Carbon Management:

Environmental Impacts, Opportunities and Challenges

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Webinar Outline

- Overview of Carbon-Management with the Focus on Transition Period of 2020 to 2050
- Energy-Water-Nexus & Carbon-Management
- CO_2 Generation, Transport & Sequestration
- Environmental Impacts
- Techno-Economics of CO_2 Capture & Utilization
- High-Priority Opportunities and Challenges
- Path Forward

Q/A and Discussion

Overview of Carbon-Management

What does it mean?

Broad meaning of Carbon-Management consists of 3-Rs

- Reduce – alternate low-carbon source or by energy efficiency
- Recycle – convert into original source such as fuel
- Recover and Reuse – capture from generation sources and convert to products
- Dispose – capture, transport and sequestration

Interlinking Carbon-Management with Renewable Energy

- Alternate Energy – solar panels, wind turbines, geothermal and ocean energy
- Product – hydrogen for conversion of CO_2 to fuel, such as methanol

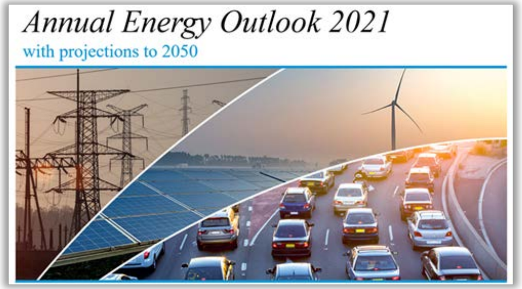
Techno-Economic Assessment Must be Based on Life-Cycle Analysis (LCA)

Overview of Carbon-Management

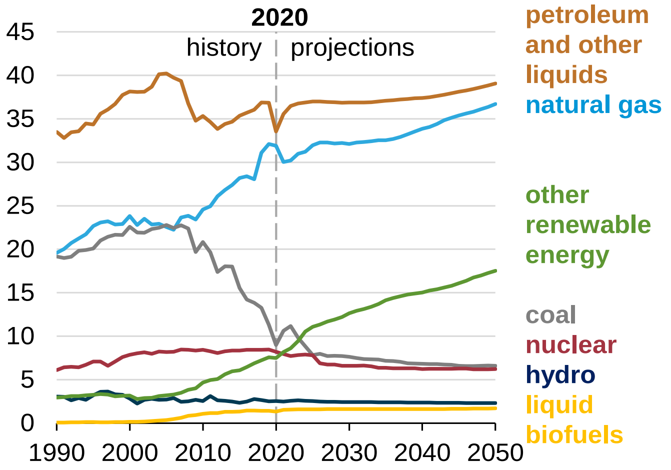
EIA Report Annual Energy Outlook 2020 with Projection to 2050

Key Message from EIA Report

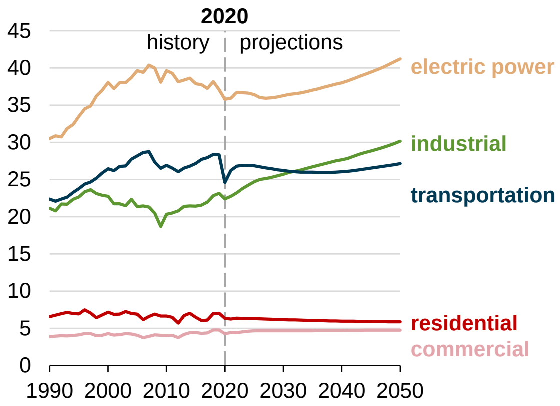
- Fossil energy will continue to contribute to US energy consumption with significant drop in coal-based power generation and continued increased use of natural gas
- Carbon-management will play key role in the transition period of 2020 through 2050
- Need a long-term Strategic Roadmap for achieving 2050 carbon-neutral goal



