CO_2 Capture R&D at EPRI

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NETL CO_2 Capture Technology Meeting
August 13–16, 2018
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.

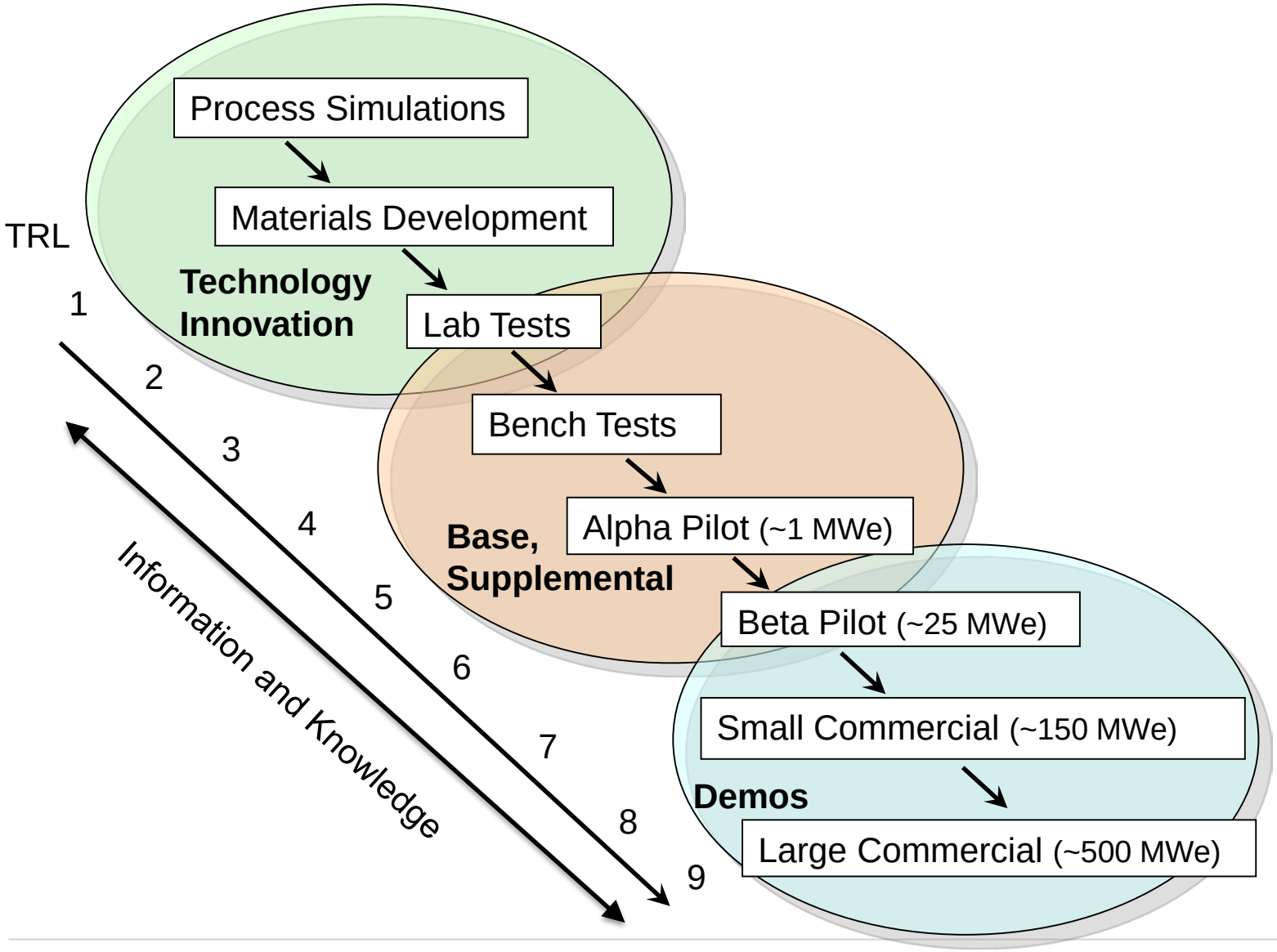
Nonprofit and Collaborative

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 ~$410 M

CO_2 Capture R&D at EPRI



Modeling and Simulations

Materials Development

Process Development

Academic Consortia

National Carbon Capture Center

Pilot Data and Verification

Techno-Economic Analysis

and

Focused Projects, e.g.,
How do we reduce capital costs?

