



CLIMATE CHANGE AND EMISSIONS MANAGEMENT CORPORATION (CCEMC) ROUND ONE PROJECTS



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CLIMATE CHANGE AND EMISSIONS MANAGEMENT CORPORATION

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FUELS

By transforming CO₂ into valuable energy sources, these projects include innovative ways to produce valuable methanol, syngas, and transportation fuels.

Pioneer Energy - USA High-Value Synthetic Chemicals and Gasoline Drop-In Liquid Fuels from Canada's CO₂ and Flare Gas Emissions

Based on over a decade of research from NASA, the DOE and a number of industrial projects, Pioneer has developed a process to create butanol from greenhouse gases. Butanol is an attractive alternative fuel substitute and has many other applications. This innovative process also addresses key production issues facing other alternative fuels, including development of an economical and reliable production process.

"We're creating a liquid fuel that is a direct substitute for gasoline and diesel directly from greenhouse gas emissions, including flare gas emissions from oil fields and flue gas from power plants."

The Bright Idea

Pioneer has developed a Butanol From Greenhouse Gases (BFGG) process that creates a liquid-fuel substitute for gas and diesel from GHG emissions. It works by combining CH₄ with the CO₂ in a unique thermochemical process to produce both high-value chemicals and liquid fuel. The process can use significant amounts of GHG from a variety of sources including flare gas, to be converted to liquid fuels, polymers, and industrial chemicals for commercial use.

Stage of Innovation and Market Potential

Pioneer expects the BFGG process to be ready for commercialization in two years. Within that time, the goal is to validate the process and prepare the groundwork for testing at a pilot plant. They currently have gained funding to further improve the economics and efficiency of the process for both conventional and unconventional oil and gas production. By the end of the two-year program, Pioneer will have demonstrated the key chemical processes, performed a complete life-cycle inventory of GHG emission reductions, conducted a detailed engineering study of the entire end-to-end system, conducted a detailed engineering study of all required supporting equipment, and a detailed market study of the applicability to the Alberta market. Western Canada is a prime starting market for the process because of the fuel supply deficit in the region, with Alberta itself having a gasoline supply deficit of 208 million litres. This gasoline supply deficit in Alberta creates a ready market for butanol in Alberta.

Benefits

Pioneer's process can help reduce environmental impacts while increasing economic growth in Alberta and other parts of the world. The BFGG process and associated catalysts are based on low-cost, non-precious metals, requiring lower pressures and temperatures while generating high yields, making the production costs more attractive than those of competitors. It is an alternative fuel that avoids food crops for feedstock, can be used in high ratios in standard vehicles, can be produced in almost any region, and avoids expensive or cost-prohibitive methods or equipment. In addition, low water requirements compared to bioprocesses makes the processes highly suitable to dry or arid regions such as Alberta and many other parts of the world where fresh water is precious. This makes Pioneer's development cycle simpler, faster and less capital intensive.



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Economic Impact

If implemented, Pioneer's BFGG process would have substantial economic benefits for Alberta, including:

- Production of alternative fuel to meet a gasoline supply deficit
- Capability to produce and ship a stable alternative fuel to other areas of the world without significant infrastructure modifications
- Access to a growing global alternative fuel and petrochemicals market
- Production of a widely used industrial feedstock for the production of other chemicals and end-use commercial and retail products
- Participation in a substantial global market for butanol

University of California Riverside - USA CO₂ Conversion to Methanol through Bi-reforming

The University of California Riverside (UCR) has created an innovative catalyst to be used in the conversion of CO₂ and Methane (CH₄) to produce methanol – a valuable fuel and intermediary chemical. This catalyst makes improvements on catalysts currently available, but still can be adopted for use by conventional processes currently in operation. This minimizes much of the technical and economic risk for the project as it reaches commercialization.

"Climate change associated with greenhouse gas emissions is a critical issue and a major global challenge. Our technology, if successfully commercialized, will be an important step towards addressing this problem."

The Bright Idea

Using a new, efficient catalyst, UCR's project combines CO₂ and CH₄ into synthesis gas. This gas can then be converted into methanol using existing conventional technology. The pathway is a thermochemical process similar to other technologies; however, it is unique in that the catalyst has a superior thermal stability comparatively.

Stage of Innovation and Market Potential

Currently, UCR plans to develop an optimized version of their existing catalyst. The University will also develop a detailed Aspen Plus process simulation of the proposed pathway as well as a detailed process economics study. The project is estimated to be five to seven years away from the marketing, design construction and production of a greenfield plant. The demand for methanol is increasing in markets all over the world, particularly in China and North America.

Benefits

The catalyst that UCR has developed can be adopted and used quite easily with proven technology and processes currently in place, minimizing technical and economic risk. Another benefit is the production of methanol as a commodity chemical that is readily and immediately marketable for a wide range of processes, both as an intermediate and as a fuel.

Economic Impact

The proposed technology will utilize resources that are plentiful in Alberta such as natural gas and large greenhouse gas emission sources to create a profitable industry that will manufacture a fuel with high demand both inside and outside of Canada.



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Quantiam Technologies - CANADA

Green Methanol From Carbon Dioxide and Renewable Hydrogen (Methanol +)

Innovating in two major areas, Quantiam Technologies has developed a technology (Methanol+) to combine hydrogen and CO₂ to produce methanol. The first innovation comes from a catalyst database that helps increase efficiency gains, while the second innovation is the generation of hydrogen with environmentally sustainable methods. This process delivers a high-value chemical with a large market and a variety of applications.

"We expect that Methanol+ will ultimately displace conventional methanol production processes and enable a low-CO₂-emissions suite of important chemical feedstock as well as downstream products. It will dramatically reduce the carbon footprint of the chemical industry and the transportation sector."

The Bright Idea

Using a unique catalyst database, Quantiam's technology Methanol+ produces methanol from captured CO₂ emissions and hydrogen. The robust catalyst system targets efficiency gains in the system while at the same time operating in less extreme conditions than similar processes. The entire process simultaneously reduces greenhouse gas emissions and produces a high-value product.

Stage of Innovation and Market Potential

Quantiam is pursuing innovation in both CO₂ conversion and in hydrogen production. Within four years, the company hopes to be able to reach an advanced prototype phase and develop a small demonstration facility. By 2020, they hope to reach commercialization of the technology. There is a large demand and major commercial opportunity expected from both the transportation and petrochemical sectors. In the transportation sector, demand will be driven by the adoption of methanol as a fuel-additive. In the petrochemical sector, methanol will be used as a primary feedstock for important industrial chemicals as the industry moves away from traditional production methods.

Benefits

Quantiam's technology provides a scalable, low-cost solution to greenhouse gas mitigation. It is a process that can be implemented on-site to turn emissions directly into a high-value product that is in high demand in global markets. Methanol can be used both as a feedstock for olefin production and as a fuel additive.

Economic Impact

The economic benefits from Quantiam's technology include:

- Production of methanol in Alberta to create revenue and meet global demand
- Job creation in Alberta to produce, handle, transport product
- Positioning the province as a key supplier of chemical feedstock



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McGill University – CANADA

Chemical Transformation of Carbon Dioxide via Solar-Powered Artificial Photosynthesis

The CO₂ transformation system designed by McGill University represents a completely new approach to carbon capture. Using direct sunlight, a technology that was developed for solid-state LED lighting converts CO₂ and non-potable water into commercially valuable chemicals like methanol. This photocatalyst enables an ultra-high conversion efficiency and presents an elegant closed-loop solution for CO₂ and wastewater.

“We believe that this solar-powered artificial photosynthesis will be the ultimate approach for the reduction of CO₂ emissions.”

