# Engineering-Scale Demonstration of Transformational Solvent on NGCC Flue Gas

## primary project goal

ION Clean Energy Inc. (ION) is empirically validating the low capital and operating costs for ION's transformational solvent with revolutionary stability technology (ICE-31) on a 1-megawatt-electric (MWe) slipstream of flue gas from Calpine's Los Medanos Energy Center (LMEC), a commercially dispatched natural gas combined cycle (NGCC) power plant. To accomplish this, the project team is designing, constructing, and operating an engineering-scale carbon dioxide ($CO_2$) capture pilot that will capture 10 tonnes per day (tpd) of $CO_2$.

## technical goals

- Validate process models on NGCC flue gas over a range of capture efficiencies (up to 99%).
- Demonstrate the exceptional solvent stability of the ICE-31 technology over a long-term operational period to determine true long-term operating costs, including solvent makeup, reclaiming, and disposal.
- Demonstrate expected capital cost savings on NGCC flue gas as compared to baseline technologies.
- Establish true long-term operating costs, including solvent makeup, reclaiming, and disposal.
- Perform an environmental, health, and safety (EH&S) assessment and a techno-economic assessment (TEA).

## technical content

The 1-MWe $CO_2$ capture pilot project leverages the benefits of ION's innovative ICE-31 solvent technology to make a transformational reduction in the levelized cost of electricity while significantly limiting $CO_2$ emissions from natural gas-fired power plants. The project builds on ION's successful and extensive lab-, bench-, and small pilot-scale testing of solvent technologies and serves as a vital step of piloting a process with actual NGCC flue gas to further validate this technology's expected suitability for future commercial-scale deployment.

In a previous screening of both commercially available amines and designer amines, ION identified the transformational, water-lean amine-based solvent technology ICE-31. ICE-31 exhibits superior regeneration energy, working capacity, kinetics, material compatibility, stability under both oxidative and thermally challenging environments, and a minimal environmental impact.

Under the previous U.S. Department of Energy (DOE)-funded project FE0031727, "Validation of Transformational $CO_2$ Capture Solvent Technology with Revolutionary Stability (Project Apollo)," ICE-31 was scaled up and validated at the National Carbon Capture Center's (NCCC) 0.6-MWe pilot solvent test unit on natural gas-fired boiler and coal-fired flue gas; this testing encompassed $CO_2$ inlet

**program area:**
Point Source Carbon Capture

**ending scale:**
Small Pilot

**application:**
Post-Combustion Power Generation PSC

**key technology:**
Solvents

**project focus:**
Water-Lean Amine-Based Solvent for Natural Gas Applications

**participant:**
ION Clean Energy Inc.

**project number:**
FE0031950

**predecessor project:**
FE0031727

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**partners:**
Koch Modular Process Systems; Sargent & Lundy; Calpine Corporation

**start date:**
10.01.2020

**percent complete:**
45%

concentrations ranging from 4.4% (simulated NGCC conditions) through 13% (real coal-fired flue gas).

In this project (Project Enterprise), ION will utilize a modular design and fabrication approach to deliver the engineering-scale system that will be designed to yield a $CO_2$ product flow with greater than 95% purity suitable for compression and dehydration into a $CO_2$ pipeline. The $CO_2$ capture process will be optimized to take full advantage of the benefits provided by the ICE-31 solvent in combination with other process improvements, all of which are derived through a process-intensification design philosophy focused on NGCC flue gas. The benefits of this holistic approach include a smaller physical plant, reduced energy requirements, improved $CO_2$ product quality, less solvent degradation, lower emissions, lower water usage, less maintenance, and lower capital costs.

The long-term test campaign will include a demonstration of end-to-end process optimization; comprehensive chemical costs of the NGCC carbon capture facility; and further validation of ION's rigorous, rate-based process model on NGCC flue gas. Upon completion of this project, ION's solvent technology will be ready for commercial deployment as defined in the Technology Maturation Plan. Learnings from the completed testing under FE0031727 have provided substantial information to support ICE-31's readiness for front-end engineering design for commercial facilities and Project Enterprise seeks to confirm these results and provide any critical operating expenses (OPEX) considerations as projects move to Final Investment Decision.

