THE CURRENT STATE OF CCS IN THE U.S – RÉSUMÉ AFTER 100 YEARS OF CO2 CAPTURE AND 25 YEARS OF EXTENSIVE FEDERAL FUNDING

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By Anja Chalmin

In the United States, CO_2 has been captured for more than 100 years and CO_2 capture combined with "storage" has been heavily funded by the US-DOE for 25 years. CCS (Carbon Capture and Storage) refers to the capture of CO_2 emissions from power plants or other industrial sources using a sorbent. The captured CO_2 is compressed and transported to locations where it is injected underground, e.g., into old oil and gas reservoirs or saline aquifers. CO_2 capture was invented to make natural gas marketable and increase profits. Since the 1970s, the former waste product CO_2 has become a way to extract larger oil and natural gas volumes, and today, thanks to new, extensive public subsidies, CO_2 capture has become a potential source of additional income for fossil fuel-driven industries in the United States.

Despite its long history, CO_2 capture technology is still in its infancy. Instead of prices falling and efficiency increasing, CCS is struggling with high costs, among other problems. Currently, the proportion of CO_2 captured is only a fraction of the emissions generated at CCS sites, the actual capture capacity at some sites is less than 50 percent of the nominal capacity, and the number of cancelled projects is very high. In addition to the high costs, the technology is also characterised by high energy consumption.

The high demand of energy is not the only reason why CCS is no solution to climate change. Theoretically, the captured CO_2 is supposed to be stored in geological formations for the long term, but the CO_2 could escape for a variety of reasons, including leaks, faulty constructions and movement underground. Also, CCS only captures CO_2 at one production step and often only a very small fraction – but not at upstream and downstream production steps, such as fossil fuel extraction and transport. In addition, a large part of the captured CO_2 is used to squeeze more fossil fuels out of mature deposits – and every additional litre of fossil oil or gas extracted causes additional climate-relevant emissions.

It is also questionable whether the transport structures of compressed CO_2 can be considered safe. Typically companies plan to use structures similar to those used to transport fossil fuels for transporting CO_2, and accidents regularly occur with these, e.g., the U.S. National Oceanic and Atmospheric Administration recorded a total of 137 known oil spills in the U.S. in 2018. However, since CO_2 is invisible and odourless, escaping gas is much more difficult to detect and at high concentrations can be deadly for humans and animals.

The fossil fuel industry is trying to give the impression of that it is using CCS to combat climate change – in reality, it is using CCS to extend the life of its fossil fuel extraction sites, significantly boost extraction rates and increase profits. After decades of research, there is no evidence that CCS can address the causes of the climate crisis or significantly reduce greenhouse gas emissions – the opposite is true. There are no benefits to society at regional or supra-regional level, only costs and risks.

RETROSPECTIVE OF 100 YEARS OF CO_2 CAPTURE IN THE USA

CO_2 capture has been promoted by the U.S. Department of Energy (US-DOE) for a quarter of a century through extensive research and development programs and subsidies. CO_2 capture has been used in natural gas production since the 1920s to make natural gas marketable. The marketable fraction of natural gas is methane, but many natural gas deposits contain a high proportion of CO_2. The CO_2 capture technology was developed and used to separate CO_2, which was not marketable at the time, from the saleable methane gas and thus make the natural gas suitable for sale.

Since the 1970s, captured CO_2 has been harnessed by compressing it, piping it from natural gas processing plants to oil or gas reservoirs and pumping it into the reservoirs to boost oil or gas production. In this way, remaining reserves from aging oil and gas fields can be tapped and otherwise inaccessible fossil fuels extracted. This process is now known as Enhanced Oil Recovery (EOR) or Enhanced Gas Recovery (EGR) and, according to the International Energy Agency, "*has proven very successful and millions of tonnes of CO_2 – both from natural accumulations of CO_2 in underground rocks and captured from industrial facilities – are now piped to and injected into oil fields in the USA and elsewhere every year*". With the invention of EOR, the fossil fuel industry was able to use the captured CO_2 profitably for the first time and produce more oil, instead of venting captured CO_2 as an unwanted waste product, at least as long as the price of oil was high enough to cover the cost of CO_2-EOR.

The world's oldest CO_2-EOR projects are in the U.S.: the Terrell gas processing plant in Texas, Koch Nitrogen's Enid fertilizer plant in Oklahoma and the Shute Creek gas processing plant in Wyoming. The CCS project at the Terrell natural gas processing plant has been in operation the longest. Here, CO_2 capture technology has been used since 1972 because the natural gas extracted has a CO_2 content of 18 – 53 percent and would not be marketable without this additional processing step. The captured CO_2 is piped through several hundred kilometers of CO_2 pipelines to mature oil fields for use in EOR. The Enid fertilizer plant uses natural gas as feedstock, and has been capturing CO_2 since 1982 and transports the captured and compressed CO_2 to depleted oil fields for EOR. ExxonMobil's Shute Creek gas processing plant produces natural gas with a methane content of 21 percent and a CO_2 content of 65 percent since 1986. Due to the very high CO_2 content in the natural gas, CO_2 capture was also used in this plant from the beginning. During the past 36 years the captured CO_2 was either sold for EOR or vented.

The Interactive World Map on Geoengineering Research Projects and Experiments, prepared by the Heinrich Böll Foundation and ETC Group, illustrates that the combination of CO_2 capture and EOR is the most common form of CCS to date in the U.S. and globally. The share of ongoing and completed CCS projects with EOR is more than 80 percent in the U.S. today. This means that CCS is predominantly used to extract more fossil fuels. Since the end of the last century, however, the fossil fuel industry has been trying to paint a different picture of CCS, marketing it as "*a vital technology to tackle climate change*" and lobbying for public funding for CCS.

In recent decades, CCS has been heavily financed by public funds in the USA. But this has not reduced CO_2 emissions, it has subsidised and increased them, not only because most CCS projects in the United States are CO_2-EOR projects:

- A high proportion of natural gas production sites have participated in the U.S. CCS funding programmes to date. In many natural gas production projects, it is a technical must to capture CO_2, otherwise the natural gas is not marketable. At such sites, funding for CCS means subsidies for and a prolongation of the lifetime of natural gas sites with high CO_2 content. According to the U.S. Environmental Protection Agency the natural gas industry is the second largest source of methane emissions in the U.S., because methane is the main component of natural gas and emitted to the atmosphere during its extraction, processing, storage, and distribution. These emissions are significant

because over a period of 20 years, methane is 86 times more harmful to the climate than CO_2.

- CCS leads to a substantial increase in emissions, because CO_2 capture, compression, transport and underground injection require significant amounts of energy. Due to the energy-intensive CO_2 capture, a power plant with CCS, for example, burns up to 30 percent more fossil fuels to produce the same amount of energy.
- EOR is not about underground storage of CO_2, it is about tapping additional extraction volumes and the extra oil produced leads to more emissions. The oil industry estimates that about one third of the CO_2 piped to an EOR site is immediately released back into the atmosphere. Moreover, long-term safe storage of injected CO_2 cannot be guaranteed, as CO_2 can escape for a variety of reasons, including leaks, faulty constructions and movement underground. The fossil fuel industry's claim that CO_2-EOR reduces emissions is false. In fact, CO_2-EOR increases emissions, because it extends the life of oil fields and significantly increases the amount of oil and gas produced.
- The US-DOE estimates that with CO_2-EOR it is possible to double the U.S. oil production with EOR. Therefore, subsidies for EOR mean a boost in CO_2 emissions due to the additional fossil fuels extracted and due to the high energy demand of CCS. Boosting oil extraction does not reduce emissions, but increases them.

Although the United Nations, among others, urge that the amount of fossil fuels extracted must decrease to limit global warming to 1.5°C, the US-DOE has been supporting and funding CCS since 1997. A report published in 2019 by the Center for International Environmental Law (CIEL) shows that 85 percent of US subsidies for CCS go to projects with EOR, meaning more climate-damaging fossil fuel is being extracted with public funds. This trend has worsened since the passage of the Inflation Reduction Act in August 2022, which subsidizes CO_2 capture and "storage" with such large amounts of federal funds that it created new revenue opportunities for power plants and other fossil-fuel dependent industries.

