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Status of Post-Combustion CO_2 Capture Technologies

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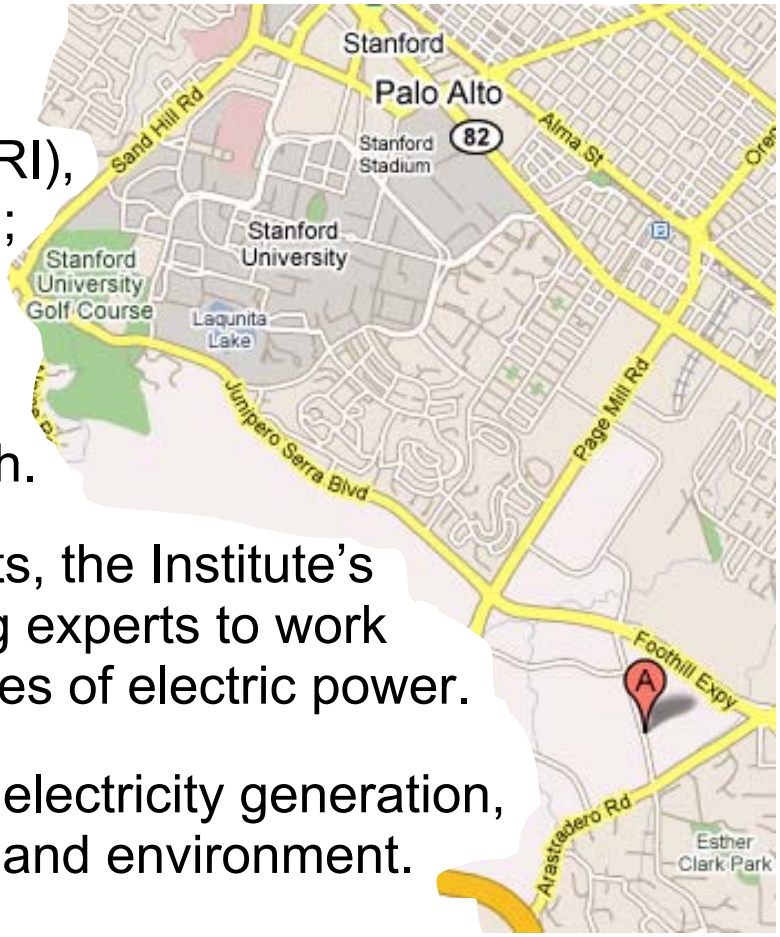

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These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment.

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EPRI ELECTRIC POWER RESEARCH INSTITUTE

Outline

- Scope and Approach
- Challenges in CO_2 Capture
- Technology Readiness Level
- Status of CO_2 Capture Technologies
- Future

