

US Clean Tech

The latest on carbon capture in the US: conference takes 2024

Industry Overview

Real development progress expected in 2024

We co-hosted our third annual virtual CCUS (carbon capture, utilization, and storage) conference with Stephen Byrne, U.S. Chemicals analyst and Kalei Akamine, U.S. Oil & Gas analyst. Attendees included 15 companies spanning the CCUS value chain with discussions on project development, technological innovation, consulting, and more. We see prospects for CCUS as meaningfully turning a corner, with developer confidence rising as several projects move toward FID in 2024. We contrast this sentiment to that for Green Hydrogen, for which expectations were significantly scaled back this December following issuance stricter-than-expected treasury draft guidelines for the 45V credit. The interrelation between hydrogen and CCUS, which are mutually supportive but can compete in enabling decarbonization of baseload and industrial power, indicates that blue hydrogen may be comparatively advantaged with stronger economic prospects and a more visible pathway to implementation given its ability to leverage existing energy infrastructure. That said, we see a delayed backdrop, with EPA Class VI well timeline likely limiting meaningful scaling for 3+ years still.

Permitting bottleneck alleviating with state primacy

Still, post-IRA optimism for CCUS has been somewhat checked by the years-long permitting application and process by the EPA, which was unanimously considered the greatest impediment to capital formation for the sector. We look for processing times for certain projects in the gulf to potentially speed up following recent designation of primacy of regulatory authority for Class VI wells to Louisiana, with Texas and other states likely to follow suit in applying. Less constructively, future economics have become more marginal in the period since the 45Q credit was scaled up to \$85/t with passage of the IRA from \$50/t prior, reflecting inflationary and supply chain impacts to manufacturing and development costs, with no inflation adjustments built into the credit until 2027. We expect organic formation of shared transport and storage infrastructure to spread capital costs across several separate projects and support overall return profiles, at the beginning collocating around existing energy and resources infrastructure in California and the gulf coast (see the report,

[US Oil and Gas: Carbon negative: a primer on vertical integration of CCUS / DAC with oil & gas 13 September 2021](#)).

More IRA certainty, more visibility: busy 2028+ window

With benefits of the 45Q credit mostly fleshed out in the years preceding passage of the IRA, the CCUS industry likely faces much less significant decision-making paralysis than that of its hydrogen credit counterpart. Once multiple high-leverage states achieve regulatory primacy from the EPA, we expect development timelines to significantly improve, which could pull industry progress forward as critical mass organizes around “hubs” in the Gulf Coast and in California specifically. While there will likely be a learning period for LA and future states granted regulatory primacy, we expect that once streamlined permitting processing is demonstrated a flurry of projects will enter queues through 2033 prior to expiration.

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CCUS – Carbon capture, utilization, and storage
DAC – Direct Air Capture
EPA – Environmental Protection Agency
FID – Final Investment Decision
IRA – Inflation Reduction Act
t – ton

Key themes from our CCUS Conference

Below we summarize what we view as themes across a full day of discussions with CCUS technology and material manufacturers, operators along the natural gas value chain, project developers, and industry experts. From our conversations, we expect there to be substantial project development for FID in 2024 as permitting application processing times begin to improve. In continuation of a general takeaway from our recent Hydrogen Conference ([see our recap report](#)), we also see stronger prospects for blue hydrogen and blue ammonia given the more challenged economics to green hydrogen with the stricter 45V credit. Still, CCUS has not garnered the same support from climate hawks that its decarbonization potential might imply; we note ongoing debate in the environmental community over the degree of support. Economics for projects require there to really be a signal for pricing and valuing carbon beyond just the \$85/t 45Q credit for the initial 12 years for CCUS to work: this means that California is likely a prime focus. But developing pipeline infrastructure there – and particularly across the Midwest – has been fought.

Where are we going to see the bulk of initial activity? Three “hubs” of activity:

The first is the Gulf Coast, where CCUS for enhanced oil recovery has a real legacy. To this end, we already see a modest pipeline network to enable use of 45Q credits for non-EOR purposes. We note that customers will need to commit some future value of carbon to get projects done considering no formalized carbon value in the gulf. Between a lack of clear Class VI injection wells, developers such as NEXT state that project FID remains years away. We look towards Louisiana to be the principle hub of activity over Texas. We watch for CCS-enabled energy export projects to be part of the mix, with decarbonization of energy required to export liquefied natural gas (LNG), for instance, one of the pathways.

A second geography that appears key to us is California given its robust decarbonization ambitions and existing sequestration focus in the central valley of the state. We watch CRC in this geography given its recent award from the EPA of a Class VI injection well. We believe that ongoing and existing carbon value in California under the LCFS program in conjunction with the 45Q program could well start to make some sense. Bottom line, we watch Calpine, the largest gas generator in the country in this geography, with its pilot with the Sutter CCGT unit; we note that its parent company, ECP, bought the technology of Ion Clean Energy in the last couple years in an effort to complement development.

The third geographical focus is the Midwest, where excellent storage capabilities existing in Illinois, among other regions. We stress pipeline development here to interconnect the best emission point sources, from the agricultural sector, and specifically ethanol to these storage caverns. Pipeline development here has been slow and particularly problematic, with the development of a 5-state pipeline, Navigator, among the principle examples of this. Bottom line, even non-fossil pipelines are facing severe challenges in permitting. We watch more modest pipelines, such as the two-state pipe being developed by Wolf Midstream, for instance.

What are going to be the sources of CO₂ that is being captured?

We see power emitters as a second mover – with a focus on Gas CCGTs over coal. Coal assets do not present a likely pathway for CCS projects given their general age and state of economic competitiveness already today. This might surprise many given the concentrated CO₂ emissions of coal assets; these should be few and far between, in our view. As CCS amine capture technologies have improved with a wider array of technologies (~half dozen key players in this field), we see capture on gas plants (CCGTs) with higher capacity factors as becoming the dominant focus. We note that multiple estimates of capture at this level of carbon from gas plants pin prices in the ~\$60/t zip-code prior to transportation and storage. This is subsequently pinned at \$15-40/t depending on the estimate (varies widely). On balance, we see economics as

“marginal” even relative to the initial 12 years with a 45Q credit. That said, finding applications where customers are willing to pay an additional carbon premium above \$85/t appears key initially.