NUMBER AND SCALE OF CCS PROJECTS IN THE U.S.– WHAT THE GLOBAL CARBON CAPTURE STORAGE INSTITUTE'S STATUS REPORT DOES NOT SHOW

The Global CCS Institute (GCCSI) is an international organization that works to accelerate the development, demonstration and deployment of carbon capture and storage (CCS). Its members are primarily fossil fuel companies such as Exxon, Chevron or Denbury, manufacturers of CO_2 capture technology such as Carbon Engineering, but also lobby groups and governments, including the U.S. Government. The GCCSI publishes an annual status report of CCS. The Global Status Report of CCS for 2022 lists 83 projects in the U.S., including 13 ongoing and two cancelled projects, two projects under construction and 66 planned projects. This information was tested against the data in the Interactive World Map on Geoengineering Research Projects and Experiments. The world map provides an overview of and insights into existing, planned, completed, and cancelled geoengineering projects, experiments, and research. However, in the absence of complete records of geoengineering projects, this map is necessarily incomplete. Data comparison revealed that the GCCSI statistic omits abandoned projects, glosses over the figures on CO_2 capture capacity, almost half of the planned projects can be attributed to the Midwest Carbon Express, and that among the planned projects there are some for which no final funding decision has yet been made.

1) THE GCCSI STATISTIC EXCLUDES MORE THAN 95 % OF CANCELLED CCS PROJECTS IN THE U.S.

The world map on geoengineering estimates that the number of US-based CCS projects is in the three digits. While the GCCSI statistics show only two cancelled projects, the geoengineering map has documented 35 cancelled projects and more than 20 sites where CCS was explored in small pilot projects and then not pursued further. The difference with the GCCSI statistics is explained by the fact that the GCCSI statistic largely conceals the number of cancelled and completed projects. A selection of the cancelled projects and the reasons for cancellation are outlined below. High costs and financing problems, technical problems and resulting delays are the most frequently cited reasons for abandoning CCS projects.

Kemper County project

In 2008, Southern Company proposed a flagship "clean coal" project in Kemper County, Mississippi. The project aimed to capture CO_2 from a lignite-fired Integrated Gasification Combined Cycle (IGCC) power plant and the captured CO_2 was to be used for EOR. Construction of the power plant began in 2010, commissioning was announced for 2014 and the project was expected to cost US$ 2.4 billion. Ultimately, the project's commercial commissioning date was repeatedly delayed by more than

three years in total, and the cost more than tripled to US$ 7.5 billion. In 2017, the Mississippi Public Service Commission ordered Southern Company to stop construction of the coal gasification project with CCS at Kemper, because it was never operational and costs were skyrocketing. The huge increase in costs was caused by technical problems and failures, including construction problems and design flaws. According to press reports, Southern Company secured nearly one billion dollars in federal grants and tax credits for the Kemper CCS project.

Indiana Gasification project

The Indiana Gasification project was announced in ~2006 and cancelled in 2015. The project planned to capture CO_2 from a coal gasification plant in Spencer County, Indiana and the captured CO_2 was to be transported via a 400 kilometres pipeline to EOR projects in Texas and Mississippi. The project was declared unviable and unfinanceable.

Medicine Bow

The Medicine Bow project was a coal-to-liquid power plant with CO_2 capture proposed by DKRW Advanced Fuels to be located in Carbon County, Wyoming. The goal of the project was to capture more than half of the CO_2 produced during the coal refining process and pipe it to oil fields in Wyoming for EOR. After being postponed twice, the project was cancelled for financial reasons.

Antelope Valley project

The Antelope Valley project was located at Basin Electric's Antelope Valley Station in North Dakota. The aim of the project was to capture CO_2 from a lignite-fired power plant and the captured CO_2 was to be fed into the neighbouring Dakota pipeline for EOR in Canada. Despite grants and loans from the US-DOE and USDA in the hundreds of millions, the project was cancelled for financial reasons. Basin Electric justified this decision on the grounds that the project costs would probably be 30 percent higher than originally assumed.

FutureGen project

The FutureGen project was to retrofit a coal-fired power plant in Meredosia, Illinois, with a CO_2 capture unit and install a 30-mile pipeline to transport the captured CO_2 for injection into saline aquifers in Morgan County, Illinois. The US-DOE terminated its agreement with the project in 2015, because of years of delays and the project's inability to complete financing. Of the US$ one billion in federal funding allocated for the project, US$ 200 million have been disbursed.

Hydrogen Energy California project

SCS Energy's Hydrogen Energy California project in Kern County, California, proposed a commercial-scale IGCC coal-fired power plant with CO_2 capture. The company planned to transport the captured CO_2 via a pipeline for EOR in an Occidental's oil field. SCS Energy applied to an US-DOE funding programme and received funding. In 2016, the US-DOE terminated the agreement with the project "*after extensive budget and schedule overruns and repeatedly missed milestones*".

Summit Texas Clean Energy project

Summit Power proposed a IGCC coal plant with CO_2 capture in Ector County, Texas. Some of the captured CO_2 was to be used for industrial production, while most was to be piped for EOR in the Permian Basin. In 2009, the US-DOE approved US$ 350 million in federal funding for the project. In 2016, the US-DOE terminated its agreement with the project, due to delays and unauthorized expenditures.

CEMEX CCS project

CEMEX and RTI International aimed to develop and demonstrate CO_2 capture technology at a CEMEX cement plant in Texas. Although US$ 1.1 million was allocated to the project under a US-DOE programme in 2009, plans for the site were cancelled. CEMEX and its industrial partners "concluded *that commercial-scale CCS in the cement industry is not yet ready for deployment*".

Boise White Paper Mill project

In ~2014, a CCS project at a Boise White Paper LLC paper mill in Walla Walla County, Washington State was cancelled for financial reasons, because costs were too high, the project was not selected for further governmental funding and the revenue forecasts for CO_2 injections were too uncertain.

BP Texas City Refinery project

Praxair Inc proposed a commercial demonstration of CO_2 capture from an existing hydrogen production facility at an oil refinery in Texas City, Galveston County, Texas. The captured CO_2 was to be piped to a Denbury oil field for EOR. After a two-year project definition phase, Praxair concluded that the project costs and integration risks in Texas City were disproportionate to the potential benefits of the project, and the project was discontinued.

2) THE GCCSI DATA INDICATE THE NOMINAL CAPACITY, BUT NOT THE ACTUAL CO_2 CAPTURE CAPACITY OF THE CCS PROJECTS

The GCCSI statistic lists the CO_2 capture capacity of the CCS projects. The capacity given is the nominal capacity for most projects, but not the actual capacity. Only a few CCS projects have published CO_2 capture capacity results. For those projects for which data are available, the actual capture capacity is often significantly, up to 70 percent, lower than the nominal capacity – despite the fact that the technology is already a hundred years old. Some examples are presented below.

Terrell Gas Processing Plant

The oldest operating CCS project in the U.S. has a nominal CO_2 capture capacity of 0.5 million tonnes of CO_2 per year. In its report on the Global Status of CCS in 2021, the GCCSI describes that the Terrel plant has captured a total of twenty million tonnes of CO_2. Since Terrel's CO_2 capture plant has been in operation since 1972, this corresponds to an annual CO_2 capture volume of 0.4 million tonnes – and ***only 80 percent of the project's potential maximum capture capacity***.

Enid Fertilizer project

For the second oldest operating CCS project in the U.S., a nominal capacity of 0.7 million tonnes of CO_2 per year was specified until 2019. The actual capacity is only 0.1 to 0.2 million tonnes of CO_2 per year, ***less than 30 percent of the nominal capacity***.

Shute Creek Gas Processing facility

The third oldest operating CCS project in the U.S. had an annual nominal capacity of 4.3 million tonnes since 1986 and a nominal capacity of seven million tonnes of CO_2 per year since 2010. The power plant has on average fallen short of ***about 36 percent of its capacity*** during its lifetime. According to the US-based Institute for Energy Economics and Financial Analysis (IEEFA), "*Shute Creek became a "Sell or Vent" project. It could either sell the CO_2 to third parties or vent the CO_2 when prices were low and EOR was uneconomic. The excess CO_2 that could not be sold for EOR has been vented over the years. [...] Essentially, just half of CO_2 emissions captured and the other half vented*".

