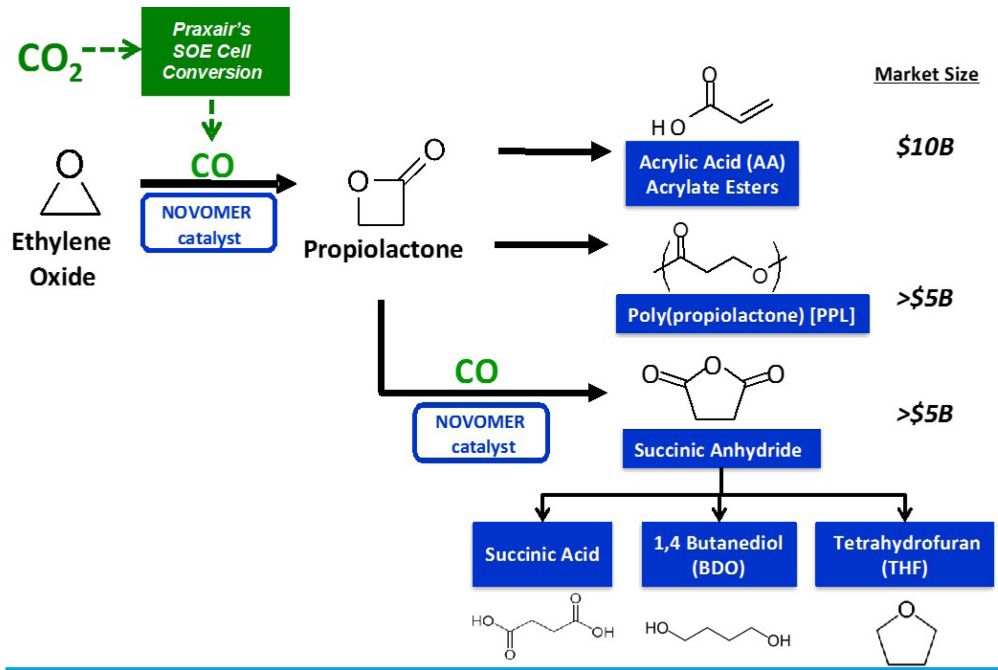
Waste CO_2 and Shale Gas to High-Value Chemicals

Conversion of Waste CO_2 and Shale Gas to High-Value Chemicals

Enabling high-yield, low-cost, low-temperature production of chemical intermediates

Chemical intermediates, typically derived from crude oil, are building blocks that undergo additional reactions to produce a wide variety of commercial products. For example, acrylic acid can be used to make paints, adhesives, or absorbent polymers used in personal hygiene products such as diapers. Typically, imports account for about half of the total U.S. crude oil supply, are subject to major price swings, and are relatively expensive. Additionally, typical chemical production processes tend to be energy intensive due to low selectivity and high operating temperatures.

The objective of this project was to combine two unique systems into one semi-integrated laboratory-scale continuous process that can produce a variety of chemical intermediates—including acrylic acid—with significantly lower energy requirements and a smaller carbon footprint, and at a lower projected cost than today's petrochemical versions. The first process converted waste carbon dioxide (CO_2) from industrial sources to carbon monoxide (CO) using a solid oxide electrolyzer (SOE). The SOE cell was adapted for combustion- assisted electrolysis, which provides the energy required for the reduction process as well as reduces the electrical potential to initiate the reduction reaction. The CO from this process was to be combined with an ethane derivative from shale gas, ethylene oxide, using a novel highly selective catalyst to form a versatile intermediate called beta-propiolactone (BPL). The BPL can be converted into



Schematic illustrating the Novomer/Praxair semi-integrated process to produce high-value chemical intermediates. *Graphic image courtesy of Novomer.*

acrylic acid using known technologies or combined with another CO molecule to make succinic anhydride (SAN). SAN can be easily converted into succinic acid by adding water or through hydrogenation to make butanediol or tetrahydrofuran.

Benefits for Our Industry and Our Nation

Using waste CO_2 and ethane derivatives as feedstocks for high-value drop-in chemicals has many benefits, including:

- Increasing energy productivity of chemical manufacturing by 30%–70% compared to existing technologies, depending on the target chemical.
- Waste CO_2 is converted to CO and incorporated into certain organic chemicals, providing a significant portion of the carbon structure.
- Increasing production of chemical intermediates from domestically-produced, ethane-rich shale gas.
- Decoupling the price of chemicals produced using this technology from crude oil, as well as reducing oil imports.

Applications in Our Nation's Industry

This technology could provide the chemical industry with a low-energy, cost-effective method of producing important chemical intermediates. The technology can be integrated seamlessly into the existing infrastructure. In addition to the chemical industry, a range of industries throughout the supply chain will benefit from the technology, including the paint and coating, textile, and polymer industries.

Project Description

The project objective was to develop, build, operate, and validate a semi-integrated laboratory-scale continuous process that converts waste CO_2 from industrial sources and ethane derivatives from shale gas into commodity chemical intermediates. The process would have dramatically reduced energy and carbon footprints with potentially much lower production costs compared to current technology.

Barriers

- Establishing a cost-effective, low-energy process for generating CO using a combustion-assisted SOE cell.
- Producing sufficient amounts of CO to adequately test the semi-integrated technology.
- Developing a reactor system that satisfies both performance and economic requirements while operating in semi-continuous mode.

Pathways

Project partners developed the carbonylation process and the SOE technology separately. For the carbonylation process, the major unit operations were tested and evaluated individually to ensure key process parameters were well understood before integrating into a single process. Novomer successfully connected the major unit operations and operated the system continuously with catalyst recycle.

SOE cell electrode and electrolyte materials were tested and preferred compositions selected and used to manufacture SOE cells. Single SOE cells operated continuously for extended periods of time before a multi-cell SOE short stack was assembled and tested to assess potential issues with combustion-assisted electrolysis technology scale-up.

The two processes were to be semi-integrated, but the project was terminated before this final step was completed. Novomer made significant investment in the carbonylation system in parallel with this project and designed, built, and commissioned an automated continuous system more than a year ahead of schedule. In April 2016, Novomer and project partner Praxair notified DOE that they would complete all remaining work on the SOE cell without Federal funding.

Milestones

This 2.5 year project began in 2013 but was terminated early in 2016.

- Develop a detailed process diagram of an integrated laboratory-scale carbonylation process based on individual evaluation of the test reactor and separation systems (Completed).
- Assemble the SOE cell and select preferred cathode and anode compositions for combustion-assisted CO/CO_2 electrolysis (Completed).
- Assemble a continuous carbonylation process, including process control instrumentation, to ensure system monitoring and data collection (Completed).
- Demonstrate successful operation of combustion-assisted electrolysis for reduction of CO_2 to CO at both ambient and elevated pressure (Completed).
- Produce high-value chemicals from the carbonylation process using CO from the SOE cell (Unmet).

Commercialization

Novomer is currently engaged in development activities for a commercial scale plant. The estimated timeframe of completion for this plant is the end of 2020. Praxair will continue to perform testing on the multi-cell SOE stack in order to support scale-up efforts.

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