FINANCING MEGA-SCALE ENERGY PROJECTS:

A CASE STUDY OF THE PETRA NOVA CARBON CAPTURE PROJECT

Prepared for the CEO Council for Sustainable Urbanization

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Executive Summary

According to the latest report submitted by the Intergovernmental Panel on Climate Change (IPCC) to the member countries, global emissions of greenhouse gases must fall 40-70% by midcentury, compared to 2010 levels. The report pointed out that low-carbon energy resources, including the solar, wind and other resources with low CO2 emissions, account to less than 20% of the current energy mix. This 20% has to be raised 3-4 times in order to achieve the 40-70% reduction.

Unfortunately, bringing new energy technologies to market is plagued by multiple financial "valleys of death," or critical stages in the progress from lab to market during which risk-tolerant investment is very difficult to obtain. Even after advanced energy technologies emerge from the lab and successfully demonstrate proof-of-concept, they often face funding challenges on the road to commercialization. At this stage, the risk that a novel technology or process will not perform well at full scale deters commercial banks and other typical investors. This challenge is particularly acute for large-scale "mega-projects," complex low-carbon infrastructure investments requiring a billion dollars or more in initial investment.

To successfully cross the "Commercialization Valley of Death," advanced energy mega-projects need a number of key ingredients: a risk-taking lead developer with enough patience and determination to see a complex, long-term project across the finish line; project partners with expertise in the full value chain and skill at managing engineering, construction, and procurement processes and mitigating related risks; and a special set of investors willing to bet on an as-yet-unproven technology that could open up new markets and big economic returns in the future. In almost all cases, governments also play a key role in offsetting initial expenditures with grants or tax credits, providing risk-tolerant loans, or otherwise reducing the risks for pioneering project developers.

This report provides a detailed description of the Petra Nova Carbon Capture Project in Fort Bend Count, Texas. The billion-dollar project will bring post-combustion carbon capture technology at an unprecedented scale and demonstrate the commercial viability of this important carbon-reduction technology.

The Petra Nova project thus provides a concrete case study of what it takes for an advanced energy mega-project to cross the Commercialization Valley of Death.

A joint-venture between the American independent power producer NRG Energy, Inc. and Japan's JX Nippon Oil and Gas Exploration Corporation, Petra Nova will be the largest application of post-combustion carbon capture at an existing coal-fired power plant in the world. Proving that carbon capture can turn a profit, CO_2 from the Petra Nova project will be piped to a nearby oil field, where the CO_2 will be pumped underground and utilized in a process known as enhanced oil recovery. In addition to sequestering the CO_2, the process will boost pressure at the aging field and significantly increase oil production. NRG and JX Nippon have both taken equity stakes in the oil field, and revenues from enhanced oil production, facilitated by a $167 million grant from the U.S. Department of Energy and risk-tolerant financing from Japenese export credit agencies, are expected to generate a healthy, risk-adjusted return on investment. The Petra Nova project thus provides a concrete case study of what it takes for an advanced energy mega-project to cross the Commercialization Valley of Death.

The Challenge: The Commercialization Valley of Death

Combating climate change necessitates wholesale changes to the way the world makes and uses energy. To avert the worst consequences of climate change, global emissions of carbon dioxide (CO_2) and other greenhouse gases must decline by 40 percent to 70 percent by 2050 and effectively to zero by the end of the century.[1] The electricity sector is expected to lead the way towards decarbonization, with most climate stabilization scenarios envisioning the global power sector emitting zero CO_2 by 2050.[2]

Getting to zero carbon will require the widespread adoption of multiple advanced, low-carbon energy technologies. While some low-carbon resources, including energy efficiency, wind power and solar photovoltaics (PV), are well established and scaling up rapidly, energy experts believe continued innovation and a new generation of advanced energy technologies will be important to meeting the decarbonization challenge. Next-generation solar, wind, and nuclear power designs, new energy storage technologies, and the ability to capture and store CO_2 emissions from fossil power plants and industrial facilities could all greatly improve the world's chances of rapidly and affordably reducing global greenhouse gas emissions.[3]

Unfortunately, bringing new energy technologies to market is a notoriously difficult challenge, plagued by multiple financial "valleys of death"—critical stages in the progress from lab to market during which risk-tolerant equity investment and commercial debt financing are very difficult to obtain.[4] In particular, a "Commercialization Valley of Death" besets many advanced energy technologies that have already passed proof-of-concept stage but still require large capital infusions to demonstrate that the full, integrated process can be brought to commercial scale. At this stage, there is often a significant risk that a novel electricity generation technology or clean energy manufacturing process will not perform well at scale or that a large and complex project cannot be executed on time or on budget. This perception makes commercial banks and many equity investors leery of investing in these first-of-a-kind or first-at-this-scale projects. This challenge is particularly acute for large-scale "mega-projects," complex low-carbon infrastructure investments requiring a billion dollars or more in initial investment.