The Bright Idea

Using direct sunlight, McGill University developed a process using a unique nitride nanowire technology to convert CO₂ into methane gas and methanol. The project uses techniques similar to natural photosynthesis occurring in nature. It only uses CO₂, sunlight and water. During the process, the CO₂ is chemically transformed into commercially valuable chemical products, including methane (CH₄), hydrogen (H₂), oxygen (O₂), and methanol (CH₃OH).

Stage of Innovation and Market Potential

Currently, McGill is working to deliver a fully functional system that can demonstrate the technology successfully. The next stage includes scaling the technology while maintaining system efficiency and testing of an integrated CO₂ delivery system within a functional plant context. At that point, the technology will be ready for commercialization. The largest market for the technology will be where large amounts of CO₂ are produced, which includes Alberta. The proximity to CO₂-emitting industries reduces the costs associated with storing and transporting the CO₂ for conversion.

Benefits

The technology for the solar conversion process is based off of a nitride nanowire technology that is currently utilized for solid-state LED lighting. Using the nitride nanowires as a platform technology enables a more streamlined development and production of a range of products and technology solutions, including the solar CO₂ converter. The system for the conversion process itself provides an elegant closed-loop solution for the use of CO₂ and wastewater. The goal is to have the technology integrated into a current process flow with minimal disruption to current operations.

Economic Impact

The economic benefits from the project would include:

- The production of value-added products from a direct and low-cost CO₂ and wastewater conversion process
- New jobs created to meet manufacturing demand for the technology
- Reduction or elimination of costs associated with CO₂ conversion



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Robert Gordon University - UK Integration of Advanced Hybrid Inorganic Membranes for Carbon Dioxide Conversion

Using a small robust catalytic converter, Robert Gordon University (RGU) has created a process that uses CO₂ directly from flue gas at coal and natural gas power stations, or oilsands upgrader plants, to create a variety of commercially important intermediary and feedstock chemicals. The technology is easily deployable and scalable, making it useful for a variety of uses.

"Our hopes for the future are extremely high as the technology has the potential to also address flue gases from other processes such as refinery/petrochemical flue gases or coke oven flue gas. In the distant future, the process could be adapted to the direct conversion of CO₂ from the atmosphere."

The Bright Idea

Using a catalytic membrane reactor, RGU has created a technology where CO₂ is converted into useful chemical components. The reactor consists of porous sintered metallic tubes, which provide a structure for a catalytic coating able to promote chemical reactions. The device will be fed using flue exhaust gases to rehabilitate the CO₂ contained in the exhaust streams into value-added chemical products. The flue gas stream consists of CO₂, water vapour and oxygen, and will be fed methane at an elevated temperature. The highly dispersed catalyst converts the feed gases into highly useful chemical constituents such as Fischer-Tropsch fuels, hydrogen and ammonia/urea. It also offers an opportunity to produce nitrogen for the commercial merchant market.

Stage of Innovation and Market Potential

The technology is expected to be ready for commercialization by 2020. Within the next two years, RGU hopes to establish a proof-of-process and develop an optimized miniature prototype reactor, helping to address any challenges presented in the catalyst's performance, mass transfer limitations, and scalability. The largest market for the technology is expected to be in North America because of the large concentration of fossil fuel generating plants and the availability of low-cost natural gas.

Benefits

This technology is a simple, economic, scalable and easily deployable system that yields a value-added product that will result in significant reduction of greenhouse gases. Synthesis gas is perfect for onward conversion using "gas to liquids" chemical engineering technologies into products such as diesel fuel, naphtha and other valuable and important feedstock compounds for the chemical industries. The technical approach delivers reactors that are mechanically strong, physically compact, and able to deal with variable flow rates. The reactors will be metallic, meaning they can be welded together, can handle corrosive feed gases and withstand mechanical vibration environments. The process uses the CO₂ in the flue gas directly and does not use any pre-separation steps. Direct utilization is a unique advantage compared to using pre-separated and purified CO₂.

Economic Impact

The economic benefits from the technology will include:

- Income from the production and sale of high-value chemicals
- Increase in employment in off-gas processing and transportation
- Further investment and development of chemical processing



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University of Alberta - CANADA

Novel Internal Dry Reforming Solid Oxide Fuel Cell Technology for CO₂ Utilization

In a unique approach, the University of Alberta (U of A) has developed a fuel cell that can combine natural gas, CO₂ and air to produce carbon monoxide (CO), water and electricity. Where traditional conversion methods consume energy, this reaction creates it. It also creates water and CO, an important and profitable commercial chemical.

"In the long term, with natural gas relatively abundant in the world, this technology can serve to significantly reduce CO₂ emissions and generate emission-free electrical power in many countries."

The Bright Idea

Using a fuel cell, the U of A has created a reaction to combine methane (CH₄), CO₂, and oxygen to produce carbon monoxide (CO) and water and electricity. Fuel cells are normally used to generate electricity while burning a fuel. When fossil fuels are used, electricity generation leads to greenhouse gas emissions. However, in this case, the fuel cell simultaneously eliminates CO₂, produces an important industrial raw material, and still generates an amount of electricity comparable to a normal fuel cell. The U of A's fuel cell consists of an electrolyte tube with the CH₄-plus-CO₂ mixture flowing on one side and air on the other. A mixture of CO and H₂O comes out from the downstream end, and the produced CO can be used as a raw material to make many important industrial chemicals.

Stage of Innovation and Market Potential

It is expected to take five years to produce the process conditions necessary to make the technology viable and ready for use with large-scale fuel companies. Based on their current research, it is expected that within the next two years the process will be proven. In that time, the development of a tubular fuel cell that meets the project requirements is expected. The market of focus is in Alberta, as it has a large availability of natural gas and many sources of CO₂ emissions. The United States will also be a large market for similar reasons.

Benefits

The U of A's proposed new fuel cell process provides many advantages. The first is that the process creates electricity. At 50% efficiency, while converting 1,000 tonnes of CH₄, the proposed fuel cell is able to generate 3,660 MWh of power and simultaneously consume 2,750 tonnes of CO₂. It is also an exothermic reaction: the opposite of traditional processes that typically convert methane and CO₂ to syngas in an endothermic reaction that requires significant energy input. Furthermore, the required fuel mixture for the cell can also come directly from biomass. As such, the proposed process could provide strong support to reach Alberta's goal of utilizing biomass to its fullest extent.

Economic Impact

From the technology, Alberta will see the following economic benefits:

- Utilization of natural gas reserve that also reduces CO₂ emissions
- Generation of electrical power without greenhouse gas emissions
- Increased availability of CO as precursor for chemical production, such as methanol



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Enerkem Inc. - CANADA

Valorizing Industrially Produced CO₂: A Reliable and Cost-Effective Solution for Carbon Capture and its Conversion to Marketable Products

The goal for Enerkem is to produce fuels and chemicals that are useful at the location they are generated. As part of this strategy, they have developed a technology to convert CO₂ into syngas (hydrogen and carbon monoxide) using a catalytic conversion. With the ability to create syngas at varying ratios, Enerkem can produce a variety of intermediary chemicals that lead to high-value chemical products. This unique value makes the technology useful in regions where transportation or storage costs are prohibitive.

"CO₂ is an easily available carbon resource and has the advantages of being nontoxic, abundant and economical. However, few industrial processes utilize CO₂ as a raw material because a large energy input is required to convert it. Production of syngas by catalytically reforming natural gas and CO₂ together addresses this and promises to be a sustainable solution worldwide."

The Bright Idea

Conceived as a bolt-on small chemical plant/refinery and using a catalytic chemical technology, Enerkem's project intends to convert carbon from industrial CO₂ to an intermediary carbon monoxide (CO). The CO can then be used to implement a carbonylation strategy that produces marketable chemical products such as propanol, propionic acid and acrylic acid. The basic process will produce CO and hydrogen (H₂) derived from CO₂ and natural gas. The ratio between CO and H₂ is then easily modulated by standard technology and will be adaptable to different chemical synthesis needs.