Inflation bites all large-scale projects

We see estimates of CCS capture applications as particularly risky given the meaningful inflation ongoing in large-scale infrastructure. Previously, it had been seen that \$85/t would suffice, but with large-scale chemical plant inflation trending up ~25% over the last 4 years since Covid, we caution on the underlying economics (hence the need for supplemental compensation). We see ongoing inflation risks as real considering still real timeline hurdles to permitting Class VI wells.

Distributed and niche applications of CO2 are intriguing too

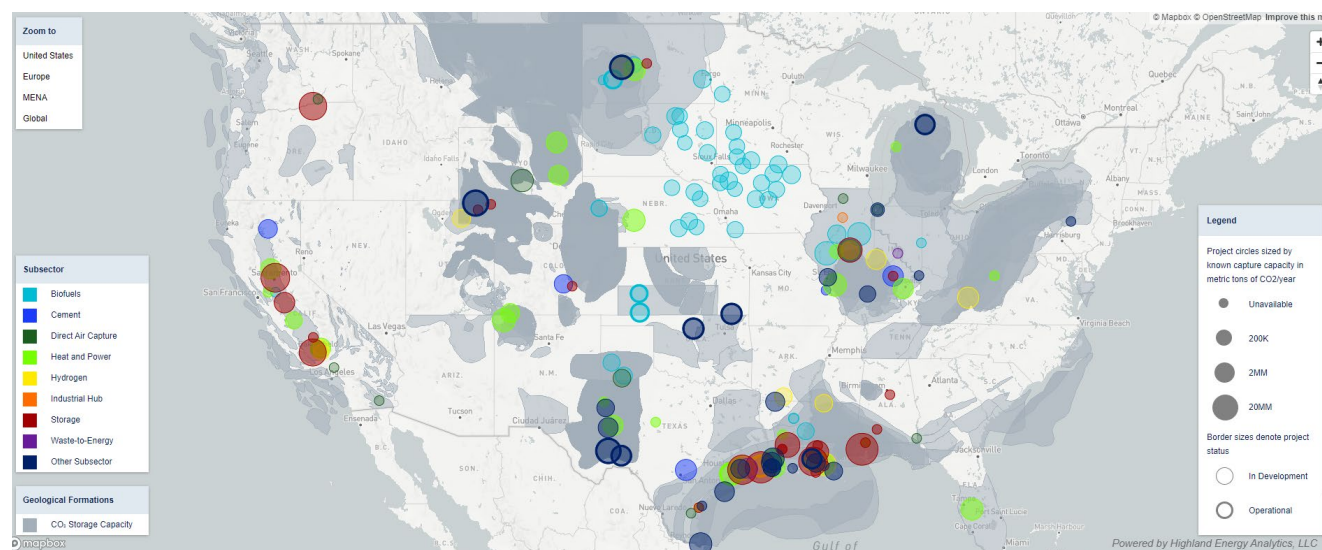
It is not all large-scale either. We see high-rent applications for CO2 as well in the context of one-off cement projects (which can meaningfully leverage streams of CO2 in their processes) and in the beverage industry. We stress that these niche applications provide high-value applications for captured CO2, albeit potentially at higher purity levels. Technology development today appears focused in part on ensuring a greater percentage of capture from the sources as well as ensuring purity of CO2 streams at ultimate site host. We watch for applications like these to see some modest success in one-off applications, albeit with the real scale of capture from a large industrial process.

We are less concerned on CCS credits staying the course in IRA repeal threats

The CCUS industry generally views a potential administration shift in the US in 2024 as less a threat relative to other renewables and hydrogen given expressed bipartisan support and significant project development across states with a diversity of ideological leanings. We stress that, if anything, participants were focused on whether a 45Q bump in credit value was possible, but here too we are sober. We watch Department of Energy (DOE) awards in 2024, with several pilot projects already recipients.

Exhibit 1: US Carbon Capture Activity and Project Map

Gulf Coast buildout beginning but several possible sequestration sites across the country