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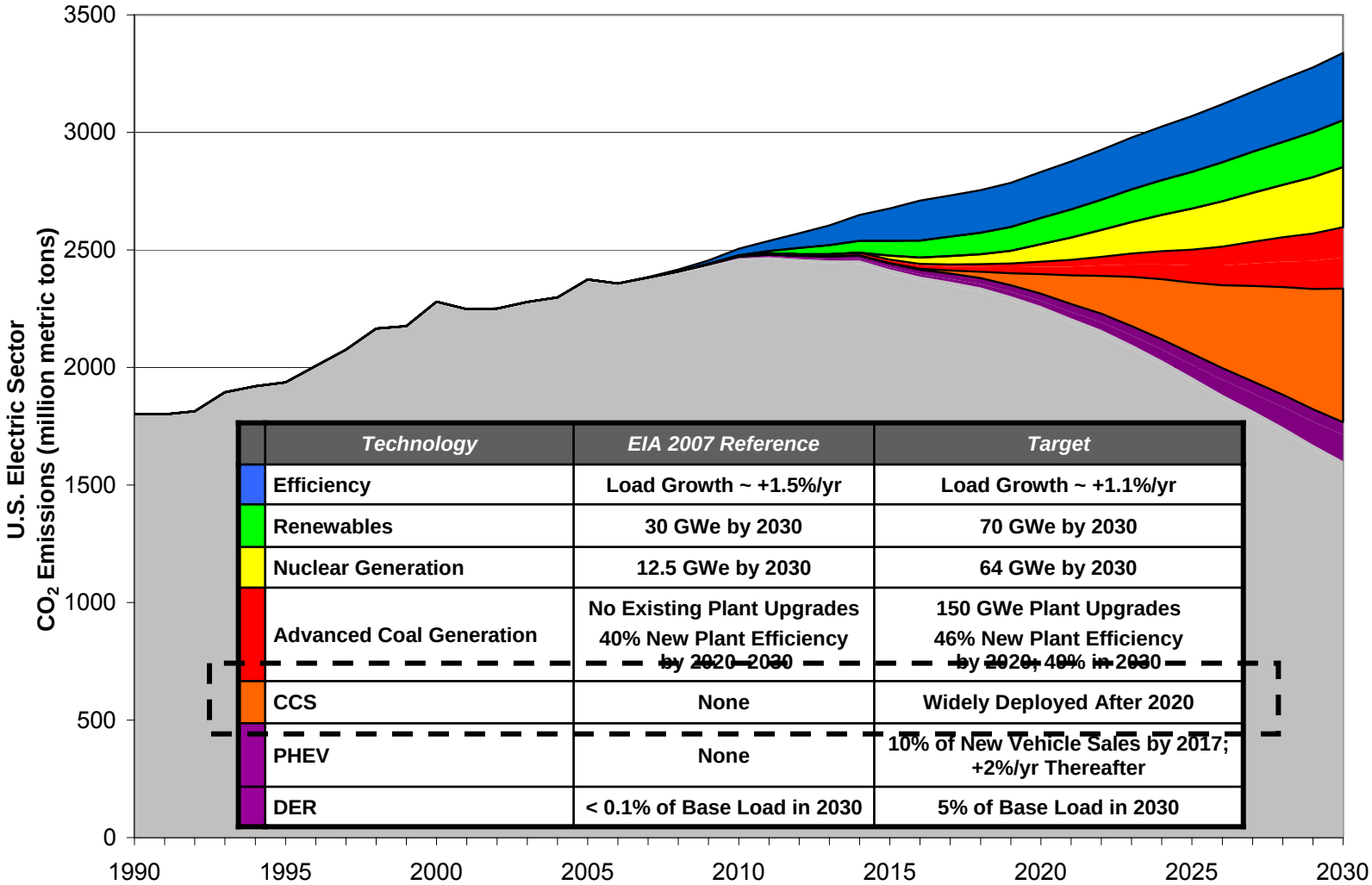
Reducing CO_2 Emissions



	Technology	EIA 2007 Reference	Target
	Efficiency	Load Growth ~ +1.5%/yr	Load Growth ~ +1.1%/yr
	Renewables	30 GWe by 2030	70 GWe by 2030
	Nuclear Generation	12.5 GWe by 2030	64 GWe by 2030
	Advanced Coal Generation	No Existing Plant Upgrades 40% New Plant Efficiency by 2020–2030	150 GWe Plant Upgrades 46% New Plant Efficiency by 2020; 49% in 2030
	CCS	None	Widely Deployed After 2020
	PHEV	None	10% of New Vehicle Sales by 2017; +2%/yr Thereafter
	DER	< 0.1% of Base Load in 2030	5% of Base Load in 2030

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Integrated CO_2 Storage Demonstrations and Accelerated Postcombustion Capture Development at EPRI

Find Improved CO_2 Capture Processes

(Select 5-10)

- Proactively mine universities, conferences; announce interest
- Develop conceptual system design
- Develop process simulations
- Evaluate & select for industry support

Scale-Up (0.25–5 MW)
(follow-on initiative)

Verify operability, energy consumption, CO_2 capture rates

- Storage uncertainty = RISK; need long-term demo, start now
- Use advanced capture processes as become available
- Leverage DOE, others

Capture and Storage Demo (~20 MW)

- Site 1 with current capture technology
- Sites 2–5 with advanced capture technologies

