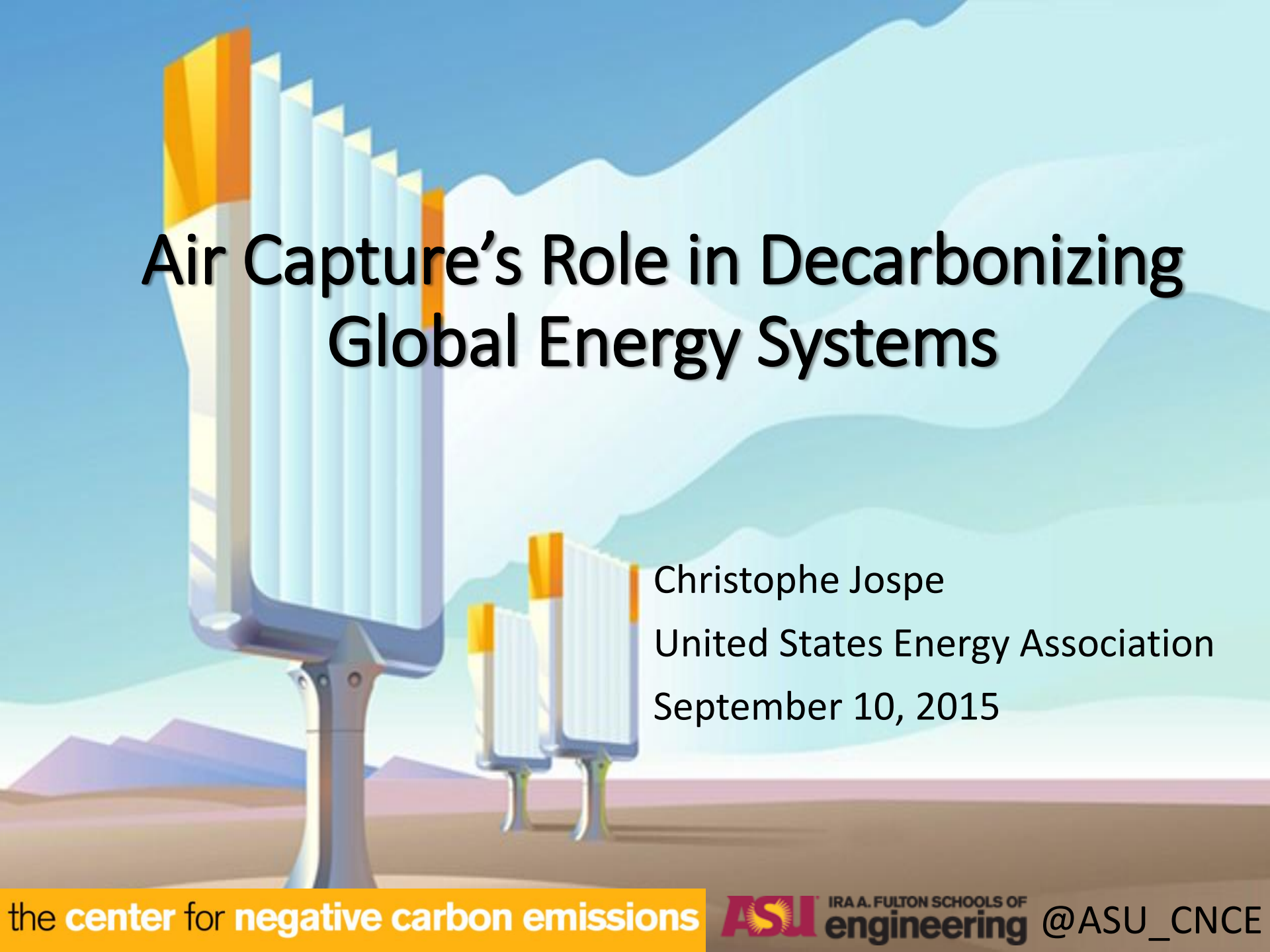
Air Capture's Role in Decarbonizing Global Energy Systems



Christophe Jospe

United States Energy Association

September 10, 2015

Agenda

- How did I get here?
- Why do we need negative carbon emissions?
- What is the relationship between air capture and other carbon management technologies?
- What is the state of air capture technology?
- What are some of the first air capture markets?
- How does the ability to economically remove CO_2 from air change the status quo?
- What will it take to drive this new business ecosystem forward?

