# Jupiter Oxygen Corporation

## High Flame Temperature Oxy-Fuel Combustion Carbon Capture

***Transitional Technology for a Zero Emission Future***

## Introduction – Carbon Capture Technologies

It is a US$25 trillion-dollar global energy infrastructure that must be replaced to eliminate all emissions in 30 years (with respect to the goal of 2050 that has been set by the Paris Agreement).

Or, transitional technologies like carbon capture, that either removes carbon dioxide directly from the air or prevents $CO_2$ from entering the atmosphere in the first place can be utilized. There are not enough renewable alternatives currently eligible to replace fossil fuels in every corner of our global energy system. While renewables have developed from a niche technology to a global industry their cost is reducing; the industry's growth is growing, their current applicability is still nascent. For full implementation, the renewable industry must improve their value chain; optimizing activities from engineering to commercial capabilities either by capitalizing on their own expertise or by engaging with partners. They must improve economies of scale and skill, capturing both sets whether globally – for technological economies of scale in areas like procurement, or locally for market understanding and analysis. Finally, renewables have to establish an agile operating model providing the key to cope with fluctuating development cycles across countries and technologies. Currently, renewable are not able to shift resources quickly to the larger value pools in response to changes in the landscape. The logic of global demographic trends is inescapable; global population is growing, cheap energy resources will always be the preferred source and CO2 emissions will continue to grow.

Until renewables can sustain the global demand, carbon capture technologies, especially Oxy-Fuel Carbon Capture, is essential. Right now, we do not just need carbon neutral technologies but carbon negative technologies. Right now, it is far less feasible to invest in a fossil fuel elimination plan than it is to invest in a current proven technology that mitigates climate change by reducing emissions from fossil fueled plants. Carbon Capture.

The earliest carbon capture technology filtered $CO_2$ from flue gasses of industrial processes. Once the $CO_2$ was "captured" it was be sequestered, stored underground. Or, it could be utilized in several industrial and manufacturing processes including cement, paper, steel, and iron. Hence, the acronym CCUS; Carbon Capture Utilization and Storage; Use it or Store it. CCUS has become a critical component in a portfolio of low-carbon energy technologies aimed at combating climate change.[1]

[1] National Academy of Sciences

The concept of capturing $CO_2$ was first explored in the 1920's when salable methane was separated from $CO_2$ found in natural gas reservoirs. In the 1970's, a novel technology was using captured $CO_2$ to increase oil recovery from oil fields that had been thought to be depleted was tested and proved effective; Enhanced Oil Recovery.[2]

Carbon capture technologies have been identified as "clean coal" technology. It is important to highlight that there *is* a technology where coal is "cleaned" before combustion. This is not a carbon capture technology. Technically to "clean coal" one would employ a coal preparation process whereby mineral matter is removed from mined coal - prior to combustion - resulting in a product that has improved combustion performance and lower GHG emissions. The primary purpose of "cleaning" coal is to increase the quality and heating value by lowering the level of sulfur and mineral constituents. Sometimes called "coal washing", this process reduces coal ash pollution. Roughly half to two-thirds of the sulfur in U.S. domestic coals occurs in a form that can be liberated by crushing and separated by mechanical processing.[3] Cleaning coal using this process has no impact on $CO_2$ emissions. The value of this process is that a lower volume of coal will be used in combustion.

The phrase "clean coal" became mainstream with the Obama campaign when then-candidate Obama said *"clean coal technology (could make America) …. energy independent…This is America. We figured out how to put a man on the moon in 10 years. You can't tell me we can't figure out how to burn coal that we mine right here in the United States of America and make it work"* (As a U.S. Senator from Illinois he was an advocate for Illinois coal and Illinois coal mining). The next major political (and rhetorical) development was in early 2009 when the phrase "War on Coal" was attributed to multiple Senators and Congress(wo)men in the wake of President Obama's cap-and-trade pledge, requiring all power plants burning fossil fuels to purchase a permit whose cost would be determined by each ton of $CO_2$ emitted. The surrogates of both Coal and its opponents concede that Cap-and-Trade was sacrificed for the Affordable Care legislation.