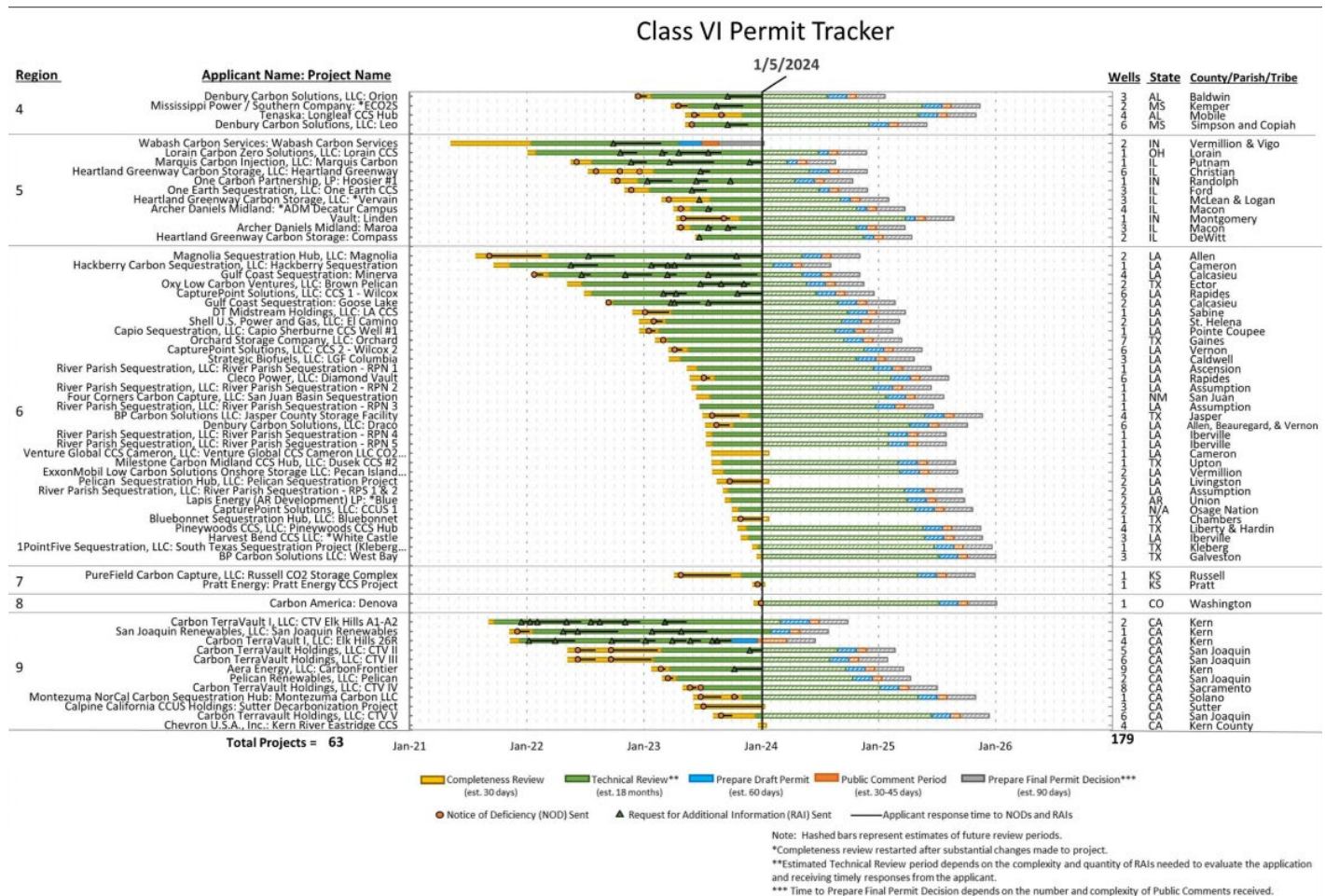
Source: Clean Air Task Force

Permitting hurdle becoming more manageable

On December 28, 2023, the U.S. EPA granted the state of Louisiana primary enforcement authority over Class VI underground injection wells. This concluded a two-year review process and provides a verifiable pathway toward gradually transitioning regulatory oversight of the CCUS industry to states, which may be able to process incoming applications at a much faster rate than the EPA. While other states, such as Wyoming and North Dakota, have been delegated such authority and have issued a number of permits over the last several years, Louisiana's positioning in the critical Gulf Coast market bodes well for general industry development given regional colocation of energy assets with potential CCUS applications. We expect other states, critically Texas and California, to follow suit, which over time will distribute the regulatory burden to localized jurisdictions with self-interest to process applications in a timely manner. Potential alleviation of the permitting queue would meaningfully improve CCUS solutions' ability to attract capital, with a number of developers and technology manufacturers remarking on current EPA wait times as the single greatest bottleneck to industry investment and development.

Exhibit 2: US Class VI Permit Tracker

Multi-year permitting process impacting development timelines but could be alleviated as more states gain regulatory authority primacy

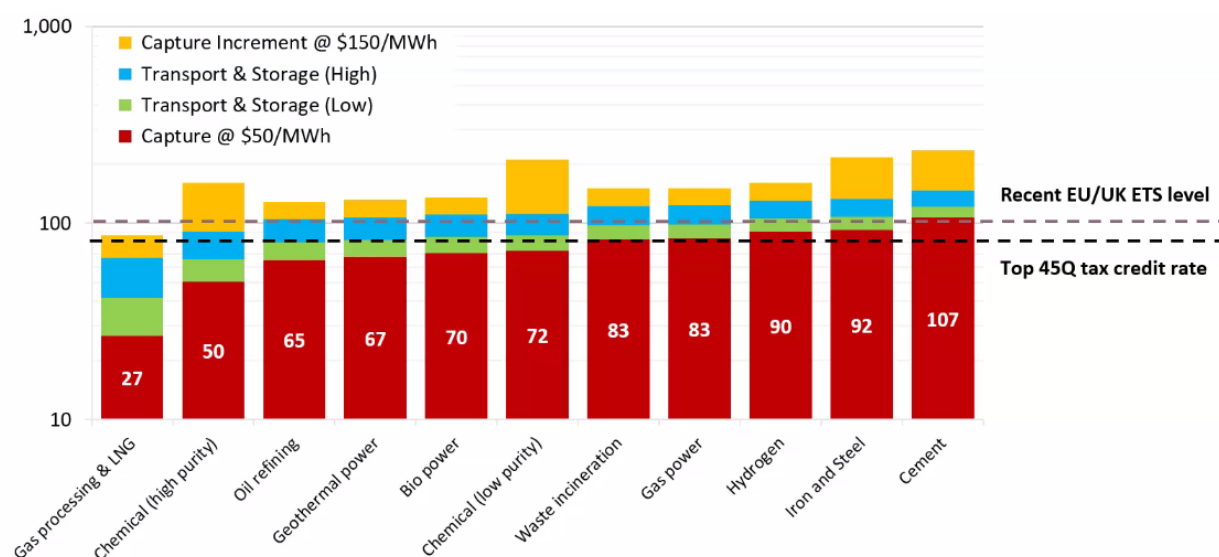


Source: US EPA

Economics more challenged but confidence in \$85/t credit

Over the past two years, passage of the IRA increased the relative attractiveness of CCUS market economics given the increase in the 45Q credit to \$85/t from \$50/t. However, inflationary pressures have drastically impacted the return profile of CCUS projects, with the credit lacking an inflation adjustment mechanism until 2027. This complicates the assessment of industry economics that were already difficult to assess given how nascent the industry is and how much the economics could depend on repurposing and developing shared energy infrastructure. At our conference, discussions of economics took more of a backseat to the narrative that market opportunities could be expanding as CCUS could step into a void left open by complications to the green hydrogen thesis. Still, we expect that the level of future sequestration could ultimately depend on the price point of voluntary carbon market for emission reduction, though how well defined the mechanics of a national or regional carbon trading regime once projects roll off the 45Q credit in the 2030s remains unclear.

