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CO_2 Capture R&D at the Electric Power Research Institute

Abhoyjit S. Bhown

NETL CO_2 Capture Technology Meeting

Pittsburgh, PA

July 9-13, 2012

About The Electric Power Research Institute

- Established 1973 as independent, not-for-profit research center
- Nearly every area of electricity generation, delivery, use, health, environment, efficiency
- Major locations in Palo Alto, CA; Charlotte, NC; Knoxville, TN
- ~$400 million/yr revenue; ~700 staff

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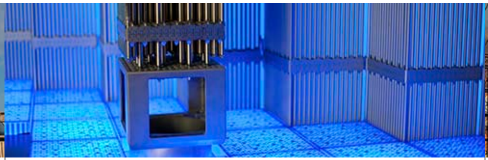
Portfolio Spans the Entire Electricity Sector



Generation

- Advanced Coal Plants, Carbon Capture and Storage
- Combustion Turbines
- Environmental Controls
- Generation Planning
- Major Component Reliability
- Operations and Maintenance
- Renewables

Nuclear Power

- Advanced Nuclear Technology
- Chemistry, Low-Level Waste and Radiation Management
- Equipment Reliability
- Fuel Reliability
- Instrumentation and Control
- Long-Term Operations
- Material Degradation/Aging
- Nondestructive Evaluation and Material Characterization
- Risk and Safety Management
- Used Fuel and High-Level Waste Management

Power Delivery & Utilization

- Transmission Lines and Substations
- Grid Operations and Planning
- Distribution
- Energy Utilization
- Cross Cutting Technologies

Environment

- Air Quality
- Environmental Aspects of Renewables
- Global Climate Change
- Land and Groundwater
- Occupational Health and Safety
- T&D Environmental Issues
- Water and Ecosystems

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Industry Needs for CCS

- Affordable, energy-efficient, demonstrated CO_2 capture and compression
- Understanding of transport systems, pipelines, and their requirements
- Permanent, environmentally-benign, publicly-accepted geologic storage
- Alternatives to geologic storage

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EPRI's Role…

Help Move Technologies to the Commercialization Stage…

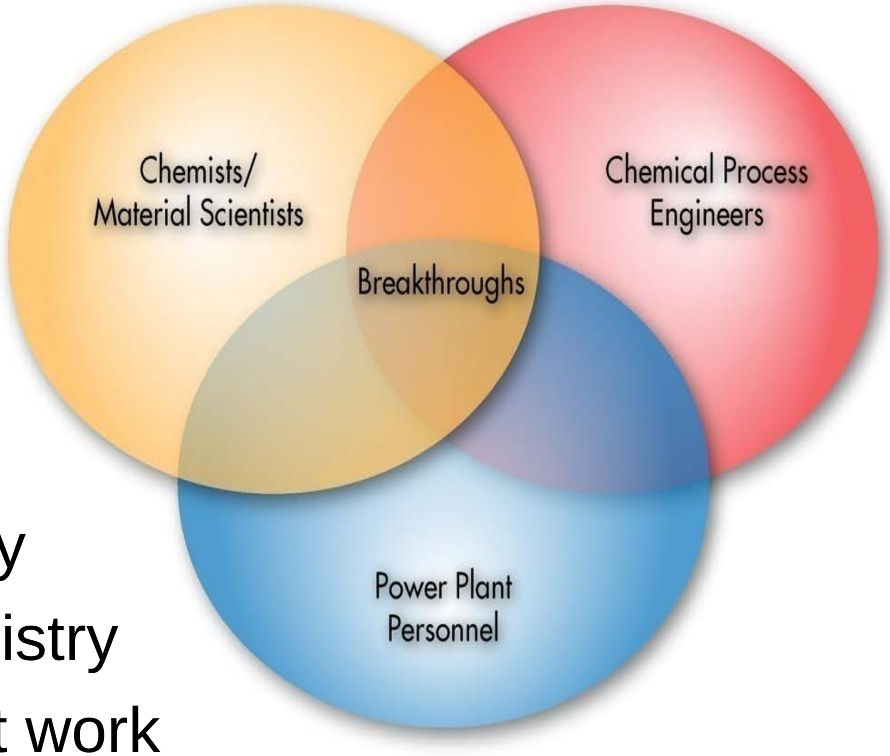
EPRI

Capture technologies are often developed here …

… but need an understanding of challenges and opportunities here

An Institutional Problem

- Disconnect today between chemistry, process, plant
- Breakthroughs will require collaboration between all 3
  - Need new capture chemistry
  - Wrap process around chemistry
  - Power plant team to make it work
- Must be synergistic, not linear



