Overview of Selected Issues Associated with the Scale of the Climate Change Challenge and the Potential Role of Large Scale Commercial Deployment of Carbon Dioxide Capture and Storage Technologies

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Joint Global Change Research Institute

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PNNL-SA-64828

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Key Points

- Climate change means more than a "warmer world" and melting polar ice caps.
- Stabilizing the concentration of CO_2 means fundamental change to the global energy system and therefore fundamental change to the entire global economy.
- Technology is essential to addressing climate change and controlling the cost of doing so.
- A strategy to address climate change while *simultaneously* meeting all of society's other goals and aspirations must include:
  - Development and subsequent global commercial deployment of advanced, cleaner energy technologies
  - Continued scientific research on the climate system and impacts
  - Emissions limitations
  - Adaptation to climate change.
- There is no "silver bullet" for addressing climate change nor is there a "silver bullet" for managing the negative consequences of a changing climate.

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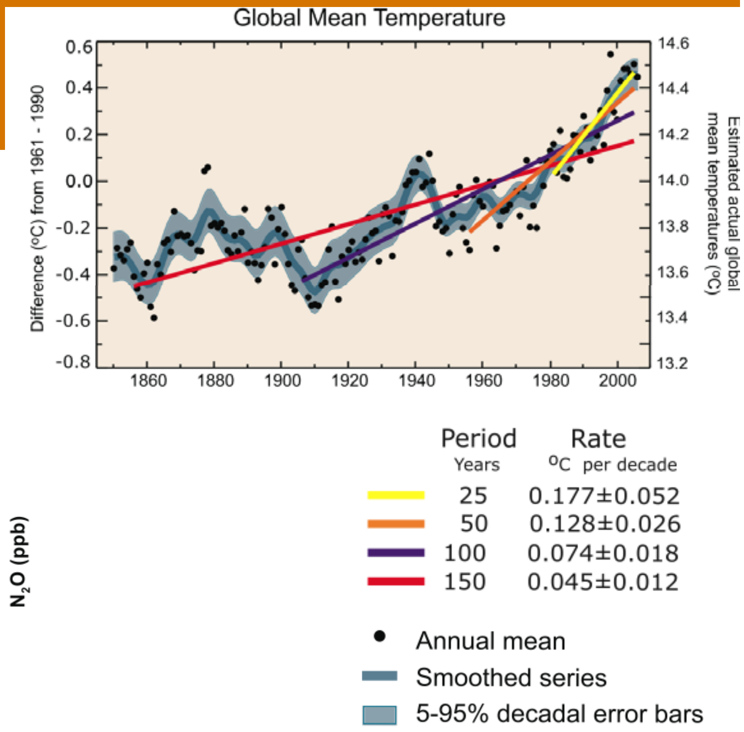
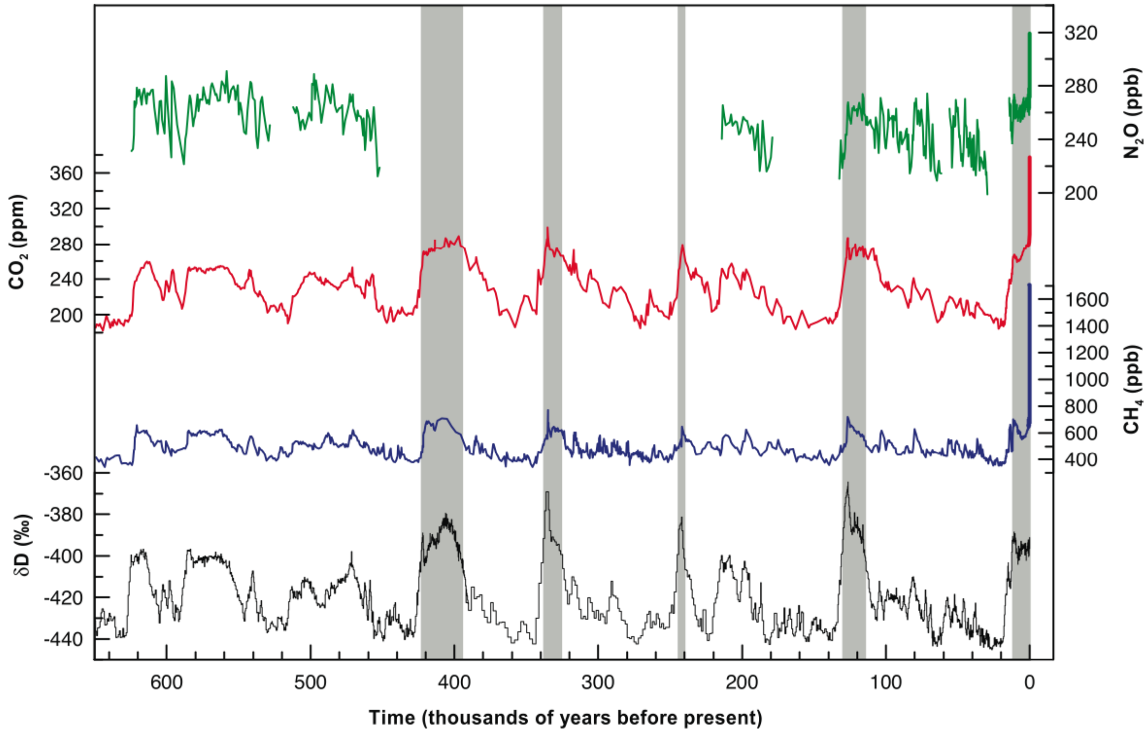
Climate Change 101

Homo erectus

Homo sapiens





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IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

“Climate Change” not “Global Warming”

Climate Changes

Temperature

Sea Level Rise

Precipitation

Health Impacts

- Weather-related deaths
- Infectious diseases
- Air quality - respiratory illnesses

Ecosystems

- Loss of habitat and diversity
- Species range shifts
- Ecosystem services

Agriculture

- Crop yields
- Irrigation demand
- Pest management

Forest Impacts

- Geographic range
- Health, composition, and productivity

Water Resources

- Changes in precipitation, water quality, and water supply

Coastal Areas

- Erosion and inundation of coastal lands
- Costs of protecting vulnerable lands

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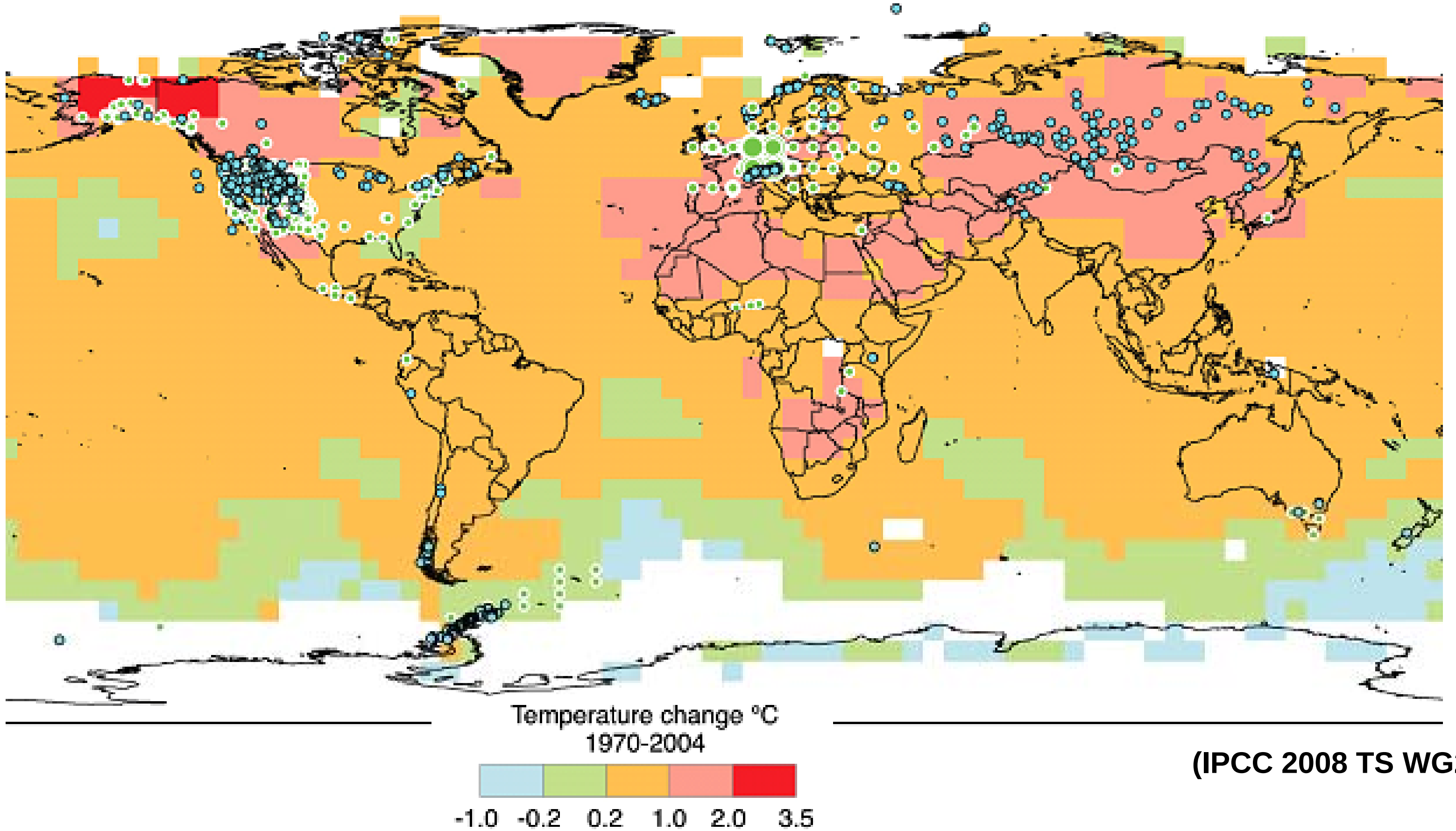
<u>Observed</u> Changes in Physical and Biological Systems and Surface Temperature 1970-2004



(IPCC 2008 TS WG2)

Observed data series

- Physical systems (snow, ice and frozen ground; hydrology; coastal processes)
- Biological systems (terrestrial, marine, and freshwater)

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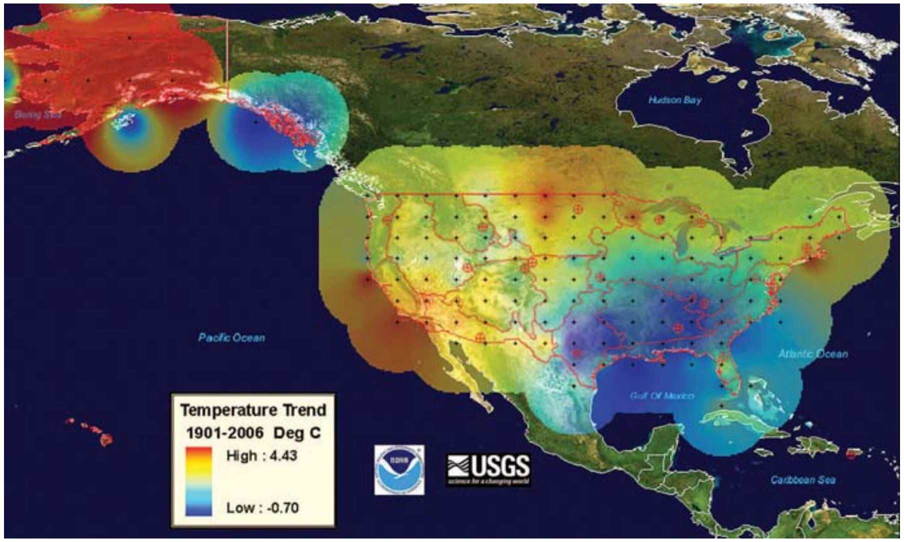
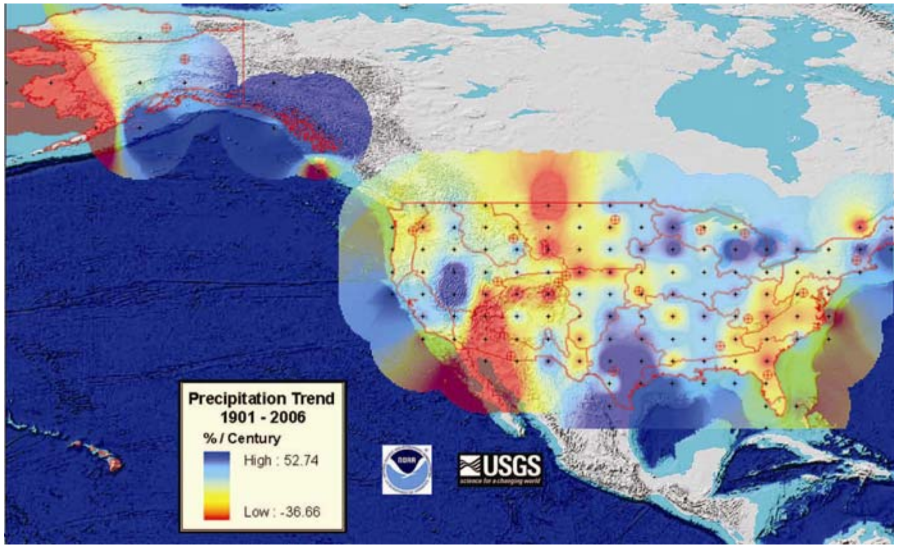
<u>Observed</u> Changes in Temperature and Precipitation in the US 1901-2006

US Temperature Change, 1901-2006



US Precipitation Change, 1901-2006



United States Climate Change Science Program. The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. CCSP Synthesis and Assessment Product 4.3 (May 2008).