Exhibit 3: Expected levelized cost of CCUS for the first generation of large-scale commercial projects coming online in 2025-2030
USD per ton



*Transportation and storage overhead is modeled with industrial cluster assumption approach

Source: Rystad Energy CCUS Solution

BofA GLOBAL RESEARCH

The hydrogen angle – blue looks better

In our discussions, we see mounting evidence of preference for the economics and visibility of blue hydrogen, supported in part by clarity in the CCUS credit versus that of the 45V credit. Blue hydrogen, and associated CCUS solutions, stand to meaningfully benefit if green hydrogen projects cannot pencil due to the stringent credit requirements. Blue hydrogen has a line of sight to actual production, with economics broadly supported by a readily understandable and applicable credit. While it may be true that blue hydrogen does not enjoy the same support in Europe, markets such as the US, South America, Asia, and others provide plenty of opportunity for the technology to play a role in the energy mix of the future. There is also significant interest in blue ammonia, which might be more significant in overseas markets at first. This sets up an interesting dynamic whereby overseas deployments can be pursued to drive costs down to open substantial markets, such as fertilizer, marine, fuel, etc. To some, there is even a line of sight for blue ammonia to become cost competitive on an absolute basis with grey ammonia.

Policy, advocacy, and finance

Clean Air Task Force

We hosted Ben Longstreth, Global Director, Carbon Capture at Clean Air Task Force, a climate-focused consulting and policy advocating organization, for a discussion of the regulatory outlook for carbon sequestration in the United States. Clean Air Task Force (CATF) is a large proponent for the advancement of carbon capture and views the technology as essential to achieving global net-zero emissions by midcentury. By focusing on emissions intensity, CATF's advocacy trends more agnostic toward generation fuel sources, provided that CCS eliminates emissions. With this in mind, as well as an understanding of the unrealistic level of infrastructure buildout theoretically required to exclusively use electrolytic hydrogen to supplement renewable intermittency, CATF acknowledges a reality that necessitates several generation technologies, including natural gas with carbon capture to support hydrogen, to support reliability of power supply across the world.

45Q credit provides visibility but economics could face pressure

Unlike the extended period of uncertainty concerning the 45V credit for production of clean hydrogen, general dynamics of the 45Q credit have been generally understood from the beginning, with the nominal value improving incrementally with passage of the IRA. However, CATF noted that there are specifications to the 45Q credit that delay inflation adjustment to 2027, remarking that the credit curiously did not include the same protections granted other credits, such as the 45V. Erosion of the credit has meaningfully impacted the proposed economics of CCUS, perhaps resulting in a lower provision of support than initially intended, particularly for those harder to capture carbon emission sources. This points to greater importance not only for acceleration of cost-down across the industry but also for development of shared infrastructure to spread the capital burden for pipelines and storage across several projects.

Class VI permitting still a bottleneck, but visibility improving

Similar to interconnection queue bottlenecks for renewables, a limiting factor CCUS development in the United States has been slow progress in EPA processing applications for Class VI wells. While the 45Q credit was already defined prior to the IRA, increase of the credit to \$85/ton versus \$50/ton prior resulted in an acceleration of applications following the landmark legislation's passage, exacerbating wait times in the application queue. CATF views the designation of primary regulatory authority of Class VI wells to Louisiana as an important indication of potential improvement in permitting timelines. Though Louisiana's application for primacy took over two years, CATF remarks that this extended timeline likely reflects FOAK processing at the EPA and that future state applications could be processed on a more accelerated rate. The benefit of states gradually gaining primacy is two-fold: not only is it possible that states themselves can perform faster application reviews versus that of the EPA, but the EPA's queue also shortens significantly as states with primacy draw applications away from the centralized list. With respect to government support and oversight, a durable theme for renewable and clean tech investors this year has been a perceived risk of IRA/policy repeal in the event of a change in presidential administration in November 2024. However, CATF pointed out that CCUS tends to garner much more bipartisan support and features significant investment opportunities in historically Republican-led states, significantly de-risking credit support for the technology.

Don't forget transportation, the silent "t" in CCUS

One overlooked consideration in the CCUS value chain is transportation, which will become more and more important as more turnkey collocated generation and sequestration sites become gradually developed. Without mature CCUS infrastructure build-up across all segments of the value chain, all new projects currently require significant coordination in the co-development of the capture technology itself, the

reserve of a suitable geologic formation which can permanently store the capture carbon dioxide (CO²) and also the interconnecting infrastructure between the two. CATF identifies a significant need for pipelines to transport CO² from site of capture to site of sequestration, though the mileage need required could pale in comparison to that of existing natural gas and oil infrastructure. This need could be greatly lessened through implementation of hubs of shareable infrastructure. The US DOE has identified a strong interest in funding projects that together create a strong potential for development of shared infrastructure, though progress may be driven by more organic means as economics are supported by reduced upfront capital requirements. This obstacle in development coordination is highly critical in the industry's nascency, and several potential projects have not moved forward due to disruption of timing to interconnection to geologic storage, which shows how interrelated each stage of development is. We look for regional coordination in the Gulf Coast and California to emerge and ultimately support CCUS migration down the cost curve.

EFI Foundation

We hosted a conversation with Stephen Comello, SVP, Strategic Initiatives at the EFI Foundation and Deputy Director of the Energy Futures Finance Forum. The Energy Futures Finance Forum provides an investor's perspective on technologies such as CCS, small modular reactors, and long-duration storage. Its work involves deep dives into various technologies, addressing barriers from commercialization to regulatory risks. The forum emphasizes the importance of understanding investor considerations in decision-making. The foundation also touched on the complexities of value chain dynamics, potential inflation-related issues with 45Q, and strategies to enhance bankability, considering the unique risks associated with industrial and power projects. Specifically, its study on CCS, conducted six months ago, highlighted root causes impeding widespread adoption. Issues such as policy reliance, technological diversity, and value chain complexities were discussed. The impact of inflation on cost estimates was mentioned, prompting the need for additional support, potentially in the form of grants. For the 45Q tax credit, in light of inflation, there could be scenarios whereby increased value or supplementary mechanisms might be important, particularly in sectors such as ethanol and power generation. EFI stressed the importance of public education and strategic project development, starting with more manageable initiatives. As it related to CCS bankability considerations, the discussion contrasted industrial and power applications, scrutinizing factors such as technology risk, output quantity risk, and revenue streams. Strategies for overcoming challenges in storage and pipeline development include leveraging federal lands and focusing on public engagement. The presentation also touched on the complexities of IRA tax credits, including the transferability and liquidity of 45Q credits, the direct pay feature's attractiveness, and the emergence of Ford purchase commitments as a tool for pricing certainty.

