CCS R&D at EPRI

Abhoyjit S. Bhown
Electric Power Research Institute

NETL CO_2 Capture Technology Project Review Meeting

August 8, 2016

Pittsburgh, PA

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

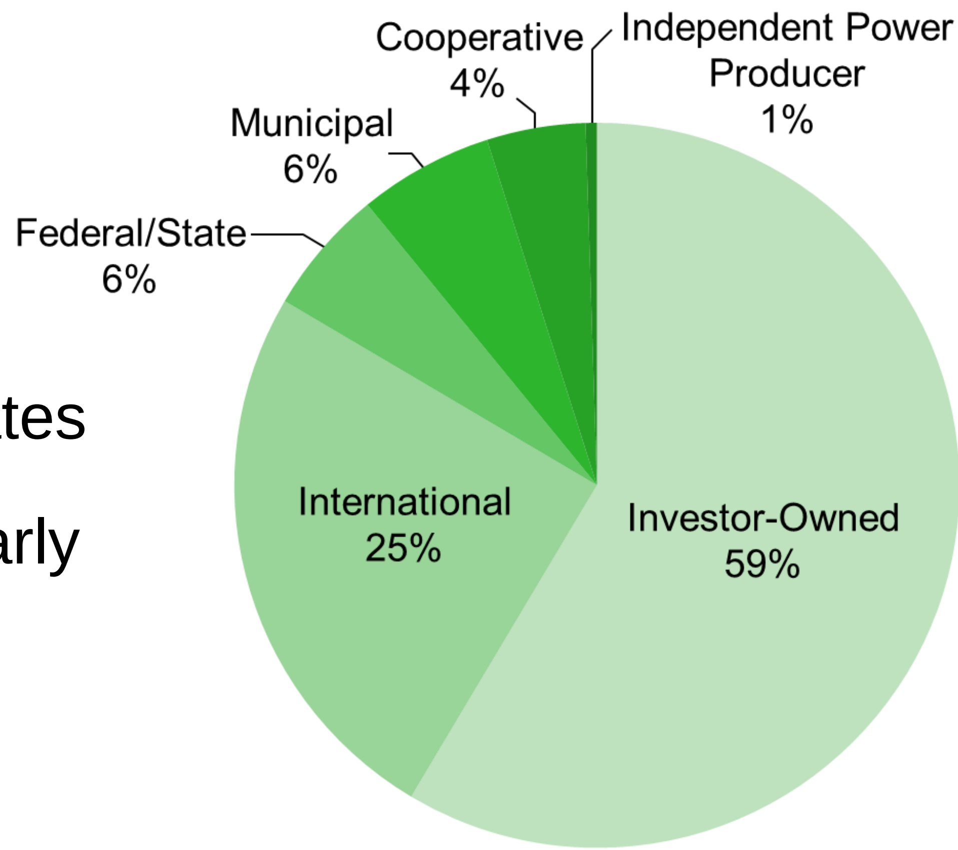
Chartered to serve the public benefit

Collaborative

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 nearly 25% of EPRI's research, development and demonstrations
- Total Revenue ~$390 M