A bit of history…

- Claire's science project
- Klaus' "aha" moment
- Self-replicating machines
- The Biosphere
- Global Research Technologies
- Lenfest Center for Sustainable Energy
- Arizona State University

CO_2 accumulates in the atmosphere

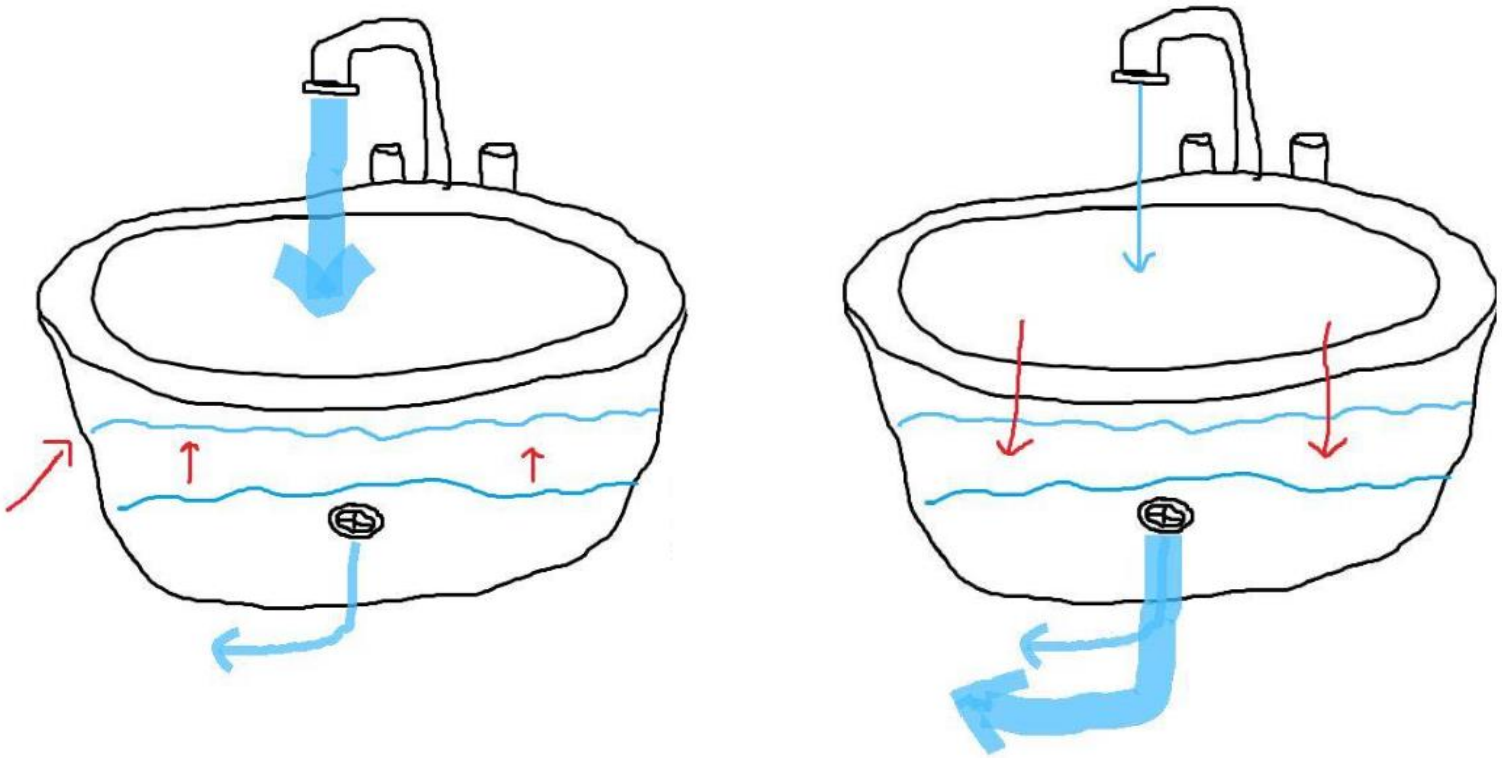
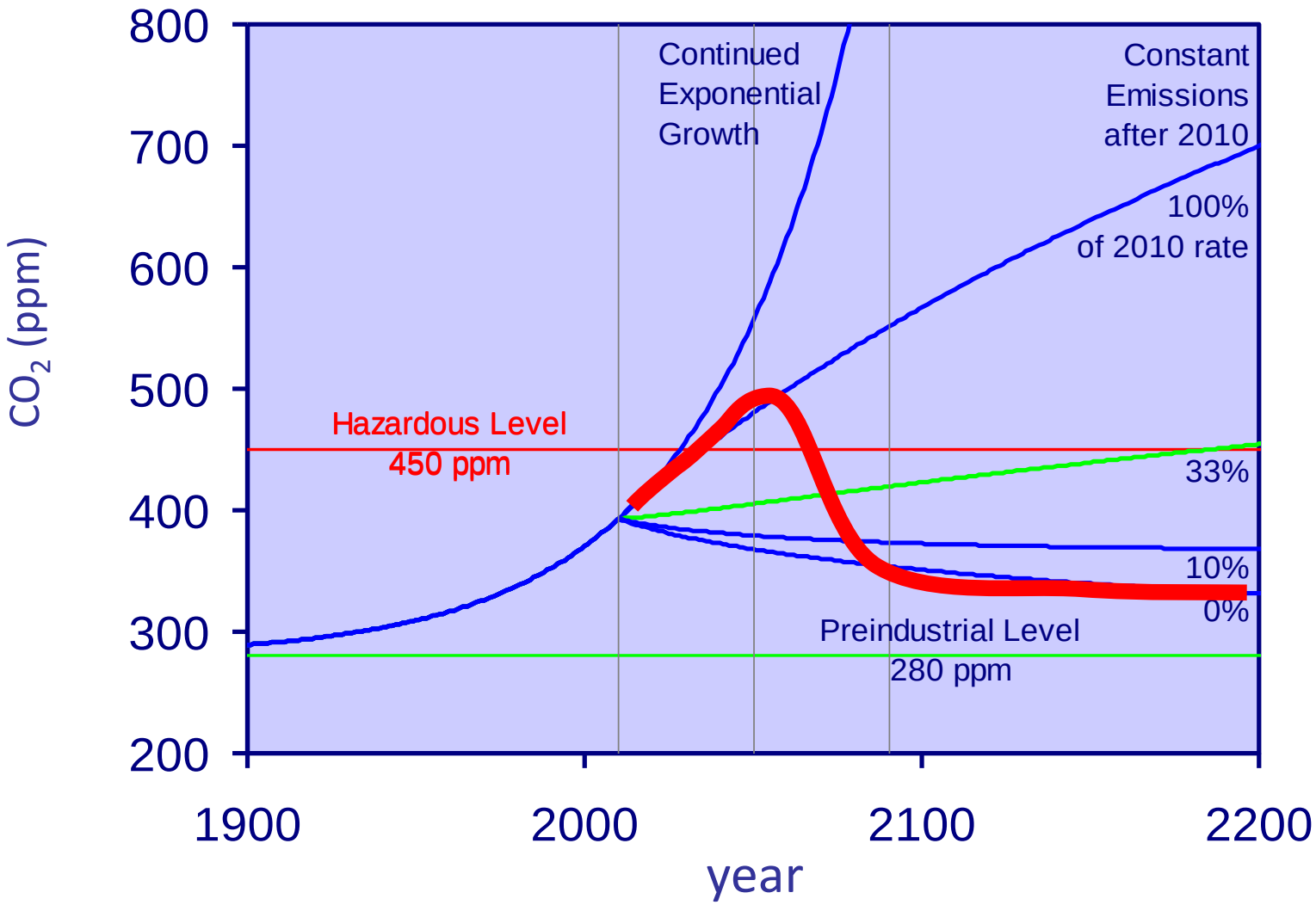