Is carbon capture a "clean coal" technology? To the extent that fossil fuels (in this case, coal) is used in a power plant or manufacturing facility and a carbon capture technology installed at that plant removes GHG emissions then one can say, yes, carbon capture technologies are clean coal technologies. Our research indicates that carbon capture technologies exponentially outperform the process described above for cleaning coal.[4]

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[2] IEA, UN IPCC, US DoE
[3] Al Gore, W.J. Clinton, U.S. DoE, MIT, Carnegie Mellon
[4] See "Technical Papers" at Jupiter Oxygen website, www.jupiteroxygen.com

## Types of Carbon Capture Technologies

***Note: These are highly simplified explanations of very complex technologies. See 'References' in footnotes for additional information.***

There are primarily four (4) types of carbon capture technology.

- Pre-Combustion
- Post-Combustion
- Oxy-Fuel Combustion
- Direct Air Capture

The first three are technologies are utilized in relation to the "combustion" process[5] in power plants and manufacturing facilities that use fossil fuels (coal, oil, or natural gas). The combustion process produces energy; either steam or power generation (electricity).

Pre-Combustion carbon capture removes $CO_2$ before the combustion process is completed. The percentage of removal has been estimated between 70% - 90% $CO_2$ capture[6]. Pre-combustion carbon capture is de-carbonization by *gasification of the primary fuel*. Most Pre-Combustion technologies today typically use physical or chemical adsorption processes. The cost to capture $CO_2$ by pre-combustion carbon capture is approximately $60/tonne[7] but recent research has indicated much higher cost.

Capture prices of pre-combustion are reduced significantly when applied to an IGCC (Integrated (Coal) Gasification Combined Cycle) power plant. For decades, pre-combustion was considered "the future" of carbon capture, the most compelling feature being it is an inherently cleaner process because coal is not combusted and pollutants can be removed with greater efficiency. Early proponents of pre-combustion point out that the $CO_2$ removed is more concentrated making for a more efficient process.[8] Further, the capture rate is substantial. However, developments in Oxy-Fuel and post-combustion indicate much higher efficiency measurements. For example, the cost to capture in pre-combustion is higher than other carbon capture technologies reducing overall efficacy.[9] There are several pre-combustion projects with funding by the U.S. DoE including Arizona State, Ohio State, State University of New York, TDA Research, and Membrane Technology and Research. The pre-combustion project that has garnered most attention is Dakota Gasification. This is the only commercial-scale coal gasification plant in the U.S. Located in North Dakota, owned and operated by Dakota Gasification company (a subsidiary of Basin Electric Power Cooperative). The captured $CO_2$ is used for Enhanced Oil Recovery by EnCana in the Weyburn and Midale oil

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[5] Combustion is a chemical process in which a substance (in our example, fossil fuels) react quickly with oxygen and gives off heat. During combustion, new chemical substances are created from the reaction and are turned into exhaust products. When fossil fuels burn the new substances are water (Hydrogen and Oxygen) and carbon dioxide (Carbon and Oxygen). Fossil fuel combustion also creates nitrous oxides and sulfur oxides. (Source: NASA)

[6] University of Edinburgh

[7] U.S. DoE Office of Fossil Energy

[8] MIT, Cornell, Science Direct, US DoE

[9] Jupiter Oxygen website/Technical Papers, Cornell, Carnegie Mellon

fields in Saskatchewan.[10] A well-known and controversial pre-combustion project was in Kemper County, Mississippi at a plant owned by Southern Company's Mississippi Power. Hailed as a first-of-a-kind with promises of jobs and revenue to the nation's poorest state and fortified with $270 million in federal subsidies, the Kemper project was an abysmal failure. The cost of the project exceeded budget by over 200% ($2.4 billion to $7.5 billion). The reasons for the failure of this project range from project mismanagement to fraud. The resulting optics for the broader carbon capture industry was devastating. Critics of carbon capture technologies point to Kemper as an example of why carbon capture technologies are not cost effective solutions to climate change mitigation.