Groundbreaking at the Petra Nova site in 2014. *Source: US Department of Energy*

The "Commercialization Valley of Death" creates a classic "chicken and egg" dilemma. "Everyone wants to be the first to go second," explains Christopher Smith, Assistant Secretary for Fossil Energy at the U.S. Department of Energy.[5] After one company takes a risk and proves a technology can work as advertised, commercial lenders and other investors are typically willing to follow this pioneering project and make further investments in subsequent projects. Yet unless financing is available to build that first-at-this-scale project, the perception of risk will continue to keep investors from funding the advanced energy technologies needed to help confront climate change.

The Opportunity: Coal Without Carbon

If the electricity sector is to lead the way towards zero carbon by mid-century, emissions from coal and other fossil-fueled power plants must ultimately be eliminated.[6] While the year 2050 may seem like a long way off, power plants and associated transmission infrastructure are very long-lived assets. That means that many power plants built today will still be generating electricity when 2050 rolls around, including a massive fleet of new coal-fired power plants built in China, India and other rapidly developing countries in recent years.

Coal has fueled nearly half of the growth in global energy supplies since the turn of the century.[7] As a result, more than one-fifth of coal plants worldwide are now less than five years old and half are younger than twenty.[8] China alone built roughly 530,000 MW of coal-fired power plants in the last decade,[9] more generating capacity than all coal plants in the United States.[10] Despite the stifling air pollution now afflicting Chinese cities and a pledge to reduce the amount of CO_2 emitted per unit of economic activity (compared with 2005 levels) by 60 to 65 percent by 2030,[11] China's coal-fired power fleet is expected to keep growing over the next decade. By 2025, China could have more than 1,360,000 MW of coal plants online.[12]

While the United States and Europe may ultimately retire their venerable coal-fired power plants by mid-century, it is unlikely that China and other emerging economies will abandon all or even a majority of their recently-built, state-of-the-art coal plants. Without the ability to eventually capture and safely store CO_2 emissions from a vast fleet of existing coal plants in China and elsewhere, mitigating climate change may thus prove impossible.

Retrofitting already operating coal plants depends on the maturation, scale-up, and improvement of a set of technologies known as "post-combustion carbon capture." Post-combustion carbon capture involves separating the CO_2 from the exhaust stream of a coal or other fossil-fueled power plant or industrial facility, similar to the way sulfur dioxide, nitrous oxides and other conventional air pollutants are scrubbed from power plant emissions. This technique typically employs special chemical solvents, called amines, which bind to and absorb CO_2 in the exhaust stream or flue gas of the power plant. Heat is then applied to strip the CO_2 from the carbon-rich amine solution. The amine is recycled and used again and the resulting high-purity CO_2 stream is compressed into a supercritical or liquefied state and either utilized for industrial applications or pumped in pipelines to a site where the CO_2 can be injected and stored underground.

While most of the key components of this post-combustion carbon capture and sequestration (CCS) process are in use today,[13] no one has yet demonstrated the operation of a fully integrated, post combustion CCS project at the scale of a commercial coal-fired power plant. Efforts to commercialize post-combustion carbon capture therefore present a concrete example of what it takes to bring a large-scale energy technology to across the Commercialization Valley of Death and prove to the world that the technology works—and is also profitable—at full scale.

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Post-combustion carbon capture integrates a variety of established technologies and techniques. Chemical amine solvents were developed over 75 years ago to remove acid gases such as CO_2 and hydrogen sulfide from natural gas.[14] The idea of separating CO_2 from power plant exhaust first arose not due to climate change concerns, but rather as a possible source of CO_2 to enhance the productivity of declining oil fields. In a process known as enhanced oil recovery (EOR), water or a gas, such as CO_2, is compressed and pumped into oil reservoirs to increase pressure and flush out more oil. CO_2 was first used for oil recovery in 1972 in Scurry County, Texas, and as of 2012, there were more than 100 active commercial CO_2 injection projects in the United States injecting over 65 million tons of CO_2 per year.[15] Most of the CO_2 used in enhanced oil recovery in the United States today is derived from naturally occurring reservoirs or removed from natural gas, and a network of over 3,400 miles of pipelines has been established in the United States to deliver CO_2 from geologic sources, mostly in Colorado, Wyoming and New Mexico, to the oil fields of west Texas and the Gulf Coast.[16] The oil and gas industry also has extensive experience storing natural gas, which behaves similarly to CO_2, in depleted oil fields, saline aquifers, and salt caverns. The capacity of underground natural gas storage in the United States today would be sufficient to store a full year of CO_2 emissions from all power plants in the country.[17]

