Issue Brief

Meeting the Goals of the Virginia Clean Economy Act Using Carbon Capture

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Introduction

To reduce emissions of carbon dioxide (CO_2) to the atmosphere, the Virginia Clean Economy Act (VCEA), enacted as identical bills *SB 851* (McClellan, 2020) and *HB 1526* (Sullivan, 2020), directs the State Air Pollution Control Board to adopt regulations to reduce carbon dioxide emissions from electric generating units for the period of 2031 to 2050, with a goal of 100 percent carbon-free electric generation by 2045. In recent years, alternative CO_2 reduction methods known as carbon capture have emerged that can accelerate achieving the VCEA carbon-reduction goals. Carbon capture technologies capture CO_2 emitted during industrial processes rather than releasing the CO_2 into the atmosphere. Such CO_2 can then be reused for power generation as a renewable resource or sold as a usable commodity to other industries.

This issue brief (1) defines and identifies established and emerging carbon capture technologies through the first three sections, followed by a (2) summary of the broad uses and applications of carbon capture. The final sections will provide a (3) summary of carbon capture technology developments in other states and globally, as well as a (4) brief summary of Virginia's carbon capture history, followed by a (5) cost comparison table of the three main carbon capture technologies that are currently available for use.

Definitions

For the purposes of this issue brief, the following definitions are provided; these terms prioritize utility rather than scientific accuracy.

"Carbon dioxide," "carbon," or "CO_2" is the predominant greenhouse gas that is emitted into the air from the burning of carbon-rich substances such as wood, coal, oil, gasoline, or natural gas, causing a greenhouse effect that warms the Earth.

"Greenhouse effect" means the accumulation of greenhouse gases such as carbon dioxide and methane in the atmosphere, trapping heat from the sun in the same way that glass traps heat in a greenhouse or as a windshield traps heat in a car on a sunny day.

"Renewable energy" in the VCEA is refered to as energy derived from wind and solar. However, the *Oxford Languages* defines "renewable energy" as a source that can be renewed: "a source that is not depleted when used". This issue brief uses the *Oxford* definition of "renewable energy."

"Carbon capture" means the process of capturing carbon dioxide emissions to prevent additional carbon dioxide accumulation in the atmosphere. This brief focuses on "carbon capture" processes using technological and man-made carbon capture methods such as retrofitting a facility to filter out carbon dioxide from smokestack emissions, rather than natural methods such as a tree taking in carbon dioxide.

Background

Climate change is caused by the emission of carbon dioxide (CO_2) and other greenhouse gases that primarily come from fossil fuel burning during power generation, transportation, as well as emissions from animal agriculture, and concrete. Fossil fuels continue to occupy 80 percent of U.S. energy needs. The resulting greenhouse gases form a heat-trapping layer in the atmosphere, somewhat like a car's windshield on a hot day, heating the entire planet. To help reduce carbon dioxide emissions to the atmosphere, there has been increased emphasis on:

- Energy efficiency, for *reduced* CO_2 emissions, including:
  - LED lightbulbs
  - Energy Star certified appliances
- Renewable energy, for *zero* CO_2 emissions, including:
  - Wind
  - Solar
- Carbon capture, for *reduced* or *zero* CO_2 emissions

The two main categories of carbon capture are (1) natural, and (2) technological. Natural methods of carbon capture, which are being evaluated by the Carbon Sequestration Task Force established in *SB 1374* (Lewis, 2021 Special Session I), include regenerative agriculture, improved forestry, wetland management, and protecting coastal marshes. The Task Force is due to issue its report by the first day of the 2022 Session. Technological methods of carbon capture, the focus of this brief, include three established types (1) pre-combustion carbon capture, (2) post-combustion carbon capture, and (3) direct air capture (DAC). Recently, a fourth type of higher efficiency carbon capture called the Allam-Fetvedt Cycle has emerged that can be categorized as a *zero*-emission technology, and potentially a *negative*-emission technology.

