

MISSION INNOVATION

Accelerating the Clean Energy Revolution

Carbon Capture Innovation Challenge

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Saudi Aramco



Mission Innovation

- A Ministerial level initiative launched on November 30th 2015
- **Mission Innovation's goal is to accelerate the pace of clean energy innovation to achieve performance breakthroughs and cost reductions to provide widely affordable and reliable clean energy solutions that will revolutionize energy systems throughout the world over the next two decades and beyond.**



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- MI seek to:
 - Double Governmental Investment in Clean Energy Innovation over 5 years (2016-2021), from \$15B to \$30B
 - Increase Private Sector Engagement in Clean Energy Innovation
 - Improve Information Sharing among MI countries

Innovation Challenges

- Global Calls for Actions in High Priority Areas of Mutual Interest
- Opportunities for Collaboration Between Mission Innovation Members
- Encourage Increased Engagement by Global Research Community, Industry, and Investors
- Support Mission Innovation goals of reducing GHG emissions, increasing energy security and creating new opportunities for clean economic growth
- Outcomes May Inform, Guide and Support MI Country Investments in R&D

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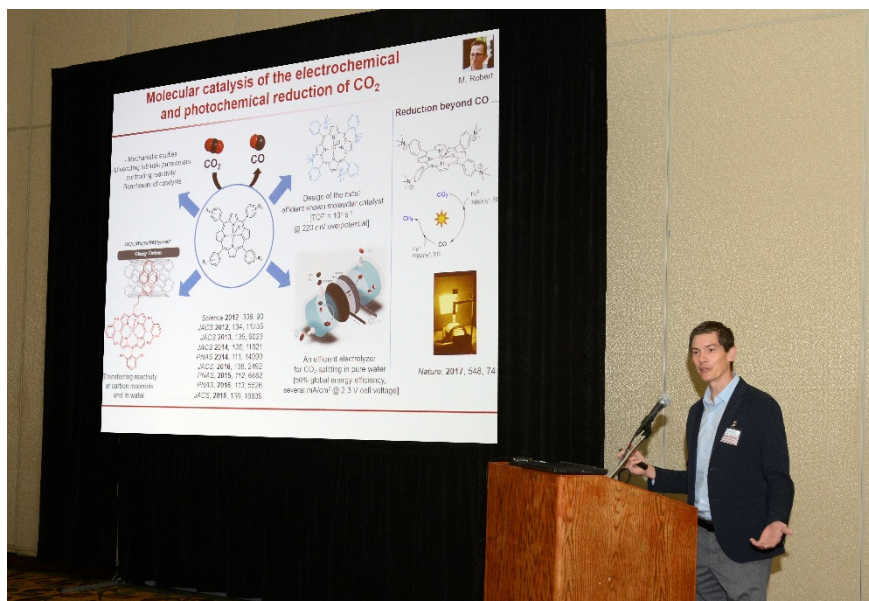
1	Smart Grids Innovation Challenge	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
2	Off Grid Access to Electricity Innovation Challenge	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
3	Carbon Capture Innovation Challenge	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
4	Sustainable Biofuels Innovation Challenge	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
5	Converting Sunlight Innovation Challenge	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
6	Clean Energy Materials Innovation Challenge	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
7	Affordable Heating and Cooling of Buildings Innovation Challenge	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Carbon Capture Innovation Challenge

- Co-Leads: Saudi Arabia, United States
- 20 Mission Innovation participating countries
- Objective
 - Enable near-zero CO₂ emissions from power plants and carbon intensive industries
- Work-Plan
 - Organize a CCUS Experts Workshop
 - Engage Stakeholder (WEF, IEA, Industry, ...)
 - Build Multilateral Collaboration Mechanisms

CCUS Experts' Workshop

- Houston Sept. 25-29
- 257 Participants from Academy and Industry
- 22 Countries participated
- 13 Parallel Panel Discussions



CCUS Experts' Workshop Structure

Focus Areas

CO2 Capture - Panels

Solvents

Sorbents and Looping Systems

Membranes

Combustion and Other Technologies

CO2 Utilization - Panels

Thermochemical Conversion and Hydrogenation of CO2

Electrochemical and Photochemical Conversion of CO2

CO2 Conversion to Solid Carbonates

Biological Conversion of CO2

CO2 Storage - Panels

Injectivity & Capacity

Monitoring, Verification and Performance Metrics

Forecasting and Managing Induced Seismicity

Well Diagnostics

Crosscuttings Topics (TEA, LCA,...)