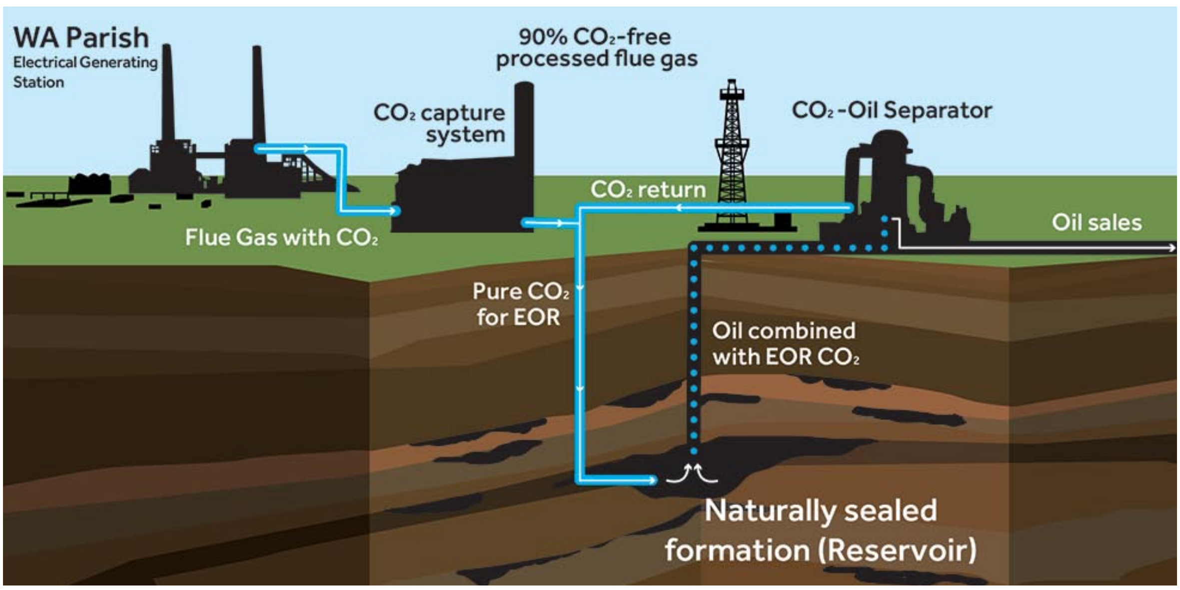
While the technologies exist to capture CO_2 from power plant exhaust and the U.S. oil and gas industry has decades of experience piping and storing gases underground at large volumes, post-combustion carbon capture at coal plants involves a novel application and successful integration of these established technologies at an unprecedented scale.

Only 13 large-scale CCS projects are in operation worldwide, and just one uses post-combustion capture at a power plant.[18] SaskPower's Boundary Dam project, the first large-scale post-combustion carbon capture project in the world, went online in Saskatchewan, Canada in October 2014. A 110-megawatt retrofit to the coal plant's Number 3 boiler, the project captures 1 million metric tons of CO_2 annually, equal to the tailpipe emissions of 250,000 cars.[19] The CO_2 is then piped 41 miles (66 kilometers) to oil fields in southern Saskatchewan as well as a research project testing sequestration of CO_2 in a deep sandstone formation.[20] While a major step forward towards integrating and scaling-up all of the components of post-combustion capture and sequestration, the Boundary Dam project is still only a fraction of the size of modern coal-fired generators, which are typically 300 MW or larger.[21] At a price tag of CAD$1.467 billion,[22] it is also much too expensive to be profitable without government assistance. The Canadian government contributed one-sixth of the project's cost,[23] and the province's ratepayers are likely paying more for the carbon capture project than other competing sources of power.[24]

Three central challenges remain on the path to commercializing post-combustion carbon capture:

- capture systems must be scaled up;
- costs must come down;
- pioneering companies must prove to commercial lenders that carbon capture projects can be reliable, profitable investments.

In short, post-combustion carbon capture has to successfully navigate the Commercialization Valley of Death.