45Q Credit Discussion with Perkins Coie LLP

We hosted Elizabeth Crouse, Partner at the law firm Perkins Coie LLP, to understand how thinking on tax credit opportunities for carbon capture has evolved since passage of the IRA and further deliberation of other energy tax credits. For more than a decade, Crouse has advised investors, developers, and operators across the renewable energy, hydrogen, and carbon capture industries. Below we discuss the risks and opportunities of carbon capture in a legal lens as we understand it today and how it interrelates to other clean generation tax credits available.

Contrasting 45Q and 45V: more constructive on the “blue” opportunities

At our annual Hydrogen Conference in December, there was general consensus that the strict 45V draft guidelines released in December could scale back investment opportunities relative to prior expectations. In relation, the 45Q CCUS tax credit incrementally improved with the IRA relative to prior expectations and provides critical support targeted to blue technologies not explicitly backed by the 45V. Given less

constructive green hydrogen economics with strict hourly matching rules that mandate intermittent renewables to support electrolytic hydrogen production, the relative economic opportunity for CCUS technologies appears more constructive and importantly, more attainable given the existing generation infrastructure that could be quickly adapted for compliance. Frankly speaking, CCUS appears relatively more possible with current infrastructure and policy support in place rather than a significant clean hydrogen buildout. The natural gas industry, across both LNG and power generation, has embraced 45Q, and support for blue ammonia and ethanol production with attractive economics appears highly attainable compared to other green applications. Alternatively, we watch further deliberation of the 45V credit, as an incrementally constructive outlook for hydrogen tax credit applicability could affect the relative attractiveness of blue applications in CCUS, given that the two technologies compete with one another as much as they be mutually supportive.

Expect few, if any, revisions to existing 45Q guidelines

Unlike 45V, which could be meaningfully altered through industry deliberation over the next several months, few adjustments to the 45Q are expected. There is not a significant amount of grey area to qualification for the credit; the industry has been ready to move around the credit, and while the economics of the \$85/t credit have been meaningfully reduced due to inflation and supply chain disruption, it is viewed as generally supportive through the 12-year life of the credit. Indications from emissions markets, such as California, point to sustained economic value of CCUS beyond expiry of the credit.

State primacy positive to queue times, but reviews still thorough

Our discussions regarding long queue times at the EPA generally pointed to benefits from more states gaining primacy of regulatory authority, as states such as WY and ND have demonstrated that they can conduct reviews at a more accelerated rate than that of the EPA. Still, the EPA will not sign off on a state's application for primacy if it is not confident the state can conduct the review with the same level of thoroughness. There is likely an upward limit to the amount of improvement in Class VI well applications, as it takes time to perform the highly technical analysis required to ensure that gas is not able to escape into air or water supplies. Still, it is imperative for the industry that high-leverage states, such as Texas and California, succeed in wresting regulatory power from the overburdened EPA.

Liability and capacity key long-term considerations

There is a significant level of coordination among different parties in order to develop an economically successful CCUS system with qualifications to earn the 45Q credit. We watch for the long-term development of capacity agreements for sequestration in particular, considering that there is likely to be plenty of shared infrastructure developed and the outlook for power and industrial production implies massive capacity needs over a 10- to 20-year span. Will traditional long-term capacity agreements be adequately specified to ensure there are no lapses between capture of carbon and ability to store it? And who bears the liability if there is carbon from energy production that cannot find safe and secure storage? While standard insurance and capacity agreements similar to other industries will be refined over time, the relatively slimmer economic margins of the 45Q credit do not imply significant room for cost overrun due to legal liability.

Rystad Energy Consultancy

We spoke with Yvonne Lam, SVP and Head of CCUS Research at Rystad Energy. Rystad Energy, an independent consulting company based in Norway, provides its database as a solution for clients exploring data independently. Globally, commercial carbon capture projects are concentrated in North America and Europe, holding about 80% of the market share, primarily in the planning stage. Projections estimate a capture capacity of 600 million tons by 2030 and 900 million tons by 2035, fueled by a growing market.

Economic viability is evident in the cost chart, especially with carbon pricing exceeding \$100 per ton. In the US, a tax credit rate of \$85 per ton places around half of the projects in a favorable economic position. This growth is underpinned by supportive policies in Europe and North America. However, a slowdown in project announcements is expected in 2023 and 2024 as policies mature and emitters shift focus to project operations.

Significant project activity in 2024 drives confidence in the CCUS industry

Permitting challenges have been a bottleneck, causing delays, but concerted efforts and increased resources are expected to alleviate these issues. Project delays, often attributed to factors such as permitting, differences in the FID, feasibility study delays, and financial deferrals, are observed, though not predominantly prolonged. A surge in permit applications, especially in 2023, and the recent addition of primacy in Louisiana, are expected to expedite the permitting process. Geographical considerations play a role, with states such as Texas and Louisiana being perceived as more CCS-friendly due to permitting ease and experienced project operators. Rystad highlighted the importance of resolving future challenges, such as space availability for CO₂ storage, and advocates for additional policies beyond the 45Q tax credit to sustain CCS market growth. Indirect capture and removal projects, encompassing various technologies, present funding opportunities. The pricing of carbon credits varies across technologies, offering additional funding avenues for CCS projects. The year 2024 is critical for CCS projects, and its outcome will significantly impact confidence in the market's long-term prospects. Business case considerations vary, with a "wait and see" attitude among emitters, influenced by the absence of a national carbon pricing mechanism.

Developers and Technology Providers

8 Rivers (Private)

We hosted Mike Adams, VP of Capital Management at 8 Rivers, to discuss the company's portfolio of carbon capture solutions and associated economics. 8 Rivers is a leading innovator in providing net-zero emissions solutions with a particular focus on carbon capture and oxy-combustion. The company has a pipeline of developmental projects spanning several zero-emission sub-spaces, including direct air capture, post-combustion carbon capture, zero-carbon fuels, and clean ethylene. 8 Rivers developed the initial concept for and provided initial seed capital to NET Power, which is currently demonstrating its innovative pre-combustion carbon capture technology for natural gas electricity generation.