Energy Production Quads BTU

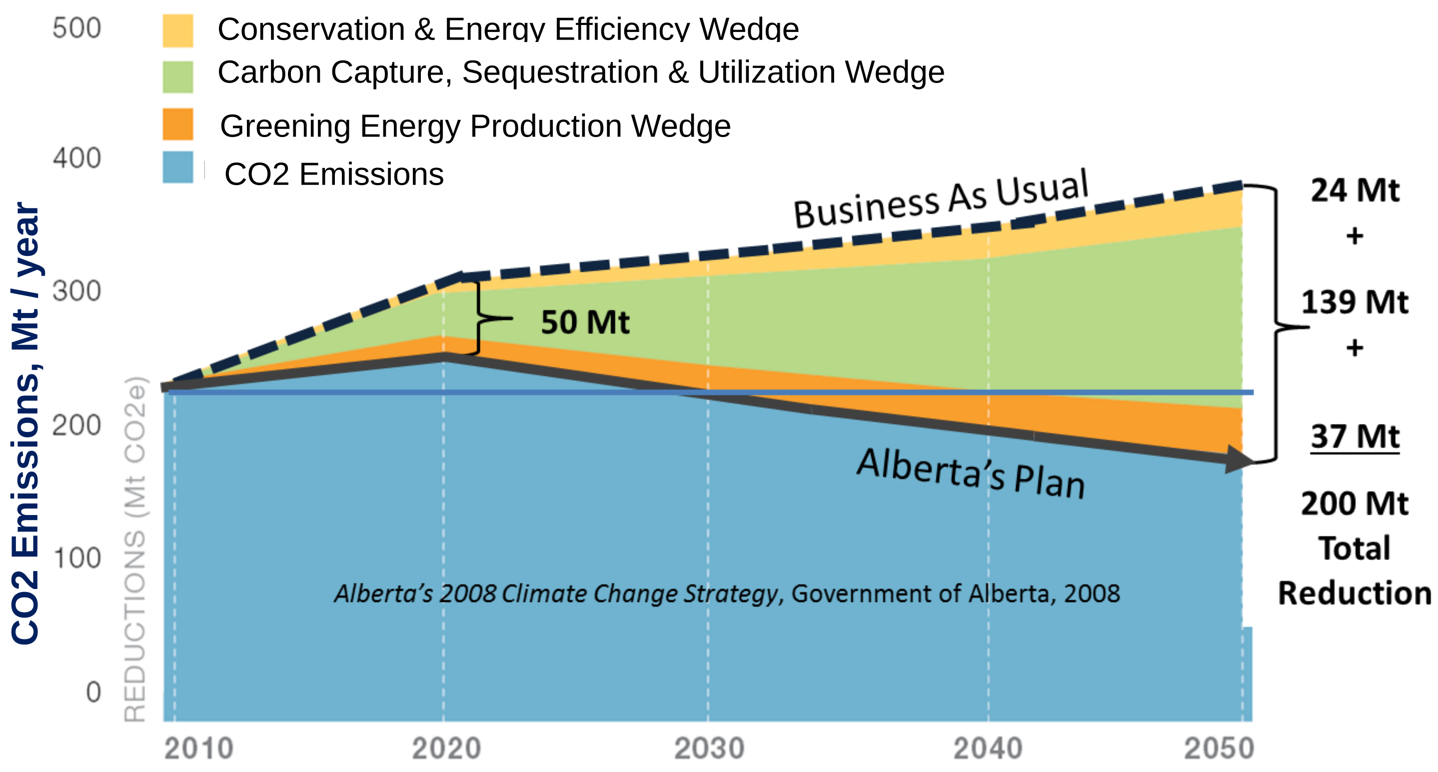


Energy Consumption by Sectors Quads BTU



Alberta's Carbon-Management Strategy

Defines Long Term Goal (Source CCEMC Grand Challenge)



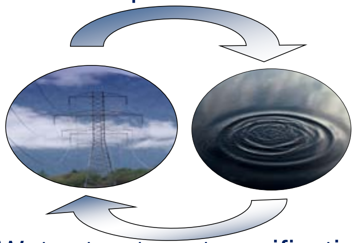
Energy-Water Nexus & C-Management

Why important to focus on Energy-Water Nexus?

- Energy-efficient and/or renewable energy for water purification for recycle and seawater desalination is expected to play a key role in coming decades
- DOE initiative of water security managed by NREL with multiple goals of desalination, recovery from process water and net-zero water consumption in industry

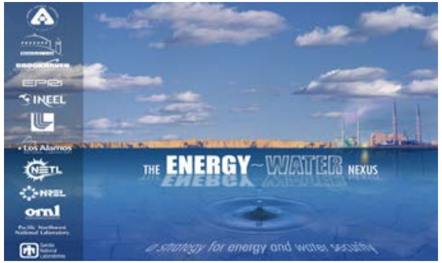
www.energy.gov/water-security-grand-challenge