An explanation of how the process will work at the Petra Nova site. *Source: NRG*

The Petra Nova Carbon Capture Project: the Next Step Across the Valley of Death

Just southwest of Houston, Texas lies one of the United States' largest power plants. Home to four coal-fired generators and six natural-gas fired units capable of generating a combined 3,700 MW, the W.A. Parish power plant in rural Fort Bend County is also one of the country's biggest emitters of CO_2. It is fitting then that this massive power plant will soon be host to the world's largest post-combustion carbon capture project, the Petra Nova Carbon Capture Project. The $1 billion project is a 50-50 joint venture between independent power producer NRG Energy's Carbon 360 unit and JX Nippon Oil & Gas Exploration of Japan. Construction of the project began in July 2014 and is on schedule for completion in late 2016, according to NRG executives.[25]

While all of the components employed at Petra Nova have been demonstrated elsewhere, the project will be a major step forward in scaling up post-combustion carbon capture technology. Once fully operational, Petra Nova will capture 1.6 million metric tons of CO_2 annually from a vent that will divert more than a third of the exhaust gas from the 650 MW Unit 8 coal-fired generator at W.A. Parish.[26] At 240 MW, Petra Nova will generate more than double the power of SaskPower's Boundary Dam project and will capture 60 percent more CO_2. The project will make use of a high performance post-combustion CO_2 capture system supplied by Mitsubishi Heavy Industries America (MHI). With a capture rate of 4,776 metric tons per day ofCO_2, the system will be nearly ten-times larger than the previous demonstration of MHI's capture technology at Southern Company's Plant Berry coal plant launched in June, 2011 (see Fig. 1).[27]

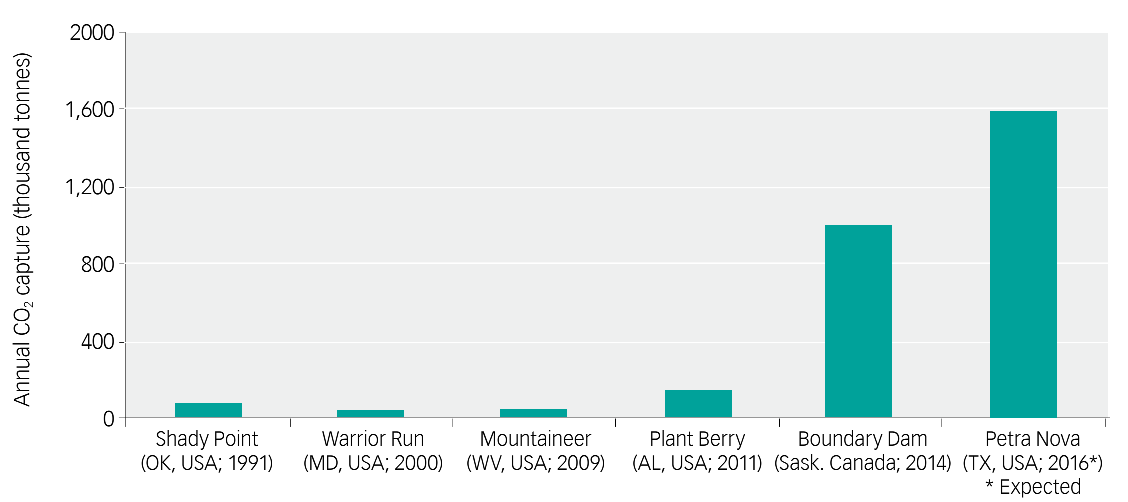
"We know all of these components work," says John Ragan, President and CEO of NRG Carbon 360. "But we are scaling the CO_2 absorption system to a new scale and integrating all of the components is new and challenging here."

The Petra Nova project thus fell solidly into the Commercialization Valley of Death.

Putting together the finances for Petra Nova required tenacity on the part of NRG and a creative combination of risk tolerant partners that make up a three-legged stool, according to Bruce Chung, Senior Vice President for Finance and Asset Management for NRG Carbon 360.

NRG began developing the Petra Nova carbon capture project in 2009, and by 2010, the

Figure 1: Scaling up CCS: post-combustion carbon capture projects at pulverized coal plants



company had secured its first key partner and the first leg in the financing stool. The U.S. Department of Energy (DOE) awarded the project a $167 million grant as part of a competitive solicitation under the DOE's Clean Coal Power Initiative, which partners with private industry to accelerate the demonstration of commercial-scale carbon capture and storage technologies.[28] The support from DOE offsets about 17 percent of the project's total cost and reduces risks accordingly for Petra Nova's equity investors.

Given the important technical, environmental, and financial experience generated by the project, the federal grant will also advance key national energy priorities.[29]

"Major demonstration projects are an important part of the technology development process," explains DOE's Assistant Secretary Smith. As such, the Department "partners with companies to do first-of-a-kind demonstrations, get projects built, and help deal with the integration issues that go along with these novel efforts."[30]

> "Not only do these projects give second movers confidence these things can be built, but they also identify opportunities for cost savings and improvements the next time around."
>
> -Christopher Smith, US DOE Assistant Secretary

The Petra Nova project comes at a time when the U.S. Environmental Protection Agency (EPA) is beginning to regulate CO_2 emissions from power plants.[31] Post-combustion capture is one way for power plant owners to comply with these new rules, but without experience from large-scale projects, the technology will remain too expensive and risky to be a viable option.