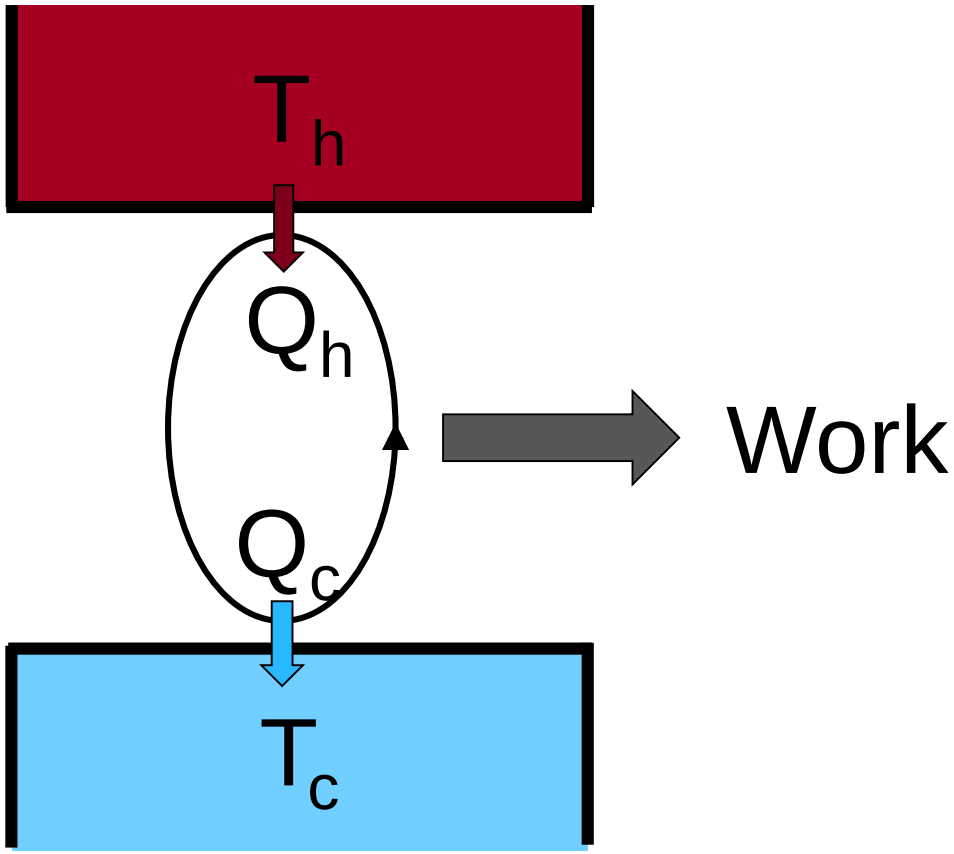
Work for CO_2 Capture and Compression, 2 bar Stripper

	90% Capture 2 bar	Compression 2-140 bar	Total
Minimum Work, GJ/t	0.203	0.203	0.406
Work*, GJ/t	0.779	0.267	1.05
Current Multiple	3.83x	1.32x	2.58x

Increasingly Harder to Reduce Without Increasing Capital Costs

*Exergy analysis based on “Cost and Performance Baseline for Fossil Energy Plants,” Rev 3, July 2015, DOE/NETL-2015/1723