Energy production and generation require water



Water treatment, purification, desalination and distribution require energy

Energy~Water Nexus Team



Representation from all DOE Multi-Program Laboratories

DOE Water Security Grand Challenge

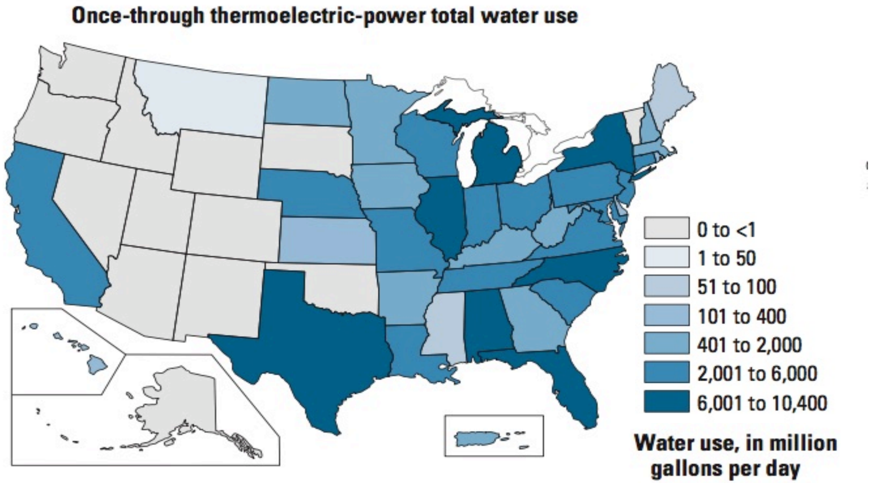
Energy-Water Nexus & C-Management

Why important to focus on Energy-Water Nexus?

As much freshwater is used for power generation as for irrigation –
need significant reduction of water consumption in power generation in terms of liters/kWh

Antelope Valley Station and Great Plains Coal Gasification Beulah, ND. 22,000 gpm water withdrawal in a zone that receives 14 in. of annual rainfall. (EIS-0072-FEIS, 1980)

Once through thermoelectric power total water use 2015 (USGS circ. 1441)

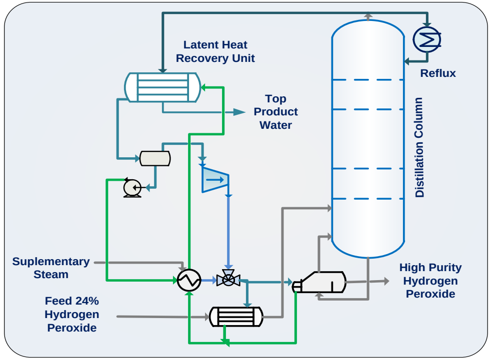


Energy-Water Nexus & C-Management

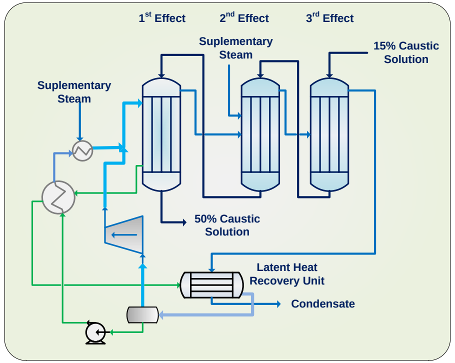
Water consumption in the process industry is equally critical

- Advanced heat pumps for recovery of latent heat from thermal processes and recycling into the process have potential for significant reduction of water consumption in the process industry
- Need to develop advanced heat pumps and thermally-efficient equipment with credible LCA analysis for water saving potentials and with favorable economics, such as enhanced productivity

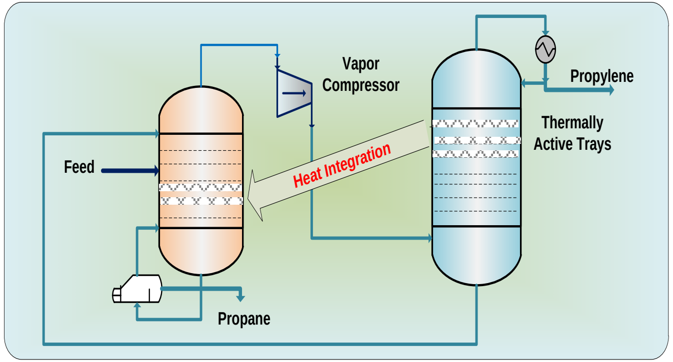
Distillation Process



Multi-Effect Evaporation



Thermally-Coupled Distillation



CO_2 Generation, Capture Transport and Sequestration

Why it has not been widely implemented ?

SC-PC thermoelectric Levelized Cost of Electricity is $64.4/MWh with no CO_2 capture, rising to $105.3/MWh with 90% capture. DOE/NETL-2019 (Dec. 23, 2020)

CO_2 transport costs are site specific, and a cost model has been developed DOE/NETL-2018/1877. Typical transport CO_2 costs for 150 mi are $1-8/ tonne CO_2 IPCC Carbon Dioxide Capture and Storage, Cambridge, 2005.

