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WHITE PAPER

CCUS hubs in Brazil: Making the case, breaking the barriers

FEBRUARY 2024

About this report

CCUS Hubs in Brazil: Making the Case, Breaking the Barriers is a report from the Oil and Gas Climate Initiative, with support from Petrobras. It is based on a proprietary study conducted by S&P Global in May 2023 regarding the potential for a CCUS hub in Brazil and its attendant economic effects, as well as additional desk research. The S&P Global study includes technical modeling on hub placement and other factors, and econometric modeling on GDP and employment.

OIL AND GAS
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About The Oil and Gas Climate Initiative

The Oil and Gas Climate Initiative is a CEO-led organization bringing together 12 of the world's largest oil and gas companies to lead the industry's response to climate change. It aims to accelerate action towards a net zero emissions future consistent with the Paris Agreement.

OGCI members are Aramco, bp, Chevron, CNPC, Eni, Equinor, ExxonMobil, Occidental, Petrobras, Repsol, Shell and TotalEnergies. Together, OGCI member companies represent almost a third of global oil and gas production.

OGCI members set up Climate Investment to create a US$1 billion-plus fund that invests in companies, technologies and projects that accelerate decarbonization in energy, industry, built environments and transportation.

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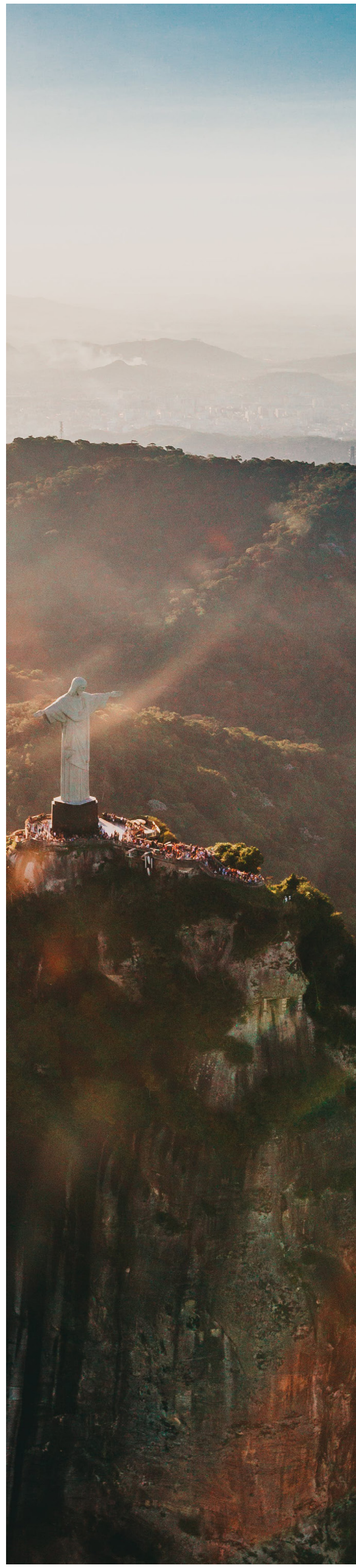

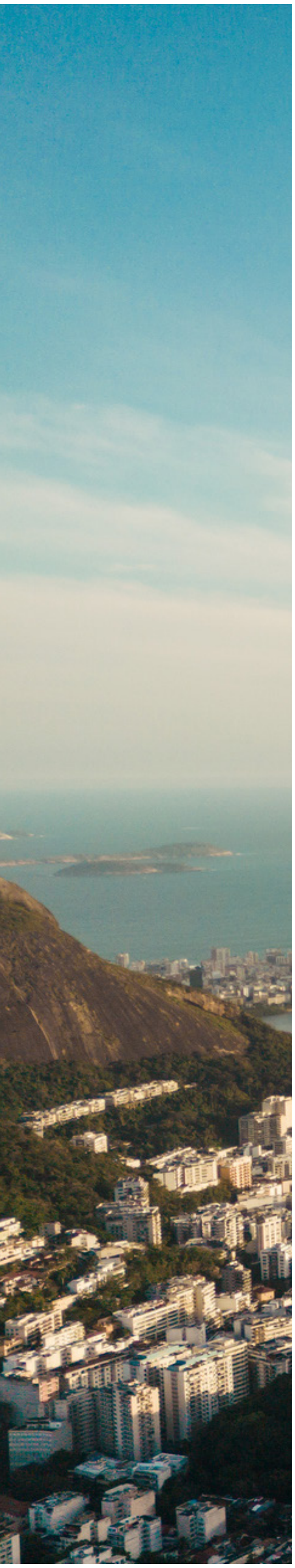

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Executive summary

Global interest in carbon capture, utilization and storage (CCUS) has never been higher. The urgency of climate action, combined with limited decarbonization options for several hard-to-abate sectors, gives CCUS prominent appeal on the menu of sustainability technologies.

In Brazil, CCUS could help the country's growing industrial sectors meet their green ambitions and boost their presence in a rapidly decarbonizing global market. This report examines the economic case for CCUS in Brazil and the business-model and policy levers the country could use to cultivate a CCUS ecosystem.

The key findings are as follows:

Decarbonization pressures – especially from top overseas trade partners – are spurring green transformations in a variety of Brazilian industrial sectors, in particular iron and steel and ethanol.

Proprietary analysis of existing data, conducted for this report, has identified eight places around the country that could store a significant amount of carbon dioxide, including two areas off the country's south-east coast that could account for roughly 95% of total domestic storage reserves.

Policy certainty, in the form of clear CCUS regulations at the federal level, combined with a reduction in import taxes, could reduce Brazilian CCUS costs by an average of 18% across seven sectors analyzed.

An economic projection calculated for this study suggests that CCUS hub development could spur up to $3.2 billion per year in GDP growth and stimulate the creation of 210,000 new jobs in Brazil.

Brazil can look to overseas models for policy frameworks that foster CCUS, including via tax and fiscal policy, research and development (R&D) support and more.

INTRODUCTION

Carbon capture and decarbonization

CCUS presents a promising opportunity for countries to reduce their carbon dioxide emissions from industrial sectors where few viable alternatives exist. The technology started as a niche application in oil extraction but has now evolved into a 360-degree decarbonization solution. This report makes the case for CCUS in Brazil as the country works to meet its climate ambitions in a way that preserves industry and boosts the economy.

CCUS on the global agenda

CCUS has been used for decades as a way to coax oil out of wells nearing depletion – a process known as enhanced oil recovery (EOR). As climate pressures grow, the technology is now seen as a prominent decarbonization lever that can be used by hard-to-abate sectors to store carbon dioxide geologically, independent of fossil fuel production. CCUS is now spreading across the industrial landscape as companies race to meet net-zero goals against a challenging technological backdrop. After years of slow growth or stagnation for much of the 2010s, CCUS has exploded in popularity since 2017, with nearly 250 megatonnes per annum (Mtpa) of carbon dioxide storage capacity online or in the works as of end-2022 – a 45% gain over the previous year.

This growth builds on momentum generated by the Paris Agreement to limit the rise in global temperatures to no more than 2°C, and ideally below 1.5°. Translated into a net-zero-by-2050 global goal, the Clean Energy Progress Tracker from the International Energy Agency (IEA) calls for 1.2 gigatonnes (Gt) of CCUS per year by 2030. The sector will need to expand rapidly in the years ahead in order to meet expectations.

01

MAKING THE CASE,
BREAKING THE BARRIERS

Decarbonization of Brazilian industy

CHAPTER ONE

Decarbonization of Brazilian industry

Brazil recently strengthened the GHG mitigation target it set under the Paris Agreement. The country now aims to reduce emissions by 48.4% by 2025 and 53.1% by 2030, both compared with 2005 levels; its plan to reach carbon neutrality by 2050 remains unchanged. CCUS could play a substantial role in helping the country meet these goals, while supporting key industries and creating jobs.

Two heavy industries in particular – iron/steel and bio-ethanol – could see significant CCUS activity. Decarbonization pressures, both domestically and emanating from overseas markets, are set to impact both sectors as Brazil looks to maintain and grow their international stature.

Iron and steel

Brazil is the world's ninth largest steelmaker, producing a total of 34 Mt in 2022. Of this, 13.5 Mt was exported, a 17% jump from the previous year. In the first half of 2022, the volume of these exports that went to Europe surged 710% compared with the same period of 2021, as Russia's invasion of Ukraine scrambled global markets. Brazil's steel industry has an immense opportunity to capitalize on this trend but will need to adapt.

Europe's carbon levy boosts the business case

Europe has one of the world's largest and arguably its most successful emissions cap-and-trade system, the EU ETS. In order to prevent a decarbonizing European industry from losing competitiveness against global peers, Europe has recently implemented the Carbon Border Adjustment Mechanism (CBAM), a tariff on imported goods – including iron and steel – made via carbon-intensive processes (Box 1). CBAM requires importers to report their emissions starting in 2023, with fee collection beginning in 2026. Tariffs increase gradually over several years.

BOX 1

Europe's Carbon Border Adjustment Mechanism

Europe's aim is to prompt its industry to decarbonize without being undercut by imports from places with no price on carbon.

What products are covered?

- Power
- Iron and steel (including some sub-products)
- Cement
- Fertilizer
- Aluminum
- Hydrogen
- Some polymers

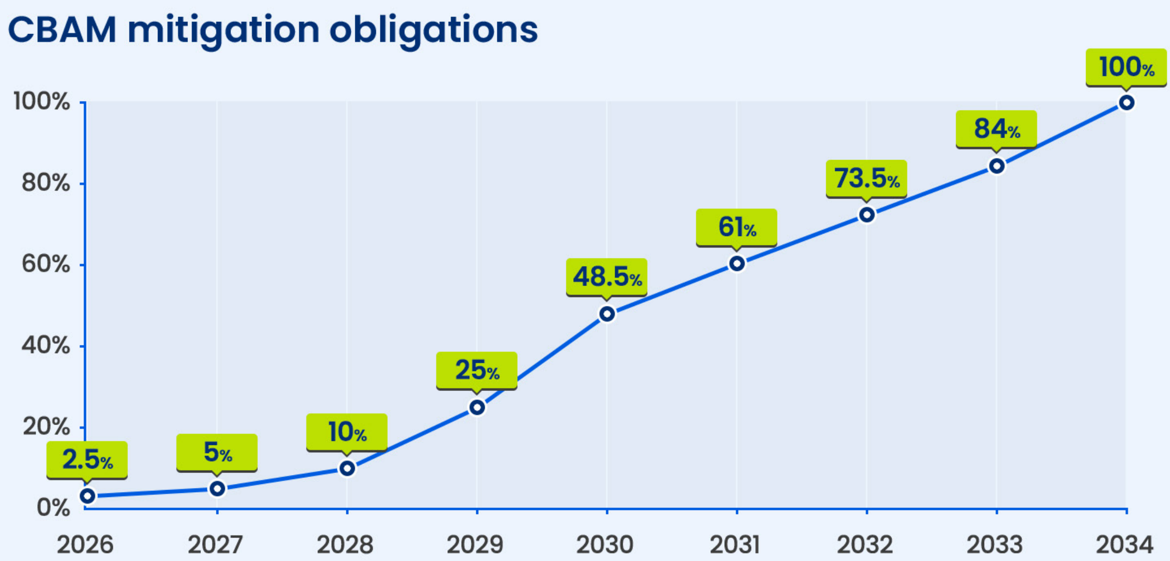
How does it work?

