Advanced Technologies for CO₂ Capture & Utilization: Power & Industrial Applications

National Coal Council – 2017 Spring Meeting

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Source: Robert Nickelsberg/Getty Images
Energy Technologies at RTI International

DELIVERING THE PROMISE OF SCIENCE FOR GLOBAL GOOD

$885 M
FY2016 Revenue

3,064 Projects (fiscal year 2016)
1,102 Clients (fiscal year 2016)
5,032 Staff Members Worldwide
90 Languages
250 Degree Fields
105 Nationalities
13 U.S. Offices
10 International Offices

Energy Technologies
Developing advanced process technologies for energy applications by partnering with industry leaders

Clean Coal / Syngas Processing
Industrial Water Treatment
Carbon Capture & Utilization / Gas Separations
Advanced Materials for Catalysis & Separations
Biomass Conversion
Natural Gas Extraction & Conversion

Focused on Applied Research (concept to demonstration) in Partnership with Government Agencies, Academia, and Industry
Coal Remains Significant for Future World Electricity Generation

CO₂ Capture Remains a Need for Long-term Utilization of Coal

- Long-term global concerns are still expected to drive ultimate reduction of carbon emissions from use of coal.
- To ensure coal remains competitive, current carbon capture costs must be reduced.

U.S. DOE Goals for Cost of CO₂ Capture

Source: US DOE-NETL
Pathway to Reducing the Cost of CO$_2$ Capture

CO$_2$ Capture Cost Elements for Current Solvent Systems

Pathway to Reducing LCOE and Cost of CO$_2$ Capture

- Primary focus on reducing energy consumption – regeneration energy / reboiler duty
- Reduce capture process capital expenditure
  - Simplify process arrangement
  - Lower cost materials of construction
- Limit operating cost increases for carbon capture

Examples of Current Large-Scale Carbon Capture and Storage Projects

SaskPower – Saskatchewan Canada
- **Company/Alliance:** SaskPower
- **Location:** Boundary Dam Power Plant, Saskatchewan, Canada
- **Source:** 115 MW coal-fired Unit #3 (retrofit)
- **Start Date:** October 2014 [world’s 1st large-scale coal boiler carbon capture project]
- **Capture:** up to 1.3 Mt of CO\(_2\)/yr (up to 5,000 tpd @ 90% capture) for EOR with backup underground storage site [~1.5 Mt captured to date]
- **Capture Technology:** Post-combustion: Shell Cansolv amine process

Petra Nova Carbon Capture Project - Richmond, TX
- **Company/Alliance:** Petra Nova Holdings: a 50/50 partnership between NRG Energy and JX Nippon Oil & Gas Exploration Corp.
- **Location:** Unit 8, W.A. Parish plant, Thompsons, 60Km from Houston, Texas, USA
- **Source:** 240 MW slip stream from 610 MW coal-fired unit
- **Start Date:** January 2017 (ribbon-cutting April 13, 2017)
- **Capture:** 1.4 Mt of CO\(_2\)/yr (5,000 tpd at 90% capture) for EOR
- **Capture Technology:** Post-combustion: KM-CDR (KS-1 amine) absorption process developed by MHI and KEPCO

Source: SaskPower
Source: NRG Energy
Examples of Current Large-Scale Carbon Capture Projects

Kemper County IGCC Project – Kemper County, MS

- **Company/Alliance:** Mississippi Power / Southern Company
- **Location:** Kemper County, about 20 miles north of Meridian, MS
- **Source:** 582-MW lignite-fueled IGCC power plant
- **Start Date:** Anticipated in 2017
- **Capture:** 3.0 Mt of CO$_2$/yr (65% capture) for EOR
- **Capture Technology:** Pre-combustion: Selexol™ physical solvent-based absorption process developed by UOP

Source: Mississippi Power
Numerous Advanced CO$_2$ Capture Technologies under Development

Most Promising New Routes

- Chemical looping
- OTM boiler
- Biological processes
- CAR process

Most advanced technologies need significant R&D to achieve performance and cost goals

Source: US DOE-NETL
Innovative CO\textsubscript{2} Capture Technology Being Developed at RTI

- RTI is developing innovative solutions for capturing CO\textsubscript{2} from large industrial sources, such as fossil-fuel power, chemical and cement plants, at lower costs and energy penalties.