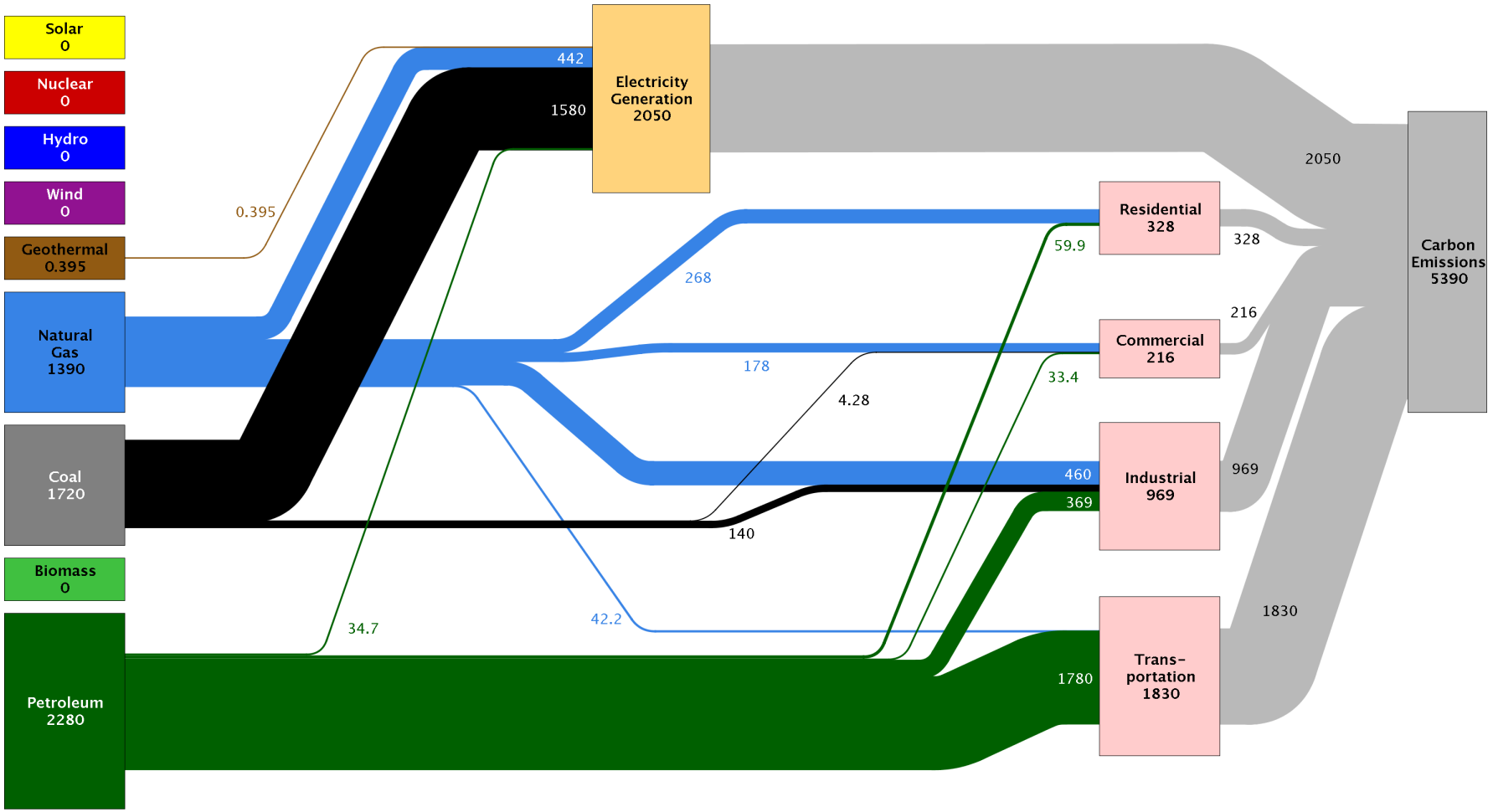
Image credit: Center for Carbon Removal

IPCC calls for negative emissions



Estimated U.S. Carbon Emissions in 2013: ~5,390 Million Metric Tons

Lawrence Livermore National Laboratory



Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Carbon emissions are attributed to their physical source, and are not allocated to end use for electricity consumption in the residential, commercial, industrial and transportation sectors. Petroleum consumption in the electric power sector includes the non-renewable portion of municipal solid waste. Combustion of biologically derived fuels is assumed to have zero net carbon emissions – the lifecycle emissions associated with producing biofuels are included in commercial and industrial emissions. Totals may not equal sum of components due to independent rounding errors. LLNL-MI-410527