Basics – Heat and Work



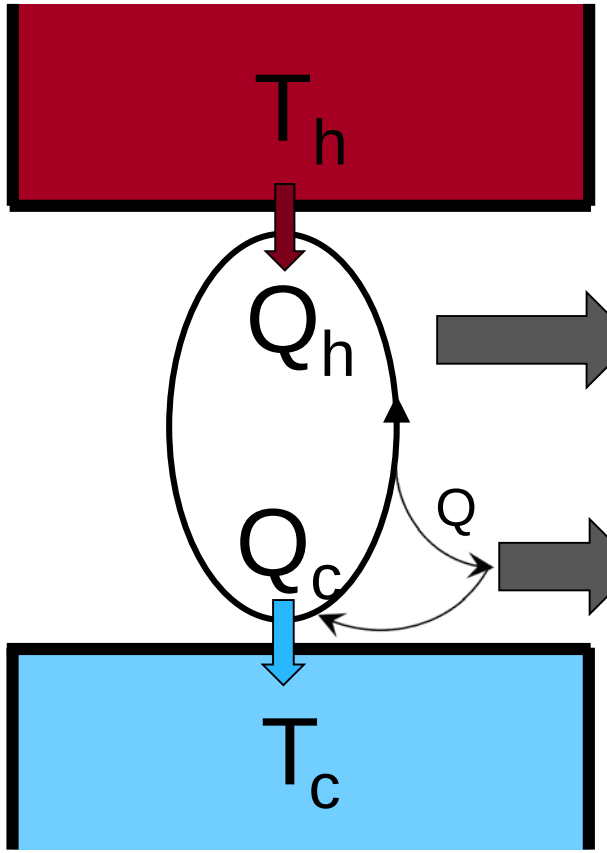
$$Define\ Efficiency \quad \eta = \frac{W}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

$$Carnot\ Limit \quad \eta_{Carnot} = 1 - \frac{T_c}{T_h}$$

Work limited by Carnot efficiency

Use work to generate electricity and…

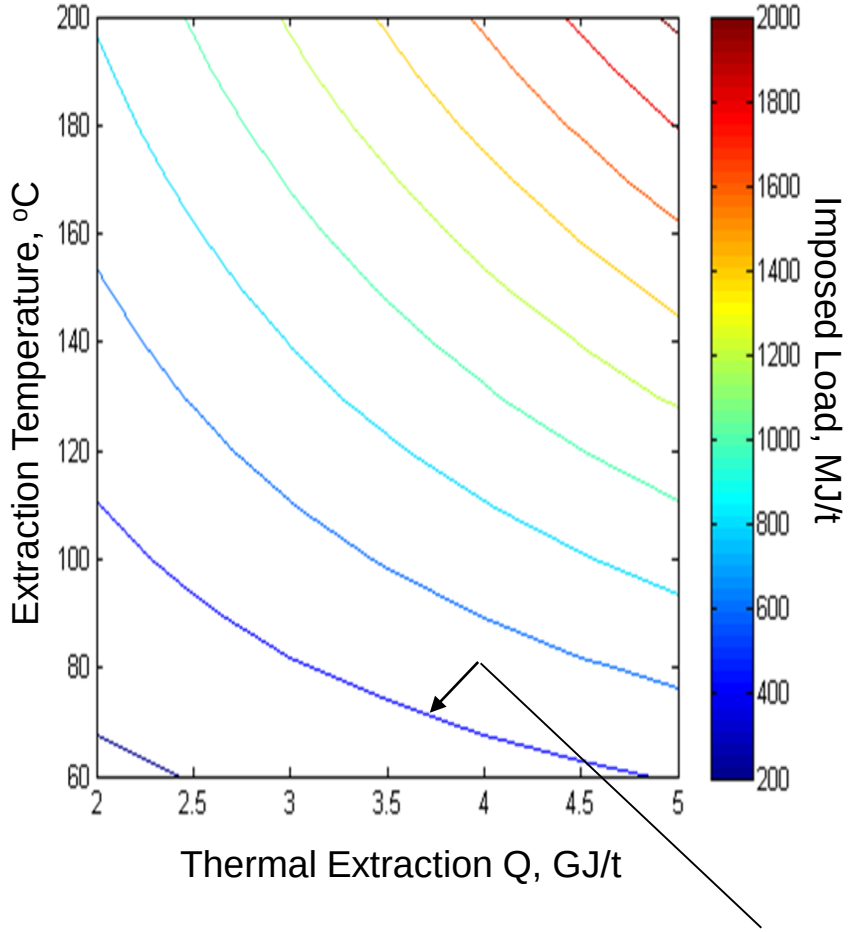
Use Work To Generate Two Products: Electricity and Pure CO_2