Post-combustion is a technology when $CO_2$ is separated from a mixture of gasses at the end of the combustion production process. Most carbon capture projects, from Feasibility to FEED to Commercial are post-combustion. The $CO_2$ that is removed in this process may be a dilute $CO_2$ and it is removed from the flue gasses. The most common post-combustion processes are solvent-based $CO_2$ capture, Sorbent. Membrane-Based and other hybrid processes (known simply as "solvent" or "membrane" systems).[11] The benefits of post-combustion includes minimized energy demand, utilized on retro-fit and new build, closest to commercial scale of all carbon capture technologies. The challenges this technology has to overcome is that the carbon capture cost is currently higher than oxy-fuel, energy efficiency is below oxy-fuel and there can be a high amount of solvent loss due to chemical and thermal degradation causing a slip into the atmosphere.[12]

Solvent-based $CO_2$ capture involves chemical or physical absorption of $CO_2$ from flue gas into a liquid carrier. Membrane-based $CO_2$ capture uses a permeable or semi-permeable material that allow for the selective separation and transport of $CO_2$ from flue gas.[13]

A further challenge to post-combustion carbon capture technologies is the amount of energy consumed in the separation of high purity $CO_2$ from the flue gas stream (the "energy penalty"). An example of the "energy penalty" is to examine the only post-combustion plant in operation, Petra Nova near Houston. This came online in 2017. Estimates from Carnegie Mellon researchers indicate that an additional 20 – 25 percent is required to run the plant with post-combustion carbon capture. The Petra Nova plant captures approximately 90% of its CO2 emissions at a cost of $67/tonne. The target price from the DoE is $30/tonne. However, the net reduction is about 70% when the additional energy capacity is considered.

In 2014, Saskatchewan Power's (SaskPower) Boundary Dam power plant (about 10 miles north the North Dakota/Canada border) became the first power plant to successfully use post-combustion carbon capture. Since it's inception, it has captured over 3.3 million tonnes of $CO_2$.

[10] Dakota Gasification Company
[11] U.S. DoE, MIT, University of Arizona, Electric Power Research Institute
[12] International Journal of Greenhouse Gas Control
[13] Stanford, Columbia, Carnegie Mellon

Direct Air Capture is the removal of $CO_2$ directly from the atmosphere; not from a source like as the 'Combustion' technologies. This carbon capture system benefits from its inherent flexibility of placement, which reduces the needs for pipelines from the capture site to the sequestration reservoir or oil field (if the $CO_2$ is being used for Enhanced Oil Recovery).[14] Direct Air Capture and is a relatively new and high-tech net zero emission technology. After Pre-Combustion, direct air capture is the most expensive form of carbon capture. Furthermore, direct air capture systems have the flexibility to produce $CO_2$ for the commodity market at a desired purity.

This brings us to a review of Oxy-Fuel carbon capture. A technology that has been advanced significantly by the research and application of Jupiter Oxygen Corporation.

## **High Flame Temperature Oxy-Fuel Combustion Carbon Capture**

Jupiter Oxygen is leading the application of oxy-fuel carbon capture worldwide. Our patented high flame temperature oxy-fuel combustion technology reduces carbon emissions 99%+; near zero emissions. Experimenting and developing the patented oxy-fuel process began in the mid-1990's and has progressed exponentially since then. Our patented technology has undergone rigorous testing at our Hammond Pilot Plant while working with the Department of Energy over a ten (10) year period.

Oxy-Fuel carbon capture is the utilization of near-pure oxygen in the combustion process resulting in a more efficient burn of fuel and less waste. Oxy-fuel carbon capture also allows for easier carbon capture.[15]

The competitive advantage of Jupiter Oxygen's technology is price and efficiency. With 99%+ of $CO_2$ emissions and one of the lowest costs per tonne of captured $CO_2$ (currently close to $30/tonne). The increased heat used with near pure Oxygen in the combustion process allows for the capture of not only $CO_2$, but also Nitrous Oxides, Sulfur Oxides, Mercury, and Particulate Matter.

