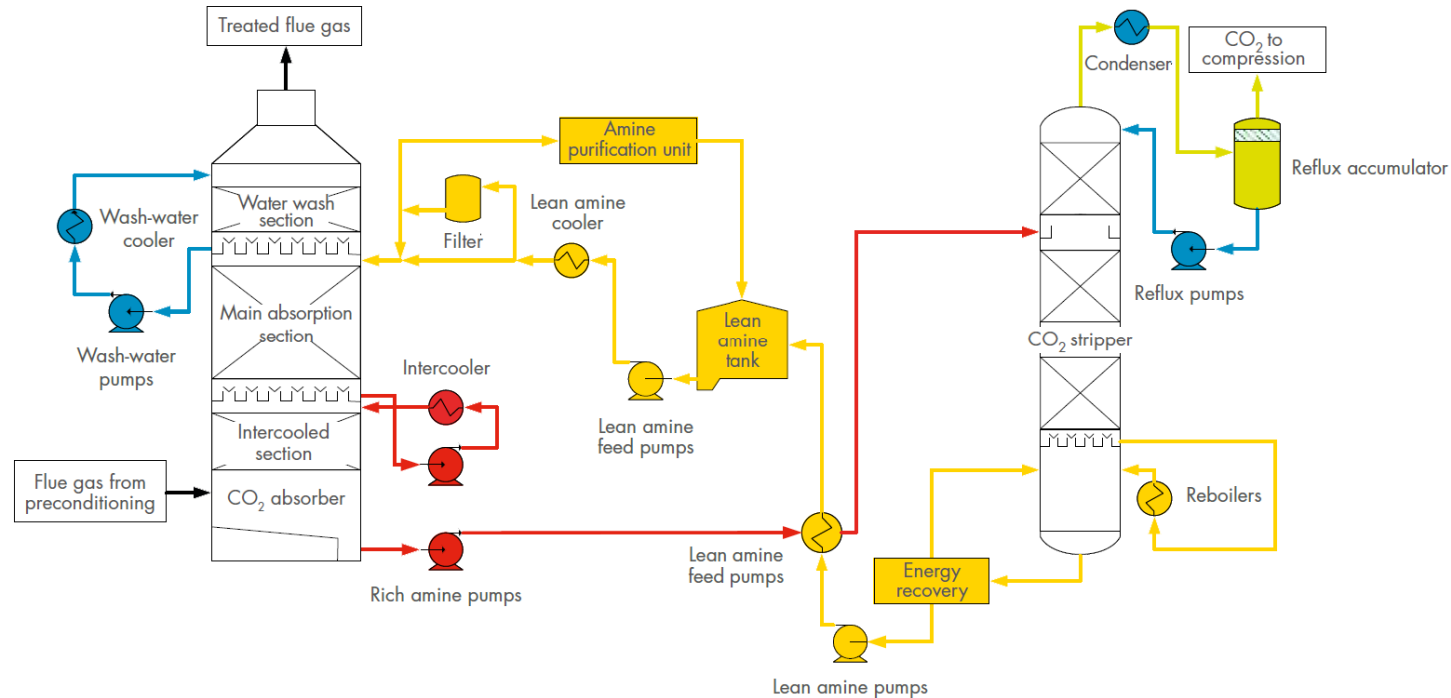
# 1) Mitigating fossil fuel power generation carbon emissions with innovative post combustion CCS technology

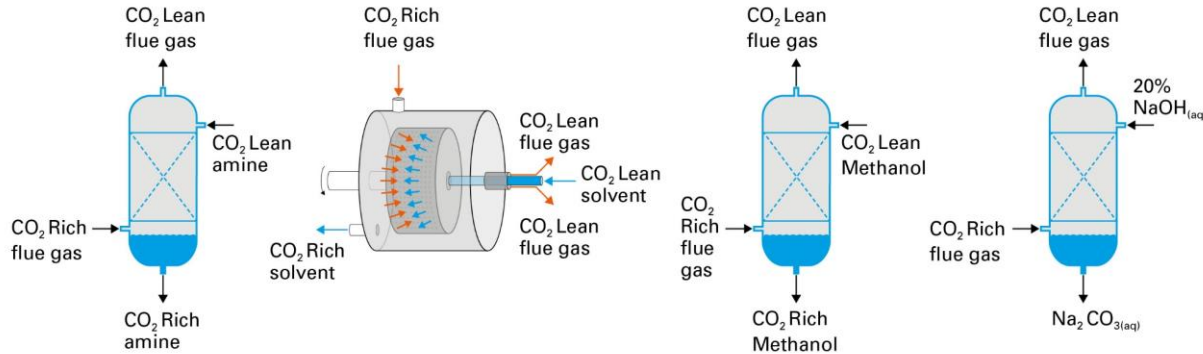
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# Coal-fired thermal power generation with retrofitted post-combustion CO<sub>2</sub> capture. SaskPower, Boundary Dam Canada.



# Amine-wash is the most used CO<sub>2</sub> capture technology across pre- and post-combustion applications





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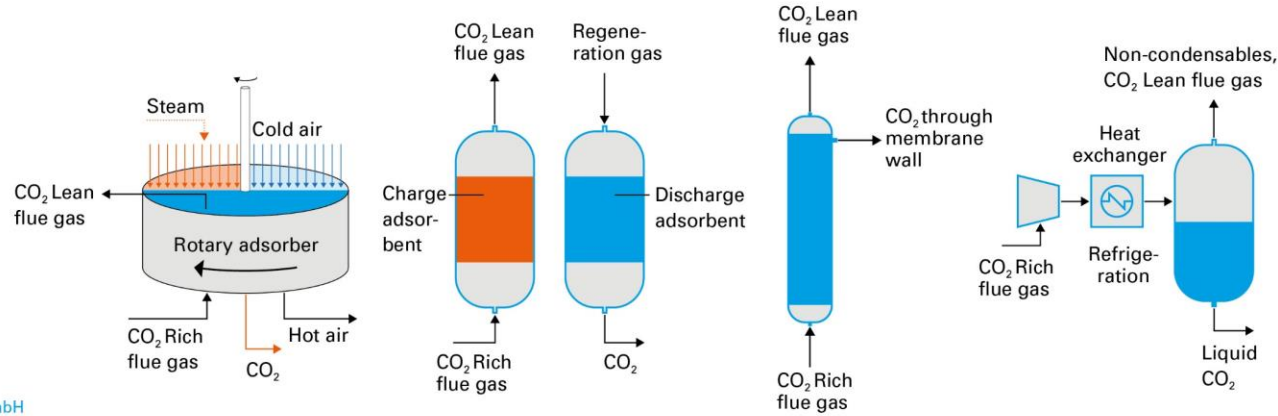
	Amine-wash with tower contactor	Amine-wash rotating disk contactor	Methanol wash	Mineralisation
Separation principle	Absorption	Absorption	Absorption	Absorption
Specific energy demand	3 GJ/t <sub>CO2</sub>	Predominantly electrical power, with heat	1.4 GJ/t <sub>CO2</sub>	8.3 GJ <sub>e</sub> /t <sub>CO2</sub>
Typical temperature	40-60°C	40-60°C	-40°C	< 35°C
Typical pressure	Ambient	Ambient	25-70 bar <sub>g</sub>	Ambient
Typical CO <sub>2</sub> removal	90%	90% (target)	Up to 100%	90%
Typical CO <sub>2</sub> purity	>99%	95% (target)	>98.5%	CO <sub>2</sub> mineralisation to Na <sub>2</sub> CO <sub>3</sub>
Typical plant size (Tonnes per year CO <sub>2</sub> removal)	40,000 – 400,000	1,000 – 500,000	>100,000,000	1,000 – 75,000
Technology maturity level	Commercial from many suppliers	Laboratory, eg ROTA-CAP from GTI & CCSL	Commercial, eg Linde Rectisol	Demonstration, eg SkyMine

