Carbon Capture Technology for Bio-Energy Applications

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Energy Technology Division at RTI International

$885 M
FY2016 Revenue

3,064 Projects
(2016)

1,102 Clients
(fiscal year 2016)

5,032 Staff Members
Worldwide

90 Languages

250 Degree Fields

105 Nationalities

12 U.S. Offices

10 International Offices

Research Triangle Park, NC
- Ann Arbor, MI
- Atlanta, GA
- Berkeley, CA
- Chicago, IL
- Fort Collins, CO
- Portland, OR
- Rockville, MD
- San Francisco, CA
- Seattle, WA
- Waltham, MA
- Washington, DC

Abu Dhabi
Barcelona
Beijing
Jakarta
Ljungskile
Manchester
Nairobi
New Delhi
San Salvador
Toronto

ENERGY TECHNOLOGIES

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

- Natural Gas
- Clean Coal / Syngas Processing
- Advanced Materials
- Carbon Capture & Utilization
- Industrial Water Treatment
- Biomass Conversion
### Biomass Conversion to Fuels and Chemicals at RTI

<table>
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<th>DOE ARPA-E Project</th>
<th>Previous DOE EERE Project</th>
<th>DOE EERE Project</th>
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<td>2019+</td>
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#### Catalytic Bio-crude Production in a Novel, Short-Contact Time Reactor

- **Funding:** ~$4,000,000
- Catalyst development and testing
- Process design and development
- Process Scale-Up
- RTI Facility Design and Construction
- 1 TPD Process Development, Fabrication, and Installation

#### Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons

- **Funding:** ~$5,000,000
- Process Operation and Optimization
- Bio-crude Upgrading
- Integrated process development

#### Improved Hydrogen Utilization and Carbon Recovery for Higher Efficiency Thermochemical Bio-oil Pathways

- **Funding:** ~$4,000,000
- Novel catalyst development
- Improved bio-crude quality
- Aqueous phase carbon recovery to maximize carbon efficiency

#### Building Blocks from Biocrude: High Value Methoxyphenols

- **Funding:** ~$2,200,000
- Develop laboratory-scale separation of methoxyphenols
- Complete product development assessment.
- TEA and LCA demonstrating < $3/gge and > 50% GHG emissions
**CO₂ Capture R&D at RTI**

**Technical Targets**
- > 90% CO₂ capture from flue gas
- > 95 mol% CO₂
- $\text{~}40/\text{Tonne-}CO₂$ captured by 2025

**Technical Barrier Areas**
- Reduce energy consumption
  - Improve reboiler duty
  - Higher CO₂ working capacity
- Reduce capital cost
  - Simplify process
  - Materials of construction
- Limit operating cost increase

**PROVEN CO₂ CAPTURE TECHNOLOGY**

**Syngas Cleanup and CO₂ Capture at 50 MW Scale**
(1,000 ton/day CO₂ at a CO₂ >99% purity)

The combination of RTI’s WDP and activated amine CO₂ capture (90% capture) results in:
- Reduced levelized cost of electricity (LCOE),
- Reduced overall IGCC capex/kW,
- Reduced overall IGCC opex/MWh
- ~75% reduction in overall sulfur emissions compared to a base case IGCC with dual-stage Selexol™

*The WDP+ activated amine process commercially available from Casale S.A.*

**RTI’s DEVELOPING CO₂ TECHNOLOGIES**

**Non-Aqueous Solvents**
- Faster absorption kinetics than MEA
- Chemically and thermally stable, less degradation
- Non-corrosive, non-toxic, and biodegradable

**Technical Challenges**
- Solvent cost, capacity, degradation, and emissions
- Reboiler duty

**Solid Sorbents**
- Non-corrosive nature
- No vapor emissions
- Higher thermal stability

**Technical Challenges**
- Sorbent CO₂ capacity and stability
- Regeneration energy
- Heat management
- Counter-current flow

RTI Warm Syngas Cleanup: 50-MWe Demonstration Project

- aMDEA® CO₂ Capture
- RTI Advanced WGS Reactors
- RTI WDP Warm Syngas Desulfurization Process

Captured 1000 tons/day of CO₂ from Polk IGCC plant
Our experience with CCS at Tampa Electric

- Designed and built a carbon capture system for a 50 MW size, capturing 1000 ton/day of CO$_2$
- Characterized the geology for on-site storage
- Found synergies with waste water injection
- Modelling indicated rapid mineralization of CO$_2$
- EPA originally granted a Class V well permit, but later insisted on Class VI permit and 50 year MVA requirements
- Drilled a 8000 ft deep well
- CO$_2$ injection was abandoned due to regulatory and legal issues
RTI Non-Aqueous Solvent Based CO₂ Capture Technology

**Initial Solvent Discovery** (2010-2013)
- Solvent formulations developed and tested at the lab (6 L) and large bench scale (300 L/hr)
- Substantial IP estate in materials and process technology

**Large Bench-Scale System** (RTI facility, 2014-2016)
- Regeneration energy reduced by ~40-50% compared to commercial aMEA solvents
  - Lower CAPEX
  - Lower increase cost of electricity
  - Clear pathway to reach DOE goal of $40/T-CO₂

