Direct Air Capture of Carbon Dioxide

ICEF Roadmap 2018

Innovation for Cool Earth Forum

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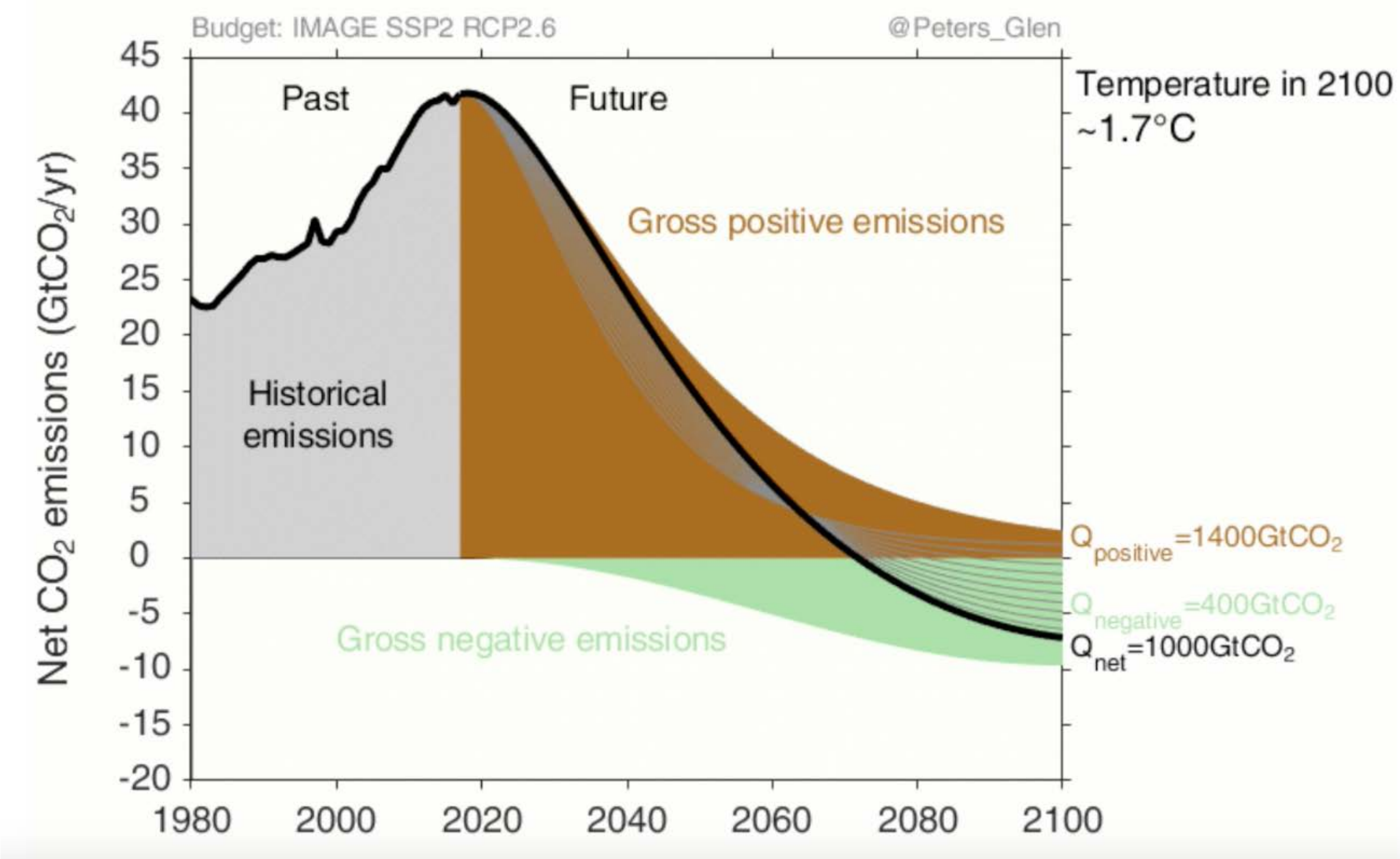
COP24

