CO$_2$ Utilization Roadmap

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ICEF Innovation Roadmap Project

GOALS

• To use the ICEF platform to help promote the development and deployment of clean energy technologies

• To promote global awareness of the ICEF conference
ICEF Innovation Roadmap Project
2016 Activities

New York Roadmapping Workshop (April)
Carbon Dioxide Utilization Roadmap
Zero Energy Buildings Roadmap
CO2 Utilization Roadmap
-- Timeline

- May: Launch project, consultations
- June: Engage CO2 Sciences
- July: Columbia University workshop
- August and September: Research and drafting
- October: Draft released at ICEF conference
- November: Final released
The Challenge

Rapidly increasing global CO₂ emissions

Annual CO₂ emissions: 35.9 gigatons
Annual Increase: 1.9%

Source: Global Carbon Project, 2015 Carbon Budget
Addressing the challenge creates an opportunity

CO₂-based products are one part of the climate solution

**Adaptation**
Managing impacts of climate change

**Decarbonization**
Energy efficiency
Clean renewable energy

**Capture and Storage**
Long-term sequestration

**Capture and Use**
Creating valuable CO₂-based products

Increasingly necessary
Progress, but not fast enough
Necessary but costly
Market-driven solution
The importance of carbon negative technology

IPCC envisages the need for large-scale deployment of net-negative CO\textsubscript{2} emissions technologies by mid-century to meet stringent climate mitigation goals...These CO\textsubscript{2} removal technologies complement low or zero-carbon energy technologies.

To prevent global temperature increase above 2 degrees Celsius, we must deploy technologies that remove carbon dioxide. Scenarios that exclude CO\textsubscript{2}-based products can’t deliver this targeted amount.

Global energy-related CO\textsubscript{2} emissions in IEA climate scenarios

1 Historical (1990-2013); Future scenarios (2013-2050) except for the INDC scenario which is up to 2030
2 Intended Nationally-Determined Contributions to CO\textsubscript{2} emission reductions for C3P21

Methodology for the Developing of the Roadmap

Part 1: Technology Landscaping
- CO₂U technologies pathways
- CO₂U technologies database
- Six major market sectors
- Sub-sector Technology Assessment

Part 2: Preliminary Market Assessment
- Prioritization: Top four market sectors
- Market assessment assumptions & methodology
- Timelines for Market Penetration
- Sub-sector Market Assessment

Part 3: Accelerating Deployment
- Integrating parts 1 & 2
- Barriers, risks and risk mitigation
- The roadmap: Accelerating Deployment: technology, policy and market levers
- The roadmap: 'Interventions' financial and environmental impacts
Technology pathways

- **Mineralization** of \( \text{CO}_2 \) is the only \( \text{CO}_2 \text{U} \) technology used for the building market.

- **Catalytic conversion** of \( \text{CO}_2 \) is widely used for production of chemical intermediates, biofuels, and polymers.

- **Fermentation** for \( \text{CO}_2 \) conversion is less well established. Two companies that are at scale, Lanzatech and NewLight Technologies, use CO and methane as the main carbon sources for their processes, respectively.

- **Photocatalytic and electrochemical** conversion technologies require more development and evidence of scalability.

- **Catalytic conversion technology** and **mineralization** are the most well developed technologies.
Technology readiness of different pathways

Mineralization

Fermentation

Photosynthetic

Thermo-catalytic

Electrochemical

Photocatalytic

Stage of Development (TRL)
6 major market sectors for CO$_2$U

Categorized the different markets for CO$_2$U technology:

1. **Chemical Intermediates**, examples are (a) methanol, (b) syngas and (c) formic acid

2. **Fuels**: (a) methane and (b) Liquid fuels.

3. **Building materials**, conversion to carbonates or infusion of CO$_2$ into building materials. Examples are (a) Aggregates and (b) concrete

4. **Algae**, processed separately to biofuels or food additives

5. **Polymers**, examples include polycarbonates, polyurethane and PHA

6. **Novel materials**, production of novel materials using CO$_2$U technology
## Market Assessment: Prioritization

### Top 4 markets in terms of environmental impact and commercial opportunity

<table>
<thead>
<tr>
<th>#</th>
<th>Stage of development</th>
<th>Addressable market size</th>
<th>Number of developers</th>
<th>Potential for CO₂ mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Building materials</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>Chemical intermediates</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>Fuels</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>Polymers</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

- **High** (>25% of developers is near commercialization, the addressable market is a mature market, number of developers >50, prolonged abatement of CO₂)
- **Medium** (<25% of developers is near commercialization, the addressable market is a developing market, number of developers between 10 and 50, mitigation of CO₂ by replacing conventional feedstock)
- **Low** (no developers are near commercialization, the addressable market is unclear, number of developers below 10, CO₂ mitigation is minimal)
**Methodology for assessing addressable market size for CO₂U**

- **Estimation market size in 2015**
  - Analysis of in-house knowledge and secondary information from annual reports, market reports, and publications.
  - Triangulation and vetting of numbers from different sources

- **CAGR of total market to 2030**
  - Analysis of in-house knowledge and secondary information from annual reports, market reports, and publications.
  - Analysis of drivers and constraints

- **Market penetration rate of CO₂U products**
  - Estimation of market penetration based on 3 scenarios. Every scenario has different timelines for mitigating barriers and driving market penetration.