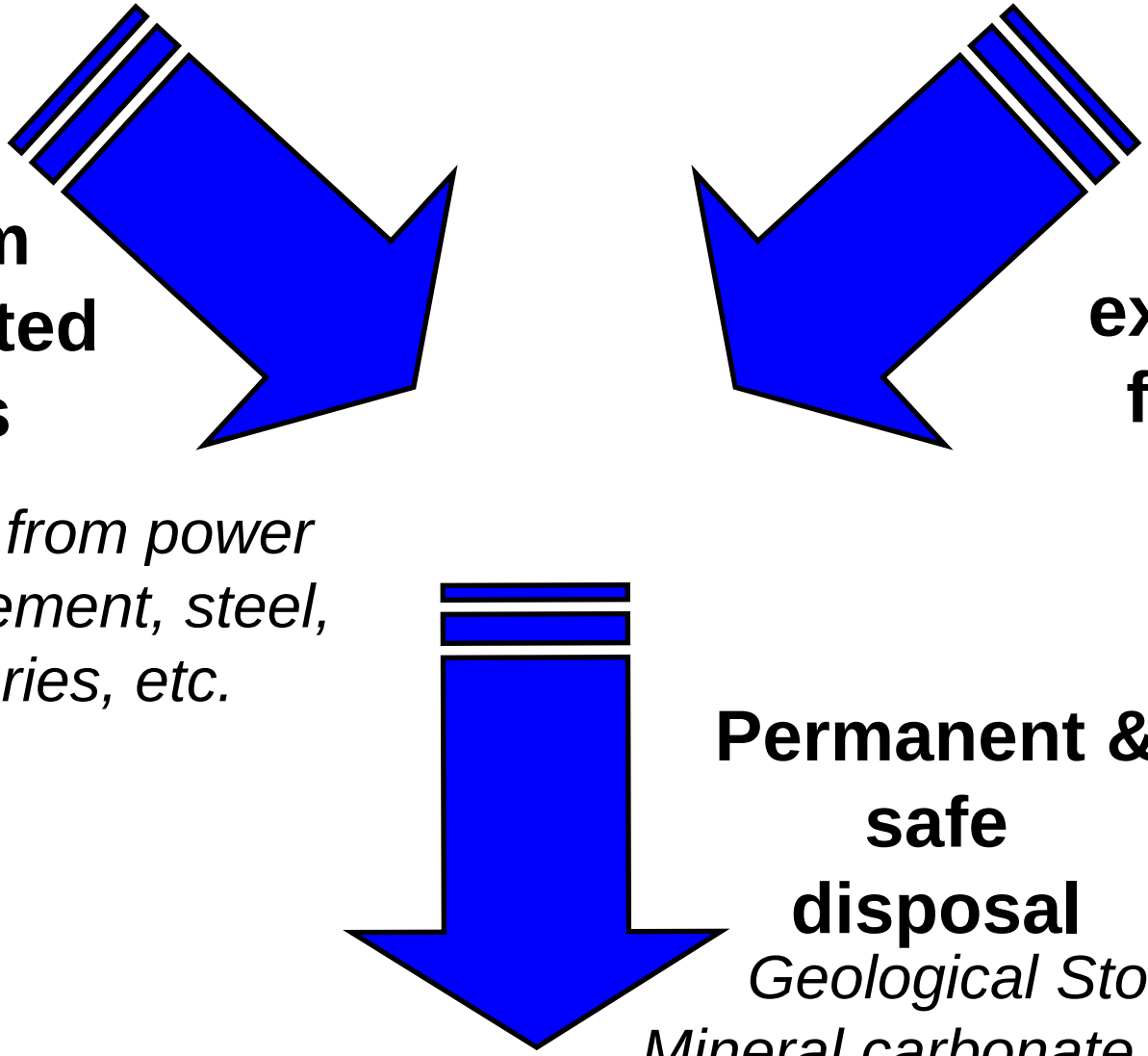
What is air capture?

- Extracts CO_2 from the air for reuse or permanent disposal
- 3 steps: contacting the air; releasing CO_2 from contactor; regenerating contactor
- Has been practiced aboard space craft and submarines for decades

Air capture ≠ Flue Gas Separation

	Air Capture	Flue Gas Separation
CO_2 concentration	0.04%	5-12%
Operating scale	1-120 tons/day	20,000 tons/day
Transport	Drop-in	Needed
Location	Optimal areas	At power-plant
Source	Any emission	Flue gas
Uses of CO_2	Can start niche	Requires large capacity

Net Zero Economy



CO_2 from concentrated sources

Capture from power plants, cement, steel, refineries, etc.

CO_2 extraction from air

Permanent & safe disposal

Geological Storage
Mineral carbonate disposal
Ocean disposal

Air capture complements with flue gas separation

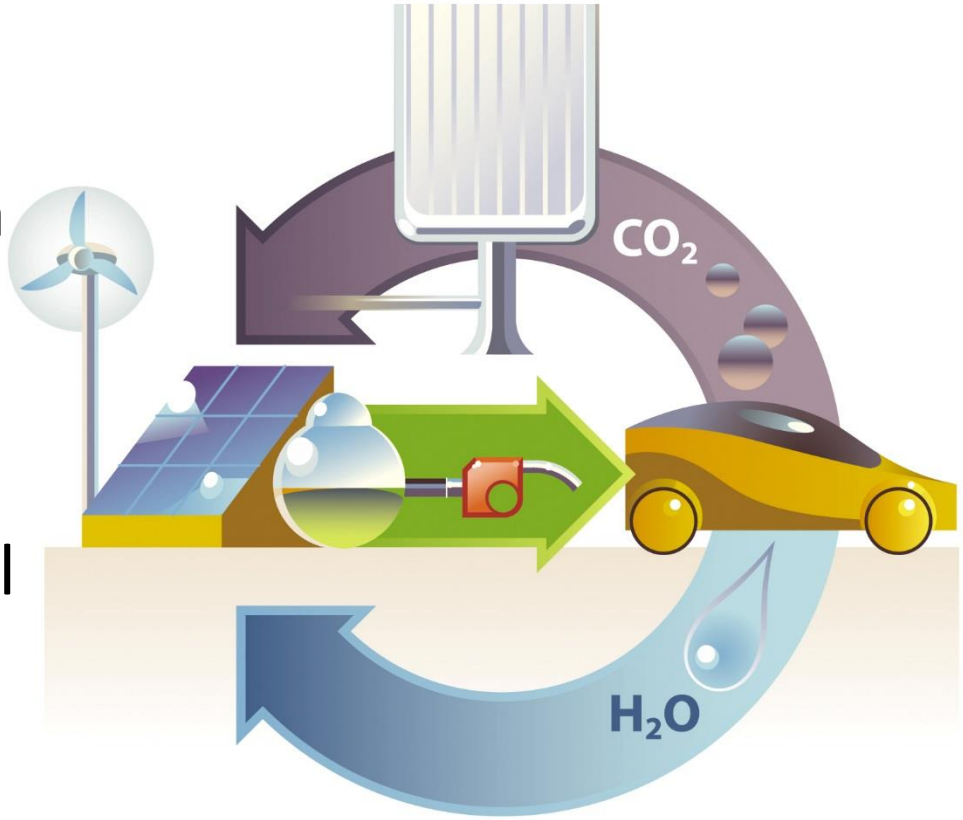
- Conventional flue gas separation is not enough; 90% reduction with a 30% energy penalty = 70% reduction
- Carbon management must deal with all emissions
- Half of current emissions are mobile/dispersed
- Carbon sequestration requires insurance
- Air capture sets the upper limits of carbon management; motivates conventional CCS