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Scope and Approach

- A 2+ year effort focused on post-combustion CO_2 capture technologies. Currently on-going.
- Scope was to find, vet, and accelerate promising CO_2 capture technologies
- Approach
  - Understand concept based on chemistry, process, energy penalty under non-disclosure agreement if needed.
  - Evaluated over 70 processes being developed globally; majority of capture processes
  - Absorbents (solvents), adsorbents, membranes, mineralization, biofixation, miscellaneous
  - Accelerate technologies with largest potential impact within funding limits and other constraints

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Challenges for CO_2 Capture – Global Scale

Rank	Chemical	2002 Production Mt *	Estimate +13% for 2007 Mt	Gmol	GWe if equimolar rxn with CO2 90% capture
1	Sulfuric Acid	36.65	41.54	423.54	2.74
2	Nitrogen	30.76	34.87	1244.65	8.06
3	Ethylene	23.67	26.83	838.44	5.43
4	Oxygen	22.04	24.98	890.27	5.76
5	Lime	18.42	20.87	372.24	2.41
6	Polyethylene	16.06	18.20	568.91	3.68
7	Propylene	14.46	16.38	380.27	2.46
8	Ammonia, Anydrous	13.20	14.96	878.51	5.69
9	Chlorine	11.39	12.91	182.02	1.18
10	Phosphoric Acid	10.81	12.26	125.06	0.81
95	Sodium Bicarbonate	0.54	0.61	7.24	0.05
96	Cyclohexanone	0.54	0.61	6.19	0.04
97	Propylene Glycol	0.53	0.60	7.92	0.05
98	Phthalic Anhydride	0.53	0.60	4.03	0.03
99	Sodium Sulfate	0.51	0.58	4.06	0.03
100	Potassium Hydroxide	0.47	0.54	9.55	0.06
	TOTAL	443.08	502.16	10339.12	66.95

Global top 100 chemicals production total ~ 0.5 Gt/yr; CO_2 Emissions ~ 30 Gt/yr

$A + CO_2 \rightarrow ACO_2$

Limited supplies of A & limited sales of ACO_2

Must regenerate A or produce A with CO_2 constraints for 335 GWe US coal power

**** Source: American Chemistry Council***

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Challenges for CO_2 Capture – Scale

- Chemicals used in once-through capture process (without regeneration) will quickly exhaust global supplies of that chemical

- Sale of chemicals resulting from CO_2 capture will overwhelm global markets if process is widely adopted, i.e., zero price.

- Separating material must be regenerated or manufactured with net CO_2 reduction