- **Captured market size**
  - Estimation of the captured market size based on the overall market size in 2015, CAGR of the total incumbent market and market penetration for the three scenarios.
Curing of concrete by CO$_2$ will pick up without additional incentives, but can be accelerated by 5 years

- The total concrete market is expected to grow to approximately 40 G metric tons by 2030 with a CAGR between 3 and 4%

Concrete curing by using CO$_2$ offers immediate investment opportunities with a potential for high ROI, while also delivering on CO$_2$ abatement.
Accelerating Deployment

- The technology landscaping and market assessment sections have presented a detailed picture of the potential and challenges of a number of CO₂ based products.
- Some market sub-sectors are ready for commercialization today; most require ‘intervention’ to accelerate deployment of CO₂U technologies. Examples include
  - Cement, polymers and aggregates that can be commercially viable in the near term
  - Fuels and Chemicals that require significant support before getting to commercial viability
- Overall, there remain challenges (risks and barriers to commercialization) that need to be addressed.
- Depending on the effort put forth to address specific challenges be it on the technology, market or policy fronts, the implementation (commercial introduction) of such products can be significantly impacted.
Accelerating Deployment

Overview of barriers to be mitigated and their relevance to the four markets

**Technology**
- A lack of coherent funding strategies exists from governments on CO$_2$U technology.
- High cost: need to improve technology of CO$_2$ reduction and electrolysis to form H$_2$.

**Market**
- A barrier is the lack of access to facilities to scale up CO$_2$U technologies.
- CO$_2$U has to compete with conventional feedstock and bio-based feedstocks. These options are often lower in cost.
- Another barrier is the lack of access to feedstocks. This is the case for hydrogen, CO$_2$, and renewable energy.
- Process integration of renewable energy, feedstock and conversion process is not cost-competitive

**Policy**
- There is a lack of long-term policy framework. Need to explore both incentives and credits as well as a carbon price.
- Governments need to fund R&D research
Conclusions

The ‘Intervention’ translates to a significant business opportunity

Potential Annual Revenue (dollars)
- Strategic actions implemented
- Without strategic actions

THE GLOBAL CO2 INITIATIVE
Conclusions

And the intervention will create a significant environmental impact

Potential Reduction in CO₂ Emissions (tons)
- Strategic actions implemented
- Without strategic actions

The Global CO₂ Initiative
Conclusions

- Global warming due to carbon dioxide emissions is one of the grand challenges of our time. Carbon Dioxide Utilization (CO₂U) technologies have the potential to significantly lower CO₂ emissions.

- This study analyzed the current state of CO₂U technology:
  - Almost 180 technology developers were analyzed to assess technology feasibility and readiness.
  - Four major market opportunities in fuel, building materials, chemical intermediates and polymers were selected.

- The study also presented a market assessment detailing potential for creating 8 different products over different time periods.

- The study estimated the market size for selected CO₂-based products for two scenarios
  - Without strategic actions
  - With strategic actions implemented

- The conclusions are
  - CO₂U must be considered a critical component of the solution set addressing the climate change issue.
  - There are products that are competitive todays; others can benefit from market, technology and policy levers.
  - CO₂U can reduce CO₂ emissions by 15%
  - CO₂U can create a market opportunity greater than $800 billion per year.
Conclusions

- Based on the cumulative analysis, a roadmap that depicts specific strategic actions that can be taken and their expected impact on accelerating implementation of CO₂U technologies was created.

- We conclude that the following strategic actions will help grow the CO₂U market size (for a handful of CO₂ based products) over $800B by 2030

  - **Technology:**
    - Fund research to improve catalysis for CO₂ reduction
    - Fund research to improve electrolysis to produce H₂
  
  - **Market:**
    - Ensure supply of CO₂ through creating significant CO₂ pipeline network.
    - Funding for collaborations between research institutes, start-ups, governments and corporations for process integration of CO₂ conversion, H₂ generation, and carbon capture

  - **Policy:**
    - Fund basic R &D
    - Individual countries and sub-national jurisdictions increasingly implement carbon price.
    - Increase mandates for renewable products and fuels.
    - Incentivize reduction of CO₂ emissions by fuel, chemical and building materials producers
Recommendations

To accelerate implementation of CO$_2$U technologies: **5 key strategic actions**

- **Increase cost of polluting competition:** Individual countries and sub-national jurisdictions increasingly implement carbon price and increase mandates for renewable products and fuels and/or incentivize reduction of CO$_2$ emissions by fuel, chemical, materials and building materials producers
- **Decrease cost of utilization of CO$_2$:** Fund research to improve catalysis for CO$_2$ reduction and to improve electrolysis to produce H$_2$
- **Scaling up production:** Funding made available to set up collaborations between research institutes, start-ups, governments and corporations for process integration of CO$_2$ conversion, H$_2$ generation, and carbon capture
- **Steady supply of CO$_2$:** Governments should incentivize development of a CO$_2$ infrastructure to anticipate growth in CO$_2$ demand
- **Maximize high potential of long shots:** Fund applied research on long-shot technologies and applications that have high CO$_2$ abatement potential
LIFE CYCLE ANALYSIS – CO$_2$U

CO$_2$ emissions

- CO$_2$ capture process (e.g. at power plant)
- Energy input
- Other feedstocks (e.g. H$_2$)
- Feedstock CO$_2$
- CO$_2$ utilization process
- End-of-life treatment of CO$_2$-based product
POLICY OPTIONS – CO$_2$U

• GOVERNMENT FUNDING OF R&D

• CARBON PRICING

• TAX AND OTHER INCENTIVES

• MANDATE

• GOVERNMENT PROCUREMENT

• GOVERNMENT SUPPORT FOR TESTING, CERTIFICATION AND LCA