Overview of Selected Issues Associated with the Potential for Large Scale Commercial Deployment of Carbon Dioxide Capture and Storage Technologies

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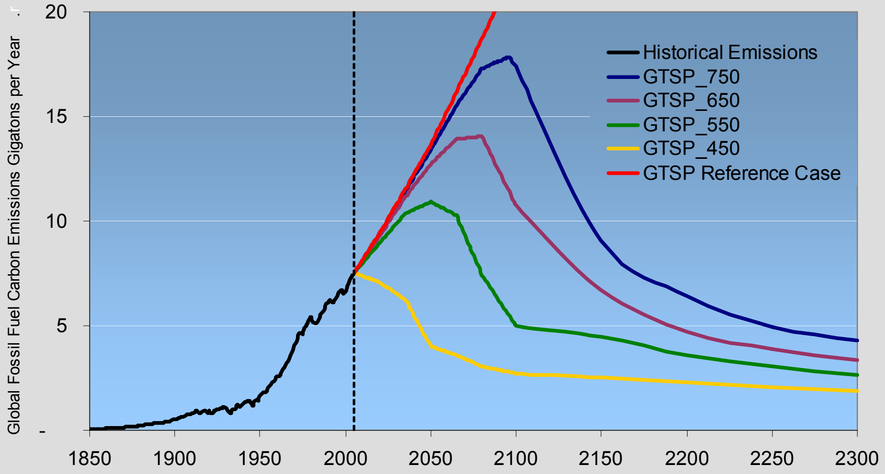
Outline

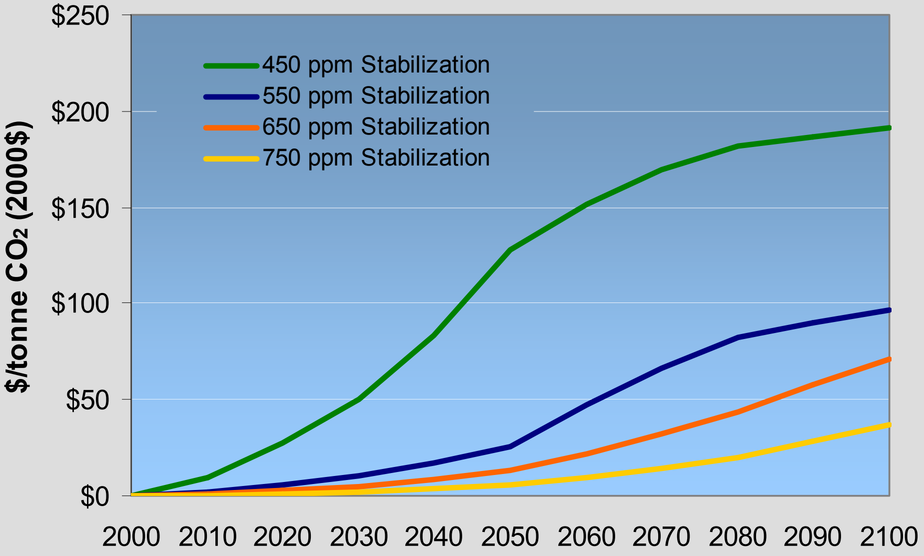
- Carbon Management 101
- The Broad Macroeconomic Role of CCS
- In the near-term, CCS ≠ IGCC+CCS
- In the mid-term to long-term, the largest markets for CCS are coal-fired electric power facilities
- Conclusions