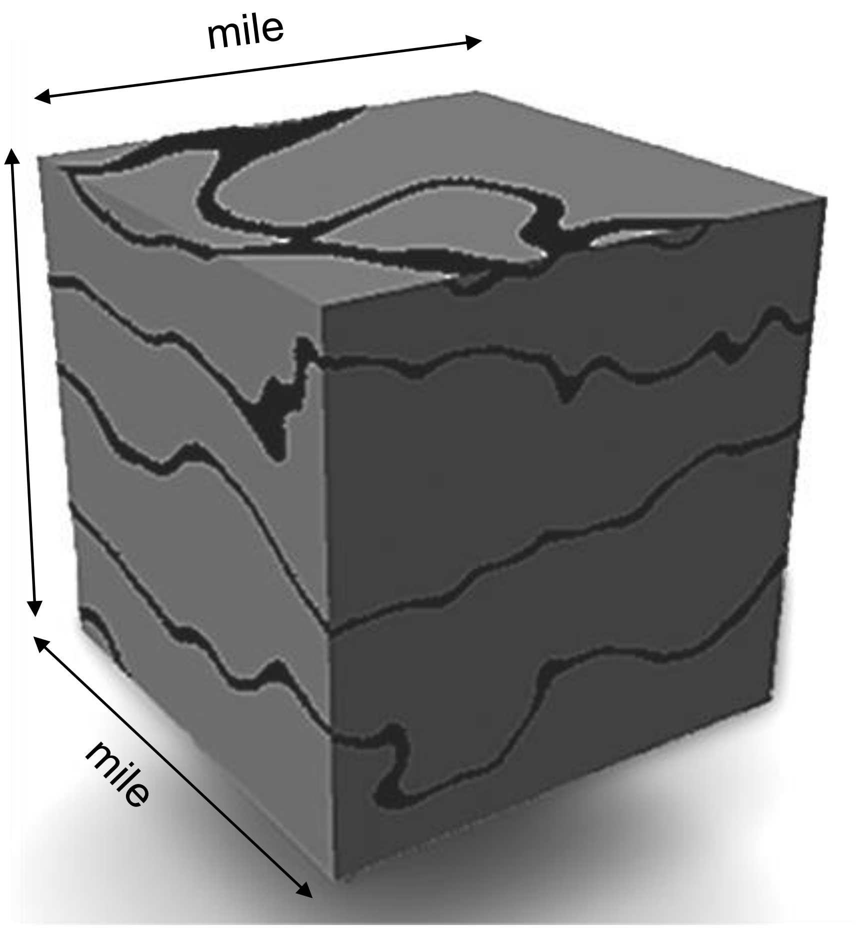


NOAA State of Climate Report 2015

Bulletin of the American Meteorological Society, 98 (8), August 2016

- Records set:
  - Highest global mean GHGs: 399.4 ppm CO_2, 1834 ppb CH_4, 328.2 ppb N_2O
  - Highest global mean surface temperature. 2nd straight year.
  - Highest number of extreme warm temperature events. Almost every continent
  - Highest sea surface temperature
  - Highest sea level
  - Highest ocean heat
  - Lowest levels of Artic sea ice
- Drought
  - Affects nearly all 1/3 global land surface. All continents.
  - 14% land surface in severe or extreme drought.
- Cyclones
  - 101 tropical cyclones vs average of 82
  - Three Category 4 storms in same basin for the first time ever
- Living systems
  - Plants and animals on the move
  - Some areas up to $8^{o}C$ higher than average
- Glaciers, permafrost, …

A Cubic Mile of Oil

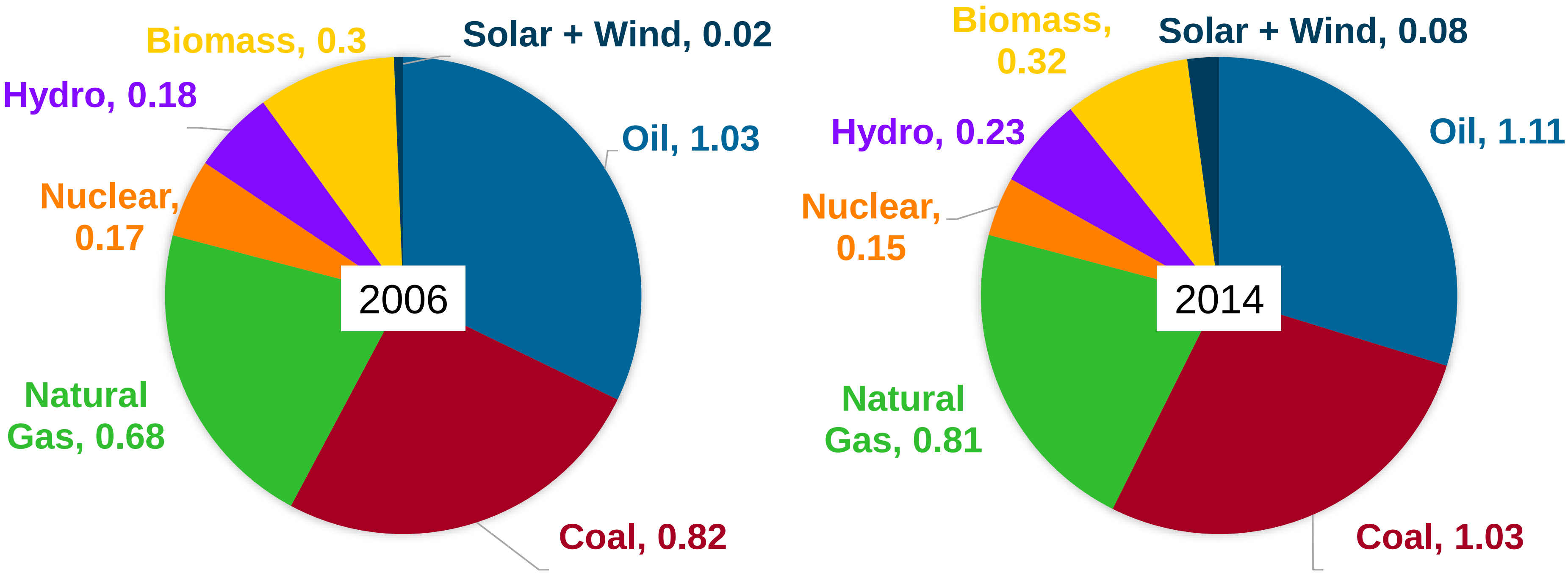


A Cubic Mile of Oil
Crane, Kinderman, Malhotra

1 Cubic Mile Oil
≅1.1 trillion gal oil
≅ 26 Billion bbl oil
≅ 153 x 10^{15} Btu (Quads)
≅ 6.4 Billion tons coal
≅ 15.3 Trillion kWh electricity
(10,000 BTU/kWh)