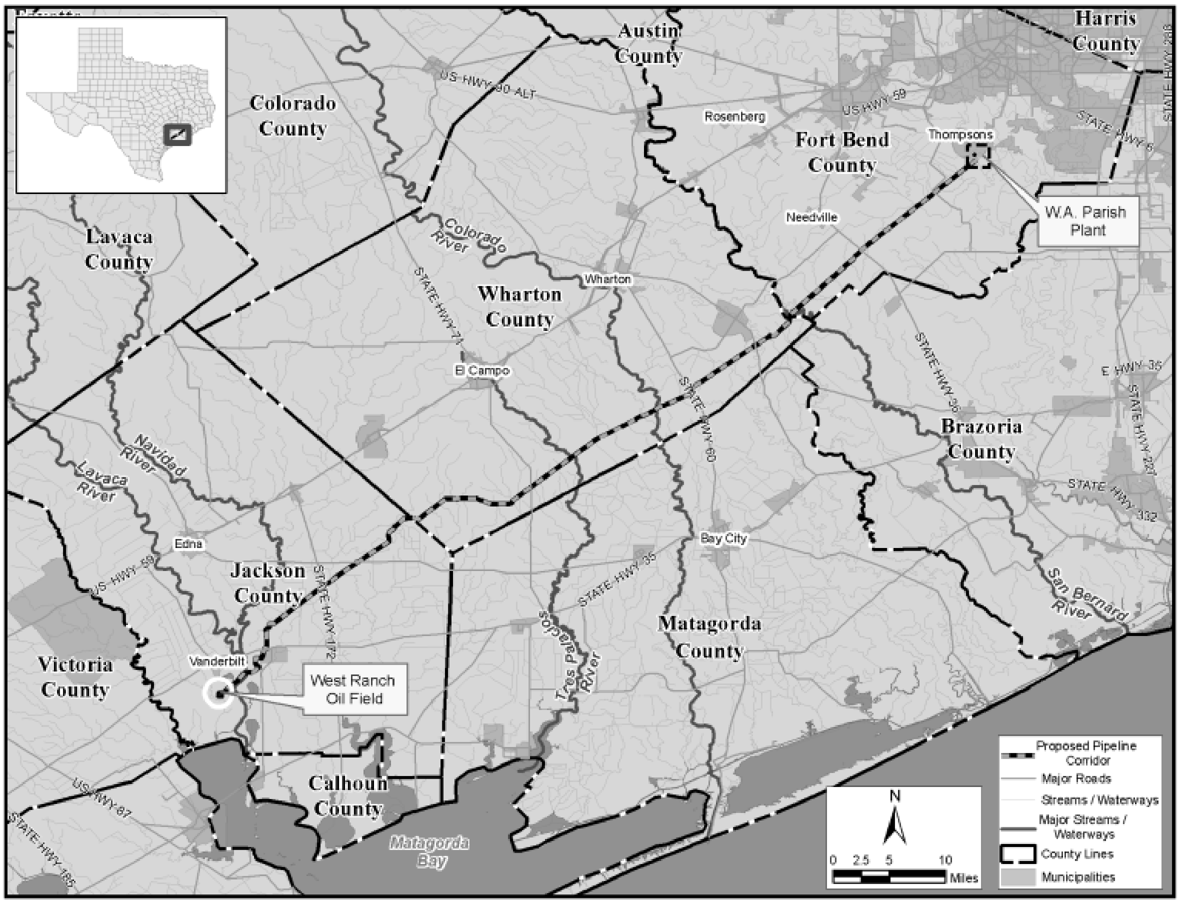
"The first time anyone completes a project like this, you inevitably find a lot of areas where you would do things differently next time," says Smith, who recently toured the construction site at the W.A. Parish plant. "Being out there on site with a construction engineer and having him point out all the things they've already identified they can do better next time really drives home the fact that getting these initial demos in place is tremendously important," Smith explains. "Not only do these projects give second movers confidence these things can be built, but they also identify opportunities for cost savings and improvements the next time around."[32]

"We're looking for ways to take 20 to 30 percent out of the cost if we repeated this kind of project again," says NRG's Ragan. Those cost reductions could render government support unnecessary for future projects, and Ragan points to four opportunities to drive down costs:

