CO$_2$ Utilization beyond EOR

Resources for the Future
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There are many reasons to advance CO₂ Utilization technologies
All resources but electricity may become net exports.

Can efficient U.S. electricity be exported by embedding into salable products derived from CO$_2$?
Abundant electric capacity


U.S. infrastructure has excess generation capacity to the extent that even new natural gas plants cannot become economical in some areas (e.g. Hughes vs. Talen Energy Marketing).

Can the existing fleet be repurposed to service an export economy?
**U.S. CO₂ Sources.** Many point sources provide high to low purity CO₂. The total CO₂ supply was 5,414 million MT in 2015. Source: NatCarb.

**U.S. CO₂ Consumption.** The majority of CO₂ is used in the Oil & Gas sector, mostly by pipeline. Adapted from IHS Markit sources.

NETL, NatCarb database: http://natcarb.netl.doe.gov

Bala Suresh, IHS Markit, “Global Market for Carbon Dioxide”, presented at 8th Carbon Dioxide Utilization Summit (Feb 2017)
Global CO₂ demand and supply

Emissions from High Concentration Large Point Sources (0.5 Gtpa, GCCSI)

Y2011 Demand & Y2016 Demand (~0.22 Gtpa, IHS)

Y2011 Demand (0.08 Gtpa, GCCSI >62% for EOR)

Emissions from Dilute Large Point Sources (18 Gtpa, GCCSI)

Total Emissions (36.3 Gtpa)

GCCSI, Parsons Brinckerhoff, “Accelerating the Uptake of CCS: industrial use of carbon dioxide” (Dec 2011);
Bala Suresh, IHS Markit, “Global Market for Carbon Dioxide”, presented at 8th Carbon Dioxide Utilization Summit (Feb 2017)
Global CO₂ Initiative provides the following perspective,

- “CO₂U has the potential to utilize 7 billion metric tons of CO₂ per year by 2030”
- Revenue potential estimated at >$800 billion by 2030
- “This is an upper bound estimate, assuming zero carbon energy is used in all production processes”
- “To the extent that climate benefits are a goal of those promoting CO₂U products, life cycle analysis (LCA) is essential.”
- “Considerable work is needed to standardize life cycle analysis methodologies for CO₂U.”
“If CO$_2$ was to be used as the source of all carbon in the global annual production of plastics (311 million tonnes (MT) per year in 2014), it would consume about 0.8 GtCO$_2$ per year.”

“By 2030, the annual global plastic production is expected to rise to 700 MT, which would require roughly 490 MtC/yr or about 1.8 GtCO$_2$/yr.”

Final report of the Secretary of Energy Advisory Board (SEAB) Task Force on CO2 Utilization
Limitations of Existing Renewable and Nuclear Energy

If CO\textsubscript{2} was converted into barrel of oil equivalents, and so used to replace the barrels of oil consumed in the US in Y2015,

- **Primary Energy Consumption**: 97.4 Q
- **Minimum Energy Required**: 41.1 Q
- **Carbon-Free Generation, net** (nuclear, wind, solar, hydro): 4.58 Q

U.S. renewable and nuclear generation would need expand by a minimum of 897% in order to displace crude oil consumption.

Comparison attributed to Final report of the Secretary of Energy Advisory Board (SEAB) Task Force on CO2 Utilization

17 large scale projects in “Operate” stage
  - 14 EOR + 3 geological storage
  - 2 power generation (EOR)

+ 5 currently active in “Execute” stage
  (i.e. beyond the final investment decision)

Can non-EOR CO₂ utilization drive a project into the “Operate” stage?
Making CCS look cheaper: high-purity CO$_2$ sources

**High-purity gas streams are easier to separate - makes CCS appear cheaper**

<table>
<thead>
<tr>
<th>Source</th>
<th>Cost Estimate [USD/tCO$_2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG plant</td>
<td>9</td>
</tr>
<tr>
<td>Offshore NGP (deep water)</td>
<td>31</td>
</tr>
<tr>
<td>Offshore NGP (shallow water)</td>
<td>18-21</td>
</tr>
<tr>
<td>Onshore NGP</td>
<td>16-19</td>
</tr>
<tr>
<td>Ammonia</td>
<td>4-47</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>15</td>
</tr>
<tr>
<td>Coal-to-Liquids</td>
<td>&lt;25</td>
</tr>
</tbody>
</table>

More than half of the 17 large-scale projects in “Operate” stage use high purity sources:

- 8 Natural Gas Processing (NGP)
- 2 Ammonia production (fertilizer)
- 2 Hydrogen production

**EOR & geological storage only**

~31.2 Mtpa CO$_2$ capacity globally

~21.9 Mtpa CO$_2$ capacity in the US

Yet >10 Mtpa merchant CO$_2$ market (non-EOR) in U.S.

**Crude CO$_2$ sources for the U.S.**
*Merchant Market 2015.* Nameplate capacity ~12.9 Mtpa; capacity factor 86%.

**Merchant demand by End-Use,**
US: 10 Mtpa (2016). Food industry drives ~70% of market.

There is plenty of carbon capture from high-purity CO$_2$ sources; very little storage.

The majority of CO$_2$ remains unreacted after being used in the merchant markets.