Climate change is a long-term strategic problem with implications for today

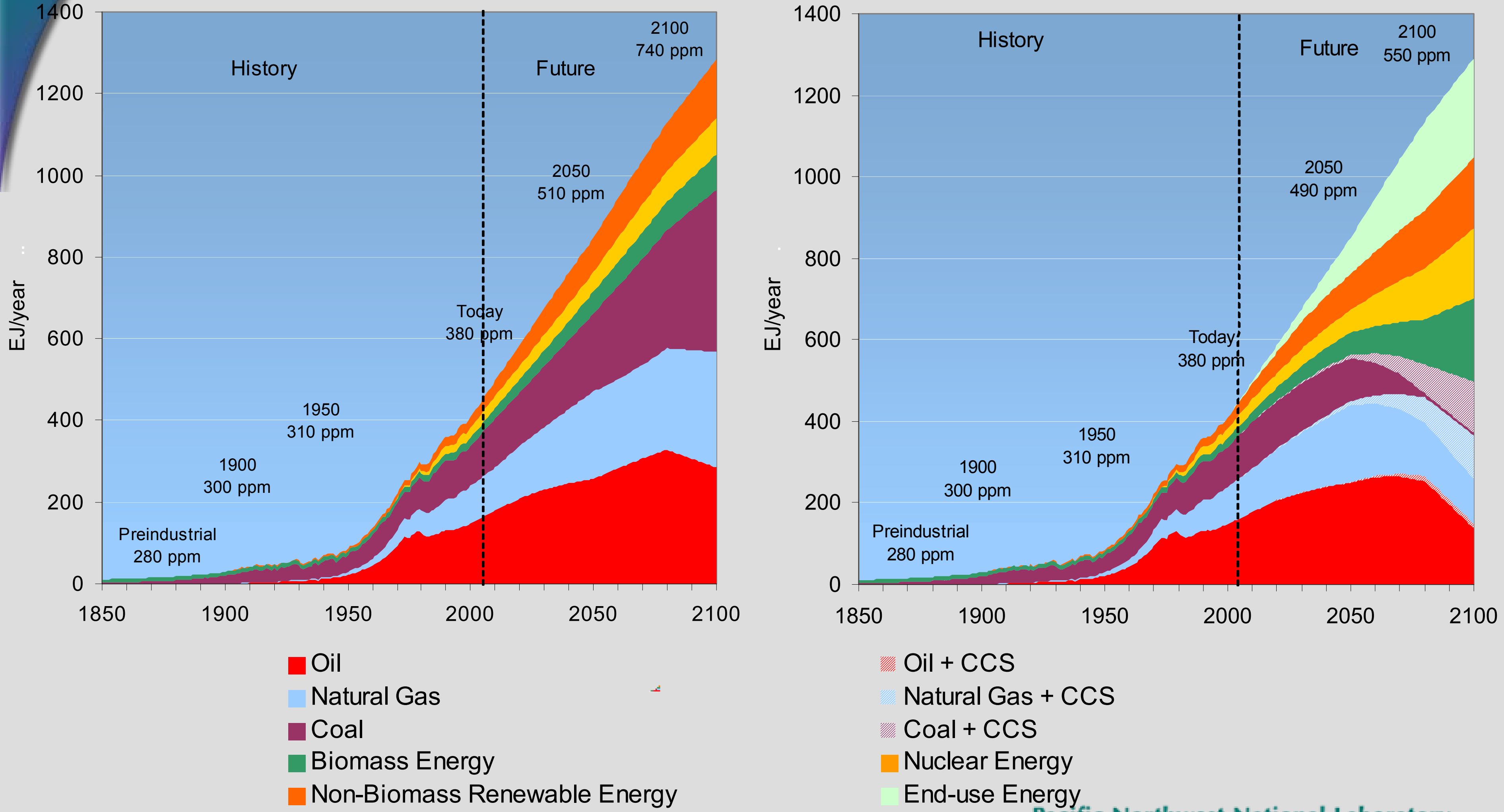
- Stabilizing atmospheric concentrations of greenhouse gases and not their annual emissions levels should be the overarching strategic goal of climate policy.

- 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.