ION worked with Calpine's LMEC facility to determine the best location for the 1-MWe pilot and identified an optimal location next to the cooling towers (Figure 1). The image shows the proposed location of the pilot system, as well as tie-in points for steam, electricity, cooling water, instrument air, and natural gas (if needed). Additional project team members include Koch Modular Process Systems, a commercial design and fabricator of modular $CO_2$ capture units who will design and supply the engineering-scale system, and Sargent & Lundy, an experienced engineering firm in the power industry who will manage all balance of plant (BOP) engineering and construction required for site preparation and installation of the pilot system.

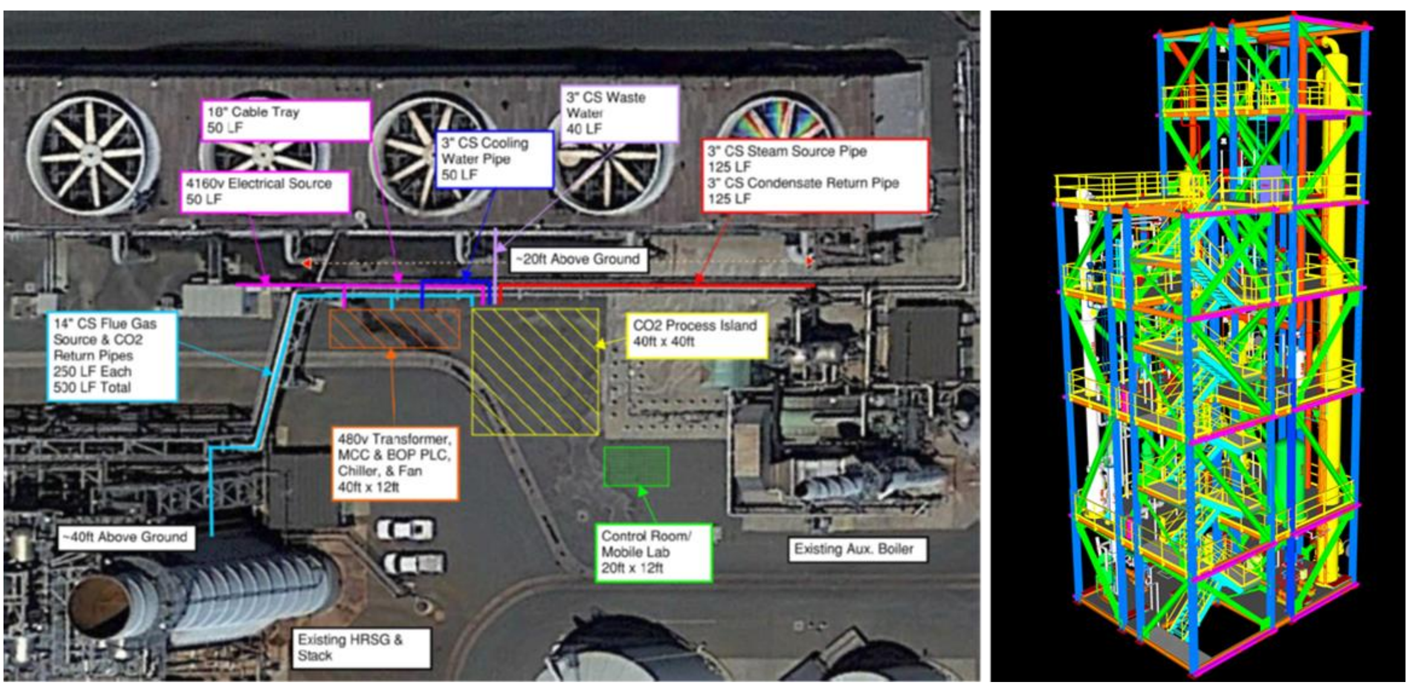


**Figure 1: (Left) Overhead view of LMEC with 1,600-ft² (150 m²) pilot site and required tie-ins identified. (Right) Image of the 3D model of the modular system.**

Project activities will be accomplished through three phases: design, construction, and operation. The Design Phase will result in a pilot system design that has the necessary flexibility for solvent performance optimization and demonstration. The project team will design the $CO_2$ capture system and the BOP systems needed to support the 1-MWe pilot at the NGCC facility. A hazard and operability analysis (HAZOP) will be conducted for the pilot system, which will help shape the detailed design. The Construction Phase will realize both the $CO_2$ capture island and BOP designs and result in a completely assembled system. It will include procurement of necessary equipment and materials, building of the BOP and $CO_2$ capture systems, and development of the control software. This phase concludes with the installation of the pilot system at the site, the necessary site tie-ins, and site-acceptance testing.