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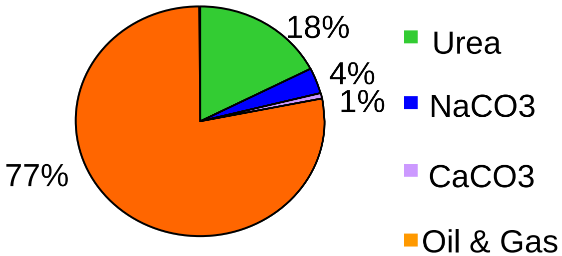
Annual U.S. CO_2 Utilization vs. Emission

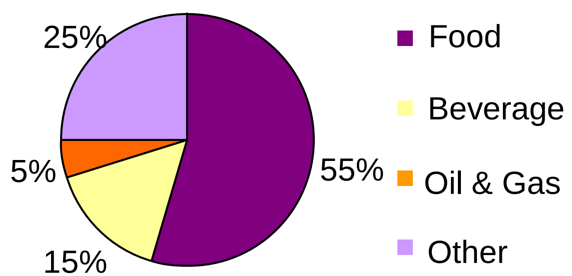
Gaseous Consumption

Mainly enhanced oil recovery



Liquid/Solid Consumption

Mainly Food



Total Utilization ~ 100 Mt

Sources: SRI Consulting, MIT, UT Austin

5 Largest CO_2 Emitters in 2009				
	Plant	Location	CO_2, Mt/yr	GWe
1	Scherer	Juliette, GA	25.0	3.56
2	Bowen	Cartersville, GA	20.8	3.50
3	Miller	Quinton, AL	23.3	2.82
4	Martin Lake	Tatum, TX	26.0	2.38
5	Gibson	Owensville, IN	22.2	3.34
		Total	**117.3**	**15.6**

U.S. Utilization = 100 Mt
= Emissions 5 large plants

U.S. Emissions = 2400 Mt from utility
= 6000 Mt total

Sources: EPA, IEA

CO_2 Scale

		US Production, Estimated 2009			Global Production, Estimated 2009		
		Mt	Gmol	GWe –yr at 90% capture	Mt	Gmol	GWe-yr at 90% capture
1	Sulfuric Acid	38.7	394	2.1	199.9	1879	10.0
2	Nitrogen	32.5	1159	6.2	139.6	4595	24.5
3	Ethylene	25.0	781	4.2	112.6	3243	17.3
4	Oxygen	23.3	829	4.4	100.0	3287	17.5
5	Lime	19.4	347	1.8	283.0	4653	24.8
6	Polyethylene(HDPE, LDPE, LLDPE, etc.)	17.0	530	2.8	60.0	1729	9.2
7	Propylene	15.3	354	1.9	53.0	1134	6.0
8	Ammonla, Synthetic Anhydrous	13.9	818	4.4	153.9	8332	44.3
9	Chlorine	12.0	169	0.9	61.2	795	4.2
10	Phosphoric Acid	11.4	116	0.6	22.0	207	1.1
...	...	...	...	...	...	...	...
45	Acetic Acid	2.3	38	0.2	8.0	123	0.7
46	Propylene Oxide	2.1	37	0.2	6.3	100	0.5
47	Phenolic Resins	2.1	21	0.1	6.8	63	0.3
48	Calcium Carbonate (Precipitated)	2.0	20	0.1	13.0	120	0.6
49	Butadiene (1.3)	2.0	36	0.2	10.3	175	0.9
50	Nylon Resins & Fibers	1.9	8	0.0	2.3	8	0.0
	TOTAL	419	8,681	46	2,412	48,385	257
	2009 Coal-fired Generation, GWe-yr			200			>1000+
	Coal-fired Capacity, GWe			314			>1000+
	CO_2 from Electricity	2,400	54,545		~9600	218,182	
	CO_2 from All Sources	6,000	136,364		~31200	750,000	