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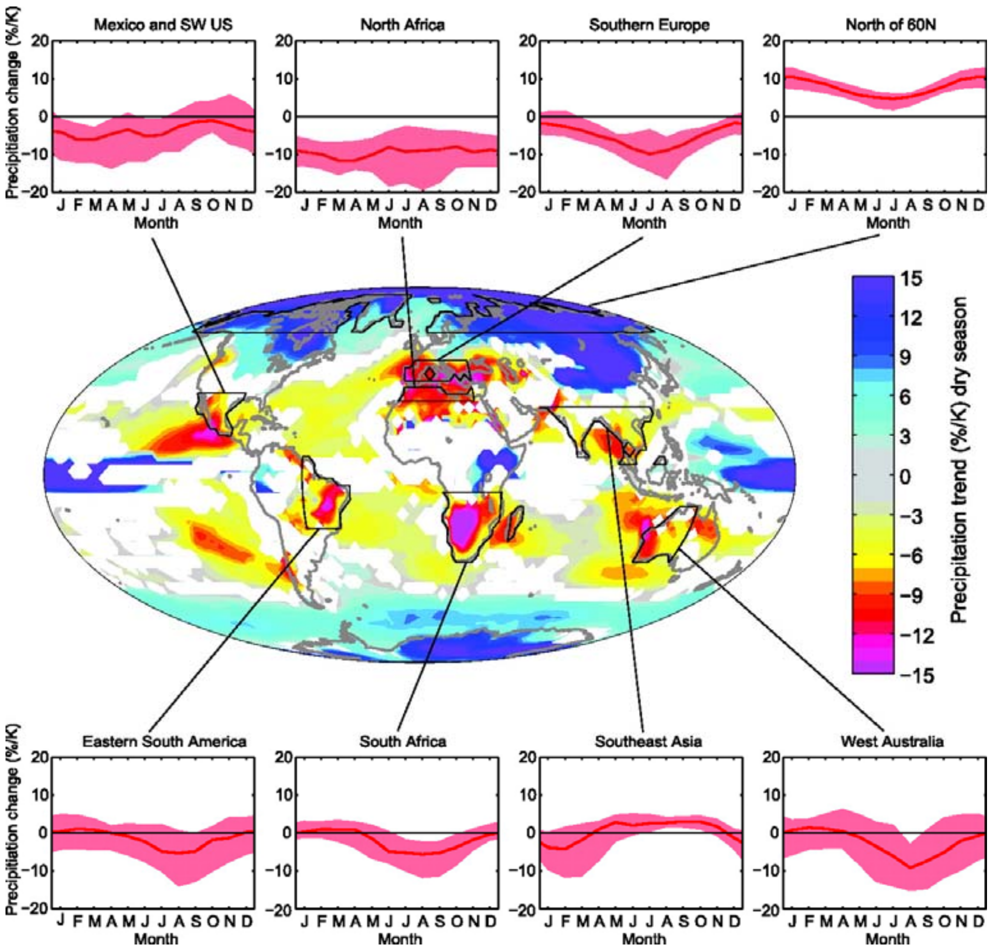
<u>Projected</u> Temperature and Precipitation Changes



Expected decadally averaged changes in the global distribution of precipitation per degree of warming (percentage of change in precipitation per degree of warming, relative to 1900–1950 as the baseline period) in the dry season at each grid point, based upon a suite of 22 AOGCMs for a midrange future scenario (A1B).

Solomon S. et.al. PNAS 2009;106:1704-1709©2009 by National Academy of Sciences

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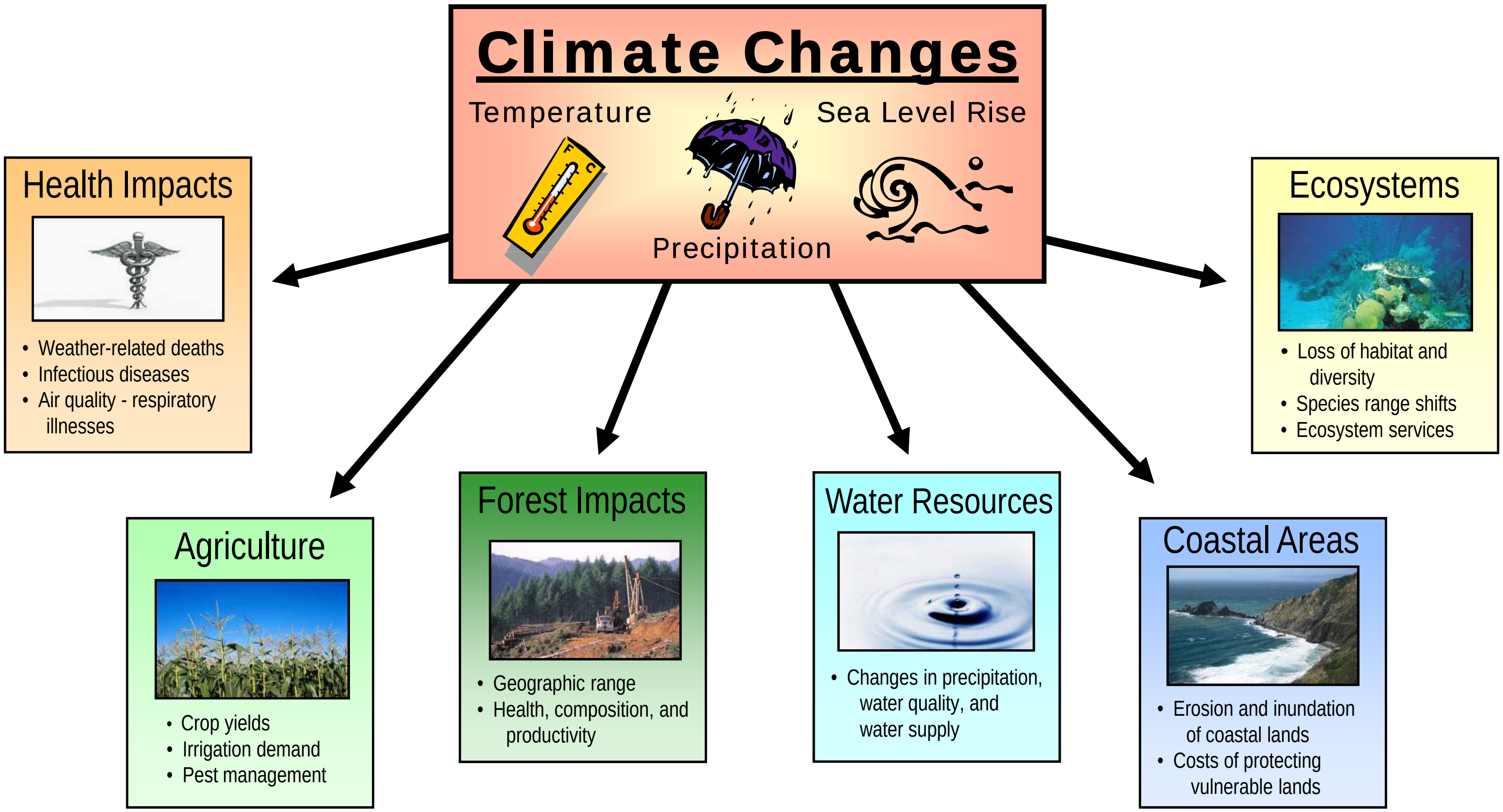
“Climate Change” not “Global Warming”



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Carbon Management Problem Summarized by Article 2 of the United Nations Framework Convention on Climate Change

- United Nations Framework Convention on Climate Change has nearly 200 member countries, including the United States, and establishes as its "ultimate objective":
  - …the stabilization of greenhouse gas concentrations…
  - …at a level that would prevent dangerous…interference with the climate system…
  - …and to enable economic development to proceed in a sustainable manner.