Stage of Innovation and Market Potential

Currently, Enerkem is looking to pre-condition industrial CO₂ streams for contaminant removal and compression, as well as evaluate the cost of the CO₂ conditioned stream. They are also looking to optimize the proprietary chemical required for the process, operating a bench scale system and improving the metals/alloys, promoters and supporters for the catalyst activity. Enerkem also plans to study the CO conversion into products via the carbonylation catalysis in two sectors: oxygenates from methanol/DME and oxygenates from ethylene. They expect to launch a pilot project and reach commercialization at the end of five years. The market potential exists wherever there is an opportunity for CO₂ capture and sequestration. It is not dependent on geological sinks or associated infrastructure. The process can also be tailored to meet local demand in specific markets.

Benefits

The process developed by Enerkem would be able to preferentially produce CO or create a specific mix tailored for unique chemical product requirements. The technology is small and independent of any significant infrastructure, making it easily deployable in a number of locations and applications. The approach also does not require the CO₂ to be sequestered in a geological sink before conversion. The nature of the technology allows for the flexible production of a diverse variety of valuable chemical products. These products can be tailored for local need, therefore reducing transportation and storage costs.



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Economic Impact

The project developed by Enerkem has a number of economic benefits including:

- The further development of the chemical sector in Alberta aimed to export into global markets
- Development of a CO₂ recycling industry that can “recycle” CO₂ from the petrochemical sector
- Utilization of Alberta’s large natural gas resource base
- Development of ethylene into intermediate ethylene oxide as a higher-value chemical product for the chemical sector in Alberta

CHEMICAL SYNTHESIS

Projects in this category focus on transforming CO₂ into high-value chemicals that can be sold or used to create further chemical products.

RTI International - USA

Captured-CO₂ Catalyst for the Production of Ethylene Oxide (C3-PEO)

Rather than using oxygen in air, RTI International has developed a process to use the oxygen in CO₂ to convert the CO₂ into useful chemical feedstock. With an environmentally responsible and economically sound process that consumes large amounts of CO₂, the primary products created are sought after in the chemical industry to make everyday products like ski boots and fishing rods.

“Global climate change is the largest challenge of the 21st century, and a market for CO₂ is necessary to incentivize large emitters to capture CO₂. Implementation of processes that use CO₂ to make valuable products, such as C3-PEO, are needed to reduce the cost of CO₂ capture and increase adoption of capture technologies.”

The Bright Idea

RTI International’s process converts CO₂ and hydrocarbon resources using the oxygen in the CO₂ as a catalyst. This is a novel approach, as other processes would require using oxygen from the air. The primary products created from the process are ethylene oxide and carbon monoxide. The process can be easily integrated into existing petrochemical infrastructure in Alberta and around the world

Stage of Innovation and Market Potential

In the next two years, RTI will look to optimize the catalyst formation, develop the process design and demonstrate the catalyst performance in a laboratory reactor. Following the Grand Challenge in 2020, the C3-PEO process will look to be proven at the demonstration scale and be ready for commercialization. Because of the usefulness of the primary products created by the process, the technology is attractive to a large group of chemical companies as a method to manufacture common chemical feedstock in an environmental and economical way.



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Benefits

The conversion process created by RTI is designed to consume high levels of CO₂. The process produces high-value chemicals that can be used by chemical industries to make commercial products. The ability to both convert high amounts of CO₂ and create valuable feedstock products make C3-PEO a valuable process. Within Alberta, the technology can be easily integrated and would have an almost immediate economic benefit if commercialized.

Economic Impact

RTI International's technology has the potential to:

- Add up to C\$359 million in the first four years of commercialization
- Provide chemical companies an environmentally responsible alternative method to manufacture common chemical feedstock
- Meet the established demand for the primary products currently in the marketplace

Liquid Light - USA

Converting Carbon Dioxide into Chemicals and Fuels Using Clean, Domestic Sources of Energy in Alberta

With the ability to create valuable organic chemicals from CO₂ emissions using renewable energy sources, Liquid Light's process provides an attractive alternative revenue source for CO₂ emitting industries. Offered as a licensable technology, industries could potentially produce more than 60 different organic chemicals that contribute to producing consumer goods like water bottles or materials like polyester.

"The world needs a means of mitigating CO₂ emissions that does not seriously disrupt the global economy. Our technology helps to do that. By allowing carbon dioxide to become a feedstock for the production of existing products, we offer a bridge to a low-carbon future."

The Bright Idea

Using power from renewable sources like wind power, Liquid Light's electro-chemical technology converts CO₂ into organic chemicals like ethylene glycol and water as primary by-products. Liquid Light's process is the only process that can convert CO₂ into important multi-carbon chemicals using exclusively chemical processes. With an artificial process similar to photosynthesis, the conversion to organic chemicals occurs without the use of any agricultural resources.

Stage of Innovation and Market Potential

Projected to be ready for commercialization as early as 2017, Liquid Light is currently looking to demonstrate an integrated process for making organic chemicals. This process will include a first-generation commercial-scale reactor that will prove the technology can be implemented commercially. If successful, Liquid Light will look to license the technology and continue to develop and scale-up the technology to be as low cost as possible. With a large and growing demand for ethylene glycol - increasing by 1 million tonnes per year - there is a solid demand for a technology that will look to offer more than 60 different chemicals as the technology matures. The full potential of the entire global market is estimated at US\$250 billion.



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Benefits

Liquid Light uses a highly efficient technology – one that is able to use intermittent sources of renewable energy such as wind to create valuable multi-carbon chemicals and produce large amounts of water. These three capabilities contribute to a quadruple benefit: growing renewable energy demand, reducing CO₂ emissions from oil and gas activities, creating water for industrial applications, and creating valuable multi-carbon organic chemicals.

Economic Impact

The electro-chemical technology developed by Liquid Light will help create economic benefits that include:

- Consumption of renewable energy resources
- Profitable technology licensing for emissions producers, creating higher profit margins
- An increase in employment to produce organic chemicals in CO₂ emitting industries

E3Tec Service, LLC - USA

Production of Dimethyl Carbonate (DMC) from Captured CO₂ and Methanol

E3Tec Service has developed a safer alternative to produce dimethyl carbonate (DMC) using CO₂ sequestration rather than the toxic chemical procedure currently used. A highly sought-after product used in the manufacture of polycarbonates, DMC can be used to produce solvents, fuel additives and lithium ion batteries. The process employed is energy efficient, environmentally responsible and flexible enough to adapt to a variety of CO₂ emitting industries regardless of location.

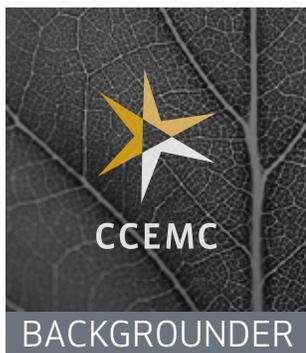
"Our proposed process of conversion of captured CO₂ to high-value DMC has significant techno-economic advantages for Alberta." - Dr. C. B. Panchal, E3Tec Service."

The Bright Idea

E3Tec's process captures CO₂ and combines it with methanol in a reactive distillation process to produce DMC. The process is based on Heat Integrated Reactive Distillation (HIRD). HIRD is an energy efficient process that reduces both energy and capital costs, and replaces the highly toxic phosgene-based process currently in use. The process is flexible enough to be integrated with major industry sectors or converted to produce a variety of alkyl carbonates beyond DMC.