Panel Outcomes Structure

Scientific challenges

- Brief overview of the underlying science challenge

Summary of priority research direction (PRD)

- What fundamental research is needed to address the challenge?
- Why can this research be done now? (e.g. are there recently developed capabilities?)

Potential scientific impact

- What impact will this research have on the CCUS scientific field?
- What impact will it have on the general scientific community?

Potential impact on CCUS technology

- How will this impact CCUS-relevant technologies?

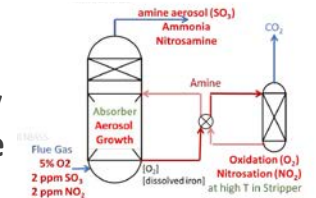
CO2 Capture PRDs

Solvents



Designing high performing solvents for CO2 capture

Creating environmentally friendly solvent processes for CO2 capture

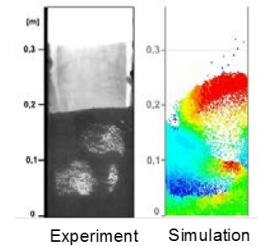


Sorbents

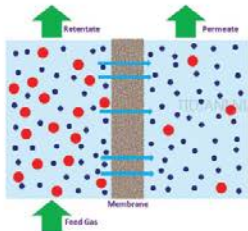


Designing tailor-made sorbent materials

Integrating sorbent materials and processes

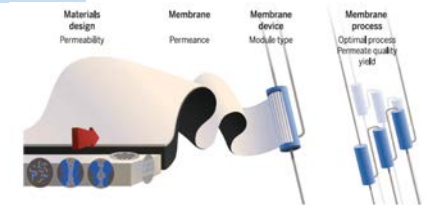


Membranes

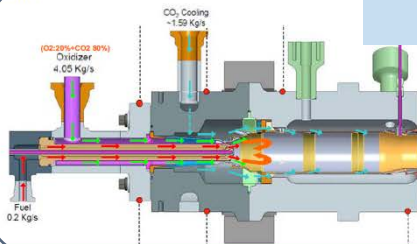


Understanding transport phenomena in membrane material

Designing membrane system architectures

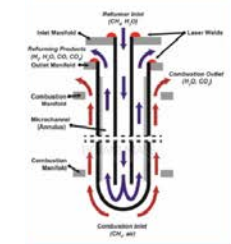


Combustion and Other Technologies

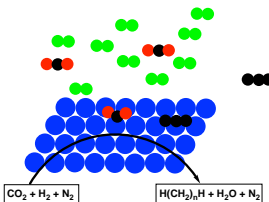


Catapulting combustion into the future

Producing hydrogen from fossil fuels with CO2 capture



CO2 Utilization PRDs

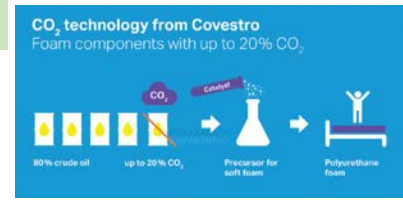


$\text{CO}_2 + \text{H}_2 + \text{N}_2$ $\text{H}(\text{CH}_2)_n\text{H} + \text{H}_2\text{O} + \text{N}_2$


Thermochemical Conversion and Hydrogenation of CO2

Valorizing CO2 by breakthrough catalytic transformations into fuels & chemicals

Creating new routes to carbon-based functional materials from CO2



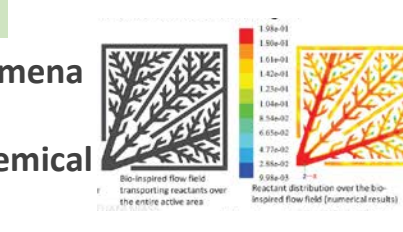
CO₂ technology from Covestro
Foam components with up to 20% CO₂



Electrochemical and Photochemical Conversion of CO2

Designing and controlling molecular-scale interactions for electrochemical and photochemical conversion of CO2

Harnessing multiscale phenomena for high-performance electrochemical and photochemical transformation of CO2



Bio-inspired flow field
transporting reactants over the entire active area

Reactant distribution over the bio-inspired flow field (numerical results)



Solid Carbonate
Brine
Feedstock
Flue Gas
200 μm

CO2 Conversion to Solid Carbonates

Accelerating carbon mineralization by harnessing the complexity of solid-liquid-gas interfaces

Tailoring material properties to enable carbon storage in products

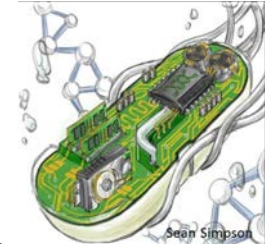


CO₂ diffusion

Unsaturation and most exposed to ambient air: higher CO₂ diffusion and higher carbonation