- Importers must report the embedded emissions of their products, verified by independent third-parties.
- Both direct and indirect emissions will be considered.
- Importers must purchase CBAM certificates to cover emissions.
- Producers from countries where a carbon price exists will pay only the difference between the EU ETS and their domestic fee.
- Importers who fail to report will be taxed the same rate as the worst-performing 10% of domestic EU producers.
- The cost of a CBAM certificate at a given moment in time is the average weekly price of the EU domestic emissions-trading allowance.

What is the timeline?

- 2023: reporting obligation kicks in.
- 2026: importers must purchase CBAM certificates covering 2.5% of emissions.
- 2026-2034: share of emissions covered by CBAM rises gradually (Figure 1).
- 2034: importers must purchase CBAM certificates covering 100% of emissions.

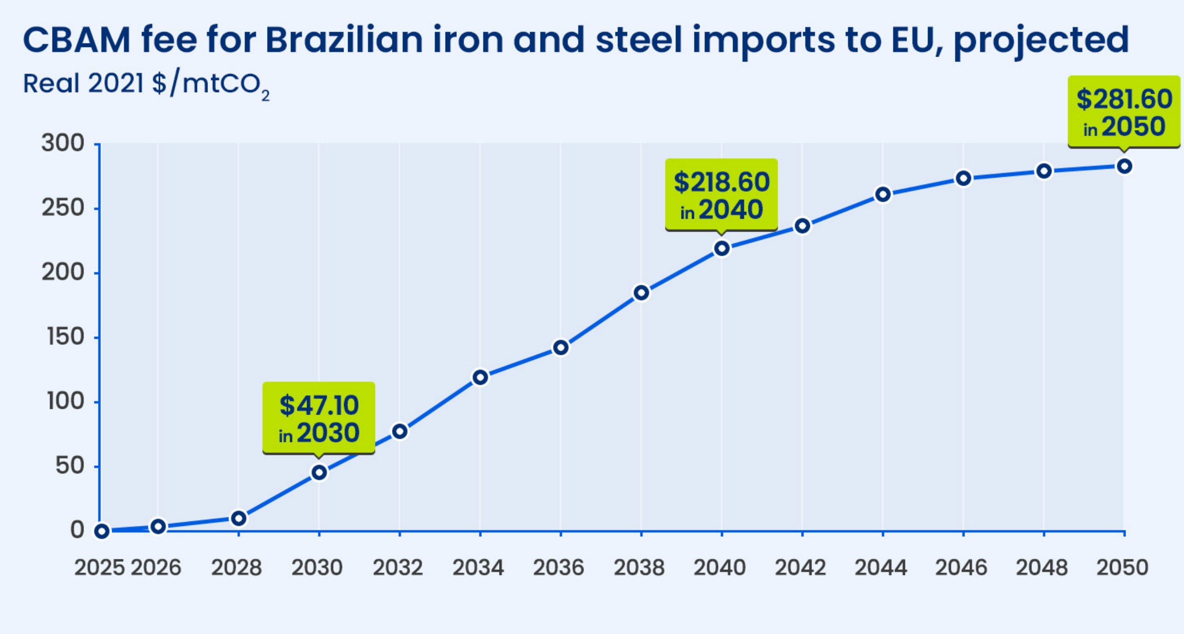
FIGURE 1



Source: S&P Global

S&P Global expects that fees Brazilian steelmakers will have to pay to import unabated products to the EU could approach $281.60 per tonne (t) of carbon dioxide by 2050, up from nothing today (Figure 2). Given the increasing importance of the European market to Brazilian steelmakers, CBAM could potentially drive significant decarbonization efforts in the sector.

FIGURE 2



Source: S&P Global

Decarbonizing steel with CCUS

The options available to decarbonize iron and steel are limited. Experts consider it one of the hardest-to-abate sectors, due both to its reliance on fossil energy to generate the high temperatures needed for processing, as well as the carbon dioxide emitted in the conversion of iron to steel.

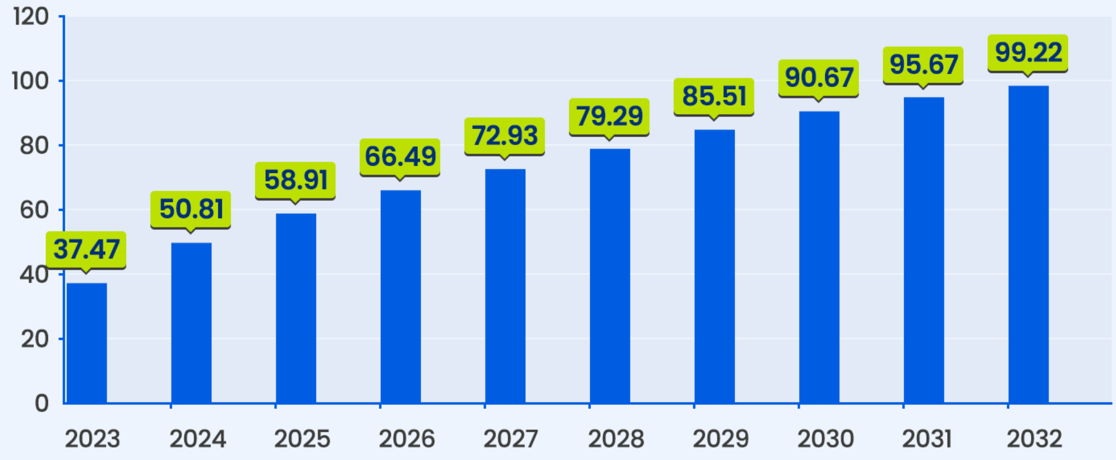
This is spurring major steelmakers to consider CCUS as a decarbonization lever. China's Baowu Group, the world's largest steel producer, is mulling a plan that could store tens of millions of tonnes of carbon dioxide per year, while second-largest steelmaker ArcelorMittal of Luxembourg also sees CCUS on its decarbonization roadmap. CCUS's importance would grow if IEA projections that it will contribute around 15% of total iron and steel industry decarbonization by 2060 are realized.

Bio-ethanol

Brazil is the world's second-largest ethanol producing country, trailing only the US and accounting for 27% of global volumes of the fuel. The country has implemented a policy framework, RenovaBio, to support the ecosystem. Fuel distributors must purchase decarbonization credits (CBIOs) in line with mandatory targets set by Brazil's government, which will increase over time (Figure 3). Ethanol producers issue CBIOs, which represent one tonne of avoided carbon dioxide equivalent (CO_2e) relative to a fossil-fuel baseline. CBIOs can be traded on the open market, with prices determined by supply and demand (Figure 4).

FIGURE 3

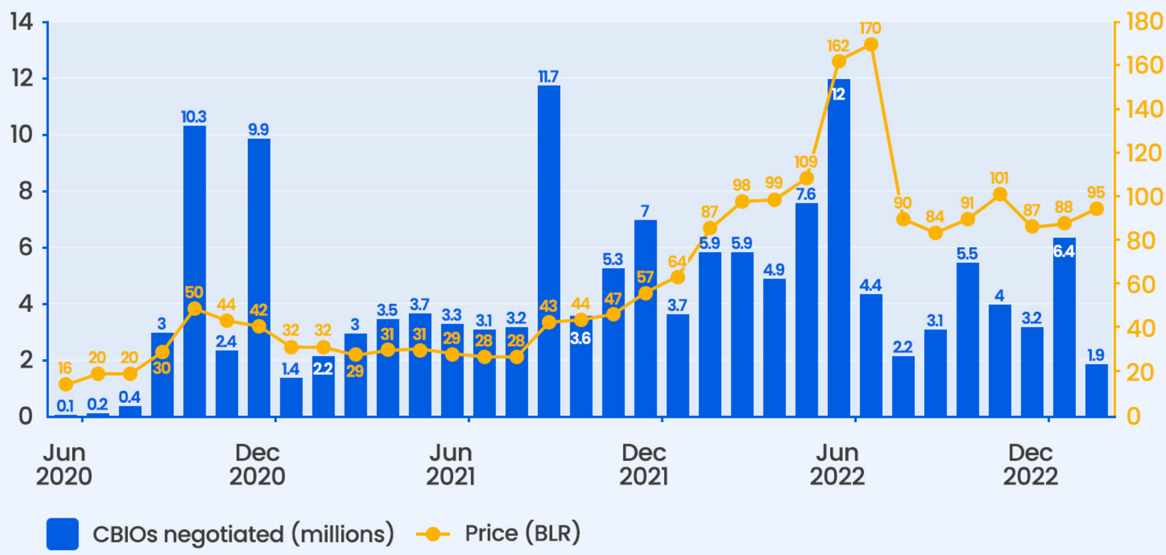
RenovaBio targets
(millions of CBIOs, in aggregate)



Source: S&P Global

FIGURE 4

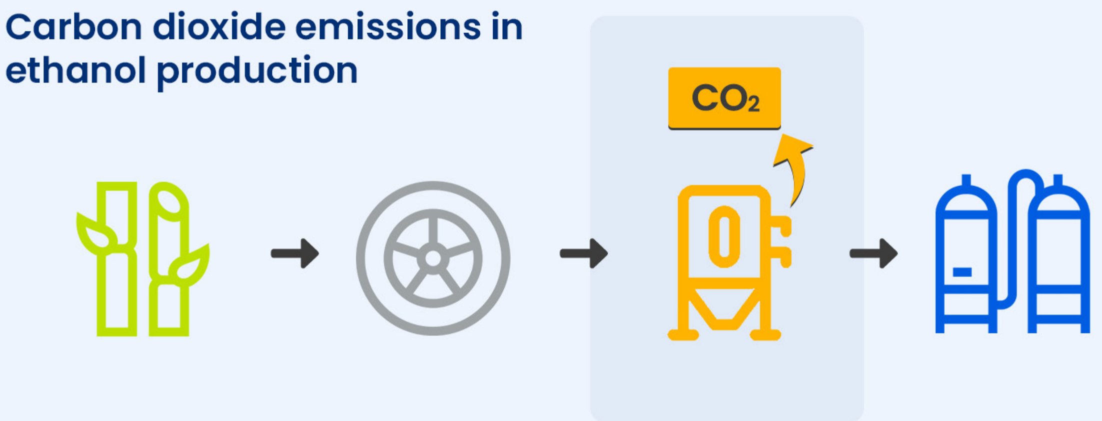
Price and quantity of CBIOs sold under RenovaBio



Source: S&P Global

The steadily rising price of CBIOs, which is expected to exceed \$50/tCO_2e by the early 2030s, could spur increased adoption of decarbonization methods, such as CCUS, along the biofuel supply chain. This includes capture of carbon dioxide released during the conversion of raw crop feedstock (in Brazil's case, usually sugarcane) into ethanol (Figure 5), where the emissions are in a highly purified form that is much less costly to process than from other sources. It could also potentially include use of ethanol as part of a bioenergy with carbon capture and storage (BECCS) process, in which biomass is burned to generate electricity or heat and the emissions captured.