## Summary of absorption based CO<sub>2</sub> capture and enrichment technologies.

- Methanol wash is generally used for very large processes, eg syngas production from coal gasification.
- The rotating disc contactor uses more power and less heat than the amine wash system. It uses the same solvent, only the contacting process changes. The main benefit is process intensification and reduction of plant size (and capex).
- The energy requirements for mineralisation shown in the graphic are for the SkyMine process and the majority of that is for NaCl electrolysis.

Adsorption is an alternative to absorption. VSA (like PSA or VPSA) proven for carbon capture at Air Products SMR, Port Arthur for SMR pre-combustion process gas emissions





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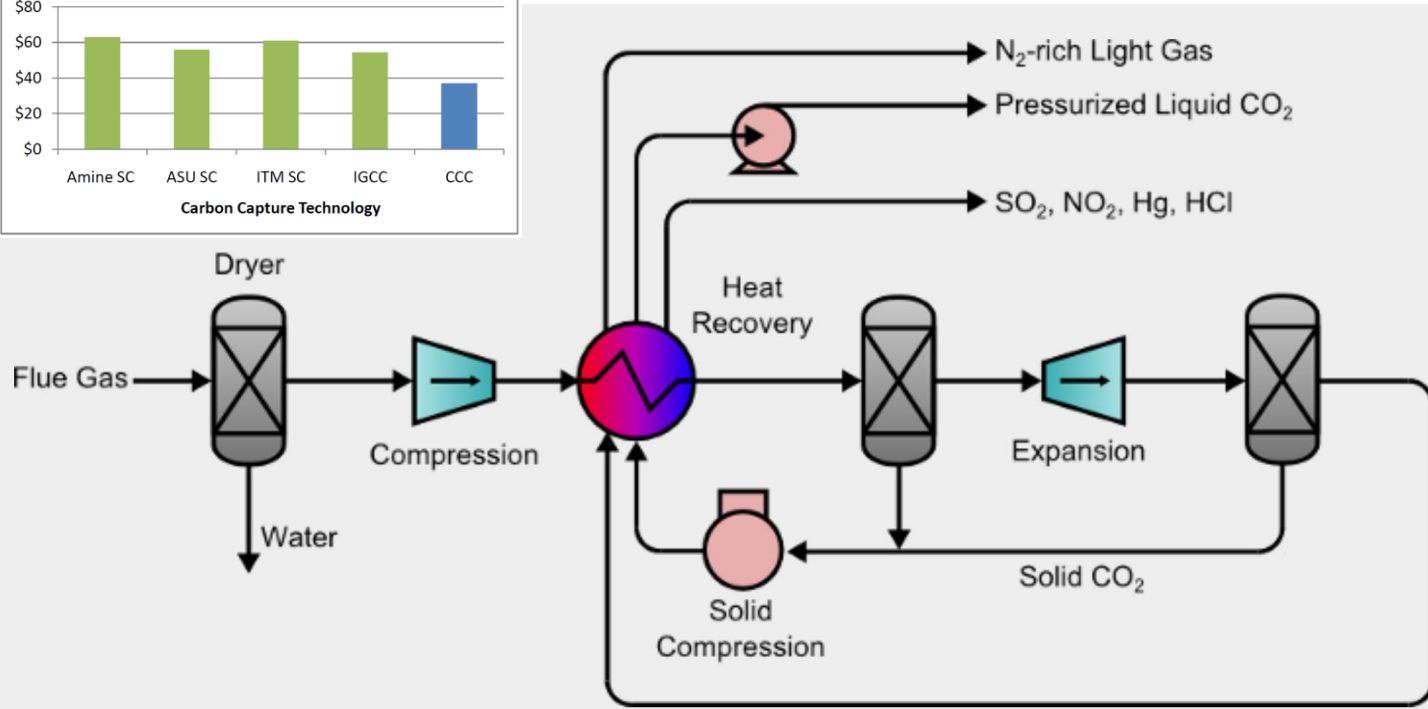
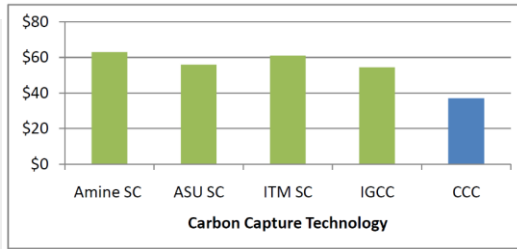
	TSA – temperature swing adsorption and desorption	VSA – vacuum (pressure) swing adsorption and desorption	Selective membrane separation	Cryogenic CO <sub>2</sub> liquefaction
Separation principle	Adsorption	Adsorption	Membrane	Physical (phase separation)
Specific energy demand	1.5 GJ/t <sub>CO<sub>2</sub></sub>	1.7 GJ/t <sub>CO<sub>2</sub></sub>	1.20 GJ/t <sub>CO<sub>2</sub></sub>	n.a.
Typical temperature	40-60°C	<40°C	30-50°C	-50°C
Typical pressure	Ambient	1 bar <sub>a</sub> / 0.03 bar <sub>a</sub>	~3 bar <sub>a</sub> / 0.196 bar <sub>a</sub>	20-50 bar <sub>a</sub>
Typical CO <sub>2</sub> removal	90% (target)	<90%	<80%	>99% (with CO <sub>2</sub> feed >50%)
Typical CO <sub>2</sub> purity	95% (target)	<95%	95%	>99% (with CO <sub>2</sub> feed >50%)
Typically combined with	Standalone	Cryogenic Liquefaction	Amine wash, Cryogenic Liquefaction	VSA, Membrane (eg Cryocap)
Typical plant size (Tonnes per year CO <sub>2</sub> removal)	200 – 2,000,000	1,000 – 500,000	1000 – 1,000,000	> 100,000
Technology maturity level	Pilot / Commercial, eg Husky Energy SK, Lafarge Holcim Cement, BC	Demonstration / Commercial, eg Air Products Port Arthur SMRs, USA	Demonstration / Commercial	Demonstration / Commercial, eg Air Liquide Cryocap at Port-Jérôme SMR, France

Summary of non-absorption based CO<sub>2</sub> capture and enrichment technologies.