Century Plant

For the Century Plant a nominal capture capacity of 8.4 million tonnes of CO_2 per year was specified until 2019. The actual capacity is only five million tonnes of CO_2 per year, ***less than 60 percent of the nominal capacity***.

Great Plains Synfuels Plant

The lignite-fired Great Plains Synfuels Plant has a nominal capacity of three million tonnes of CO_2 per year and an actual annual capacity of ~1.9 million tonnes, ***a 35 percent shortfall from the nominal capacity***.

Farnsworth EOR Project

The Farnsworth project was conducted from 2013 to 2018 and had a total nominal CO_2 injection capacity of one million tonnes. A total of 0.6 million tonnes of CO_2 was injected, ***only 60 percent of the planned capacity***.

Core Antrim Shale plant

The CCS project at Core Energy's Antrim Shale gas processing plant has a nominal capture capacity of 0.35 million tonnes of CO_2 per year. The plant captured two million tonnes of CO_2 from 2003 to 2015, this corresponds to an annual quantity of 0.167 million tonnes, ***a 47.6 percent shortfall***.

Petra Nova CCS project

The Petra Nova CCS project had a lifetime of thee and a half year, experienced more than 360 downtime days from 2017 to 2019 due to technical problems ***and has only achieved 83 percent of its CO_2 capture target***.

Illinois Industrial CCS Project

The Illinois Industrial project aimed to capture one million tonnes of CO_2 per year. The actual capture capacity is approximately ***50 percent of the nominal capacity***.

3) CLASSIFICATION OF THE PLANNED PROJECTS

The GCCSI Global Status Report of CCS for 2022 lists 66 planned projects in early or advanced development. Of these, 36 projects are Bioenergy with Carbon Capture and Storage (BECCS) projects, which in theory aim to capture CO_2 from bioenergy applications and store it through Carbon Capture and Storage (CCS). Thiry of the planned projects can be attributed to the Midwest Carbon Express, a BECCS project proposed by Summit Carbon Solutions (SCS). SCS was founded by Summit Agricultural Group in 2021, is headquartered in Ames, Iowa, and aims to capture, transport and store about twelve million tonnes of CO_2 annually. Its proposed BECCS project, the Midwest Carbon Express, involves building a 2,000-mile pipeline network that will pump captured and liquefied CO_2 from more than 30 ethanol plants to North Dakota for underground injection. Each of the ethanol plants will install a CO_2 capture device, liquefy the captured CO_2, and receive a pipeline connection leading to the main pipeline. SCS will own the pipeline and the capture equipment at all plants. To date, SCS has partnered with more than 30 ethanol plants in five states, with the largest number of ethanol refineries and over 680 miles of pipelines in Iowa. The project is facing growing opposition from Indigenous people, local communities, landowners and environmental groups, because of the health and environmental risks associated with CO_2 pipelines and because CCS has failed to reduce CO_2 emissions. In the Iowa permit application, SCS has not only sought permission to lay the pipelines, but also permission to expropriate landowners, after it failed to obtain voluntary easements for the land to build the pipeline in Iowa. In response to this, there are a number of activities in Iowa to mobilise against the pipeline. Fifteen counties have raised objections to the pipelines. The Progressive Caucus of the Iowa Democratic Party overwhelmingly passed a resolution in March 2022 opposing the development and construction of the SCS pipelines. The resolution was justified as follows: "*The resolution said carbon capture and sequestration is currently unproven technology, asserts increases in jobs will be minimal, and poses safety risks*." The Iowa Utilities Board classified the proposed pipeline as a "*hazardous liquid pipeline*", requiring SCS to hold informational meetings in affected counties under Iowa law. But protests and concerns are also being raised in the other US states affected. For example, in North Dakota, the list of counties raising concerns is growing and some counties have passed resolutions against the expropriation of land for the pipeline, and in South Dakota, landowners have joined forces to speak out against the project. In Illinois, a coalition to stop CO_2 pipelines has been formed.

A study conducted by scientists at the University of Wisconsin-Madison found "*that ethanol is likely at least 24 % more carbon-intensive than gasoline due to emissions*". The production of ethanol accounts for only a fraction of the total emissions. For the greenhouse gas footprint, however, not only combustion but the entire life cycle must be taken into account, including the transport of fuel and raw materials, agricultural emissions for corn cultivation and changes in land use.

Despite the opposition and the required permits, Summit Carbon Solutions expects that the project will be operational in 2024.

There are also protests at other project sites that are at an early or advanced stage of development according to GCCSI statistics. In addition, project sites are mentioned where no final decision has been made on the implementation and financing of the projects. Some examples are given below.

Broadwing CCS project (GCCSI: early development, Illinois Allam-Fetvedt Cycle power plant)

The Broadwing project is among the planned projects where a final investment decision has not yet been made. The project proposed a 280-megawatt natural gas power plant with CCS in Decatur, Illinois, and has announced that the CCS plant will create about two dozen jobs in the long term. In 2022, the Wyoming Energy Authority approved funding for a pre-FEED study for the project. The next step would be a FEED study, but that has not yet been decided.

Coyote CCS project (GCCSI: advanced development, Coyote Clean Power Project)

The Coyote project is a 280-megawatt natural gas-fired power plant with CCS in the state of Colorado. It has been classified as a project in advanced development by the GCCSI and is awaiting a final investment decision.

Heartland Greenway BECCS project (GCCSI: advanced development, Galva Biorefinery CCS)

Like the Midwest Carbon Express, the Heartland Greenway is facing growing opposition "*from citizens, environmentalists, property rights advocates and landowners in all of the impacted states*", for the same reasons as the Midwest Carbon Express. The project involves the construction of a 1,300-mile pipeline network to pump captured and liquefied CO_2 from more than 30 ethanol or other industrial plants into the Mt. Simon sandstone formation in central Illinois.

Air Products Louisiana (GCCSI: in construction, Louisiana Clean Energy Complex)

In 2021, Air Products announced plans to invest US$ 4.5 billion to build and operate a blue hydrogen plant near Burnside in Ascension Parish, Louisiana. Air Products intends to capture, compress and transport more than five million tonnes of CO_2 per year at this site. The captured CO_2 is to be injected under nearby Lake Maurepas, an area used for local and commercial fishing and adjacent to a protected swamp. In October 2022, the Council of Livington Parish decided on a one-year moratorium on drilling and seismic survey on its territory, while Air Products announced plans that it would begin work on two test wells to explore the geology of the proposed CO_2 storage site. As a result, Air Products' geological work had to be halted. "*Council members say the moratorium will provide time for local review of the project and cite the need to prevent pollution of the parish's freshwater aquifers and Lake Maurepas' ecosystems.*" Livingston Parish and neighbouring St. Helena Parish also passed ordinances banning injection wells for CO_2 storage, and environmentalists in Louisiana are preparing to challenge permits for carbon pipelines applied for by Air Products and other energy companies in the state. The project and the production of blue hydrogen are seen as a "*false solution for climate change*" and "*residents of Livingston Parish were 'right to be wary' of Air Products' plans*".

Lake Charles Methanol (GCCSI: advanced development)

The project has been "in development" since 2007 and was discontinued in 2015 and then resumed. Fifteen years after it was announced, the project is not yet under construction, has reduced the planned CO_2 capture volume by almost 80 percent, announced seven times higher construction costs per tonne of CO_2 captured, and has been supported with substantial public subsidies.

25 YEARS OF FEDERAL SUPPORT FOR CCS IN THE U.S.

The US-DOE has offered diverse funding and research programmes since 1997 to advance the development of CCS technologies. Among them programmes on CO_2 capture, point-source CO_2 capture, post- and pre-combustion capture, CO_2 removal and storage, offshore and onshore EOR, EOR field tests, geological storage and industrial CCS. For these keywords alone, the US-DOE's project database has information on almost 200 research projects with a US-DOE funding share of over US$ 1.2 billion. In total, the project database currently lists 675 projects related to CO_2 capture and storage, including projects on direct air capture (DAC), wellbore integrity, coal-related research and the use of captured CO_2 (CCUS). The following provides an overview of the most important federal support programmes for CCS over the past two and a half decades.

