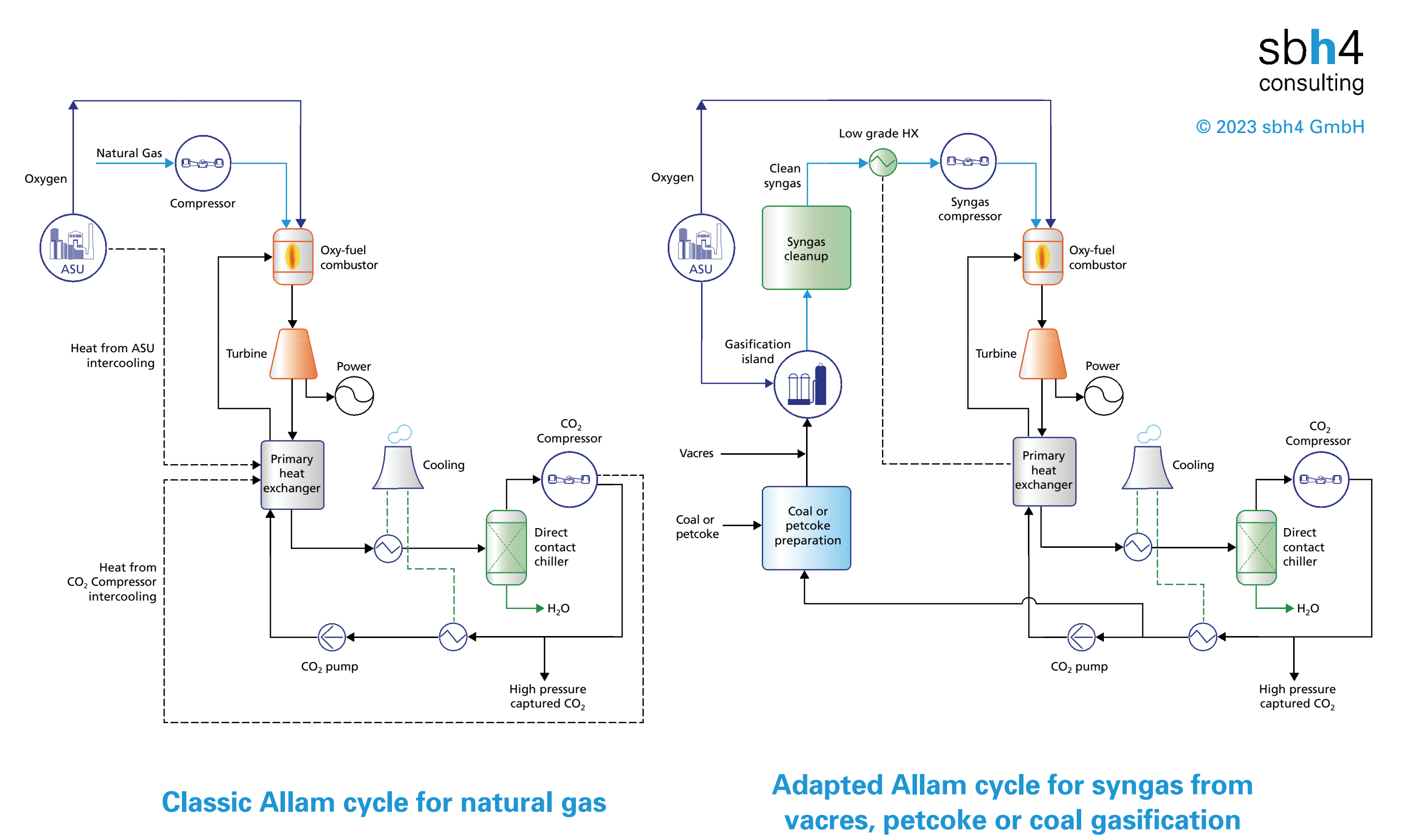
Oxy-fuel combustion for CO2 capture from thermal power generation

With the Allam-Fetvedt cycle CO2 capture is integrated into the process, providing a pure high pressure CO2 stream at high efficiency. By Stephen B. Harrison, sbh4 consulting.

The Allam cycle for natural gas or coal: oxy-fuel thermal power generation with integrated CO_2 capture



Affordable, clean power is essential to drive sustainable economic development and prosperity. Renewables such as wind, solar, hydro, and tidal power will be integral in the energy mix, as will nuclear power generation.

Alongside those, the Allam-Fetvedt cycle can offer thermal power generation with zero CO2 emissions to air. Thermal power generation can thereby continue to contribute to the baseload capacity and compliment intermittent and variable renewable sources.

The Allam-Fetvedt cycle relies on oxy-fuel combustion which ensures that pollutant emissions are avoided and carbon dioxide from hydrocarbon combustion can easily be captured. It offers high-efficiency power generation from traditional fossil fuels in an innovative process that avoids greenhouse gas emissions, allowing coal and natural gas to contribute to a cost-effective, net-zero future.

Oxy-fuel combustion of natural gas enables CO2 capture

In the case of oxy-fuel combustion of methane, the main products are carbon dioxide (CO2) and water vapour. These can be separated simply by cooling the flue gas to condense the water vapour. The resultant CO2 can be liquefied or compressed and the transported from the site for utilisation or sequestration.

In the Allam-Fetvedt cycle, efficient heat exchange is essential to achieve a high process efficiency. In the cycle, the burner feed gases are pre-heated by the exhaust gases. The equipment used for heat recovery is a printed circuit heat exchanger. This is a mature technology that has been used at scale in the oil gas sector for decades. Its compact nature has made it popular for offshore deployment on rigs where space is at a premium.