December 10, 2018 – Katowice, Poland

Carbon dioxide removal (CDR) essential for meeting climate goals



"All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 GtCO2 over the 21st century." – IPCC 1.5°C Report (2018)

- ***CDR is additional and complementary to conventional mitigation***

Many approaches to carbon dioxide removal

Center for Carbon Removal

		Cost	Energy Requirements	Land Use	Water Consumption	Risk of Reversal	Verifiability	Implement Readiness
NATURAL	Reforestation & Enhanced Forest Management	Green	Green	Red	Orange	Orange	Green	Green
NATURAL	Wetland & Coastal Restoration	Green	Green	Green	Green	Orange	Orange	Green
NATURAL	Soil Carbon Restoration	Green	Green	Green	Green	Orange	Red	Orange
TECHNOLOGICAL	DACS	Red	Orange	Green	Green	Green	Green	Orange
TECHNOLOGICAL	Terrestrial Enhanced Weathering	Orange	Orange	Green	Orange	Green	Green	Orange
TECHNOLOGICAL	Ocean Alkalinity Modification	Orange	Orange	Green	Green	Green	Orange	Red
HYBRID	Hybrid Bioenergy with CCS (BECCS)	Orange	Green	Red	Orange	Green	Orange	Green
HYBRID	Bioenergy with Biochar Sequestration (BEBCS)	Orange	Green	Red	Orange	Orange	Red	Green

LEGEND

- Green: Generally Acceptable/ Available
- Orange: Exercise Caution
- Red: Potentially Unacceptable/ Unavailable

Direct Air Capture (DAC)

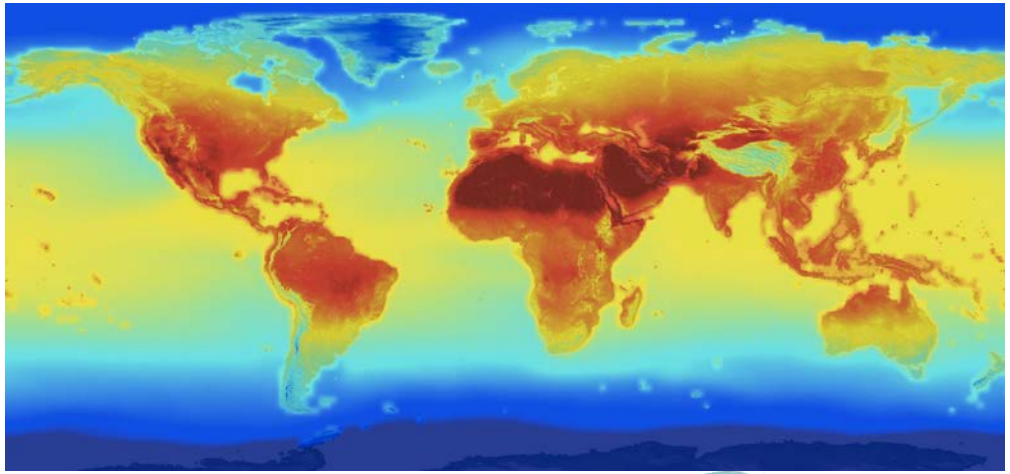
An engineered process to separate CO_2 from ambient air

Original applications:

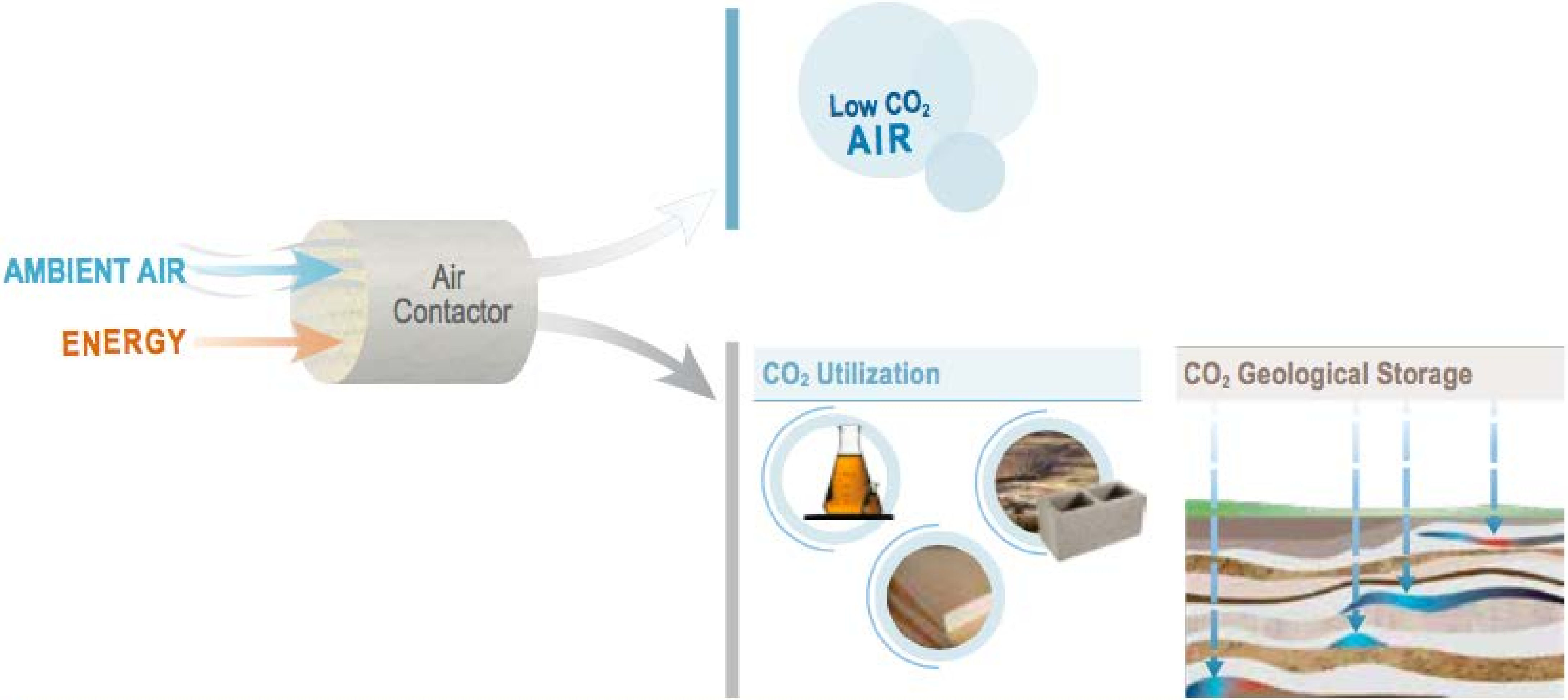
- Defense (aerospace & submarines)

New applications:

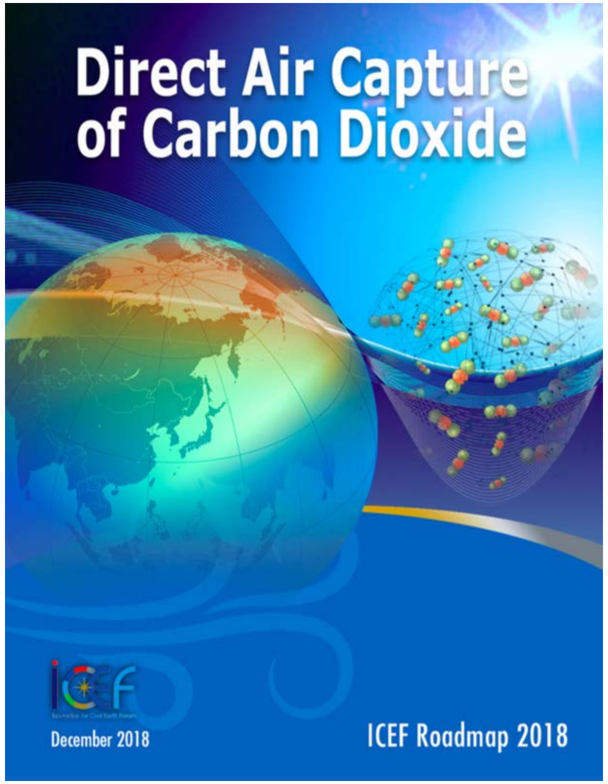
- Climate mitigation
- Distributed CO_2 production for commercial use