1. Streamlining procurement, reducing structural steel used, and other "learning-by-doing" generated by Petra Nova
2. Standardization of design and pre-fabrication of modular components which can then be more rapidly and easily assembled on-site
3. Improvements in the efficiency and performance of the amine solutions used, which will reduce the amount of energy needed to run the CO_2 capture process
4. Improvements in financing costs such as reduced fees, less due diligence required, improved time to complete financing, and higher debt to-equity leverage[33]

"On the order of a 50 percent reduction in cost is ultimately within the realm of possibility through engineering optimization and experience from initial projects," says Sasha Mackler, Vice President of Summit Carbon Capture, an energy project development company working on its own carbon capture projects. Mackler points out that scrubbers that capture sulfur dioxide and nitrogen oxides from coal plant exhaust experienced a similar decline in costs after air pollution regulations required their widespread adoption.[34]

Figure 2: Map of W.A. Parish Plant and West Ranch Oil Field



The second leg of the stool is the revenue generated by using the CO_2 captured at the W.A. Parish plant for enhanced oil recovery (EOR). The captured CO_2 will be compressed and transported 81 miles (130 kilometers) via a new 12-inch underground pipeline to the West Ranch oil field in Jackson County, Texas (see Fig. 2). There, the compressed CO_2 will be pumped roughly a mile (1.6 kilometers) underground to enhance oil production at the site and sequester the CO_2 in the geologic formations.[35] Working with the University of Texas and the U.S. Department of Energy, the Petra Nova project partners will closely monitor the CO_2 in the oil field to ensure it becomes permanently sequestered.[36]

Using captured CO_2 to pump more fossil fuels out of the ground diminishes the overall environmental benefit of the project, but not as much as it might appear. Individual projects do not produce enough oil to move prices in global markets, and as a result, the increased production at the West Ranch field "will just push more expensive oil suppliers out of the market somewhere else," according to Sasha Mackler of Summit Carbon Capture.[37] In the long run, significant increases in oil production from CO_2 EOR *could* reduce global oil prices, which would lead to more overall oil consumption (and associated emissions). Accounting for these macroeconomic implications of CO_2 EOR is difficult, however, and it is hard to say how these changes should be attributed to an individual project, like Petra Nova. "We don't do these kinds of calculations when talking about buying a Tesla or a more fuel efficient car," points out John Thompson, Director of the Coal Transition Project at Clean Air Task Force, an environmental advocacy group.[38] For its part, the U.S. EPA considers any CO_2 captured at a coal plant that is permanently stored in oil fields as a reduction in electricity sector emissions.[39] It regulates emissions from oil production and consumption directly via other mechanisms, such as Corporate Average Fuel Economy standards for automakers, which were recently ratcheted up to 54.5 miles per gallon as part of the Obama Administration's overall climate action plan.[40]

Storing CO_2 in saline aquifers and other geological formations without increasing fossil fuel production is possible, and over 10 million metric tons of CO_2 have been geologically sequestered in demonstration projects in the United States, according to DOE's Christopher Smith.[41] In the near-term, however, revenues from EOR or other valuable uses for CO_2 will be indispensable to commercializing post-combustion carbon capture.

"NRG quadrupled the size of the project at no additional cost to the tax payer,"explains DOE's Christopher Smith."They saw that this was a profitable investment they could sell to their board of directors.

"All the economics of the Petra Nova project are based on the oil field production," explains NRG's Bruce Chung. Capturing CO_2 comes at a substantial cost, and in the absence of an equally substantial penalty for carbon emissions, the only way to make the project financially viable is to employ the captured CO_2 for a productive use. Injecting CO_2 captured at the W.A. Parish site is expected to increase oil production at the depleted West Ranch field from 500 barrels per day to approximately 15,000 barrels per day and will ultimately help recover 60 million additional barrels of oil.[42]

Most carbon capture projects sell the CO_2 to an oilfield operator for use in EOR. Going down this route keeps the project simpler, but it also leaves a lot of value on the table. "These are negotiated, bilateral contracts, and there is a lot of bargaining in these deals," explains Howard Herzog, an expert on carbon capture and sequestration at the Massachusetts Institute of Technology. According to Herzog, the oil field owner typically ends up with the better end of the deal. As a result, CO_2 for EOR operations is typically sold for just a fraction of the value of the oil it helps extract and may secure $10-35 per ton of CO_2 delivered to the oil field.[43] In contrast, at $50-100 per barrel of oil, the West Ranch field would produce an additional $150-300 worth of oil for each ton of CO_2 delivered from the W.A. Parish plant.