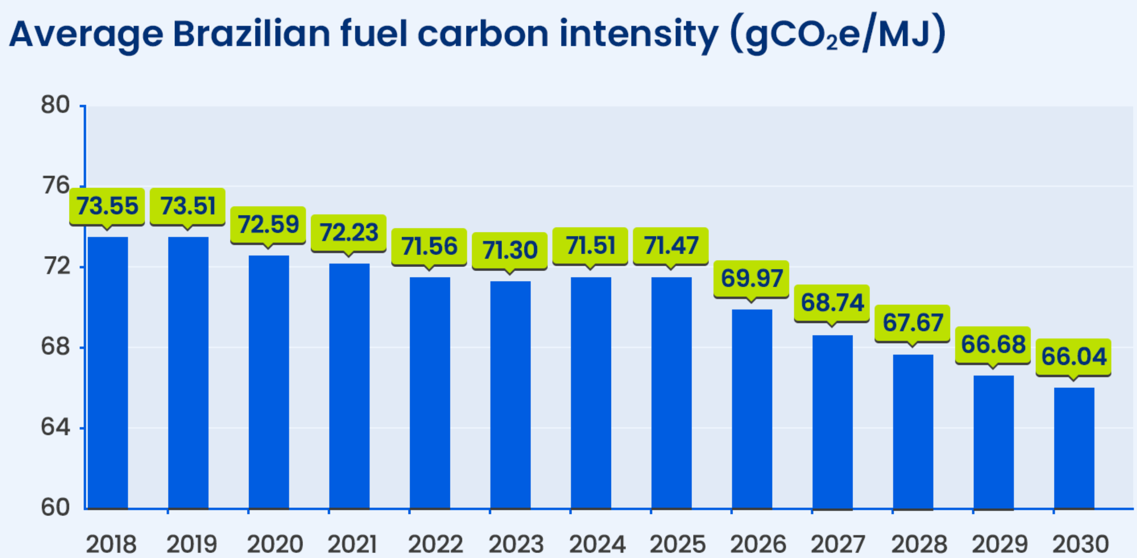
FIGURE 5



Source: S&P Global

The growth of CCUS – including BECCS, which the IEA says must reach 190 Mt/year globally by 2030 in order for the world to reach net-zero emissions by 2050 – could be a factor that will help drive down the average carbon intensity of Brazil's overall fuel mix, a key lever of the country's broader decarbonization strategy (Figure 6).

FIGURE 6



Source: Brazilian Ministry of Mines and Energy

This will also help boost the prospects of Brazilian ethanol in overseas markets with their own low-carbon fuel standards (LCFSs). California is a prominent example: in 2009 it was the first jurisdiction in the world to implement a LCFS, which was updated in 2019 to allow fuels decarbonized via CCUS. It provides credits for fuel producers – including those based outside the state – whose products meet or undershoot a carbon intensity level set by state regulators. This level will decline over time. Modeling indicates that the credit value could exceed $200/t$CO_2e$ by 2040.

Brazil's sugarcane-based ethanol is already present in the state due to its lower carbon footprint compared with the corn-based ethanol prevalent in America's Midwest. CCUS has the potential to further boost its popularity – as well as the price premium Brazilian producers can enjoy on the California market. This, in combination with CBIOs, could help defray the cost of ethanol CCUS, which is around \$75/tCO_2e, including transport.

Other sectors

Although the economic case for CCUS adoption in Brazil's iron and steel and ethanol sectors is compelling, CCUS technologies can capture carbon from virtually any point-source of emissions, giving them wide applicability across industries. According to S&P Global analysis, other sectors in Brazil that could also benefit from CCUS adoption include cement, oil refining, ammonia, methanol, power generation and gas processing. Brazil's global position in cement and oil refining in particular is sizeable and growing.

Cement
Brazil is the world's seventh largest maker of this essential good, according to one estimate. The cement industry accounts for about 8% of global emissions and faces a particularly difficult path toward decarbonization, due to the large share of carbon dioxide released by the industrial process itself, rather than from energy use.

CCUS may be able to fill much of this gap, and the IEA forecasts it will account for 18% of the sector's emissions reductions globally by 2060. This is spurring a number of leading cement companies, including Holcim, the world's top producer, to integrate CCUS technologies. HeidelbergMaterials, another major player, is working on a plant in Norway that could capture 400,000 tonnes of carbon dioxide per year starting in 2024.

Oil refining
New discoveries have increased Brazil's known oil deposits significantly in recent years, making it one of the world's top-10 producers of liquid fuels, with an annual refining capacity of 2.3 million barrels per day. With a potential boost to domestic oil refining capacity looming, CCUS could potentially reduce the emissions generated in this process. Globally, refining is responsible for around 5% of global greenhouse gas emissions, meaning that any dent in its carbon footprint could make a meaningful contribution to the climate battle.

02

MAKING THE CASE, BREAKING THE BARRIERS

CCUS in Brazil: Considerations for a hub

CHAPTER TWO

CCUS in Brazil: Considerations for a hub

What is a CCUS hub?

CCUS is a capital-intensive activity that requires significant resources and technical know-how. Its value chain can broadly be divided into three components:

1. **Capture:** carbon dioxide is separated from other chemicals emitted during an industrial process before it can enter the atmosphere.
2. **Transport:** carbon dioxide is moved from the point of capture to a storage site.
3. **Storage:** carbon dioxide is sequestered underground, permanently, with no leakage.

Complex considerations colour each step, making the creation of a full CCUS value chain a difficult proposition for a single company. Especially on the storage side, CCUS benefits from the economies of scale that a consortium of players can provide. Many viable storage sites are massive underground reservoirs that a single company would be hard-pressed to fill. Transport infrastructure – usually in the form of pipelines or ships – is also more cost-efficient when several partners work together in cooperation and co-investment.

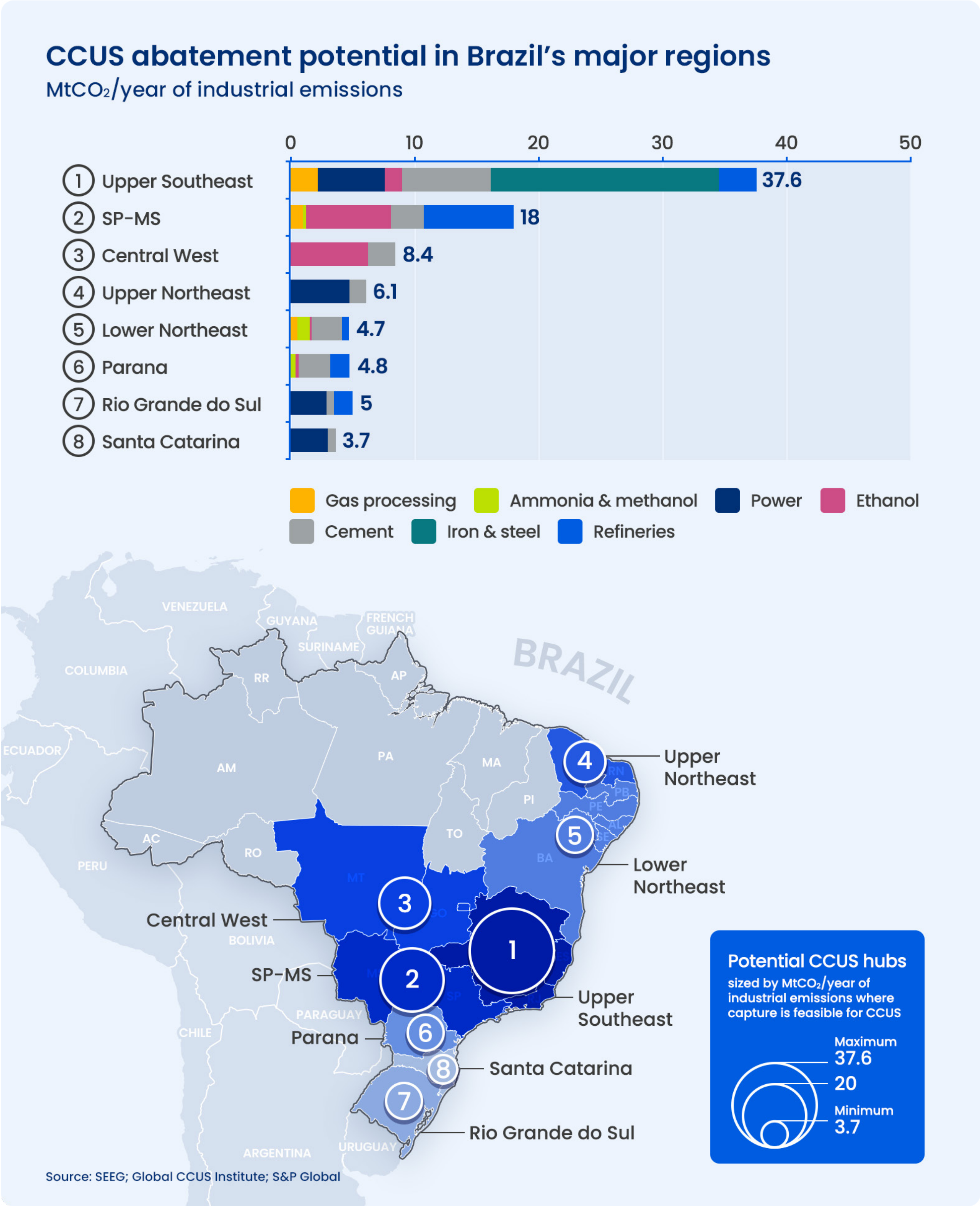
This is where CCUS hubs come in: they are collections of industrial facilities, all plugging into a single shared transport and storage apparatus. Several countries are playing host to active or nascent CCUS hubs (see Chapter 4) to provide the right conditions to meet the needs of industrial decarbonization and net-zero goals.