Figure courtesy R. Malhotra/SRI International

Global Energy Consumption, CMO Units



3.2 CMO

3.73 CMO

Data from R. Malhotra/SRI International

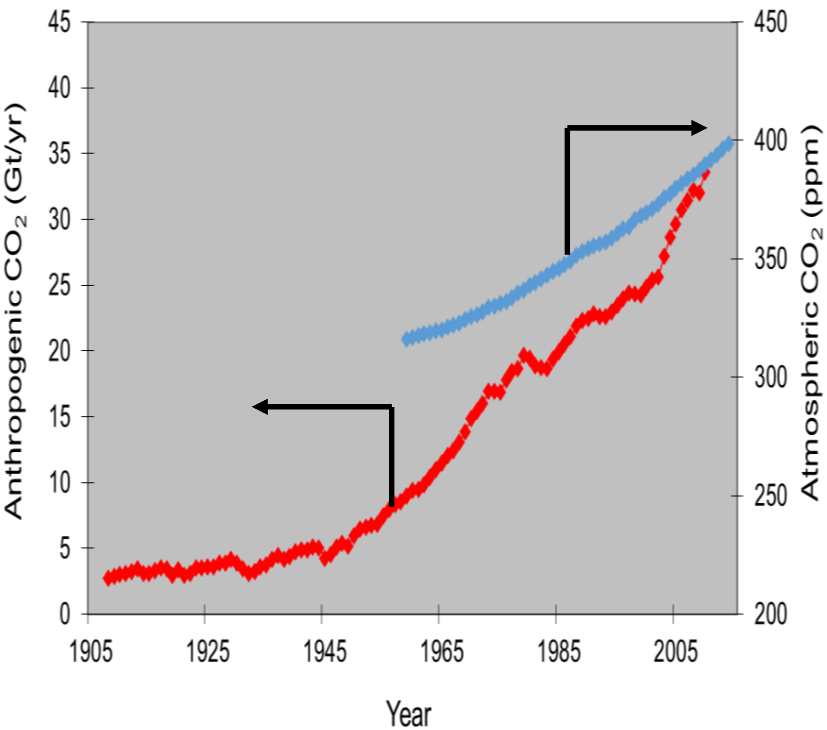
Total Energy Consumption Increased +16.5%
Fossil Fuel Share Unchanged ~80%

ELECTRIC POWER RESEARCH INSTITUTE

Growth in Fossil ≅ 4x Growth in Non-Fossil → CO_2 Emissions Continue

∆ 2006 to 2014	CMO
Fossil	
Oil	0.08
Coal	0.21
Natural Gas	0.13
Sub-total	**0.42**
Non-Fossil	
Nuclear	-0.02
Hydro	0.05
Biomass	0.02
Solar + Wind	0.06
Sub-total	**0.11**
TOTAL	**0.53**

Data from R. Malhotra/SRI International



Data from http://www.esrl.noaa.gov/gmd/ccgg/trends/
http://cdiac.ornl.gov/trends/emis/glo_2010.html

CCS is the ONLY Option For Fossil Fuels

Energy Options by 2050

Courtesy: R. Malhotra

- Historical +2.6%/yr growth in energy consumption → Need ~9 CMO by 2050

Option	Size	Availability	Needed for 1 CMO	Build by 2050
Hydro	18 GWe	50%	200 Dams	1 every 2 months
Nuclear	900 MWe	90%	2200 Plants	6 every month
Solar Parks	900 MWe	25%	7000 Parks	5 every week
Windmills	1.65 MWe	35%	3 Million	2000 every week
Solar Rooftop	2.1 kWe	20%	4.2 Billion	380,000 every day

- Fossil fuel reserves are 100's CMO; resources are 1000's CMO

Fossil Fuels Are Unlikely to be Displaced in the Next Few Decades

EPRI ELECTRIC POWER RESEARCH INSTITUTE

CO_2 Utilization for Chemicals

		US Production, Estimated 2015				Global Production, Estimated 2015			
		Mt	Gmol	GWe Coal at 90% Capture	GWe Gas at 90% Capture	Mt	Gmol	GWe Coal at 90% Capture	GWe Gas at 90% Capture
1	Sulfuric Acid	39.3	401.1	2.3	5.6	210.0	2.1	11.0	26.8
2	Nitrogen	31.2	1114.8	6.4	15.5	123.8	4.4	22.7	55.3
3	Ethylene	26.0	813.9	4.6	11.3	150.0	4.7	24.1	58.6
4	Oxygen	24.4	869.4	5.0	12.1	88.7	3.2	16.2	39.5
5	Lime	19.9	355.3	2.0	4.9	367.1	6.5	33.6	81.8
46	Propylene Oxide	2.1	35.5	0.2	0.5	5.5	0.1	0.5	1.2
47	Phenolic Resins	1.5	14.7	0.1	0.2	6.0	0.1	0.3	0.8
48	Calcium Carbonate	3.1	31.5	0.2	0.4	14.7	0.1	0.8	1.8
49	Butadiene (1.3)	2.7	50.5	0.3	0.7	12.9	0.2	1.2	3.0
50	Nylon Resins & Fibers	0.8	3.4	0.0	0.0	2.8	0.0	0.1	0.1
	TOTAL	453	9368	53	130	2620	57	290	708
	2015 Net Generation, GWe-yr			155	152			>1000+	
	CO2e from Electricity	2,000	45,500			10,500	239,000		
	CO2e from All Sources	6,890	156,600			37,000	841,000		