Electricity

CO_2

Want to maximize electricity generation per unit pure CO_2 generation



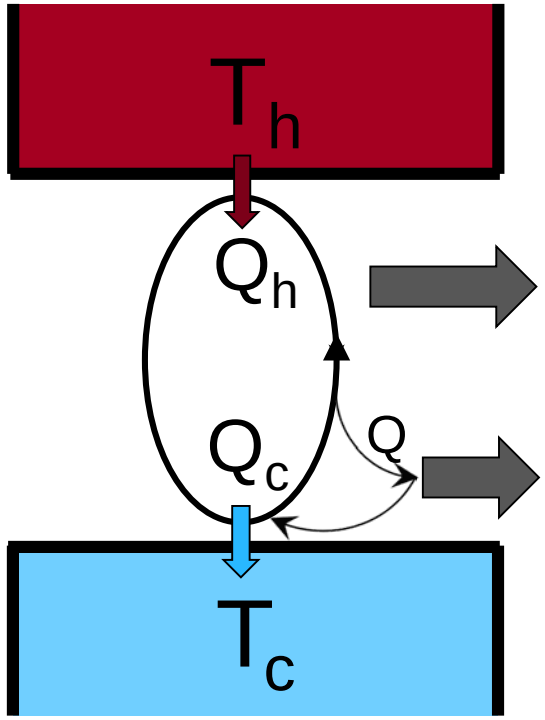
If oxygen comes from air,

separation work will always be required!

[True for post, pre, oxy, CLC, fuel cells,…]

Q = 2 GJ/t @ 110°C is equivalent to
Q = 5 GJ/ton @ 60°C

Capital-Energy Trade Off “Electrical Work” vs “Separation Work”



	Electricity	Capture + Compression	90% Capture 2 bar	Compression 2-140 bar
Energy In, MW	1,694	140	104	36
Energy Out, MW	690	54.3	27.1	27.1
Thermo Efficiency	40.7%	38.8%	26.1%	76.0%
Capital, $M	1,730	654	552	102
$/kW (in)	1,021	4,674	5,297	2,852
$/kW (out)	2,507	12,040	20,314	3,751

Estimated from “Cost and Performance Baseline for Fossil Energy Plants”, Rev 3, July 2015, DOE/NETL-2015/1723

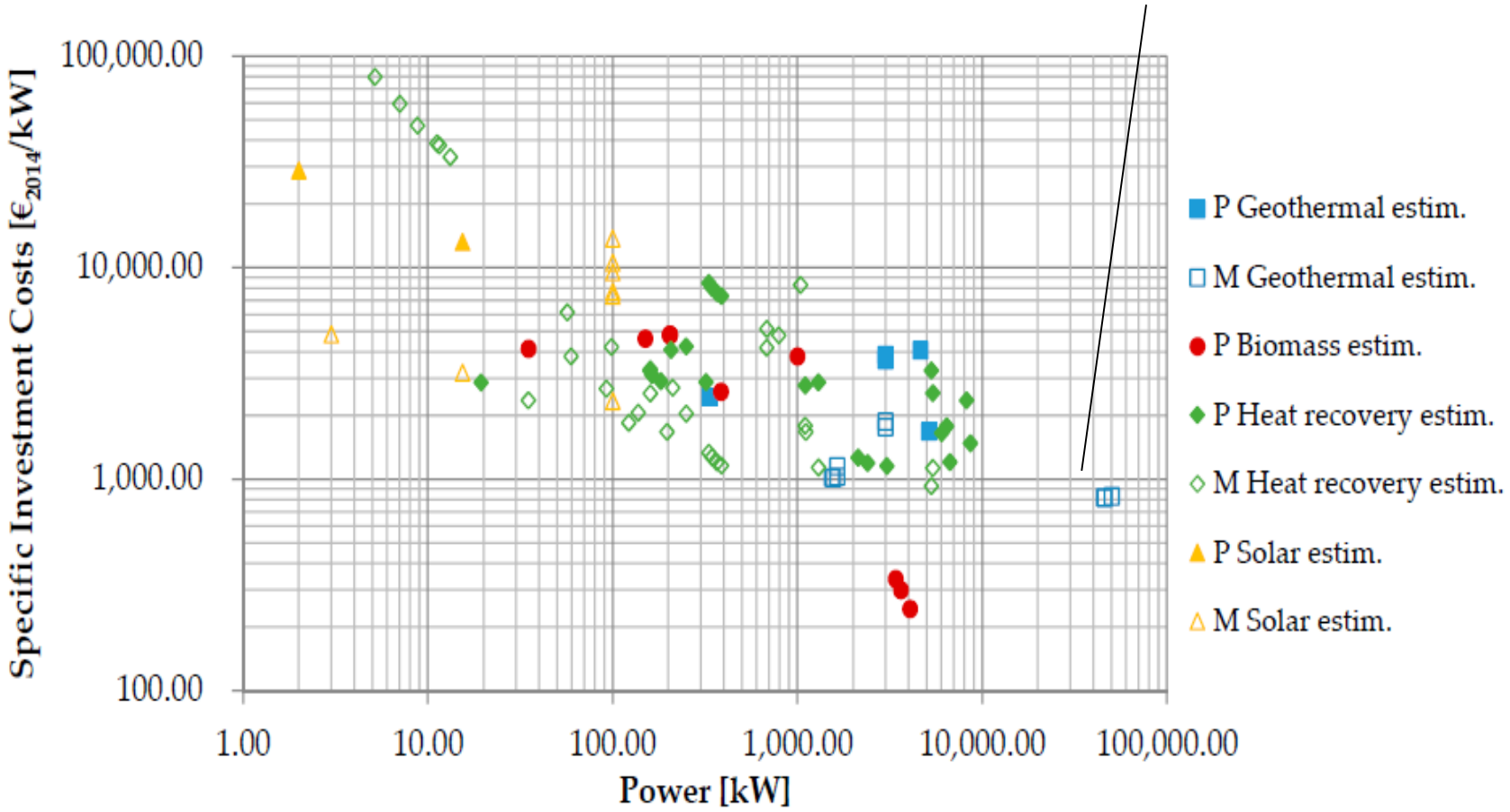
Separation work is 2/3rd as efficient and 8x the capital cost of mechanical/electrical work