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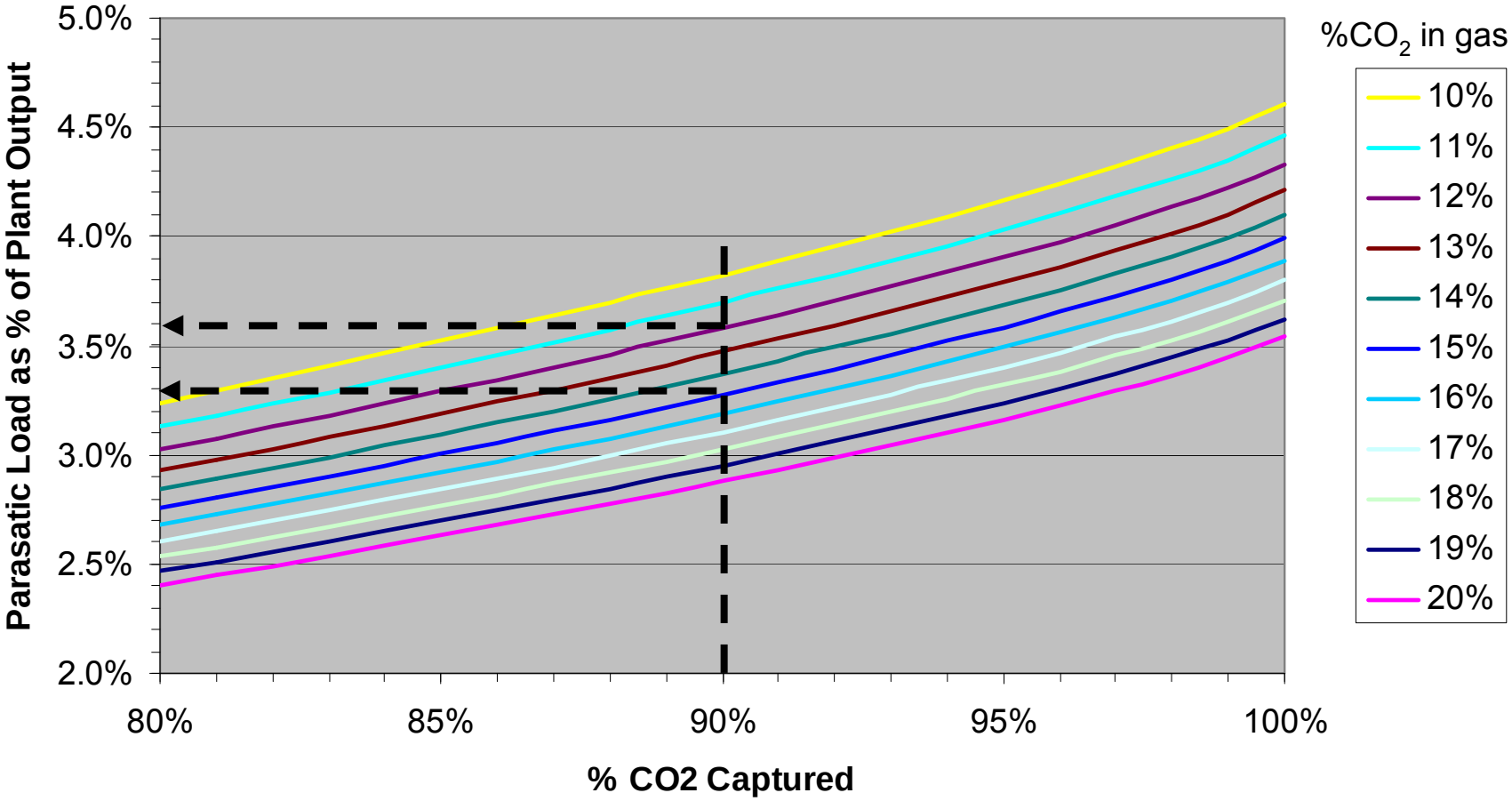
Minimum Energy for CO_2 Capture



If all capture energy comes from net power output, then the process independent thermodynamic minimum parasitic load for 40°C flue gas is ~3.5% to capture 90% CO_2

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Minimum Energy for CO_2 Capture

- Need a thermodynamic minimum of about 3.5% of energy from power plant to capture 90% CO_2
  - Minimum energy is equivalent to 0.165 GJ/t CO2
  - Does not include compression
  - Assumes all energy comes from net electrical output
  - 40°C flue gas
  - 20.7 t CO_2/day/MWe
- Expect 3-5x the minimum energy for a good process
- Minimum energy for capturing 385 ppm CO_2 from air
  - 0.524 GJ/t CO_2 (100% recovery)
  - 0.465 GJ/t CO2 (near 0% recovery)
  - About 3x the minimum energy from flue gas

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Challenges for CO_2 Capture

- Broad Challenges
  - Capture large amounts of CO_2 (multiples of global chemical industry)
  - Energy penalties
- Additional Constraints
  - Limited water availability (cooling)
  - Limited land availability
  - Tolerate other flue gas constituents
  - Existing balance of plant
  - Features that limit to only certain regions
  - Once-through capture processes
  - Saleable products

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CO_2 to Carbon or Fuels

- "Convert" CO_2 to carbon
  - $C + O_2 \rightarrow CO_2$; $\Delta H \sim -393.5$ kJ/mol
  - About 1/3 ΔH converted to electricity in power plant (-131 kJ/mol)
  - The same ΔH (393.5 kJ/mol) energy input is needed to reverse reaction and make carbon, i.e., minimum 3x power plant output
  - Practically, need far more than 3x power plant output
- "Convert" CO_2 to fuels
  - Identical issue as with carbon
  - All fuels are combusted to produce CO_2 and H_2O to generate ΔH
  - Reversing reaction will consume far more energy than available from combusting fossil fuels
- If such usable energy is available, then it may likely be better to use that energy to make electricity instead, and avoid generating CO_2 from fossil fuel combustion in the first place.