To secure a greater share of that value, NRG decided on a novel project structure. Instead of just capturing the CO_2 at its power plant and selling the oil to a third party, the company would build and own the CO_2 delivery pipeline and take a 50 percent equity stake in the West Ranch oil field itself. "Essentially, what NRG is doing is shifting the split in revenues produced from EOR more equitably between CO_2 supplier and oil producer," explains Thompson at the Clean Air Task Force.[44]

In the process, NRG would integrate downstream into the CO_2 delivery, injection, and oil production sectors. To succeed, the veteran electric power producer needed new partners with expertise in these unfamiliar market segments.

By purchasing a direct stake in the West Ranch field, NRG brought in the first of these partners: Texas-based oil exploration and production company Hilcorp, the original owner of the oil field. Working together on the front-end engineering design for the project, NRG, Hilcorp, and MHI soon realized that NRG's original plans for a 60 MW carbon capture project would produce an insufficient supply of CO_2 to pressurize the West Ranch field and would not produce enough oil to make the project financially attractive. The project partners decided that the financial reward from enhanced oil production at West Ranch justified a much larger project, even without any further support from the DOE.[45]

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While buying a stake in the oil field brought NRG sufficient revenues to justify what would become the world's largest post-combustion carbon capture project, integrating downstream also brought plenty of new challenges.

"Oil is not something NRG is talented at as a company, so having an equity partner that understands oil is very helpful," says NRG's Ragan of the decision to turn the project into a joint venture with JX Nippon. "Partnerships are something we as a company are very comfortable with," Ragan notes, "and from a project development standpoint, when the project involves something that isn't one of our core competencies, we find the right partner to execute the project."

JX Nippon eventually matched NRG's own approximately $300 million equity stake in the project,[47] and the Japanese firm's expertise and involvement was key to securing project finance, according to Takeo Tanei, Vice President of Petra Nova Parish Holdings and JX Nippon's point person for the project. JX Nippon brought its prior experience with EOR projects in the North Sea, Middle East, and Vietnam to the venture, and the company played a key role in drafting the Full Field Development Plan to justify project finance.[48]

JX Nippon's involvement was essential to securing the third and final leg of the financing stool: risk-tolerant debt financing from unconventional lenders.

Due to the unprecedented scale and complex financial structure of the Petra Nova project, "commercial banks saw the project as first-of-a-kind of risk," explains NRG's Ragan. "So the financing strategy that we undertook had to be one that didn't involve traditional commercial lending avenues."

Instead, JX Nippon's involvement opened the door to $250 million in loans from two Japanese export credit agencies, the Japan Bank for International Cooperation (JBIC) and Nippon Export and Investment Insurance (NEXI).

These two agencies think about project risk and return in a very different way than commercial banks. "The key function of these organizations is to cover financial risks which are beyond the private sectors' ability to finance but where there is potential to open new venues to the future for the Japanese economy," explains Takeo Tanei.[49] The goal of both JBIC and NEXI is to advance the competitiveness of Japanese industry overseas, support the growth of emerging markets for Japanese products and services, and in the case of JBIC, promote overseas businesses that help preserve the environment and confront global warming.[50]

"This project is expected to make it possible to produce additional crude oil from the existing oil field and contribute to simultaneously reducing burden on the global environment and increasing energy resources," says Noriyasu Matsudo, a division director at JBIC's Oil and Gas Finance Department.[51] "In addition, expanding this scheme to other regions will support the obtaining of oil field interests by Japanese companies and further the business of Japanese companies."

Given that the project also utilizes MHI's carbon capture technology, jointly developed with Japan's Kansei Electric Power Company, "this project financing has also an aspect of supporting the propagation of Japanese company's environment technology," Director Matsudo notes.

"This project is expected to make it possible to produce additional crude oil from the existing oil field and contribute to simultaneously reducing burden on the global environment and increasing energy resources."

— Noriyasu Matsudo, Division Director, JBIC

In the end, the two Japanese credit agencies considered the Petra Nova project an important strategic investment and were willing to step in where commercial banks were reluctant to supply the debt financing needed for the project. NEXI ultimately insured a $75 million loan provided by Japan's Mizuho Bank,[52] while JBIC provided $175 million in debt financing in exchange for $90 million in preferred shares of JX Nippon's stake in the project.[53] Both loans mature in April 2026 and were secured at favorable rates: 1.75% over the London Interbank Offer Rate, or LIBOR, for the NEXI-based loan and 0.5% above LIBOR during construction and 1.5% above LIBOR thereafter for the JBIC loan.[54]

With all three legs of the stool in place, the creative financial solution put together for the Petra Nova project should generate an appropriate profit for the equity partners, according to NRG and JX executives.

"Petra Nova is a billion dollar project, so we expect to get the economics and risk-adjusted return that our investors are happy with."

