CO_2 Capture R&D at EPRI

Abhoyjit S. Bhown
Electric Power Research Institute
Palo Alto, California, USA

NETL CO_2 Capture Technology Meeting
August 21-25, 2017
Pittsburgh, Pennsylvania

Electric Power Research Institute

Mission

Advancing ***safe***, ***reliable***, ***affordable*** and ***environmentally responsible*** electricity for society through global collaboration, thought leadership and science and technology innovation

Independent

Objective, scientifically based results address reliability, efficiency, affordability, health, safety and the environment

Nonprofit and Collaborative

Chartered to serve the public benefit. Bring together scientists, engineers, academic researchers, industry experts

EPRI Members

- 450+ participants in more than 30 countries
- EPRI members generate approximately 90% of the electricity in the United States
- International funding is approximately 25% of EPRI's research, development and demonstrations
- Total Revenue ~$400 M

Overall Status

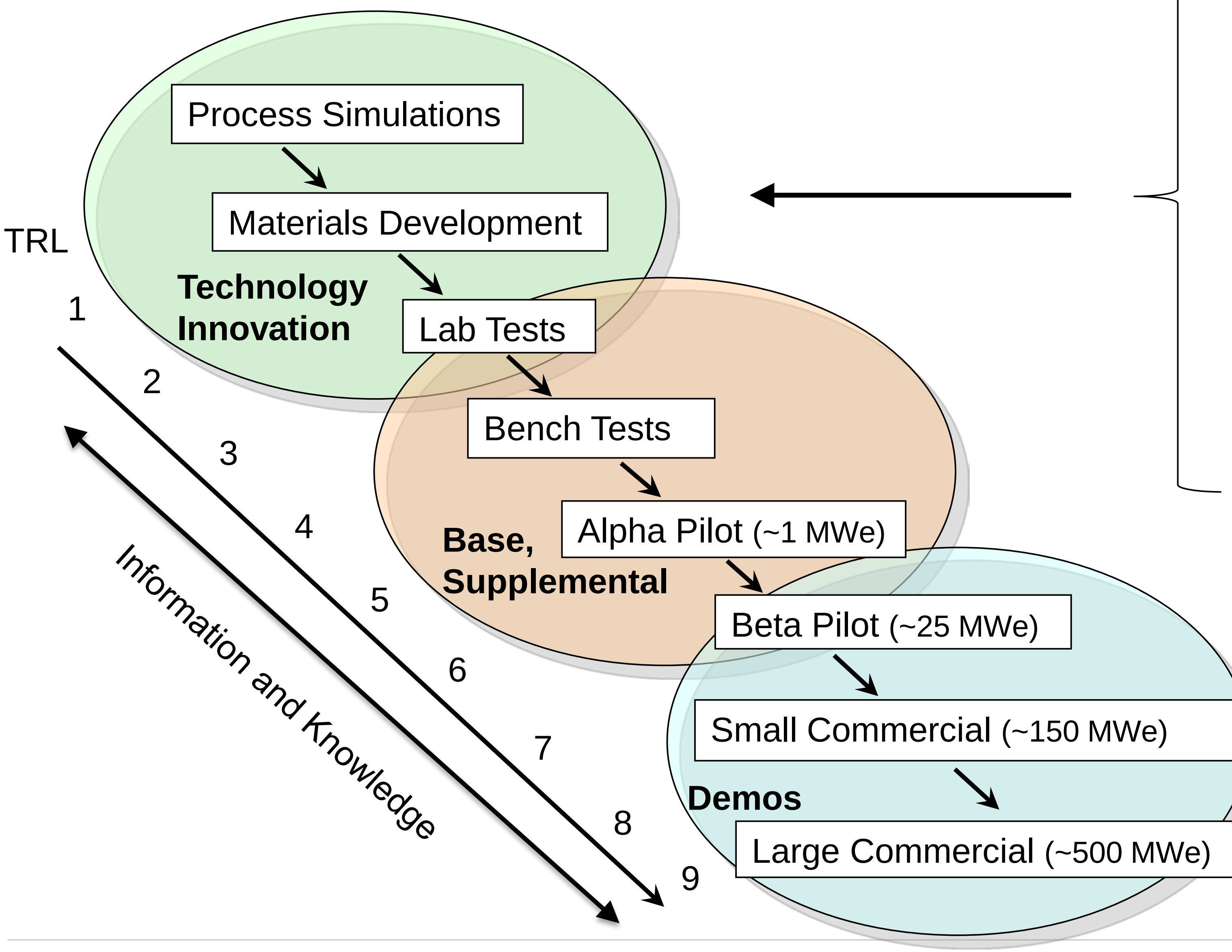
- Global interest in CCS has declined
- Power industry recognizes CCS is a key strategic technology
- Based on industry and public stakeholder input, EPRI has a long-term Research Imperative on Advanced Fossil Generation with CCS

EPRI's Long-Term Research Imperatives
Grid Modernization
Advanced Fossil Power with CCUS
Water Use and Availability
Advanced Nuclear Energy Systems
Bulk Energy Storage

EPRI's Research in Fossil-Based Generation: One Key Objective is to Reduce CO_2 Emissions

- Supercritical CO_2 & Other Novel Power Cycles
- Gasification & Combustion Technology Status
- Bulk Energy Storage
- Reciprocating Engines
- Detailed Feasibility Studies
- Economic Evaluations of Fossil Power Options

CO_2 Capture R&D at EPRI



Process Simulations – solvents, membranes, adsorbents, cryogenic, coal plants, NGCC… (Currently adding geologic storage)

Guide development of novel solvents, adsorbents, membrane processes

Detection of Membrane Fouling

Sorbent Polymer Composite

Inertial CO_2 Extraction* (Supersonic Expansion)