Jupiter Oxygen's patented high flame temperature oxy-fuel combustion technology creates more efficient heat transfer for industrial furnaces with moderate process temperatures. Improved efficiency is due to elimination of airborne nitrogen, more radiant heat transfer, and longer gas residence time. In the aluminum recycling furnaces using technology licensed by JOC, equivalent production was achieved with exciting economic results.

The greatest value of Jupiter Oxygen's technology is that it will be the fastest to market of any carbon capture technology which is critical given the nascent stage of development of renewable energy technologies. We are an immediate solution for climate change mitigation.

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[14] McKinsey, U.S. DoE, GCCSI

[15] MIT, 2009

## Going Forward

There are two forces concurrently (and drastically) impacting CCUS; COVID and decreasing oil prices. Leading companies will use these crises as opportunities; to affirm and/or re-define their mission and strategies.

*COVID 19 and Economic Recovery:* The coronavirus pandemic and the resulting economic shock pose at least a short-term threat to all clean energy investments, and could compromise long-term climate action to reduce emissions. Following 9/11 and the 2008 market drop, sustainability investments declined and corporate CSR (the Corporate Sustainability Responsibility movement) waned. Today, supply-chain disruptions, lack of demand, and a collapse of tax equity could delay clean-energy projects and/or put them at risk of missing deadlines to qualify for time-sensitive tax credits, specifically Section 45Q.

*Falling Oil Prices:* The fall in oil prices has driven both oil and gas companies around the world to focus on reducing production costs and managing a glut of inventory. This the third price collapse within the oil & gas industry in 12 years. After the first two shocks, the industry rebounded, and business as usual continued. This time is different. The current context combines a supply shock with an unprecedented demand drop and a global humanitarian crisis. Additionally, the sector's financial and structural health is worse than in previous crises. The advent of shale, excessive supply, and generous financial markets that overlooked the limited capital discipline have all contributed to poor returns. Today, with prices touching 30-year lows, and accelerating societal pressure, executives' sense that change is inevitable. The COVID-19 crisis accelerates what was already shaping up to be one of the industry's most transformative moments.

While the depth and duration of this crisis are uncertain, our research suggests that without fundamental change, it will be difficult to return to the attractive industry performance that has historically prevailed. On its current course and speed, the industry could now be entering an era defined by intense competition, technology-led rapid supply response, flat to declining demand, investor skepticism, and increasing public and government pressure regarding impact on climate and the environment. However, under most scenarios, oil and gas will remain a multi-trillion-dollar market for decades. Given its role in supplying affordable energy, it is too important to fail. The question of how to create value in the next normal is therefore fundamental. Further, the value of Enhanced Oil Recovery is retained as it is preceding technology is critical in an emissions-constrained world. IF a goal of synthesizing fuels from CO2 is part of the value chain of reducing GHG emissions, then using energy to power the synthesis makes sense only if the energy is both cheap and low or zero carbon.

To change the current paradigm, the industry will need to dig deep and tap its proud history of bold structural moves, innovation, and safe and profitable operations in the toughest conditions. The winners will be those that use this crisis to boldly reposition their portfolios and transform their operating models. Companies that don't will restructure or inevitably atrophy.

Given the recent crash in oil prices, the ability for CCUS projects to secure long-term contracts to supply $CO_2$ for EOR is unknown. Due to high up-front capital costs, early oil produced through EOR may be considered among the most expensive. Therefore, declining oil prices risks the most important revenue stream to keep CCUS projects competitive.

Simply put, future spending across the world's oil producing fields will depend on just two things: first, the level of economically viable activity required to maintain existing production and to capture new opportunities at the current prices and, second, the cost of executing that activity, driven by market prices and the efficiency and effectiveness of the industry. Both these drivers will depend largely on oil price, as that determines what activity is economic, and therefore drives demand on the supply chain.