For $4/tonne this adds $5/MWh

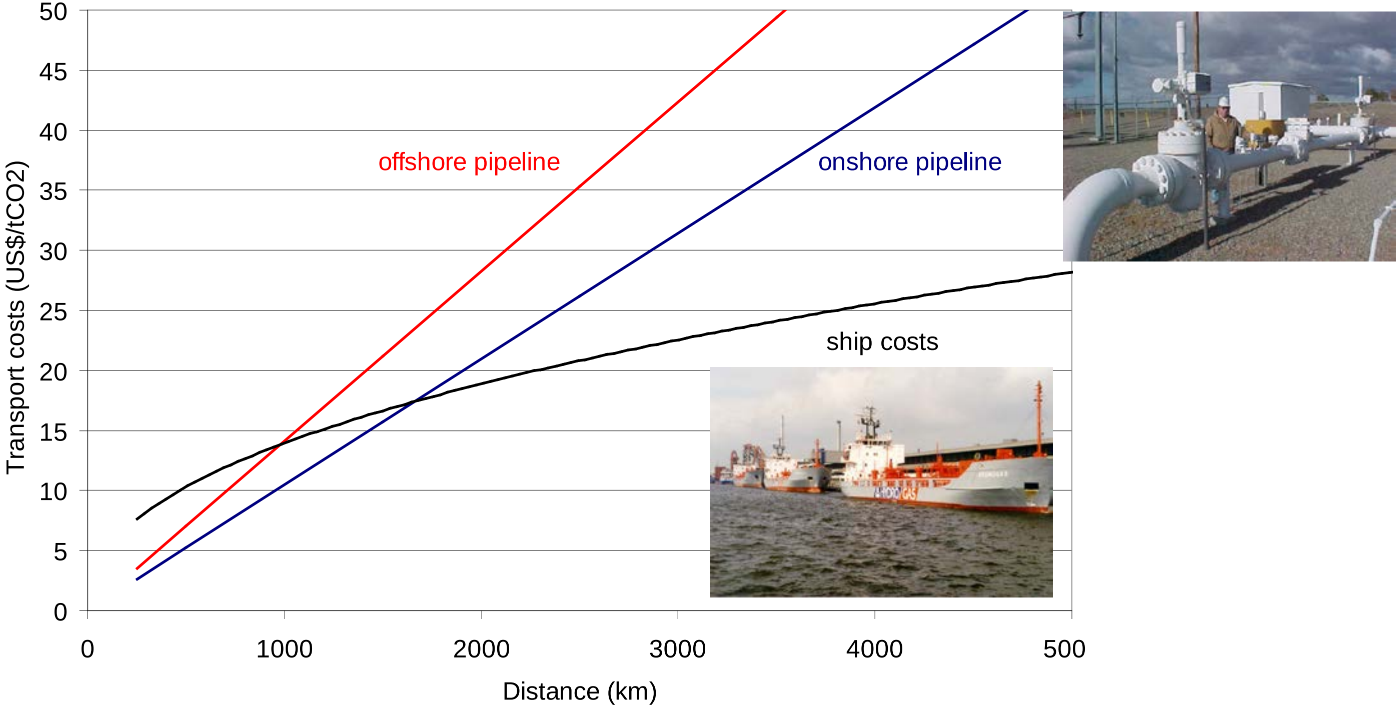
CO_2 Sequestration $7(low)/tonne - $33(median)/tonne have discouraged projects not linked to EOR. FE/NETL CO2 Saline Storage Cost.BaselineModelingResults_093017.xlsm

For $16/tonne this adds $20/MWh

CO_2 Generation, Capture Transport and Sequestration

Why it has not been widely implemented ?

Pipelines are used for transporting CO_2, but ships could be economically attractive