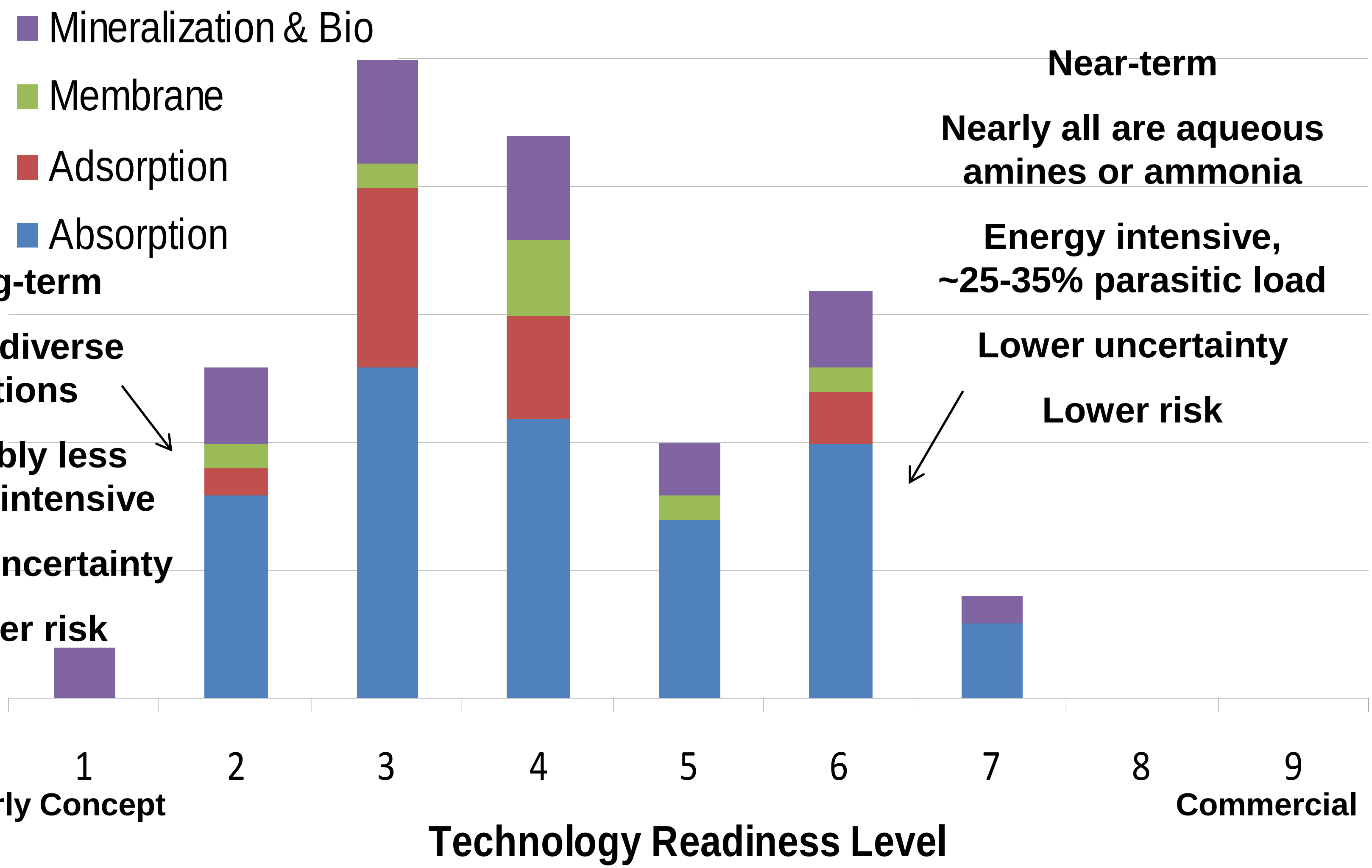
$A + CO_2 \rightarrow ACO_2$

Limited supplies of A & limited sales of ACO_2

Need to regenerate A or make A with CO_2 constraints

Bhown and Freeman: EPRI Reports1016995 (2008), 1017644 (2009), *Environ Sci Technol*. (2011)