Conditions could be ripe for a hub in Brazil

Much of Brazil's population and industrial activity are concentrated in the country's south-east coastal areas. Significant iron and steel activity in particular takes place in a cluster of three states – Rio de Janeiro, Espírito Santo and Minas Gerais – labelled by S&P Global as Upper Southeast. Ethanol production, meanwhile, is concentrated in two regions: SP-MS, composed of the states of São Paulo and

Mato Grosso do Sul, and Central West, composed of the states of Goiás, Distrito Federal and Mato Grosso (Figure 7).

FIGURE 7

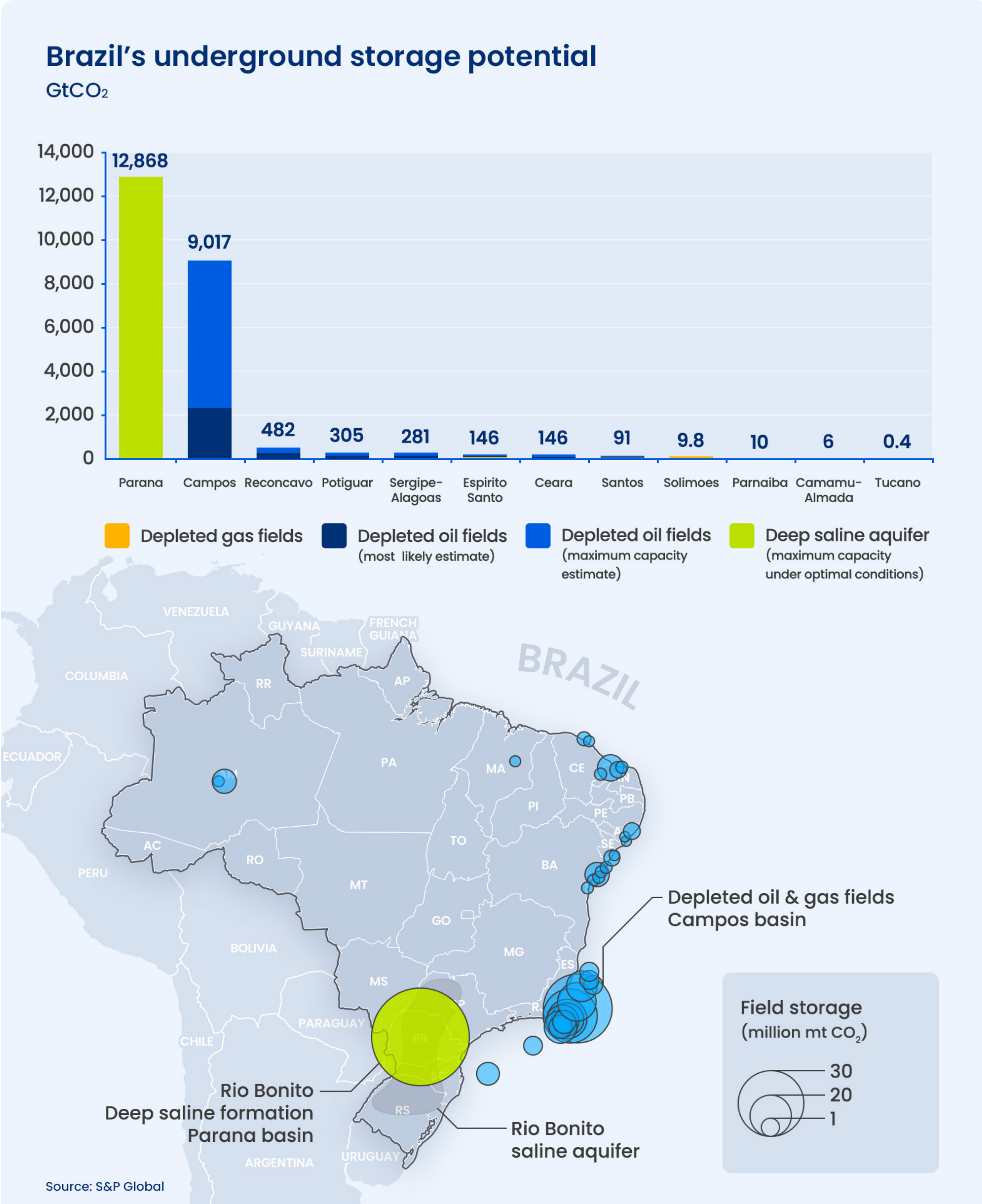


S&P global analysis of existing data has unveiled eight places that could potentially store a significant share of emissions from these and the other sectors described above.[1]

NOTES
[1] No original on-site surveys were conducted for this study; potential fitness as a carbon dioxide reservoir could differ from real-world findings.

It found substantial capacity in two areas in particular: the Campos depleted oil and gas fields, off the coast of the Upper Southeast, and the Parana basin, where a massive deep saline formation has storage potential of over 12 Gt of carbon dioxide (Figure 8). Public data on the aquifer is virtually non-existent, but Petrobras has conducted initial subsurface work to better understand pressure-based storage resources. This combination of highly concentrated industrial emissions and vast storage potential positions these areas well for a CCUS hub, provided various hurdles can be overcome.

FIGURE 8



Barriers to Brazil's hub development

Brazil faces a number of challenges in implementing a CCUS hub. These factors have sown hesitation among potential industrial players and must be overcome in order to spur the creation of a CCUS value chain akin to overseas peers. Barriers generally fall into three categories: **financial and commercial, regulatory,** and **technological.**

Financial and commercial

- Cross-sector risks make investment challenging for a typical investor. All links in the value chain – from the capture plant to transport and storage assets – must be operating simultaneously in order for the economics to work out.
- CCUS is capital-intensive and the cost of capital is critical in improving project economics.
- Non-CCUS alternatives (e.g., plant retirement, fuel switching, renewable energy) can sometimes be deployed at lower cost and with incremental value streams; CCUS is pure cost (unless captured carbon can be monetized) and must be justified with clear price signals or incentives.

Regulatory

- Brazil currently lacks detailed CCUS regulations (legislation is under consideration but has yet to be passed).
- A bill on the Brazilian carbon market is under discussion in Congress.

Technological

- CCUS technology is proven but costs remain significantly high for Brazilian operators.
- Technology cost reduction roadmap remains unclear (see next section).
- Capture technology is less efficient for retrofitted facilities than greenfield sites.

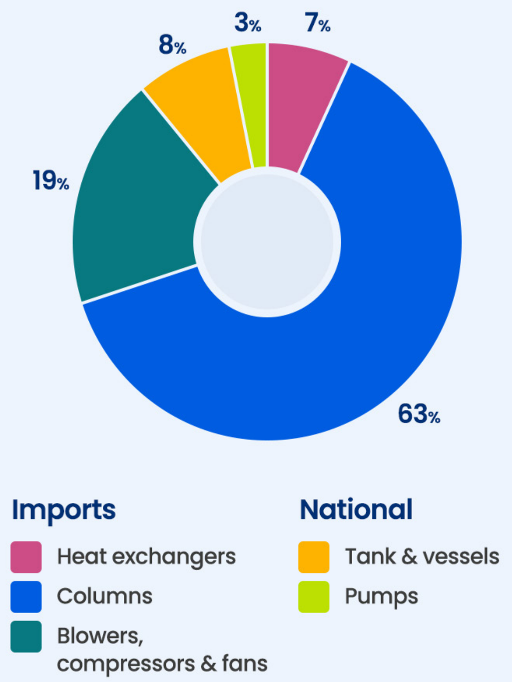
Bending Brazil's CCUS cost curve

Policy certainty is needed to not only spur the kind of value-chain coordination that CCUS players require. It can also help cut technology costs. In some cases, this could be a function of tax credits and subsidies along the lines of the US Inflation Reduction Act (IRA). While some factors affecting technology cost are subject to global trends, Brazil must tackle two policy-related fiscal barriers that prevent substantial savings for hub developers: high import taxes and high weighted average cost of capital (WACC).

Taxes are the first barrier. According to S&P Global calculations, direct and indirect import taxes together average 65% for carbon capture equipment. This helps drive up the cost of imports, which occupy an outsized share – roughly 90% – of total capital expenditure (capex) on capture equipment (Figure 9).

FIGURE 9

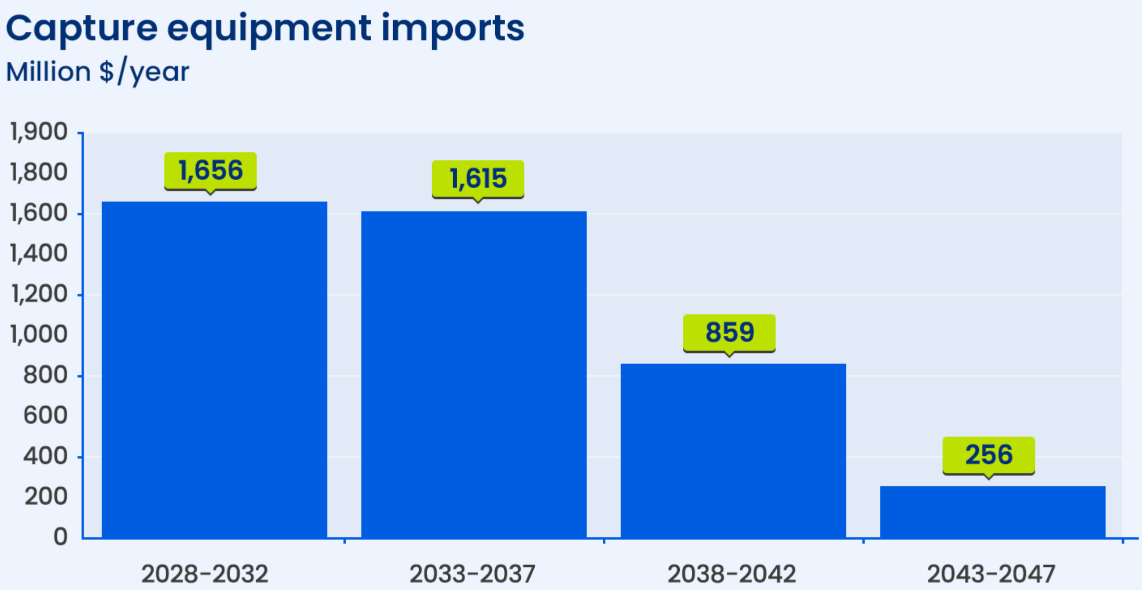
Capture equipment cost breakdown



Source: S&P Global

S&P Global projects that while a domestic supply chain could eventually eat into imports, through the late 2030s at least, Brazil will spend high sums on imported equipment, barely budging from current levels under a business-as-usual scenario (Figure 10). This implies that a significant sum of money that could go toward developing a local supply chain is being spent on imports and their associated taxes.