8 Rivers Hydrogen gaining steam

Within its broad portfolio of zero-emissions technologies, 8 Rivers is perhaps most excited about its 8RH2 (8 Rivers Hydrogen) opportunity, which is an alternative to existing steam methane reformation (SMR) and autothermal reforming hydrogen production processes that uses oxy combustion to produce ultra-low carbon hydrogen. 8RH2 can produce hydrogen from natural gas with 99% CO₂ capture. The process is designed in such a way that CO₂ is used as a working fluid transferring heat back through combustion process; The resulting CO₂ is produced at pipeline quality and pressure. To support cost competitiveness of hydrogen as an energy carrier, a significant goal in the energy transition that could enable decarbonization of heavy industry, carbon capture needs to be as efficient as possible, and there needs to be a pathway to where carbon capture and energy production attain cost parity with grey hydrogen. 8 Rivers sees the potential for 8RH2 to be a solution that is both lower cost (from an operating expense and capex perspective) and highly efficient.

Reforming a broken economic model

8 Rivers has formulated its business model around being the initial owners of the first projects it develops. This allows the company to understand firsthand how the operator could view the technology working practice and provide insights to what stages of

implementation might require additional tinkering. Customers are highly sensitive to projects that are difficult to construct or implement or could carry significant exposure to cost overruns. As such, 8 Rivers looks to leverage the skills and talents of EPCs while owning the technology of the projects, and views this as an essential formula to drive a scalable solution in what has historically been a challenged economic model with unbalanced risk/reward. Over time, 8 Rivers seeks to become licensors of their innovative technologies and seeks to drive implementation that is seamless to the customer. This requires strong Intellectual Property (IP) protection in order to protect shareholder value but will ultimately enable a broader dissemination of innovative technologies that can drive meaningful progress in the energy transition.

Chart Industries, Inc. (NYSE: GTLS; not covered)

We hosted John Walsh, VP, Investor Relations of Chart Industries. Chart Industries delivers technology and molecule-agnostic solutions across diverse end markets and geographies (New Zealand, Australia, Brazil, Asia-Pacific, Europe, and the U.S). Within these markets, the company is concentrated in brewing, biogas, and emerging energy applications, including fuel cell carbon capture. As it makes a strategic pivot toward the energy transition in emerging markets, it emphasized how mission-critical equipment from conventional energy seamlessly integrates into these novel sectors. In terms of specific instances, an air-cooled heat exchanger, conventionally deployed in midstream oil and gas, extends its utility to carbon capture and water applications. Similarly, a compressor, a staple in downstream oil and gas and refinery operations, demonstrates versatility across hydrogen, helium, carbon capture, and water contexts, embodying its "menu of clean" solutions catering to different markets. In carbon capture, Chart Industries mentioned that it is delivering solutions across key technologies: direct air capture, pre-combustion carbon capture, and solid sorbents. Its portfolio spans from small-scale breweries to substantial industrial applications such as cement plants.

Strong US pipeline with international optionality long-term

Acknowledging the nascent carbon capture market, its focus is on strategic partnerships. Post the merger with Howden in March 2023, the CCS US pipeline stands at \$2.7 billion (30 projects). Diving deeper into operational diversity, many solutions provided are at an advantage, given that there are no permitting requirements. Integration with Howden's compression technology not only improves the customer experience but also reduces the total cost of ownership. Technological offerings include heat exchange, compression, and storage. In terms strategy, its "color agnostic" stance positions it as a supporter of various hydrogen projects, encompassing blue hydrogen and low carbon intensity hydrogen. Currently, its priority is deleveraging, targeting a net leverage target ratio of 2 to 2.5. Looking at the carbon capture landscape's growth potential, Chart Industries expects expansion, with less than 5% of its current business dedicated to CCS. Management alluded to the pipeline signaling growth, particularly in the cement and lime industries due to its technology's "easy retrofitting nature." Positive trends in Europe, the Middle East, and global markets help in diversification efforts as it navigates the evolving carbon capture landscape. Aside from 45Q tax credits and federal incentives (grant of \$4bn from the EPA), it expects that state level state-based incentives (California and Colorado) should also drive near-term opportunity.

ION Clean Energy (Private)

We hosted ION Clean Energy founder and Chief Executive Officer Buz Brown to discuss natural gas CCS technologies being piloted at combined cycle gas turbine facilities across the world. Founded in 2008, the Colorado-based company is commercializing proprietary liquid absorbent process technology, with the goal of delivering a more effective and cost-efficient solution to capture CO₂ emissions from utility and industrial point sources. The company's goal is to be the frontrunner in industrial scale carbon

capture, and it intends to eliminate 1 billion tonnes of CO₂ by 2050. The company has entered into strategic partnerships with Koch Engineered Solutions, SK Inc, and Denbury, and has secured over \$85Mn in competitive awards from the DOE.

Amine-based solvent with unique chemistry

According to Brown, Ion Clean Energy utilizes a high performance and degradation resistant solvent in its sequestration process. Over time, the company has developed several different solvents with progressively stronger sequestration efficiency and now believes that its latest amine-based iteration is market leading. The durability of its solvent enables lower emissions and shorter downtimes for maintenance relative to other solutions, according to the company. Brown points to its success in a pilot program with Equinor (covered by our BofA Global Research colleagues) in the North Sea, where it claims to have captured over 99% of CO₂ for weeks at a time from even low concentrations. The company is currently operating in 3 pilot programs across the world with commercial customers of varying sizes.

CCS project with Calpine selected by DOE for major demo

In December, Calpine announced that its Sutter Decarbonization Project had been selected by the DOE Office of Clean Energy Demonstrations to enter into a cost-sharing agreement to build a commercial-scale CCS project to capture and store up to 1.75Mn metric tons of CO₂ per year. The facility will use ION Clean Energy's post-combustion carbon capture technology. ION Clean Energy and Calpine have collaborated for test projects in the past, such as the Los Medanos Energy Center pilot project, which also received DOE funding.