Air capture derisks carbon bubble

- First emissions must be stopped
- Air capture + sequestration cancels out any emission
- Separates source from sink
- Can draw down CO_2 levels
- Provides optionality in carbon constrained world

Air capture maintains access to liquid hydrocarbons

- Liquid fuels in the transportation sector
- Synthetic fuel production from CO_2 and H_2O
- Biofuel production with renewable feedstock
- Requires cheap non-fossil energy



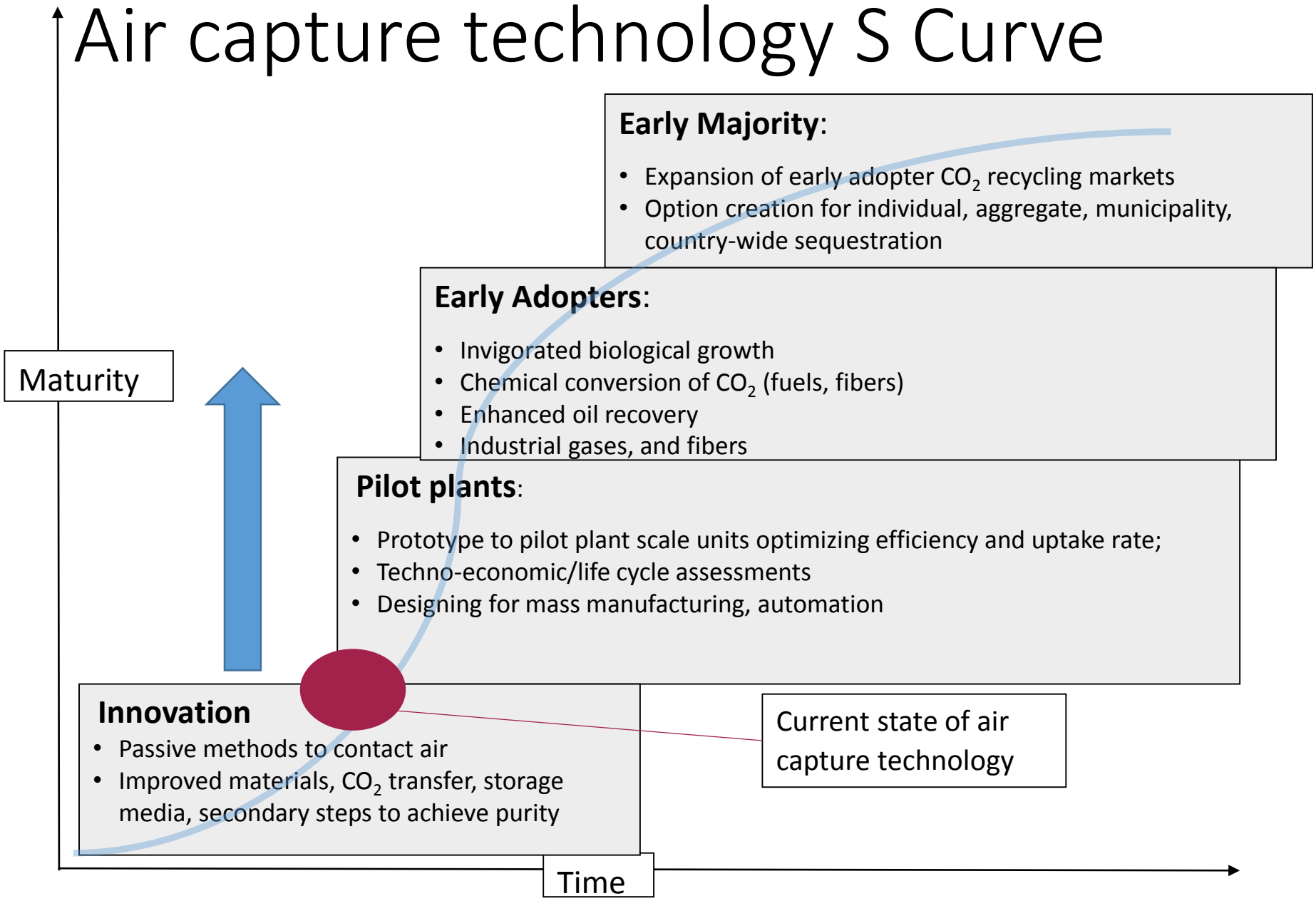
Air capture complements renewable energy