DIRECT AIR CAPTURE OF CARBON DIOXIDE



Direct Air Capture of CO_2
ICEF Roadmap *(released today)*



Key Messages

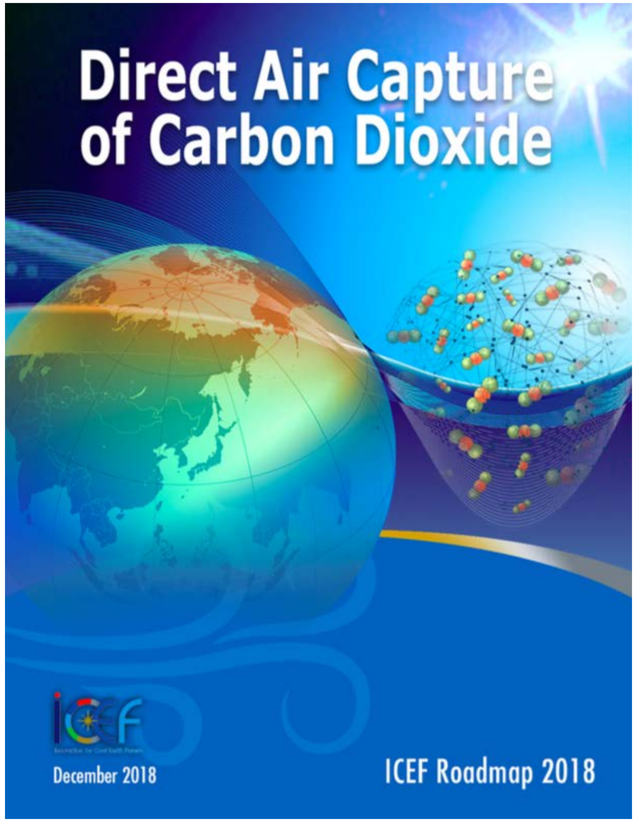
- Direct air capture technologies exist today, but are expensive
- Several important benefits to DAC
- RD&D is essential to making DAC commercial
- Many policy options available

Important attributes of direct air capture

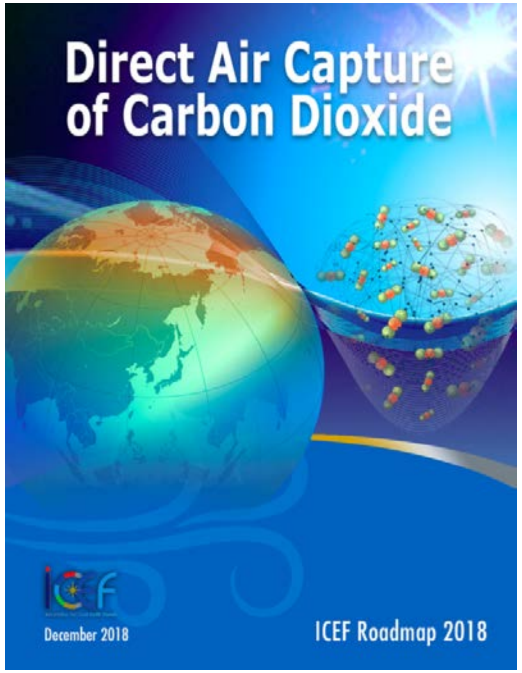
- Can be located anywhere
- Technical capacity: effectively unlimited
- Small footprint and water needs
- Inherent challenge: dilute stream magnifies costs
- Practical limit: low-carbon power and heat

Core technology components – sorbents and solvents

- React with CO_2 in passing air.
- Must be treated (usually with heat) to release CO_2 once saturated.
- R&D needs include new materials with with low regeneration energy requirements, fast kinetics and good longevity.



Core technology components – contactors



- Bring air into contact with the sorbent/solvent to enable CO2 removal.