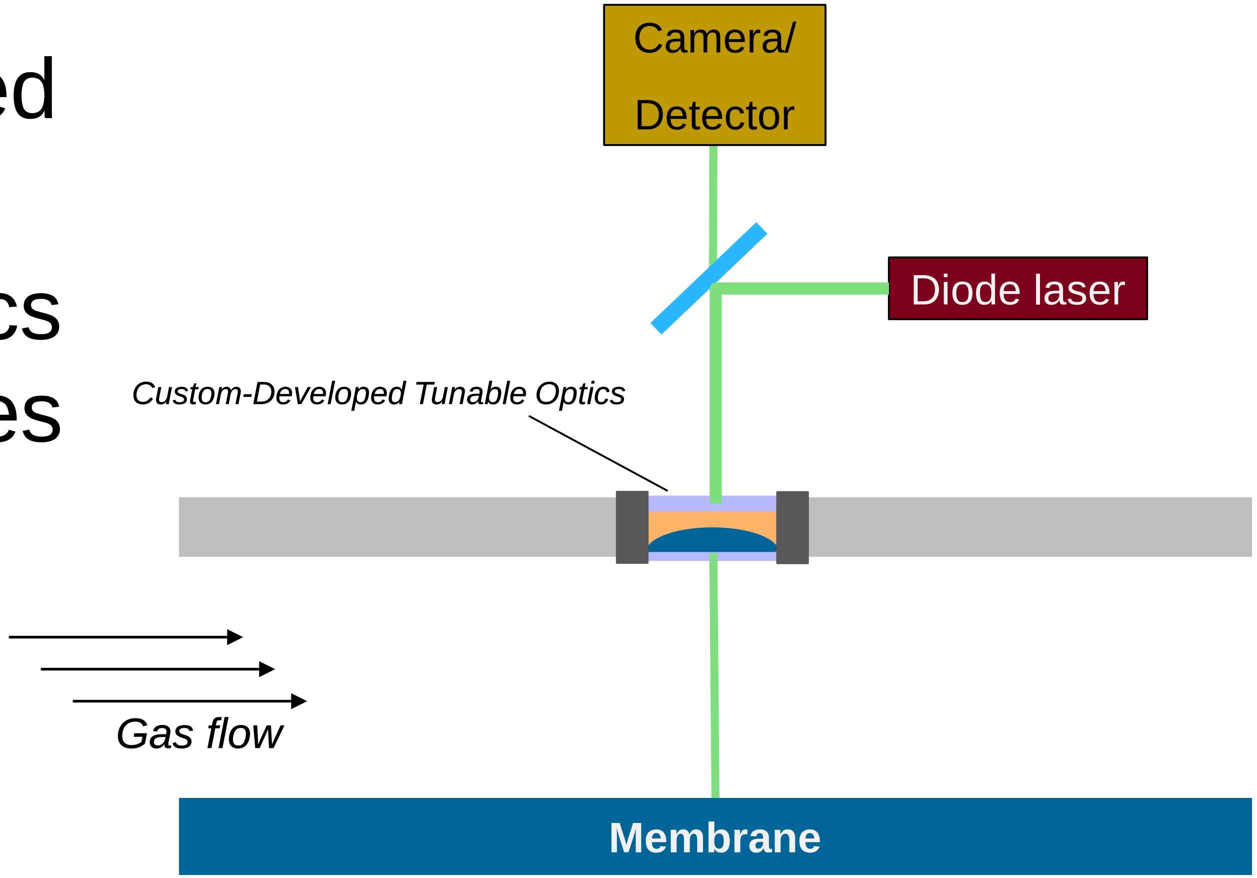
Sustainable Energy Solutions* (Cryogenic)

Analysis of Industrial CCS

*DOE/NETL

Membranes: Real-Time Detection of Foulants

- **Motivation**: determine the rate and structure of deposited layers on membranes
- **Technique**: use tunable optics to facilitate multiple techniques to measure
  - Thickness of deposits
  - Chemical composition
  - Rate of deposition



Membranes: Real-Time Detection of Foulants

Results Thus Far

- Successful discrimination of different kinds of particles on model membrane materials
- Detection of particles deposited on membranes at the NCCC
- Demonstration of the ability to use variable focal length to accurately determine particle heights
- Proof of principle of a tunable lens

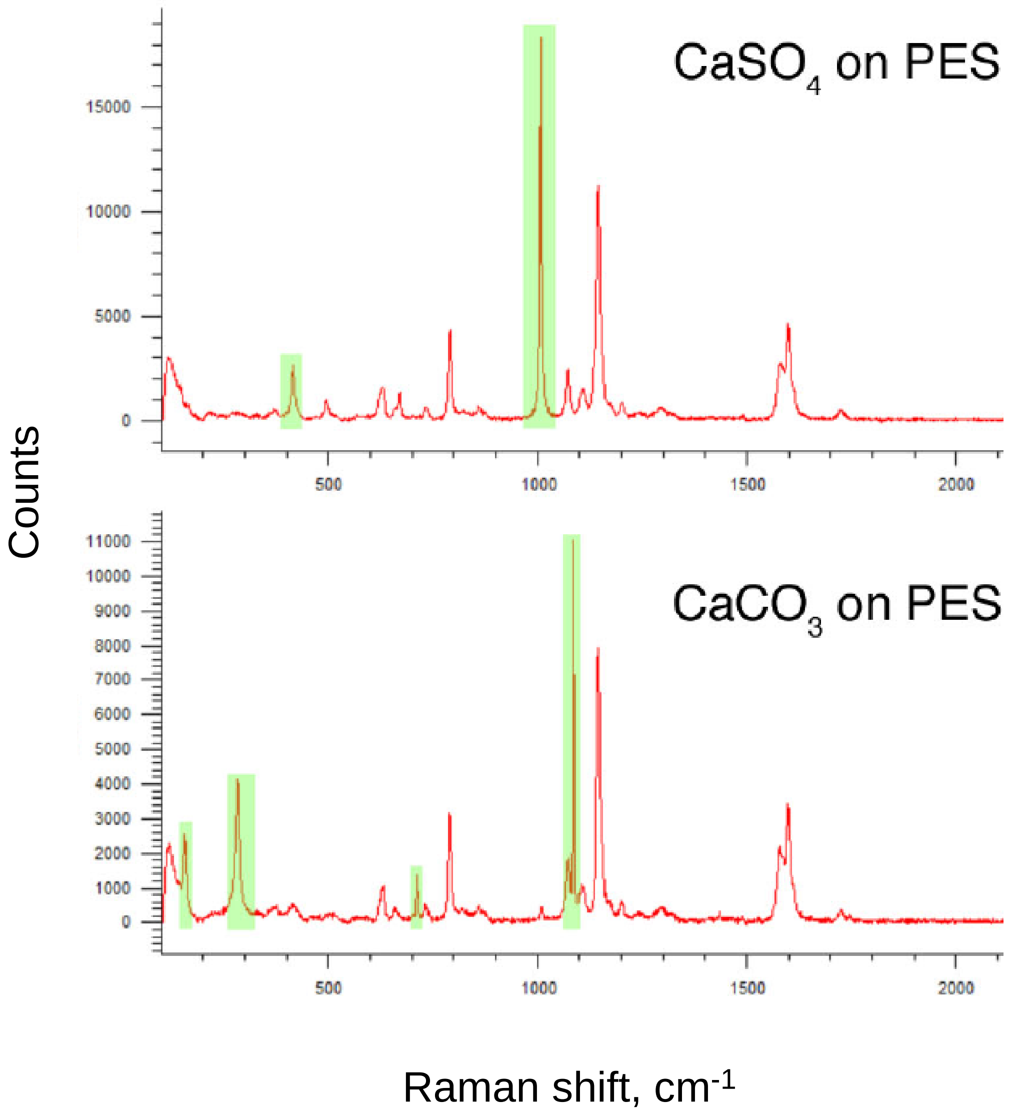
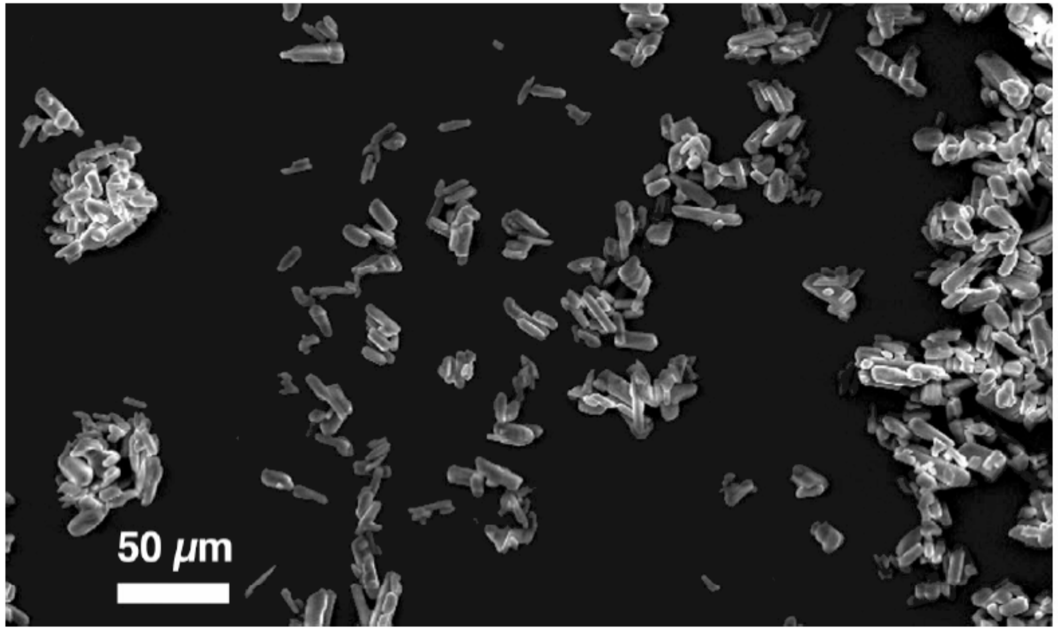