Concentrations** __not__ **Emissions

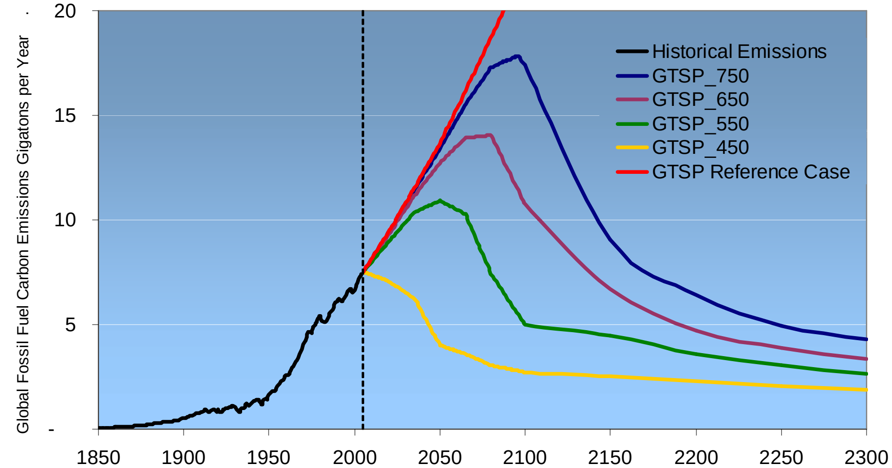
Don't Know What is Dangerous

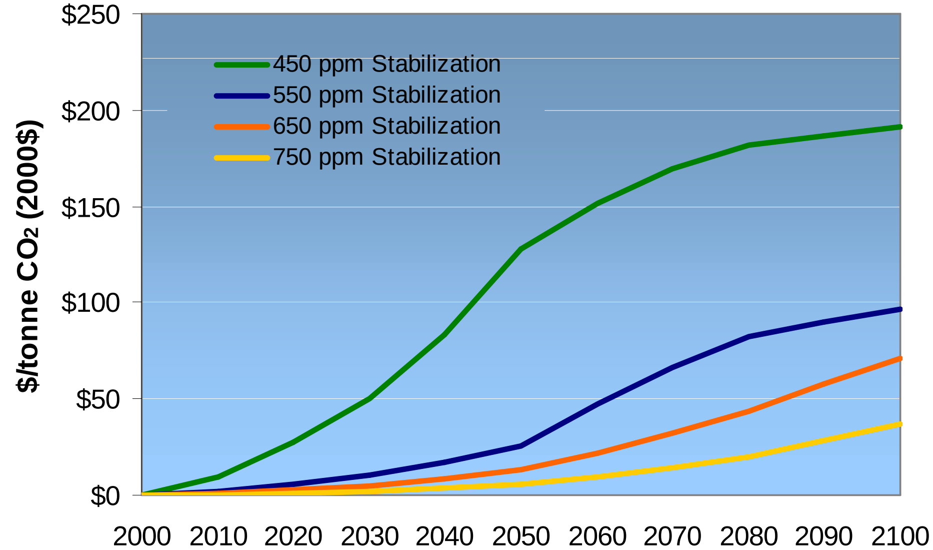
Economic Development Matters

Climate Change Is a Long-term Strategic Problem with Implications for Today

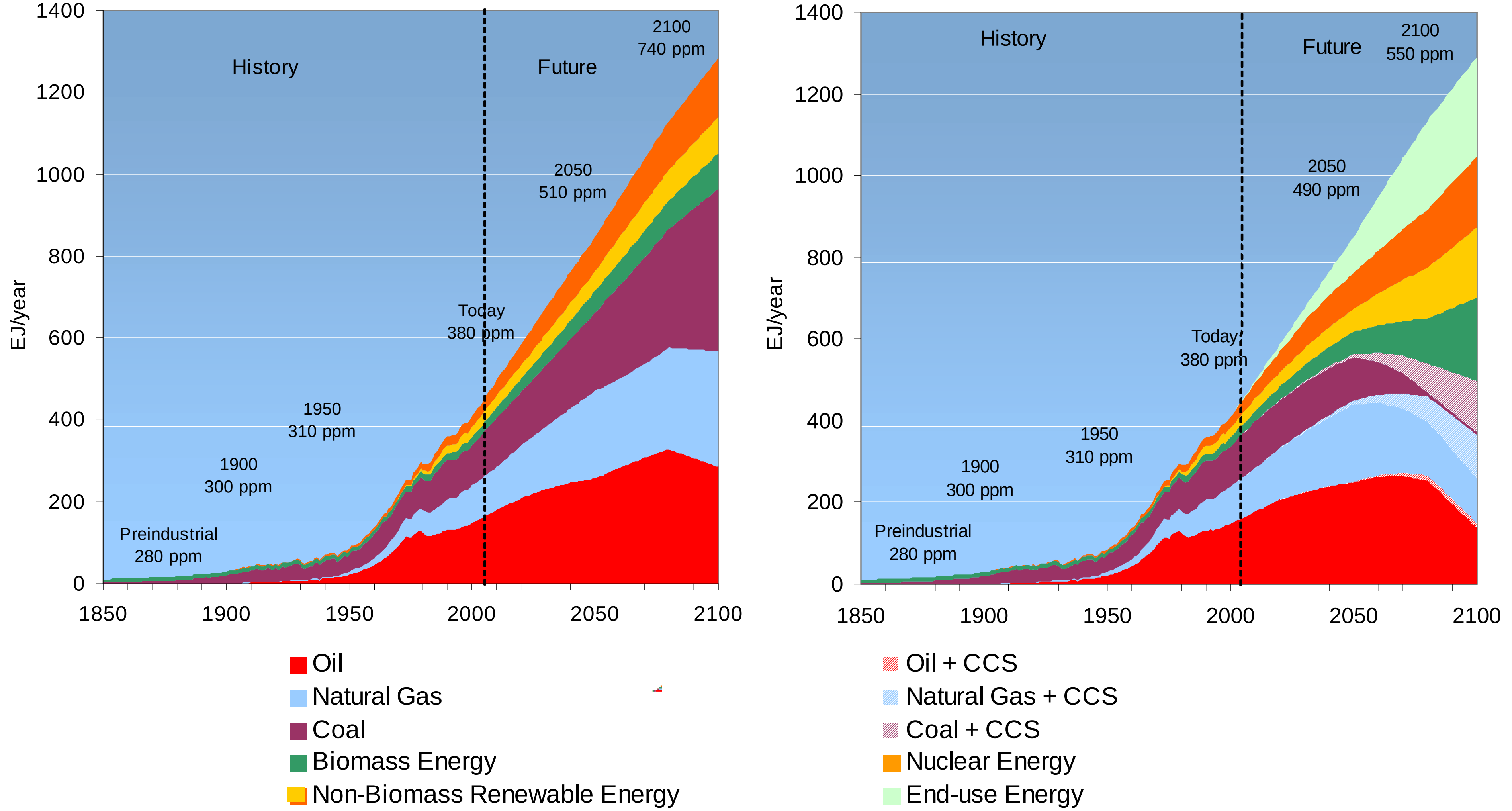
- Stabilizing atmospheric concentrations of greenhouse gases and not their annual emissions levels should be the overarching strategic goal of climate policy.

- This tells us that a fixed and finite amount of CO_2 can be released to the atmosphere over the course of this century.
  - We all share a planetary greenhouse gas emissions budget.
  - Every ton of emissions released to the atmosphere reduces the budget left for future generations.
  - As we move forward in time and this planetary emissions budget is drawn down, the remaining allowable emissions will become more valuable.
  - Emissions permit prices should steadily rise with time.





Stabilization of CO_2 Concentrations Means Fundamental Change to the Global Energy System (550 ppmv stabilization)



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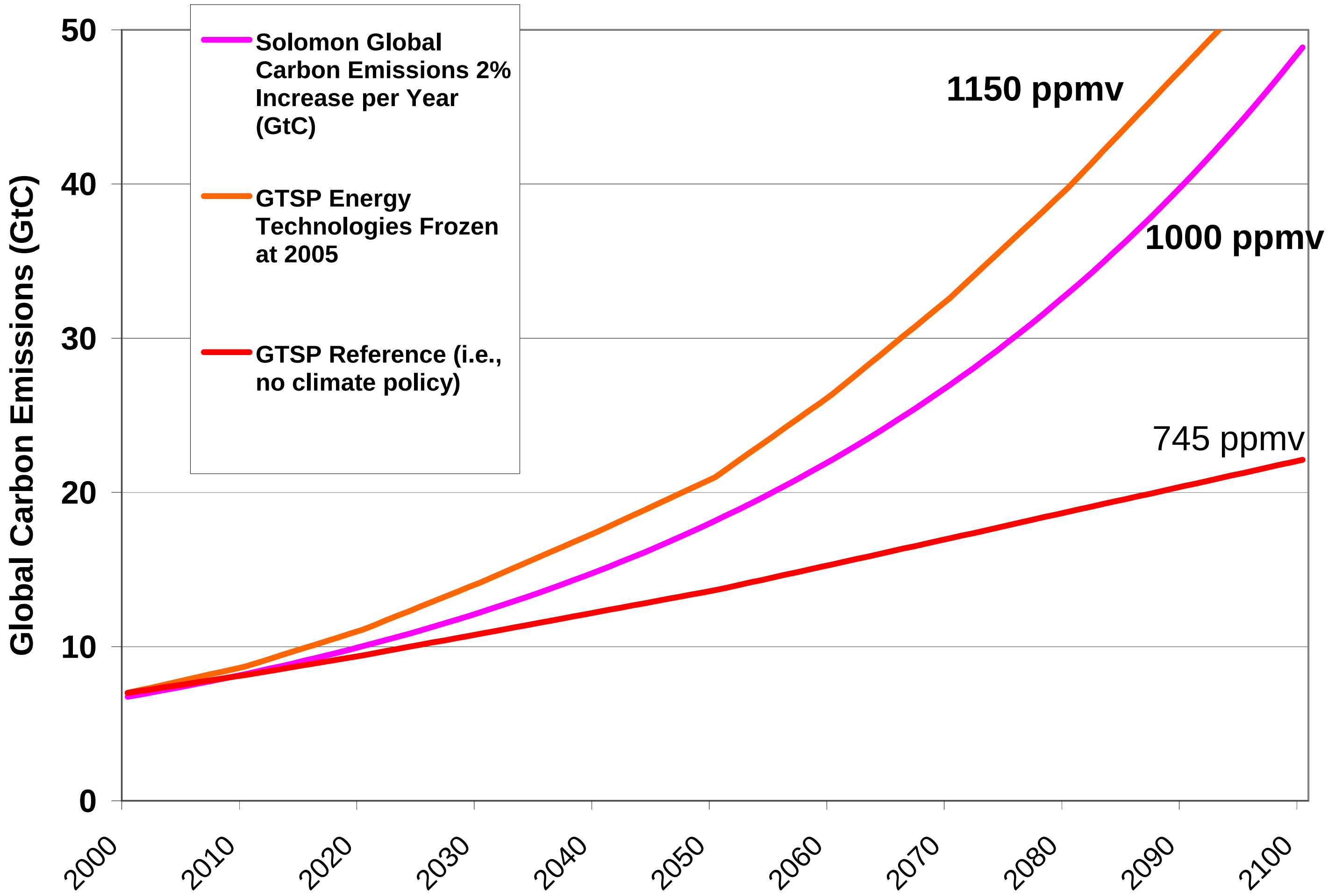
What will happen if we choose to do nothing about climate change?



Future Reference Case (i.e., a world with no climate policy) greenhouse gas emissions are expected to increase and perhaps increase significantly over today's levels.

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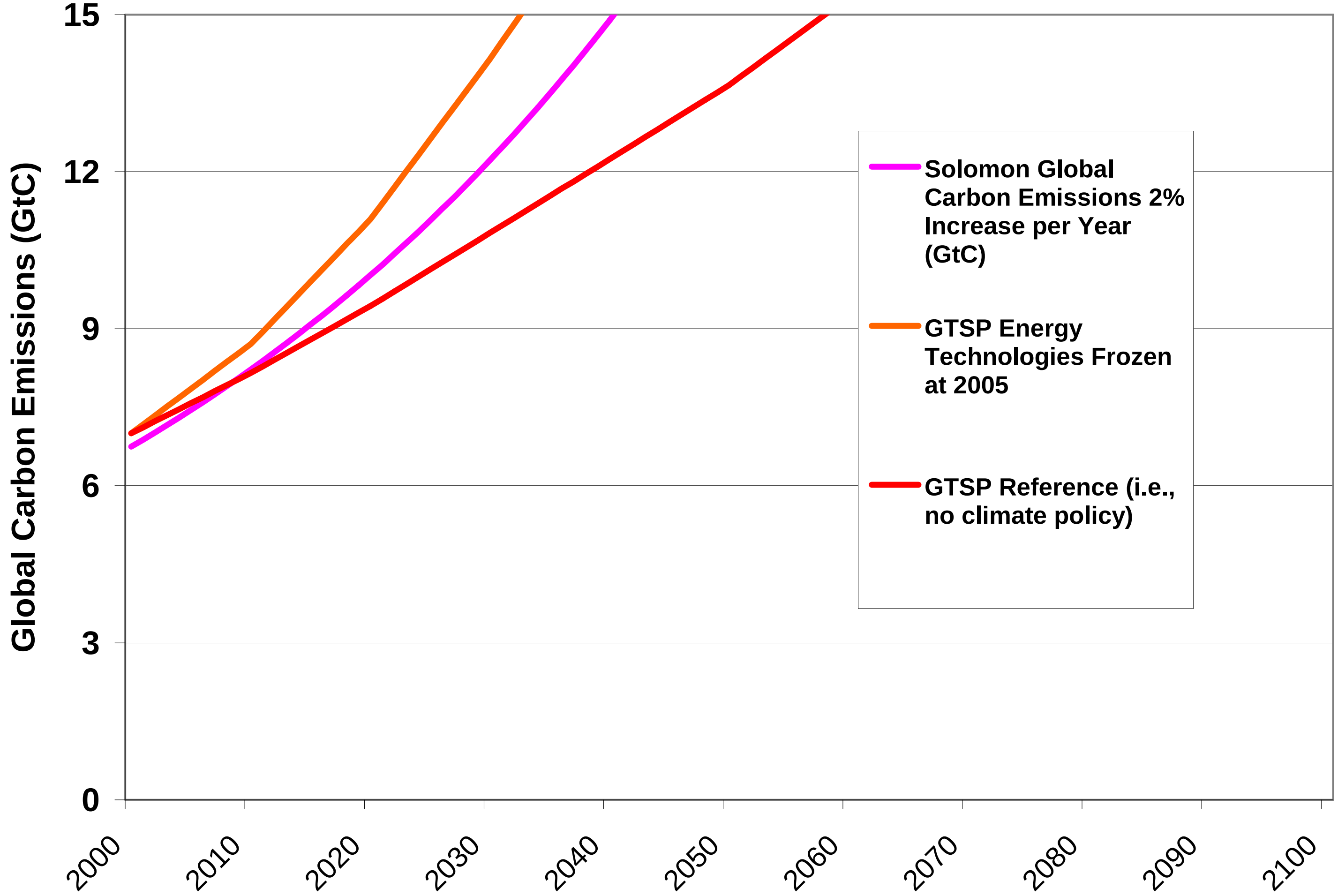
What needs to happen if long term atmospheric concentrations of CO_2 need to be kept close to current levels of about 380 ppmv?