- R&D needs include designs with enhanced surface area, low pressure drop and reduced capital costs (possibly through minimizing structural steel)

Current systems and companies

Climeworks

- Sorbent-based
- Modular design (50 t/y)
- Three operating commercial projects:
  - Zurich (food)
  - Iceland (CDR)
  - Italy (C2V)

Carbon Engineering

- Solvent-based
- All units have catalog numbers + internal innovation
- Published cost estimates
- Operating CO2-to-fuel project

Global Thermostat

- Sorbent-based tech
- Claim v. low heat of recovery, low opex
- Pilot plant in Palo Alto (SRI)
- Strong partners
- Operating plant: Alabama (food)

Improvement/deployment of DAC involves trade-offs

Trade-offs determine system cost, acceptability

- Source of low-C energy: solar (land use) vs. nuclear
- Technology base: solvents (water & capital) vs. sorbents (loading, batch systems)
- Geography: humidity, temperature vs. low-C energy

Key R&D needs (1)

Improving DAC efficiency, cost, & performance

- Improved contactors
- Better solvents and sorbents
- More efficient designs

Key R&D needs (2)

Ensuring low-C outcomes

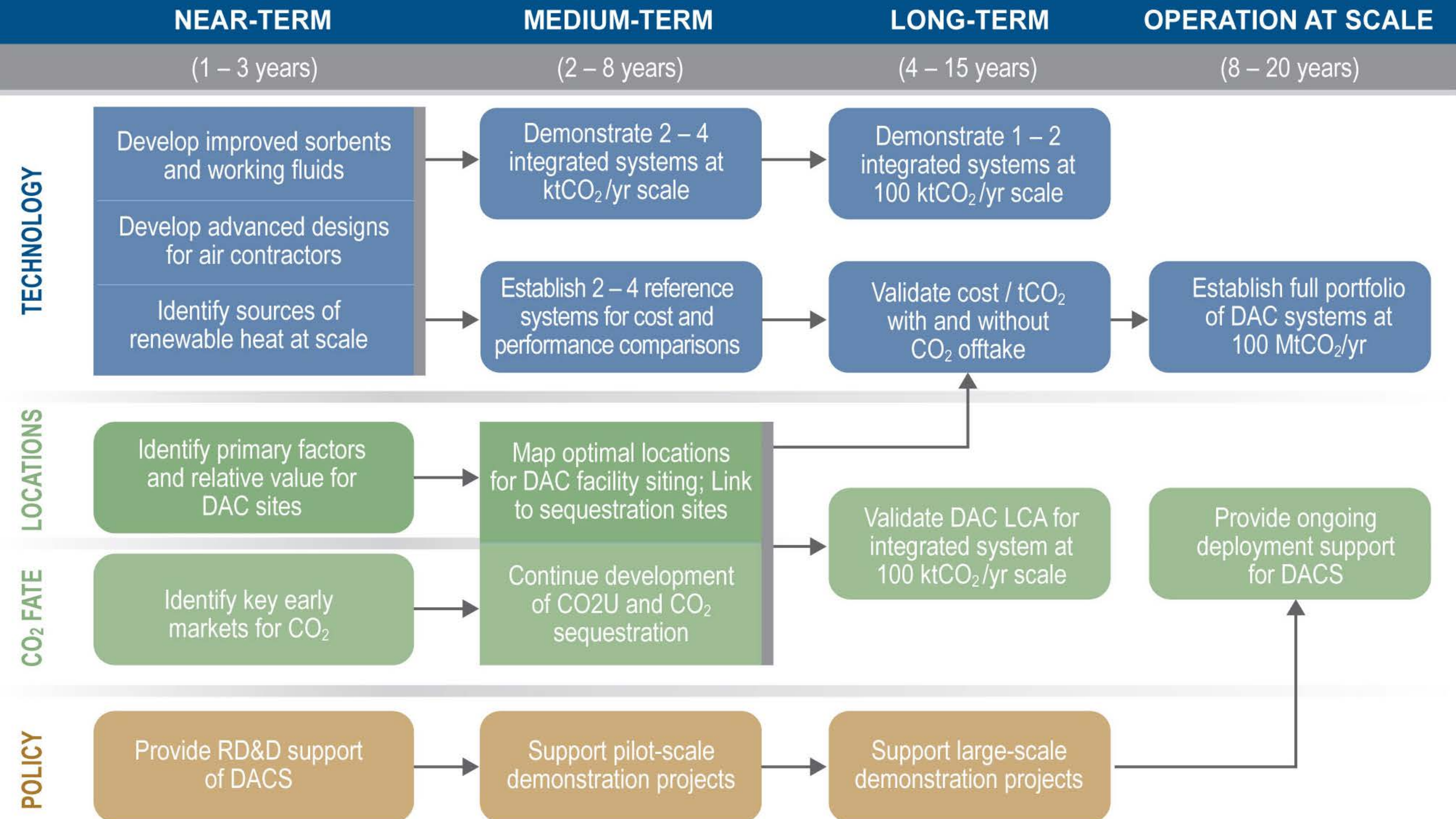
- Low-C heat
- Life-cycle assessments
- Dynamic loading with renewable systems

