The Allam-Fetvedt Cycle

Low-carbon power generation with oxyfuel combustion

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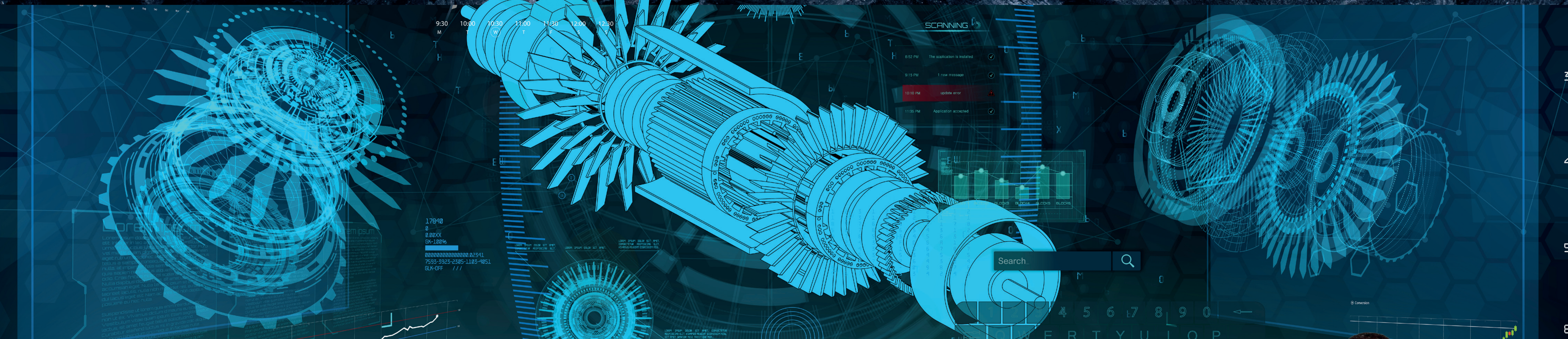

Affordable, clean power is essential to drive sustainable economic development and prosperity. Renewables such as wind, solar, hydro, and tidal power will be integral in the energy mix, as will nuclear power generation. In addition, the Allam-Fetvedt cycle can enable the use of coal and natural gas or LNG to contribute to a climate-friendly, Net Zero future.

It offers high-efficiency power generation from traditional fossil fuels in an innovative process that avoids greenhouse gas emissions. It is independent of weather conditions and can complement variable and intermittent modes of power generation.

With its roots in industrial gases, the cycle's main inventor is a former Air Products engineer. Furthermore, the process relies on oxy-fuel combustion to ensure that pollutant emissions area voided and carbon dioxide (CO_2) from hydrocarbon combustion can easily be captured.

Clean oxyfuel 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 desulfurisation where lime is reacted with sulfur 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 CO_2 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 CO_2 molecules from the stream of nitrogen is very energy intensive and since the gas is at low pressure, the size of the equipment is extremely large.

In the case of oxyfuel combustion of methane, the main products are carbon dioxide (CO_2) and water vapour. These can be separated simply by cooling the flue gas to condense the water vapour. The resultant CO_2 can be liquefied or compressed and the transported from the site for utilisation of sequestration.

"The Allam-Fetvedt cycle leverages all the above benefits of classical oxyfuel combustion and takes the process further," says Steve Milward, Senior Vice-President of Engineering and Operations at 8 Rivers in Durham, North Carolina. "It simultaneously produces high pressure CO_2 for sequestration and very high energy efficiency within the power generation cycle."

Milward adds that "at 8 Rivers, we develop and deploy sustainable infrastructure-scale solutions that will contribute to a Net Zero future. The Allam-Fetvedt cycle can either be fed with natural gas or syngas from a gasification process. 8 Rivers is the exclusive licensor of the technology for syngas-fed applications."


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Air separation and gasification

Air separation is required to produce oxygen used in the Allam-Fetvedt cycle oxyfuel burner. The use of oxygen, rather than air, as the oxidant source in gasification has significant cost and environmental benefits. "Oxy-fuel combustion is well known for its simplicity and emission reduction potential," says Milward. "We could equally refer to oxyfuel gasification as a

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clean means of producing syngas."

CO_2 from the Allam-Fetvedt cycle is captured at high pressure, enabling ease of sequestration or liquefaction. Coal, petcoke or vacres gasifiers can also be operated at pressure. This enables cost-effective pre-combustion CO_2 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 CO_2 capture equipment can be compact and CO_2 is produced at high pressure, enabling efficient transportation off-site.