"Solomon" cases from Solomon S. et.al. PNAS 2009;106:1704-1709©2009 by National Academy of Sciences.
"Overshoot" case from KV Calvin et. al. 2009. "Preliminary Results from the miniCAM EMF-22 Scenarios." Forthcoming.

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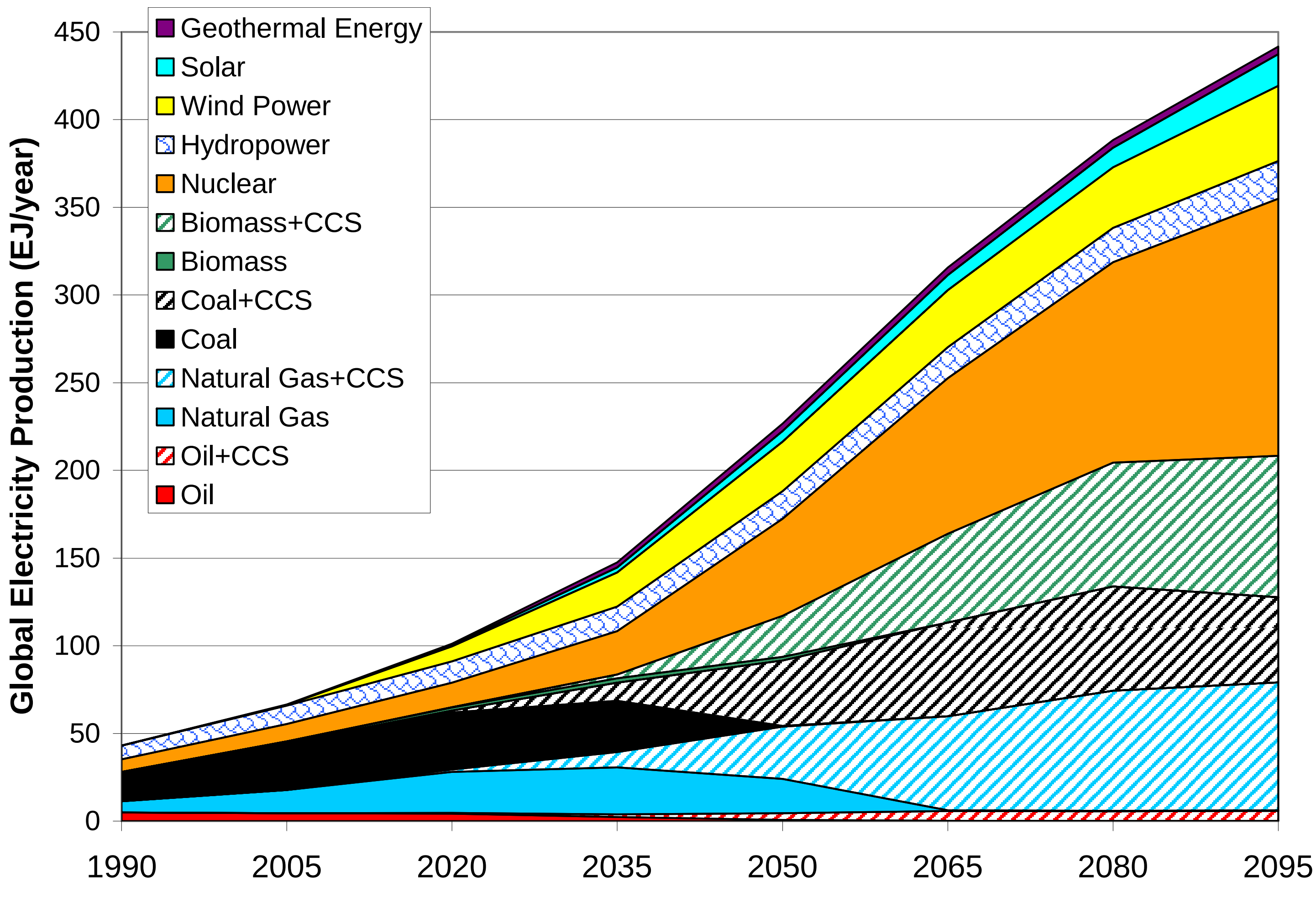
Global Electricity Production in "Overshoot" Scenario



Post 2050

- **Half of all electricity generated with CCS**
- **Bio+CSS electricity 25-40% of all CCS-generated electricity**

"Overshoot" case from KV Calvin et. al. 2009. "Preliminary Results from the miniCAM EMF-22 Scenarios." Forthcoming.

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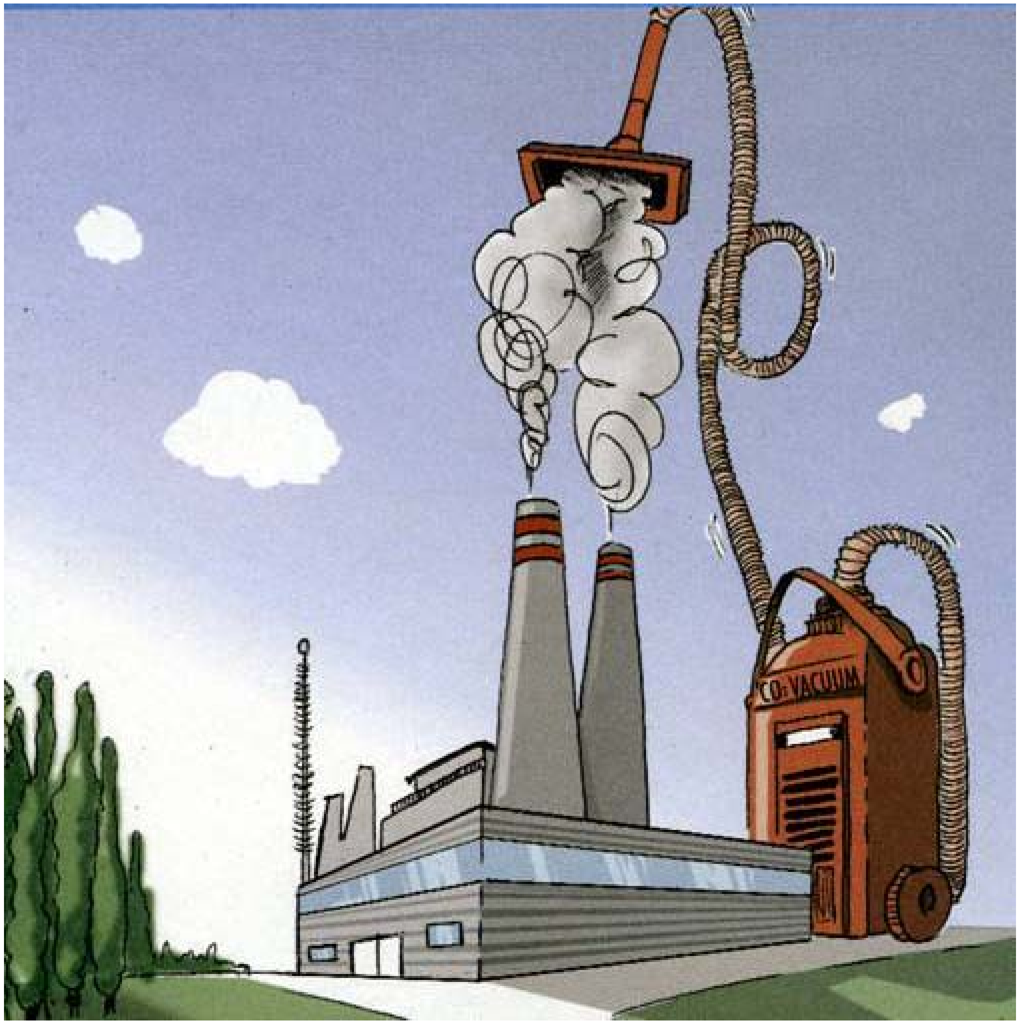
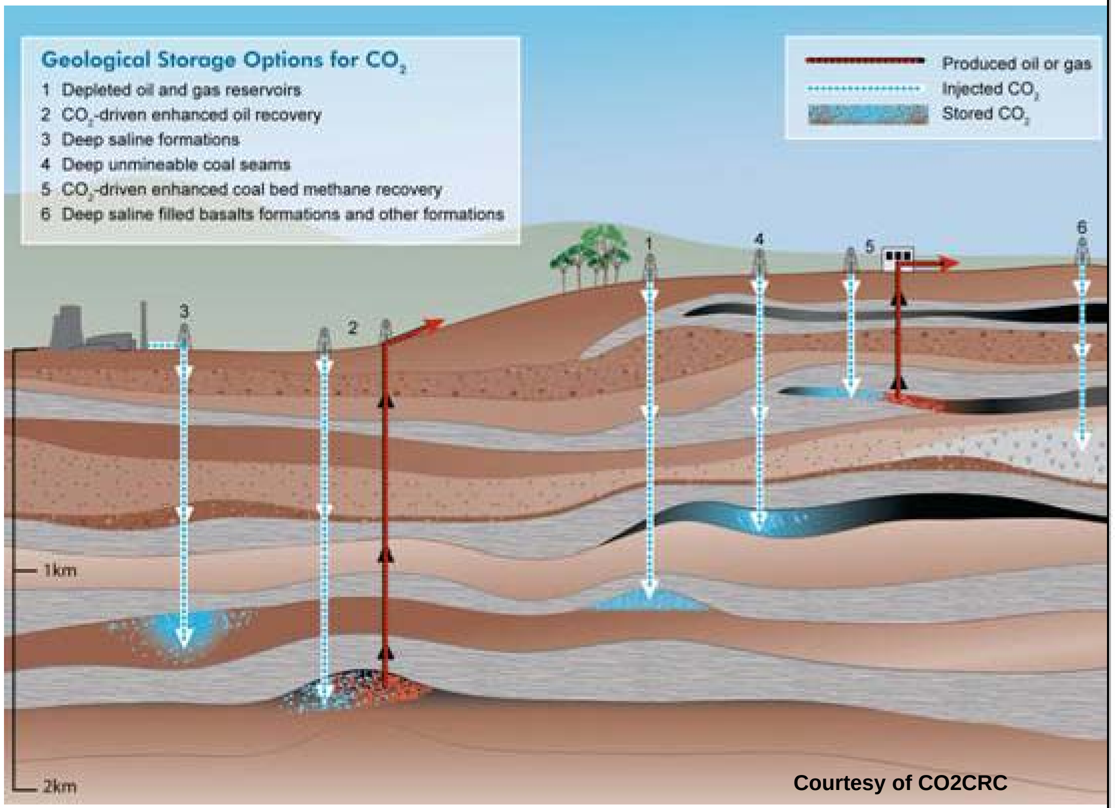
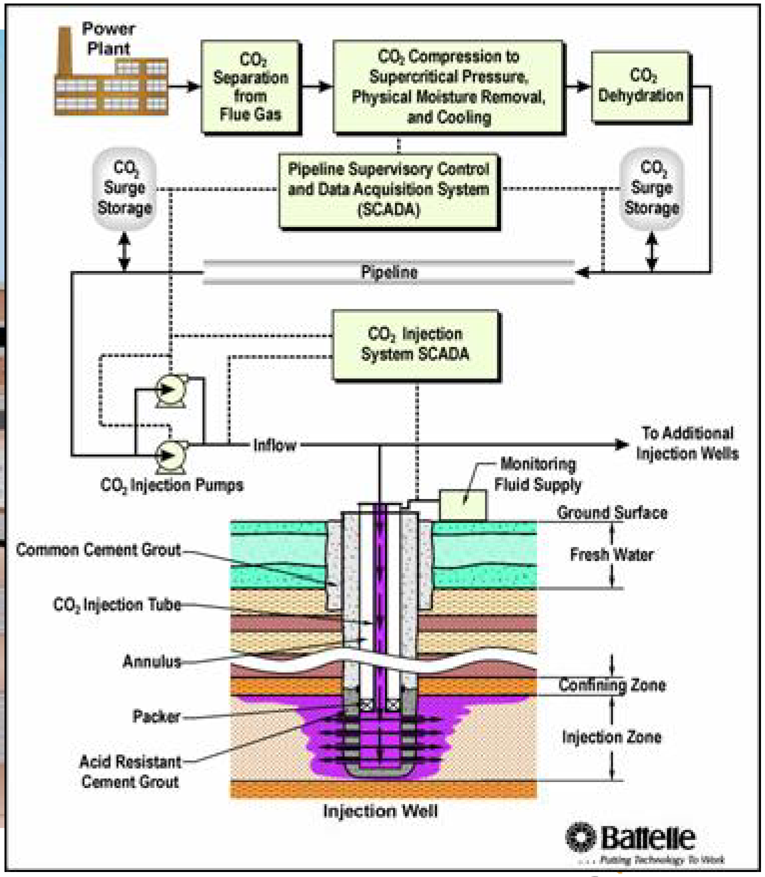
CO_2 Capture and Storage: Not Nearly this Simple