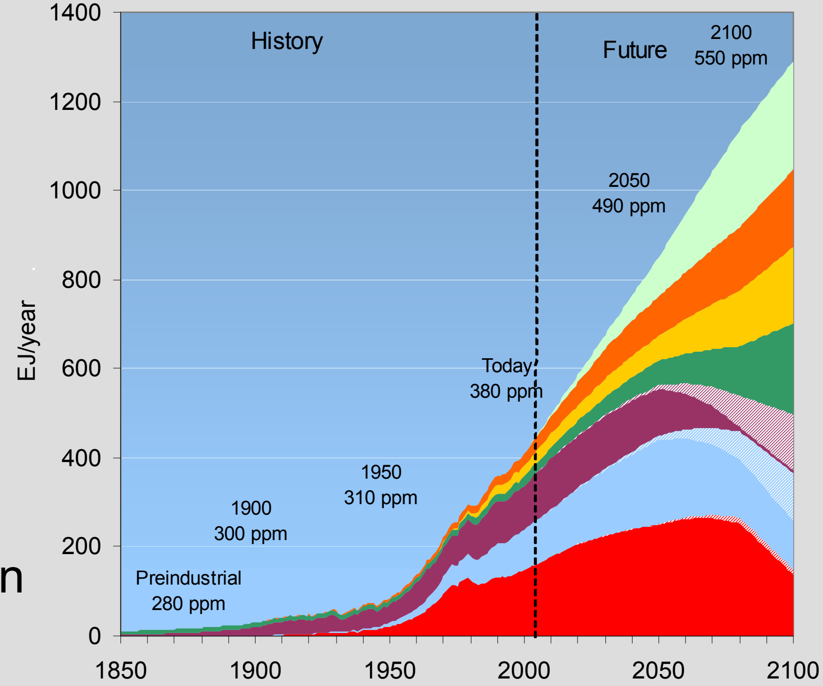


Stabilization of CO_2 concentrations means fundamental change to the global energy system



Stabilization of CO_2 concentrations means fundamental change to the global energy system…

- CO_2 capture and storage (CCS) plays a potentially large role assuming that the institutions make adequate provision for its use.
- Bioenergy crops have dramatic potential, but important land-use implications.
- Hydrogen could be a major new energy carrier, but requires important technology advances in fuel cells and storage.
- Nuclear energy could deploy extensively throughout the world but public acceptance, institutional constraints, waste, safety and proliferation issues remain.
- Wind & solar could accelerate their expansion particularly if energy storage improves.
- End-use energy technologies that improve efficiency and/or use energy carriers with low emissions can also play significant roles, e.g. continued electrification of the global economy.