REGIONAL CARBON SEQUESTRATION PARTNERSHIPS (2003 – 2024)

Behind the term Regional Carbon Sequestration Partnerships (RCSPs) stand seven regional networks created and funded by the US-DOE with the aim of promoting CCS. The RCSP programme was divided into three phases. From 2003 to 2005, the first phase was conducted to collect data on CO_2 sources and geological formations in preparation for future CO_2 injection field trials. In the second phase, from 2005 to 2013, initial field trials were conducted with CO_2 injections of up to one million tonnes of CO_2. In the third phase, from 2008 to 2021, RCSPs were to carry out injections of one million tonnes of CO_2 or more. NETL provides an interactive map with information on the individual projects undertaken.

In 2019, the seven regional networks [West Coast Regional Carbon Sequestration Partnership (WESTCARB), Big Sky Carbon Sequestration Partnership (BSCSP), Southwest Regional Partnership on Carbon Sequestration (SWP), Plains CO_2 Reduction Partnership (PCOR), Southeast Regional Carbon Sequestration Partnership (SECARB), Midwest Geological Sequestration Consortium (MGSC) and Midwest Regional Carbon Sequestration Partnership (MRCSP)] were merged into four programmes. The four new regional initiatives are intended to build on the previous RCSPs, coordinate current and future demonstration projects, identify and promote potential CCS projects, promote "*low-emission*" coal and advance the commercial use of CC(U)S.

- SECARB-USA is led by the Southern States Energy Board (SSEB) and aims to identify and address regional challenges

that impede the transport and onshore storage of CO_2 in the U.S. southeastern states. The US-DOE is providing US$ 14.7 million for these activities, from 2019 to 2024.
- MGSC and MRCSP formed the Midwest Regional Carbon Initiative (MRCI). The MRCI is led by the Battelle Memorial Institute and aims to conduct further risk assessments, evaluate offshore CCS, attract new sites and partners for CCS and strengthen public outreach, among other things. The US-DOE is providing US$ 14.8 million for the MRCI from 2019 to 2024.
- SWP, WESTCARB and BSCSP formed the Carbon Utilization and Storage Partnership of the Western United States (CUSP). The CUSP is led by the New Mexico Institute of Mining and Technology and aims to accelerate the deployment of onshore CC(U)S technology in the western U.S., e.g., by collecting data, improving modeling tools for economic scenario analysis and highlighting technical CC(U)S challenges. The US-DOE is providing US$ 12.98 million for the CUSP from 2019 to 2024.
- Plains CO_2 Reduction Partnership Initiative (PCOR) is led by University of North Dakota's Energy and Environmental Research Center. PCOR's goals are to catalyse CC(U)S projects, advance CC(U)S technologies and facilitate the regulatory framework for CC(U)S in the Northern Great Plains states, adjacent Canadian provinces and Alaska. The partnership consists of over 200 industrial, organisational and governmental partners and is funded by the US-DOE with US$ 15 million from 2019 to 2024.

45Q TAX CREDIT (SINCE 2008)

Section 45Q of the U.S. Internal Revenue Code was introduced as an incentive in the form of a tax credit for power plants and further industrial facilities to capture and "store" CO_2. When first enacted in 2008, the CO_2 credit was US$ 10 per tonne of CO_2 captured and used for EOR and US$ 20 per tonne of CO_2 captured and injected into geologic formations. In 2018 and in 2022, the U.S. Congress increased incentives for CO_2 capture combined with EOR, other industrial uses (CCUS) or geologic sequestration. In August 2022, the Inflation Reduction Act (IRA) also expanded and extended the 45Q tax credit. The requirements for eligible projects were lowered and the credit value was increased from US$ 35 to US$ 60 per tonnes of CO_2 captured when used for EOR or other industrial uses (CCUS) and from US$ 50 to US$ 85 when used for geologic sequestration. With this development, the US federal 45Q tax credit creates additional revenue streams for power plants and other fossil-fuel dependent industries. This means that taxpayers finance projects via the 45Q tax credit that increase the extraction and consumption of fossil fuels – and thus the emission of greenhouse gases – including because CCS consumes a lot of energy and EOR increases fossil fuel extraction. In December 2022, the Washington-based organisation Taxpayers for Common Sense (TCS) criticized the use of public funds to support CCS, citing the following reasons, among others:

- *"There is mounting evidence that CCS is not economically viable nor an answer to our environmental challenges. Building, proving, and implementing CCS technology is prohibitively expensive. […]*
- *The effectiveness of CCS technology as a greenhouse gas emissions reduction strategy is largely untested and unproven. […]*
- *Additionally, sequestering billions of tons of CO_2 underground annually could have unintended negative consequences, such as potentially contaminating ground water when leaks happen, and leave taxpayers with long-term environmental liabilities. […]*
- *Whether using captured carbon oxides for EOR reduces emissions on net is the subject of ongoing study. Recent papers suggest that increasingly less CO_2 is trapped underground as EOR projects continue, and the carbon footprint becomes positive (no net emission reduction)."*

The results of the US-DOE funding programmes for CCS projects presented below confirm the organisation's points of criticism.

CLEAN COAL AND CLEAN INDUSTRIAL PROJECTS (2009 – 2017)

In 2009, the US-DOE approved investments of US$ 1.1 billion in eleven commercial-scale CCS demonstration projects, "*with the aim of* accelerating *the development and commercial deployment of CCS technologies*". Eight CCS projects at coal-fired power plants were allocated US$ 684 million and three CCS projects at industrial facilities were allocated US$ 438 million.

Seven of the eight Clean Coal projects were abandoned before commissioning due to high costs and technical problems. Only one of the Clean Coal projects was commissioned and was often visited as a showcase project. However, the operation was stopped after 3.5 years and it became known afterwards that the project had major technical problems and long downtimes.

The three Clean Industrial projects are also characterised by technical problems. Two out of three projects have been implemented but do not reach the planned CO_2 capture capacity, in one case it only reached 50 percent of the planned capture

capacity. But even with nominal capacity, the emission problems of the industrial plants are not solved by CCS, in part because they only compensate a small part of the plants' total emissions, and this despite receiving funding in the hundreds of millions of dollars. The long-term economic benefit of CCS projects for their local region is not discernible, as the operation of the CCS projects provide little employment, for example only eleven staff in one of the Clean Industrial projects. Long-term economic benefits from ongoing CCS projects are only visible for fossil-fuel consuming industries under the new 45Q scheme. The eight Clean Coal and three Clean Industrial projects funded by the US-DOE as commercial-scale CCS demonstration projects are briefly presented below:

1) Basin Electric's Antelope Valley Project (cancelled in 2010)

The Antelope Valley Project was located at Basin Electric's lignite-fired Antelope Valley Station, in Beulah, North Dakota. The aim of the project was to capture CO_2 from a 120 megawatt gas stream from the power plant. The captured CO_2 was to be fed into the neighbouring Dakota pipeline for EOR in Canada. Despite hundreds of millions of dollars in grants and loans from the US-DOE and USDA, the project was cancelled for financial reasons.

2) Southern Company's Plant Barry Project (withdrew participation in 2010)

This CCS project was operated by Southern Company and is located at the J.M. Barry Power Station, in Bucks, Mobile County, Alabama. The power plant, with a capacity of approximately 1,500 megawatt, is fired by coal and fossil gas. Initially, the plan was to retrofit the power plant with a unit to capture one million tonnes of CO_2 in a 160 megawatt flue gas stream from a coal-fired unit. Southern Company applied for the US-DOE's The Clean Coal Power Initiative in 2009 and received a US$ 295 million commitment in December 2009. In February 2010, Southern Company withdrew from the program for financial reasons.

Further development: From 2011 to 2017, the company completed a much smaller CCS project at Plant Barry. The project captured CO_2 from a 25-megawatt unit until December 2015. The captured CO_2 was transported via a ten-kilometre pipeline to the Citronelle oil field for underground injection. The post-injection monitoring programme ended in September 2017. The project was used by various players such as Southern Company, Alabama Power, FuelCell Energy & ExxonMobil, and SECARB for research and pilot testing of CO_2 capture. The US-DOE supported this small-scale project with US$ 77 million. Since 2022, Southern Company is conducting an 18 months FEED study at Plant Barry. The study is funded by the US-DOE with US$ 5.77 million and focuses on the integration of CO_2 capture technology in natural gas combined cycle power plants. The aim of the project is to improve the CO_2 capture process while minimising the impact on the power plant's performance and profitability. According to the Global CCS Institute, the commissioning of a new CCS plant at this site is envisioned for the year 2030. There are no details yet on the financing and size of the venture.