**Pilot Testing at Tiller Plant**
60 kWeq - 200 lbCO₂/day
(Norway, 2015-2016)
- 400 hours of baseline testing (propane and coal flue gas)
- Verified reduced regeneration energy
- Additional long-term testing with coal flue gas scheduled for this year

**Pre-Commercial Demonstration at TCM ~10 MWeq**
(Norway, 2018+)
Planning and pre-qualification stage

**TRL**
- TRL 1 – 3
  - $2.7MM
- TRL 4
  - $3.0MM
- TRL 5 – 6
  - 2.7MM
- TRL 7 – 8

From discovery through large scale (10 MW) demonstration
RTI Solid Sorbent Based CO₂ Capture Technology

1st and 2nd Generation Sorbents

Initial Sorbent Discovery
(10 – 200g: TRL 2-4)
- >25% reduction in cost of CO₂ capture, potential for up to 40% cost reduction
- ~ 40% energy reduction compared with SOTA MEA based technology
- Lower CAPEX
- High CO₂ loading capacity (~10 wt%)
- No evaporative emissions
- Low cost, commercial support

$3.8MM
2011 – 2015

NORCEM Cement Plant Pilot Testing
(150kg : TRL 5)
- Fluidized bed adsorption/desorption process testing with actual cement plant flue gas at a sorbent circulation rate of 100 kg/hr and CO₂ capture rate of 110 kg/day
- Commercial design for cement plant application
- Design, build, and test a prototype of RTI’s solid sorbent CO₂ capture technology

$2.1MM
2013 – 2016

3rd Generation Sorbents

3rd Generation Sorbent Development
(1-100g: TRL 1-3)

$2MM
2016 – 2018

Hybrid MOF-based CO₂ adsorbents:
- Highly tunable shapes and particles size
- Good hierarchical micro/mesoporosity
- High attrition resistance – excellent fluidizability
- High CO₂ capacity (≥ 12wt.%) coupled with excellent stability
- Cost effective and easy scalable
Challenges of CO$_2$ Reuse

**Challenge**
- Identify low cost reducing agents that have a small CO$_2$ footprint

**CO$_2$ Properties**
- Most fully oxidized form of carbon
- Extremely chemically stable
- Conversion to useful products requires abundant reducing agents and energy

Source: Banholzer, 2008
Pathways to Transform CO$_2$ and Create Valued Products

Corollary: How do we produce renewable hydrogen at <$2/kg at scale?
CO₂ Utilization Markets

Captured CO₂

Materials
- Carbon Fibers
- Polycarbonate Polymers

Food/Products
- Carbonated Beverages
- EOR, EGR, ECBM

Biological Conversion
- Algae
- Greenhouse Gases

Extractant
- Flavors/Fragrances
- Decaffeination

Mineralization
- Methanol
- Urea
- CO
- Methane

Refrigerant
- Refrigeration
- Dry Ice

Miscellaneous
- Inerting Agent
- Fire Extinguishers
- Blanket Products
- Protection for Carbon Powder
- Shield Gas in Welding
- 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
Large and growing market for EtO in North America and globally
- Global demand expected to grow 6% per annum

Ethylene oxide demand in Alberta is greater than 1.4 Mt and over 24 Mt globally (~$40 billion USD)
- 14th most produced organic chemical
- 4th largest industrial emitter of CO₂ (6.3 Mt per annum globally)

Pursuing other chemistries using CO₂ as a mild oxidizer for selective oxidation of hydrocarbons:

- Ethylene Oxide
- Propylene Oxide
- Acrylic Acid
- Acrolein
- Acrylonitrile
Opportunities for CO$_2$ Capture in Biomass Pyrolysis

CO$_2$-rich Regenerator Off-gas

- Recycle for fluidization and purges
- Chemical Looping Char Combustion (heat integration with regenerator)
- Sorbent Capture
- Solvent Capture
- Membrane Separation and Concentration
ThermoChem Recovery International, Inc. will work in collaboration with project partners to:

- Design a pilot-scale integrated biorefinery to produce transportation fuels from woody waste and agricultural feedstocks

- The project proposes many improvements throughout the system, which in combination would allow for smaller, more cost-effective integrated biorefineries with increased liquid fuel yield
Additional Options for CO₂ Capture and Utilization

1st and 2nd Generation Ethanol Plants – CO₂ Capture from Fermentation

Anaerobic Digestion – CO₂ Capture for Bio-methane production and purification

Algae Production – CO₂ Utilization
Other Opportunities - Low Hanging Fruits

Paper and Pulp Industry
- Lime kiln, Bark boiler, Recovery boiler

Iron and Steel Industry
- Co-feeding biomass with coal
- Removal of CO₂ from coke oven gas

Cement Industry
- Co-feeding of biomass in the kiln (Norcem)
Synergistic Use of Biomass with Other Fuels

- Coal + Biomass (CBTL)
- Biomass + natural gas (BETO)
- Biomass + Solar/Wind
- Biomass + MSW
- Biomass + Fecal Sludge
- Circular Economy
- Rewiring of Anaerobic Digesters to produce $\text{H}_2$ and other HCs
- Modular Systems

- Market-Based Solutions
- Policy Drivers
- Reliability, Availability and Maintenance (RAM) of the Biosystems
RTI’s Energy Technology Team

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