FIGURE 10



Source: S&P Global

The second barrier – high WACC – describes a conservative financing environment in which capital is both scarce and relatively expensive. This results from a confluence of factors, including overall prospects for CCUS amid rising decarbonization pressures. Policy certainty could go a long way to lowering WACC for carbon capture, which S&P Global research suggests could be as high as 14% without any change to the regulatory framework, compared with single-digit WACCs in places like Canada and the US. A clear regulatory framework – potential models for which will be explored further in Chapter 4 – could shave four percentage points off this figure, according to S&P Global modeling. Combine this with repeal of import taxes, and savings could be substantial.

03

MAKING THE CASE,
BREAKING THE BARRIERS

The business and economic case for CCUS

CHAPTER THREE

The business and economic case for CCUS

The global context

Industrial decarbonization can be an intimidating prospect for companies whose business models depend on fossil fuels and unabated emissions. The IEA projects that 5 million workers will need to shift out of the fossil-fuel industry in order for the world to reach net-zero emissions by 2050; not all will have clean-energy jobs waiting for them.

This makes CCUS an appealing way for industrial firms to maintain their operational structures and reduce pollution while planning future steps of their energy transition. As new technologies and market incentives arise, different options may become more competitive, but CCUS can provide specific sweeteners of its own. These arise through mechanisms like carbon markets (both mandatory and voluntary), tax credits, low-carbon product premiums and carbon dioxide as a commodity. The latter requires utilization of carbon dioxide rather than storage, but could be an option for emitters if markets for products like synthetic fuel (which use captured carbon dioxide combined with hydrogen) mature.

Price premiums on low-carbon products are now found in jurisdictions around the world, such as the California LCFS. These are often spurred on by carbon markets or regulations. This again points to the essential role governments play in fostering the kind of decarbonization that CCUS can enable.

Governments have several reasons of their own to support CCUS value chains (Box 2). Such value chains can be an integral part of a "just transition" away from a carbon-based economy. They can catalyze new industries and provide scale for nascent innovations like direct air capture with storage (DACS). Beyond simply providing decarbonization roadmaps for heavy industry, CCUS hubs can have trickle-down effects on the wider economy.

Box 2: The macroeconomic case for CCUS hubs

Evidence is accumulating that points to the macroeconomic benefits from CCUS hubs. From job creation and preservation to kickstarting carbon markets, hubs provide value beyond climate and decarbonization levers:

1 Enabling a just transition

Roles in the fossil-fuel industry that may be at risk in a transition to clean energy can be repurposed to support CCUS. Oil and gas industry skills such as subsurface exploration are a vital part of CCUS value chains. Similarly, CCUS can help industrial regions hold onto – and even increase – employment while decarbonizing. This could help minimize disruption to the wider community from economic dislocations like job losses.

- One study from the UK estimates that CCUS could preserve 53,000 jobs in energy-intensive industries by 2030.
- Developers of the East Coast Cluster, a UK hub, include several economic projections for their project:
  - Supporting and/or creating roughly 25,000 industrial jobs between 2023 and 2050
  - More than £2 billion average gross value added to 2050

2 Scaling up carbon markets

Article 6 of the Paris Agreement establishes a mechanism through which countries can buy, sell and trade carbon credits. The aim is to form a robust carbon market that unlocks incentives for carbon dioxide to stay out of the atmosphere. Given the immense quantities of carbon dioxide that could potentially be sequestered in underground storage sites, CCUS can serve as a pathway to carbon-market formation, with countries that boast significant geological storage resources managing carbon for larger regions.

3 Boosting hydrogen and DACS

Hydrogen's role in decarbonization is growing as industries look to this versatile energy carrier for power and heat that cannot come from electrical sources. Producing hydrogen from natural gas with CCUS is currently the cheapest way to produce low-carbon hydrogen, which could subsequently provide energy for other industrial applications in the hub area. Pre-existing transport and storage infrastructure also helps build the business case to locate DACS facilities around CCUS hubs, which could accelerate development of this nascent sector.

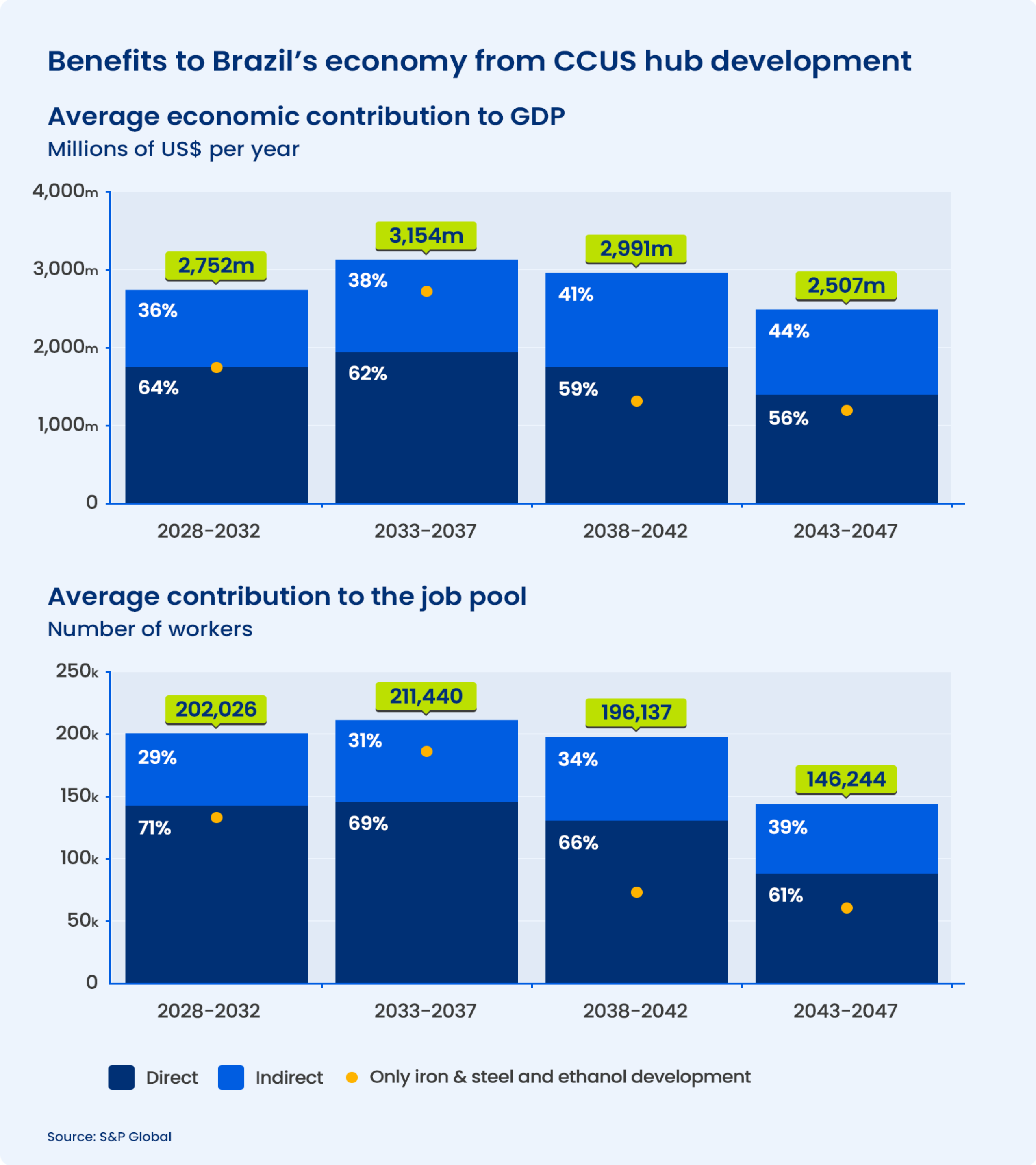
The economic case in Brazil

Brazil could see similar broad-based benefits from CCUS. According to S&P Global modeling, successful implementation of all eight potential hubs could contribute up to $3.2 billion per year to Brazil's GDP and stimulate the creation of 210,000 new jobs (Figure 11).[2] Most employment over the first decade would occur in hub construction, while operations roles

NOTES
[2] This assumes a best-case scenario in which all hubs are built relatively quickly and with no major hurdles.

would take over subsequently. Multiplier effects amplify the spillover benefits to the wider economy, with $819,000 worth of GDP in areas adjacent to the CCUS value chain generated for each $1 million invested in capex or operating expenditure (OPEX) (Figure 12).