Overview of Carbon Dioxide Capture and Storage



Courtesy of CO2CRC



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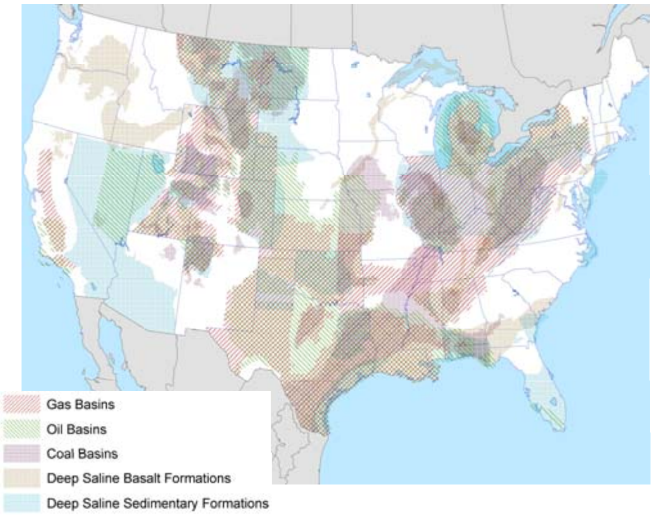
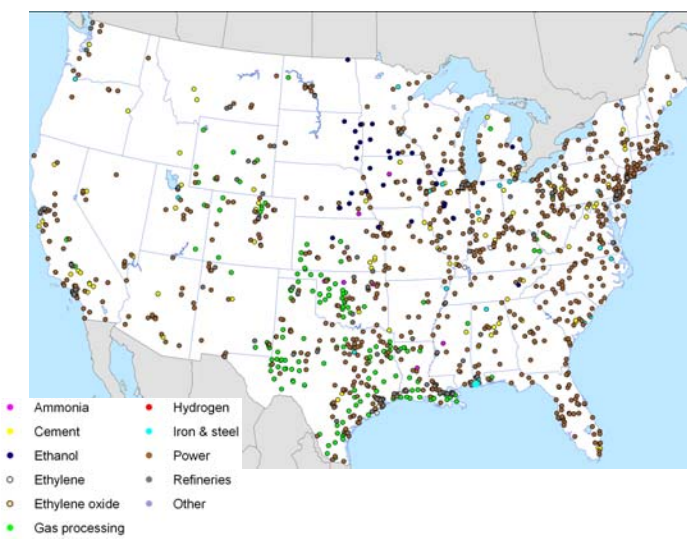
Within the U.S. There Is a Large Geologic CO_2 Storage Resource and Large Potential Demand for CO_2 Storage



3,900+ $GtCO_2$ Capacity within 230 Candidate Geologic CO_2 Storage Reservoirs

- 2,730 $GtCO_2$ in deep saline formations (DSF) with perhaps close to another 900 $GtCO_2$ in offshore DSFs
- 240 Gt CO_2 in on-shore saline filled basalt formations
- 35 $GtCO_2$ in depleted gas fields
- 30 $GtCO_2$ in deep unmineable coal seams with potential for enhanced coalbed methane (ECBM) recovery
- 12 $GtCO_2$ in depleted oil fields with potential for enhanced oil recovery (EOR)



1,715 Large Sources (100+ $ktCO_2$/yr) with Total Annual Emissions = 2.9 $GtCO_2$

- 1,053 electric power plants
- 259 natural gas processing facilities
- 126 petroleum refineries
- 44 iron & steel foundries
- 105 cement kilns
- 38 ethylene plants
- 30 hydrogen production
- 19 ammonia refineries
- 34 ethanol production plants
- 7 ethylene oxide plants

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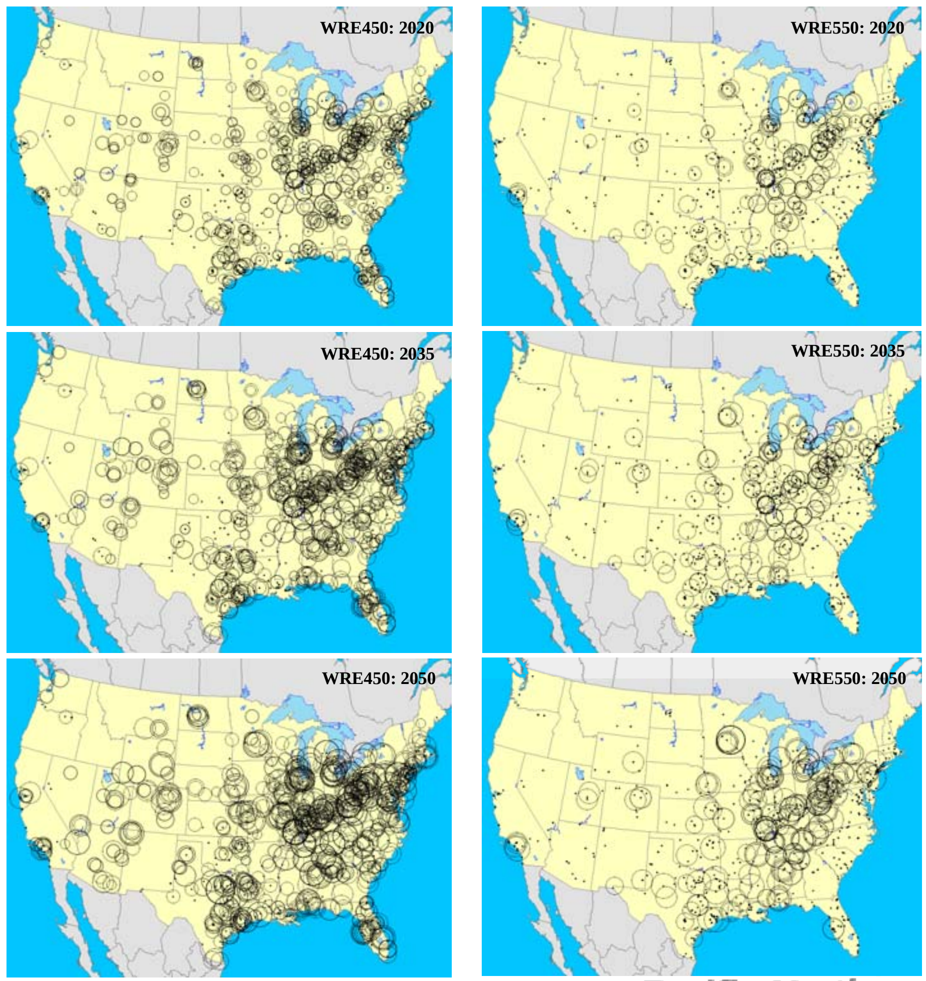
The Principal Role for CCS in the U.S. Is to Help Decarbonize the Electric Utility Sector

- It is important to realize that we are in the earliest stages of the deployment of CCS technologies.
- The potential deployment of CCS technologies could be truly massive. The potential deployment of CCS in the US could entail:
  - 1,000s of power plants and industrial facilities capturing CO_2, 24-7-365.
  - 10,000s of miles of dedicated CO_2 pipelines.
  - 100s of millions of tons of CO_2 being injected into the subsurface annually.

WRE450 WRE550



2020
2035
2050

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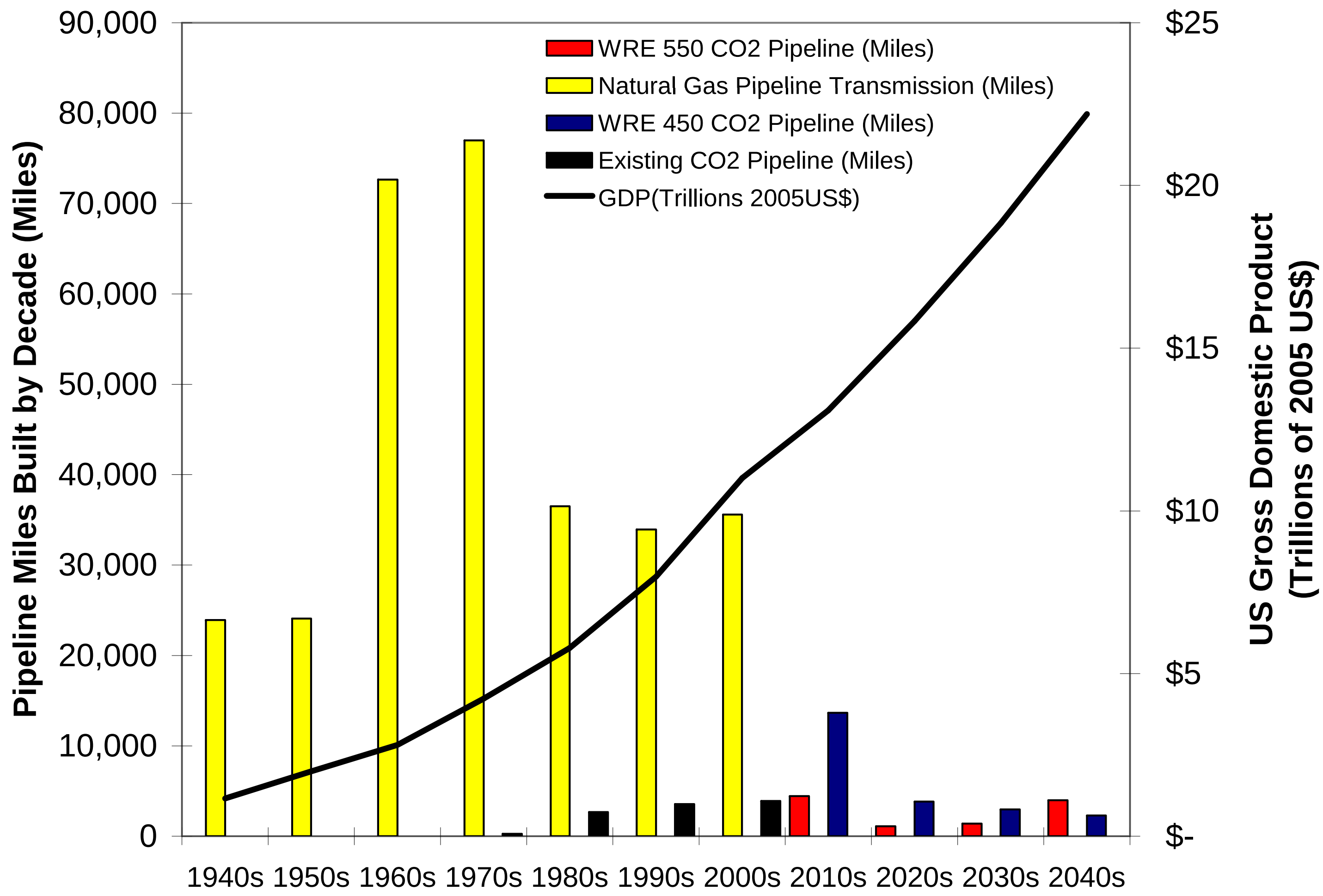
Comparing the Existing U.S. Natural Gas Pipeline Transmission System, Potential Future CCS-Driven CO_2 Pipeline Systems and the Size of U.S. Economy