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Sun as Energy Source for CO_2 Conversion

- Organisms use sun as energy source to convert CO_2 to fuels
- Process is slow and with poor use of sun's incident energy for purposes of CO_2 capture
- Fastest algae capture ~24 g C/m^2/day (~1.5x of switch grass)
- About 45 mi^2 for 500 MWe coal-fired power plant. Amine scrubbing is estimated at 12 acres, already viewed as a "very large" area
- For non-biological processes that use solar energy to drive CO_2 conversion, it may likely be better to convert the solar energy directly to electricity and avoid generating CO_2 from fossil fuel combustion in the first place

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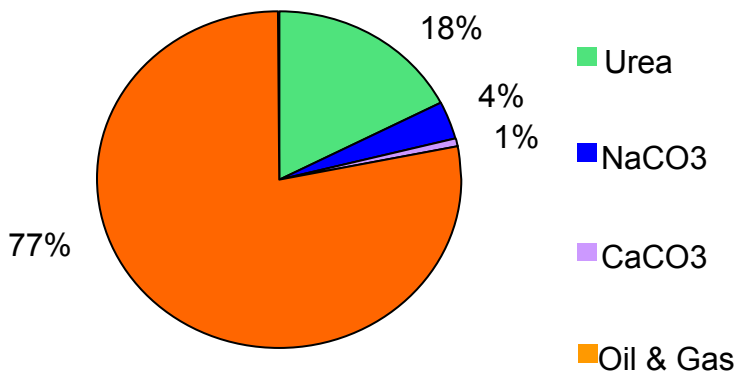
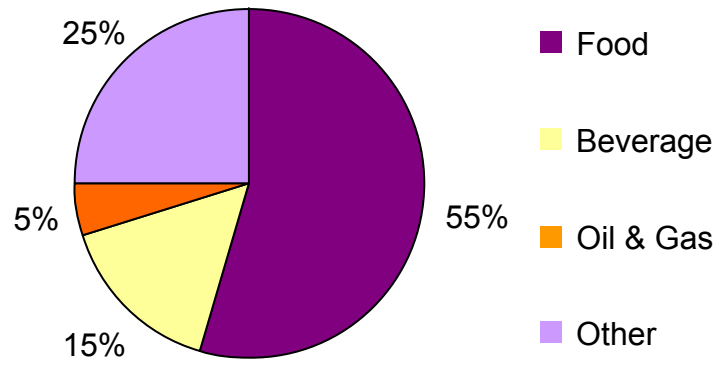
CO_2 Usage – United States

Gaseous Consumption = 30.9 million metric tons



Mainly EOR

Liquid/Solid Consumption = 7.1 million metric tons



Mainly Food

~40M Tonnes of Use vs. 6B Tonnes Currently Emitted (2.5B Tonnes from US Utility Sector)

Source: Howard Herzog / MIT Laboratory for Energy and the Environment

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Limits on CO_2 Capture Technologies

- Second law violators
  - CO_2 to fuels need energy source, and only energy source is sun at large scales
  - Sometimes do not account for overall total CO_2 footprint
- Real Estate Moguls
  - Biological processes use solar energy for CO_2 conversion, but need substantial land
  - Solar energy may likely be better used to make electricity directly instead of converting CO_2 in non-biological processes
- Massive Material Mismatch (once-through capture)
  - Limited global supply of chemicals to capture CO_2 or make saleable products
  - Limited use of CO_2 directly
- CO_2 gold mine ≠ CO_2 solution