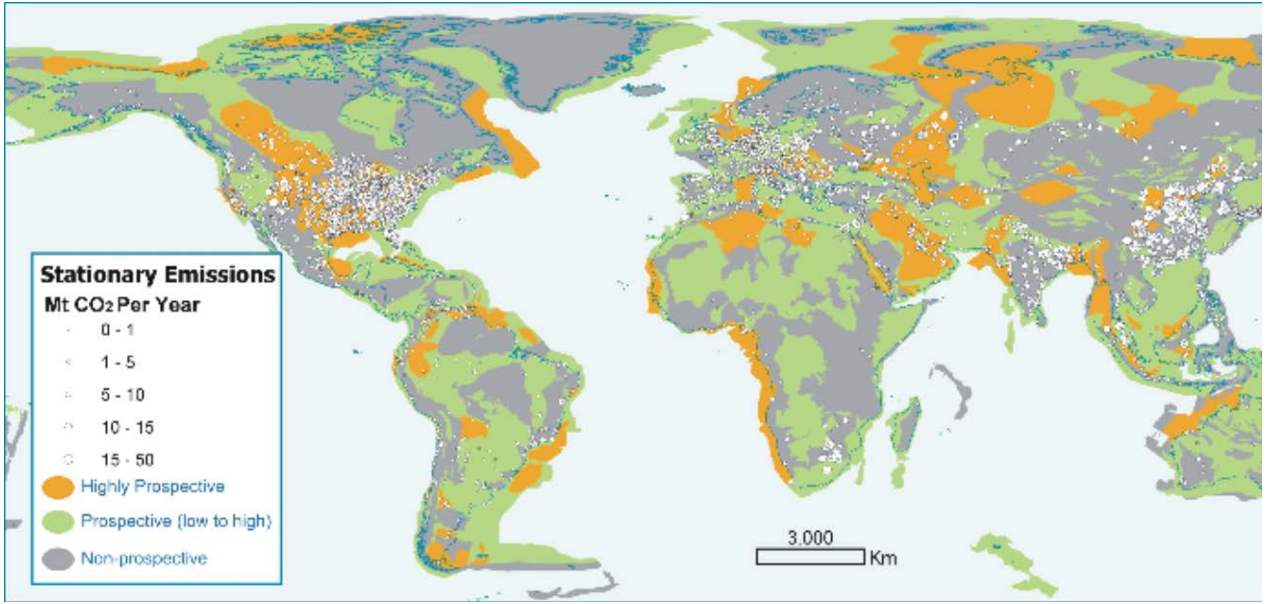


CO_2 Generation, Capture Transport and Sequestration

Why it has not been widely implemented ?

Potential CO_2 Sequestration Zones Costs estimated from $6-33/tonne for 324 reservoirs

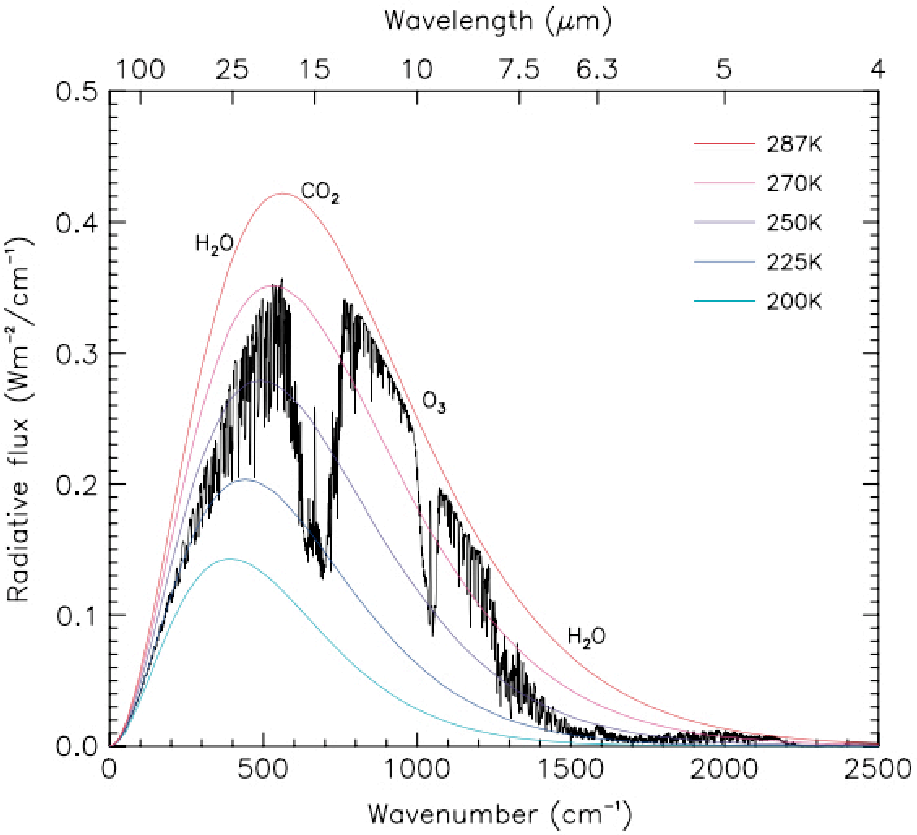
DOE/NETL – 2017/1670



IPCC Carbon Dioxide Capture and Storage, Cambridge, 2005.