Near saturation/saturation: lower CO₂ diffusion and lower carbonation

(Kandji et al., 2017)

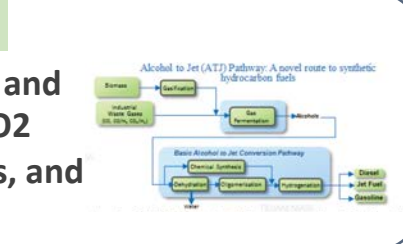


Sean Simpson

Biological Conversion of CO2

Tailoring microbial and bio-inspired approaches to CO2 conversion

Hybridizing electrochemical and biological processes for CO2 conversion to fuels, chemicals, and nutrients



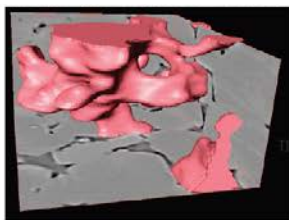
Alcohol to Jet (AT) Pathway: A novel route to synthetic hydrocarbon fuels

Basic Alcohol to Jet Conversion Pathway

Designing complex interfaces for enhancing hydrocarbon recovery with carbon storage

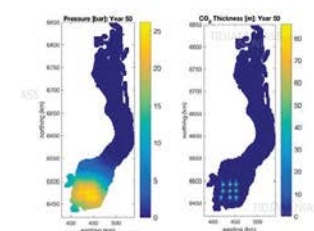
CO2 Storage PRDs

Injectivity & Capacity

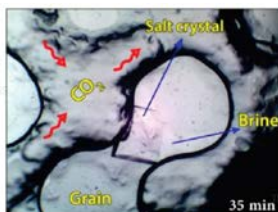


Advancing multi-physics and multi-scale fluid flow to achieve gigatonne/year capacity

Understanding dynamic pressure limits for gigatonne-scale CO2 injection

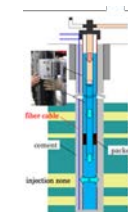


Monitoring, Verification and Performance Metrics

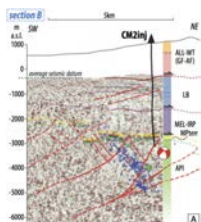


Optimizing injection of CO2 by control of the near-well environment

Developing smart convergence monitoring to demonstrate containment and enable storage site closure

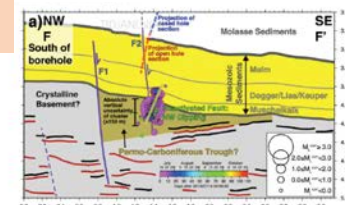


Forecasting and Managing Induced Seismicity



Realizing smart monitoring to assess anomalies and provide assurance

Improving characterization of fault and fracture systems



Well Diagnostics



Achieving next-generation seismic risk forecasting

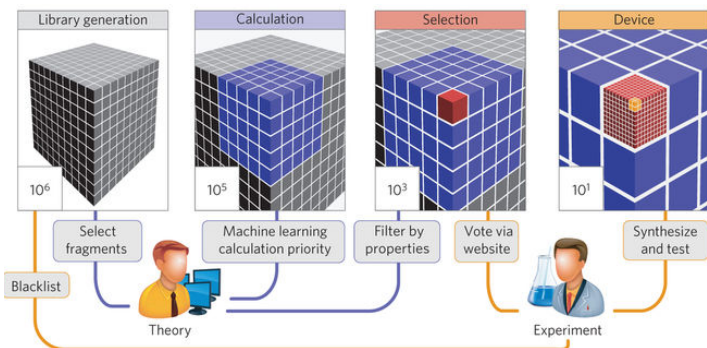
Locating, evaluating, and remediating existing and abandoned wells