- Seeks carbon neutral sources of energy
- Enables distributed models
- Provides carbon neutral feedstock for liquid fuels energy storage to deal with intermittency

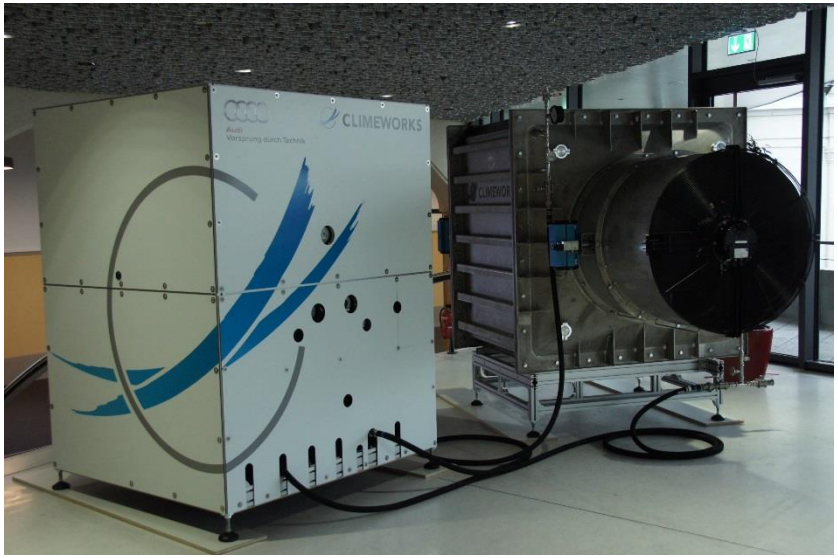
The challenges

- First of a kind will be expensive
- Move huge volumes of air cheaply
- Make good contact at low pressure drops
- Avoid water capture
- Avoid emissions of entrained liquid, vapors etc.
- Avoid expensive energy
- Requires vast production capacity
- Initial markets are small

Air capture technology S Curve



Who is doing this?



Images credit clockwise: Klaus Lackner, virgin earth challenge, Business Insider, Vancouver Sun ,

Air capture markets

Merchant CO_2

- Markets are small and distributed

Chemical commodities

- E.g. urea, often attached to point sources

Biomass production

- Greenhouses, algae reactors

Enhanced oil/gas recovery

- Air capture aims at small fields, exploratory work in the absence of pipelines

Synthetic renewable fuels

- Input is excess, intermittent renewable power, often distributed
- Energy rather than CO_2 drives cost

Sequestration

- Remote locations engender less resistance
- Mineralization can handle small initial quantities

New business ecosystem

Air capture companies	Business Enabled Models	Manufacturers of devices	Carbon Constrained
• CO_2 enriched air • Pure CO_2	• Foods • Fuels • Fibers • Chemical commodities • Sequestration	• Materials • Systems • Automation	• Philanthropists • Aggregate • Governments • Utilities • Oil and Gas • Transport sector

Chicken and the egg

Image credit: Christophe Jospe

What is needed to drive this new industry?