Policy support is essential

- Significant R&D needs
- Climate mitigation benefits not captured by markets
- Market barriers need identification and work to change
- Will never be lowest-cost source of CO_2 for commercial purposes

Policy tools

1. Government support for R&D
2. Tax Incentives
3. Carbon Price
4. Low Carbon Fuel Standard
5. Mandates
6. Government procurement
7. Life-Cycle Assessments



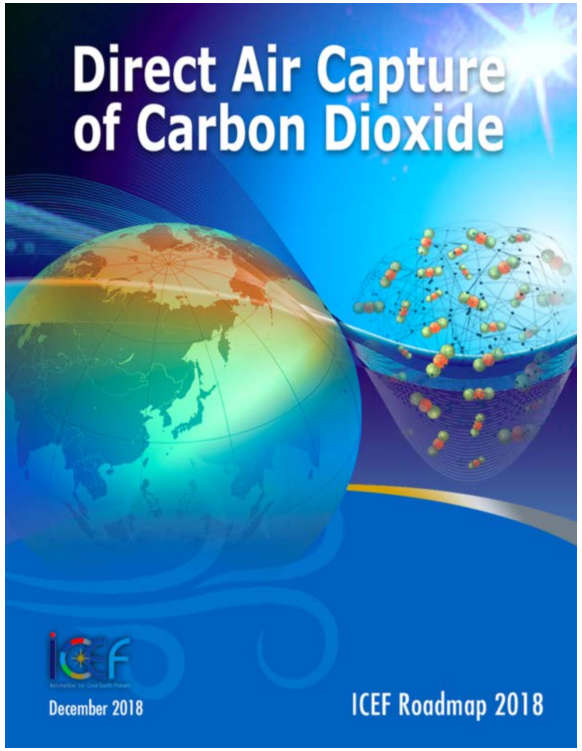
NEAR-TERM
MEDIUM-TERM
LONG-TERM
OPERATION AT SCALE
(1 – 3 years)
(2 – 8 years)
(4 – 15 years)
(8 – 20 years)
TECHNOLOGY
Develop improved sorbents and working fluids
Develop advanced designs for air contractors
Identify sources of renewable heat at scale
Demonstrate 2 – 4 integrated systems at $ktCO_2$/yr scale
Demonstrate 1 – 2 integrated systems at 100 $ktCO_2$/yr scale
Establish 2 – 4 reference systems for cost and performance comparisons
Validate cost / tCO_2 with and without CO_2 offtake
Establish full portfolio of DAC systems at 100 $MtCO_2$/yr
LOCATIONS
Identify primary factors and relative value for DAC sites
Map optimal locations for DAC facility siting; Link to sequestration sites
CO_2 FATE
Identify key early markets for CO_2
Continue development of CO2U and CO_2 sequestration
Validate DAC LCA for integrated system at 100 $ktCO_2$/yr scale
Provide ongoing deployment support for DACS
POLICY
Provide RD&D support of DACS
Support pilot-scale demonstration projects
Support large-scale demonstration projects

Conclusion: DAC could play a role in climate mitigation

Recommendation #1: Governments around the world should begin RD&D on direct air capture today.

Recommendation #2: Direct air capture programs should include fundamental research, applied science and scale-up.

Recommendation #3: Governments, industry and financial institutions should work together to scale up direct air capture.



FAILURE IS NOT AN OPTION