Kiewit (Private)

We spoke with Bob Slettehaugh, Director of Carbon Capture & Carbon Removal for Kiewit, a North American EPC with over \$10Bn in annual revenues, half of which relate to either oil & gas or power industries. Slettehaugh also serves as a sponsor for the Department of Energy carbon capture and carbon removal projects supported by Kiewit. Kiewit has been explicitly involved within the carbon capture industry since the mid-2010s and maintains strong relationships with major carbon capture technology providers. Kiewit participated as a key EPC in the US's first CCS project, the Petra Nova Carbon Capture Project, helping to deliver the project under budget and ahead of schedule. Over the last four years, Kiewit provided services on over 70 projects ranging from early engineering phases to pilot projects.

EPC Perspective: CCS markets look good in 2024, especially power

Given the DOE's primary goal of driving development of the CCS market so that it can eventually stand on its own, Kiewit expects 2024 to feature continued growth, with a number of projects hitting FID before the end of the year. Kiewit observes the most opportunity in power-related markets, matching the historical priority of the DOE dating back to when initial applications were expected to see implementation on existing coal-fired generation plants. However, other markets such as cement, agriculture, and heavy industrials are likely to also see additional development this year. However, similar to other industry participants, Kiewit remarked on the erosion of economics the industry faces given recent inflation and rising labor costs with no protection from the credit until 2027. Delivering an economic project now requires strong and effective coordination of the various individual elements, including high-capacity factor and good transportation and storage attributes.

Seeing amine-based post-combustion capture most; all techs have opportunities

As EPC for these projects, Kiewit does not own any of the technology and is largely agnostic to what technology is ultimately selected for each project. Kiewit sees the prominent technology selection of customers to be amine-based post-combustion capture, which is more commercially proven with over 100 years of collective

experienced in the field, featured in certain projects, including Petra Nova. Still, Kiewit observes a number of opportunities for application of more recent new technologies, including absorption-based and membrane-based depending on individual project characteristics.

NET Power (NYSE: NPWR; not covered)

We spoke with Daniel Rice, Chief Executive Officer and Director of NET Power, which has patented an innovative pre-combustion carbon capture technology that also eliminates air pollutants such as sulfur oxides, nitrogen oxides, and particulates. NET Power has demonstrated its NET Power Cycle at its 50 MWth Demonstration Plant in La Porte, Texas, which began testing in 2018. Over the next several years, NET Power will continue additional testing and validation campaigns at the Laporte facility while also developing its first utility-scale plant. NET Power ultimately will seek to license its technology and sell kits of varying industrial- and utility-scale configurations for customers to implement and operate in competitive power markets.

Huge TAM NET Power is uniquely positioned to address

Of 8 Rivers' portfolio of technologies, NET Power has progressed furthest toward broader commercialization, and appears to address a large total addressable market (TAM) of baseload generation that, under qualifications of fully decarbonized generation (from the atmosphere), the company is highly advantaged to serve. Between the next 5 and 15 years, a majority of the US generation fleet is expected to face retirement and will require significant replacement with clean energy attributes. Between now and 2050, there are over 3,000 TWh of baseload generating facilities retiring in the United States. The future licensing value of these facilities being replaced with NET Power plants could amount to \$87Bn. The operating economics are attractive as well – a NET Power generating facility can generate more cash flow from the capture of CO₂ than it can from selling power, which also allows for the facility to operate in competitive energy markets where abundant renewables can often clear at zero cost. Additionally, all of the ongoing cost of carbon capture to the operator is embedded in the upfront capital expenditures; on an operating expenses basis, there is no material difference between operating a combined cycle gas turbine that emits CO₂ into the atmosphere versus a NET Power plant.

DAC projects with OXY designate NET Power as preferred power source

Additionally, 40% shareholder Occidental (OXY, covered by our BofA Global Research colleagues) has announced plans to use NET Power as a preferred source of zero emission power for its DAC facilities, with the world's largest DAC facility under construction in West Texas with a targeted commercial operation date in 2025. The project will place a NET Power facility within OXY's existing midstream system, having already secured Class II permitting with class VI permitting possibly achieved in a year depending on progress with primacy in TX.

Risk shifts from technology to supply chain

After several successful demonstrations at the Laporte facility, NET Power assesses its greatest risks not to lie with the technology or market adoption of said technology but in its ability to deliver a timely and on-budget product given the impact of supply chain disruption to critical power infrastructure materials. There will likely need to be investment across all parts of the supply chain to support NET Power's desired growth targets. When orders start accumulating in the 2026 to 2027 time frame, NET Power wants to be prepared to deliver on a scale of 50-100 units longer term.

NEXDecade (NASDAQ: NEXT; not covered)

We hosted a discussion with NEXDecade Chairman and Chief Executive Matt Schatzman and SVP, Carbon Solutions Michael Mott. NEXDecade asserts that LNG is a

critical technology that can provide a steadying function to the energy transition given its dispatchability, provided that emissions can be reduced to a minimum. As such, the partnership between natural gas and CCUS provides a compelling business opportunity to deliver clean energy solutions without sacrificing reliability or economics. The company operates under subsidiaries Rio Grande and NEXT Carbon Solutions.

Sees need for more optimized EPA permitting process

NEXTDecade remarked on the significant pent-up investment that is currently waiting for individual projects to progress through the EPA's years-long CCUS project queue. Given the industry's nascency, there is not a great deal of individuals with the requisite experience in this type of permitting for Class VI wells. This dynamic should improve over time, but the government will need to commit to building out an organization to support application processing, or primacy will need to be delegated to the state level. Until permitting timing is improved, it will likely be very difficult to accelerate the general timeline of the carbon solutions side of the business.

Line of sight for economics to be strong enough to incentivize demand

Resolution of the prolonged permitting process will be important in unleashing idle investment in the space, given the importance of the \$85/t credit from Class VI permitting to the overall economics of the investment. NEXTDecade sees CCUS as an inherently inexpensive option to decarbonize as it takes existing energy assets that are currently productive and proven and improves their emissions profile. The company points to Texas' status as the most successful renewable energy market in the world, enabled by its expansive fleet of natural gas generation to support baseload. In its estimation, this amplifies the importance of CCUS to effecting the energy transition and limiting greenhouse gas emissions. Specifically remarking on the economics of the 45Q credit, its preliminary cost estimates assume that the system cost will trend above the \$85/t credit but that the technology will not be cost prohibitive to the customer.