Establishing, demonstrating and forecasting well integrity

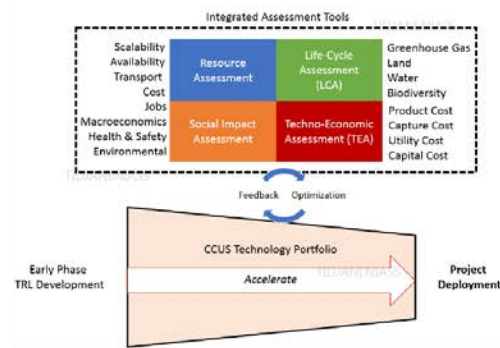


CCUS Crosscutting PRDs

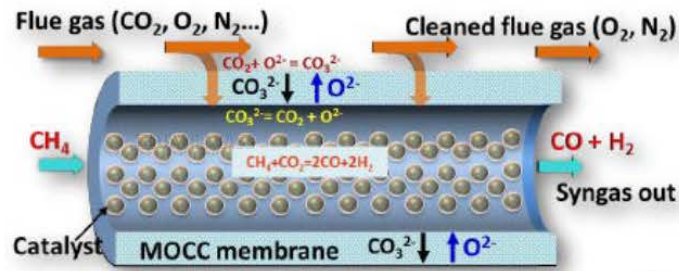
Integrating experiments, simulation, and machine learning across multiple length scales to guide materials discovery and process development in CCUS



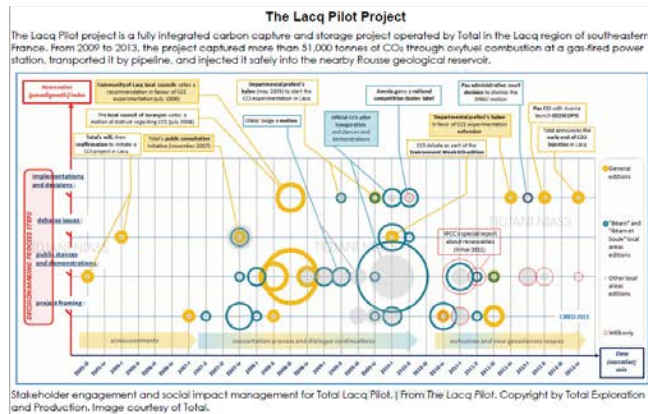
Developing tools to integrate life-cycle techno-economic, environmental and social considerations to guide technology portfolio optimization



Coupling basic science and engineering for intensified carbon capture, purification, transport, utilization and storage processes

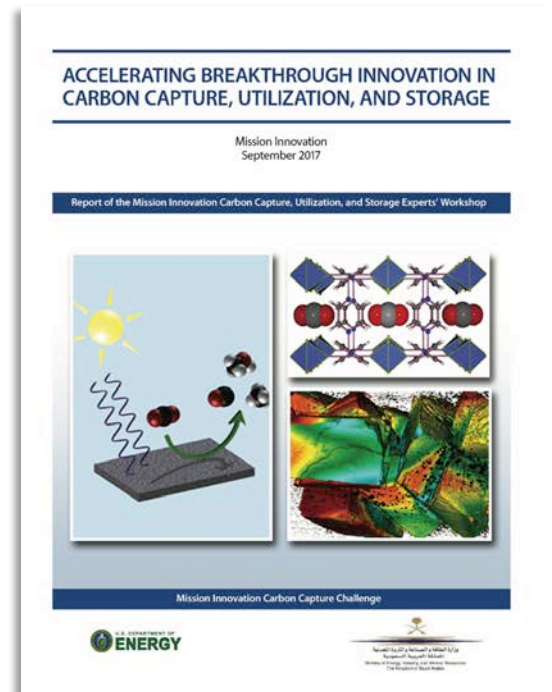


Incorporating social aspects into decision-making



CCUS Experts' Workshop Outcomes

- Established current state of technology in CO2 Capture, CO2 Utilization, and CO2 Storage
- Created an international consensus on the most critical scientific challenges on CO2 Capture, CO2 Utilization, CO2 Storage, and Crosscutting CCUS topics
- Established internationally agreed **Priority Research Directions (PRDs)**
- Completed a report on CCUS Basic Research Needs
 - Intended to serve as a key resource for the international CCUS research community, governments, and the private sector, helping to inform national R&D policies and programs
 - The PRDs are not meant to be prescriptive and all-inclusive. Rather, they are designed to inspire CCUS research community to elucidate the foundational scientific phenomena that underpin CCUS.



Next Steps

- Report progress at the Mission Innovation 3rd Ministerial (MI3)
 - May 2018, Malmo/Copenhagen, in conjunction with the 9th Clean Energy Ministerial
 - Co-hosted by the European Commission, Denmark, Finland, Norway, and Sweden
 - Carbon Capture Challenge is part of a [public-private cooperation on clean energy innovation](#) roundtables
 - Setup include 6 high-level government reps & 6 high-level private-sector actors, investors, international organizations, (BEC, IEA, WEF,)
 - Official launch of the CCUS experts' workshop report
- Develop collaboration mechanisms
- Foster engagement with industry and other multilateral CCUS initiatives
 - CSLF, IEAGHG, GCCSI, OGCI, ...

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Thank You