Figure courtesy of Univ. of Colorado, Boulder

Membranes: Real-Time Detection of Foulants

Next Steps

- Develop real-time tracking capability of instrument using liquid-phase apparatus
- Determine accurate Raman cross sections for quantification of the mass of deposits
- Expose more membrane samples to flue gas and analyze what adheres
- Develop methodology to foul membranes with controlled gas-solid suspensions



SEM image of $CaSO_4$ particles

Figure courtesy of Univ. of Colorado, Boulder

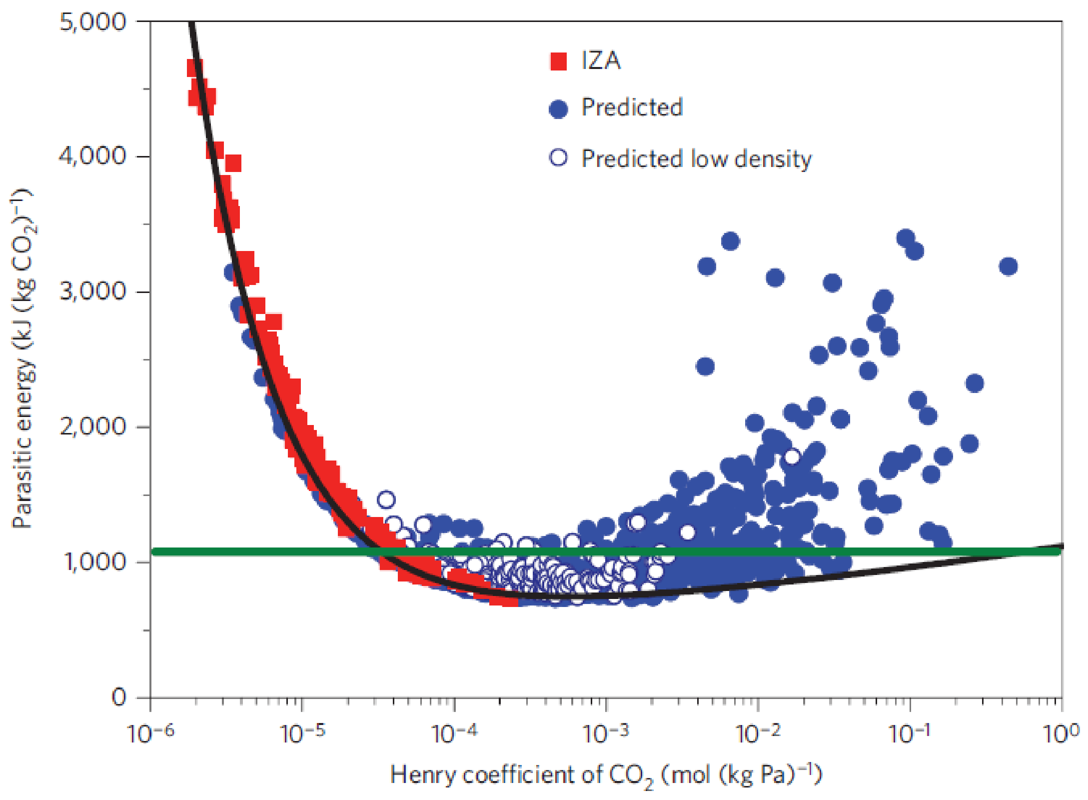
ELECTRIC POWER RESEARCH INSTITUTE

Adsorption: A Sampling of Materials

Adsorbent	ΔH	Capacity	Benefits	Challenges
Activated Carbons	Low	Low	Robust, low cost	Low selectivity, high energy use
Zeolites	Low	Medium	Abundant, tunable	Low H_2O tolerance
Carbonates	High	High	Can operate at high T	Low stability, high energy use
Amine Silicates	Tunable	Medium	Low energy use, moisture tolerant	Low stability
Metal Organic Frameworks	Tunable	High	Large change in CO_2 uptake with small ΔP or ΔT	Low stability, expensive

Adsorption: Optimal Materials

- Ideal materials
  - High CO_2 capacity, selectivity
  - Stability to moisture, impurities, temperature, attrition
  - Large response in CO_2 uptake from a small temperature/pressure change
- Designer materials
  - Materials with optimal adsorption properties
  - EPRI modeling has identified low-energy sorbents
  - Lowest energy sorbents not necessarily best in a process