Some of the world's largest ASU schemes have been associated with gasification and POx to generate syngas. As an example, vacres gasification at Aramco's Jazan refinery is fed with oxygen from six Air Products ASUs, each one rated at 3,000 tonnes per day (tpd). At Shell's Bintulu Gas-to-Liquids plant in Malaysia, it is a mega-scale ASU from Air Liquide that produces 3,200 tpd of oxygen for the POx unit. In India, Reliance operates coal and petcoke gasifiers fed with oxygen from five Linde ASUs, each rated at 5,250 tpd of oxygen.

Another link between the Allam-Fetvedt cycle and industrial gases is the critical importance of heat exchange to process efficiency. In an air separation unit, the incoming air is cooled using the outgoing gases in the main heat exchanger. To deal with the cryogenic temperatures inherent in the process, this will be a brazed aluminium heat exchanger.

In the Allam-Fetvedt cycle, the burner feed gases are pre-heated by the exhaust gases. "The equipment used for heat recovery is referred to as a printed circuit heat exchanger, or PCHE," adds Milward. This is a highly 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.

CO_2 as a thermodynamic working fluid

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, which are commonly fed with revaporised LNG, 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 97% CO_2 and 3% water vapour flows through the turbine.

The temperature and pressure mean that the CO_2 is supercritical at the turbine inlet. And the presence of moisture means that carbonic acid formation is possible. Milward continues to say that "materials selection and coating technologies are the key to successful turbine production in this operating environment."

"CO_2 is a fascinating molecule," he declares. "Its thermodynamic properties mean it is ideal as the working gas in closed loop refrigeration cycles and it is seeing increasing application as the working fluid for power generation."

Reducing Asia's reliance on LNG imports

Australia, the US and the Middle East are major LNG exporters. The alignment of LNG trade from these producers to markets in Asia had stabilised in the first two decades of this millennium. However, as Russian pipeline gas supplies to Europe dwindled in 2022, large, industrialised nations such as Germany ramped up their LNG imports. The resulting LNG price spike in Q2 and Q3 of 2022 led to unaffordable energy prices in countries such as Pakistan, which is dependent on imported LNG for power generation.

Use of indigenous fuels such as India's bagasse post-harvest crop waste and Indonesia's abundant coal reserves can mitigate the reliance on LNG imports. Gasification of these solid feedstocks to generate syngas to feed to the Allam-Fetvedt cycle will be a cost-effective way to generate power. And, since CO_2 emissions from the gasifier and the Allam-Fetvedt cycle can readily be captured, the use of these fuels can be climate-friendly.

Milward says that "bagasse is a waste material generated during sugar cane processing. It grows on an annual cycle which means that when combined with CO_2 capture and storage, it is carbon-negative within

12-months." CO_2 capture and storage (CCS) from bioenergy generation using slower growing woodchips, known as BECCS, is also carbon-negative over a longer timescale.

"In Europe and North America, we have experienced industrialisation and the prosperity it has brought for many decades. Nations in Asia are seeking to achieve similar results and simultaneously develop a Net Zero economy. 8 Rivers is convinced that the Allam-Fetvedt cycle can support the achievement of those goals in parallel."

Ready for CCUS

CO_2 capture is often divided into pre-combustion and post-combustion processes. Pre-combustion CO_2 capture is possible on steam methane reformers within the process. It can take place at high pressure and high CO_2 concentrations, reducing the capital and operating costs of decarbonisation.

Post-combustion CO_2 capture generally takes place at the end of a process where the gas stream is very low pressure, and the CO_2 is often diluted with nitrogen from combustion air. "Uniquely, the Allam-Fetvedt cycle enables low-cost post-combustion CO_2 capture," declares Milward.

A steady flow of CO_2 is recycled within the cycle as the thermodynamic working fluid. But, during combustion of the syngas or natural gas feedstock additional CO_2 is generated. This is released from the cycle at about 80 bar. CO_2 from the Allam-Fetvedt cycle can either be directly liquefied or introduced into a CO_2 pipeline without the need for additional mechanical compression energy to be expended.

"There is no other route out of the process for the CO_2, other than through seals of rotating equipment, so the capture rate is close to 100%," states Milward. "We are not aware of any other combustion-based power generation process that can achieve zero carbon emissions to air."

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