Stage of Innovation and Market Potential

E3Tec has technically proven the basics of their proposed process and expects to advance to technology readiness level (TRL), which is close to commercialization. Currently, the team hopes to complete a life-cycle analysis to establish net CO₂ sequestration and have the project ready for commercialization in three years. The current focus is on four major industrial applications for DMC: producing a monomer for polycarbonate, a low-VOC solvent, an oxygenated diesel additive, and an electrolyte solvent used in lithium-ion batteries. Global consumption of DMC is at 4.9 million tonnes per year with a 7% annual growth rate. E3Tec is looking to capture a good percentage of the U.S. market of 0.9 million tonnes where the toxic phosgene-based process is currently in use.



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Benefits

The ability to produce DMC from CO₂ is important as it is a very desirable product and consumers are looking for less toxic methods for producing the chemical. Because of its desirability, E3Tec's technology represents significant techno-economic advantages over other CO₂ sequestration methods and products. With a modular design, the process will be highly adaptable to numerous CO₂ emitting industries.

Economic Impact

Production of DMC in Alberta would have large economic benefits, including the attraction of DMC end-user industries to Alberta such as polycarbonate or lithium-ion battery manufacturers.

Gas Technology Institute - USA

Direct Catalytic Synthesis of Acetic Acid from CO₂ AND CH₄

The current method for producing acetic acid uses carbon monoxide (CO) and methanol, and emits CO₂. The Gas Technology Institute (GTI) has developed a technology that uses CO₂ from greenhouse gases and natural gas (CH₄) to produce acetic acid. The innovation in GTI's process removes the need for purchasing methanol, provides a net reduction of CO₂ emissions, and reduces the energy needed to produce the same amount of acetic acid. With a growing demand for acetic acid in Asia and the United States, Alberta would be poised to become a key producer.

"Most commercial virgin synthetic acetic acid is produced by reacting carbon monoxide with methanol, known as the methanol carbonylation process. This process is quite energy intensive. With increasing global demands for acetic acid, the development of a lower-cost process will have an economic driver as well as the environmental driver."

The Bright Idea

With GTI's approach, CO₂ arising from greenhouse gases is reacted with CH₄ from natural gas in a two-step isothermal, catalytic process. The intermediates from the process yield acetic acid and ethanol with minimal net H₂ consumption and a net CO₂ reduction. This two-step catalytic process replaces the conventional method for producing acetic acid using carbon monoxide and methanol, providing a cheaper, more efficient method of producing acetic acid.

Stage of Innovation and Market Potential

Currently, GTI's engineering scale demonstration and testing of an actual system prototype is targeted to take place by early 2017. A full-scale demonstration and plant construction - the first of its kind - is targeted to take place by 2020. By partnering with for-profit partners, GTI is planning to license the technology to companies in greenhouse gas producing industries. With large markets in China and the United States, the global demand for acetic acid has been steadily increasing over the last 10 years. In 2000, the global acetic acid demand stood at 5.5 megatonnes before increasing to 9.3 megatonnes in 2011 and the demand is forecast to grow annually by 4.7 percent to reach 14.1 megatonnes by 2020.

Benefits

The technology created by GTI would help reduce greenhouse gas emissions in CO₂ producing industries. It also has the potential to become the most economically sound process for producing acetic acid. With a licence for the technology, CO₂ emitting companies would be able to both reduce emissions and produce valuable chemical products for domestic use and international



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markets. The differential between the current market value of virgin acetic acid and the raw material CH₄ needed is substantial and represents a significant margin for recovery of capital and revenue for licence holders. This new process is also more energy efficient and does not use carbon monoxide, so it reduces energy used to produce acetic acid and avoids CO₂ emissions.

Economic Impact

With GTI's proposed technology, Alberta's economic benefits would include:

- Positioning Canada as a key producer and net exporter of acetic acid rather than a net importer.
- Creation of jobs to help produce and ship the new product
- Increase of income to CO₂ emitting industries in the province

University of British Columbia - CANADA

A Coupled CO₂ and Wastewater Treatment Process to Create High Value Gas/Oil Field Chemicals

The University of British Columbia (UBC) has developed a technology that has the potential to have a large impact on global CO₂ emissions while addressing the issue of dwindling global water reserves. The novel technology uses CO₂ to desalinate industrial wastewater, creating a smaller carbon footprint and an economical alternative to conventional desalination technology. The process uses these inputs to create desalinated water and high-value chemicals that are particularly useful for the oil and gas industry. In what could possibly become the standard desalination and wastewater treatment, UBC's technology could have a significant impact on carbon dioxide removal.

"Many technologies have tried to address the issue of carbon dioxide sequestration, removal or mineralization, and wastewater treatment or desalination. However, the coupling of these processes to simultaneously address both these issues is unique and is highly valuable for the oil and gas sector."

The Bright Idea

The technology combines salts present in industrial wastewater with carbon dioxide in an electrochemical cell to mineralize the carbon dioxide in the form of high-value oil-field chemicals such as acids and carbonate salts. This coupled process simultaneously removes CO₂ and desalinates the wastewater or brine. The amount of CO₂ that can be mineralized is dependent on the salt content of the wastewater. Designed as a process operated from a modular facility, the technology can be easily scaled based on wastewater volume treatment requirements. The modular design also means the technology will be easy to transport and simple to operate on site.

Stage of Innovation and Market Potential

A pilot scale electrochemical cell that overcomes the technical challenges of the project will be ready for demonstration in the next two years. In 2018, the technology is expected to be ready for commercialization. With collaboration from industrial partners and potential partners in Alberta, UBC expects to be in a position for in-field testing of the main electrochemical cell with industrial wastewater. Based on products from the process, a major market for the technology is the fast-growing tight oil and shale gas industry. Based on industrial activity, the key demand would come from Alberta, the United States, Russia and China.



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Benefits

Because of the modular and transportable design, the technology utilizes aspects of industrially scaled processes to meet varied demand from site to site. It also addresses a major concern for the oil and gas sector as it converts on-site waste materials to high-value chemicals required by the industry. Due to both the availability of on-site raw materials and on-site requirements of the products, the technology is particularly useful for oil and gas. As such, the project does not pose major technical risks and makes economic sense. Wide-scale adoption of the technology in Alberta would result in the removal of approximately 3.5 megatonnes of carbon dioxide while conserving up to 170 million barrels of water every year in Alberta alone.

Economic Impact

The implementation of the technology in Alberta would:

- Expedite the development of Alberta's significant tight oil and shale gas reserves
- Provide better access to remote reserves in the province
- Meet the demand for desalinated water for industrial use
- Provide better on-site wastewater treatment for the oil and gas sector

SOLID PRODUCTS

This area of CO₂ conversion technologies focuses on converting and entrapping CO₂ into an assortment of solid materials. These projects include those that create concrete products, solid fertilizers, carbonates, and pure carbon materials.

New Sky Energy - USA

Soda Ash and Bicarbonate from a Low Energy Natural Gas Sweetening Process

Using an energy-efficient natural gas purification process, New Sky's project will convert CO₂ and hydrogen sulphide (H₂S) contaminants from sour gas into valuable commodity chemicals, including soda ash, bicarbonate, and sulphur. The process uses a non-toxic, water-soluble base to capture CO₂ and H₂S, leaving pure natural gas for use as a low-carbon fuel. Instead of venting the CO₂ from sour natural gas into the atmosphere, New Sky's process would put that CO₂ to use as carbonates to manufacture glass, paper, and dozens of other common products.

"Sour gas has been a big problem for the natural gas industry for decades. The industry's approach has been to use reversible scrubbing agents, such as amines, which rely on energy-intensive processes. We're taking a fundamentally different approach and converting acid gases into useful products."