$R + CO_2 \rightarrow RCO_2$

Limited supplies of R & limited sales of RCO_2

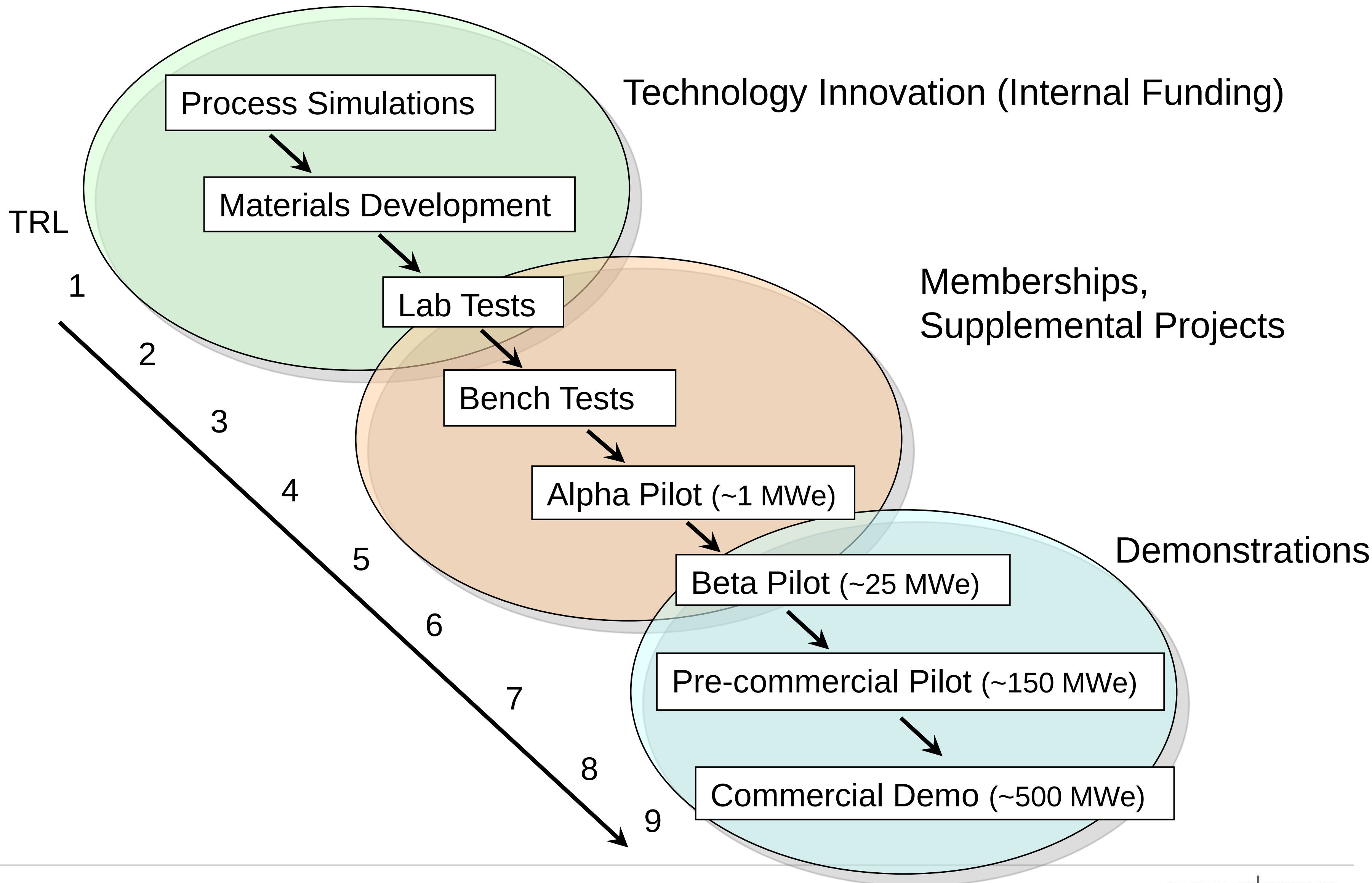
CO_2 Emissions >> CO_2 Utilization

Utilization Schemes Often Overlook Life Cycle Analysis

- Urea production
  - $2NH_3 + CO_2 \rightleftharpoons H_2N\text{-}COONH_4H \rightleftharpoons (NH_2)_2CO + H_2O$
- But ammonia is manufactured by $3H_2 + N_2 \rightleftharpoons 2NH_3$
- And H_2 is mostly generated by steam methane reforming:
  - $CH_4 + 2H_2O \rightleftharpoons 3H_2 + CO + H_2O \rightleftharpoons 4H_2 + CO_2$
- Overall balance: $\frac{3}{4}CH_4 + 2N_2 + \frac{1}{2}H_2O + CO_2 \rightleftharpoons (NH_2)_2CO + \frac{3}{4}CO_2$
- Net: ¼ mole CO_2 per mole of urea
- 90% capture from 200 MW coal generation:
  - 1,200,000 t/y CO_2 captured → 6,600,000 t/y urea produced
  - Represents >100% of US urea consumption

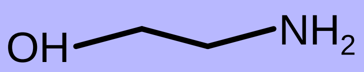
Cash Positive ≠ CO_2 Negative

Post-Combustion CO_2 Capture R&D at EPRI



EPRI ELECTRIC POWER RESEARCH INSTITUTE

Structure-Property Model for Solvent Screening



Solvent Structure

Thermo. Props.