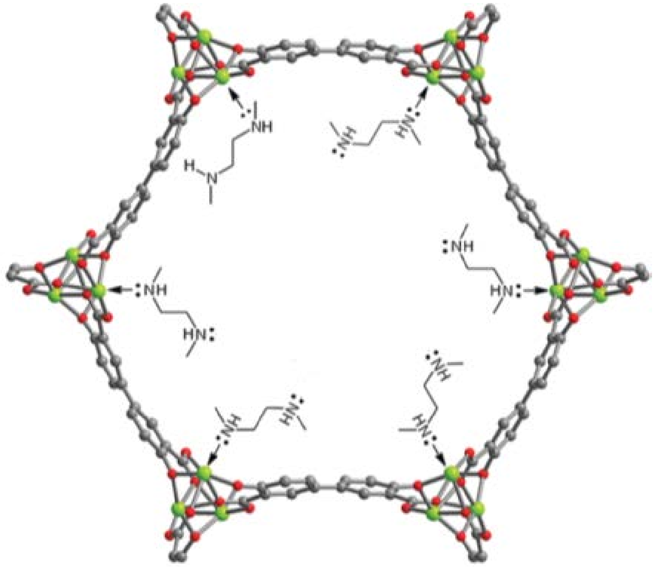


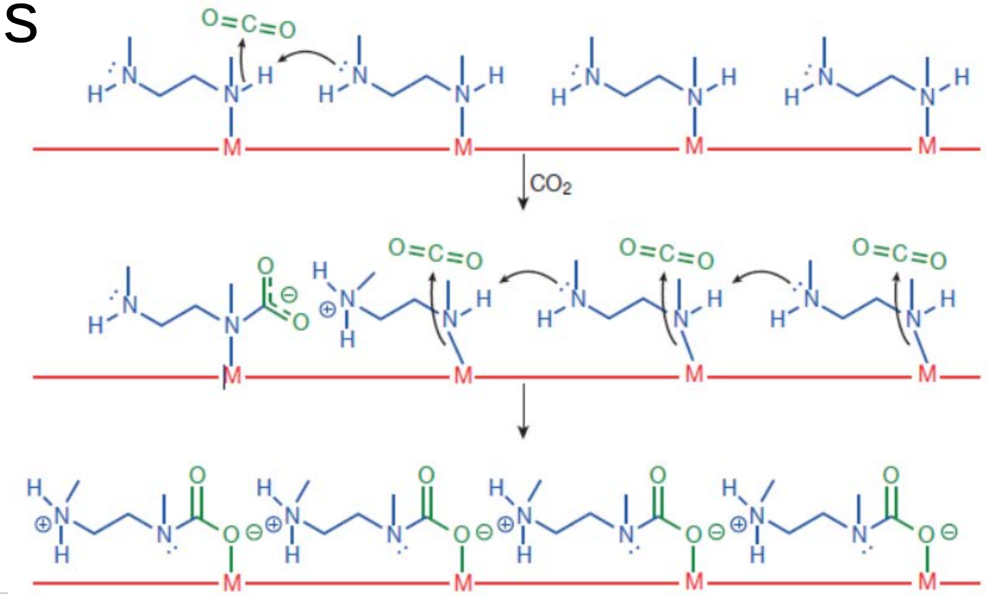
Lin *et al., Nature Materials, 2012*

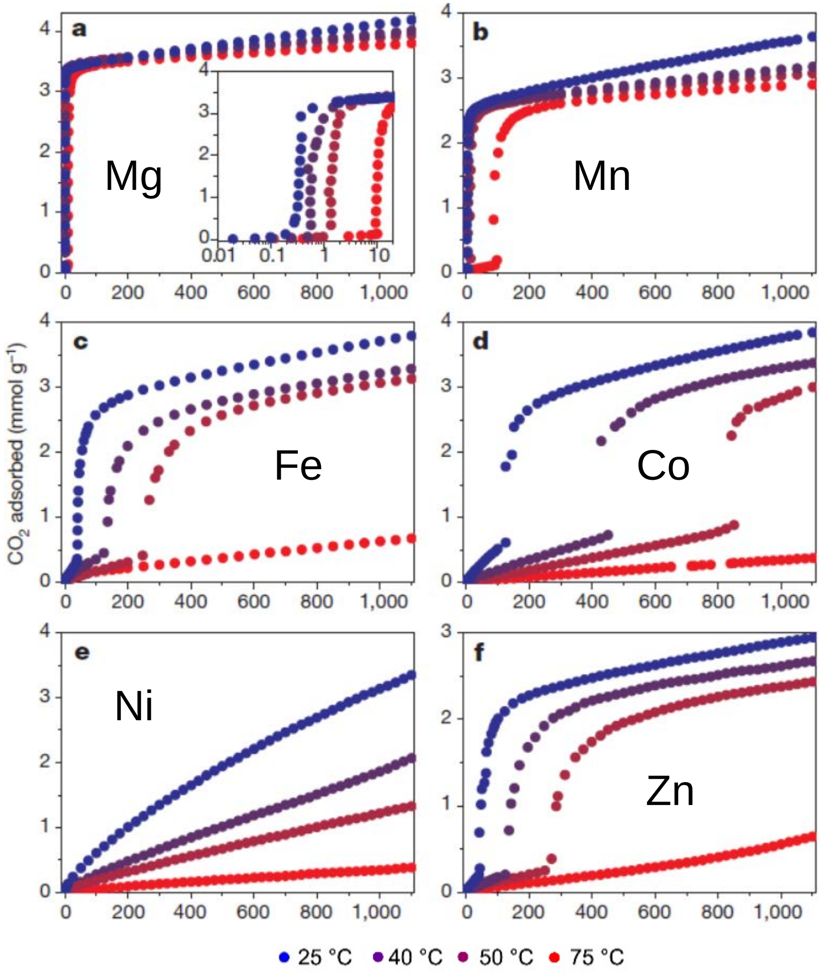
EPRI ELECTRIC POWER RESEARCH INSTITUTE

Adsorption: Diamine-Appended MOFs

- Metal Organic Frameworks with appended diamines
- Developed by UC Berkeley (Long group), LBNL, and Mosaic Materials
- Exhibits cooperative insertion that leads to distinct step-change isotherm





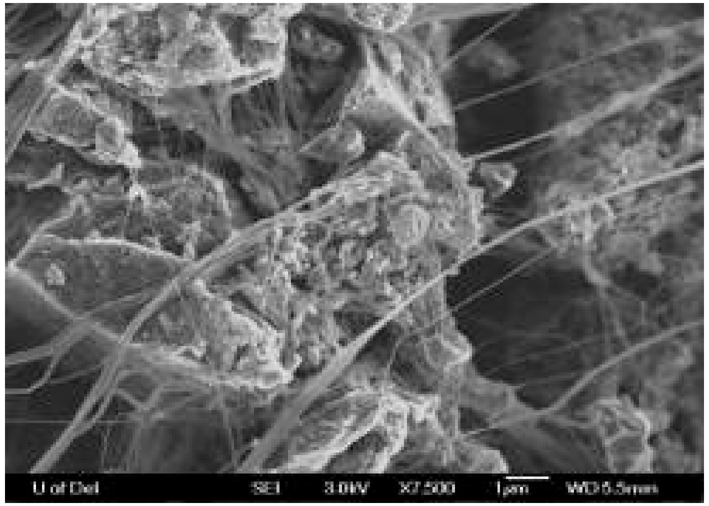


McDonald et al. *Nature* **2015**, *519* (7543), 303.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