The Bright Idea

New Sky's gas sweetening technology efficiently scrubs both CO₂ and H₂S from sour natural gas, and uses the inherent chemical energy of H₂S to regenerate the capture agent at very low energy cost. The net result is three useful, low carbon products: sweet natural gas, sulphur, and carbonates such as soda ash and bicarbonate. The New Sky process is energy efficient and economically favourable, with minimal chemical inputs (mostly water and salt) and virtually no waste. Equipment for the process is scalable, inexpensive, and requires no exotic materials.



CLIMATE CHANGE AND EMISSIONS MANAGEMENT CORPORATION

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Stage of Innovation and Market Potential

New Sky's gas treatment and CO₂ mineralization technologies will be ready for broad commercialization as soon as early 2016. At this stage, New Sky will begin to build a full-scale pilot operation in an Alberta-based sour gas field. The pilot will focus on production of sweet natural gas, sulphur and carbonates produced from CO₂ captured from the gas stream. The Alberta pilot will be followed by initial commercial operations in Canada and the U.S. Simultaneous commercialization efforts will be underway in the U.S. beginning in the spring of 2014 and will focus on cost effective production of sweet gas. Two years from now, New Sky expects to be able to present customers and partners with a robust, scalable, and cost-effective technology that meets the needs in the field. New Sky's gas treatment technology benefits from carbon taxes but is profitable without them, giving the company and its investors confidence that global adoption of its gas treatment technology in the next decade is a realistic goal.

Benefits

New Sky's technology can dramatically reduce CO₂ emissions from two major polluting industries: natural gas production and carbonate manufacturing. At sour gas sites, the technology will significantly reduce gas treatment costs and CO₂ emissions, as well as generate new revenues from the sale of carbonates and sulphur-based products. At the same time, New Sky's technology would displace carbon-intensive soda ash, reducing the CO₂ footprint of glass, paper, building materials and other everyday products. If deployed throughout Alberta's sour gas fields, New Sky's technology could reduce CO₂ emissions by more than six million metric tonnes each year. Deployed worldwide, the technology could bring potential direct greenhouse gas emission reductions in the tens of millions of metric tonnes per year.

Economic Impact

New Sky technology brings several important economic benefits to Alberta, including:

- Energy-efficient sour gas sweetening at much lower cost than conventional sweetening technologies
- Potential development of sour gas fields that were previously uneconomic to operate
- Use of abundant, low value salt reserves in Alberta to produce high value soda ash and bicarbonate for export or use within Alberta
- Reduction or elimination of costs for sour gas reinjection and/or CO₂ emission to the atmosphere

Skyonic Corporation - USA

Skyonic SkyCycle™ Pilot Demonstration

At its core, Skyonic's SkyCycle™ technology uses waste-heat from the source – a CO₂ emitting plant – to mineralize CO₂ emissions from that same plant. SkyCycle™ uses a synthetic base to capture the mildly acidic CO₂, and mineralizes it as a solid carbonate. The primary, profitable product from the proposed Canadian SkyCycle™ Plant is hydrochloric acid (HCl).

"SkyCycle™ successfully addresses the need for carbon and emissions clean up and supplies carbon-negative chemicals to market."



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The Bright Idea

SkyCycle™ uses a synthetic base to capture the mildly acidic CO₂, which is formed from the thermal decomposition of a hydrated salt. During the CO₂ absorption process, a second salt is added to produce a product carbonate and the previously decomposed salt is regenerated as a chloride. The thermal decomposition yields HCl gas, and the resulting hydrochloric acid regenerates the second salt by reacting with mineral silicates.

Stage of Innovation and Market Potential

By early 2015, Skyonic will be prepared to install a commercial-site pilot plant, in preparation for a full-scale commercial SkyCycle™ plant in 2016. SkyCycle™ has been proven at bench-scale and has proven operational in the field-test unit on site at Skyonic's research facility at Capitol Cement. Skyonic will scale the SkyCycle™ process to a pilot scale. Within two years, Skyonic hopes to have pilot-scale module that captures approximately 5,000 tonnes of CO₂. The CO₂ captured in the SkyCycle™ process is mineralized as solid carbonates and the market for these materials (PCC or limestone) is extraordinarily large.

Benefits

SkyCycle™ is retrofittable and scalable to existing emitters, and is designed to produce commercial chemical products at a profit. The technology delivers many benefits over other carbon-capture technologies: it is indifferent to CO₂ concentrations in flue gas, needs no previous scrubbing as it captures sodium oxide (SO_x), nitrogen oxide (NO_x) and heavy metals concurrently, and stores the CO₂ as a solid, thereby eliminating the need for costly compression, transport, and storage. The mineral byproducts, and the co-generated acid are food-grade and suitable for market sale.

Economic Impact

By 2016, Skyonic could be building a 1.3 megatonne/year SkyCycle™ plant in Alberta. This will help Alberta:

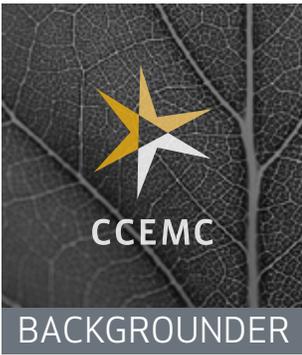
- Make a significant impact in reducing the province's emissions
- Supply much-needed green chemicals to markets
- Create green jobs in the province

Solidia Technologies - USA

Solidia Concrete - A Sustainable Method For Cement Production and CO₂ Utilization

Solidia Technologies produces a new form of concrete – Solidia Concrete – that reduces the CO₂ footprint associated with the production of cement and the use of cement in concrete products by up to 70 percent. The cement industry is the second largest industrial emitter of CO₂, surpassed only by electric power generation. Solidia Cement will dramatically help reduce the industry's CO₂ emissions.

"Our project has the potential for rapid deployment on a large scale because the technology uses the same raw materials, supply chains, and equipment that are already in use by cement and concrete manufacturers. This brings large cost efficiencies to both cement and concrete manufacturers who work with thin profit margins."



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The Bright Idea

Solidia Technologies captures CO₂ emitted at the cement plant and then stores the CO₂ during the curing of the concrete. Based on cement designs and curing technologies jointly developed by Rutgers, the State University of New Jersey, and Solidia, the innovation does not significantly alter any elements of the current cement manufacturing process.

Stage of Innovation and Market Potential

Solidia, in partnership with Lafarge, plans to produce the new cement on an industrial scale by 2015 at Lafarge's plant in Exshaw, Alberta. Precast concrete products will be the first to be produced with this plan. Commercialization of the technology will be expected before the fall of 2015. The largest markets for the technology will be in geographies currently using large amounts of cement and concrete products – namely China and India. Markets for precast concrete products in North America and Europe will also be targets. Precast concrete represents 20 percent of a US\$1-trillion global concrete market. With Lafarge as a partner, Solidia expects a rapid adoption of the technology over the next five years.

Benefits

The cement industry is the second largest producer of CO₂. With the ability to reduce CO₂ emissions paired with the ability to sequester CO₂ during curing, Solidia Concrete presents an attractive double benefit. The process can be rapidly deployed because the technology does not alter materials or equipment required for cement production. There is also the potential to reduce the cost of manufacturing cement by up to 40 percent – a large benefit for an industry with relatively low profit margins.

Economic Impact

With a substantial cement industry in the province, Alberta is uniquely positioned to enjoy economic benefits including:

- Increase in profitability from the cement industry in Alberta
- Production of new CO₂ efficient precast concrete products in the province
- Greater participation in larger concrete consuming markets in China and India

Blue Planet Ltd. – USA

Carbon Capture and Mineralogic Sequestration: Addressing the World Wide Epidemic on a World Wide Scale

Blue Planet has developed a technology platform called Liquid Condensed Phase (LCP) that creates usable green building products that contain sequestered CO₂. Their LCP solution provides a more efficient, cost-effective method for CO₂ emission control for industries from, cement, power, and petrochemical industries. At the same time, it creates a highly flexible primary raw material and a range of marketable end-use building materials.