- TSA is being piloted by Svante for refinery and cement emissions.
- PSA has been implemented by Air Products for refinery SMR applications.
- Membranes have a lower TRL than TSA or PSA but have the potential to be energy efficient.
- Cryogenic separation has been / is being piloted by SES / Chart Industries on refinery and cement applications.



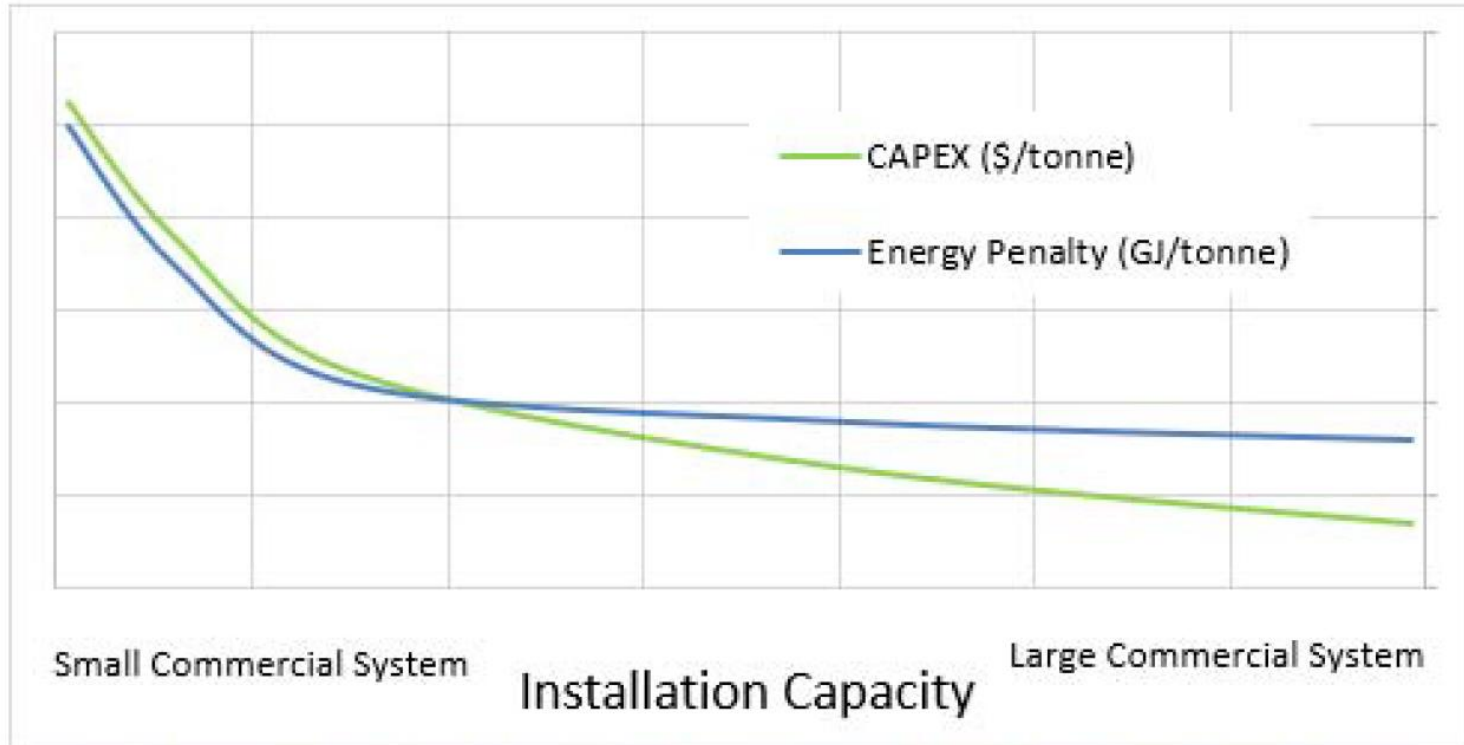
# Chart Industries (SES innovations) Cryogenic Carbon Capture (CCC)



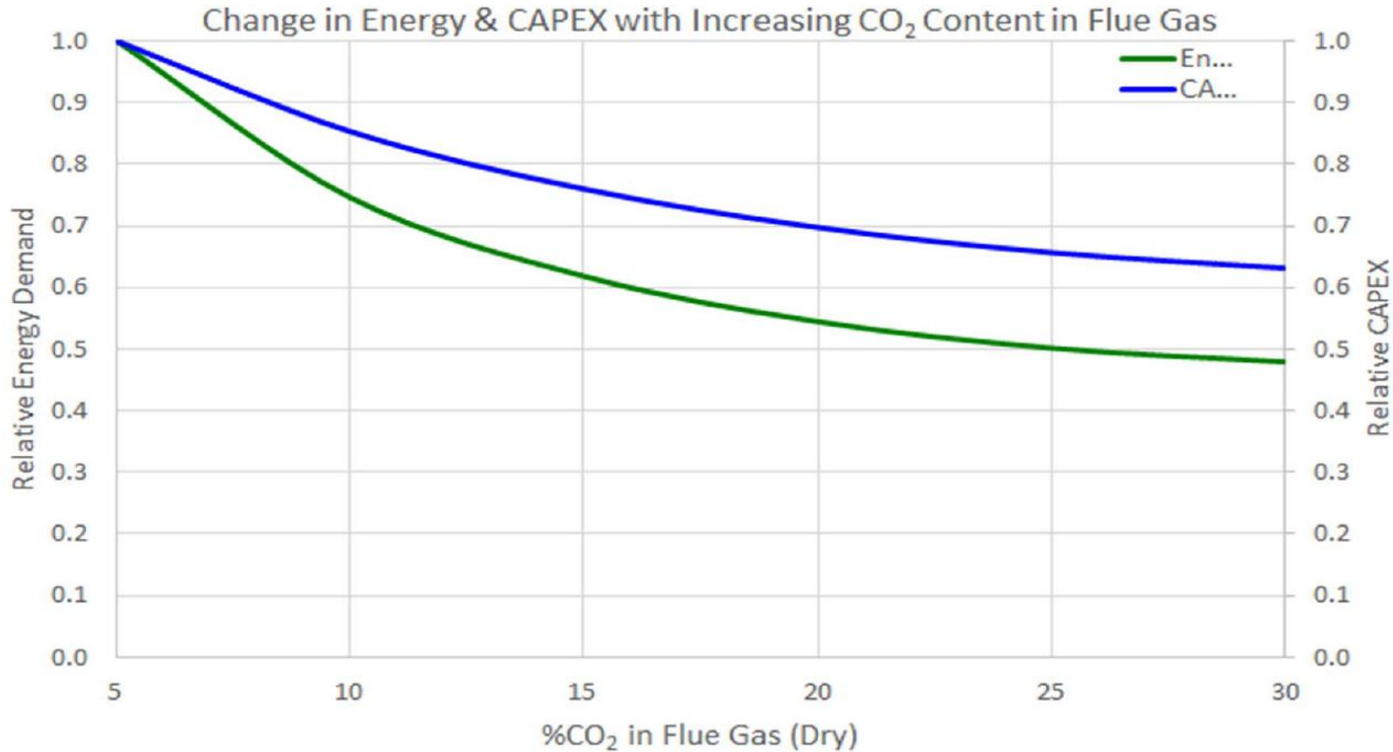
SES Innovations claims a 30 to 40% reduction in overall cost (capex and opex) versus amine wash.