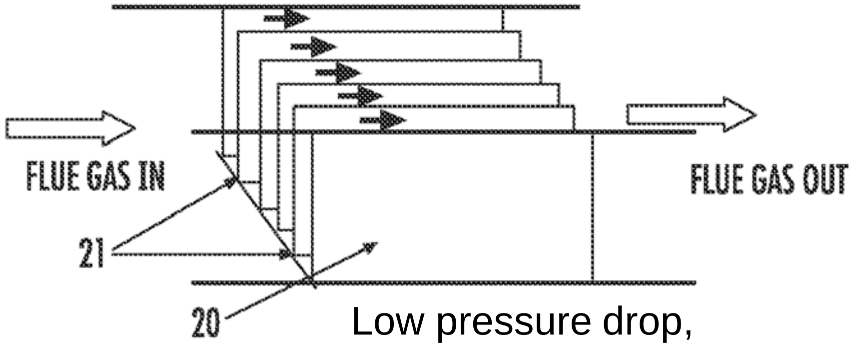
Adsorption: Sorbent Polymer Composites (SPC)

- SPCs incorporate a solid sorbent within a polymer framework
- Working with EPRI, W.L. Gore & Associates developed SPCs for different applications
- For CO_2 capture, we want:
  - Hydrophobic polymer to reject liquid water
  - Open structure to promote mass transfer
  - Proper selection of sorbent to minimize energy consumption



Images from W.L. Gore & Associates

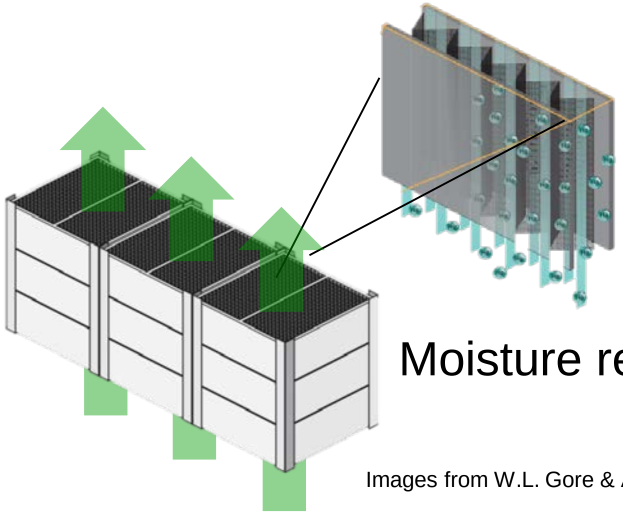
Adsorption: Possible SPC Embodiments



Low pressure drop,
liquid collection at bottom

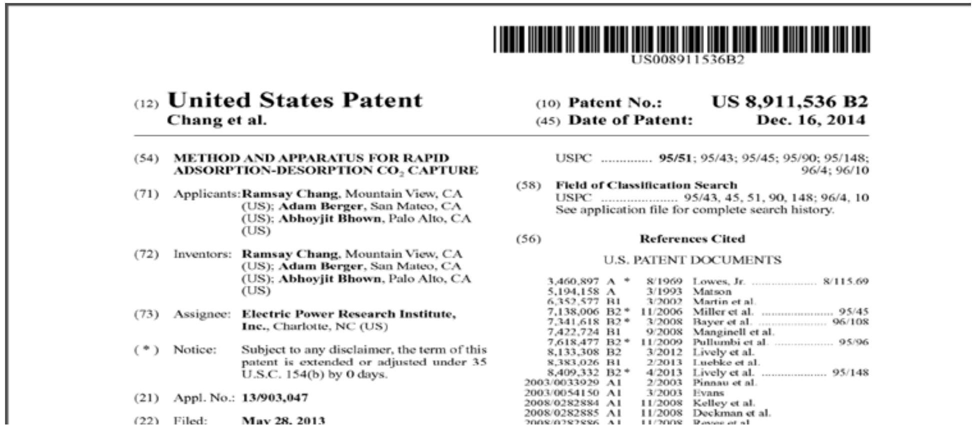
U.S. Patent 8,911,536 (2014)

Low pressure drop
Vertical configuration



Moisture rejection

Images from W.L. Gore & Associates



US008911536B2

(12) **United States Patent**
Chang et al.

(10) **Patent No.:** **US 8,911,536 B2**
(45) **Date of Patent:** **Dec. 16, 2014**

(54) **METHOD AND APPARATUS FOR RAPID ADSORPTION-DESORPTION CO_2 CAPTURE**

(71) Applicants: **Ramsay Chang**, Mountain View, CA (US); **Adam Berger**, San Mateo, CA (US); **Abhoyjit Bhown**, Palo Alto, CA (US)

(72) Inventors: **Ramsay Chang**, Mountain View, CA (US); **Adam Berger**, San Mateo, CA (US); **Abhoyjit Bhown**, Palo Alto, CA (US)

(73) Assignee: **Electric Power Research Institute, Inc.**, Charlotte, NC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/903,047**

(22) Filed: **May 28, 2013**

USPC **95/51**; 95/43; 95/45; 95/90; 95/148; 96/4; 96/10

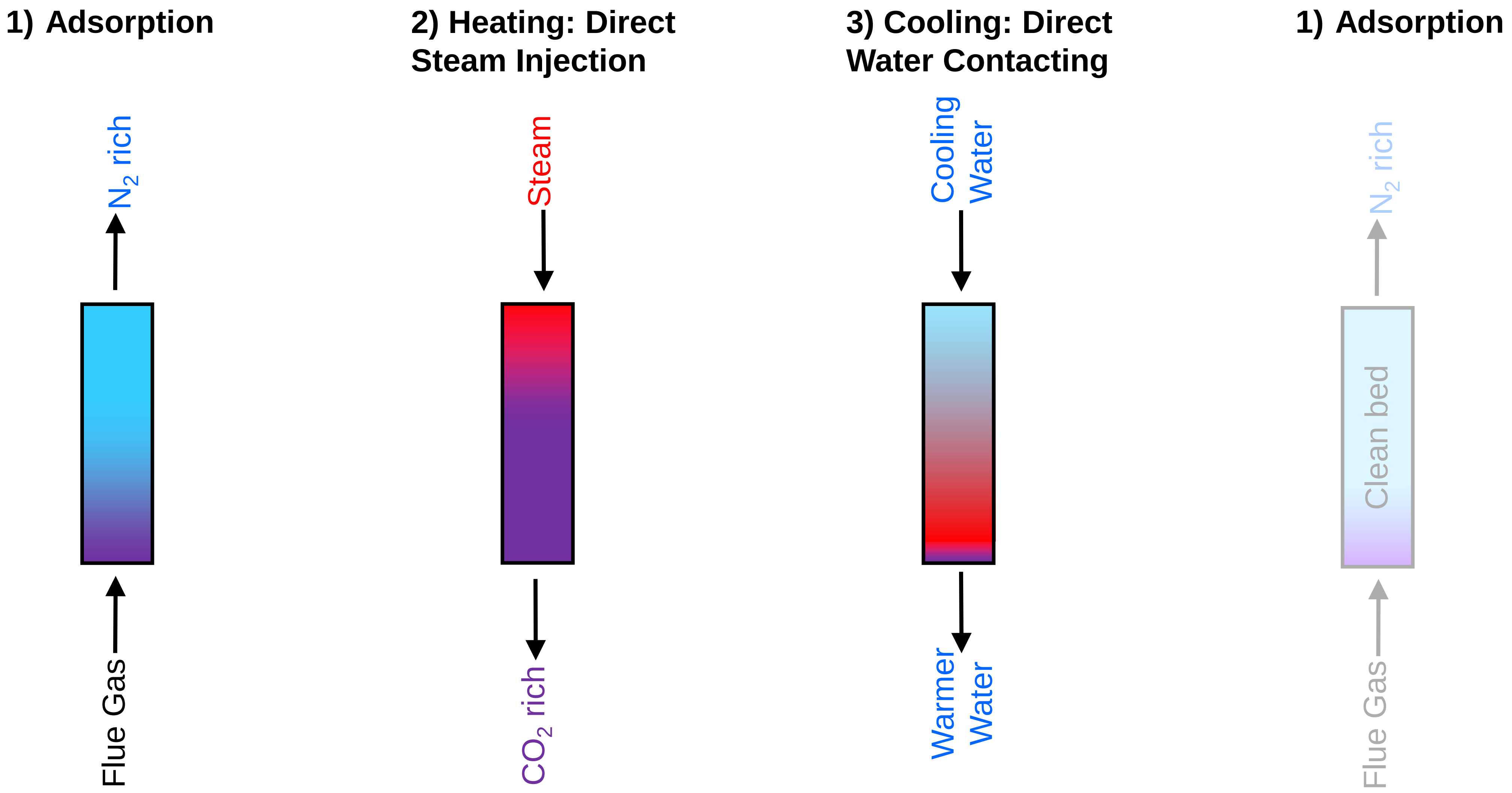
(58) **Field of Classification Search**
USPC 95/43, 45, 51, 90, 148; 96/4, 10
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