Key Question: Why Does Separation Need So Much More Capital per Unit Work ($/kW)?

1. Chemical Engineers are 2/3rd as efficient and cost 8x more than Electrical and Mechanical Engineers
2. Electro-mechanical work is at the top of the steam cycle (higher steam quality) while separation work is at the bottom of the steam cycle (lower steam quality)
3. Other ideas?

Lower Temperature Electro-Mechanical Work: Organic Rankine Cycles

Large Scales ~$1,000/kW

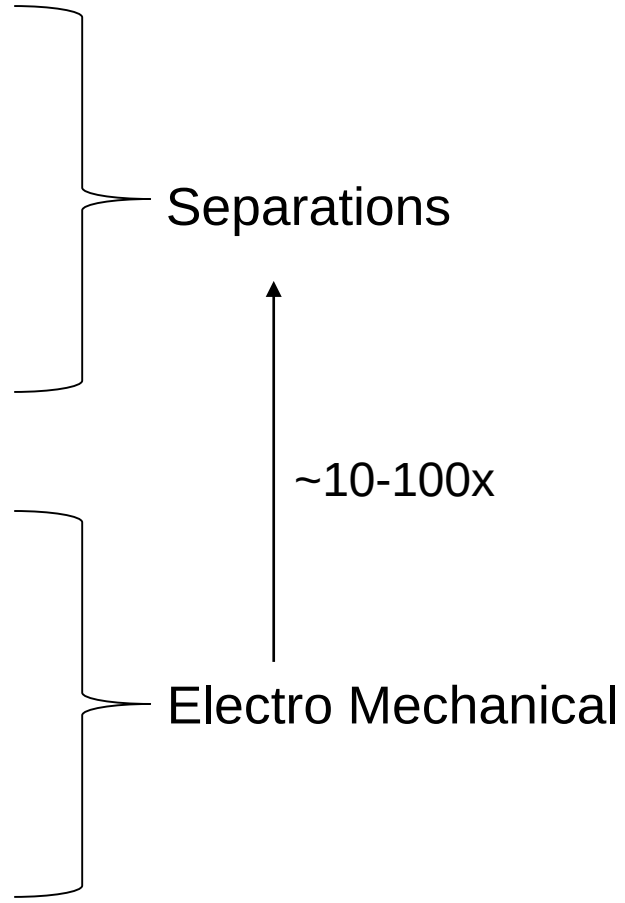


At larger scales, capital cost for electro-mechanical work is still lower than separation work