TRL of Post-Combustion Capture Technologies



Long-term

More diverse options

Possibly less energy intensive

Higher uncertainty

Higher risk

Near-term

Nearly all are aqueous amines or ammonia

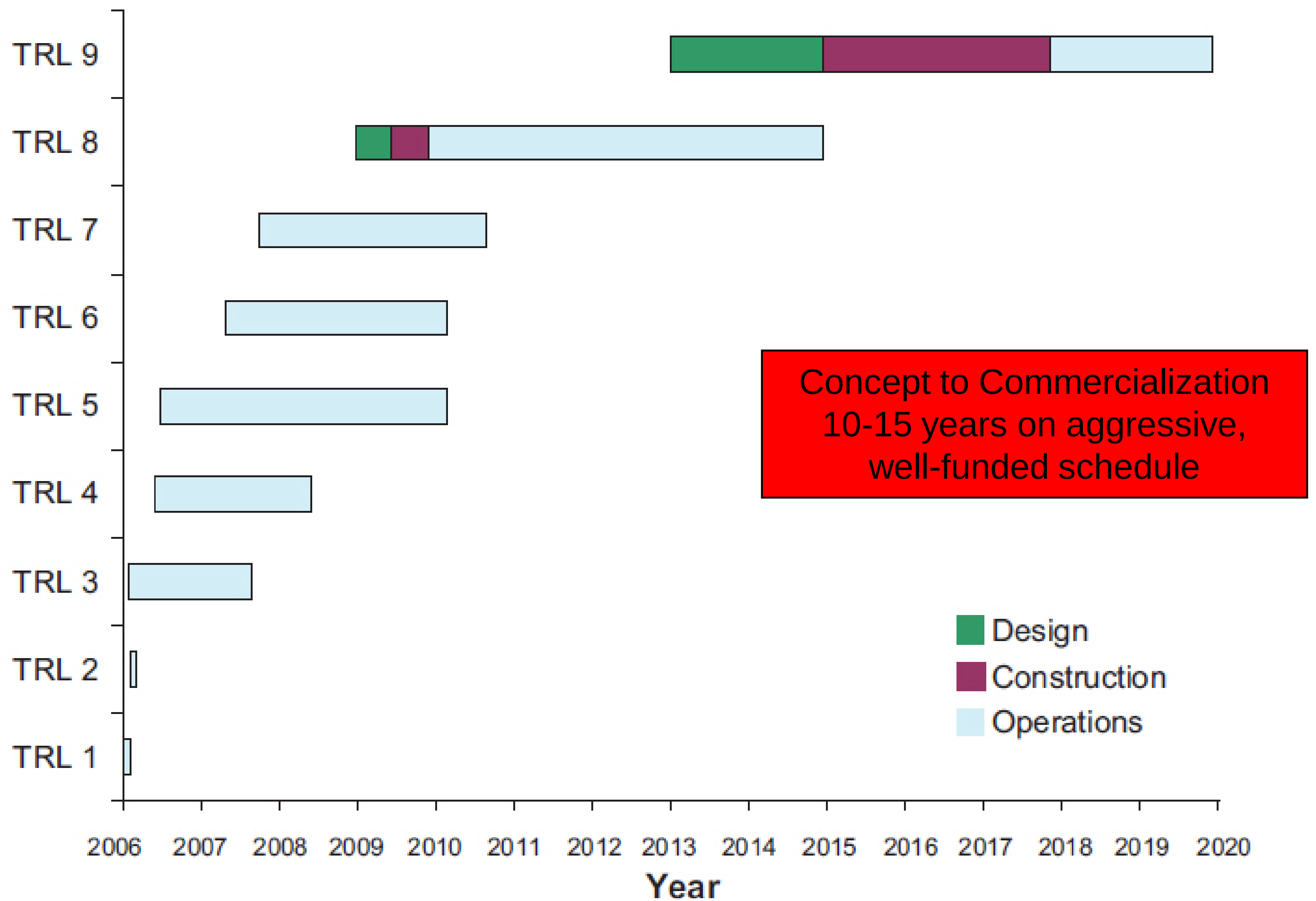
Energy intensive, ~25-35% parasitic load