$\Delta_f G$

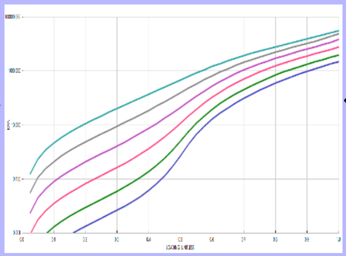
$\Delta_f H$

C_p

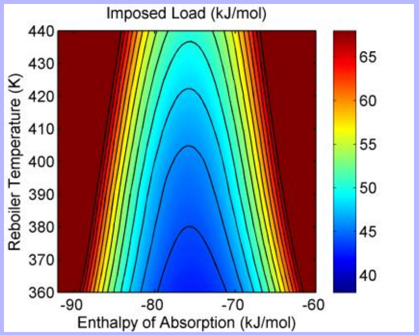
γ_i

H_i

VLE



Optimize System for Min. Equiv. Work



Input
Solvent Structure

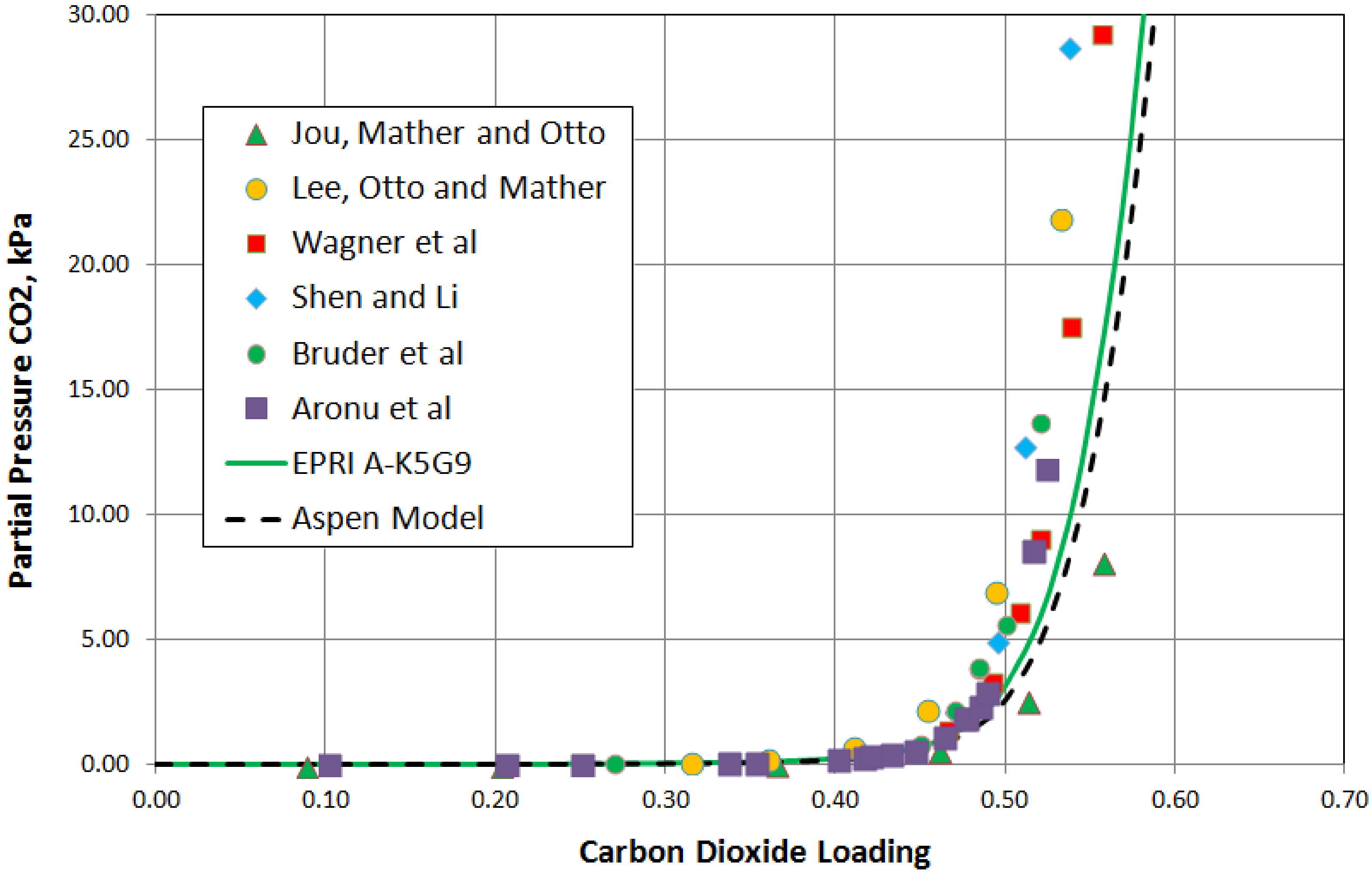
Output
Imposed Load on Power Plant

Test & tune structure-property model against known solvents

Use optimal properties to suggest new solvent structures

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Structure-Property Model for 30 wt% MEA