The CCC process uses power and the amine wash uses heat, which could be waste heat or from a natural gas burner.

As with most CO<sub>2</sub> capture systems, mid- and large-scale units have favourable capex and opex per tonne of CO<sub>2</sub> captured



# As with most CO<sub>2</sub> capture systems, higher CO<sub>2</sub> concentrations in the flue gas yield favourable capex and opex per tonne of CO<sub>2</sub> captured



# Chart Industries (SES innovations) Cryogenic Carbon Capture (CCC)



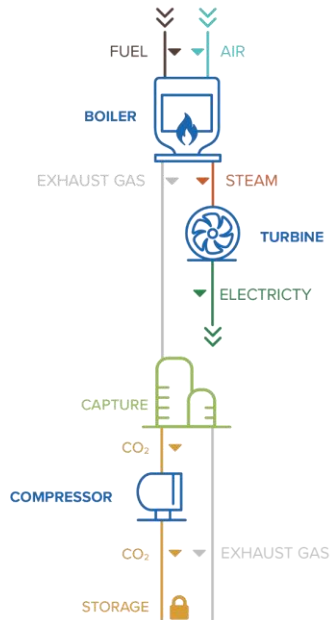
SES Innovations CCC  
process pilots completed

## 2) Simplification of CCS with CO<sub>2</sub> capture on the IGCC oxy-fuel process with coal, Vac Res or petcoke gasification

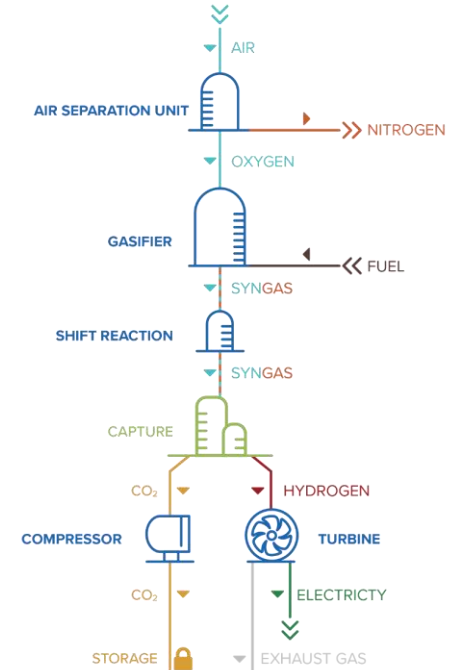
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# Pre-combustion CO<sub>2</sub> capture from oxygen-fed gasification does not need to treat nitrogen from combustion air

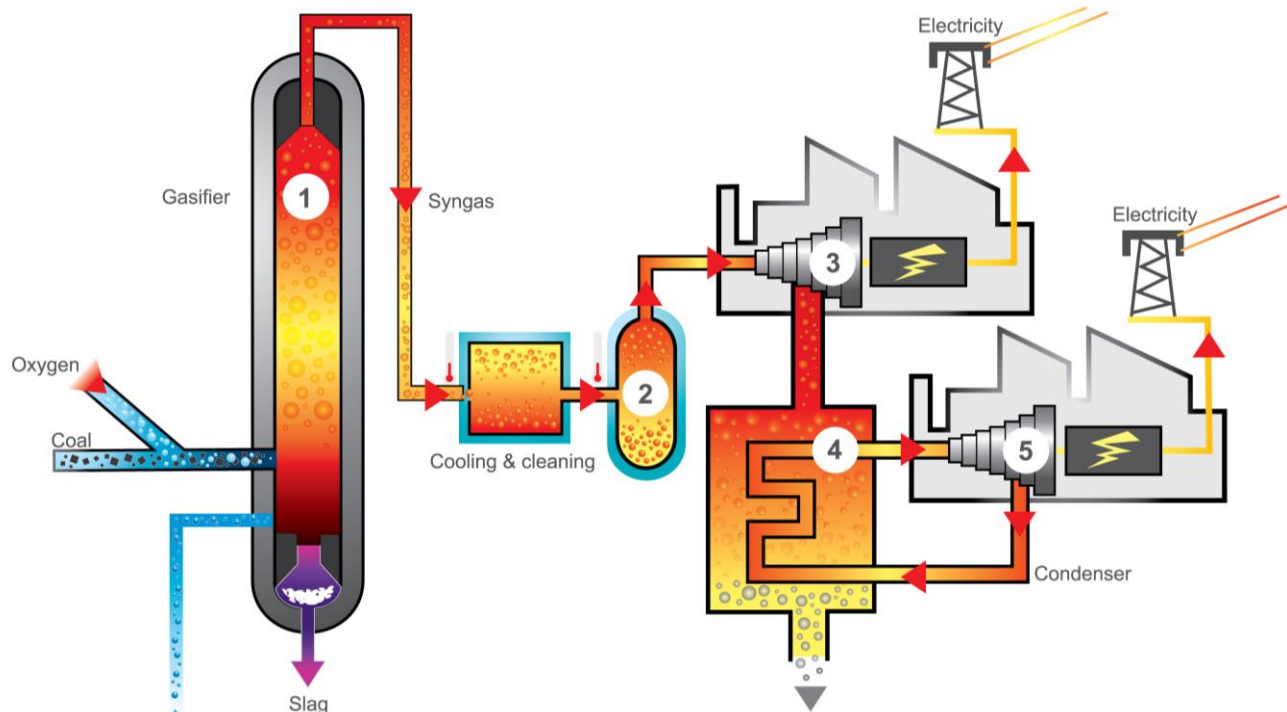
POST-COMBUSTION CO<sub>2</sub> CAPTURE



PRE-COMBUSTION CO<sub>2</sub> CAPTURE



Syngas can be used for thermal power generation in the Integrated Gasification Combined Cycle (IGCC). Oxygen feed simplifies CO<sub>2</sub> capture by avoiding nitrogen ballast gas flow.