3) American Electric Power's Mountaineer project (cancelled in 2011)

The Mountaineer CCS project was to be operated by American Electric Power (AEP) and adjacent to the Mountaineer coal-fired power plant in New Haven, West Virginia. The total capacity of the power plant is 1,300 megawatt. AEP planned to capture CO_2 from less than one-fifth of the power plant (235 megawatt). The captured CO_2 was to be injected into a nearby underground formation 1.5 miles deep in the saline Mount Simon sandstone. Although public funding from the US-DOE was promised for 50 percent of the project costs, AEP abandoned the project for financial reasons and complained about insufficient support from authorities and project partners.

4+5) FutureGen Project and FutureGen 2.0 initiative (cancelled in 2015)

The FutureGen Project was coordinated by the FutureGen Industrial Alliance and included two main components: (1) The project proposed to retrofit Ameren's coal-fired power plant in Meredosia, Illinois, with an oxy-combustion unit for CO_2 capture. (2) The project provided for a 30-miles onshore pipeline to transport the captured CO_2 for injections into saline aquifers near Jacksonville in Morgan County, Illinois. The US-DOE terminated its agreement with the project in January 2015, due to years of delays and the project's inability to complete financing.

6) Lake Charles Methanol (withdrew participation in 2015)

The Lake Charles Methanol plant was initially proposed by Leucadia Energy. The project aimed to convert petcoke into syngas in order to obtain methanol and hydrogen from the gas. CO_2 was to be produced as a by-product. The project envisaged capturing 4.5 million tonnes of CO_2 per year from a new methanol plant in Lake Charles, Louisiana. The CO_2 was to be delivered via a twelve-mile connector pipeline to an existing interstate CO_2 pipeline for Denbury Resources' EOR operations in the Houston area, Texas. In 2009, Leucadia Energy applied to the US-DOE's Clean Coal Initiative and received funding. In 2015, the Leucadia Lake Charles project was withdrawn due to cancellation of the associated methanol gasification facility, which was to use CCS technology.

Further development: In the same year (2015), the project was revived by a former employee who promised to build a CCS plant at the same site. The project has given varying details on the planned use of the CO_2, including press reports citing that the captured CO_2 „*is expected to be able to unlock about 4.5 million barrels of oil per year*".

Fifteen years after its announcement, the project still is not under construction. Construction on the revived project was announced for 2018, delayed until 2020, and is now announced for the second half of 2023.

Since 2007, the project has been supported with extensive public subsidies: US$ 1 billion of tax-exempt bonds, US$ 2 billion of conditional loan guarantees, and more than US$ 274 million in funding. According to the project website, the US-DOE is presently evaluating further commitment.

The project announced in 2007 aimed to capture 4.5 million tonnes of CO_2 and was expected to cost US$2.5 billion. The follow-up project announced in 2015 aims to capture one million tonnes of CO_2 and is expected to cost US$ 4 billion – which implies that the cost per million tonnes of CO_2 has increased sevenfold.

7) SCS Energy's Hydrogen Energy California Project (cancelled in 2016)

The Hydrogen Energy California Project (HECA, formerly the Carson Project) was coordinated by SCS Energy and located in Elk Hills, Kern County, California. SCS Energy acquired the project in 2011 from the original developers BP and Rio Tinto. HECA proposed a commercial-scale integrated gasification combined-cycle coal plant with CO_2 capture. The company planned to transport the captured CO_2 via a 6.4 kilometres pipeline for onshore EOR in Occidental's Elk Hills oil field. SCS Energy applied to the US-DOE's The Clean Coal Power Initiative and received funding. In 2016, the US-DOE terminated the agreement with the HECA project "*after extensive budget and schedule overruns and repeatedly missed milestones*". The proposed plant was never built.

8) Summit Power's Texas Clean Energy Project (cancelled in 2016)

Summit Power proposed a new 400 megawatt integrated combined gasification coal plant with CO_2 capture. The project was to be implemented in Ector County, in Texas. Summit aimed to capture two million tonnes of CO_2 in a 190 megawatt flue gas stream. Some of the captured CO_2 was to be used for ammonia or urea production, while most was to be piped into the Kinder Morgan pipeline system for EOR in the Permian Basin in West Texas. In December 2009, the US-DOE approved US$ 350 million for the project. In 2016, the US-DOE terminated its agreement with the project due to delays and unauthorized expenditures. In 2017, the project filed for bankruptcy.

9) Petra Nova Project (cancelled in 2021)

The Petra Nova Carbon Capture Project was operated by Petra Nova, a subsidiary of NRG Energy, and JX Nippon Oil & Gas Exploration Corporation in a 50/50 partnership. Petra Nova had a total capacity of 3.7 gigawatts and aimed to capture CO_2 from one of ten production units at the W.A. Parish power plant, southwest of Houston, Texas. The coal-fired 240-megawatt Unit 8 was retrofitted with an amine post-combustion CO_2 capture facility. The captured CO_2, which corresponded to only 6.2 percent of the plant's total emissions, was transported via an 82 kilometre pipeline to the West Ranch oil field near Houston, where it was used for EOR. In 2020, after a lifetime of three and a half years, the project was halted. In 2021, the CCS project was abandoned indefinitely for financial reasons.

Several years, Petra Nova was presented as a show-case project and example of "clean coal technology". After the closure it became known that the CCS project was struggling with a number of technical failures and further problems. According to press reports, the CCS plant experienced more than 360 downtime days from 2017 to 2019 due to technical problems, missed its CO_2 capture target by about 17 percent and faced problems with high water consumption and complaints related to the CO_2 pipeline. During the project lifetime, Petra Nova captured 3.5 million tonnes of CO_2. This enabled 4.2 million barrels of oil to be boosted by EOR. In order to supply the energy-intensive CCS facility with energy, a separate natural gas power plant was built and commissioned, whose CO_2 emissions were not captured. The CCS project had no influence on all other emissions generated by the coal project, e.g. methane and nitrous oxide. The US-DOE financed the project with at least US$ 195 million in public funds, but the projects had virtually no impact on the power plant's emissions and caused additional emissions.

10) Archer Daniels Midland's Illinois Industrial CCS Project (ongoing)

The Illinois Industrial CCS Project captures CO_2 at Archer Daniels Midland's (ADM) corn-to-ethanol plant in Decatur, Illinois. The project was announced in ~2007 and launched in 2009, with the completion of a CO_2 injection well 1.5 kilometre deep in the Mt. Simon Sandstone formation, one mile from the ADM plant. That same year, ADM announced the construction of a CO_2 capture facility at its Decatur plant and a pipeline to transport the captured CO_2 to the Mt. Simon formation. From 2011

to 2014, the project conducted small-scale trials that captured a total of one million tonnes of CO_2.

Further development: In 2017, a new CO_2 capture facility was added to the plant, which ADM expects to capture about one million tonnes of CO_2 annually. To date, the project has achieved only 50 percent of its target at 0.5 million tonnes, which corresponds to less than twelve percent of the plant's total reported CO_2 emissions (4.2 million tonnes in 2021), but even at its nominal capture capacity it would capture less than 25 percent of the power plant's CO_2 emissions. Although ADM generates billions of dollars in annual profits, the Decatur project has received more than US$ 414 million in public funding since 2009, but this has not solved the power plant's emission problem.

11) Air Product's Steam Methane Reformer (ongoing)

Air Products' CCS project aims to capture one million tonnes of CO_2 from steam-methane reformers in Port Arthur, Texas. The company turns fossil gas into hydrogen and retrofitted its two steam methane reformers for CO_2 capture. The captured CO_2 is transported to Denbury oil fields in Texas for EOR. For this, a twelve-mile pipeline was built to connect to an existing interstate CO_2 pipeline. The project is achieving about 70 percent of its nominal capacity.