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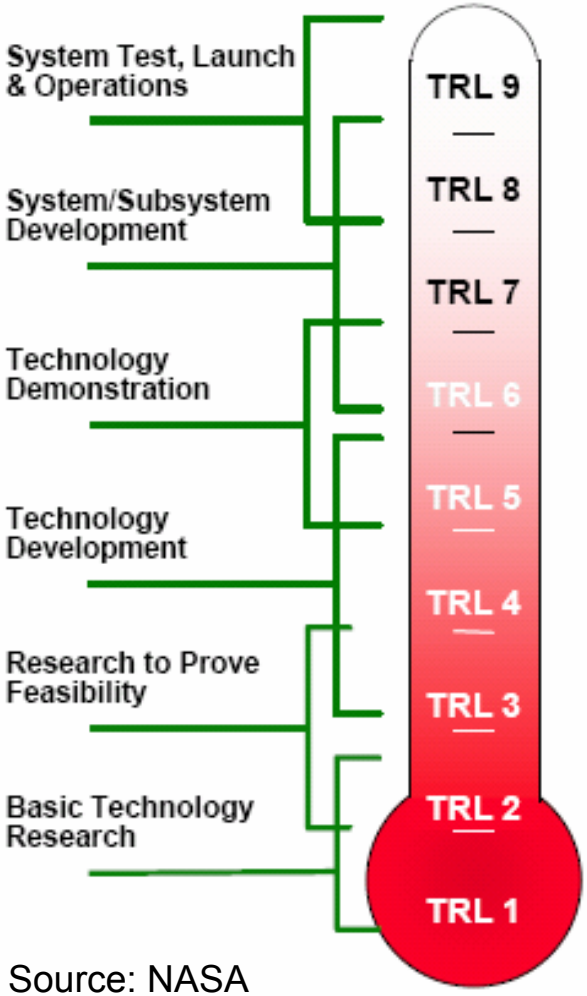
Carbon Capture Technology Profiles – Technology Readiness Level (TRL)

- Used to categorize and describe technologies under development

- Predict and better understand:
  - Relative risk
  - Time to market or a key development stage
  - Cost to reach market or a key development stage



Source: NASA

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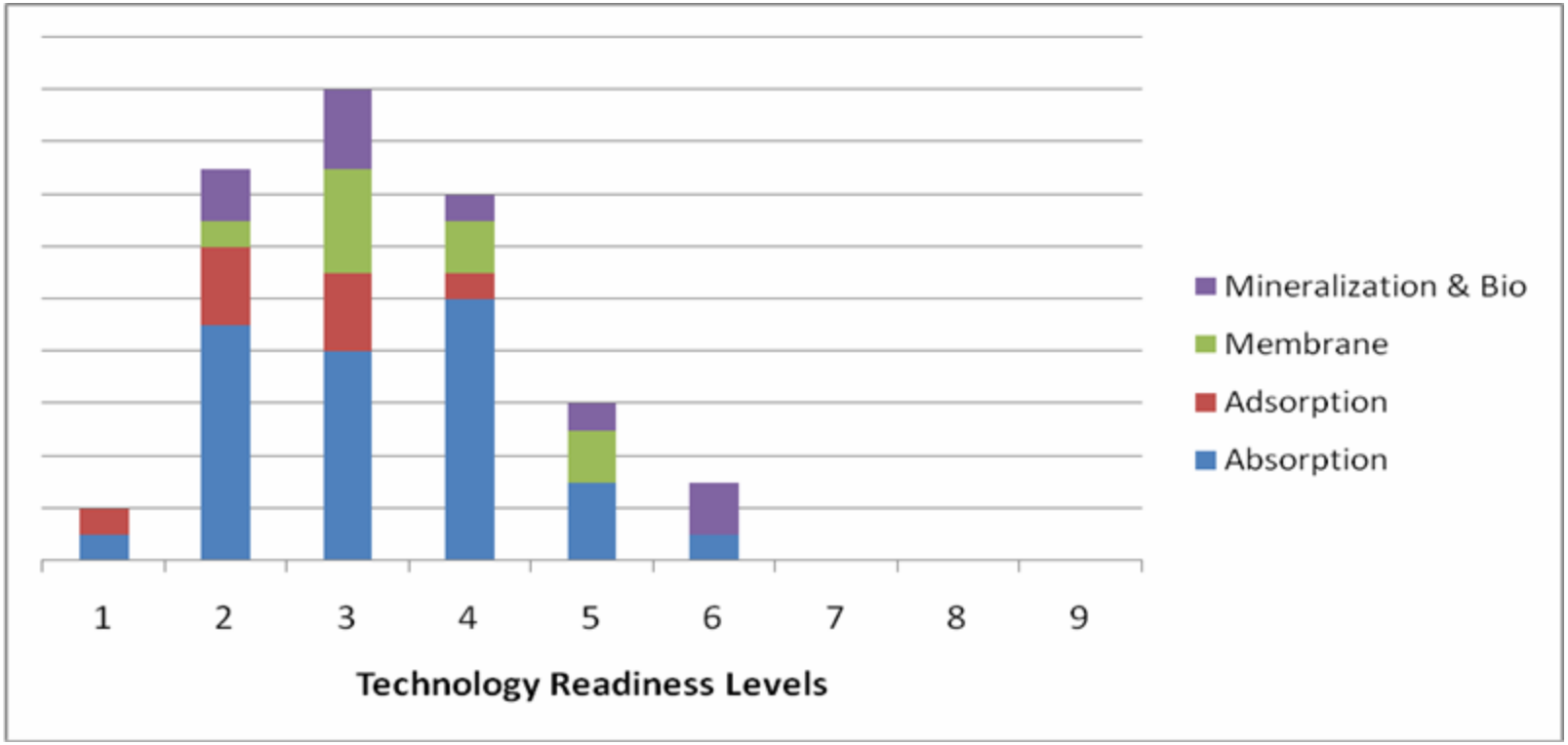
Capture Technologies: TRL Ranking