*These commercial approaches rely on carbon capture and are sufficiently addressed by the private sector. Most emit CO$_2$ and operate on a small scale.*
Case Study: exporting excess electricity from Iceland

CRI first of its kind Emissions-to-Liquids facility - Iceland

Electricity is used to convert CO₂ from a natural source (at $7/tonne) to a transportation fuel for a Swedish ferry operator, Stena.
Review and potential whitespace

- Typically lowest cost
- Typically highest cost
- [*=net emitter of CO₂]
- [Σ=small scale]

**Purity of Starting CO₂**
- **High**
  - Ammonia Plant (SMR) → Merchants
  - H₂ plant (SMR) → Merchants
  - Natural Gas Processing → Merchants
- **Low**
  - Power/CCS → EOR

**State of CO₂ at Sale**
- Converted
  - [ Urea plant → End-Users ]*
  - [CRI Methanol plant → End-Users]Σ
  - [Polyol plant → Polymer industry]Σ

**Potential Whitespace**
- E.g., opportunities for reactive capture
- Typically highest cost
Infrastructure – concepts that may improve resilience

U.S. farmers expect volatile weather to be the norm. *WSJ, May 15, 2017.*


Potentially suitable lands for algae facilities. *EERE, 2016 Billion Ton Report*

Saline formations and CO₂ point sources. *NETL, NatCarb 2015.*

**CO₂-enhanced water recovery & CO₂-enhanced food production (e.g. algae for animal feed) may supplement current sources in times of need.**
Aggregates and their qualities are essential to well functioning and durable concrete structures. They can be made by mineralizing CO₂.

Key Challenges*. Forming stable mineral carbonates is

- highly process-dependent and thus has the potential to emit more CO₂ than is sequestered
- may be constrained to a limited scale due to the supply of make up materials

Key trend: Urbanization

By 2030, 60% of the population will live in an urban world. Less developed regions will add more than 1 billion people to urban centers.

DATA: UN DESA
IMAGE: Erla Zwingle (National Geographic)

UN Department of Economic and Social Affairs, Urban and Rural Areas wallchart 2014.
Energy storage

Energy Density. Products from CO$_2$ conversion have more energy density than other storage solutions. Source: DNV 2011.

Power to Gas. Excess energy can be stored as CH$_4$ in natural gas pipelines, at least in theory. Source: M Gotz et al.

The value of deferred investment in transmission and distribution (T&D) is the likely driver for deployment of such technologies instead of arbitrage revenues (at least in current U.S. power markets). Urbanization will continue to be a key trend placing stress on T&D.

Carbon - the backbone of advanced economies

**Advanced Polymers**
- Polyurethane Insulation

**Advanced Materials**
- Carbon Fiber I-75 Repair

**Chemicals and Fuels**

CREDITS: DOE Big Ideas Carbon Team comprising national lab colleagues
Sample of Marketable Products and Services derived from CO₂ Use

- **Energy Services**
  - Compressed Gas Energy Storage
  - Chemical Energy Storage
  - Heat Transfer Working Fluid

- **Biological Conversion**
  - Algae
  - Biogases
  - Glasshouse gas

- **Extraction**
  - Flames/Fragrances
  - Decaffeination

- **Mineralization**
  - Carbonates
  - Methanol
  - Urea
  - CO
  - Methane

- **Chemicals**
  - Liquid Fuels
  - Fertilizer
  - Secondary Chemicals

- **Food Products**
  - Food
  - Pharmaceutical Additives
  - Flavored/Fragrances Decaffeination

- **Working Fluid**
  - Compressed Gas Energy Storage
  - Chemical Energy Storage
  - Heat Transfer Working Fluid

- **Plastics**
  - Polycarbonate

- **Fire Suppression**
  - Fire Extinguishers

- **Inerting Agent**
  - Blanket Products
  - Protect Reactive Powders
  - Shield Gas in Welding

- **Miscellaneous**
  - Refrigeration Dry Ice
  - Injected into metal castings
  - Added to medical O₂ as respiratory stimulant
  - Aerosol-can propellant
  - Dry ice pellets for sand blasting
  - Red mud carbonation

**FE/NETL supported area**
$5.9 million to advance novel CO$_2$ utilization strategies

OBJECTIVE: to support efforts to develop technologies that utilize CO$_2$ from coal-fired power plants as a reactant to produce useful products without generating additional CO$_2$ or greenhouse gas emissions validated via a product Life Cycle Analysis.

- Biological based concepts
- Mineralization based concepts
- Novel physical and chemical processes
$5.9 million to advance novel CO₂ utilization strategies

CO₂ to light olefins via a low temperature process using nano-engineered catalysts. [Southern Research Institute]

CO₂ to Bioplastics, beneficial re-use of carbon emissions using microalgae. Image: pilot-scale cyclic flow photobioreactor at Duke’s East Bend Station [U. Kentucky]

Dry reforming by nano-engineered hollow-fiber supported catalysts in a modular reactor for syngas production. [Gas Technology Institute]

Direct Electron Beam Synthesis for highly selective conversion of CO₂ [Gas Technology Institute]
$5.9 million to advance novel CO$_2$ utilization strategies

**CO$_2$ to Alcohols**, electrochemical conversion to liquid C2/C3 alcohols using nanostructured catalysts [U. Delaware]

**CO$_2$ to Fuel**, mixed-oxide sorbent-based, thermo-catalytic process to convert CO$_2$ to syngas [TDA Research]

“CO$_2$-negative” construction materials via industrial waste re-processing and power plant heat integration. [UCLA]
Novomer received $20.4 million in ARRA funding from DOE/FE + had lower TRL support from DOE/AMO and NSF.

Ford tests foams based on CO\textsubscript{2}. Materials partially consist of CO\textsubscript{2}-based polyols; considered for use as insulation.

Covestro inaugurates production facility for foams with 20wt\% CO\textsubscript{2}. Plant capacity of 5,000 tons/year.
Thank You

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