To power the CO_2 capture unit, Air Products installed a new 21 megawatt natural gas turbine, requiring 270 million British Thermal Units per hour (MMBtu/h) to capture 116,7 tonnes of CO_2 per hour. One MMBtu of natural gas emits ~53.1 kilograms of CO_2. If the project captures one million tonnes of CO_2 per year as planned, it emits 0.128 million tonnes of CO_2 by burning natural gas to generate the energy for the CO_2 capture process. This does not yet take into account the methane emissions caused by natural gas consumption, which over a period of 20 years are 86 times more harmful to the climate than CO_2. Methane is the main component of natural gas and emitted to the atmosphere during its extraction, processing, storage, and distribution. According to the U.S. Environmental Protection Agency, the natural gas industry is the second largest source of methane emissions in the United States. The project generates additional climate-relevant emissions through EOR and has received at least US$ 285 million in public funding so far.

INDUSTRIAL CARBON CAPTURE AND STORAGE PROJECTS (2009 – 2014)

In 2009, the US-DOE provided funding for CCS and CCUS, for twelve projects each, aiming to test the use of CO_2 and large-scale industrial CO_2 capture and storage. Project Phase 1 investigated the technical and economic feasibility of the twelve proposed large-scale industrial CCS projects. It had an average project duration of seven months and was evaluated in 2010. Following the successful completion of Phase 1, Phase 2 was to undertake detailed design studies and ultimately the construction of CCS demonstration projects. In 2010, the US-DOE selected three CCS projects for Phase 2. Phase 1 projects were funded with a total of US$ 44.1 million, with the US-DOE's share accounting for 49 percent of this amount. Phase 2 projects were funded with a total of US$ 1.075 billion, with the US-DOE's share accounting for 64 percent of the total amount. Project funding was provided by the US-DOE's American Recovery and Reinvestment Act (ARRA). According to the US-DOE, ARRA "*was designed to spur economic growth while creating new jobs and saving existing ones*".

Of the twelve projects funded, only two are still running today. Both projects were also funded by the US-DOE Clean Coal and Clean Industrial programme. These two ongoing projects remain 30 to 50 percent behind their nominal capacity, have made no visible progress since their launch, and CO_2 capture has been introduced at the industrial facilities for only a small portion of total emissions. One project has been announced since 2007 but is still not operational, despite being funded by the US-DOE to the tune of billions of dollars. The remaining nine projects have been abandoned, mostly for financial and technical reasons or because the CCS technology was not yet considered mature or too risky. The large-scale industrial CO_2 capture and storage selection in Phase 1 included the following twelve projects.

CEMEX CCS project (cancelled)

CEMEX and RTI International aimed to develop and demonstrate a dry sorbent CO_2 capture technology at a CEMEX cement plant in Odessa, Texas. No decision was made on the fate of the captured CO_2. Although US$ 1.1 million was allocated to the project under the US-DOE programme in 2009, plans for the site were cancelled. CEMEX and its industrial partners "concluded *that commercial-scale CCS in the cement industry is not yet ready for deployment*".

Boise White Paper Mill (cancelled)

This CCS project was to be carried out at the paper mill of Boise White Paper LLC near Wallula in western Walla Walla County, Washington state. The project involved capturing CO_2 using post-combustion technology and demonstrating geological storage of the captured CO_2 in basalt formations in Eastern Washington. The project planned to cooperate with researchers from

Battelle Memorial Institute and Fluor Corporation. Fluor Corporation aimed to test its Econamine FG Plus℠ CO_2 capture technology at this site. The project was cancelled for financial reasons: costs were too high and the project was not selected for further governmental funding and the revenue forecasts for CO_2 injections too uncertain. The US-DOE funded the project with US$ 0.5 million.

BP Texas City Refinery (cancelled)

This project proposed a commercial demonstration of CO_2 capture from an existing hydrogen production facility at an oil refinery in Texas City, Galveston County, Texas. The project was led by Praxair Inc. and conducted in collaboration with BP Products North America, Denbury Onshore LLC and the Gulf Coast Carbon Center (GCCC) at the Bureau of Economic Geology of the University of Texas at Austin. The refinery is owned by BP, and Praxair owns and operates a large hydrogen production facility within the refinery. Praxair was responsible to build a CO_2 capture and compression plant, in order to demonstrate a novel vacuum pressure swing adsorption capture technology. The captured CO_2 was to be purified, compressed and piped to a Denbury site in the Hastings field in Brazoria County, Texas, for EOR. A connector pipeline was to be built to Denbury's Green Pipeline. The GCCC was responsible to manage the research and monitoring work. The goal of the project was to exceed the US-DOE's target of capturing one million tonnes of CO_2 per year by 2015. After completion of the project definition Phase 1 the project was cancelled. Praxair had decided not to pursue funding for Phase 2 and had concluded that the project costs and integration risks at Texas City were disproportionate to the potential benefits of the project. The US-DOE awarded US$ 1.7 million to the project.

Sweeny Gasification project (cancelled)

The Sweeny Gasification project was proposed by ConocoPhillips and was to be located in Sweeny, Texas. The project envisioned capturing CO_2 in a 683-megawatt integrated gasification combined cycle petroleum coke-based power plant adjacent to an already existing refinery in Sweeny. The plan was to inject captured CO_2 into adjacent deep saline aquifers and/or for EOR activities. In 2012, the project was discontinued for financial reasons. The US-DOE awarded US$ 3 million to the project.

Wolverine CCS project (cancelled)

Wolverine Power Supply Cooperative Inc. proposed a large-scale CCS demonstration project. CO_2 capture using an amine-based CO_2 capture system from Hitachi was to be carried out at the Clean Energy Venture power plant in Rogers City, Michigan, which is owned and operated by Wolverine. The captured CO_2 was to be compressed and transported 54 kilometres for EOR in the state of Michigan. Core Energy was to be responsible for the construction and operation of the 54 kilometres CO_2 pipeline and the EOR component of the project. There is no indication that the project continued after completion of project definition Phase 1. Plans for the CCS project were cancelled in ~2010 and plans to build the Wolverine Clean Energy Venture plant were halted in 2013. The US-DOE awarded US$ 2.7 million to the project.

University of Utah CCS project (cancelled)

In 2009, the University of Utah was awarded US$ 2.7 million from the US-DOE for a large-scale CCS demonstration project. The goal of the project was to capture more than one million tonnes of CO_2 per year from various industrial sources, compress, and transport the captured CO_2 for EOR and geological storage. The captured CO_2 was to be transported via two new pipelines to oil fields and saline aquifers in Kansas. There is no indication that the project continued after completion of project definition Phase 1. Plans for the CCS project were cancelled in ~2010.

Shell Mississippi project (cancelled)

The Mississippi Plant was a CCS project proposed by Shell Chemical Capital Company. The project planned to capture one million tonnes of CO_2 from facilities located along the Mississippi River between Baton Rouge and New Orleans. The captured CO_2 was to be conditioned and transported by pipeline for geological storage, e.g., via a Denbury pipeline. The project was cancelled in ~2014, because Shell prioritised its Quest CCS project in Canada. The US-DOE awarded US$ 3 million to the project.

Northern California CO_2 Reduction project (cancelled)

The Northern California CO_2 Reduction project aimed to capture one million tonnes of CO_2 per year at facilities in California's Bay Area. The captured CO_2 was to be transported to California's Central Valley to be injected 3.2 kilometres underground into a saline formation. Small-scale CO_2 injections were conducted in the Montezuma Hills, Solano County. The project was to be carried out by C6 Resources, a subsidiary of Shell Oil Company, Lawrence Berkeley National Laboratory and Lawrence Livermore National Laboratory. The project was discontinued in 2010 because C6 Resources was no longer willing to continue,

more specific reasons are not available. The US-DOE funded the project with US$ 3 million.

Leucadia Mississippi (cancelled)

Leucadia Energy LLL and Denbury Onshore planned to demonstrate CO_2 capture technology at a proposed petcoke-to-substitute natural gas plant in Moss Point, Mississippi. Leucadia planned to sell four million tonnes of captured CO_2 per year under long-term contracts for EOR activities in the surrounding area. In 2013, Leucadia decided against the project, citing the fact that it had switched its product range from natural gas to methanol. The US-DOE awarded US$ 0.8 million to the project.