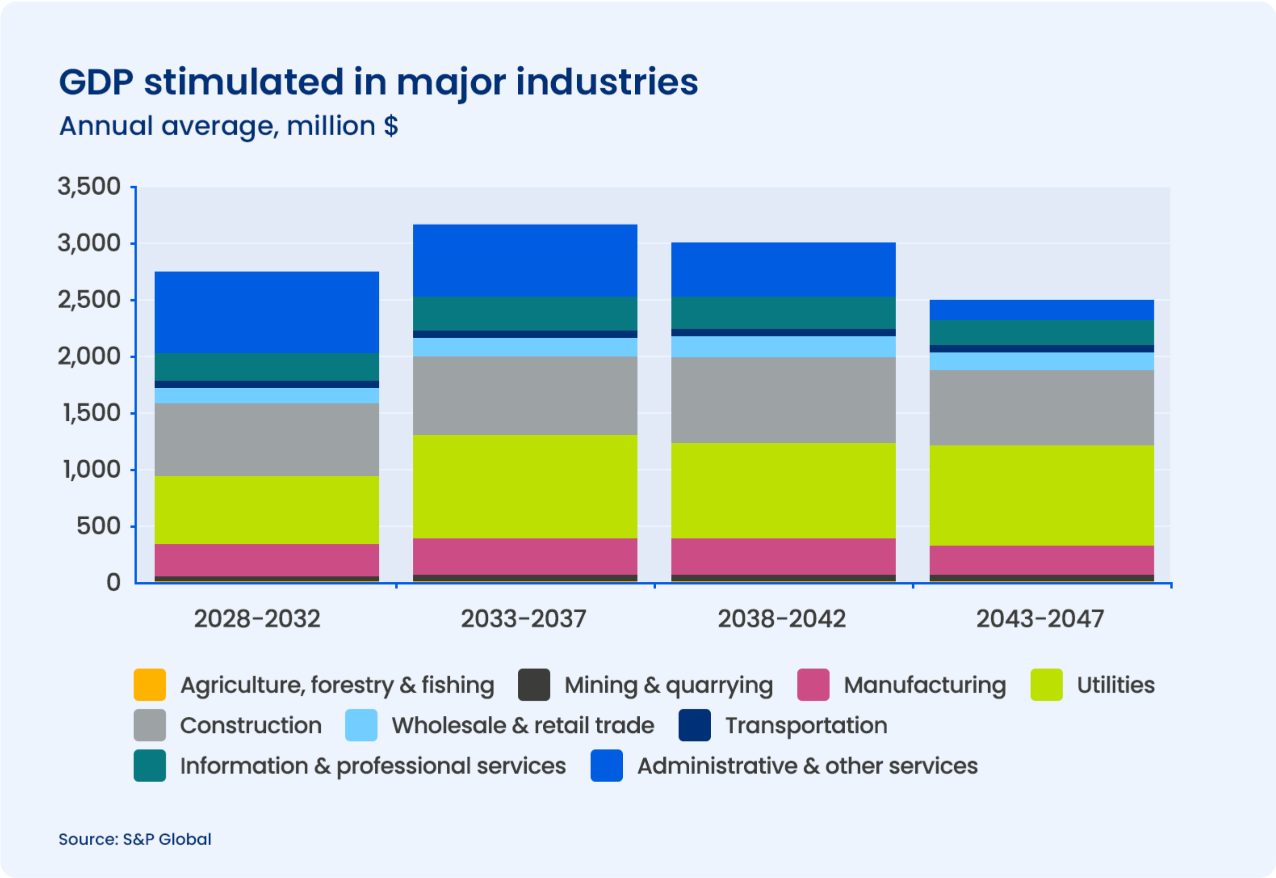
FIGURE 11



From 2028–2037, construction of plants and installation of CCUS equipment capex would support 83% of new jobs, including an average of 186,000 jobs per year from 2028–2032 and 155,000 jobs per year from 2033–2037. From 2038–2042, operation and maintenance activities would support 61% of new jobs – an average of 90,000 jobs per year, rising to 118,000 jobs per year from 2042–2047, as the CCUS industry continues to scale. This equates to 53 new jobs for every $1 million in direct capex or opex spending.

Utilities and construction will see significant GDP gains from the hub development, with 29% of the total added value flowing to the former, which includes electricity, steam, gas and water. Total added value for this sector could equal $18.4 billion from 2028–2050, while the construction sector could see $15.8 billion in added value over the same time frame.

FIGURE 12



04

**MAKING THE CASE,
BREAKING THE BARRIERS**

The path forward

CHAPTER FOUR

The path forward

Fostering a CCUS value chain depends on the willingness of industrial participants – including transport and storage operators – to commit to long-term investments. This takes policy certainty, an amenable financing environment and clear-eyed judgments about which business model will work best in a given context.

CCUS hub business models: three options

CCUS hub business models generally fall into three categories: full vertical integration, transport and storage integration, and independent operators.

- **Full vertical integration:** the same entity – either a single company, a joint venture or a public-private partnership – owns and operates the entire CCUS process, including capture, transportation and underground storage.
- **Transport and storage (T&S) integration:** the emitter installs capture equipment themselves or hires a third-party provider to do it. A separate entity, meanwhile, owns and operates the T&S infrastructure, charging a fee to the emitter.
- **Independent operators:** a range of separate transport operators and storage providers, owned and operated by separate entities, collaborate across the value chain, collecting fees from the emitter.

Each model has benefits and drawbacks, summarized in the table below:

	Benefits	Drawbacks
Full vertical integration	• Full control over the process • Maximum efficiency and cost savings	• Limits entrants to those with sufficient resources to establish a full value chain • May face regulatory scrutiny over anticompetitive behavior
T&S integration	• Reduces costs • Improves coordination between T&S components	• Lower level of specialization on different skillsets could lead to redundancy and inefficiency
Independent operators	• With different skillsets, companies can focus on one area and specialize • More flexible solutions	• Introduces various points of friction and competing interest between different companies • Lowest level of efficiency and cost savings

A mix of the three models can be found across top global hubs, although T&S integration is relatively popular as a midway point between full integration and full independence. Oil and gas companies in particular typically already have both T&S expertise and infrastructure at the ready. They will likely gravitate toward a T&S integration model, as seen in the below examples:

Country	Project	Model	Sponsor
UK	East Coast Cluster	T&S integration	Capture (C): NZT Power, H2Teesside and Teesside Hydrogen carbon dioxide capture T&S: bp, Equinor and TotalEnergies
UK	HyNet North West	T&S integration	C: Padeswood, Runcorn, Protos, BNL0 and HPP1 T&S: Eni
US	Bayou Bend	T&S integration	C: undefined T&S: Chevron, Talos Energy and Equinor
US	Illinois BECCUS	Full vertical integration	C, T&S: ADM
US	Donaldsonville	Independent operators	C: CF Industries T: EnLink Midstream S: ExxonMobil
Norway	Northern Lights/ Longship	T&S integration	C: Hafslund and Heidelberg T&S: Northen Lights JV (Equinor, Shell and TotalEnergies)
Netherlands	Porthos	T&S integration	C: Air Liquide, Air Products, ExxonMobil and Shell T&S: Porthos JV (EBN, Gasunie and Port of Rotterdam Authority)

A promising model sees oil and gas companies that run T&S repurposing existing gas pipelines and depleted fields for carbon dioxide. This is what Eni intends to do at HyNet North West, for instance. The Northern Lights JV – comprised of Equinor, Shell and TotalEnergies – on the other hand, will compress and liquefy carbon dioxide from a variety of industrial emitters across Europe, transport it by ship and store it in a saline aquifer under the seabed of the North Sea.

How to bring CCUS costs down

As discussed in Chapter 2, Brazil has some notable policy levers it could pull to lower the cost of CCUS in key sectors. At a global level, cost reductions from technological advancement and other factors could help make CCUS yet more economical, compounding the benefits accrued by favorable tax policy and a clear regulatory regime. In general, capture constitutes the costliest component of a CCUS project. Several companies are working on new, cheaper forms of capture; technologies in early rollout or drawing-board stages include next-generation solvents, membranes and sorbents, all of which could potentially solve problems with current capture methods.

Savings can also be found in other parts of the CCUS value chain beyond capture. Compared with improvements in capture technology, gains in these areas may be more incremental, but they are worth keeping an eye on:

- **Enhanced saline formation mapping:** better understanding of the subsurface terrain where carbon dioxide could be stored could help increase knowledge about the quality of reservoirs near industrial clusters. Although spent oil and gas fields can be repurposed for storage, these are not always located close to the sources of carbon dioxide. Better characterization of the subsurface could help reduce transport distances.

- **Carbon dioxide compression:** in post-combustion capture processes, significant amount of energy are used to prepare the captured carbon dioxide stream for transport. Low-pressure carbon dioxide streams could be compressed to a dense phase (>8 megapascals), easing transport and reducing associated costs.

- **Technologies enabling high utilization of shared infrastructure:** these include sensors and machine-learning applications that can help operators prevent downtime, detect wear-and-tear before it causes problems, forecast usage schedules and generally get the most out of each piece of equipment.

Policy enablers: the global context

Carbon regulations

Governments over the world are weaving together different strands of policy to incentivize CCUS. While the regulatory landscape in Brazil is still nascent, the country can learn from overseas peers where CCUS hubs are already in place or taking shape.

At the highest level, countries can foster CCUS by regulating GHG emissions. This will force companies to either switch to non-fossil forms of energy or capture emissions before they enter the atmosphere. Countries have enacted a slew of policies targeting GHG emissions, many involving carbon pricing; they generally fall into the following categories:

1 Regulations

Regulators set rules and standards and punish non-compliance

- For example, an emitter needs to reduce its carbon footprint by adopting a technological solution (or emissions management) or it will pay a fine for unabated emissions.

2 Pricing

Regulators set a tax on carbon emissions and/or enact an emissions-trading scheme (ETS).

- **Tax:** this is linked directly to emissions or carbon intensity of inputs. Governments collect the taxes to fund climate policies or return money to taxpayers. Compliance costs may be passed down to products and services.
- **ETS:** sometimes referred to as a cap-and-trade system. An ETS caps the total level of greenhouse gas emissions and allows those industries with low emissions to sell their extra allowances to larger emitters. By creating supply and demand for emissions allowances, an ETS establishes a market price for greenhouse gas emissions. The cap helps ensure that the required emission reductions will take place to keep the emitters (in aggregate) within their pre-allocated carbon budget. A carbon tax directly sets a price on carbon by defining a tax rate on greenhouse gas emissions. It is different from an ETS in that the emissions-reduction outcome of a carbon tax is not pre-defined, but the carbon price is.
- **Compensation mechanisms (baseline and credit):** these focus only on positive mitigation measures. Participation is voluntary and may or may not interface with regulated systems (such as an ETS). A parameter (baseline) is established, normally with reference to a business-as-usual scenario. Once this parameter is established, project activity proponents generate carbon credits by reducing their emissions to levels below those of the defined baseline. This generates emissions-reduction credits that can be used both for regulated entities (functioning as offset credits for an ETS), and also by companies or corporations, not covered by ETS regulations, that wish to voluntarily offset.

CCUS-specific policy enablers

Beyond emissions regulations, CCUS-specific policy enablers can take many forms. A robust, science-based framework for CCUS use and deployment is often the first step in any policy agenda; many countries will pair this with R&D support, direct grants and more; these are defined in the table below and matched with various global markets in Figure 13.