CO_2 Generation, Capture Transport and Sequestration

Environmental Impacts



W. Zhong and J.D. Haigh, "*The greenhouse effect and carbon dioxide*," Royal Met. Soc., *Weather,* 68(4) April 2013.

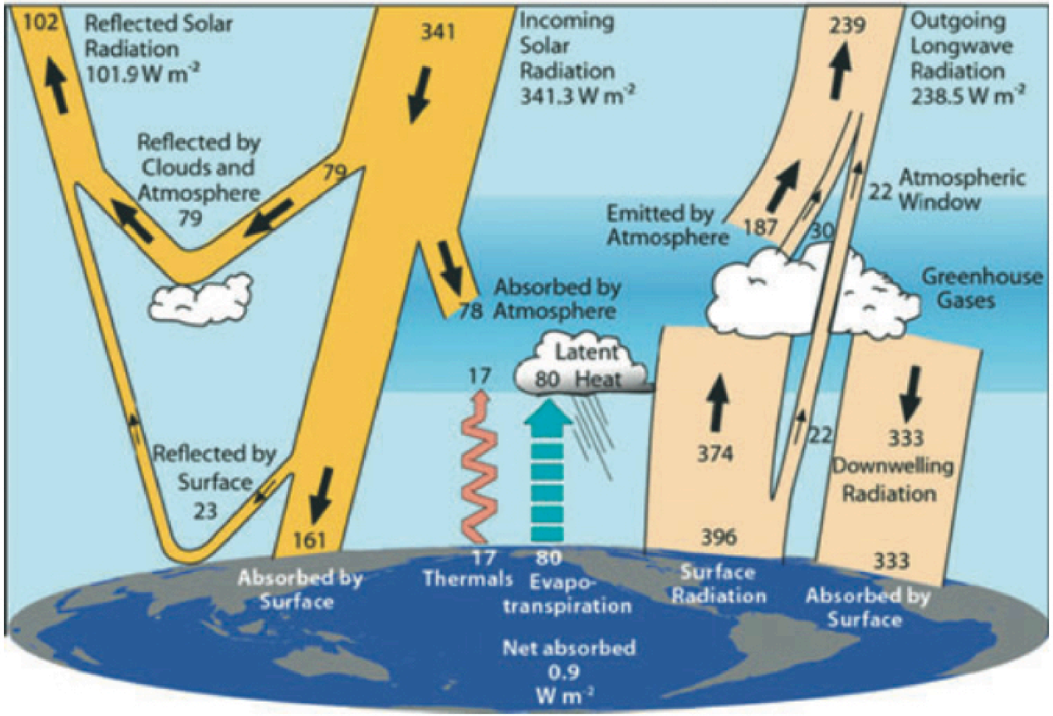
The Greenhouse is a good thing, *but* there can be too much of a good thing.

Earth $T \approx 287K = 14°C = 59°F$

Moon $T \approx 236K = -37°C = -35°F$

Environmental Impacts

When should we take action – before or after major environmental impacts?



Global Energy Flows Wm^{-2} Trenbeth and Fasullo (2012)

Environmental Impacts

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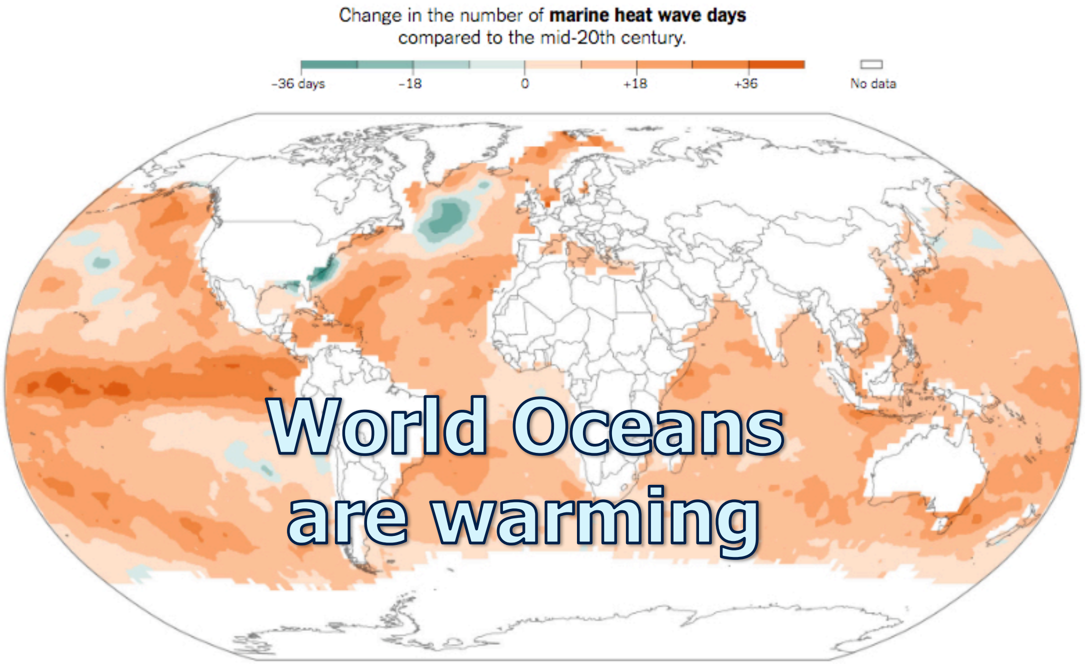