Lower uncertainty

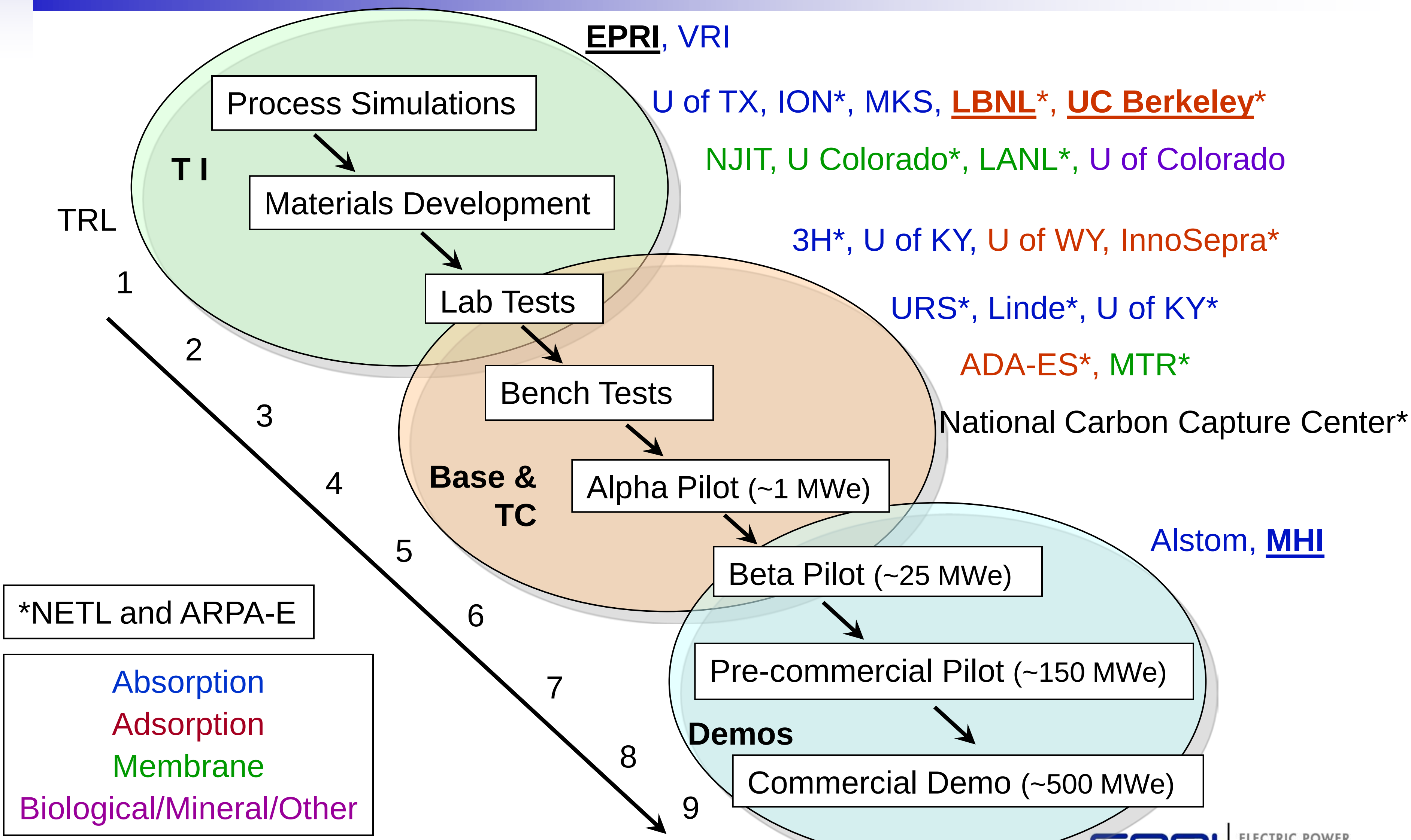
Lower risk

Bhown and Freeman: EPRI Reports1016995 (2008), 1017644 (2009), *Environ Sci Technol*. (2011)

Timescale for Capture Process Development



Post-Combustion CO_2 Capture R&D at EPRI



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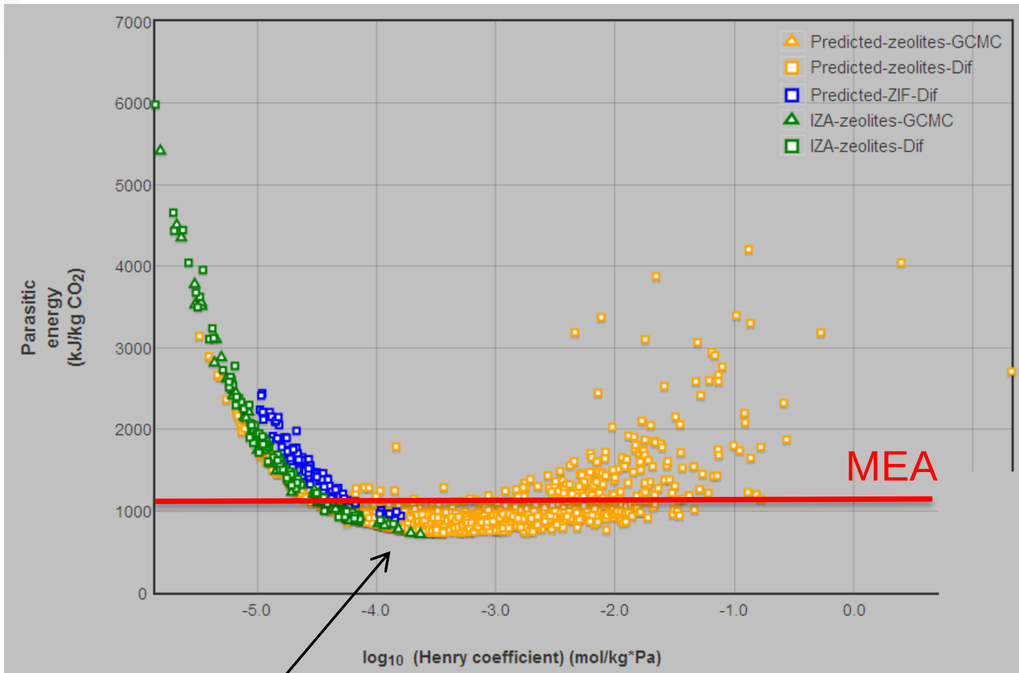
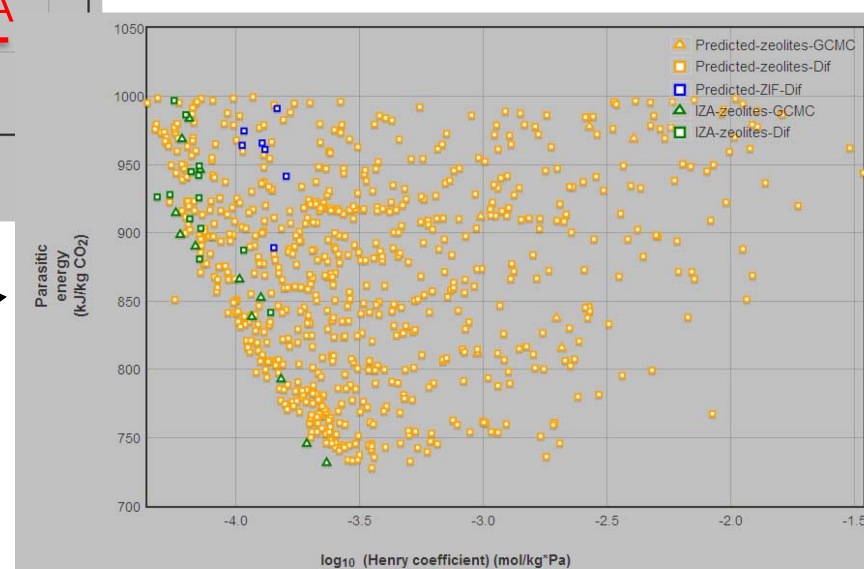
Combining Basic Science and Engineering: Screening of Low-Energy Capture Adsorbents