In 2010, the US-DOE selected the Illinois Industrial CCS project **(ongoing since 2009)**, Air Products Steam Methane Reformer (ongoing since 2012) and Lake Charles Methanol (planned since 2007) for Project Phase 2 and supported the projects with a total of US$ 686 million in public funding. The three projects were also funded under other US-DOE programmes. For more information on the projects, please see the Clean Coal and Clean Industrial Projects chapter above.

CARBONSAFE (SINCE 2016)

The Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative is a US-DOE-led programme designed to accelerate commercial-scale CCS projects. CarbonSAFE aims to advance CCS deployment on the one hand by identifying and characterizing geologic storage sites, and on the other hand by reducing technical risks and costs of commercial-scale carbon storage projects in saline formations. In 2016, the US-DOE announced US$ 68.4 million for Phase I and Phase II. Phase I conducted pre-feasibility studies at 13 project sites, including economic feasibility, evaluation of storage sites and infrastructure, and modelling. In Phase II, six projects were carried out to assess the feasibility of storage complexes in order to identify CO_2 storage complexes with a storage volume of at least 50 million tonnes of CO_2. The Phase I projects were funded with about one million US dollars and the Phase II projects with about ten million US dollars. Since 2020, CarbonSAFE Phase III is being carried out in five areas and includes the identification of CO_2 storage sites in the selected areas, the preparation of injection permits, the identification of anthropogenic CO_2 sources and the implementation of FEED studies. The US-DOE provided US$ 86 million for Phase III, with US$ 16 to 10 million per project. The final phase of CarbonSAFE, Phase IV aims to complete injection and monitoring wells, complete risk plans and obtain permits for CO_2 injection. In September 2022, the US-DOE provided US$ 2.25 billion for Phase III and Phase IV "*to support the development of new and expanded large-scale, commercial carbon storage projects with capacities to store 50 or more million metric tons of CO_2, along with associated CO_2 transport infrastructure. Projects will focus on detailed site characterization, permitting, and construction stages of project development under CarbonSAFE*". The following is a selection of cancelled, completed and planned projects that have been or are being subsidised by CarbonSAFE funds:

Wabash Valley CCS Project (planned since 2016)

In 2016, Wabash Valley Resources (WVR), an affiliate of Phibro LLC, acquired a gasification plant near West Terre Haute, Indiana, and announced plans to convert it into a CCS ammonia production facility. The project was scheduled to come on stream in 2022. Since 2021, there is no sign that the ammonia CCS project is still alive. Instead, WVR is talking about developing an (Integrated Gasification Combined Cycle (IGCC) plant for hydrogen production with CCS. The captured CO_2 is to be injected into the Wabash CarbonSAFE storage hub, two kilometres below the Mount Simon Sandstone, a saline sandstone aquifer. WVR is campaigning to grant it the right to inject CO_2 deep underground without fear of liability claims or having to compensate landowners. Representatives of water utilities, agriculture, community members and civil rights organisations, oppose limited liability for the project, point to the potential dangers and risks such as earthquakes, leaks and contaminated groundwater, and ask: "*Would you want to live where carbon is being stored? We don't really know what the damages will be in the future*".

Prairie State Energy Campus (completed?)

Part of CarbonSAFE was a FEED study for retrofitting the Prairie State Generating Station with a CO_2 capture plant using Mitsubishi Heavy Industries' post-combustion CO_2 capture technology. The coal-fired power plant is located on the Prairie State Generating Company (PSGC) energy campus in Marissa, Illinois. The FEED study was conducted by the University of Illinois at Champaign. The project's final report was released in 2022 and states, among other things, that the project is "*not currently economic without additional enhancements to federal tax credits*". The PSGC last reported on the project in 2020. Current plans to establish a CCS project are not apparent. According to the PSGC website, the company controls the following air pollutants: nitrogen oxides, sulphur dioxide, particulate matter and mercury, but there is no mention of CO_2. The Global CCS Institute has stated in 2022 that a CCS system with an annual CO_2 capture of six million tonnes is planned at this site, but there is no indication of this on the PSGC website.

San Juan Generating Station (cancelled)

Part of CarbonSAFE was a FEED study for retrofitting the San Juan Generating Station in Waterflow, New Mexico, a coal-fired power plant, operated by the Public Service Company of New Mexico (PNM), with CO_2 capture technology. The study was conducted by Enchant Energy in collaboration with the City of Farmington, New Mexico, to determine the technical and economic viability of extending the life of an existing power plant using a CO_2 capture system. Originally, the plant consisted of four units that were commissioned between 1973 and 1983. In 2017, Units 2 and 3 were decommissioned and Units 1 and 4 were scheduled to close in 2022. In February 2019, it was agreed to keep the power plant in operation after 2022, in order to extend the life of the coal-fired power plant by means of CO_2 capture. The captured CO_2 was to be compressed and transported to the Kinder Morgan Cortez CO_2 pipeline for geological storage and/or EOR in the Permian Basin. The project did not go ahead, the estimated cost increased from US$ 1.4 million to 1.6 million and in September 2022, the San Juan Generating Station was shut down by PNM and co-owners. Enchant Energy Corp. is seeking to reopen the coal-fired power plant in combination with CCS, which is unlikely in the near future due to legal disputes with the owners.

Project Tundra (planned)

Project Tundra aims to retrofit the lignite-fired Milton R. Young power plant with a post-combustion CO_2 capture system developed by Fluor. The 705 megawatts plant is owned by the Minnkota Power Cooperative, was commissioned in the 1970s, generates electricity, consists of two units and is located six kilometres southeast of Center, Oliver County, North Dakota. Since 2018, Project Tundra has received more than US$ 50 million in public funding and a US$ 100 million loan provided by the US-DOE, North Dakota's Lignite Research Fund and North Dakota's Industrial Commission. The Bank of North Dakota, had initially declined to support the loan programme, citing the risks of the carbon capture technology among other reasons. It agreed to the deal after liability for the project was shifted to taxpayers. The funds were used to design and determine the costs of installing a carbon capture retrofit at the power plant, as well as a FEED study to provide data on the technology's deployment and economic viability. Minnkota plans to store the captured CO_2 on site in a porous rock layer about one mile underground and has obtained a permit to inject 100 million tonnes of CO_2 near Center. Until ~2021, the project was seeking partners for EOR to finance the project. Meanwhile, the project, whose estimated cost has risen to US$ 1.45 billion, is to be financed through the 45Q federal tax credit: "*The current plan is to form partnerships that will allow for the use of 45Q federal tax credits to offset the approximately $1.4 billion capital project cost.*" According to the project website, "*Project Tundra is still in the research and engineering stages*". The project has been in the planning stage since 2018 and has since faced delays, technical problems and the departure of a key contractor.

Dry Fork Station (planned)

Part of CarbonSAFE was a FEED study to retrofit Basin Electric's Dry Fork power plant with a membrane-based CO_2 capture system. The 385 megawatts coal-fired electric generating station Dry Fork Station, was commissioned in 2011 and is located eleven kilometres north of Gillette, Wyoming. The power plant is owned by Basin Electric (92.9 percent) and the Wyoming Municipal Power Agency. Membrane Technology and Research Inc. is the developer of the membrane-based CO_2 capture technology and was responsible for conducting the FEED study. The study was designed to provide data on the technology's deployment and economic viability and builds on previous US-DOE funding for this CO_2 capture technology. The results of the study are not yet publicly available.

Basin Electric's most recent sustainability report (11/2022) describes the Dry Fork power plant as the site of the Wyoming Integrated Test Center and the Wyoming CarbonSAFE project, both research projects to advance CO_2 capture technology. The Sustainability Report does not indicate whether the FEED study will result in a CCS project at the plant.