- 1) Oxygen-fed gasifier
- 2) Syngas clean up
- 3) Syngas-fired gas turbine
- 4) Heat recovery loop
- 5) Steam turbine

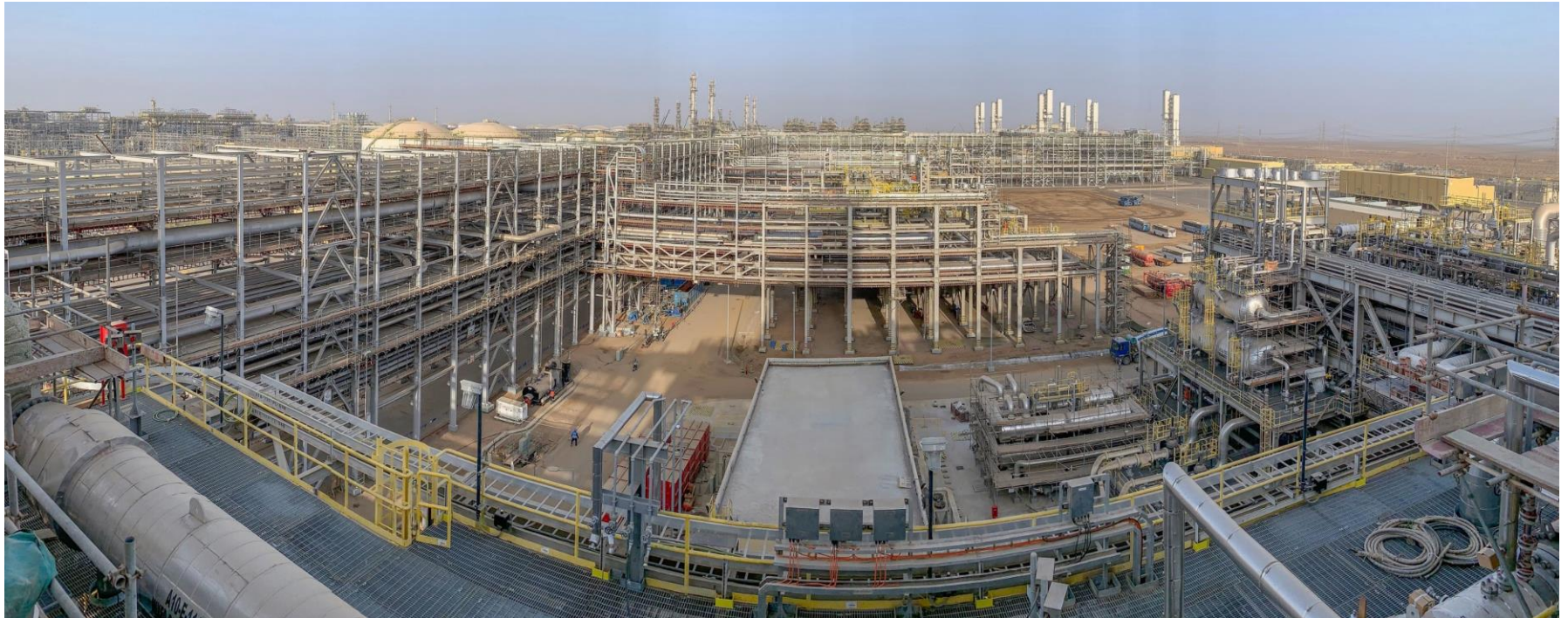
Flue gas to Carbon Capture unit

# Elcogas oxygen-fed coal gasification IGCC thermal power plant, Puertollano Spain





# Aramco Refinery, Jazan KSA – Vac Res gasification for syngas, hydrogen, steam and 2.4 GW IGCC



# Reliance Industries Limited (RIL): 10x petcoke + coal gasifiers produce 20,000 Sm<sup>3</sup> of syngas per day. Captured CO<sub>2</sub> to be used for chemical production.

## Gasification

10 gasifiers  
2 mscm/d syngas/gasifier  
0.85 mmt/yr petcoke  
1.0 mmt/yr petcoke + coal