- Apply computational chemistry and engineering models to a database of 4 million zeolites
- Rapidly calculate minimal energy consumption for each material
- Thousands of new adsorbents identified



- Most promising materials
- Very broad minimum
- 2×10^{-4} < Henry's Coefficient < 2×10^{-3}
- No single defining characteristic
- www.carboncapturematerials.org

Lin et al., Nature Materials, 11, 633 (2012)

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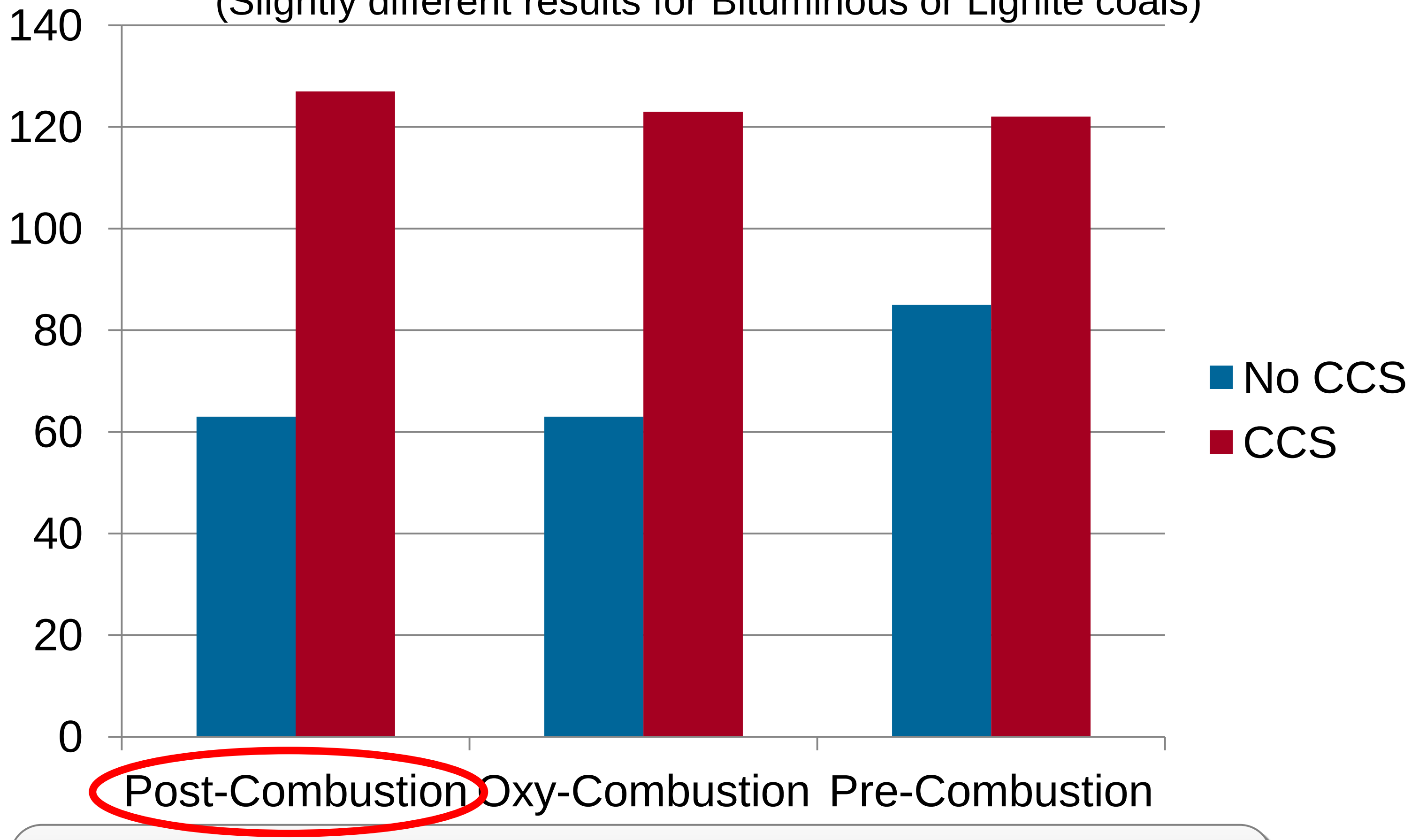
PC with CCS – Southern
Demonstration Project Overview