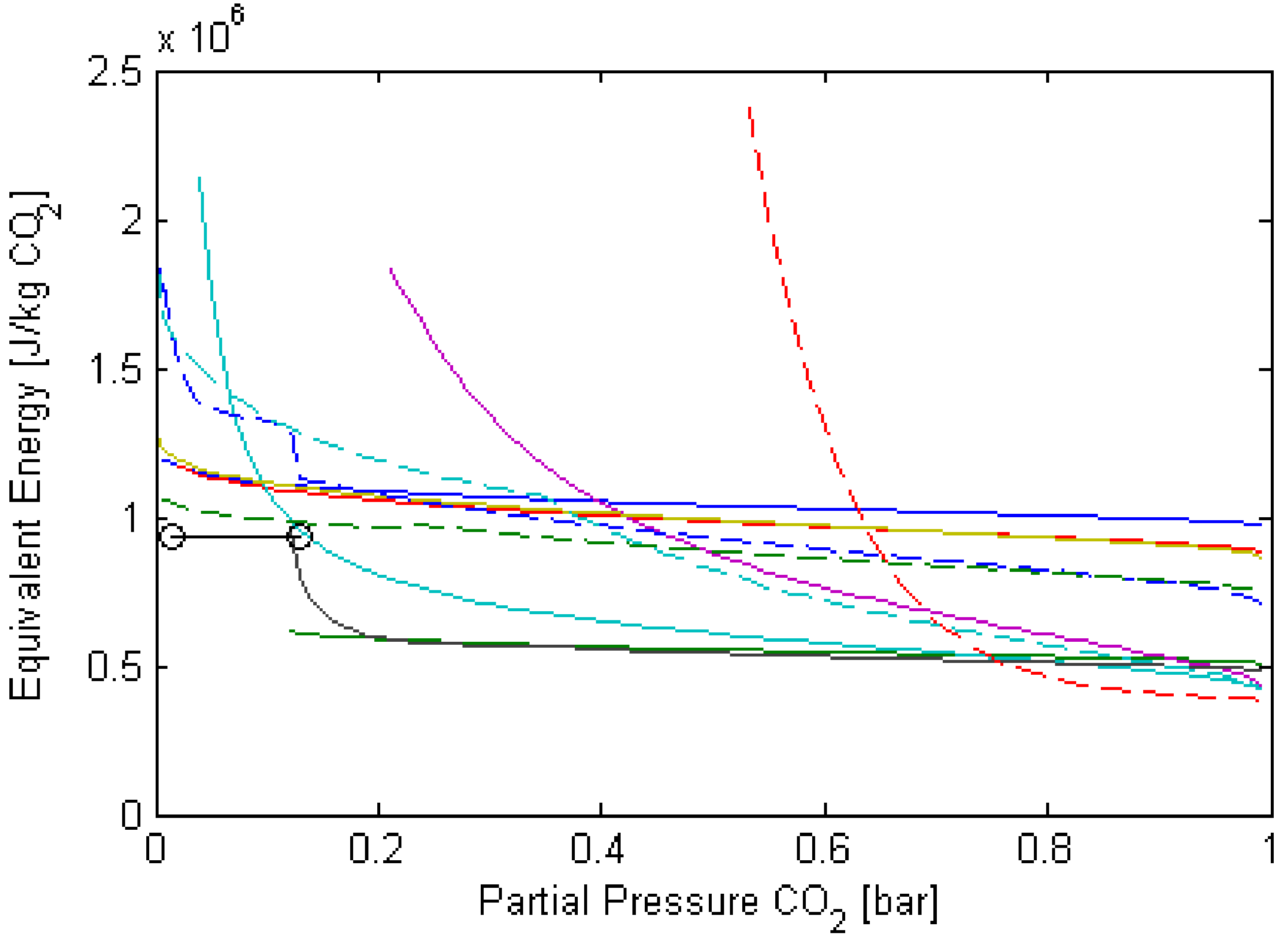
3,460,897	A *	8/1969	Lowes, Jr.	8/115.69
5,194,158	A	3/1993	Matson	
6,352,577	B1	3/2002	Martin et al.	
7,138,006	B2 *	11/2006	Miller et al.	95/45
7,341,618	B2 *	3/2008	Bayer et al.	96/108
7,422,724	B1	9/2008	Manginell et al.	
7,618,477	B2 *	11/2009	Pullumbi et al.	95/96
8,133,308	B2	3/2012	Lively et al.	
8,383,026	B1	2/2013	Luebke et al.	
8,409,332	B2 *	4/2013	Lively et al.	95/148
2003/0033929	A1	2/2003	Pinnau et al.	
2003/0054150	A1	3/2003	Evans	
2008/0282884	A1	11/2008	Kelley et al.	
2008/0282885	A1	11/2008	Deckman et al.	