## ASU

5 trains  
O<sub>2</sub> to gasifier  
5250 t/d O<sub>2</sub>/ASU

ASU = Air separation unit

OGBL = Outside gasification battery limit

OSBL = Outside battery limit

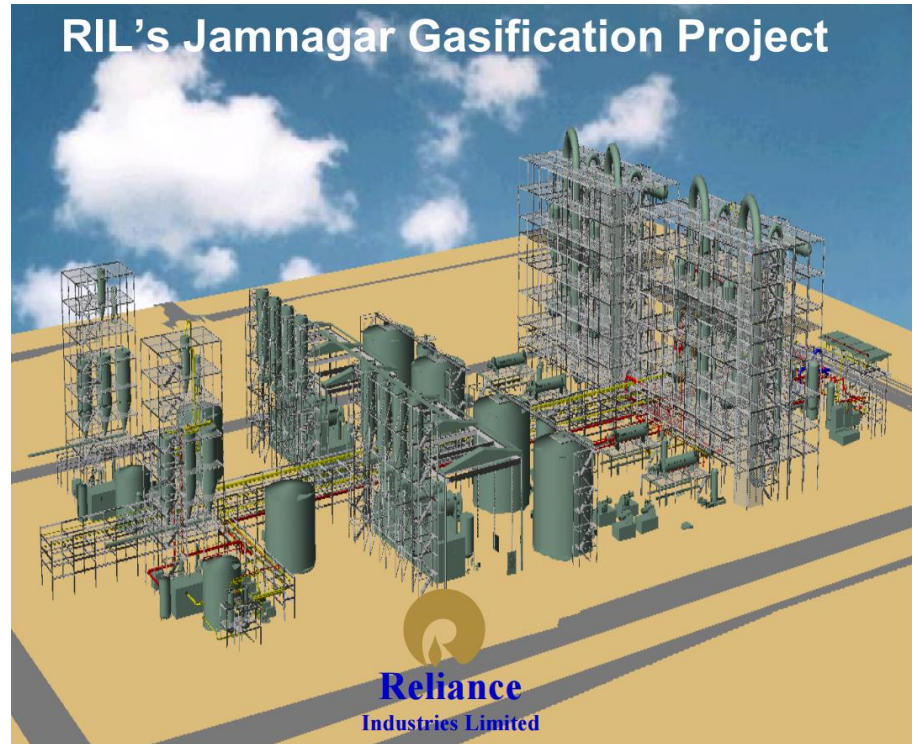
## OGBL

### Processing

AGR  
SRU/TGT  
SWS  
CO shift

### Product

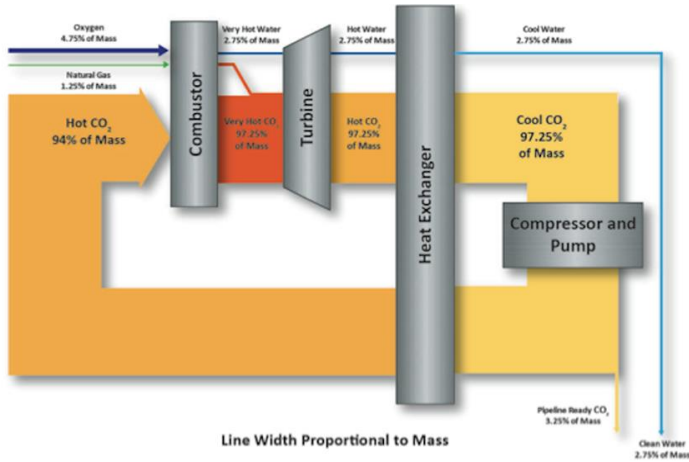
PSA for H<sub>2</sub>  
SNG  
CO recovery



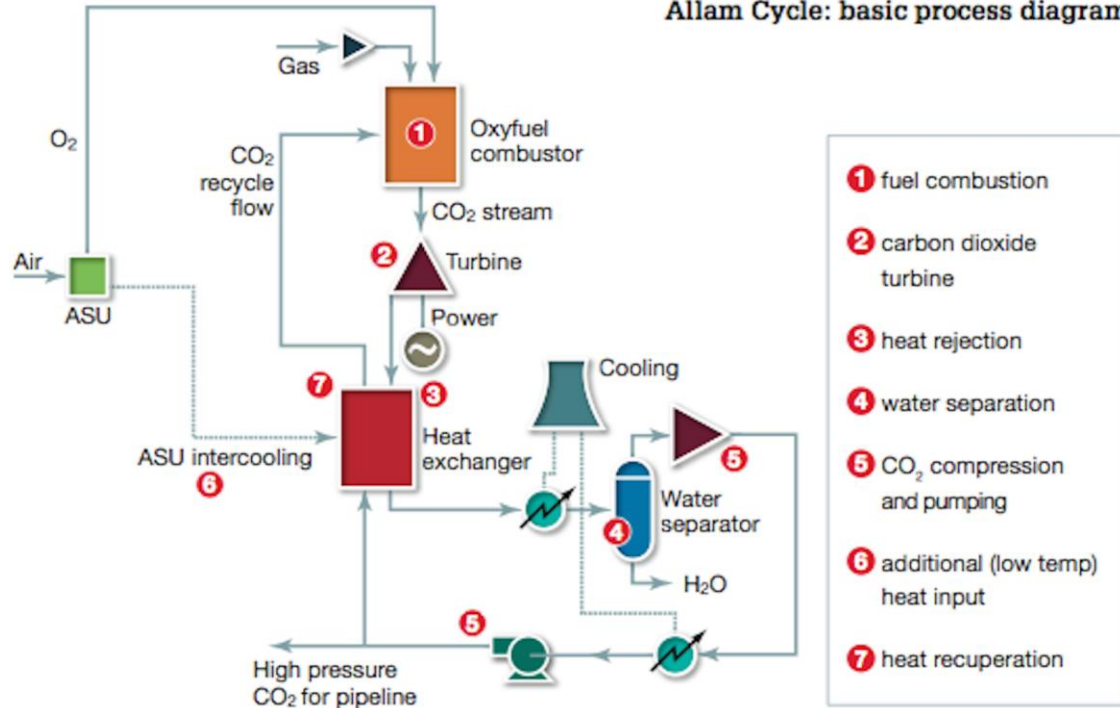
3) The Allam cycle, an oxy-fuel based advanced thermal process with CCS to achieve clean power from coal and gas

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# The Allam cycle – indicative mass flows and basic process flow diagram for gas feed