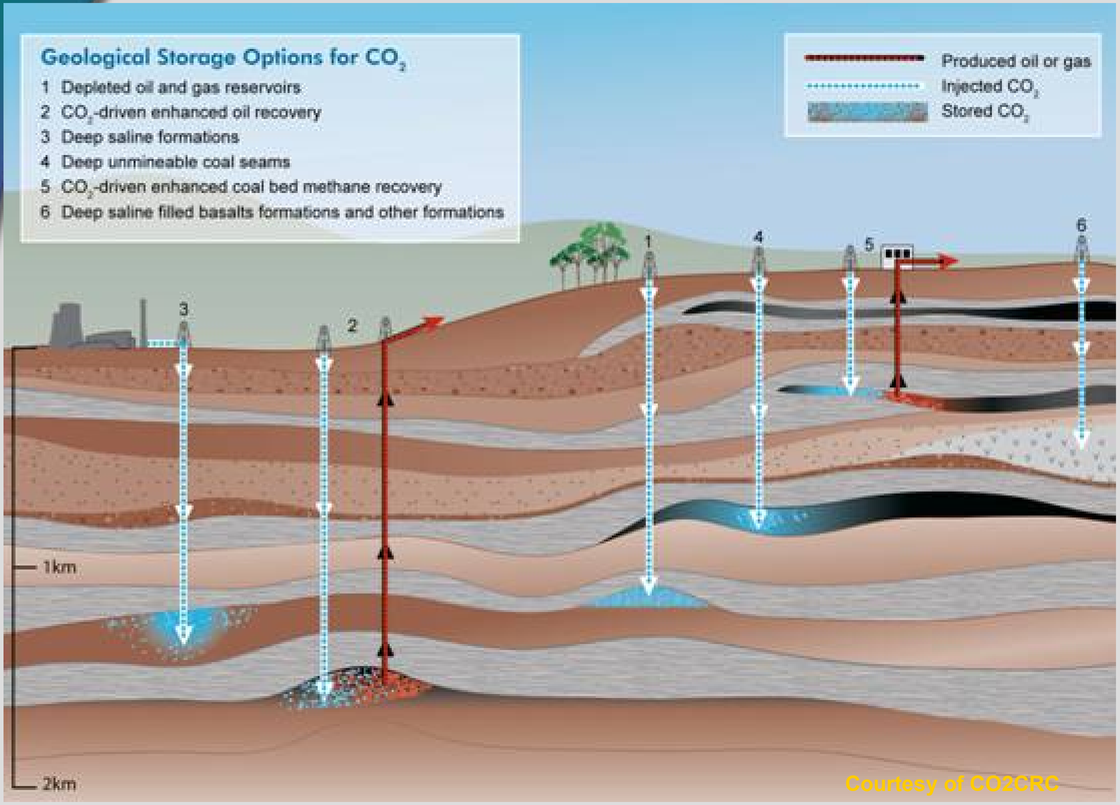


The Macroeconomic Role of CCS Technologies in Addressing Climate Change

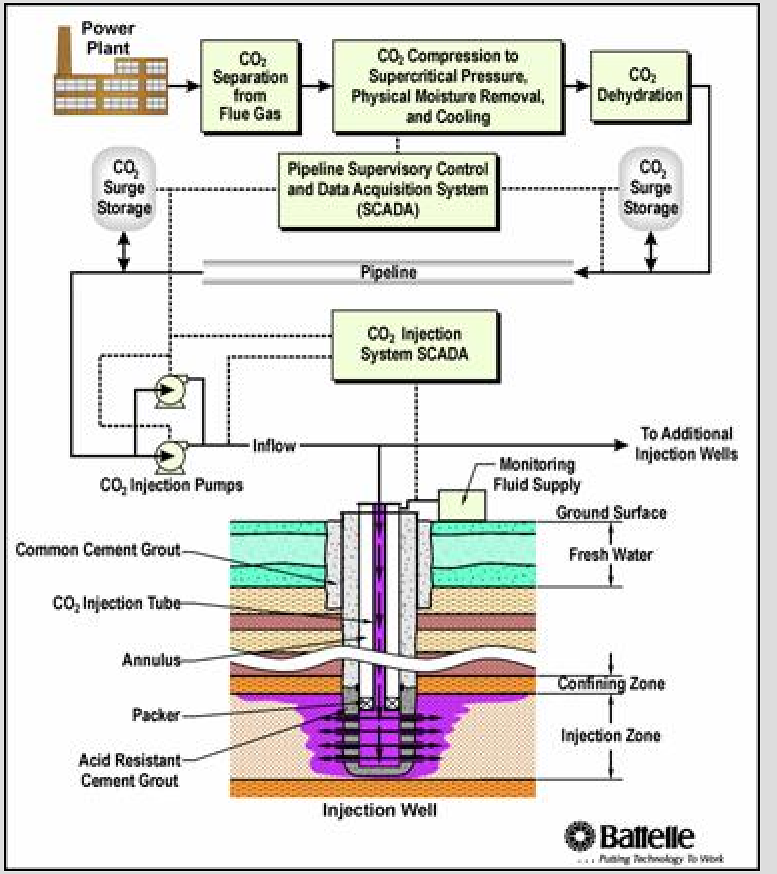
- Plenty of theoretical CO_2 storage capacity; however this natural resource is not evenly distributed around the world
- Knowing whether a country, region, or specific locale has suitable geologic CO_2 storage reservoirs provides a powerful insight into how that region’s energy infrastructure will evolve in a greenhouse gas constrained world.
- The potential market for CCS technologies is and will remain very heterogeneous.
- In the mid to long term, baseload coal-fired power plants and potential coal-to-liquids facilities are the largest potential market for CCS technologies.
- The potential deployment of CCS technologies could be massive.

CO_2 Capture and Storage: Not Nearly this Simple

Overview of Carbon Dioxide Capture and Storage (CCS)