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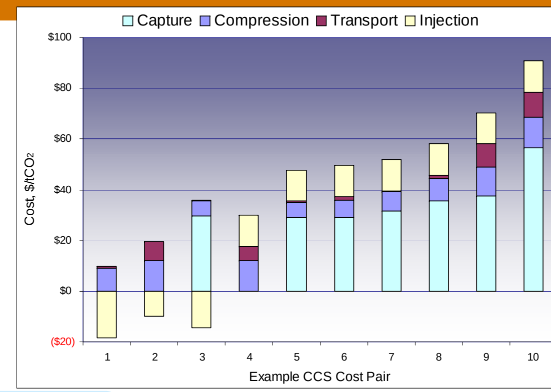
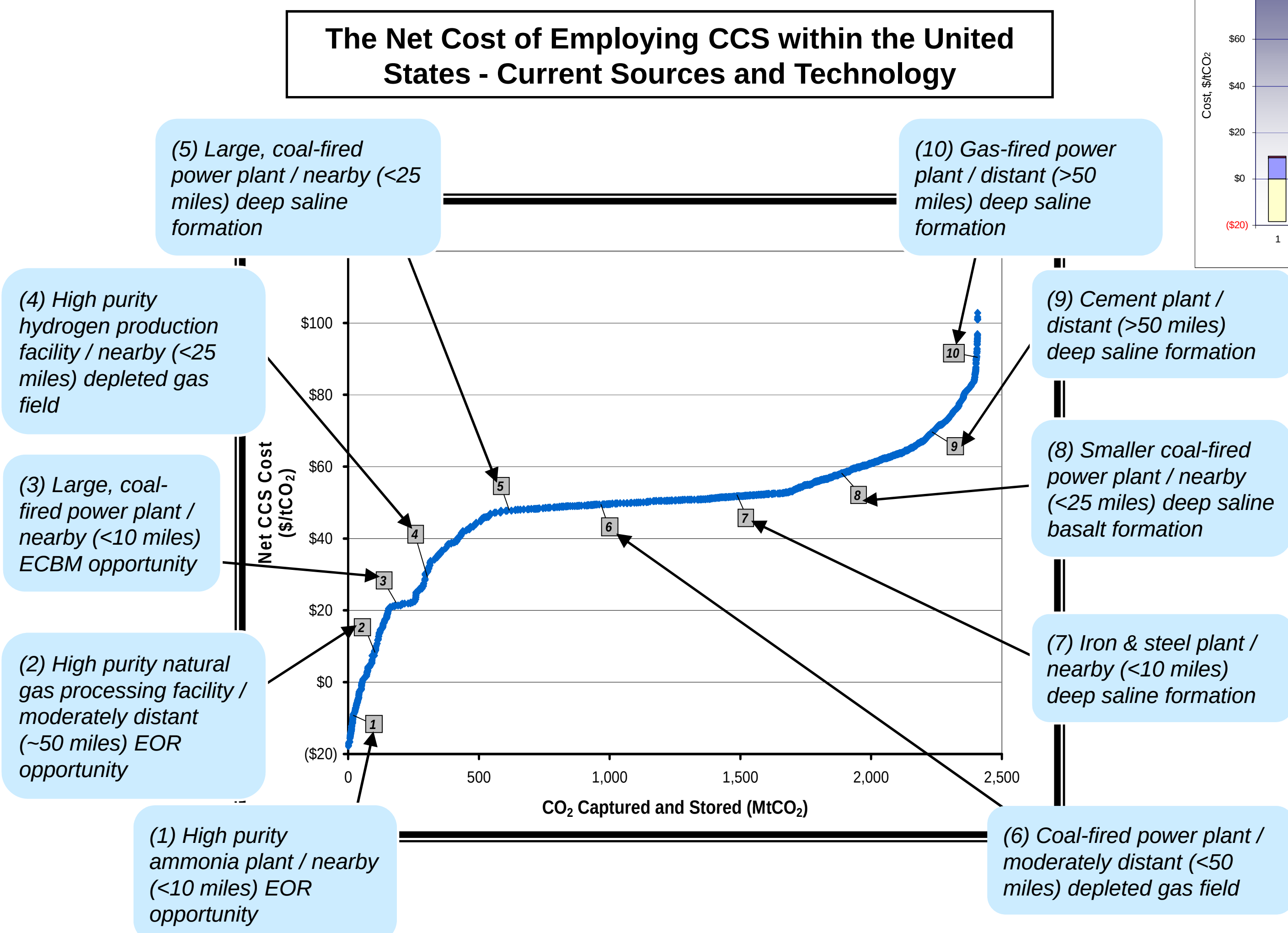
CCS Will Deploy Heterogeneously Across the U.S. Economy





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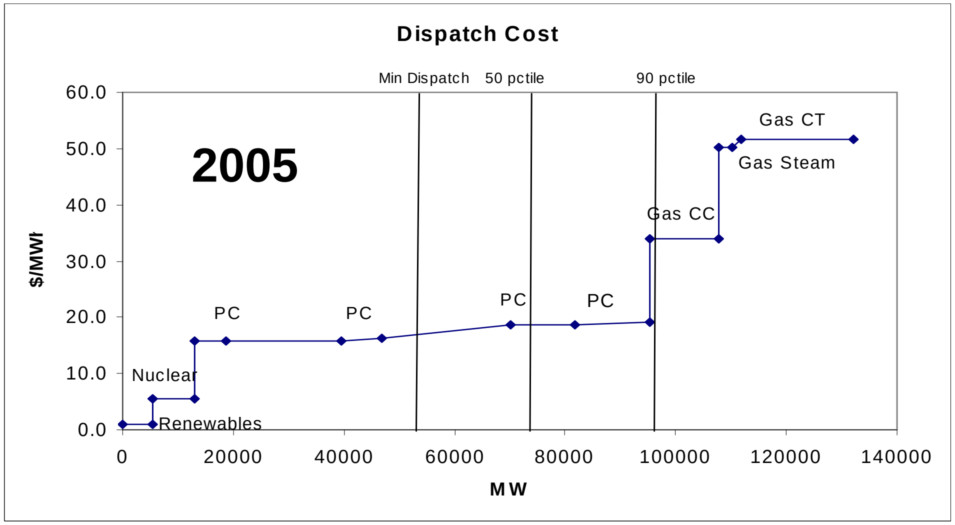
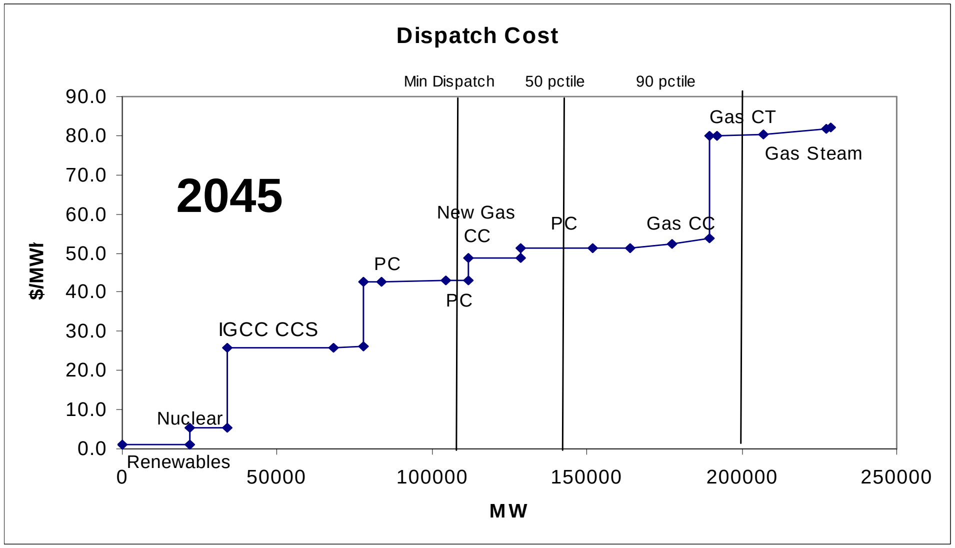
IGCC+CCS and Nuclear Are Keys to Decarbonizing Baseload Power





- In 2005, conventional fossil-fired power plants were the predominant means of generating competitively priced electricity.
- However, given today's and (likely) tomorrow's higher natural gas prices and the imposition of a hypothetical binding greenhouse gas control policy,
  - While renewables are likely to grow substantially, IGCC+CCS and nuclear become -- in some regions of the U.S. -- the dominant means of generating low-carbon *baseload* electricity.

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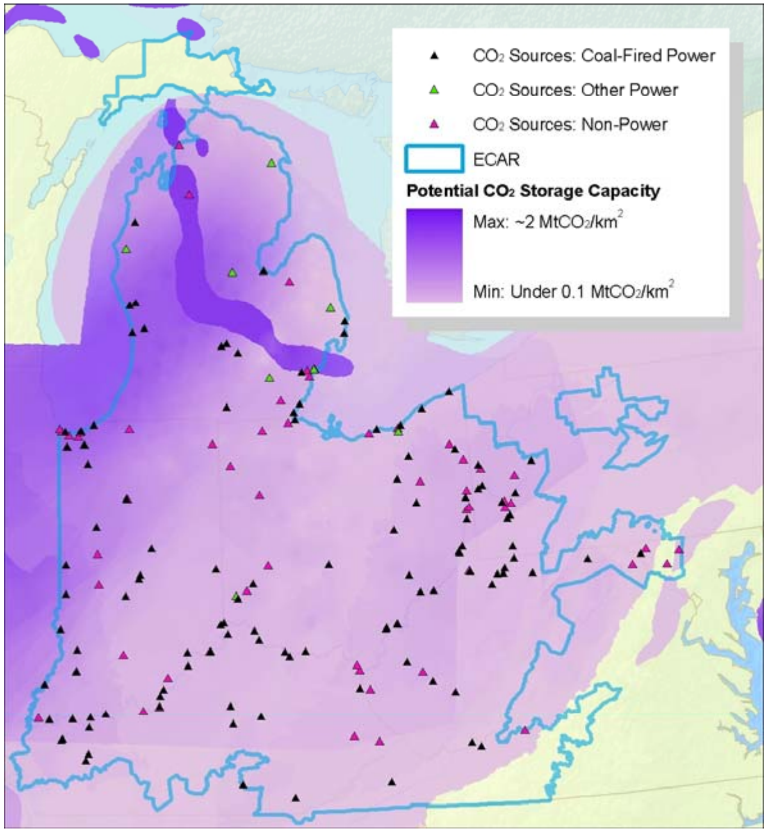
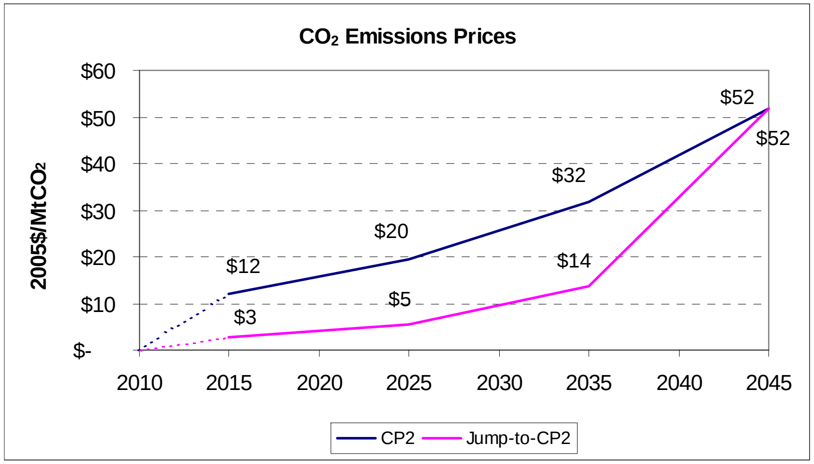
Uncertainty about Future Greenhouse Gas Constraints Increases the Value of Post-Combustion CCS Technologies



ECAR region, its large, heterogeneous potential geologic storage capacity and large (greater than 0.1 $MtCO_2$/year) stationary CO_2 emissions point sources by type



	CP2: Base PC+CCS	CP2: Improved PC+CCS	Jump to CP2: Base PC+CCS	Jump to CP2: Improved PC+CCS
Existing (pre-2005) PC units that are retrofit with CCS by 2045 (GW)	0	22	0	22
New (post-2005 builds) PC units that adopt CCS by 2045 (GW)	0	0	0	17.7
IGCC+CCS by 2045 (GW)	81	70	72	57
Cumulative CO_2 Stored in ECAR by 2045 ($MtCO_2$)	4,300	4,900	3,200	3,600

MA Wise and JJ Dooley. 2008. "The Value of Post-Combustion Carbon Dioxide Capture and Storage Technologies in a World with Uncertain Greenhouse Gas Emissions Constraints." *International Journal of Greenhouse Gas Control.* In press.