Allam Cycle: basic process diagram

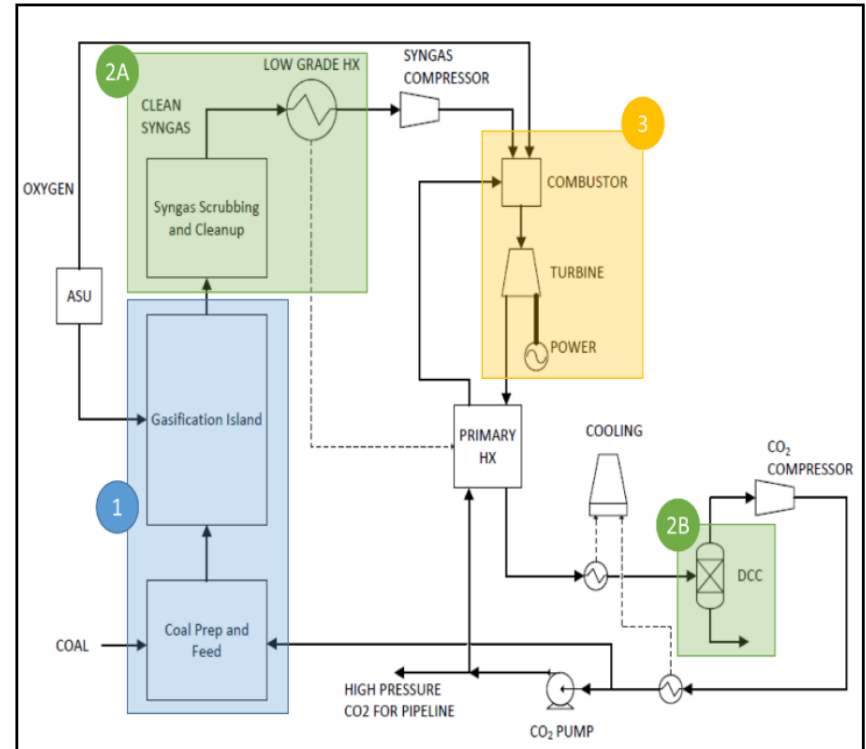
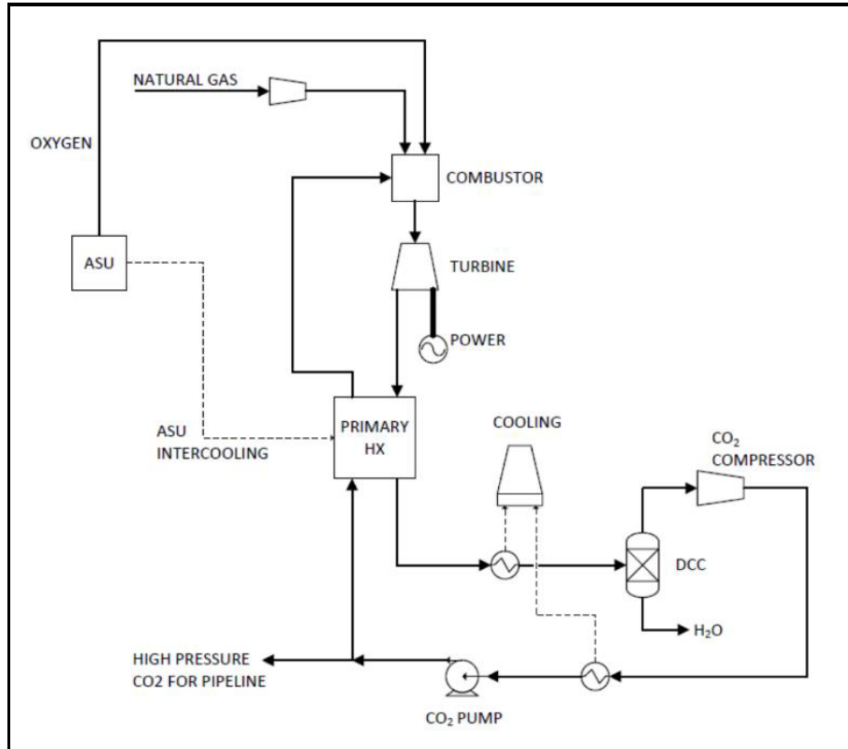


- 1 fuel combustion
- 2 carbon dioxide turbine
- 3 heat rejection
- 4 water separation
- 5 CO<sub>2</sub> compression and pumping
- 6 additional (low temp) heat input
- 7 heat recuperation

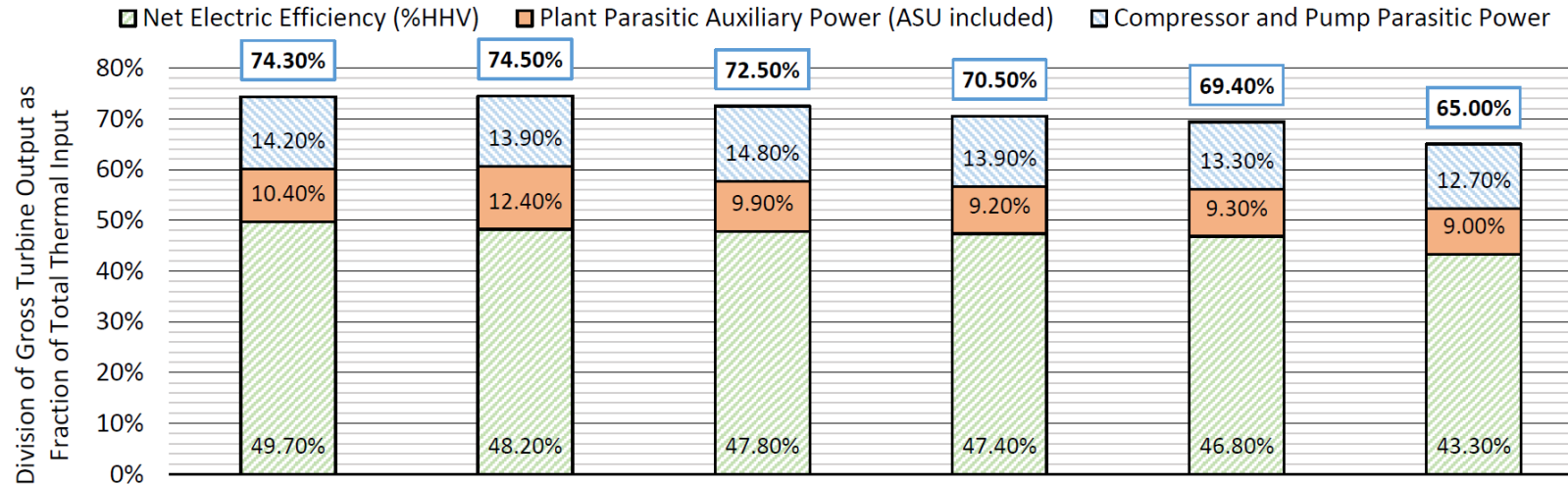
# Allam cycle demonstration facility, Net Power LLC, La Porte USA



# The Allam cycle – core process for natural gas and adaption for coal



# Modelled efficiencies of the Allam cycle for various coal types and gasification regimes



Coal Type	Bituminous	Lignite	Bituminous	Lignite	Bituminous	Lignite
Gasifier Type and Operation	Entrained flow, dry-feed	Moving bed	Entrained flow, dry-feed	Entrained flow, dry-feed	Entrained flow, slurry	Fluidized bed
	Slagging	Slagging	Slagging	Slagging	Slagging	Non-slagging
Heat Recovery Scheme	Syngas cooler	Full water quench	Full water quench	Full water quench	Syngas cooler	Syngas cooler

# Concluding remarks

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# Clean thermal power from fossil fuels - concluding remarks