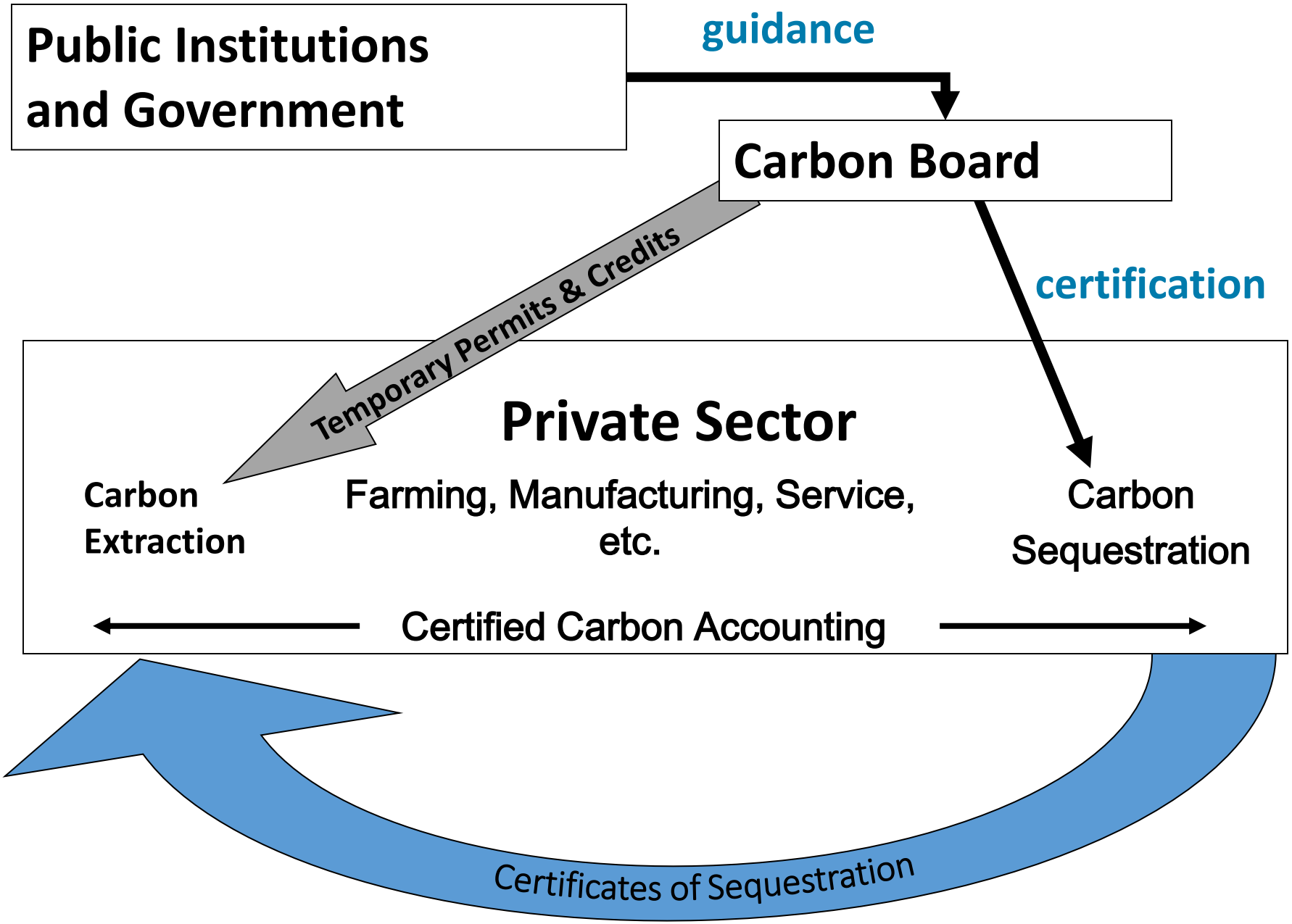
- Public demonstration -> move from “bleeding edge to cutting edge”
- Standardized criteria to verify costs and footprints
- Collective action between first movers in academia and industry
- Philanthropic support for first of a kind prototypes
- Public support for air capture technology as sustainable solution
- Access to intellectual property
- Incentives for carbon removal
- Price on carbon

Technological fix

I. **The technology must largely embody the cause-effect relationship connecting problem to solution.**

II. **The effects of the technological fix must be assessable using relatively unambiguous or uncontroversial criteria.**

III. **Research and development is most likely to contribute decisively to solving a social problem when it focuses on improving a standardized technical core that already exists.**


Public Institutions and Government
guidance
Carbon Board
Temporary Permits & Credits
certification
Private Sector
Carbon Extraction
Farming, Manufacturing, Service, etc.
Carbon Sequestration
Certified Carbon Accounting
Certificates of Sequestration

Utility of the future?

- Air capture + sequestration = upper limit on carbon management
- Negative carbon emissions is a public good
- Waste removal service: motivate reduction, reuse and recycling
- 36 billion ton/yr industry
- Individuals/aggregates are unlikely able to do this for themselves

Stay in touch!

- Visit website; sign up to mailing list www.engineering.asu.edu/cnce
- Follow @ASU_CNCE on twitter
- Attend Climate Week NYC event at National Grid on 9.22.15
- Christophe.Jospe@asu.edu