- Majority of processes are absorption based
- Most are at TRL 2 -4 (preliminary design to laboratory validation)



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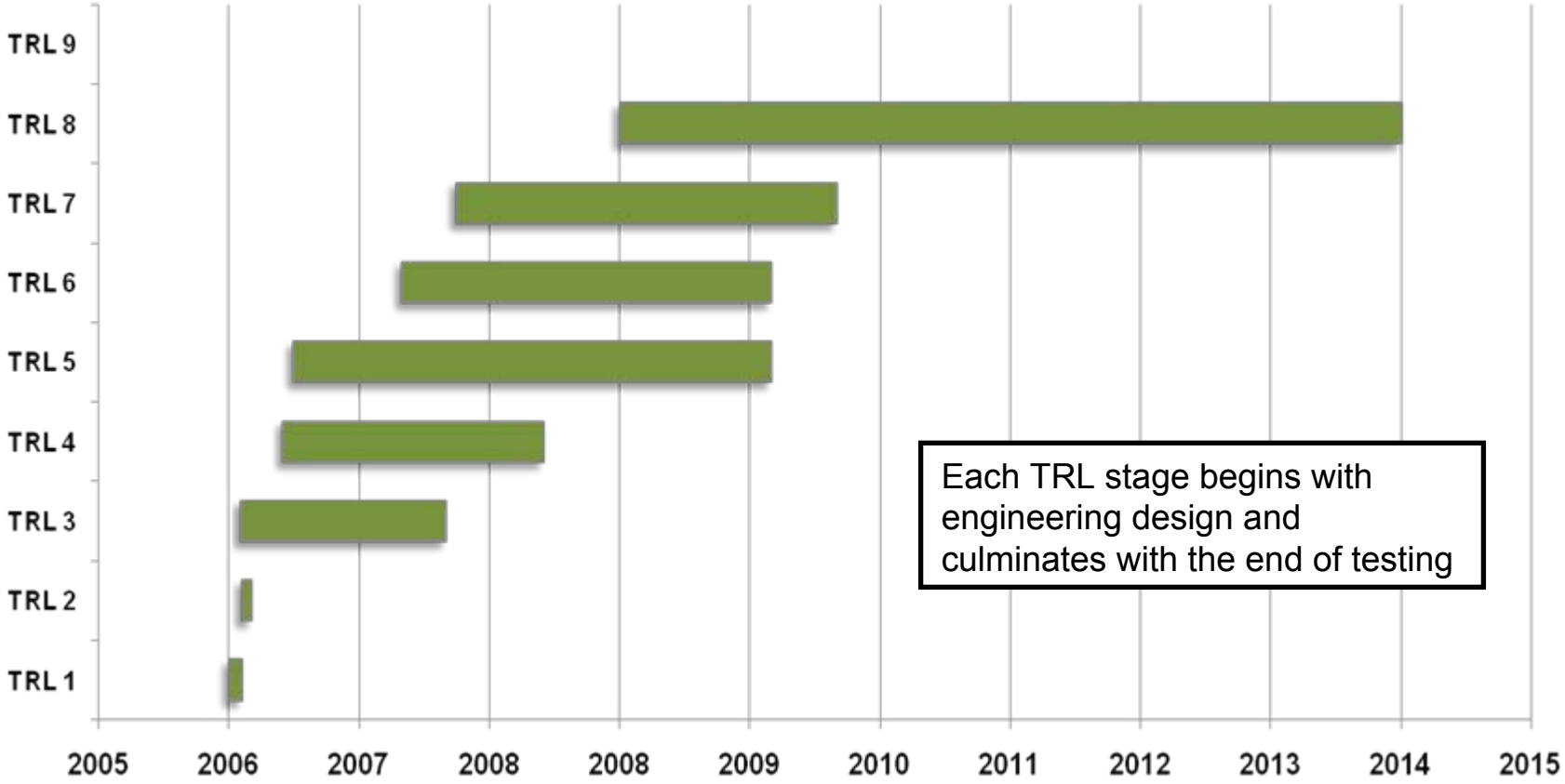
Timescale for Capture Process Development