SER Capital Partners

We hosted SER Capital Partners Principal Edward Kim, who formerly served as Bloom Energy's VP of Business Development. SER Capital is a clean energy-focused private equity firm, managing \$0.5bn is solely focused on power generation and the "clean molecule" side within the energy transition. SER's established partnerships predate Ed's tenure at Bloom, providing a unique perspective on the energy transition landscape. Fund one's current focus is on Carbon Capture and Storage (CCS), particularly in the "blue" space, where proven technologies make blue projects more conservative than emerging green technologies. Recent industry trends, such as Exxon's acquisition of Denbury and OXY's acquisition of Carbon Engineering, highlight the increasing interest in CCS projects.

Parsing out the economics; sees strategics favoring blue projects

SER's approach extends beyond large-scale sequestration, concentrating on distributed carbon capture and utilization, particularly in smaller urban markets. Targeted returns range from 20% to 30% internal rates of return (IRR), with a goal of a 2-3x multiple on invested capital. The firm explores opportunities in niche markets such as beverage-grade CO₂, creating value where larger players may lack interest. Trucking is important in SER's distribution strategy, especially for local markets, though facing challenges such as local opposition (NIMBYism) in both carbon capture and the broader energy transition. SER remains cautious about potential downsides, considering factors such as future supply shocks impacting commercial CO₂ prices. In the current industry landscape, SER observes significant momentum in blue projects, driven by large strategics with lower costs of capital. Blue applications, such as blue hydrogen, ammonia, and methanol, are expected to emerge earlier within the clean molecule space. The firm exercises caution regarding green projects, aligning with recent IRS guidance, and believes the present investment cycle favors blue projects. It notes that tangible opportunities do exist

despite challenges such as permitting issues and costs encompassing transportation, sequestration, and extraction.

Tenaska (Private)

We spoke with Bret Estep, VP at Tenaska. Tenaska is involved in community power gas operations, particularly emphasizing natural gas trading. With around 8 gigawatts (GW) in generation capacity, it manages over a 100,000 megawatts (MW) of third-party power plants. The company is organized into two teams: the Green team focuses on hydrogen, solar, and battery storage, while the Blue team concentrates on thermal development and carbon capture and storage (CCS). It started developing CCS sites a year before the Infrastructure Investment and Jobs Act (IIJA). With ten projects across the U.S. in locations such as the Ohio River Valley, Texas, Louisiana, Oklahoma, and Florida, Tenaska is working on grassroots development for sequestration fields. Its goal is to build a 50-million-ton-per-year platform across these ten sites. Tenaska aims to be the sequestration field developer, helping emitters transport CO₂ to their well sites. It deals with various aspects, from sub-surface modeling to Class six permits, infield piping, and pipeline development. The focus is on developing fields of around 30,000 acres to support 5 million tons per year for 20-30 years. Regarding the business model, Tenaska engages in transport and storage, aiming for smaller regional hubs to minimize pipeline impacts and localize costs and benefits. The company has diversified its portfolio geographically and across different customer classes, including power generation, ethanol, blue ammonia, cement, and steel.

Visibility to being injection-ready by 2028

Challenges faced by Tenaska include coordinating with emitter companies to align timing with tax credits and facilitating the engineering and capital processes for transport and storage. It evaluates projects on a case-by-case basis, considering its natural gas fleet when proximity and viability align. In contrast to large interstate transmission line projects, which often face opposition and disconnection from project benefits, Tenaska's alternative strategy emphasizes smaller regional hubs. Regarding project timelines, Tenaska expects to be injection-ready by 2028, with a phased approach. The Class VI permitting process resembles the interconnection queue, creating a resource bottleneck, but with early involvement, it aims to navigate this process efficiently. Economic viability is a big factor, with competitive transport and storage rates ranging from low teens to mid-twenties, making capture costs feasible. Beyond the 12-year tax credit period, additional revenue streams from voluntary carbon markets, carbon taxes, and potential movement in commodity prices contribute to long-term sustainability. Management mentioned that while Gulf Coast projects excel due to favorable geology and emitter concentration, Central Appalachia presents unique challenges with higher capex, contributing to a balanced portfolio of geographic diversity and strategic industry alignment.

Wolf Midstream

Wolf Midstream, in collaboration with CPP Investments, launched the Mount Simon Trunk Line, an innovative Carbon Capture and Transport system. LeBlanc mentioned the "hub" concept drives the project and attracts diverse industries to leverage the extensive sequestration capacity of the Mount Simon formation. The strategic plan starts with Ag Ethanol and fertilizer in the Midwest for economic and proximity reasons and envisions expansion into broader industrial decarbonization, covering sectors such as steel, chemicals, aluminum, and petrochemicals. Regulatory efficiency is prioritized, limiting initial operations to two states (Iowa and Illinois) during the first phase. The Mount Simon formation's sequestration potential enables long-term and large-scale carbon storage. Economic incentives, including the creditworthiness of anchor partners such as ADM, play a big role in attracting additional customers. Targeting a commercial operation date by the end of 2026, the pipeline is designed to handle up to 12 million tons annually.

Aims to be next-generation utility with decarbonization focus

As for costs, there is a strategic emphasis on economies of scale in transport costs, benefiting from a massive trunk line. Wolf Midstream mentioned it is not building laterals as they are economically challenging with a fixed revenue price point of \$85 per ton. Laterals are considered uneconomic and dilutive unless connected to a growth area or multiple facilities. The cost of sequestration is relatively fixed, with a focus on enhancing efficiency and capital utilization. The pipeline aims to position itself as a next-generation utility, providing a valuable resource for companies looking to decarbonize and make long-term investments in low-carbon facilities. The expectation is that as the global focus on zero-carbon and low-carbon products intensifies, the pipeline will become a critical component in decision-making for new facilities, creating a significant volume driver over the long term. Regulatory efficiency was a key theme, highlighted by a strategic withdrawal of the ICC application to align with anticipated guideline changes. Keith also emphasized transparency and thoroughness in the permitting process.

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