"We can help the concrete industry go from being a major contributor to the world's CO₂ emissions to a major sink for CO₂."



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The Bright Idea

The LCP process uses natural and waste-waters along with CO₂ to produce a solution that is rich in bicarbonate ions. This solution can then be used to produce a large variety of carbon-mitigating concrete building materials. These materials include LCP liquids used in ready-mix and precast concrete formulations or concrete aggregates produced with the LCP solution. These building materials also have an emission control service component for refineries, cement plants, natural gas and coal-fired power plants.

Stage of Innovation and Market Potential

Blue Planet expects the LCP technology to be ready for initial deployment in Alberta in spring 2015 and full-scale deployment commencing in 2017. The marketing plan includes a strategy to commercialize the LCP technology within marketable end-use products, as well as licensing the technology to other manufacturers and CO₂ emitters. Blue Planet can provide an emission control solution for CO₂ that is both economical and easily utilized in a number of high-value applications. This makes market opportunities viable in the cement industry, the building materials sector, the power sector, and the petrochemical industry.

Benefits

Blue Planet's membrane-based alkalinity system is more efficient at carbon mitigation than current state-of-the-art amine scrubbing systems, making it a more cost-effective solution. The Blue Planet technology is easily implemented and scalable for a variety of industries with capital costs much smaller than technologies currently being implemented. Moreover, the sequestered CO₂ can be permanently sequestered in solid carbonate materials that are directly useable as building materials, roads, or pavements.

Economic Impact

The economic impacts for Blue Planet's technology include:

- Extra revenue for CO₂ emitting industries from licences and service agreements
- The production of high-value end-use products that contain permanently sequestered CO₂
- The production of building materials used for key provincial infrastructure like roads and buildings

McGill University – CANADA

Use of Carbon Dioxide in Making Carbonate-Bond Precast Concrete Products

Carbonation in the cement of concrete products is readily available. McGill's process builds on that process and uses CO₂ to produce an artificial aggregate to be used in the concrete. Because of the unique properties of carbonated concrete, the end product is stronger and more durable than traditional concrete products. This process can be deployed anywhere, and will contribute to the global reduction of CO₂ emissions.

"McGill's technology was studied 40 years ago but never got chance to go large scale. The barrier was the cost of CO₂ gas. With the advanced CO₂ capture technology today, it makes carbonate-bond concrete economically feasible to replace steam process to save energy and gain improved strength and durability performance. The production can be carried out anywhere in the world, making a big contribution to global emission reduction."



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The Bright Idea

McGill's process uses an advanced self-concentrating absorption process to produce a low-cost CO₂. This CO₂ will be collected and converted into calcium carbonates and carbonate bond aggregates for use in concrete products. The process is similar to existing precast concrete production methods but both the cement binder, as well as the aggregates, are carbonated with sequestered CO₂ in the process developed by McGill.

Stage of Innovation and Market Potential

McGill is currently researching the utilization of CO₂ within artificial aggregates in concrete, and the technology will be ready for commercialization in 2016. At the commercialization stage, an integrated carbon-capture and utilization process will be developed and made ready for production.

Benefits

The technology developed by McGill utilizes carbonated artificial aggregate to produce concrete, but it also converts the calcium compounds into strength-contributing phases that make the final concrete products stronger and more durable than traditional concrete products. The carbonated content in the concrete will help products win LEED certification and will enhance the economic competitiveness.

Economic Impact

The economic benefits for the process include:

- Direct energy savings if natural gas is replaced by CO₂ gas in the concrete curing process
- A green, durable product that is competitive in the marketplace
- Waste utilization for value-added products
- Direct emission reduction through utilization

CCm Research - UK

High Efficiency Capture Using Novel Fibres in the Production of Soil Conditioning Agents Polymer Replacements

CCm has created a unique process that fixes CO₂ to base fibre materials to be used for soil conditioners, fertilizers and other polymers. The process delivers a highly efficient permanent capture of CO₂ and creates high-demand products that can help create a positive long-term environmental impact.

"We are combining an excellent method of short-term capture underpinned by long lasting environmental benefits to the soils into which our materials are delivered."

The Bright Idea

During the production of soil agents, CCm activates a base fibre material and exposes the material to CO₂ in a specialized mixing unit. The CO₂ fixes to the fibres and is then exposed to another chemical to permanently stabilize the CO₂ to the fibre in carbonate form. The base fibre material can then be subjected to other chemical processes to produce a final product that can be used as either a soil-conditioning material or a functional filler for use in polymers.



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Stage of Innovation and Market Potential

Currently, CCm is looking to obtain accurate quantification of CO₂ capture at scale. They expect trial launches in two years with large-scale production coming online in three to five years. There is also interest in better understanding the long-term environmental benefits of the soil-conditioning materials in acid soil. From a commercial perspective, CCm is developing a full determination of the economic value of the process outputs as well as determining the real market potential. The largest market in both geographic and financial terms for the process will be in soil conditioner materials. CCm has the ability to develop soil conditioners that can be delivered to a wide variety of soil types in temperate and tropical environments. Demand for these products is growing at stable rates in both the developed and developing world.

Benefits

The process developed by CCm combines immediate CO₂ capture savings with the ability to create long-term environmental improvements from product use. The process permanently removes CO₂ from the system and makes money through the sale of products like soil conditioners, making it both environmentally and economically sustainable.

Economic Impact

CCm's process produces income from high-demand products while helping industries avoid CO₂ production charges. The process will also reduce the production costs for fertilizers and polymers, and create economic benefits for environmentally sustainable agricultural production.

Carbon Cycle Limited - UK

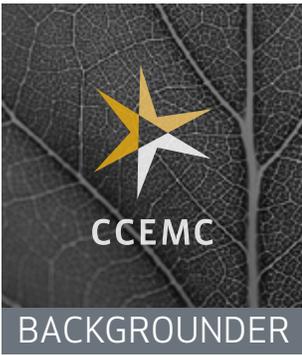
Process to Capture Carbon Dioxide and Produce Structured Calcium Carbonate and Fertilizer

The premise for Carbon Cycle's project is simple: permanently capture large amounts of CO₂ in a process that produces precipitated calcium carbonate (PCC) and ammonium sulphate fertilizer. With a new technology, Carbon Cycle's process uses dramatically less energy and creates a carbon-negative outcome rather than the current carbon-positive methods currently used. With low energy use and high efficiency capabilities, CO₂ is reduced in a process that creates valuable products for both paper and agricultural industries.

"Our business model is quite straightforward. In essence, we have built a better mousetrap. Our process to make PCC and ammonium sulphate fertilizer will cost less to operate than current processes and has the key benefit in that it is carbon negative compared to existing methods of production."

The Bright Idea

The process created by Carbon Cycle utilizes otherwise-wasted CO₂ and permanently mineralizes it into PCC during the process of creating ammonium sulphate fertilizer. It replaces two carbon-intensive processes into a single carbon-negative process. The PCC can then be used in a variety of applications, including the paper products industry, while the fertilizer can be used in the agriculture industry.



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Stage of Innovation and Market Potential

The Carbon Cycle process evolved out of efforts to create an economically-viable method to capture CO₂ from the air. Currently, Carbon Cycle is continuing to validate the process and prove it at scale. In 2015, the process is expected to reach commercial optimization and be ready for a large-scale production design. The demand for the technology will be global; however, Canada and Alberta represent a specifically valuable market for the technology. Because of the paper-products industry in Canada, the PCC will be attractive because it can be used to create high-value paper products. The fertilizer created from the process will be equally useful for the agriculture sector in Alberta and Canada.