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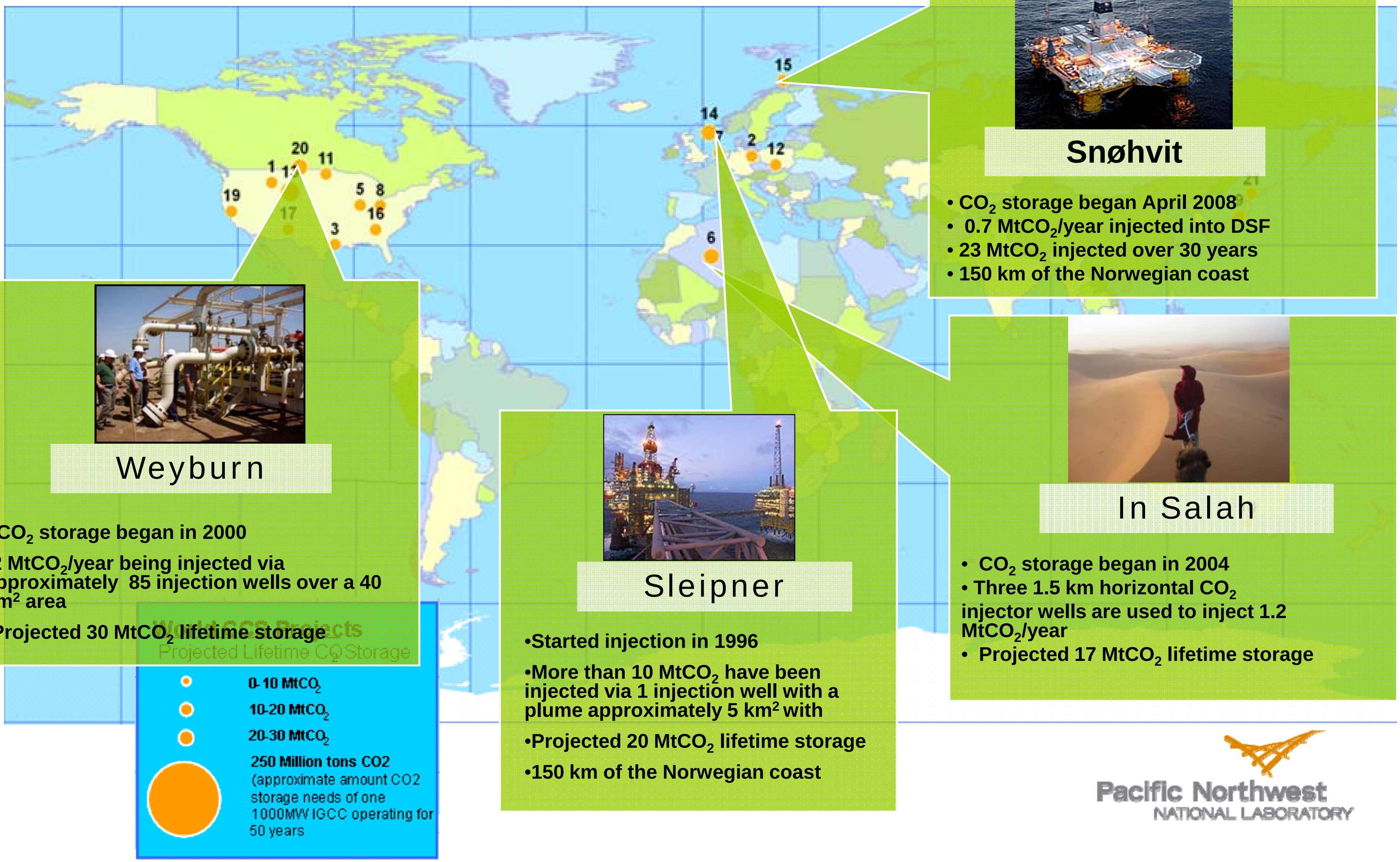
The Scope of the Scale-up Challenge



Snøhvit

- CO_2 storage began April 2008
- 0.7 $MtCO_2$/year injected into DSF
- 23 $MtCO_2$ injected over 30 years
- 150 km of the Norwegian coast

Weyburn

- CO_2 storage began in 2000
- 2 $MtCO_2$/year being injected via approximately 85 injection wells over a 40 km^2 area
- Projected 30 $MtCO_2$ lifetime storage

Sleipner

- Started injection in 1996
- More than 10 $MtCO_2$ have been injected via 1 injection well with a plume approximately 5 km^2 with
- Projected 20 $MtCO_2$ lifetime storage
- 150 km of the Norwegian coast

In Salah

- CO_2 storage began in 2004
- Three 1.5 km horizontal CO_2 injector wells are used to inject 1.2 $MtCO_2$/year
- Projected 17 $MtCO_2$ lifetime storage

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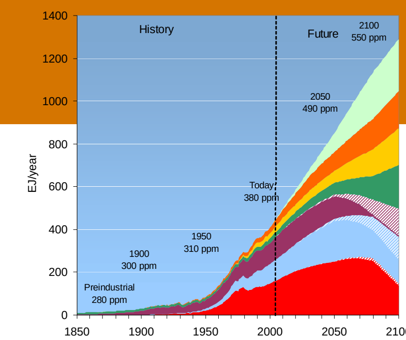
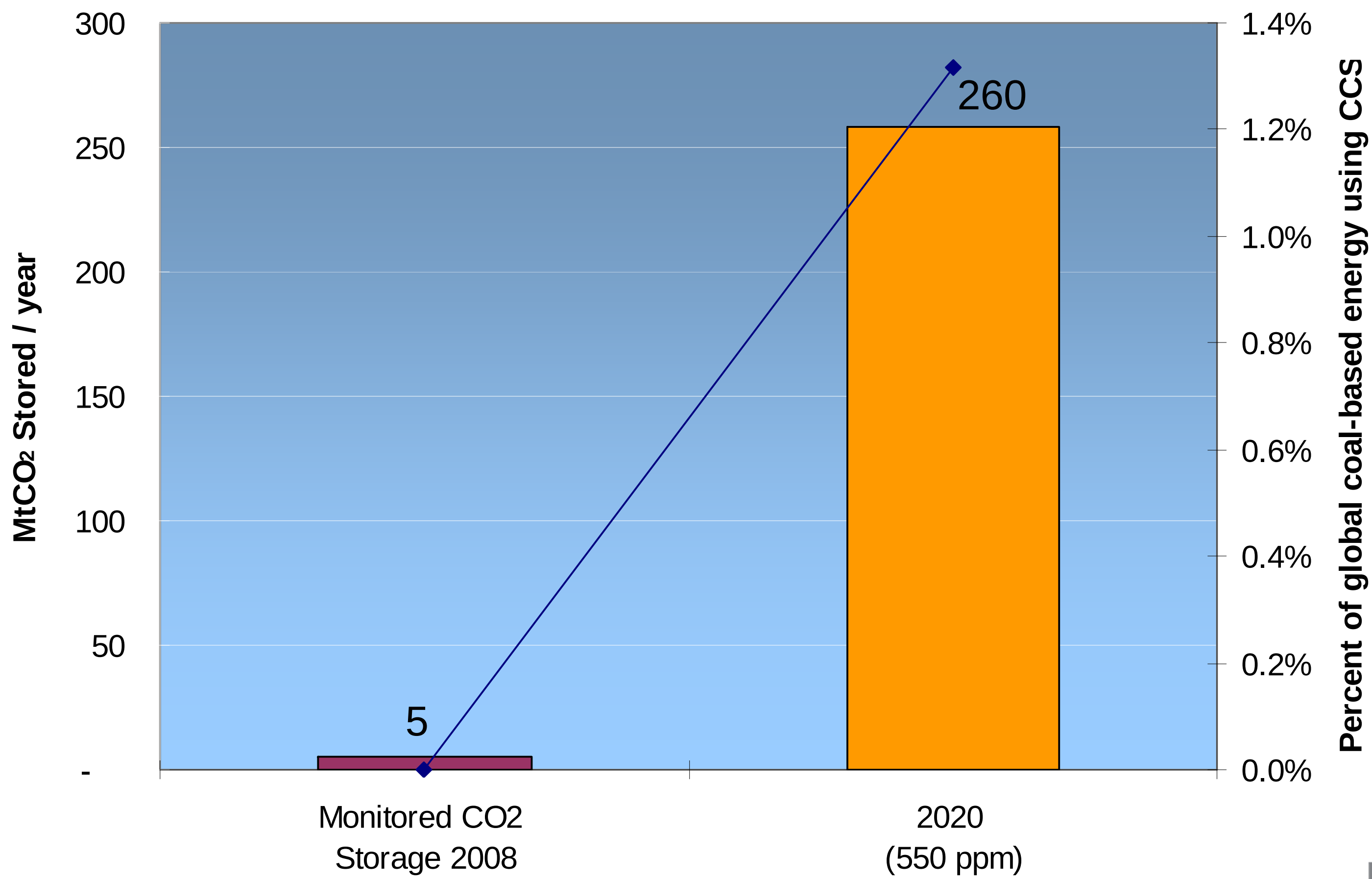
The Challenge of Scale Grows with Time — the near term