MHI's KM-CDR Process, Progress Photo July 2011
Property of MHI and/or Southern

- **MHI KM-CDR advanced amine CO_2 post-combustion capture**
  - ~25-MW_e demonstration at Alabama Power's Plant Barry in AL
  - ~550 tons (500 tonnes)-CO_2/day
  - Capture started on June 3, 2011; over 50,000 tonnes captured so far
  - Injection program under U.S. DOE's Southeast Regional Carbon Sequestration Partnership (SECARB) Project
  - Wells drilled, pipeline in place, and injection to begin in 3Q 2012
  - Up to 4 years injection followed by 3-4 years monitoring
- EPRI's role:
  - Measure and report CO_2 capture performance and economics
  - Responsible for the storage work under SECARB

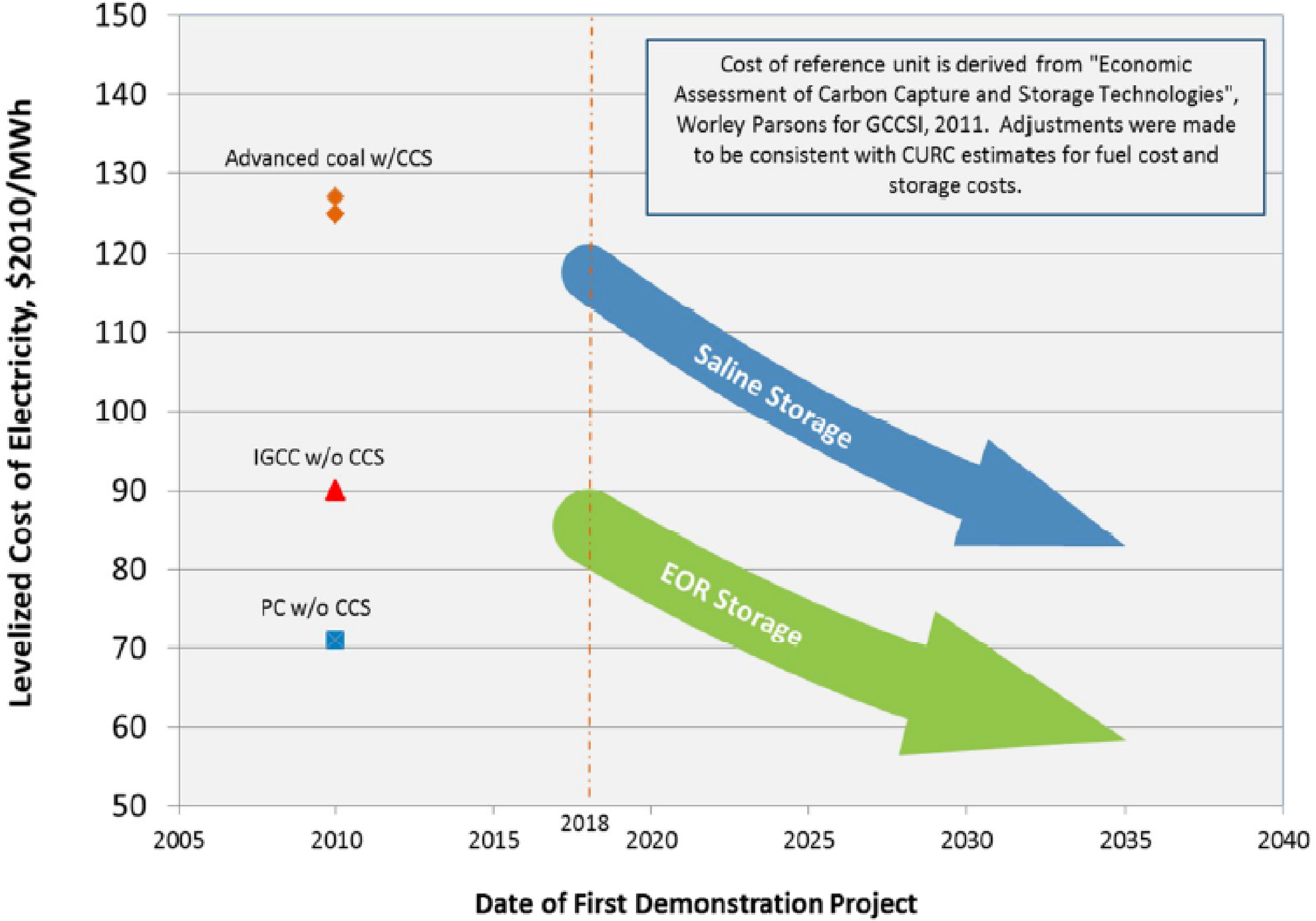
Levelized Cost of Electricity Estimates ($/MWhr) for New 600-700 MW Plants

Based on Powder River Basin Coal, Midwest US site and $10/ton cost for storing CO_2
(Slightly different results for Bituminous or Lignite coals)