Benefits

Currently, the production of ammonium sulphate and PCC is very energy intensive and requires extremely high heat. Carbon Cycle's process produces the products at ambient temperatures and pressures, making it a better way to produce the products regardless of carbon price. The method is very efficient at containing sorbent vapour within flowing gas streams, allowing highly volatile sorbents to be used at ambient temperatures - avoiding costly temperature manipulation. The ability to contain certain gases in a flowing gas stream is unique and opens the door to the process and a raft of other new and highly useful applications.

Economic Impact

The economic benefits for the Carbon Cycle project would include:

- The production of PCC to meet demand for the wood and paper industries, as well as for export
- The production of low-cost nitrogen fertilizer for the agriculture industry in Alberta and for export
- Fertilizer to sweeten Alberta's acidic soils to increase agricultural output
- Growth of the labour market for production

ARCTECH, Inc. - USA

HUMASORB®-L for Removal of CO₂, NO_x GHGs, along with SO_x and Trace Metals from Fossil Fuel Combustion Gases and Recycling of CO₂ into a Value Generation HUMASORB®-CS, a Stable Multipurpose Water Filter

With two innovative products, ARCTECH offers solutions to capture CO₂ from GHG-emitting industries and filter industrial wastewater with a solid filter that uses captured carbon. Positioned as passive, low-cost products ARCTECH's HUMASORB®-L and HUMASORB®-CS can be used in a number of industries and applications with very little modification.

"Greenhouse gas concerns and mandates for control of toxic emissions from fossil and biomass use are major global issues, and the impacts are felt globally. Our HUMASORB technology and use of coal biotechnology is a transformational solution with underpinnings of a value proposition for economic and environmental sustainability."



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The Bright Idea

ARCTECH captures CO₂ using a unique liquid absorbent and converts the captured carbon into a solid water filter product. This filter has the capability to remove multiple types of contaminants from wastewater. The filter can be used in variety of applications: within water-treatment plants, storm-water drainage systems, and even as a sub-surface barrier for groundwater-contaminated sites. Once the product is used up, the captured CO₂ and wastewater contaminants remain permanently bound to the product and are ready for disposal. The liquid absorbent is a coal-derived organic humic liquid that has been proven to remove 100 percent of CO₂ from coal combustion gases in bench scale tests. The absorbent also has the added benefit of removing NO_x, SO_x, and toxic trace metals from greenhouse gas emissions. The liquid can be deployed at a low-cost treatment in standalone tower reactors, or it can be retrofitted for use in existing liquid reagent based SO_x scrubbers commonly used for flue gas treatment.

Stage of Innovation and Market Potential

Currently, ARCTECH is looking to demonstrate the capabilities of both the liquid absorbent and the solid water filter products. As a commercial producer of the product for a similar industry in Virginia, ARCTECH would look to validate the application of the technology for industries in Alberta. In Alberta, the demonstration would focus on the absorption capability in coal power and oilsands industries. In three to five years, ARCTECH expects to be ready for full commercialization of the technology in Alberta. With significant capabilities in the absorption of CO₂ and the filtering of wastewater, ARCTECH expects to reach greenhouse gas emitting industries as well as municipalities.

Benefits

The products ARCTECH produces are flexible and low cost with a variety of unique applications. From capturing CO₂ at the source to being used for environmental cleanup, the products are useful to a number of industries. Because the products are passive, they can also replace or support costly active processes and systems that require high capital and O&M costs.

Economic Impact

ARCTECH's products have the potential to contribute value to all major areas of Alberta's economy that generate contaminated wastewater. This includes municipal, manufacturing, mineral extraction, and especially power generation.

JRE Petroleum Services - CANADA CO₂ to Graphene Reactors

JRE Petroleum Services has developed a technology the captures CO₂, combines it with graphite and converts it into graphene. The technology required is small and easily implemented by producers with high CO₂ emissions from a variety of industries. The graphene product created from the process is a brand new family of nanoparticle. The uses for graphene are continually being developed and represent significant potential.

"Eventually the goal is that this technology will gain enough traction in Alberta to make a significant difference in meeting greenhouse gas reduction targets in North America, while helping facilitate significant progress in tackling other major issues like sustainable housing and the global water crisis through the graphene produced in the process."



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The Bright Idea

JRE's process aims to convert CO₂ into graphene, an allotrope of carbon. To accomplish this conversion, a mill reactor is used to process CO₂ and graphite into the high-quality graphene. The feed CO₂ may be in a gaseous state or in a dry-ice state. The resulting reaction with graphite produces carboxylated layers of graphene that can be used for adding mechanical strength to cement or for use in water-purification membranes. While many greenhouse gas reduction methods involve storage or conversion into another fuel – only delaying CO₂ emission – this process binds the CO₂ into the graphene structure, serving to create a new family of nanoparticle.

Stage of Innovation and Market Potential

Currently, JRE has plans to develop, test, and evaluate reactor prototypes. They also hope to establish a quality-control protocol for the manufacturing process. In the next two years, the important technical parameters relevant in the milling process will be validated and a continuous operating mechanism will be designed and optimized. The technology could be ready for commercialization as early as 2015, subject to prototype development and field testing. Oil and gas producers represent the majority of the market for the technology. These producers are responsible for a significant quantity of greenhouse gas emissions in Alberta and the technology would provide major CO₂ emitters with an opportunity to both reduce their carbon footprint and create a value-added product for an additional source of revenue.

Benefits

From a technical standpoint, the process created by JRE leans strongly towards mass production of small milling reactors to capture CO₂ and create graphene, as opposed to scaling up the idea through a large refining facility. This keeps the capital costs for the technology low, minimizes project risks for emissions producers and keeps supply responsive to the cyclical nature of the demand for graphene. From a technology perspective, the process creates a stable product that has the ability to keep the captured CO₂ sequestered structurally for over 100 years. The process creates a new family of nanoparticle. This reinforced material can be used for a diverse range of applications – from increasing mechanical strength, to filter water, to potentially serving as a base for high-end electronics.

Economic Impact

The economic benefits for the technology created by JRE include:

- Cost reduction based off of greenhouse gas emission reduction
- Extra revenue stream and job creation from the production of graphene
- Innovation in applications for a new family of nanoparticle



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BIO-FIXATION

Bio-fixation is the use of biological organisms to sequester and convert CO₂ into a variety of products. These projects include bio-fixation from algae, bacteria, and yeast.

Industrial Microbes, Inc. - USA

Biological Co-fermentation of Carbon Dioxide and Methane to Malate

Using a biological fermentation process, Industrial Microbes can create malate – a valuable organic compound – from the combination of CO₂ and natural gas. The process is cost-efficient and outperforms traditional malate production methods, consuming CO₂ where other methods create CO₂. Malate has many direct and intermediate applications and uses, which makes it highly sought-after in a growing global market.

“Biological fermentation is the best method to inexpensively and efficiently remove massive amounts of CO₂ from the atmosphere. Almost all CO₂ currently removed from the atmosphere is removed by living organisms, because cells have evolved incredibly efficient means to fix CO₂ into an astounding array of valuable products.”

The Bright Idea

Industrial Microbes is developing a process to combine CO₂ and natural gas into malate, a valuable organic compound used to manufacture biodegradable plastics and fibres. Malate is produced by natural enzymes inside living cells, similar to how alcohol is produced during beer brewing. In Industrial Microbes' process, CO₂ emissions from an oilsands operation or power plant are bubbled through a fermentation tank, along with natural gas. Designer microbes consume these carbon sources to produce malate, which is then purified into solid crystals. Malate can be used directly as a food or beverage additive, or it can be chemically converted into a high-performance biodegradable plastic. Industrial Microbes' malate replaces petroleum-derived malate, which is made in a process that emits (rather than absorbs) CO₂.