Each TRL stage begins with engineering design and culminates with the end of testing

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State of Capture Development

	Absorbent	Adsorbent	Membrane
Commercial Usage in CPI*	*High*	*Moderate*	*Low/Niche*
Operational Confidence	*High*	*High, but complex*	*Low to moderate*
Energy Penalty No Compression	*<18% to 25%*	*~14% to 20%*	*~12%-15%*
Source of Energy Penalty	*Solvent Regen thermal*	*Sorbent Regen thermal/vac*	*Vacuum on permeate*
Trends	*New chemistry, thermal integrat.*	*New chemistry, process config*	*New membrane, process config*

*Chemical Process Industries

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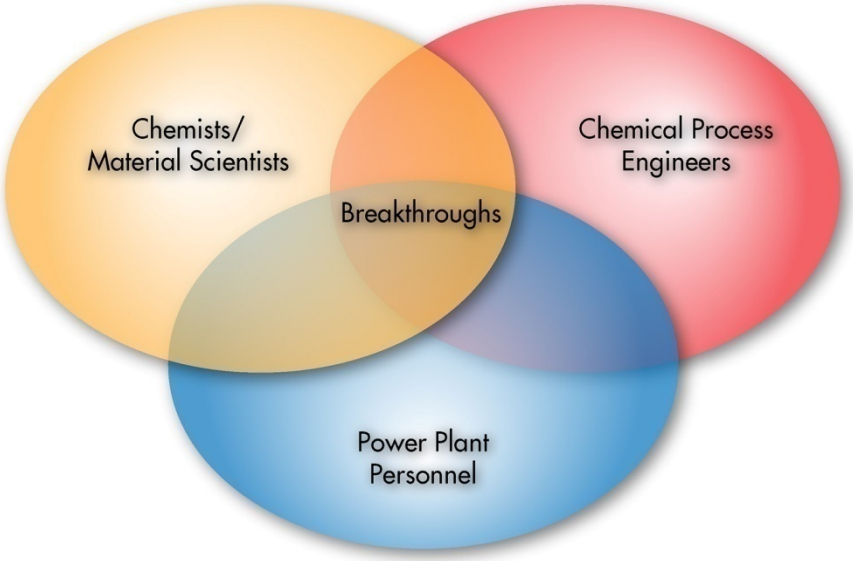
Carbon Capture Technology Profiles - Trends

- Disconnect between chemistry, process, plant
  - Breakthroughs require collaboration between all 3



Broad Challenges

- Capture large amounts of CO2
- Energy penalties

Additional Constraints

- Limited water availability (cooling)
- Limited land availability
- Tolerate other flue gas constituents
- Existing balance of plant
- Features that limit to only certain regions
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Current and Future Activities

- Current
  - Find additional technologies
  - Continuing evaluations
  - Support promising technologies from concept to pilot
  - Process modeling of CO_2 capture processes
- Future
  - Streamlined and objective information from process developers to utility companies
  - Additional development projects
  - Larger pilot demonstrations at power plants
  - Exploring coordination of university-based, capture research

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