Annual Rate of Deep Geologic CO_2 Storage



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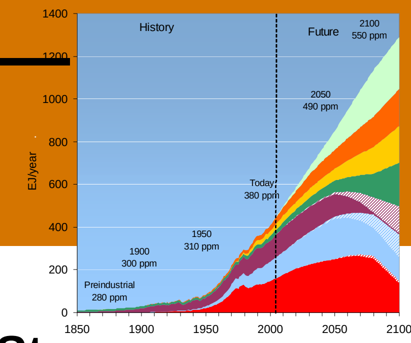
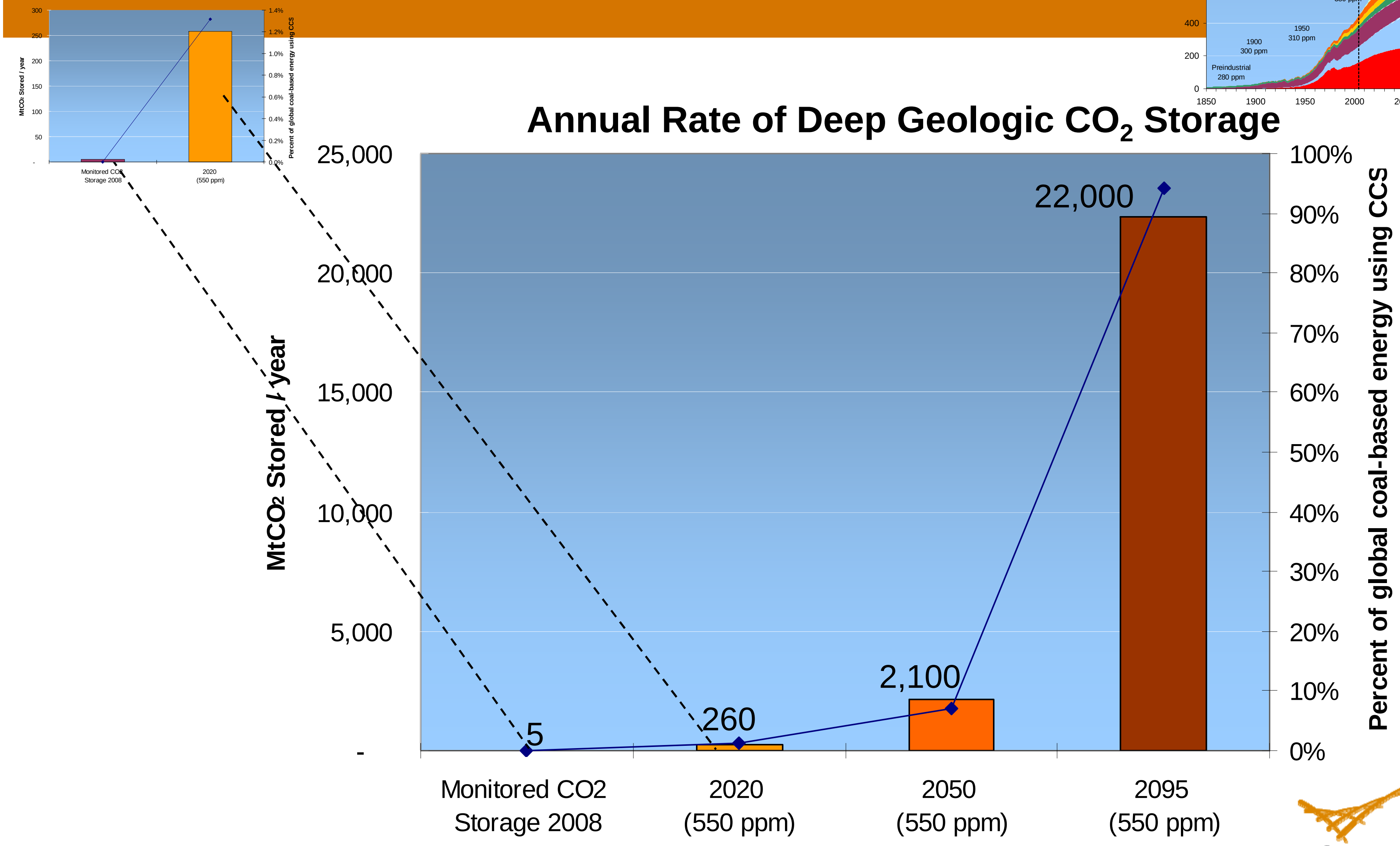
The Challenge of Scale Grows with Time — the mid to long term





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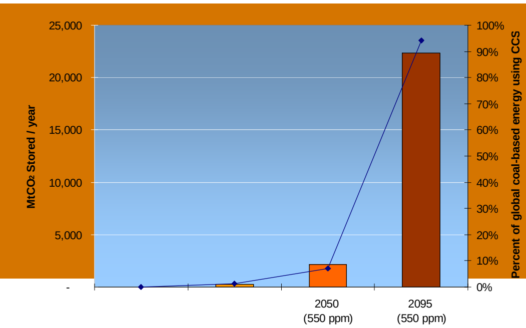
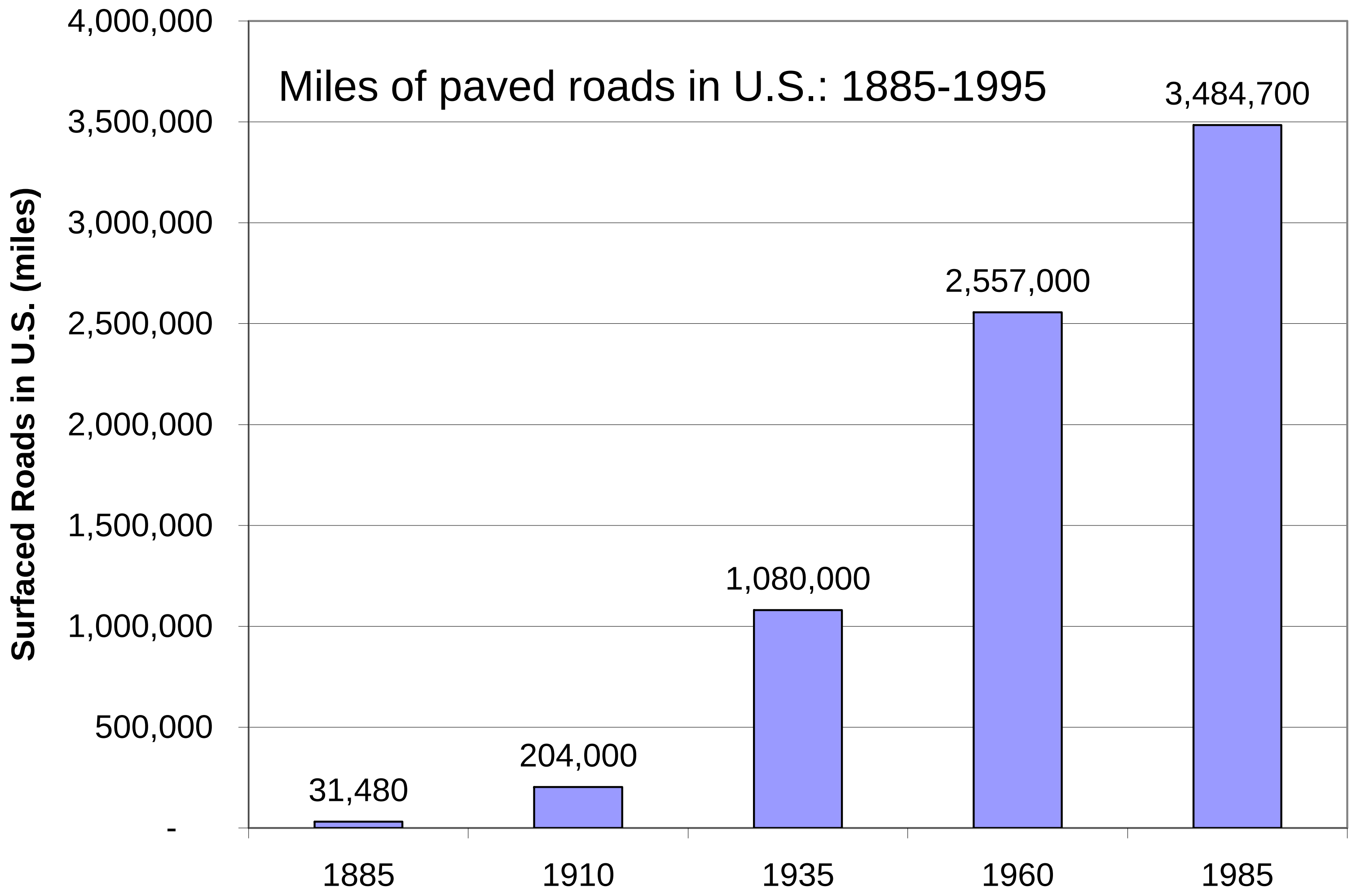
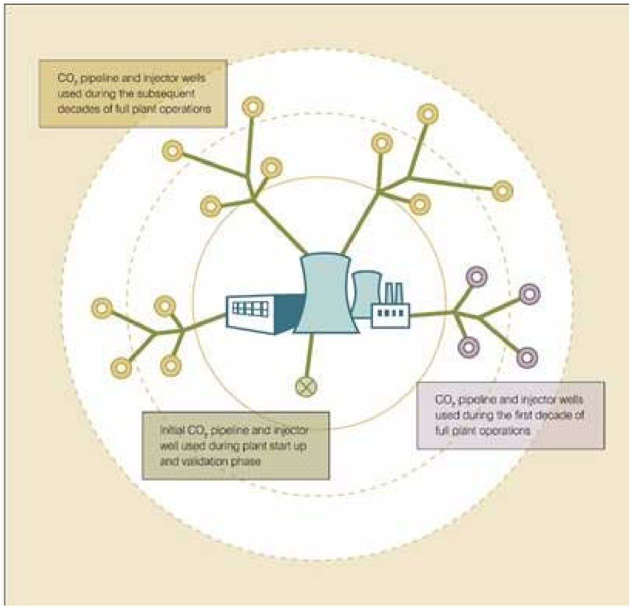
Scale-up Challenge





Experiential Knowledge Is Needed to Move CCS Forward

- The cost of capturing CO_2 is **not** the single biggest obstacle standing in the way of CCS deployment.
- When thinking about storing 100% of a large power plant's emissions for 50+ years, there are a number of things that we would like to know today but are likely to only learned through real world operational experience:
  - Can the same injector wells be used for 50+ years?
  - Are the operational characteristics that make a field a good candidate CO_2-driven enhanced oil recovery similar to the demands placed upon deep geologic formation that is being used to isolate large quantities of CO_2 from the atmosphere for the long term?
  - What measurement, monitoring and verification (MMV) "technology suites" should be used and does the suite vary across different classes of geologic reservoirs and/or with time?
  - How long should post injection monitoring last?
  - What are realistic, field deployable remediation options if leakage from the target storage formation is detected?
  - Who will regulate CO_2 storage on a day-to-day basis? What criteria and metrics will this regulator use?



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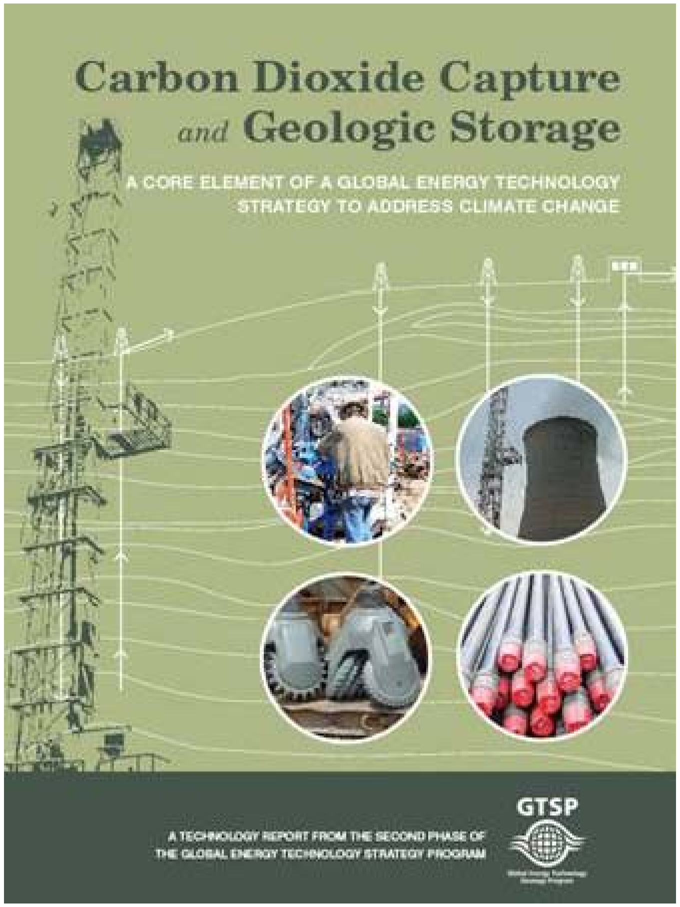
GTSP Phase II Capstone Report on Carbon Dioxide Capture and Storage

- CCS technologies have tremendous potential value for society.
- CCS is, at its core, a climate-change mitigation technology and therefore the large-scale deployment of CCS is contingent upon the timing and nature of future GHG emission control policies.
- The next 5-10 years constitute a critical window in which to amass needed real-world operational experience with CCS systems.
- The electric power sector is the largest potential market for CCS technologies and its potential use of CCS has its own characteristics that need to be better understood.
- Much work needs to be done to ensure that the potential large and rapid scale-up in CCS deployment will be safe and successful.



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