As shown in Figure 1, there are two main categories of CO_2 reduction solutions, (1) Renewables, and (2) Carbon Capture. Each of these categories represent various methods and technologies. Renewables generally refer to methods of generating energy that produce *zero* emissions. Carbon capture methods can either be (1) natural, or (2) technological.

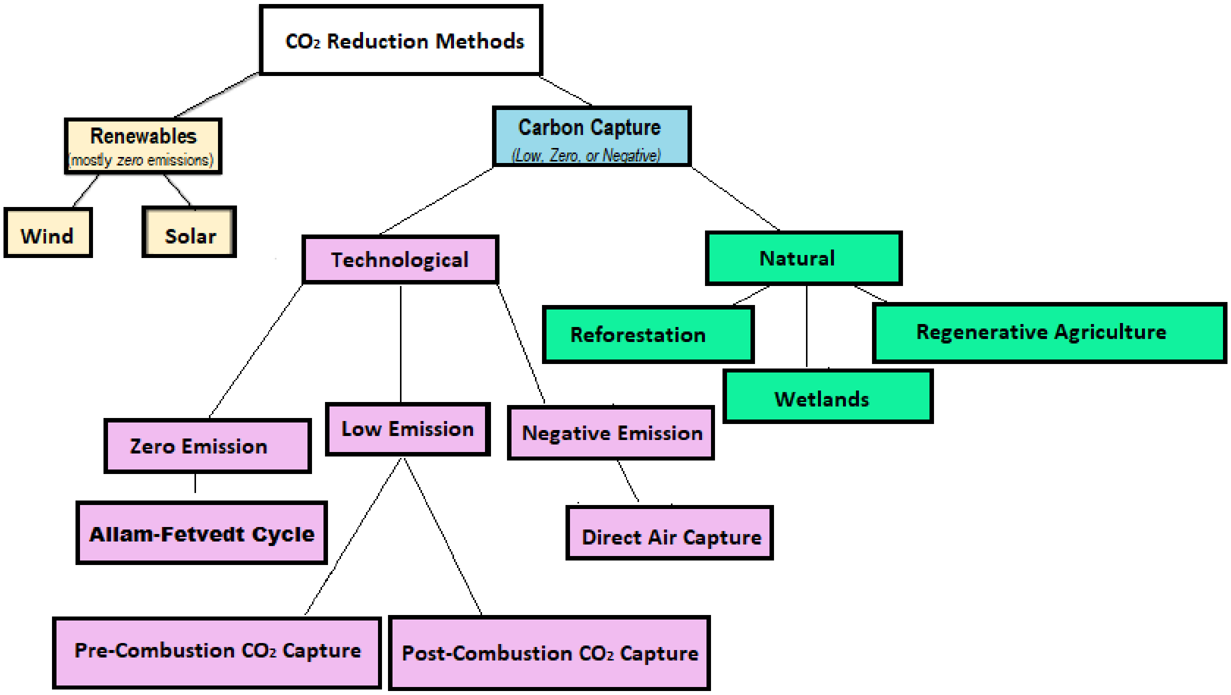

Figure 1: Chart displays two distinct categories of CO_2 reduction solutions: renewables and carbon capture. Each category is further broken down into various methods and technologies.

Technological carbon capture solutions offer three main types of carbon reduction: the solutions can either produce *low* carbon emissions, *zero* carbon emissions, or *negative* carbon emissions.

Low carbon emission solutions are those that reduce the level of CO_2 emissions that are released to the atmosphere. *Zero* carbon emission solutions are those that prevent all CO_2 emissions from reaching the atmosphere. *Negative* carbon emission solutions are those that actively remove CO_2 from the atmosphere.

This issue brief focuses on carbon capture technologies. The next section expands on these three types of carbon capture technologies.