The Allam-Fetvedt cycle leverages oxy-fuel combustion and takes the process further. It simultaneously produces high-pressure CO2 for sequestration and very high energy efficiency within the power generation cycle. CO2 from the Allam-Fedvedt cycle can either be directly liquefied or introduced into a CO2 pipeline without the need for additional mechanical compression energy to be expended.

Avoiding the pollution from air-fed combustion

In air-fed power generation using coal-fired burners, flue gas treatment is highly complex. A typical coal fired power plant will have filtration or electrostatic precipitation equipment to knock down dust and ash particles. It will also be fitted with flue gas desulphurisation where lime is reacted with sulphur dioxide to form gypsum. Then there is likely to be a DeNOx process based on selective catalytic or non-catalytic reduction of oxides of nitrogen (NOx) emissions to inert nitrogen gas. Mercury removal on activated carbon filters may also be required.

Finally, to reduce CO2 emissions, post-combustion carbon capture will need to be implemented from the coal fired power plant. Since air is used to introduce oxygen for combustion, a huge volume of nitrogen gas is also flowing through the power plant furnace the is contained in the flue gas. Picking out the CO2 molecules from the steam of nitrogen is very energy intensive and since the gas is at low pressure, the size of the equipment is extremely large.

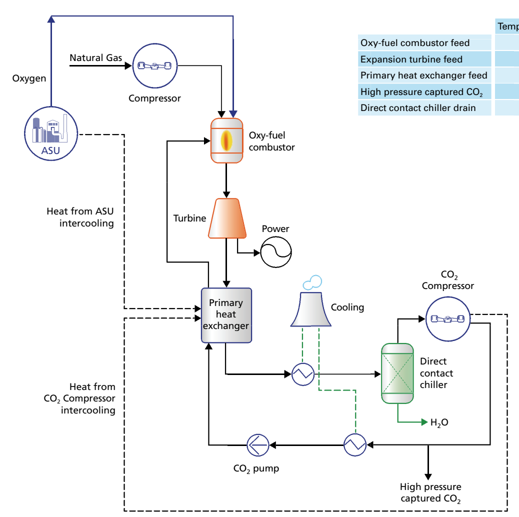
Integrated CO2 capture

CO2 capture is often divided into pre-combustion and post-combustion processes. Precombustion CO2 capture is possible on steam methane reformers within the process. It can take place at high pressure and high CO2 concentrations, reducing the capital and operating costs of decarbonisation.

Post combustion CO2 capture generally takes place at the end of a process where the gas stream is very low pressure, and the CO2 is often diluted with nitrogen from combustion air. Uniquely, the Allam-Fetvedt cycle enables low-cost post-combustion CO2 capture.

A steady flow of CO2 is recycled within the cycle as the thermodynamic working fluid. But, during combustion of the syngas or natural gas feedstock additional CO2 is generated. This is released from the cycle at about 80 bar. There is no other route out of the process for the CO2, so the capture rate is 100%.

The Allam cycle for natural gas: oxy-fuel thermal power generation with integrated CO_2 capture



			Stream composition, referenced to combustor feed			
	Temperature °C	Pressure bar	CO_2 wt%	Natural gas wt%	Oxygen wt%	H_2O wt%
Oxy-fuel combustor feed	700	300	94	1,25	4,75	0
Expansion turbine feed	1150	300	97,25	0	0	2,75
Primary heat exchanger feed	720	30	97,25	0	0	2,75
High pressure captured CO_2	60	80	100	0	0	0
Direct contact chiller drain	20	30	0	0	0	100

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CO2 as a power system working fluid

The US DOE-funded STEP demonstration project which has been executed by GE and GTI uses a closed cycle with supercritical al CO2 as the working fluid. The Italian startup Energy Dome uses sub-critical CO2 in a closed cycle in their CO2 battery, a technology aligned to long duration energy storage.

Beyond its use in modern power systems, CO2 is a versatile molecule. Its thermodynamic properties also mean it is ideal as the working gas in closed loop refrigeration cycles.

Conventional coal-fired power generation heats up steam, which is the working fluid within the power generation turbines. In conventional air-fed, gas-fired turbines, the nitrogen-rich combustion gases themselves drive the generator.

In the Allam-Fetvedt cycle, combustion gases are also used to spin the main turbine. However, in this case, a mixture of approximately 97.3% CO2 and 2.7% water vapour flows through the turbine.

The main turbine for the Allam-Fetvedt cycle was developed by Toshiba. The temperature and pressure mean that the CO2 is supercritical at the turbine inlet. And the presence of moisture means that carbonic acid formation is possible. Materials selection and coating technologies are the key to successful turbine production in this operating environment.

Syngas as an alternative gaseous fuel

Air separation is required to produce oxygen used in the Allam-Fetvedt cycle oxy-fuel burner. The use of oxygen, rather than air, as the oxidant source in gasification has significant cost and environmental benefits. Similarly, oxy-fuel gasification is a clean means of producing syngas, which is also a viable fuel for the Allam-Fetvedt cycle.

Coal, petcoke or vacres gasifiers can be operated at pressure. This enables cost effective pre-combustion CO2 capture. Similarly, when syngas is produced from natural gas through gasification (known as partial oxidation, or POx) the process can operate at up to 80 bar, meaning the CO2 capture equipment can be compact and CO2 is produced at high pressure, enabling efficient transportation off-site.

The release of CO2 at high pressure from gasification contrasts to post-combustion CO2 capture from conventional thermal power generation, where the CO2 capture equipment operates at close to atmospheric pressure. From these low pressures, CO2 must be compressed or liquefied to be moved to a storage or utilisation location. CO2 compression consumes parasitic power from the power generation process, resulting in a lower overall efficiency.

More information

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