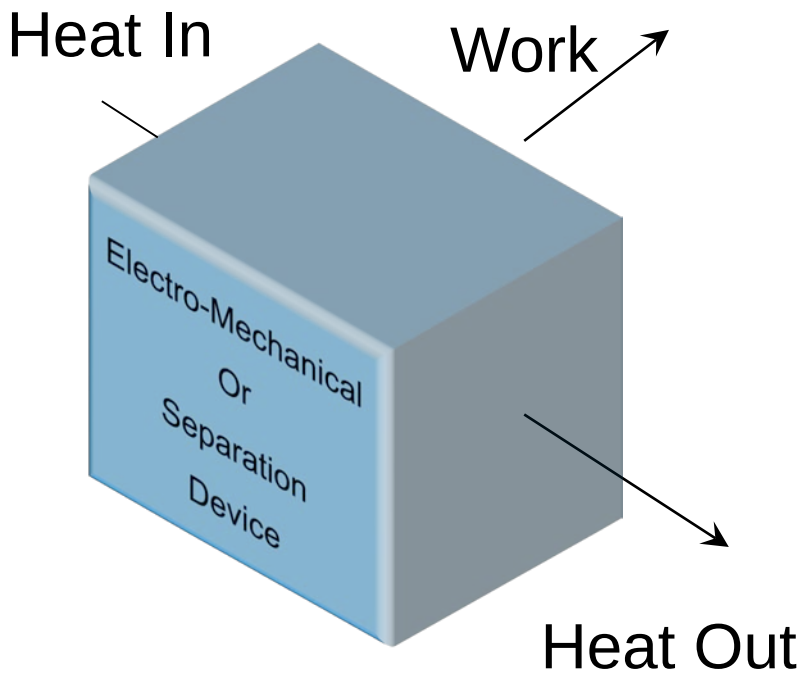
Energies **2016**, 9, 485; doi:10.3390/en9070485

Electro-Mechanical Work vs Separations Work (Some examples…)

Process	Source	Capital Cost, $/kW
Seawater RO	Carlsbad	164,000
Seawater Desal	CPP Report	130,351
Capture at 2 bar	NETL Baseline	20,314
Capture at 2 bar - 20% capture	CPP Report	34,816
Compression 2-140 bar	NETL Baseline	3,751
Supercritical coal plant	NETL Baseline	2,507
Organic Rankine Cycle (Extrapolated to ~100 MWe)	Various Refs	1,000



It’s Something Else, Probably



- Consider a electro-mechanical or separation device that converts heat or other form of energy to work
- Rate of work generation dependent on underlying principle
- Electro-mechanical based on convection with characteristic velocity ~10^2 m/s
- Separation work based on diffusion with characteristic velocity 10^{-4} m/s (in liquids)

Electro-mechanical work ~10^6 faster

Convection vs Diffusion

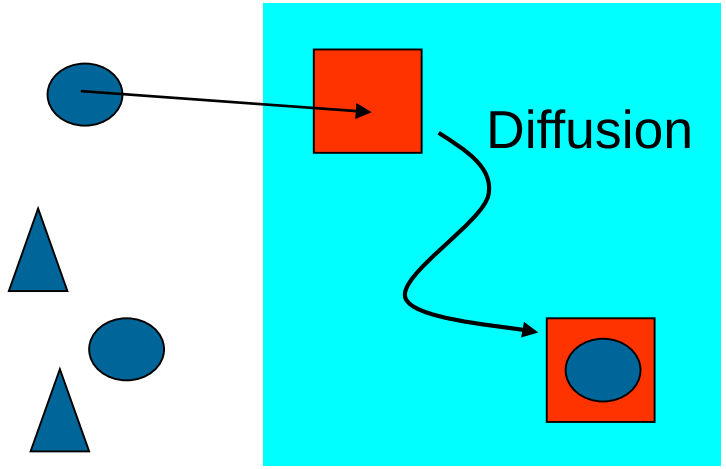
	Electro-mechanical 	Separation 
Driving Force	Mechanical Pressure	Chemical Potential
Fluid Movement	Convection	Diffusion
Characteristic Velocity	~10^{2} m/s	~10^{-4} m/s
Volume	Small	Large
$/Volume	High	Low
$	Comparable	Comparable
kW	Large	Small
$/kW	Low	High

convection vs diffusion

Seems explains why $/kW for electromechanical << $/kW for separations

Can Molecular Separations Be Sped Up?