- Technologies (pre- and post-combustion):
  - Non-Aqueous Solvents
  - Solid Sorbents
  - Chemical Looping Systems
  - Membranes
  - Hybrid Systems

- Benefits: Substantial improvements to the cost and energy demands of CO\textsubscript{2} capture and utilization compared to conventional technologies
  - Regeneration energy reduced by as much as 40-50% (compared to MEA)
  - Overall cost of electricity reduced ~10-12% for powergen (compared to a DOE baseline study)
  - Capex of carbon capture block reduced by up to 50%
RTI’s Partnerships in CO₂ Capture & Utilization

Solid Sorbent-Based

Novel NAS Solvents

CO₂ Capture from Cement Plants

CO₂ Utilization

Warm Syngas Cleanup
RTI has developed a solid sorbent-based CO₂ capture process that uses a supported, polymeric sorbent and a fluid-bed process arrangement for post-combustion applications.

- Technology benefits:
  - >25% reduction in cost of CO₂ capture, potential for up to 40% cost reduction
  - ~ 40% energy reduction
  - Reduction in CAPEX
  - High CO₂ loading capacity
  - Relatively low heat of absorption; no heat of vaporization penalty
  - No evaporative emissions
  - 4-yr cooperative effort between RTI, Masdar, and DOE has developed the technology to pilot scale
  - Additional tests in U.S. and on-site in Norway are ongoing through 2017

Promising sorbent chemistry

CO₂-philic polymer (e.g., polyethylenimine)

Immobilize polymer into nano-porous material

RTI bench-scale unit
Technology Roadmap – RTI Solid CO$_2$ Sorbents

Bridge to Pilot Testing

Knowledge Gained:
- Lessons learned from bench-scale testing
- Optimal process design and operating conditions
- Sorbent scale-up and optimization

Additional Work:
- More extensive performance testing
- Testing in flue gas
- Application to multiple CO$_2$ sources
- Sorbent cost reduction

Objective

Demonstrate the technical and economic feasibility of RTI’s advanced, solid sorbent CO$_2$ capture process in an operating cement plant

Period of Performance:
• 5/1/2013 to present

Two Phases

Phase I – Feasibility Review – Complete
• Sorbent exposure to actual cement plant flue gas
• Economic evaluation
• Commercial design for cement application

Phase II – Demonstration – In Progress
• Design, build, and test a prototype of RTI’s solid sorbent CO$_2$ capture technology
• Evaluate CO$_2$ capture performance
• Update economics with pilot test data
RTI Process Development

- Developing a solid sorbent-based CO₂ removal process that integrates directly with RTI’s overall warm syngas clean-up technology package
- Sorbent removes CO₂ from syngas at ~400°C
- Formulation and stability optimized
- Transitioning to a fluidizable particle form
- Developed a novel process arrangement that:
  - Maximizes sorbent utilization and capture/release rate
  - Integrates heat between absorber and regenerator
  - Combines water-gas-shift and CO₂ absorption
- Experimental work shows concept is feasible
- Preliminary techno-economic assessment completed
RTI Non-aqueous Solvent (NAS) Based CO$_2$ Capture

- Novel non-aqueous solvents have been developed and tested by RTI.

- Projected technology benefits of NAS systems:
  - Don’t absorb water like conventional amine systems
  - Reduce regeneration energy penalty ~40-50% lower than MEA solvents (and better than state-of-the-art systems)
  - Reduce the increase in cost of electricity associated with CO$_2$ capture
  - Substantially reduce capital costs for carbon capture

- Scale-up testing underway at SINTEF pilot facility:
  - Successful cooperation between RTI, Linde, and SINTEF (Scandinavia’s leading research organization)
  - Cooperation between the U.S. and Norway governments enables a lower cost, lower risk, but accelerated pathway for CO$_2$ capture technology development.
Objective:
• Design/build unique process modifications for the existing Tiller unit
• Demonstrate the process on coal-derived flue gas
• Compare and benchmark performance versus conventional amine solvents
• Techno-economic and EHS evaluations