Types of Carbon Capture Technologies

Low Carbon Emission Options

- Pre-combustion carbon capture reduces the amount of CO_2 emissions that reach the atmosphere by separating CO_2 from fuel gases *before* the fuel gas is burned to generate electricity. During pre-combustion carbon capture, the gas is passed through substances that selectively "pull out" the CO_2 before it is finally burned. This way the final burned gases that are emitted to the atmosphere contain less CO_2 than they otherwise would have. Pre-combustion carbon capture is cheaper and more efficient than post-combustion carbon capture.

- Post-combustion carbon capture also reduces the amount of CO_2 emissions that reach the atmosphere but does so by separating the CO_2 from the exhaust *after* fossil fuels are burned. When a fossil fuel, such as coal or natural gas, is burned to generate electricity, exhaust is produced. This exhaust contains CO_2. Post-combustion carbon capture is a process that "pulls out" CO_2 from the exhaust after fossil fuels have been burned so that less CO_2 reaches the atmosphere. However, post-combustion carbon capture is less efficient, more energy intensive, and more costly than pre-combustion carbon capture.

Zero Carbon Emission Options

- The Allam-Fetvedt Cycle produces zero carbon emissions by functioning both as a *renewable* and as a *carbon capture* technology. The purpose of carbon capture technologies is to reduce the amount of carbon dioxide (CO_2) emissions to the atmosphere. Most carbon capture technologies do this by either absorbing CO_2 from the atmosphere (like direct air capture) or filtering out some of the CO_2 before it reaches the atmosphere (like pre- and post-combustion carbon capture). However, the Allam-Fetvedt Cycle does both.

  While pre- and post-combustion carbon capture generate electricity by burning fossil fuels and emitting some CO_2, the Allam-Fetvedt Cycle traps all of the CO_2 that is created from burning minimal amounts of natural gas. This trapped CO_2 is then used as a renewable resource by circulating through closed pipes to generate electricity, similar to the way the flow of water through turbines generates electricity. Therefore, rather than emitting CO_2 as an environmentally harmful waste product, the Allam-Fetvedt Cycle makes use of the CO_2 in a closed loop to cycle within its pipes.[1] This trapped CO_2 can then be used, reused, stored underground, or sold as a marketable commodity to offset the costs of the electricity production. Thus this process provides a valuable use of CO_2 before, during, and after the electricity has been generated,which creates the potential for a circular carbon economy for energy independence.

Negative Carbon Emission Options

- Direct air capture (DAC) facilities are designed exclusively to pull CO_2 from the air, resulting in negative carbon emissions. The resulting captured CO_2 can be sold for industrial purposes or stored in geologic storage sites underground.

Status of Carbon Capture Use

The purpose of carbon capture technologies is to reduce CO_2 emissions to the atmosphere from the burning of fossil fuels. Fossil fuels continue to be used primarily during power generation, transportation, while animal agriculture, and concrete also produce substantial CO_2 emissions. Carbon capture technologies may offer transitional reduced-carbon energy options to reduce the emissions of these industries while traditional renewable energies, such as wind, solar, and battery storage, continue to improve in reliability, affordability, and accessibility.

Operational carbon capture facilities across the globe have resulted in 340 million tons of CO_2 captured to date. The United States currently averages 33 million tons of captured CO_2 annually. However, global carbon emission rates average over 40 billion tons per year.

[1] "Award-Winning Breakthrough Technology." NET Power. 2021. https://netpower.com/technology/.

Therefore, in order to close the gap with current carbon emission rates, the rates of carbon capture (using natural and technological methods) would need to increase by over 1000-fold.[2]

Among current carbon capture options, the Allam-Fetvedt Cycle stands out for being capable of serving both as a *renewable energy* and *carbon capture* method, by first capturing carbon and then using it as renewable resource. While the Allam-Fetvedt Cycle is currently a *zero* carbon emission technology by burning natural gas and capturing all of the resulting CO_2, it is also capable of being modified to be a *negative* carbon emission technology by using CO_2 from a DAC facility (that absorbs CO_2 directly from the atmosphere). Therefore, if future natural gas sources were to be limited, the Allam-Fetvedt Cycle could continue to produce electricity as a *negative* carbon emission method.