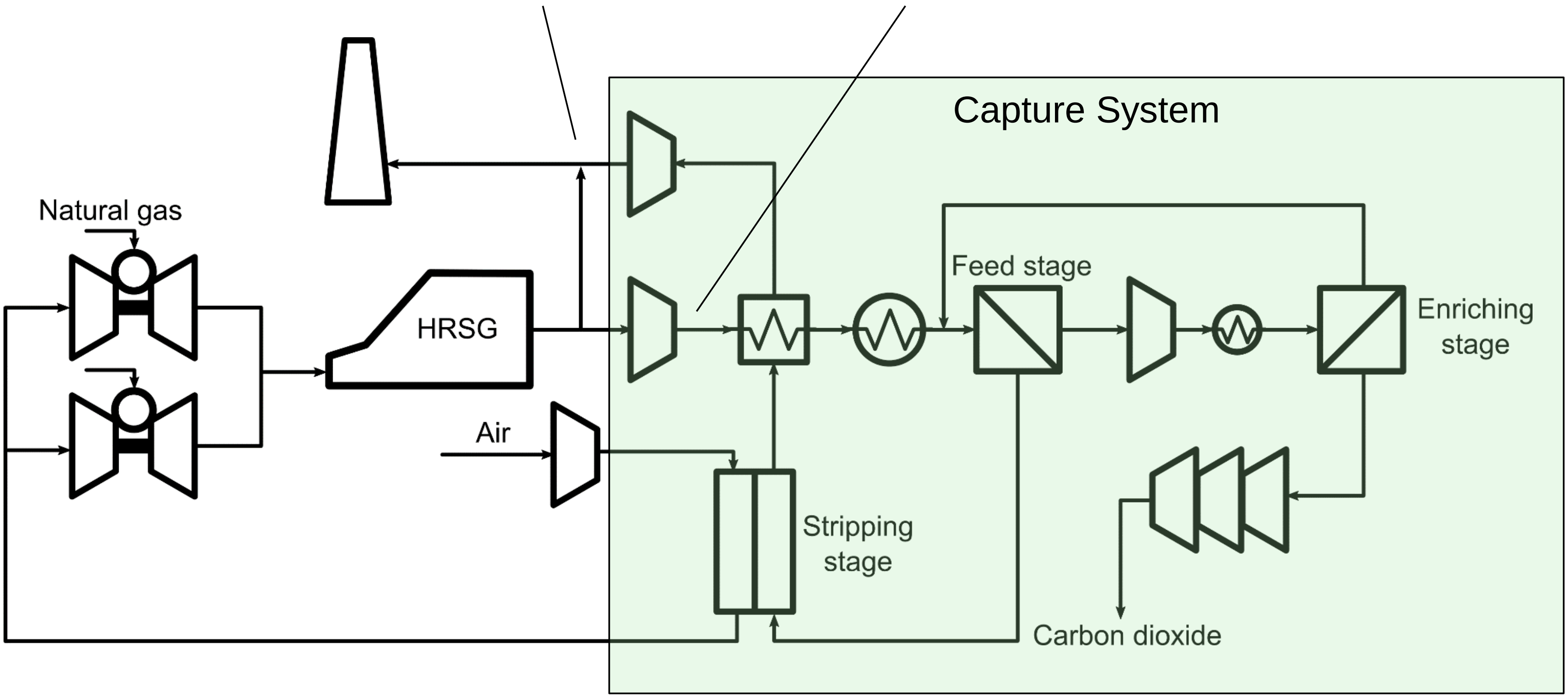


Model Results for Known Solvents are Close to Experimental Data

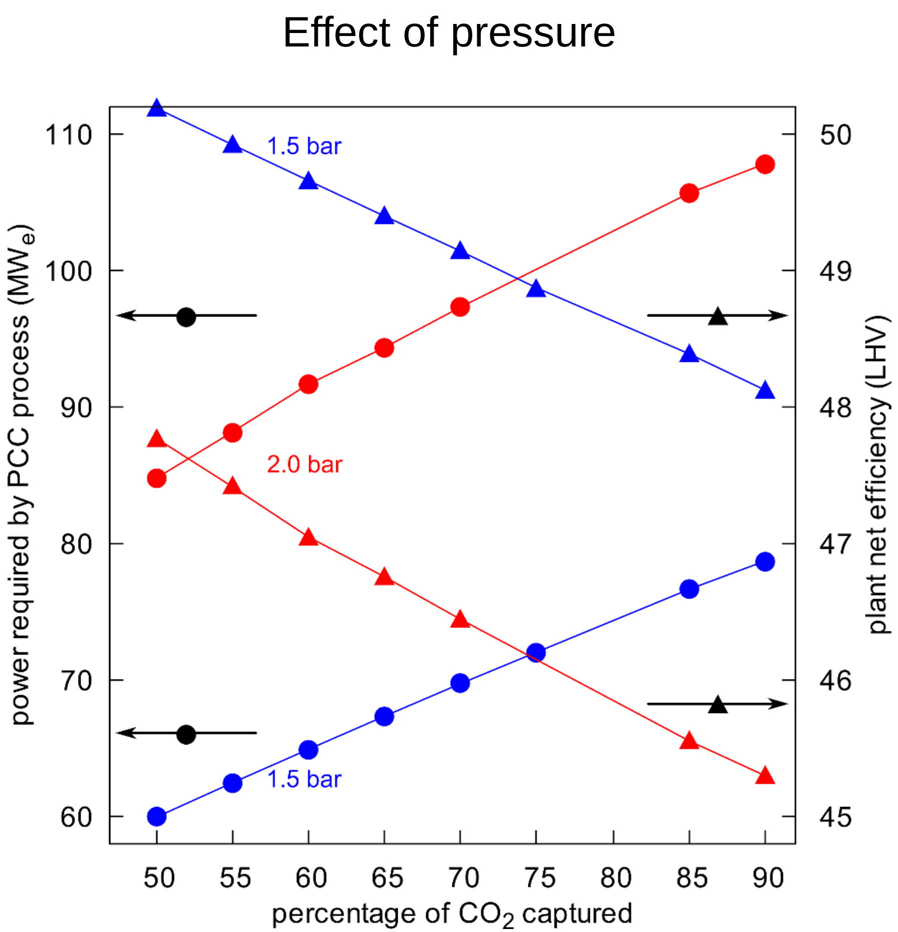