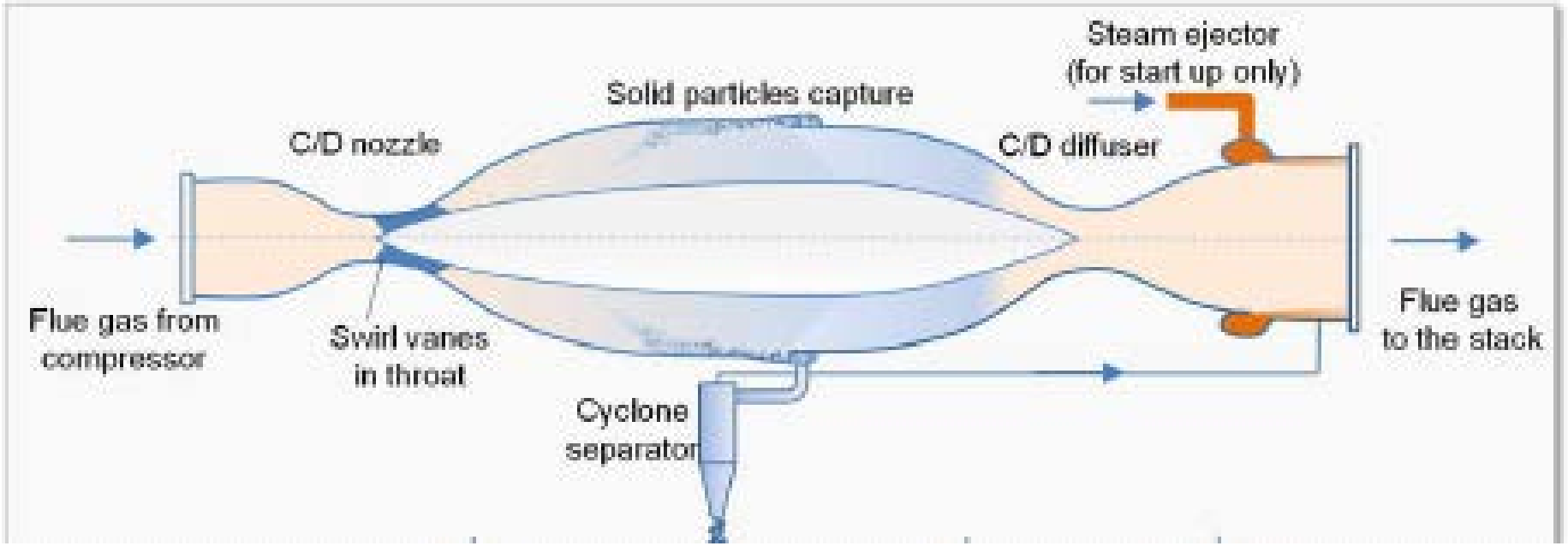
- Yes, use chemistry to increase gas partition into liquids
  - Helps, but diffusion still dominates in boundary layer. Nearly impossible to get boundary layer below ~10 μm



- Are convective separations possible?
  - Yes, if based on properties like bulk mass or size, e.g., filtration
  - No (probably), if based on molecular-level properties

Convective Separation: ATK's Inertial CO_2 Extraction System

- Convective separation of solid CO_2 particles, if particles have sufficient mass to separate from flue gas by inertia. Fast. Low capital cost.
- Particle growth, however, is by diffusion. Slow. Leads to large vessel, high capital cost.



What Does This Mean?