Progress:
• MEA baseline testing completed
• Confirmed reported reboiler heat duty of 3.5-3.6 GJ/T-CO₂ for amine (MEA)
• NAS pilot testing now underway with coal-based flue gas
• Initial results are validating projected regeneration energy reductions
• All testing expected to be completed this year

Source: SINTEF
Technological Roadmap: RTI Novel Non-Aqueous CO₂ Solvents (NAS)

- **Lab-Scale Development & Evaluation (2010-2013)**
  - Solvent screening
  - Lab-scale evaluation of process

- **Large Bench-Scale System (RTI facility, 2014-2016)**
  - Demonstration of key process features (≤ 2,000 kJ/kg CO₂)

- **Pilot Testing at Tiller Plant (Norway, 2016-2018)**
  - Demonstration of all process components at pilot scale (~60 kWe)

- **Future Demonstration (2018+)**
  - Pre-commercial Demonstration at Technology Centre Mongstad, Norway (~1-10 MWe)
  - Planning and pre-qualification ongoing (will test range of flue gases – coal, NG, etc.)

Source: SINTEF
Source: Technology Centre Mongstad
Applicability of RTI NAS for Gasification Syngas Carbon Capture

Since syngas is at pressure, we expect the NAS to work even better for syngas-based carbon dioxide capture than in the flue gas case, but they need to be coupled with upstream sulfur removal (such as RTI’s warm gas desulfurization process).

- NAS is both a chemical solvent and a physical solvent.
- Therefore, it will behave as a chemical solvent and a physical solvent.
- At higher pressures, the overall absorption of CO$_2$ should be enhanced.
• Designed, built, and operated an aMDEA™ based CO₂ capture system as part of a demonstration of RTI’s novel warm syngas desulfurization technology.
• Processed over 2MMscfh (~50,000 Nm³/hr) of syngas and captured up to 1,000+ ton/day of CO₂, which was subsequently released.
• Original plans were to sequester CO₂ in a saline aquifer on-site, but permit issues (e.g., monitoring requirements for extended years beyond the project timeline and funding) led the site to decide against actual sequestration.
RTI Technology for Coal to Ultra Clean Power, Chemicals, and Fuels

- RTI completed large-scale (50-MW_e) pre-commercial testing of its warm gas desulfurization process (WDP) technology at Tampa Electric Company’s Polk 1 IGCC Power Station in April 2016, and the technology is now ready for commercial licensing via Casale S.A.

- **Benefits:**
  - RTI WDP removes ~99.9% of sulfur contaminants from syngas at warm process temperatures (250-600°C) with up to 50% lower capital and operating costs and up to 10% higher efficiency (pressure independent process).
  - RTI advanced water-gas-shift (WGS) process can enrich H_2 content requiring ~50% less steam and 30% lower capital cost.
  - Coupled with carbon capture, WDP can produce ultra-clean syngas (up to 99.999% total S removal, down to sub-ppmv) suitable for ultra-clean power generation or rigorous coal-to-chemicals/fuels applications.
  - WDP is proven with ~7,000 hours of testing at pilot scale (Eastman Chemical) and demonstration scale (Tampa).
OASE® has the lowest specific energy consumption of any standard amines for acid gas removal. OASE®’s higher absorption kinetics and capacity reduce equipment size resulting in lower capex and opex. OASE® is chemically and thermally stable, non-corrosive, non-toxic, and readily biodegradable.

But, exploiting OASE® for CCS in IGCC requires upstream selective sulfur removal technology for syngas.