All three approaches with CCS cost about the same

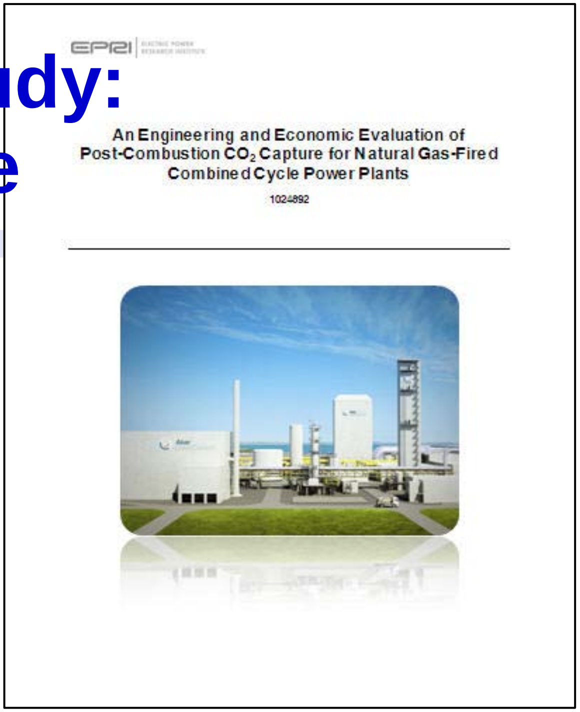
Projected Future LCOE



NOTE: 2010 costs reflect best engineering estimates at the time for first of a kind units, and do not represent commercial costs.

Source: CURC-EPRI Coal Technology Roadmap, 2012

NGCC with Capture Study: Objective and Scope


An Engineering and Economic Evaluation of Post-Combustion CO_2 Capture for Natural Gas-Fired Combined Cycle Power Plants

1024892

- Evaluate the performance and cost impact of applying post-combustion capture (PCC) to today's NGCC
  - Reference 556-MWe (Net) base NGCC plant
  - Retrofit post combustion plant to baseplant
  - New build NGCC plant designed with capture
  - New build NGCC plant designed with capture and exhaust gas recycle (EGR).
- Essentially 3 cases of full-scale 90% capture at the same Kenosha, Wisconsin, USA site location
- Aker Clean Carbon generated a PCC design based on their current commercial offering with an advanced amine solvent
- Norsk Energi assisted in the steam cycle analysis, optimization, and costing for the overall advanced capture process assessment and integration

Performance Results

	Reference NGCC Plant	NGCC plant RETROFITTED with PCC	NEW BUILD NGCC Plant Designed with PCC and Exhaust Gas Recycle	NEW BUILD NGCC plant Designed with PCC
Gross power output (MW)	566	566	566	566
Aux Load (MW)	9.5	78.8	72.3	78.8
Net Power Output (MW)	556.5	487.2	493.7	487.2
Net plant Heat Rate (BTU/KWh) HHV	6625	7560	7470	7560
Net plant efficiency % HHV	51.5%	45.1%	45.7%	45.1%
Efficiency reduction % points	-	6.4%	5.8%	6.4%

Shows 0.6% point performance saving with Exhaust Gas Recycle

Source: EPRI Report 1024892

Where Do We Go from Here?

- Closely monitor development of capture technologies
- Maintain comprehensive understanding of capture technology landscape
- Identify gaps, areas to accelerate, strategic thrusts
- Actively guide development of materials based on predicted system-level performance
- Establish proof of concept, lab-, bench-, bench-, pilot-, and commercial-scale

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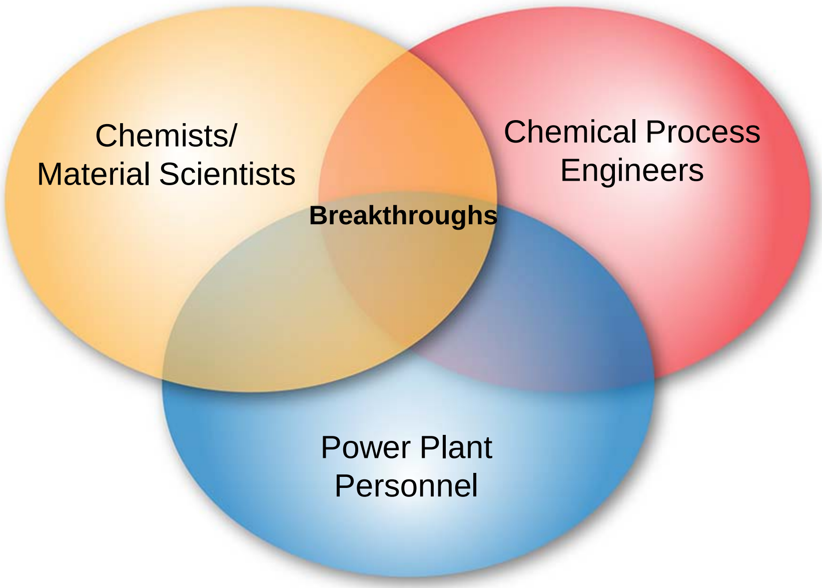
Together…Shaping the Future of Electricity



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