Adsorption: Possible Cycle



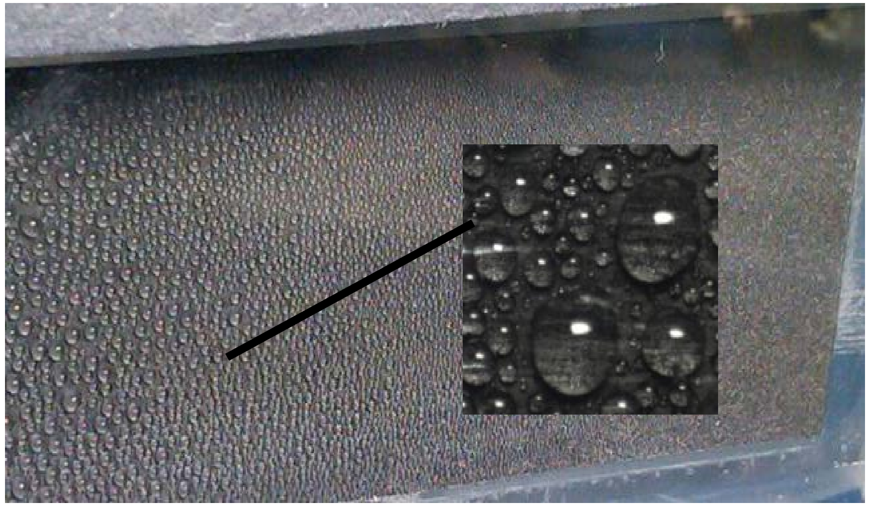
Adsorption: Energy Consumption Different Diamine MOFs

- Imposed load on power plant for TSA processes with different diamines
- Significant energy savings possible
- BUT high CO_2 capture rates difficult; requires multi-step process



Siegelman et al. *JACS (2017)*

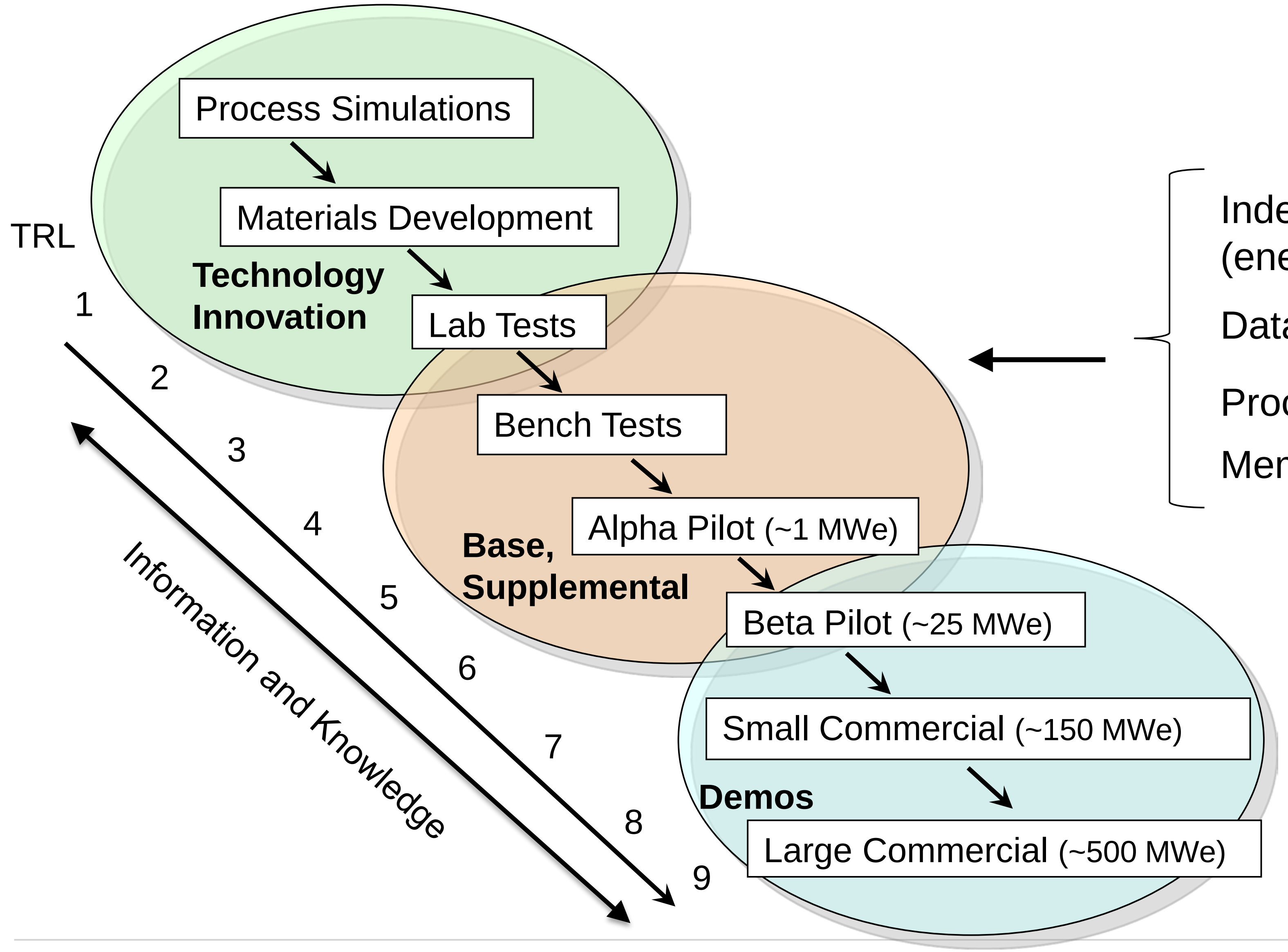
Adsorption: Results of Lab-scale Experiments



Images from W.L. Gore & Associates

- Embedding sorbent does not decrease CO_2 uptake
  - No pore blocking or site deactivation
- Gaseous water can infiltrate materials
- Liquid water excluded
  - Powdered sorbents lost capacity each cycle, SPC’s were constant
  - Pores still accessible after moisture condensation
- Fast steam heating (<2 s) and water cooling (<5 s)
- Mass transfer indicates sorbent saturated within 3-7 seconds
- Total cycle time <1 minute
  - 1/30th the size of half hour ‘rapid TSA’ cycles
  - Smaller size means lower capital, O&M, can use more exotic sorbents
- Now focused on more complex cycles to match materials