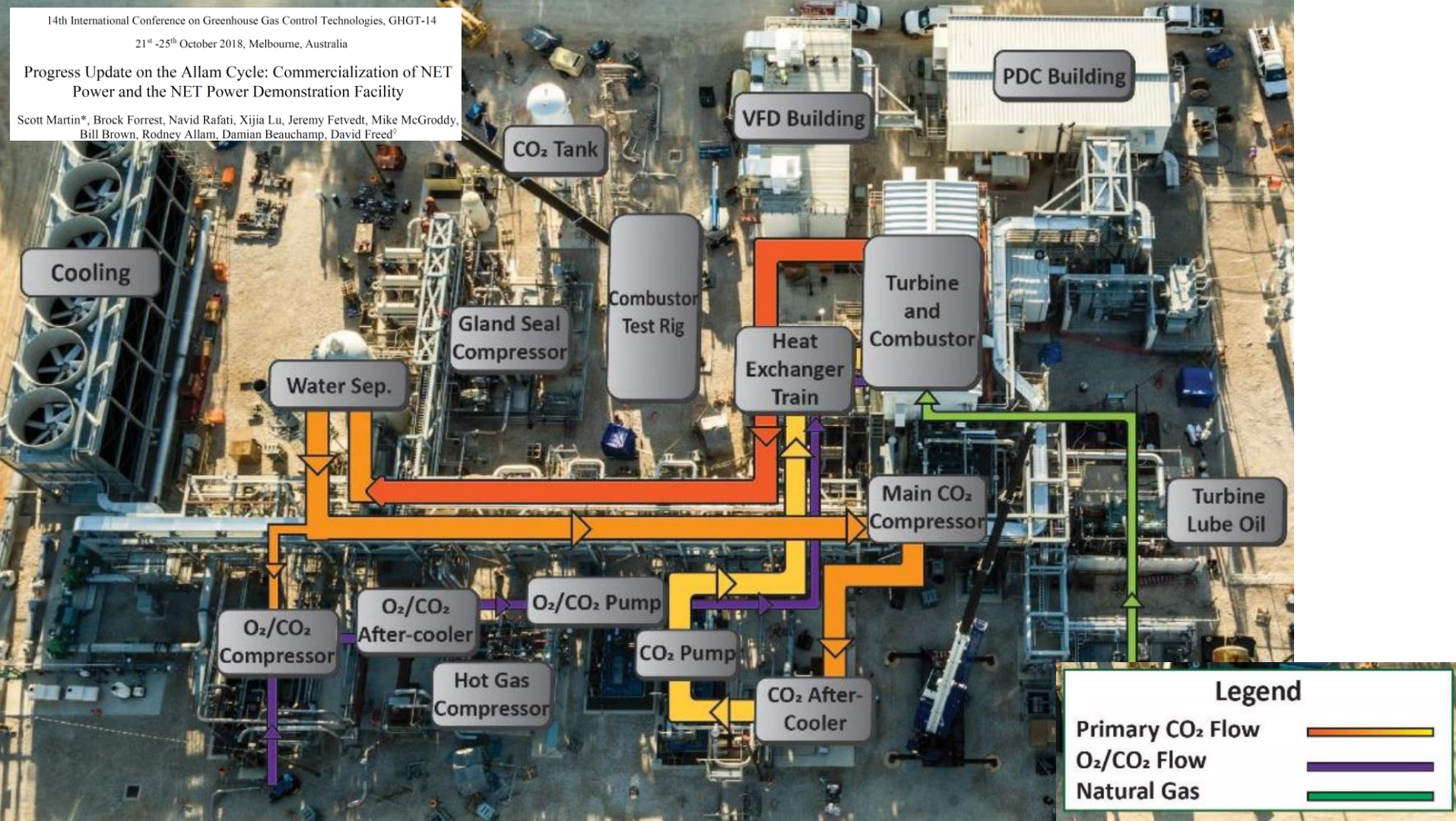
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- 1) CCS can help to decarbonise thermal power generation from fossil fuels: natural gas, petcoke, Vac Res and Coal
- 2) Post-combustion CO<sub>2</sub> capture is the simplest retrofit option to existing power plants
- 3) Amine wash is the dominant CO<sub>2</sub> capture technology, but many other carbon capture technologies are emerging and will challenge its dominance
- 4) IGCC with CO<sub>2</sub> capture can be more cost-effective than post-combustion CO<sub>2</sub> capture for new-build thermal power generation
- 5) Oxygen-fed gasification for IGCC can further reduce the cost of CO<sub>2</sub> capture by increasing CO<sub>2</sub> concentration in the flue gas
- 6) Advanced thermal cycles, also with oxy-fuel combustion, such as the Allam Cycle are likely to be cost-effective clean technologies for thermal powergeneration from both natural gas and coal
- 7) CCS scheme infrastructure for CO<sub>2</sub> transmission and utilisation or sequestration (eg with underground injection) is a critical enabler for all of the above

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### Progress Update on the Allam Cycle: Commercialization of NET Power and the NET Power Demonstration Facility

Scott Martin\*, Brock Forrest, Navid Rafati, Xijia Lu, Jeremy Fetvedt, Mike McGroddy, Bill Brown, Rodney Allam, Damian Beauchamp, David Freed\*



# RIL – proposal to capture and utilise CO<sub>2</sub> from coal and petcoke gasification

## Repurpose Gasification Assets - CO<sub>2</sub> as an Asset



1. Hydrogen production from gasification provides highly concentrated CO<sub>2</sub> stream which provides unique opportunity to capture ~15 MMTPA of CO<sub>2</sub> at 30% of typical cost of carbon capture.
2. CO<sub>2</sub> can be monetized with application in following products / end-uses -
  - ✓ Urea production - using green ammonia (nitrogen from ASU + green hydrogen)
  - ✓ E-products, and fuels - using green hydrogen, facilitating circular carbon economy
  - ✓ Synthetic Aviation Fuel
  - ✓ Construction mineralization, Dry Ice
  - ✓ Algal oil, super proteins made through synthetic biology pathways
3. Biomass based gasification, coupled with CO<sub>2</sub> capture can potentially lead to significant cut in emissions

CO<sub>2</sub> as a product can be captured at much lower cost to sell as feedstock for chemicals production

# Coal gasification for “coal to liquids” via syngas. Lu’an, Shanxi province, China.



# 4x Giga-scale oxygen plants, each 2,500 tonnes per day O<sub>2</sub> for coal gasification – Lu'an CTL, China



# Introduction to Stephen B. Harrison

**Stephen B. Harrison** is the founder and managing director at sbh4 GmbH in Germany. His work focuses on decarbonisation and greenhouse gas emissions reduction. Hydrogen and CCS are fundamental pillars of his consulting practice. He has also served as the international hydrogen and CCS expert for multiple ADB projects in Pakistan, Palau and Viet Nam.

Stephen's background is in industrial and specialty gases, including 27 years at BOC Gases, The BOC Group and Linde Gas. For 14 years, he was a global business leader in these FTSE100 and DAX30 companies.

Stephen has extensive buy-side and sell-side M&A due diligence and investment advisory experience in the clean-tech sector. Private Equity firms, investment fund managers and hydrogen start-ups are regular clients.

As a member of the H2 View and **gasworld** editorial advisory boards, Stephen advises the direction for the leading hydrogen and CO<sub>2</sub> focused international publications. He is also on the Technical Committee for the Green Hydrogen Summit in Oman in December 2022, CEM 2023 in Barcelona and on the Advisory Board of the International Power Summit in Munich in September 2022.