- Assuming this analysis holds true, i.e.,

  convection : electromechanical :: diffusion : separation

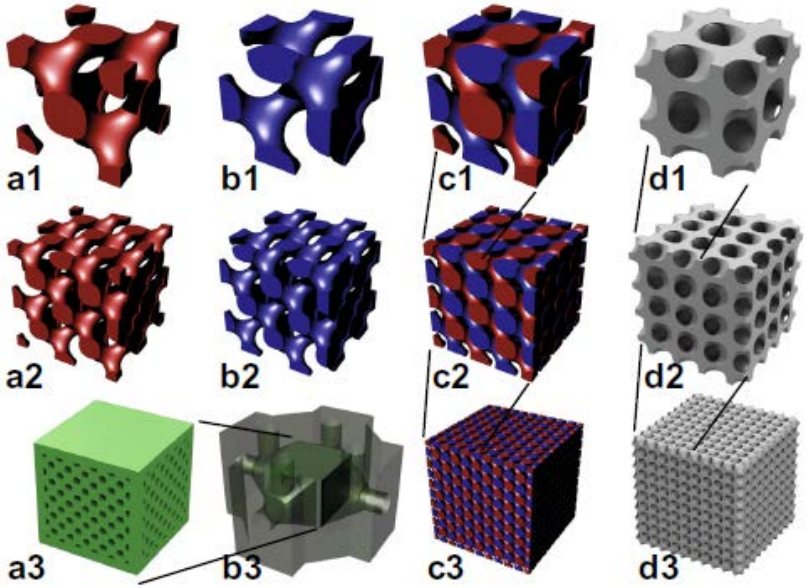
  - Diffusive separations are slow and unlikely to significantly reduce capital costs (true for solvents, membranes, adsorbents, etc.)
  - Convective separations are fast and can significantly reduce capital costs (filtration, inertial, cryo??)
- Energy consumption not considered in this analysis, but there's still a trade-off between capital cost and energy consumption (reversibility of the separation)

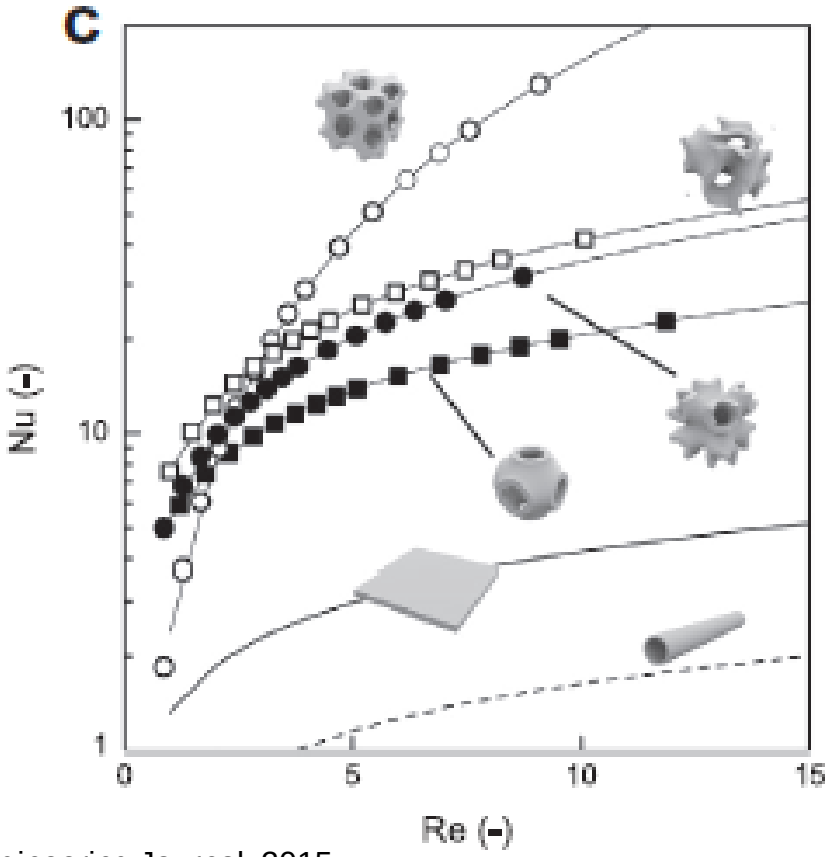
Key Question: Why Does Separation Need So Much More Capital per Unit Work ($/kW)?

- Chemical Engineers are 2/3rd as efficient and cost 8x more than Electrical and Mechanical Engineers
  - NO WAY!!
- Electro-mechanical work is at the top of the steam cycle (higher steam quality) while separation work is at the bottom of the steam cycle (lower steam quality)
  - Not a satisfactory answer as exceptions clearly exist
- Other ideas?
  - Diffusion vs convection offers a plausible answer
  - Are convective separations possible in carbon capture?

Additive Manufacturing – Gyroids

- Gyroids by additive manufacturing
- Heat transfer coefficients are 10-50x higher
- Higher pressure drop
- Mass transfer should behave similarly





Femmer *et al.,* Chemical Engineering Journal, 2015

Together…Shaping the Future of Electricity