Partial Capture on NGCC using Membranes

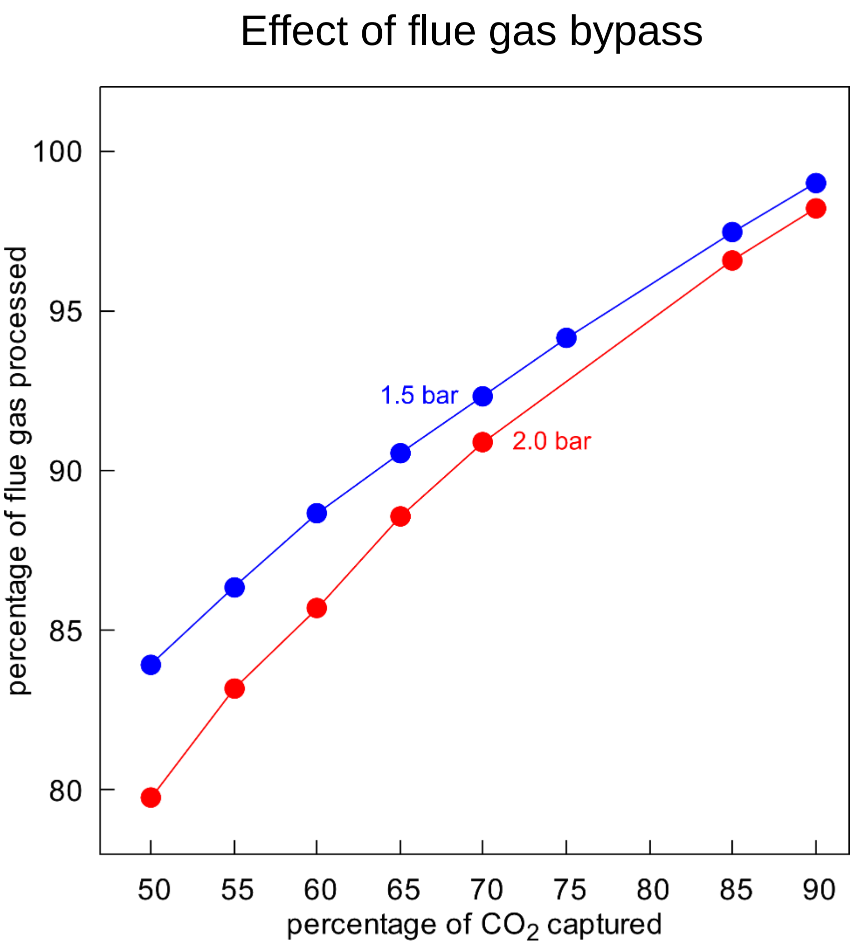
Can flue gas bypass the capture system?