The Operational Phase will commence with baseline testing using first- and second-generation solvents before parametric and long-term testing of ICE-31. The test plan will involve the same baseline parametric testing performed on the previous solvents for a direct comparison, before moving on to a long-term testing strategy to evaluate the solvent lifetime under continuous cycling of operations required to follow the NGCC system. The long-term test campaign will include demonstration of end-to-end process optimization, as well as produce comprehensive technology costs of the NGCC carbon capture facility. The purpose of this long-term testing is to evaluate the solvent performance for a long enough duration to fully understand the interactions and degradation pathways when interacting with the flue gas. This phase will conclude with the decommissioning of the plant and the reversion of the site to its prior state.

## TABLE 1: SOLVENT PROCESS PARAMETERS

| Pure Solvent | Units | Current R&D Value | Target R&D Value |
|---|---|---|---|
| Molecular Weight | $mol^{-1}$ | 80–150 | 100–150 |
| Normal Boiling Point | °C | 220–250 | 220–250 |
| Normal Freezing Point | °C | <-15 | <-20 |
| Vapor Pressure @ 15°C | bar | <0.0001 | <0.0001 |
| Manufacturing Cost for Solvent | $/kg | Proprietary | Proprietary |
| **Working Solution** | | | |
| Concentration | kg/kg | 650–800 | 650–800 |
| Specific Gravity (15°C/15°C) | - | 0.8–1.1 | 0.8–1.1 |
| Specific Heat Capacity @ STP | kJ/kg-K | 1.5–2.5 | 1.3–2.0 |
| Viscosity @ STP | cP | <10 | <10 |
| Surface Tension @ STP | dyn/cm | <50 | <50 |
| **Absorption** | | | |
| Pressure | bar | 1.0 | 1.0 |
| Temperature | °C | 40 | 40 |
| Equilibrium $CO_2$ Loading | gmol $CO_2$/kg | 0.5–1.0 | 0.5–1.0 |
| Heat of Absorption | kJ/kg $CO_2$ | -1,600 to -1,750 | -1,600 to -1,750 |
| Solution Viscosity | cP | <20 | <20 |
| **Desorption** | | | |
| Pressure | bar | 1.5–2.0 | 1.5–4.5 |
| Temperature | °C | 110–125 | 110–140 |
| Equilibrium $CO_2$ Loading | gmol $CO_2$/kg | 0.05–0.20 | 0.05–0.20 |
| Heat of Desorption | kJ/kg $CO_2$ | <1,800 | <1,800 |

### Definitions:

***STP*** – Standard temperature and pressure (15°C, 1 atmosphere [atm]).

***Pure Solvent*** – Chemical agent(s), working alone or as a component of a working solution, responsible for enhanced $CO_2$ absorption (e.g., monoethanolamine [MEA] in an aqueous solution).

***Manufacturing Cost for Solvent*** – "Current" is market price of chemical, if applicable; "Target" is estimated manufacturing cost for new solvents, or the estimated cost of bulk manufacturing for existing solvents.

***Working Solution*** – The solute-free (i.e., $CO_2$-free) liquid solution used as the working solvent in the absorption/desorption process (e.g., the liquid mixture of inorganic salt and water).

***Absorption*** – The conditions of interest for absorption are those that prevail at maximum solvent loading, which typically occurs at the bottom of the absorption column. These may be assumed to be 1 atm total flue gas pressure (corresponding to a $CO_2$ partial pressure of 0.13 bar) and 40°C; however, measured data at other conditions are preferable to estimated data.

***Desorption*** – The conditions of interest for desorption are those that prevail at minimum solvent loading, which typically occurs at the bottom of the desorption column. Operating pressure and temperature for the desorber/stripper are process-dependent (e.g., an MEA-based absorption system has a typical $CO_2$ partial pressure of 1.8 bar and a reboiler temperature of 120°C). Measured data at other conditions are preferable to estimated data.