Elk Hills Power Plant (Cal Capture, planned)

Part of CarbonSAFE was a FEED study to determine the technical and economic feasibility of retrofitting California Resources Corporation's (CRC) 550 megawatt Elk Hills power plant with post-combustion carbon capture technology. The natural gas-fired power plant in Kern County, California, which began operation in 2012, was to be retrofitted with Fluor's amine-based Econamine FG Plus process, aiming to capture 75 percent of the emitted CO_2. The FEED study was conducted by the Californian Electric Power Research Institute. In 2022, the CRD announced another FEED study to be conducted by NEXT Carbon Solutions (NCS), a subsidiary of NextDecade Corporation. This 2nd FEED study began in June 2022, is expected to last approximately six months, and will examine the technical and economic prospects of NCS's post-combustion carbon and compression technology at the Elk Hills Power Station. The CRC plans to make a final investment decision after the FEED is completed and reviewed. In 2022, local organisations expressed concerns about the project, because:

- *"California is one of the most seismically active states in the U.S. and earthquakes pose a risk in the project area*";
- "*Elk Hills is in a seismically active region that has generated structurally significant earthquakes in recent times*";

- "*Studies link CO_2 injection to earthquakes. For example, a 2012 study concluded that large-scale geologic storage of CO_2 carries has a "high probability" of triggering earthquakes*";
- "*large-scale CCS is a risky, and likely unsuccessful, strategy for significantly reducing greenhouse gas emissions*".

U.S. FEDERAL SUPPORT PROGRAMME FOR CCS (2019)

In 2019, the US-DOE announced an additional US$ 110 million in federal funding for research and development related to CO_2 capture, use, and storage. The new fund supported three programmes:

- FEED studies for commercial-scale CO_2 capture systems for coal and natural gas-fired power plants at nine project sites (US$ 55.4 million, from 2019 to 2021/2022);
- Regional initiatives to accelerate CCUS deployment at four project sites (US$ 20 million);
- CarbonSAFE Phase III- site characterization and assessment of CO_2 capture to accelerate wide-scale CC(U)S deployment (US$ 35 million).

The FEED studies were conducted at the following nine power plants: Panda Energy Plant, Prairie State Energy Campus, Elk Hills Power Plant (Cal Capture), San Juan Generating Station, Gerald Gentleman Station, Dry Fork Station, Plant Daniel project, Mustang Station, and Project Tundra. Three of the nine FEED sites have so far decided against a CCS project. With the exception of the Tundra project, no investment decision for a commercial CCS plant is imminent at any of the sites. The planning of the CCS project at Project Tundra has already been funded with more than US$ 50 million in public funds. The US$ 1.45 billion project is expected to be funded by federal 45Q tax credits.

Panda Energy Sherman plant (completed)

The FEED study at Panda Energy Fund's 803 megawatts Sherman power plant in Grayson County, Texas, looked at retrofitting Panda's natural gas-fired combined cycle gas turbine power plant with CO_2 capture and compression equipment. The proposed post-combustion technology was based on an amine-based absorbent. The FEED study estimated capture costs of US$ 114,50 per tonne of CO_2, a 67.3-megawatt reduction in the net output of the power plant in supplying steam and electricity to the post-combustion technology, and recommended a pilot testing programme to resolve design uncertainties. Following the completion of the FEED study, there is no indication that Panda intends to implement CCS technology at its Sherman site.

Mustang Station (planned)

This FEED study aimed to retrofit Golden Spread Electric Cooperative's (GSEC) Mustang Station with solvent-based post-combustion CO_2 capture technology. The 925 megawatts natural gas-fired power plant was commissioned from 2000 to 2006 and is located in Denver City, Texas. The FEED study was conducted by the University of Texas at Austin and tested a Piperazine Advanced Stripper process, a CO_2 capture process with solvent regeneration, at plant Daniel. The study was designed to provide information on the benefits and economics of integrating CO_2 capture from a power station. The results of the study are not yet publicly available. GSEC's 2020 and 2021 annual reports did not address the FEED study and did not announce plans for a CCS project.

Gerald Gentleman Station (planned)

This FEED study aimed to retrofit Nebraska Public Power District's (NPPD) Gerald Gentleman Station with solvent-based post-combustion technology for CO_2 capture and compression. The 1,363 megawatts plant is located near Sutherland, Nebraska and generates electricity from two coal-fired units that were commissioned in 1979 and 1982. The FEED was conducted by Ion Engineering, the developer of the proposed CO_2 capture system. The study assessed the deployment of the technology and the economic viability for the 700 megawatts Unit 2 of the power plant. The results of the study are not yet publicly available. The US-DOE funded the FEED study with US$ 5.8 million.

Plant Daniel (planned?)

This FEED study aimed to retrofit Mississippi Power Company's Plant Daniel with Linde- BASF's aqueous amine solvent-based post-combustion CO_2 capture technology. Plant Daniel has two coal-fired and two natural gas-fired units and is located in Jackson County, near Escatawpa, Mississippi. The FEED study was conducted by Southern Company Services for Plant Daniel's natural gas-fired Unit 4. The results of the study are not yet publicly available. The US-DOE funded the FEED study with US$ 5.6 million.

U.S. FEDERAL SUPPORT PROGRAMME FOR CARBON CAPTURE RESEARCH AND DEVELOPMENT (2020)

In 2020, the US-DOE announced federal funding of US$ 51 million for research and development in the field of CO_2 capture. The fund will support engineering studies of CO_2 capture from industrial sources and further development of materials and processes for CO_2 capture. The projects are conducted at nine selected sites, including two cement plants, a steel mill, a hydrogen plant with steam methane reforming, an ethanol plant, and coal and natural gas power plants. The lifetime of the projects is up to five years. The US-DOE's National Energy Technology Laboratory (NETL) is responsible for managing the selected projects.

US-DOE'S FLEXIBLE CARBON CAPTURE AND STORAGE (FLECCS) PROGRAM (2020)

In 2020, the US-DOE announced federal funding of US$ 43 million in the field of CO_2 capture. The FLECCS program aims to "*quickly advance our carbon capture technology to bring us closer to flexible, low-cost, net-zero carbon electricity systems*".

INFRASTRUCTURE INVESTMENT AND JOBS ACT (2021)

The Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law Program includes US$ 12.2 billion to demonstrate carbon capture, transport, utilization, and storage (CCS, CCUS) and direct air capture (DAC) in the U.S., including:

- up to US$ 2.54 billion to develop "*six integrated carbon capture, transport, and storage demonstration projects that can be readily replicated and deployed at fossil energy power plants and major industrial sources of CO_2, such as cement, pulp and paper, iron and steel, and certain types of chemical production facilities*";
- up to US$ 2.25 billion to develop large-scale, commercial storage projects with capacities to store at least 50 million tonnes of CO_2, along with associated CO_2 transport infrastructure (CarbonSAFE Phase III and IV);
- up to US$ 92 million to design regional CO_2 pipeline networks.

INFLATION REDUCTION ACT (2022)

In August 2022, the Inflation Reduction Act (IRA) was passed and includes far-reaching commitments for the CO_2 capture industry. IRA expanded and extended the 45Q tax credit, by lowering the threshold requirements for eligible projects, extended the timeframe for facilities to claim credits to twelve years, and significantly increased the value of the 45Q tax credits created in 2008. For CO_2 capture on industrial and power generation facilities, the tax credit was raised to US$ 60 per tonne of CO_2 captured when used for EOR or other industrial uses (CCUS) and to US$ 85 when used for geologic sequestration. For CO_2 captured by direct air capture (DAC), the tax credit was raised to US$ 130 per tonne of CO_2 captured when used for EOR or other industrial uses (CCUS) and to US$ 180 when used for geologic sequestration (DACCS). With this development, the US federal 45Q tax credit creates additional revenue streams for power plants and other fossil-fuel dependent industries, and wastes taxpayer money on technologies that are neither efficient nor a solution to climate change.

In response to the subsidies for carbon capture in the IRA, the Indigenous Environmental Network stated that "*the Inflation Reduction Act (IRA) is a distraction from the need to declare a Climate Emergency, while allowing polluting industries to continue business as usual*". People vs. Fossil Fuels, a coalition of over 1,200 organizations campaigning for the end of the fossil fuel era, delivered a petition with more than 500,000 signatures calling on the White House to declare a climate emergency in order to rapidly advance just, renewable energy, to end onshore and offshore drilling and to stop the federal approval of new fossil fuel projects and exports. The Climate Justice Alliance compiled a list of threats, weaknesses and missed opportunities arising from IRA, concluding that "*the harms of the bill as it is currently written outweigh its benefits*" and that the IRA "*is not a climate justice bill*".