Enabler	Definition	Example(s)
Robust framework	Countrywide rules or strategic energy plan specifying intention to either capture/transport/store carbon dioxide or accelerate CCUS technology development	• Norway: carbon dioxide storage and transport regulations • UK: Goal of 20–30 $MtCO_2$/year of CCUS by 2030
Carbon dioxide standards	Regulations meant to drive down carbon dioxide emissions across the economy (see section above)	• UK: Road Vehicle Carbon Dioxide Emission Performance Standards
R&D support	Any R&D initiative that could provide innovation and technology for CCUS	• Norway: SkatteFUNN
Tax credits	Credit for carbon dioxide capture and storage/use to offset part of the investment and/or qualified research expenses for CCUS	• US: 45Q

Grants/direct funding	Financial aid that directly supports CCUS projects	• The Netherlands: SDE++
Carbon dioxide offtake/ storage guarantee	Assurance of CCUS commercial viability, needed to attract private capital and limit price risk	• UK: Contracts for Difference (CfD)

FIGURE 13

Countries with supportive CCUS policies

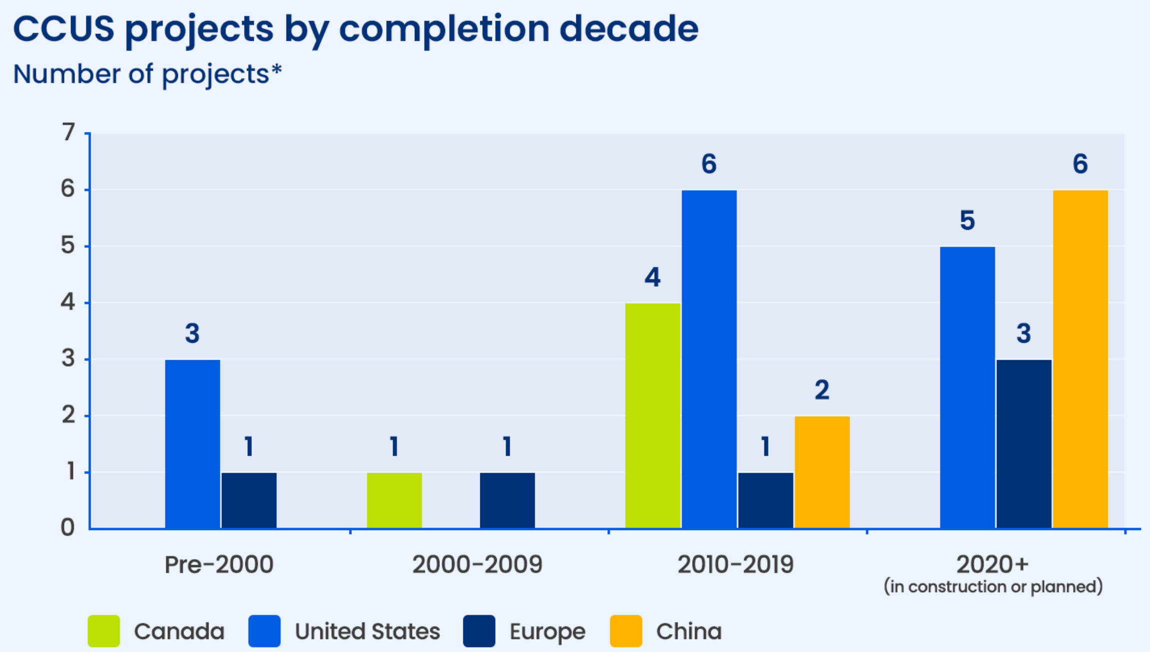
	Robust framework	CO_2 standards	R&D program	Tax credits	Grants/ funding	CO_2 offtake/ storage guarantee
Australia	X		X			X
Canada		X	X		X	
China		X				
France	X	X	X			
Japan	X		X	X		X
Netherlands	X		X		X	
Norway	X		X		X	
Saudi Arabia			X			
UAE			X			
UK	X	X	X		X	X
USA	X		X	X	X	

Source: S&P Global

National examples of CCUS support

Although there is no one-size-fits-all model for CCUS policy incentives, lessons learned from individual countries can prove instructive to nations like Brazil that are still in the early stages of formulating their regulatory framework and incentive schemes. CCUS hubs are advancing in no small part thanks to these support structures (Figure 14).

FIGURE 14



Source: S&P Global

*Excluding pilot projects; Europe projects include three in Norway and one each in France, the Netherlands and the UK

- **Canada**'s toolkit includes a price on carbon and investment tax credits for CCUS. The province of Alberta and Saskatchewan have also issued grants. Alberta in particular was an early mover, amending its Mines and Minerals Act in 2010 to allow the provincial government to assume long-term liability for storage sites and to create a post-closure stewardship fund.

- In 2016 **China** listed carbon capture among its strategic focus areas for its 13th Five-Year Plan. Officials have since instructed the central bank to issue low-cost loans to carbon mitigation projects, including CCUS.

- **The EU** has enacted several pro-CCUS policies, including an ETS and carbon border tariff (see Chapter 1), innovation grants, expedited permitting for cross-border projects and quantitative targets for carbon storage (50 Mt/year by 2030). These are generally on top of individual country incentives.

- **The Netherlands**' chief CCUS enabler is SDE++, which grants operating subsidies based on a CfD. The country's flagship CCUS project, Porthos, benefits from a €2.1 billion grant for capture, divided between capex and opex. Several state-owned enterprises are also part of the consortium managing Porthos's T&S, including EBN and Port of Rotterdam Authority.

- **Norway** has pumped resources into Longship, likely to be the world's first full-fledged CCUS hub when it starts operating in mid-2024. This includes over €2 billion across the project's set-up phase and for two Norwegian capture projects.

- **The UK** has set up several direct funding sources for CCUS. This started as £1 billion to fund four clusters (currently HyNet North West, the East Coast Cluster, Acorn CCS and Viking T&S), each currently in different stages of planning and evaluation. The pot of money has since ballooned to £30 billion over the next 20 years, with a goal to store 20–30 Mt/year. UK hubs also benefit from a government-backed CfD.

- **The US**'s key driver for CCUS development is its 45Q investment tax credit. First introduced in 2008, it has been revised several times, most recently as part of the IRA, which boosted the credit amount, extended the time window for deployment and streamlined payment processing. The US also disburses grants for various activities along the CCUS value chain, most notably R&D, and supports a number of DACS hubs.

Strong regulatory frameworks also clarify oversight and risk-sharing for CCUS projects. To this end, the following table provides examples of legally-codified oversight and risk-sharing arrangements:

Jurisdiction	Netherlands	Norway	UK	US (Texas)
Licensing authority	Ministry of Economic Affairs and Climate Policy	Ministry of Petroleum and Energy, Norwegian Petroleum Directorate	North Sea Transition Authority	Railroad Commission of Texas, School Land Board**
Monitoring obligations	Operator: during operations and for 20 years post-closure State: for the following 30 years	Operator: during operations and for 20 years post-closure State: for the following 30 years	Operator: during operations and for 20 years post-closure State: discretionary monitoring time-frame and activities	Operator: during operation and until demonstration that storage site will not endanger underground sources of drinking water
Post-closure liabilities	Transferred to regulator 20 years from site closure*	Transferred to regulator 20 years from site closure*	Transferred to regulator – Department for Energy Security & Net Zero – 20 years from site closure*	Transferred to School Land Board immediately upon site closure**

**Timeframe may be reduced at regulator's discretion*
***In state waters up to nine nautical miles offshore*

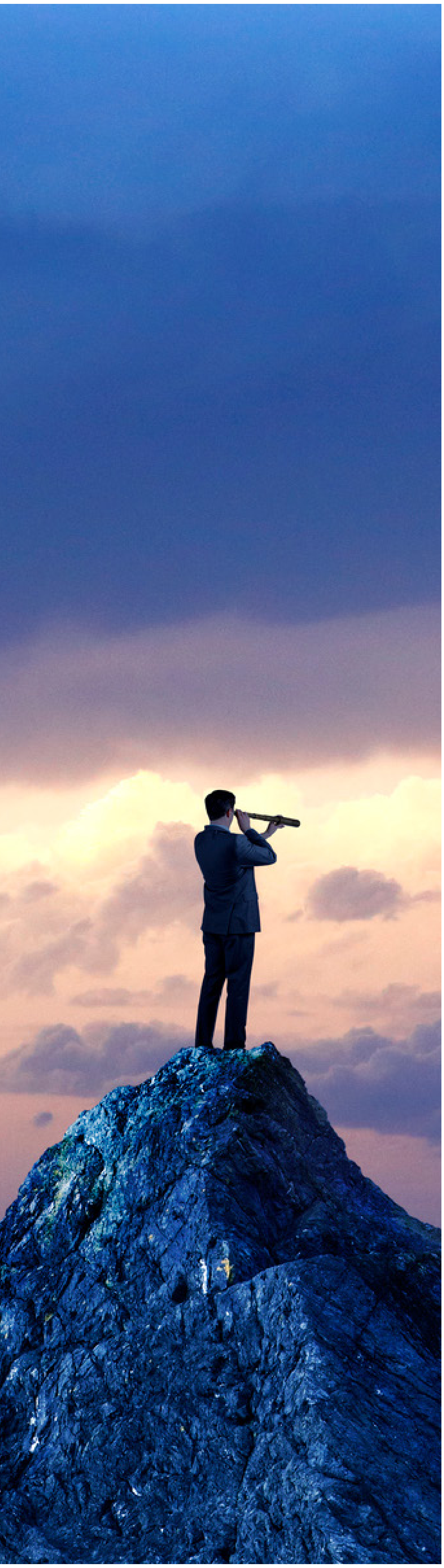
Potential policy enablers for Brazil

The Fuel of the Future government bill, introduced in September 2023 and currently in the legislative process, provides a promising goals-based framework for carbon capture and storage. It gives the National Petroleum Agency, as regulator, sufficient agility to adapt to developments in the nascent CCUS industry.

It does not address policy incentives, but Brazil has an opportunity to build on successful policy activations elsewhere. The best policy mix includes support at various stages of implementation, including R&D, pilot and scale-up. It also clarifies that more targeted levers of policy support may eventually be withdrawn as CCUS businesses become self-sustaining.

S&P Global has compiled options for Brazil's CCUS policy roll-out, grouped by stage of implementation (R&D, pilot and scale-up):

<table>
<tr><th>R&D</th><th>Pilot</th><th>Scale-up</th></tr>
<tr><td>Public funding/grants for R&D</td><td>Continued support for and scale-up of RenovaBio</td><td></td></tr>
<tr><td>Categorizing CCUS as an R&D category that oil and gas exploration and production companies must invest in under current Brazilian law</td><td>Government investment into carbon dioxide pipelines</td><td></td></tr>
<tr><td colspan="3">Low-carbon industrial policy to foster local supply-chain development</td></tr>
<tr><td colspan="3">Fiscal incentives (tax credits, carbon price)</td></tr>
<tr><td colspan="3">Obligations for capture and storage</td></tr>
<tr><td colspan="3">Support from Brazil's National Development Bank, potentially in collaboration with the World Bank</td></tr>
<tr><td></td><td colspan="2">Streamlined legal and regulatory framework for underground storage</td></tr>
<tr><td></td><td colspan="2">Lower import taxes and customs duties – or full exemption – for equipment and services</td></tr>
<tr><td></td><td colspan="2">Pipeline third party access</td></tr>
<tr><td></td><td></td><td>Fully operational ETS</td></tr>
<tr><td></td><td></td><td>Building-code changes that incentivize low-carbon cement and/or steel</td></tr>
<tr><td></td><td></td><td>Price premiums for low-carbon products</td></tr>
</table>



CONCLUSION

Seizing the opportunity

CCUS hubs are complex undertakings that require sustained buy-in from a wide range of stakeholders. Yet they can underpin the decarbonization ambitions of industries and regions as various actors look to this vital lever to meet their climate goals. Hubs can help CCUS benefit from powerful economies of scale that diffuse risk and reduce costs.