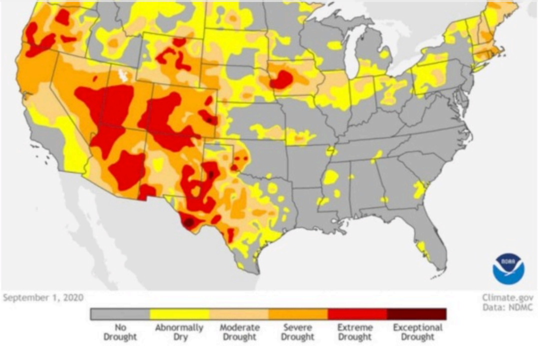
The average number of marine heat wave days for the period 1987-2016, compared to the average for 1925-1954.
Source: Nature Climate Change | By The New York Times

Ocean Warming with Direct Impact on Jet Streams Causing Localized Heavy Rain and Draught

Environmental Impacts

When should we take action – before or after major environmental impacts?

Persistent drought conditions and wildfires



Drought Index September 1, 2020.

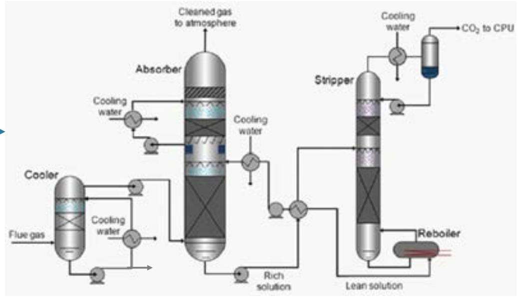
Techno-Economics of CO_2 Capture & Utilization

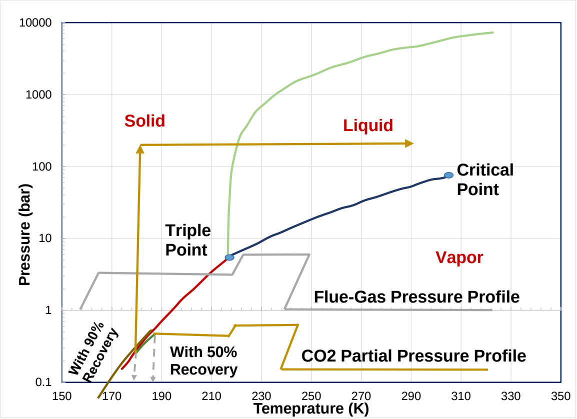
Will play a key role in the transition period of 2020 to 2050

CO_2 Capture Technologies

- Absorption process – commercial amine and new absorbents
- Membrane separation
- Adsorbent – solid adsorbent and Metal Organic Framework (MOF)
- Hybrid – membrane and absorption
- Cryogenic CO_2 capture

Amine process





CO_2 De-sublimation Profile

Techno-Economics of CO_2 Capture & Utilization

C-footprint varies from 0.16 to 0.53 based on source & CO_2 capture technology

Composition	Coal Utility	GTCC	SMR Process Location 1	SMR Flue Gas	Ethanol
CO_2 Concentration by Volume %	13%	6%	15%	5% to 10%	95%+
CO_2 Source	Post combustion	NG Combustion	SMR Reaction	NG Combustion plus CO_2 from process	Fermentation
Pressure, bar	1.01	1.01	20.0	1.01	1.01
Other Major Components	N_2, O_2, SO_x, NO_x, Steam	N_2, O_2, Steam	Hydrogen, Steam	N_2, O_2, Steam	Water vapor
C-footprint, tonne CO_2 / tonne CO_2 Capture					
Commercial Amine process	0.53	0.41	0.23	0.41	
Alternate Solvent Process	0.38	0.30	0.16	0.30	
Membrane Process (50% recovery)	0.27	Not applicable*	Not applicable**	Not applicable*	
Condensation or membrane separation of water vapor					Relatively small

Techno-Economics of CO_2 Capture & Utilization

Cost penalty is major challenge

CO_2 Capture Costs with DOE Target of 90% Recovery

Coal Plants

- Amine Process $70 to $100 per tonne CO_2
- DOE Target of $40 per tonne with new CO_2 capture technologies

GTCC Plants

- CO_2 capture costs higher than coal plants

Steam Methane Reforming for Hydrogen Production

- CO_2 capture costs lower than coal plants

Cost of electric (COE) penalties varies between $50 and $100 / MWh

Techno-Economics of CO_2 Capture & Utilization

Conversion to high-value products to offset the cost of CO_2 Capture

Fuels

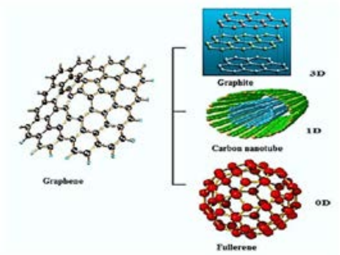
- Catalytic conversion to alcohol & ethers