What is effect of pressure?



Partial Capture on NGCC using Membranes with Energy Minimization



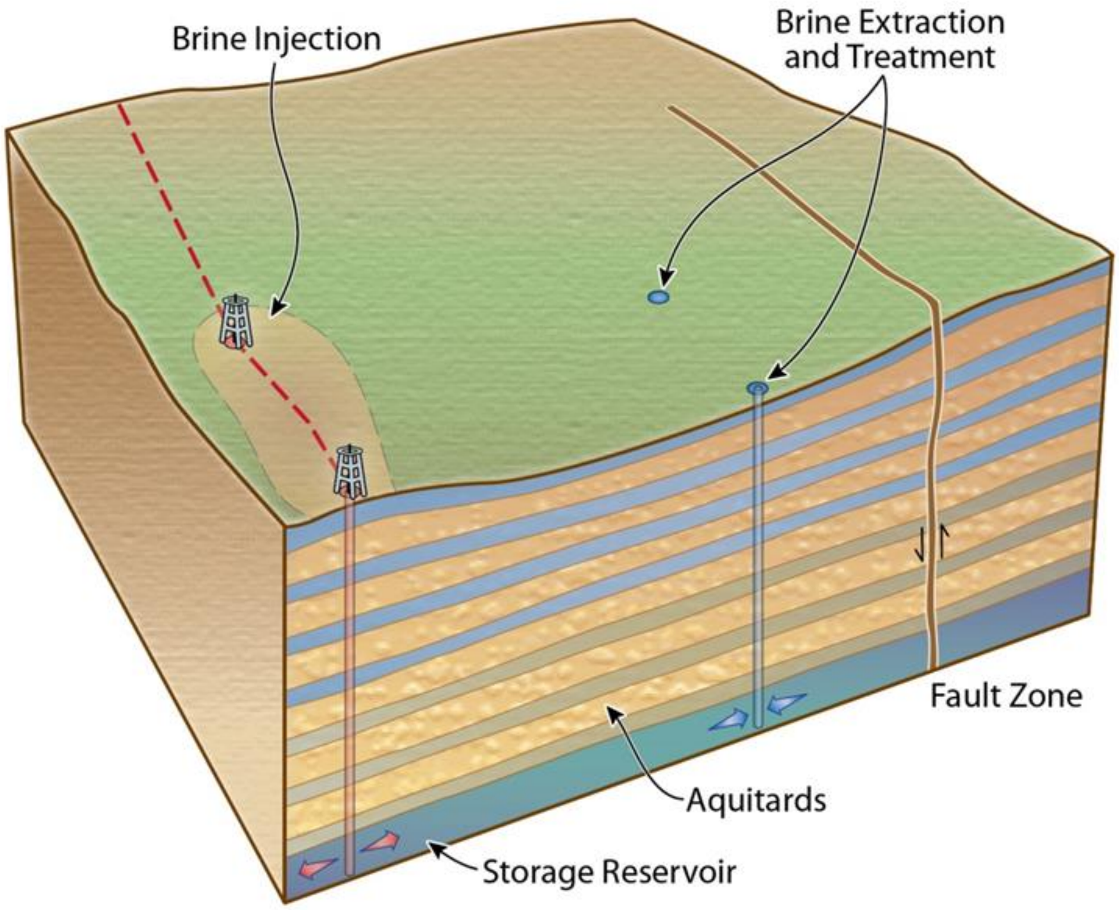


Lower pressure results in less energy (at expense of capital).
Partial capture of CO_2 may require processing most of the flue gas.

Brine Extraction Storage Test

DOE Project DE-FE0026140

- Lower Tuscaloosa formation in SE U.S.
- Use waste water injection as a surrogate for CO_2
- Extract brine to manage reservoir pressure and control plume
- Treat brine (high TDS) to make usable water



ESD15-015

Potential Cost to CCS

- Phase I: 2015-16
  - Initial assessment indicated brine treatment will add between \$3-\$25/t CO_2 but some estimates as high as \$71/ tCO_2.
  - Cost depends heavily on the amount of brine extracted, chemistry of the brine, and the particular treatment technology employed.
- Phase II: 2016-18
  - Project team will conduct field tests at Gulf Power's Plant Smith.
  - This will include a site where water treatment vendors can test their technologies on the extracted brine.

Together…Shaping the Future of Electricity

EPRI | ELECTRIC POWER RESEARCH INSTITUTE