Carbon Capture in Virginia

The only identified activity related to carbon capture in Virginia is a case that was brought by Appalachian Power Company to the State Corporation Commission on July 7, 2007.[3] In this case, Applachian Power Company sought a rate adjustment to its customers' energy bills to accommodate the added cost of a pre-combustion carbon capture facility. The timing of this case was in response to the Virginia law[4] requiring the State Corporation Commission to review and determine appropriate adjustments to rates of electrical generation and distribution based on changes to circumstances, including the plants' energy generation efficiency. The final order, issued on May 29, 2008, denied Appalachian Power Company's request for a rate adjustment.

Carbon Capture in Other States

The information available about carbon capture development in the United States is sparse. With greater focus on renewable sources, such as wind and solar, there exists less tracking and documentation on carbon capture. At this time, one known reliable source, the Global CCS Institute, tracks the development of carbon capture facilities throughout the world, including the United States, in an annual report.

The Global CCS Institute's 2020 report on carbon capture and storage (CCS) indicates that there has been strong growth in operational commercial carbon capture facilities around the globe over the past three years. As of 2021, there are 65 carbon capture facilities worldwide at various stages of development, of which 26 are operational. The United States claims 38 of the world's carbon capture facilities.[5] Geographic clustering of facilities, known as "hubs," allows for CO_2 transport and storage pipelines that significantly reduce the unit cost of storing the captured CO_2. In the United States there are currently four main hubs in the Midwest, South, and Northeastern regions.

The largest and longest running post-combustion carbon capture facility in the United States was Petra Nova in Texas. Petra Nova was also the only carbon capture *coal* plant in the country. However, due to the high cost of the less efficient post-combustion carbon capture process, Petra Nova was shuttered in early 2021, highlighting the need for more efficient technologies.

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[2] "Global Status of CSS Report 2020." Global CCS Institute. December 4, 2019. https://www.globalccsinstitute.com/resources/global-status-report.
[3] State Corporation Commission, PUE-2007-00068.
[4] VA. CODE § 56-585.1 (A)(6).
[5] "Global Status of CSS Report 2020."

The Allam-Fetvedt Cycle is showing promise as a cheaper and zero-emission method of energy production. The Allam-Fetvedt Cycle was first validated at large scale in a facility in La Porte, Texas.

Carbon Capture Cost Comparison

The costs of the three different carbon capture technologies that are shown in Table 1 are not well publicized. This may be due to the protected or proprietary nature of the operational details and costs of these technologies. Therefore, there are limited sources for corroborating the data listed in Table 1.[6,7,8]

Carbon Capture	Methods	Cost
Technological	Pre-combustion carbon capture	6.1 cents/kWh
	Post-combustion carbon capture	6.2 cents/ kWh
	Allam-Fetvedt Cycle	1.9 cents/ kWh

Table 1: Energy cost comparison of carbon capture technologies in cents per kilowatt hour (kWh)

Conclusion

To reduce emissions of carbon dioxide (CO_2) to the atmosphere and meet the goal of the General Assembly of Virginia as provided in the Virginia Clean Economy Act (VCEA) of 100 percent carbon-free electric generation by 2045, multiple approaches are needed. In recent years, alternative CO_2 reduction methods known as carbon capture have emerged that can accelerate achieving the VCEA carbon-reduction goals. Carbon capture technologies capture CO_2 emitted during industrial processes rather than releasing the CO_2 into the atmosphere. Such CO_2 can then be reused for power generation as a renewable resource or sold as a usable commodity to other industries.

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[6] Di Lorenzo, Giuseppina. "*Pre-combustion carbon-capture technologies for power generation: an engineering-economic assessment*." *International Journal of Energy Research*. March 11, 2013. Wiley Online Library, p. 1.
[7] "*Improvement in Power Generation with Post-Combustion Capture of CO2*." ieaghg.org, p. 4.
[8] Conca, James. "*Net Zero Natural Gas Plant -- The Game Changer*." July 31, 2019. Forbes.com.

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