— John Ragan, President and CEO of NRG Carbon 360

"We don't do loss leaders," says NRG's Ragan. "Petra Nova is a billion dollar project, so we expect to get the economics and risk-adjusted return that our investors are happy with."[55]

At the same time, if Petra Nova succeeds as planned, it will prove to commercial banks that post-combustion carbon capture and EOR projects are safe investments. "Commercial banks can point to [Petra Nova] and see that someone else took the risk and they were rewarded," says Bruce Chung of NRG. That will pave the way for much more straightforward project finance for future carbon capture efforts.[56]

When the project goes online in late 2016, it will be seven years since NRG started down this path. In the intervening years, the NRG team successfully executed what John Ragan calls "one of the most interesting and complex projects we've ever put together." The project took tenacity, patience, and a willingness to find the right partners to complement the company's own core competencies.

While being the first across the "Commercialization Valley of Death" carries big risks, it can also generate real rewards. NRG, JX Nippon, and the other Petra Nova partners will gain valuable, hands-on experience on what it takes to successfully execute a post-combustion carbon capture project, identify opportunities for further cost reductions from learning-by-doing, and potentially secure a first-mover advantage in the market.

To capitalize on these opportunities, NRG has already spun the Petra Nova project team into a new business unit, NRG Carbon 360. "We're trying to transition this effort from a project to a company," says Ragan, who helms the new business. NRG Carbon 360 is actively looking for additional oil fields in proximity to the W.A. Parish plant or NRG's other coal assets that are suitable for EOR operations. According to Ragan, the company is also exploring other beneficial uses of CO_2 including conversion to liquid fuels or solid construction materials.

In short, Petra Nova may just be the beginning.

Going Forward: Lessons from Petra Nova

The Petra Nova project is a pioneering step across the Commercialization Valley of Death for a "mega-scale" advanced energy technology. The complex, billion-dollar project demonstrates a number of key lessons applicable to similar efforts to finance and commercialize novel low carbon energy technologies:

- Developers of "mega-scale" advanced energy projects need the patience and tenacity to see the project to completion. The development of the Petra Nova project will span seven years, and companies seeking to bring a novel and complex technology like this to market must be prepared for the long road ahead.

- Financing first-of-a-kind or first-at-this-scale advanced energy technologies requires creativity and a willingness to put together a novel and complex deal. To unlock the necessary financial returns, NRG had to be willing to integrate downstream into an unfamiliar sector—oil and gas production—and bring in multiple partners to successfully execute the project.
- Indeed, successful advanced energy projects will bring together a range of partners with diverse core competencies that collectively span all aspects of the venture. NRG is adept at developing electric power projects and managing engineering, construction and procurement processes. By all accounts, the company has managed the Petra Nova project efficiently. Yet NRG could not have executed this project on its own. MHI's expertise in designing and building carbon capture systems, Hilcorp's intimate knowledge of the West Ranch oil field's geology, and JX Nippon's experience with EOR projects were all fundamental to Petra Nova's success.
- Government agencies should be willing to partner with industry on first-at-this-scale demonstrations and mitigate the risks for companies willing to forge a path across the Commercialization Valley of Death. From jet engines, microchips, and the Internet to nuclear, wind, and solar power, public-private partnerships to develop and demonstrate advanced technologies have been a regular facet of the U.S. innovation system.[57] DOE's support for the Petra Nova project may play a similar role in commercializing post-combustion carbon capture and paving the way for more cost-effective and widespread adoption of this important low-carbon technology.
- Access to risk-tolerant project financing from investors that take a strategic view is also essential to crossing the Commercialization Valley of Death. Lenders willing to finance as-yet-unproven technologies typically look beyond simple project economics and value potential future market opportunities, economic development impacts, or the energy security or environmental benefits that a successful project may unlock. JBIC and NEXI were willing to take a risk on the Petra Nova project due to the potential to position Japanese companies at the forefront of a nascent market opportunity, secure an important natural resource, as well advance an environmentally friendly technology developed by Japanese firms.
- Finally, emerging energy technologies must have a clear path to profitability. Strategic-minded companies might be willing to take a risk on an advanced technology or novel project structure, but only if they see an opportunity for sufficient economic returns if all the pieces fall into place. NRG is an independent electricity producer that operates in competitive electricity markets. Unlike regulated utilities, the company doesn't have captive ratepayers or guaranteed returns on invested capital to fall back on if the project is delayed or costs overrun. To tackle a project like Petra Nova, NRG and its partners need to know that if they execute on time and on budget, they will earn sufficient returns to satisfy investors. When developing an advanced energy project, the path to profit is not guaranteed—but the potential reward must be worth the risk.

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