In Brazil, the fundamentals of two industries in particular – iron and steel and ethanol – lend credence to arguments in favour of a hub. Both could plug into colossal storage resources in the country's south-east corner. Both may require CCUS in order to remain competitive on global markets, where products made via business-as-usual processes will face increasing competition from greener alternatives. If it can decarbonize in line with international targets, growth opportunities in Brazil's ethanol sector in particular are tantalizing.

Beyond the benefits to these two fields, other sectors and Brazil's wider economy have the potential to gain as jobs and GDP in adjacent sectors flow from hub development. This mirrors the expectations from hub developers in overseas markets like the UK, who see an important role for CCUS in maintaining the vitality and economic contribution of entire industrial clusters.

In order for these projections to bear fruit, Brazil must overcome a number of challenges. Tax, fiscal and regulatory policy should be reformed to lower CCUS costs, provide certainty and predictability, and demonstrate the government's commitment to CCUS hubs. CCUS pioneers like the US and EU provide extensive examples of such support that Brazil can emulate.

This opportunity comes as Brazil's rising obligations under the Paris Agreement heighten the need for rapid and systemic decarbonization. The clock is ticking on implementation of the roadmap to meet the country's ambitions. One or more CCUS hubs can help turn these ambitions into reality.

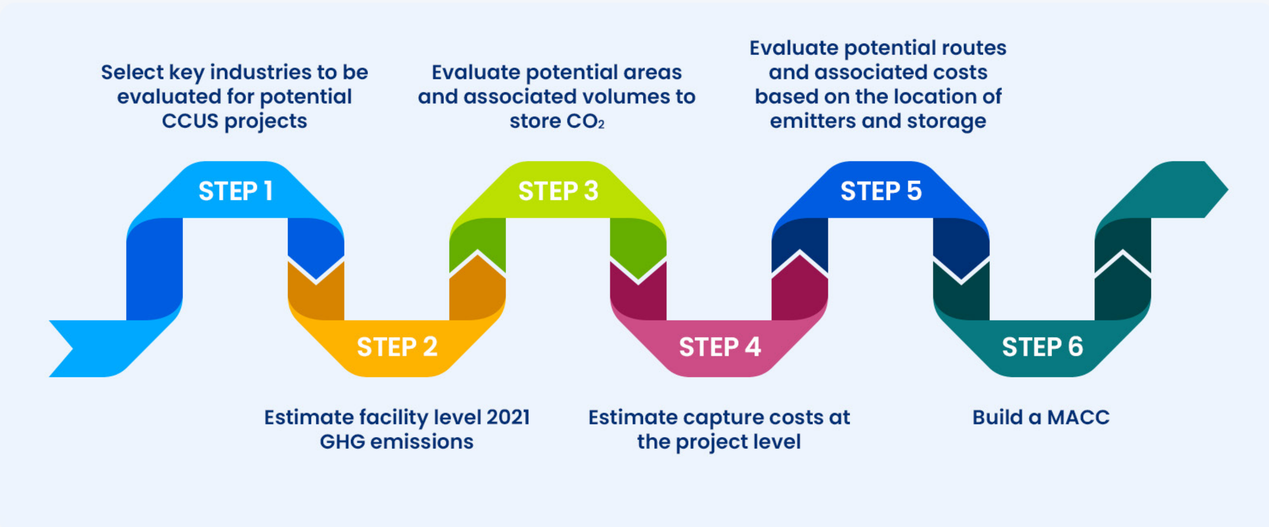
Appendix: Methodology

CCUS costs have a high degree of variance as all costs through the value chain have different factors to consider, resulting in a specific total cost for each project.

S&P Global has developed a methodology to leverage extensive publicly-available data and proprietary databases to better estimate overall abatement potential using CCUS and associated costs broken down by capture, transportation via pipeline and storage, to build a facility-level marginal abatement cost curve (MACC). The outputs of the calculations are then cross-checked to calibrate the parameters against uncertainties and align results.

The six-step process, with a recursive update, is shown in the image below (Figure 15):

FIGURE 15



Economic contribution analysis overview

This economic impact analysis quantifies how specific economic activity catalyzes multiple rounds of contributions to key metrics such as economic output, employment and value added. Using input-output data from the OECD, S&P Global generated a model to trace how streams of economic activity initiated by CCUS-related spending would stimulate two levels of economic contribution in the Brazilian economy. The first level, direct contributions, encompasses the economic contributions resulting from direct purchases of goods and services from local Brazilian businesses. The second level, indirect contributions, captures the follow-on effects that ripple through multiple tiers of in-country extended supply chains (i.e., suppliers' suppliers, etc.).

The direct and indirect contributions were reported for the following economic indicators:

- **Employment.** To produce their goods and services, companies must hire and retain employees. This indicator measures the number of workers required to support a given level of sales activity within a national economy.
- **Value added (contribution to gross domestic product).** Value added is the difference between the revenue businesses receive for a product or service and their non-labour

input costs. GDP is the sum of all value added across an economy.

- **Sales activity (economic output).** In the context of this analysis, economic output represents the value of sales activity occurring within the Brazilian economy that was ultimately attributable to transactions initiated by operational or capital expenditures.

The following flow diagram (Figure 16) presents the process by which the economic contribution cycles (direct and indirect) interact and affect the key economic contribution metrics (sales activity, GDP contribution and employment). The "direct economic contribution" cycle initiates with purchases products or services from local businesses (displayed in the upper left portion of the flow diagram). At this point, money is paid to local businesses in return for a product or service. The sales revenues then enable local businesses to accomplish two primary objectives:

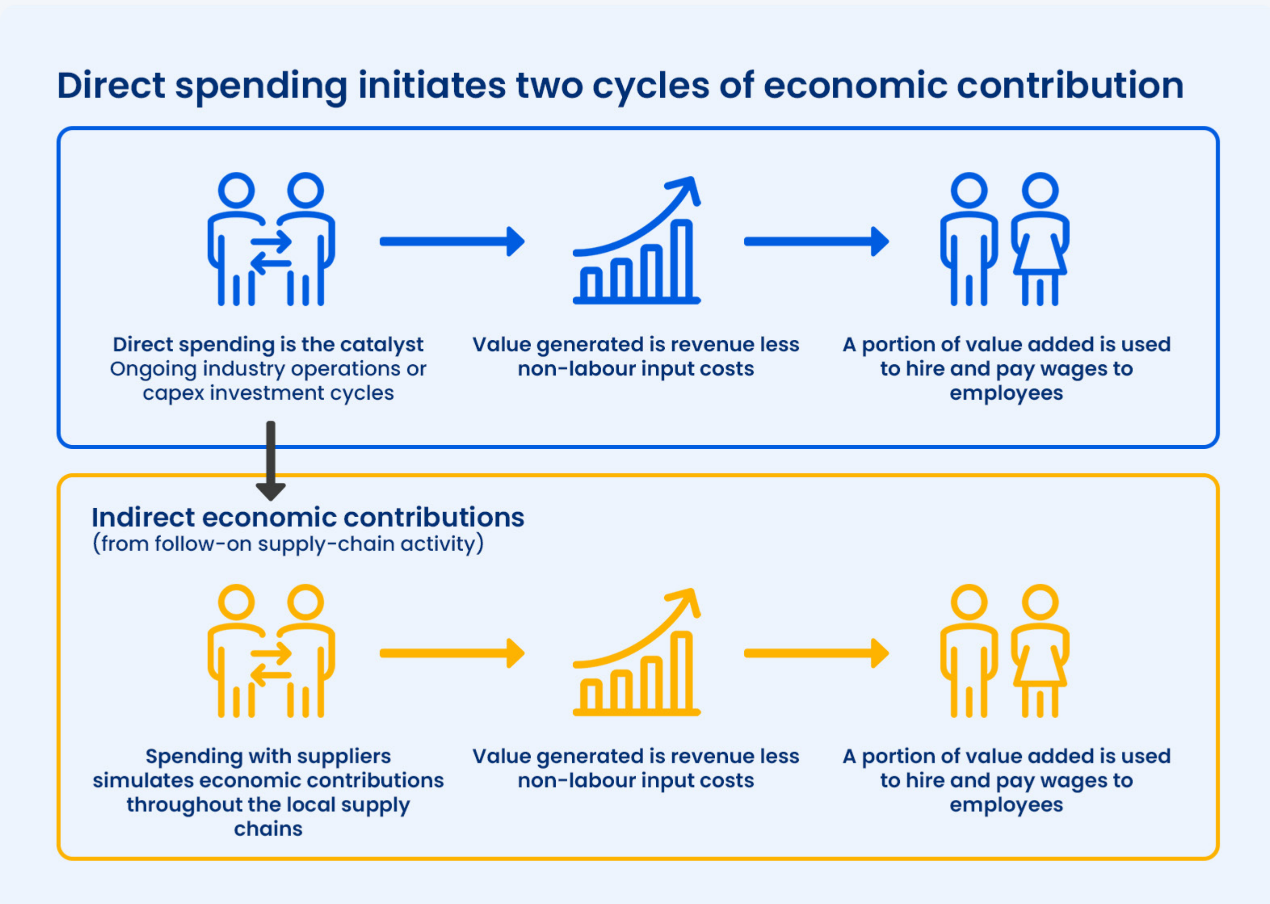
- First, they buy the non-labour inputs (also known as intermediate purchases) needed to make and deliver their products and services from their supply network. This initiates the "indirect economic contribution" cycle, which will be discussed later.
- Second, they generate what economists call "value added", which, for the purposes of this analysis, is the difference between the value of the sales transactions and the intermediate purchases, also known as contribution to GDP.

Value added, in turn, can be considered a pool of funds that the local businesses use for three primary purposes:

- Hire, retain and pay their workers
- Pay taxes to national and regional authorities
- Draw gross profits

After the value added is distributed to workers, paid to tax authorities or retained as gross profits, the direct economic contribution cycle ends.

FIGURE 16



As previously mentioned, the local businesses utilized as direct suppliers subsequently make intermediate purchases from their supply networks. This commences the “indirect economic contribution” cycle. For this part of the discussion, we will designate the direct suppliers as “tier-one suppliers.” The tier-one suppliers make intermediate purchases from their suppliers (tier-two suppliers). The tier-two suppliers then make intermediate purchases (from tier-three suppliers), compensate their workers, pay taxes and derive profits. This cycle repeats through the remaining tiers of the extended supply chain. The sum of the contributions stimulated by these multiple rounds of economic activity are the indirect impacts.

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