***Pressure*** – The pressure of $CO_2$ in equilibrium with the solution. If the vapor phase is pure $CO_2$, this is the total pressure; if it is a mixture of gases, this is the partial pressure of $CO_2$. Note that for a typical pulverized coal power plant, the total pressure of the flue gas is about 1 atm and the concentration of $CO_2$ is about 13.2%. Therefore, the partial pressure of $CO_2$ is roughly 0.132 atm or 0.130 bar.

***Concentration*** – Mass fraction of pure solvent in working solution.

***Loading*** – The basis for $CO_2$ loadings is moles of pure solvent.

***Estimated Cost*** – Basis is kg/hr of $CO_2$ in $CO_2$-rich product gas; assuming targets are met.

***Flue Gas Assumptions*** – Unless noted, flue gas pressure, temperature, and composition leaving the flue gas desulfurization unit (FGD; wet basis) should be assumed as:

| | | Composition | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pressure | Temperature | vol% | | | | | ppmv | |
| psia | °F | $CO_2$ | $H_2O$ | $N_2$ | $O_2$ | Ar | $SO_X$ | $NO_X$ |
| 14.7 | 135 | 13.17 | 17.25 | 66.44 | 2.34 | 0.80 | 42 | 74 |

### Other Parameter Descriptions:

***Chemical/Physical Solvent Mechanism*** – Chemical absorption/desorption of $CO_2$ to/from working solution.

***Solvent Contaminant Resistance*** – Sulfur oxide ($SO_X$) and nitrogen oxide ($NO_X$) are manageable. Extremely stable towards oxygen ($O_2$).

***Solvent Foaming Tendency*** – No issues (more than 3,000 hours experience).

***Flue Gas Pretreatment Requirements*** – As for any stable amine-based solvent.

***Solvent Makeup Requirements*** – Aimed at less than 0.010 kg/t$CO_2$.

***Waste Streams Generated*** – Similar profile but estimated to be less than other stable amine-based solvents.

***Process Design Concept*** – Similar to stable amine-based solvents, just a smaller footprint.

***Proposed Module Design*** – N/A.

## technology advantages

- Fast kinetics, coupled with low water content, enhances the carrying capacity and reduces regeneration energy.
- Environmentally benign (i.e., low parasitic load, near-zero emissions, and negligible solvent makeup).
- Low thermal and oxidative degradation rates result in revolutionary solvent stability, reducing solvent makeup rates and associated OPEX.
- Low specific reboiler duty (SRD) and solvent stability result in smaller capture plant equipment, reducing capital expenditure (CAPEX).
- ICE-31 solvent is currently available from commercial chemical manufacturers.

## R&D challenges

- Acquiring sufficient long-term solvent performance on natural gas-fired flue gas from a commercially dispatched power station.
- Developing a robust test plan to investigate the necessary conditions required for commercial operations.

## status

The project team completed the process design package, updated modular pilot system cost estimate with detailed engineering of the $CO_2$ island and necessary BOP integration systems. All permit applications were submitted, with favorable results expected as ION's solvent and process mitigate hazardous emissions. For host site preparations, the project team continued meetings to coordinate with the host site for pilot fabrication, updating design criteria, identifying tie-in locations, supporting the modular delivery study, updating the system-level electrical load list, and engaging the general contractor. The modular pilot system will go into fabrication in late Q2 2022, with expected installation in Q4 2022.

## available reports/technical papers/presentations

"Engineering-Scale Demonstration of Transformational Solvent on NGCC Flue Gas (Project Enterprise)," DOE Project Kickoff Meeting, December 9, 2020. *https://www.netl.doe.gov/projects/plp-download.aspx?id=11039&filename=Engineering-Scale+Demonstration+of+Transformational+Solvent+on+NGCC+Flue+Gas+(Project+Enterprise).pdf*.

"Engineering-Scale Demonstration of Transformational Solvent on NGCC Flue Gas (Project Enterprise)," 2021 NETL Carbon Management Research Project Review Meeting, August 13, 2021. *https://netl.doe.gov/sites/default/files/netl-file/21CMOG_PSC_Fine_0.pdf*

"Validation of Transformational $CO_2$ Capture Solvent Technology with Revolutionary Stability (Apollo)," 2021 NETL Carbon Management Research Project Review Meeting, August 12, 2021. *https://netl.doe.gov/sites/default/files/netl-file/21CMOG_PSC_Fine.pdf*