Stage of Innovation and Market Potential

Within two years, Industrial Microbes hopes to build a prototype fermentation process that can produce malate from CO₂ and natural gas. The results will guide the manufacturing scale up to a pilot plant and demonstration facility as the technology is prepared for commercialization, which is expected between 2018 and 2020. Malate is a global specialty chemical with significant markets in North America, Europe, and Asia. Used as a flavour enhancer in beverages and processed foods, or as a pharmaceutical stabilizer in products such as cough syrups, there is a large potential market for malate that is organically produced.

Benefits

Industrial Microbes' CO₂-based malate is a drop-in replacement for the traditional petroleum-derived malate. This process absorbs CO₂ at high efficiency while petroleum-derived malates produces CO₂ during production. It is estimated that Industrial Microbes' production costs are 50-80 percent lower than traditional production methods currently in operation. Fermentation plants are less capital intensive compared to chemical plants and are easily scalable and replicable. Furthermore, the production cost for the process will remain competitive even if natural gas prices double.



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Economic Impact

The economic benefits from the adoption of Industrial Microbes' technology in Alberta would include:

- The development of the first cluster of world-scale manufacturing plants for the product in Alberta
- An increase in tax revenue and high-quality jobs in biotechnology, industrial fermentation, chemical recovery, and plant operations
- Opportunities to build downstream product industries including chemical and biological processing, biodegradable plastic production, and biodegradable product manufacturing of consumer goods
- Participation in an emerging market for a growing global market for biodegradable plastics
- Diversifying a strong export economy currently dominated by the energy sector

University of Maryland - USA

An Innovative and Highly Efficient Microalgae-Based Carbon Sequestration System to Reduce CO₂ Emission and Produce Valuable Byproducts Including Biofuels in all Climates

The University of Maryland's (U of M) technology integrates multiple breakthrough technologies that efficiently mitigate CO₂ and other greenhouse gases on an industrial scale. The technology uses a biological process that can work anywhere in the world, in any climate. At the same time, the technology provides the ability to generate additional revenue streams to fund its implementation and maintenance via the sale of valuable byproducts.

"In essence, we use a natural biological process to reduce the world's air pollution, animal waste pollution, and create valuable byproducts. This is truly a breakthrough technology that can change how the world addresses the causes of climate change."

The Bright Idea

In their process, the U of M uses microalgae to mitigate CO₂ from an industrial air pollution source. They then harvest the algal biomass to produce biofuels, lutein and other byproducts. The process takes place in a facility housing large photo bioreactors. Flue gas is captured from an adjacent methane-fired power plant and is injected into the bioreactors, which are filled with a newly isolated strain of fast growing, high CO₂-tolerant microalgae. The algal strain then consumes the C₂, NO_x and other greenhouse gases and vent oxygen via the photosynthesis process. The algal cultures are harvested from the bioreactors on a continual basis, which is then either dried or converted to biofuel using an innovative enzyme.

Stage of Innovation and Market Potential

The U of M's goal is to remove at least 50 tonnes of CO₂ per year by 2016 using four full-scale HY-TEK Bio photobioreactors (6,800 L each) on 25 square metres of land. This modest goal provides the opportunity to move the process forward in terms of increased automation and improved harvesting techniques that must be addressed in order to handle larger volumes of CO₂ in larger facilities. After two years, the process will be ready to mitigate greenhouse gas emissions from the power plants at small landfills and wastewater treatment plants. Power plants represent



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the largest market since the technology works with coal, oil, natural gas, biomass and any other combustible fuel source. The initial target market will be landfills and wastewater treatment plants that use their digester and landfill gases to generate electricity while emitting CO₂ at small to medium scale.

Benefits

The U of M's innovative technology incorporates a natural biological process that makes it possible to mitigate massive volumes of greenhouse gas emissions on an industrial scale - anywhere in the world and in any climate - while generating byproducts that generate a revenue stream. CO₂ is a natural food for algae, and U of M's algal strain devours CO₂ on an industrial scale; it is easily convertible to biodiesel, health and food additives, and many other marketable products that generate a revenue stream to pay down the cost of deploying the technology. In addition to CO₂ pollution, animal waste is also fouling our environment. The U of M's technology can turn animal waste into a useful fertilizer for growing algae, thereby reducing potential nutrient pollution resulting from animal waste.

Economic Impact

The use of U of M's technology in Alberta can create economic benefits including:

- The reduction of CO₂, NO_x, SO_x and VOCs throughout the province
- Additional revenue streams from the generated by-products
- Investment returns creating jobs for installation, operation maintenance, and operation of the technology
- Downstream economic benefits from a clean environment

OakBio - USA

Conversion of Industrial CO₂ Emissions into Biofuels and Chemicals

In the effort to make use of CO₂ and H₂ emitted from industrial flues, OakBio has developed a biomanufacturing platform that uses a strain of microbes to create bioplastics like butanol for commercial use. OakBio's project can grow on cement industrial flues, continuously converting CO₂ and hydrogen into valuable chemicals with little to no post-processing. The project provides a solution for major CO₂-emitting industries to monetize waste emissions, with a market for the product as a carbon-neutral biofuel that already has a large demand as a substitute for petroleum fuels.

"Increasing atmospheric CO₂ concentration contributes to climate change and many essential industries release large amount of CO₂ into the atmosphere. We offer a novel method for large-scale capture and conversion of CO₂ into butanol - a renewable fuel that replaces gasoline as transportation fuel."

The Bright Idea

OakBio's approach uses a novel microbial system to convert industrially emitted CO₂ into butanol, a renewable liquid transportation fuel. By bubbling hydrogen and industrial flue gases through a bioreactor, microbes grow and consume both CO₂ and H₂ and in turn secrete butanol. The process can continuously separate butanol from the bioreactor from Alberta's highest CO₂-emitting industries - including oilsands mining and upgrading, power generation, and mineral product manufacturing. At the same time, this project minimizes downstream processing, as butanol is the only product removed in the final step.



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Stage of Innovation and Market Potential

OakBio's biomanufacturing platform will be ready for commercialization in six years. At that point the process will be validated for commercial scale-up and will be ready to convert carbon into butanol on a large scale. Based on information from the U.S. Energy Information Administration, worldwide demand in this market will average 91 million barrels of oil equivalent per day in 2014. The enormous size of the transportation fuels market and the possibility of renewable butanol as a substitute for gasoline offer a realistic opportunity for the technology to significantly reduce CO₂ emissions globally. Butanol has further market potential through the possible production of a valuable chemical feedstock and an industrially relevant solvent.

Benefits

OakBio's technology leverages low upfront technical risk to create a flexible platform capable of greatly reducing CO₂ emissions from multiple Alberta industries while producing high-quality drop-in biofuels. This is a valuable benefit for both CO₂ emitting industries and markets looking to replace petroleum-based fuels. In Alberta, both cement and oilsands industries would benefit directly from this technology. The potential is a truly transformative technology as it leverages existing infrastructure, and has a low implementation risk.

Economic Impact

OakBio's solution has economic benefits in Alberta that include:

- Reduction of Alberta's dependence on oil imports for local fuel supply
- Extra revenue for large CO₂-emitting industries through sale of fuels
- Expense reduction for CO₂-emitting industries that can use the fuel they produce - especially beneficial for remote industrial sites
- Potential job creation in Alberta with the creation of a new "green field" renewables industry in Alberta
- Integration of alternative / intermittent energy sources like wind power used to produce H₂, a key feedstock for the OakBio process