CO_2 Capture R&D at EPRI



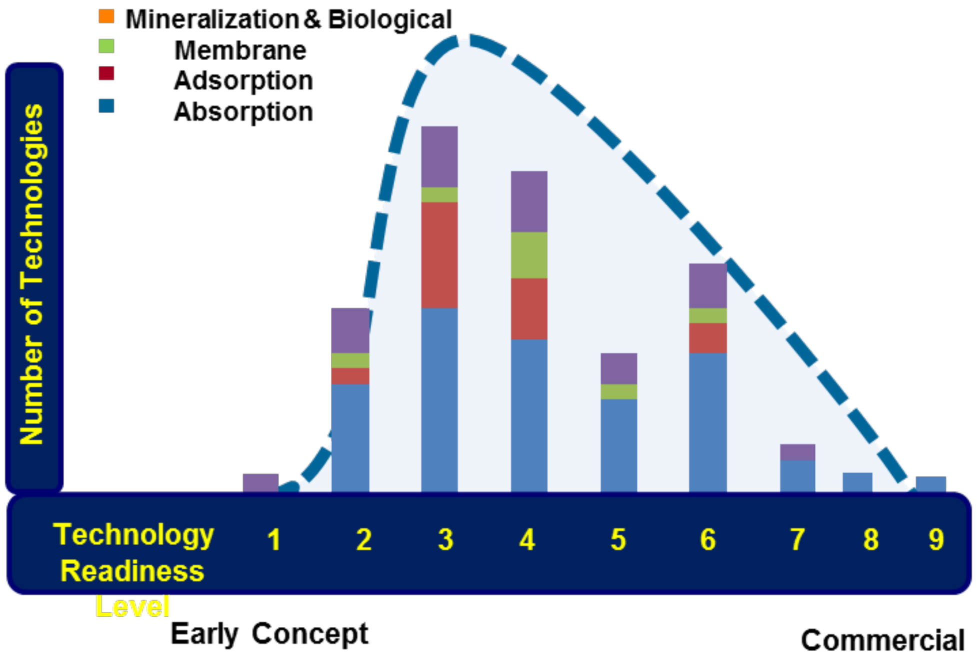
- Independent Process Evaluations (energy, capital, costs)
- Database of Capture Processes
- Process Simulations (need proprietary info)
- Member-selected focused projects

Projects are often with DOE/NETL, Process Developers, Utilities

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Global CCUS Technology Watch

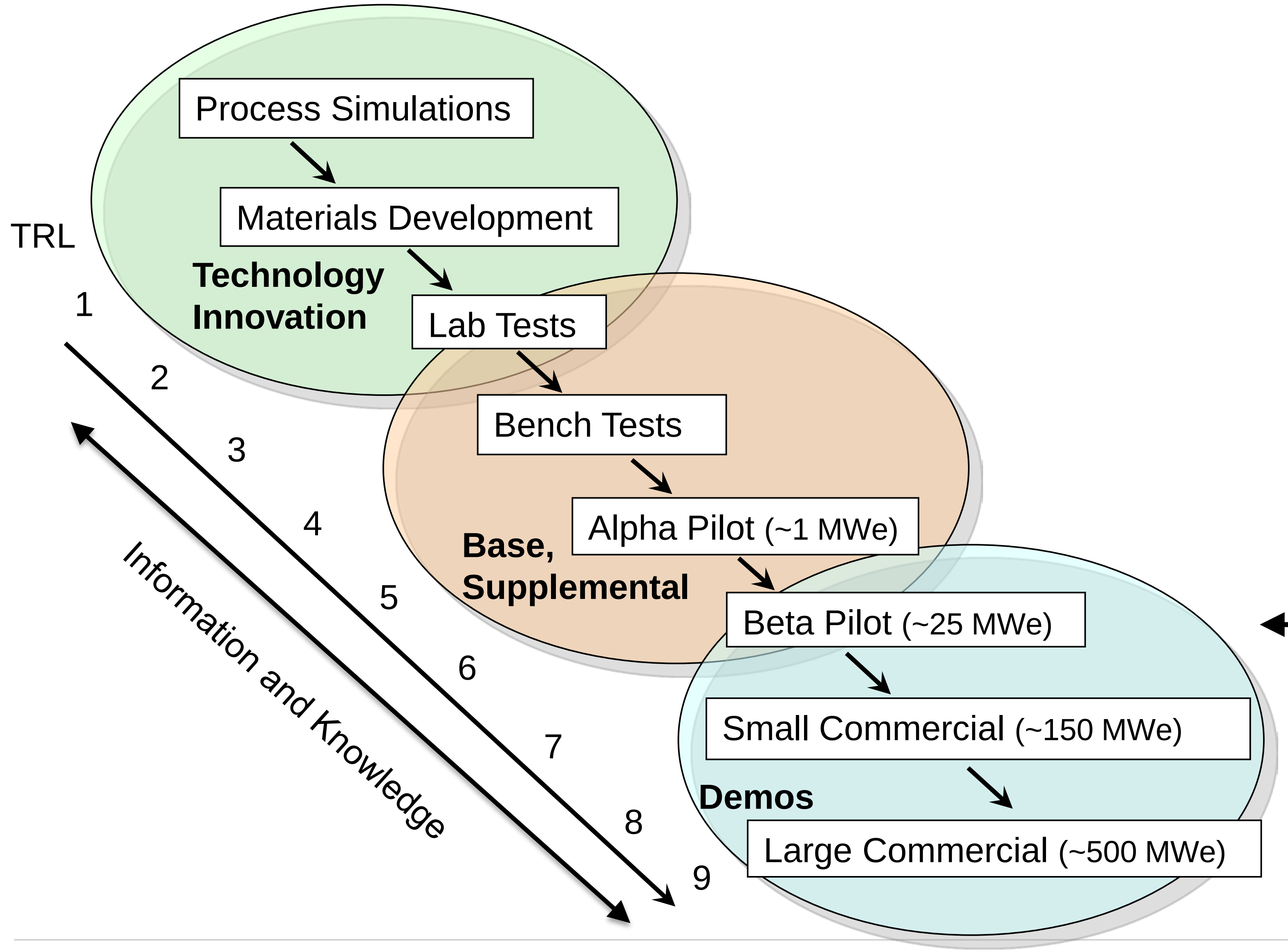
Monitor new technologies and projects for CO_2 capture, environmental safety, and permanence of geostorage, and identification of promising CO_2 utilization concepts.



Provides Landscape of CCS

EPRI ELECTRIC POWER RESEARCH INSTITUTE

CO_2 Capture R&D at EPRI



- Data Collection for Heat and Mass Balance, Performance
- Process Simulations (need proprietary info)
- Techno-Economic Analysis

Projects are often with DOE/NETL, Process Developers, Utilities, Test Centers

Data Collection

- Technology Centre Mongstad Solvent Campaigns
- University of Kentucky
  0.7 MWe, LG&E-KU, NETL
- Process Developer Test Campaigns

ELSEVIER
Energy Procedia
Volume 63, 2014, Pages 5938-5958
open access

Results from MEA testing at the CO_2 Technology Centre Mongstad. Part I: Post-Combustion CO_2 capture testing methodology ☆

ELSEVIER
Energy Procedia
Volume 63, 2014, Pages 5994-6011
open access

Results from MEA testing at the CO_2 Technology Centre Mongstad. Part II: Verification of baseline results ☆

Memberships and Sponsorships

- National Carbon Capture Center*
- U California Berkeley EFRC Center for Gas Separations*
- U of Kentucky Center for Applied Energy Research
- U of Texas Carbon Management Program
- U of Texas CO_2 Capture Pilot Plant Project
- U of Colorado/NJIT/Univ Arkansas MAST Membrane Center
- Canadian Clean Power Coalition (completing)
- IEA Greenhouse Gas Programme

*DOE

Together…Shaping the Future of Electricity