Design rate ~1200 tpd of carbon dioxide captured by RTI demonstration plant.
Carbon capture process performed as expected.
Carbon dioxide capture efficiency was >99%.
RTI achieved >90% overall carbon capture goal.
Primary impurities in the captured and released carbon dioxide were H₂ (about 1 mol%), CO (anticipated <1,000 ppmv or 0.1 mol%), and H₂S and COS (<100 ppmv).
The combination of RTI’s WDP and activated amine CO₂ capture (90% capture) results in:
  - A reduction in levelized cost of electricity (LCOE),
  - A reduction in overall IGCC capex/kW,
  - A reduction in overall IGCC opex/MWh, and
  - A significant (~75%) reduction in overall sulfur emissions compared with a base case IGCC using dual-stage Selexol™.
The WDP + activated amine process is now commercially available from Casale S.A.
Safe storage of CO₂ is being proven but still faces legal and regulatory risks that need to be addressed through policy measures.

Innovations in CO₂ utilization offer interesting technology and business options beyond CO₂ storage.
CO₂ Utilization – Broad Market Potential but Must be Economically Competitive

- **Carbonated Beverages**
  - • EOR
  - • EGR
  - • ECBM

- **Polycarbonate Polymers**
  - • Oil
  - • Gas

- **Fire Extinguishers**
  - • Blanket Products
  - • Protection for Carbon Powder
  - • Shield Gas in Welding

- **Carbon Fiber**

- **Fuels**
  - • Algae
  - • Greenhouse Gases
  - • Flavors/Fragrances
  - • Decaffeination

- **Food**
  - • Methanol
  - • Urea
  - • CO
  - • Methane

- **Carbonates**
  - • Refrigeration
  - • Dry Ice
  - • Injected Into Metal Castings
  - • Respiratory Stimulant (Added to Medical O₂)
  - • Aerosol Can Propellant
  - • Dry Ice Pellets Used for Sand Blasting
  - • Red Mud Carbonation

Source: National Energy Technology Laboratory
RTI Novel CO₂ Utilization Approach

CONCEPT

Novel catalyst platform for CO₂ utilization for oxidation reactions

INNOVATION

• Utilizing CO₂ as a feedstock for large volume chemicals with broad industrial interest.
• Based on novel catalysts that can extract an oxygen (O) atom from CO₂, co-producing carbon monoxide (CO), while driving reactions such as dry methane reforming or oxidations such as ethylene to ethylene oxide (EtO).
Example: Utilization of CO₂ for Ethylene Oxide (EtO) Production

- **RTI’s technology is based on a novel catalyst**
  - Extraction of an O atom from CO₂ and transfer to ethylene, at lower energy threshold
  - Consumes CO₂ and ethylene, producing EtO and CO

- **Enables EtO + CO process simplification**
  - Removes need for energy intensive air separation unit
  - Eliminates CO₂ emissions from EtO process
  - Eliminates conventional CO production by steam methane reforming plus its CO₂ emissions

- **Enables safer operation**
  - Removes explosion potential of conventional ethylene oxide production
  - Changes highly exothermic process to moderately endothermic process

- **Acceptable economics** (at current EtO prices)
  - Penalty for CO₂ use offset by process simplification
  - Byproduct CO is also a valuable chemical intermediate

- **Reduces CO₂ emissions**
  - >2.8 net tons of CO₂ reduction per ton of EtO product
  - 350 Kta EtO plant could reduce CO₂ emissions 1 Mta
Closing Thoughts

- Coal will continue as a key feedstock for world-wide energy, but long-term global concerns are still expected to drive the need to reduce carbon emissions from use of coal.
- Several large-scale carbon capture projects are now being demonstrated, but to keep coal use competitive, current carbon capture costs must be substantially reduced.
- Advanced technologies are being developed and demonstrated by RTI and others that offer hope for substantial cost reductions for low-carbon utilization of coal.
- Safe storage of CO\textsubscript{2} is being proven, but still faces legal and regulatory risks that need to be addressed through policy.
- Innovations in CO\textsubscript{2} utilization offer interesting technology and business options beyond CO\textsubscript{2} storage.

Source: Robert Nickelsberg/Getty Images
Acknowledgement:
RTI’s Energy Technology Team + U.S. DOE and Other Public/Private Partners

Innovation focused R&D for solving clients’ problems

State of the art facilities and capabilities

Talented staff produce novel technologies from ideation to pilot-scale to commercial systems
QUESTIONS?

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