Bio-Fixation

- Microalgae to high-value chemicals

Solid Products

- Concrete, Graphene, Graphite

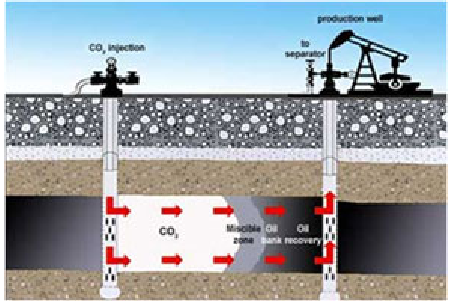


Chemicals

- Methanol, Organic acids and Alkyl carbonates

Enhanced Oil Recovery (EOR)

- Depends on oil price and CO_2 source near oil production sites (demonstrated in Texas)



Techno-Economics of CO_2 Capture & Utilization

E3Tec process of CO_2 conversion to high-value alkyl carbonates with low C-footprint

	E3Tec Process	Syngas Based Process
Plant Capacity, kTA (thousand tonnes/year)		
Dimethyl Carbonate (DMC)	**52.0**	**50.0**
Mono-Ethylene Glycol (MEG)	**36.0**	**0.0**
Capital Costs (CAPEX), $ Million	**$164**	**$223**
Cost of Production, $ / tonne DMC**	**10 to 15 % lower**	**Base case**

**** By taking into account coproduction of MEG**

CO_2 → DMC → Alkyl Carbonates

LITHIUM-ION BATTERIES

POLYCARBONATES

LOW VOC SOLVENTS REPLACING KETONES

DMC AS OXYGENATED FUEL ADDITIVE (DIESEL)

Application	Global DMC Market Potential - kTA*	
	2017	2030
DMC in Polycarbonate Production	2,440	4,910
Li-Ion Battery Electrolyte	45	350
Solvents (replacing ketones)	1,430	1,820
Chemical Intermediate, e.g. Polyurethane	11,350	18,470
Potential diesel oxygenate additive**		1,580,000

*kTA - Thousand Tonnes Per Year ** Based on government approval for pollution control

High-Priority Opportunities and Challenges

With the 2030 Goals of Significant Reduction of CO_2 emissions

E3Tec

Opportunities

1. Enhanced energy efficiency – power generation, process intensification, innovative process equipment, waste heat recovery and utilization
2. CO_2 capture and conversion to high-value products
3. Water management technologies – desalination, purification and recycle
4. Integration of renewable energy with power generation and manufacturing processes

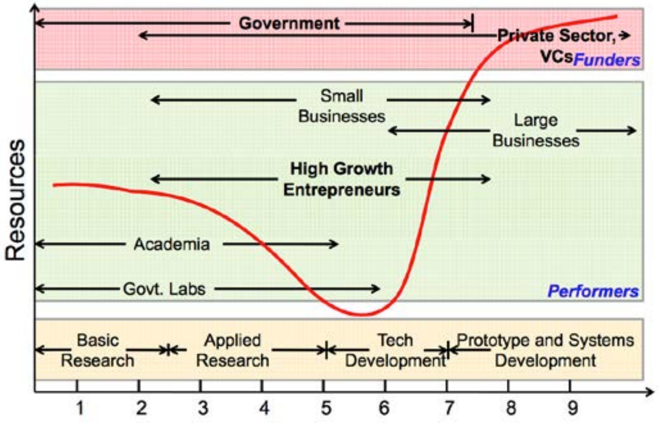
Carbon-footprint Based Development of New Technologies

High-Priority Opportunities and Challenges

Overcoming the Valley-of-Death Syndrome

Challenges

1. Uncertain government long-term policies with direct impact on industry responses and action
2. Investment on new technologies developed by small businesses and research institutes
3. Credible techno-economic merits of new technologies developed by research institutes
4. Participation of major energy corporations in developing new technologies



Path Forward

Collaboration and Consortium with Focus Technology Areas

Technology Areas

1. CO_2 capture and utilization – DOE/NETL Programs and Industry Interests
2. DOE/EERE – Innovative Technology of Energy Efficiency and Renewable Energy
3. Hydrogen Production – Green and Blue Hydrogen
4. DOE Water Security Grand Challenge
5. Biobased and Waste Product (spent oil) Based Chemicals

Recommend Pursuing SBIR/STTR Grants – DOE, DOD, NSF and ARPA-E

Investing Existing *Finite* Carbon-Based Energy & Material Sources on Future *Sustained* Energy & Fresh Water Supplies

Thank You

Q/A & Discussion