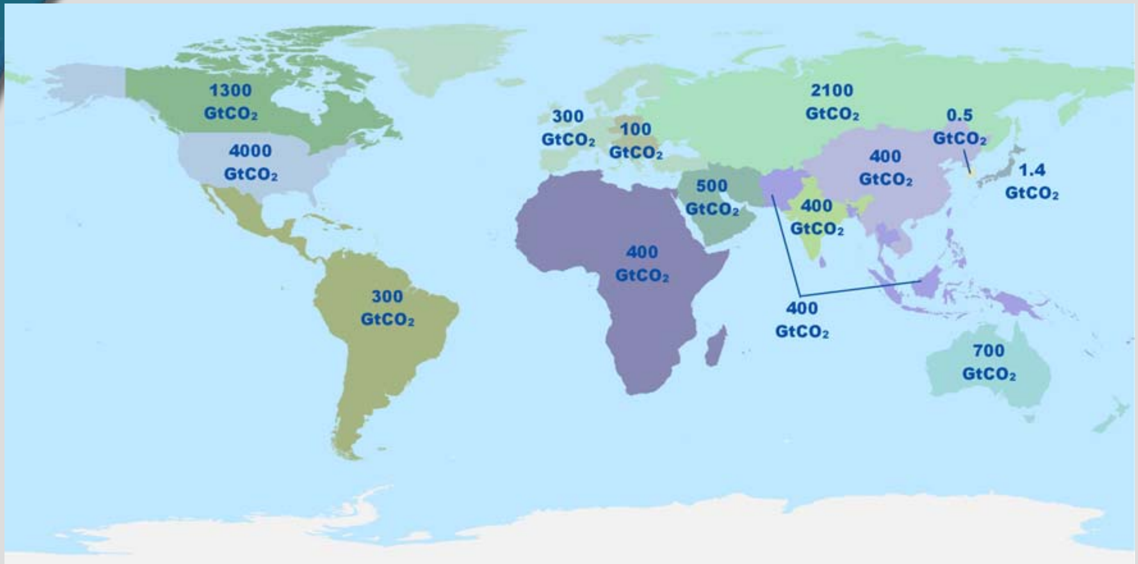


Courtesy of CO2CRC



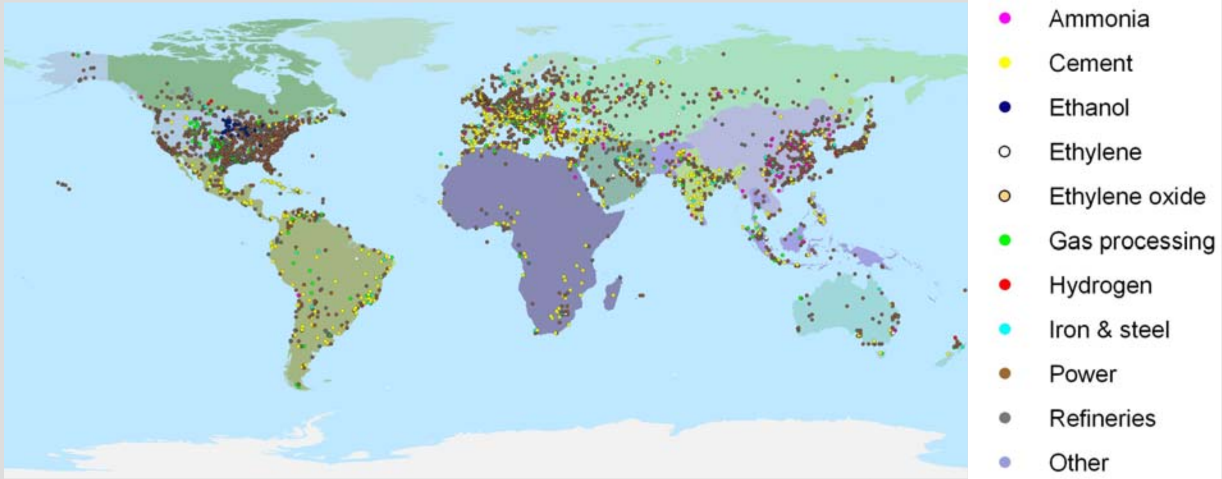
Global CO_2 Storage Capacity:

Abundant, Valuable and Very Heterogeneous Natural Resource



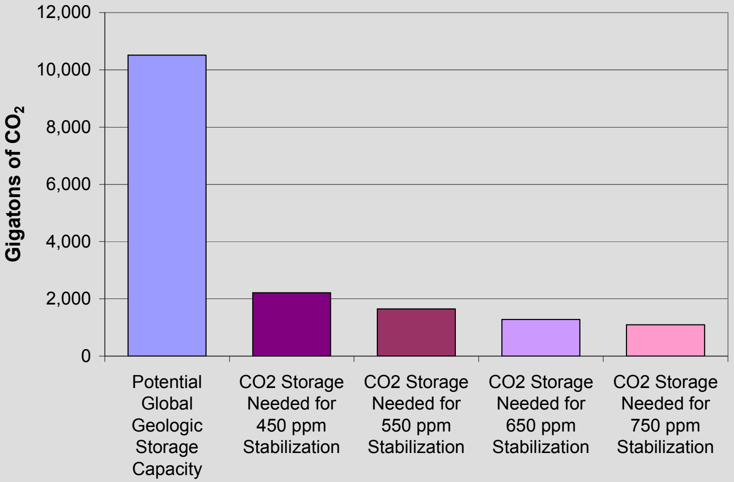
- 11,000 $GtCO_2$ of potentially available storage capacity
- U.S., Canada and Australia likely have sufficient CO_2 storage capacity for this century
- Japan and Korea’s ability to continue using fossil fuels likely constrained by relatively small domestic storage reservoir capacity

- ~8100 Large CO_2 Point Sources
- 14.9 $GtCO_2$/year
- >60% of all global anthropogenic CO_2 emissions

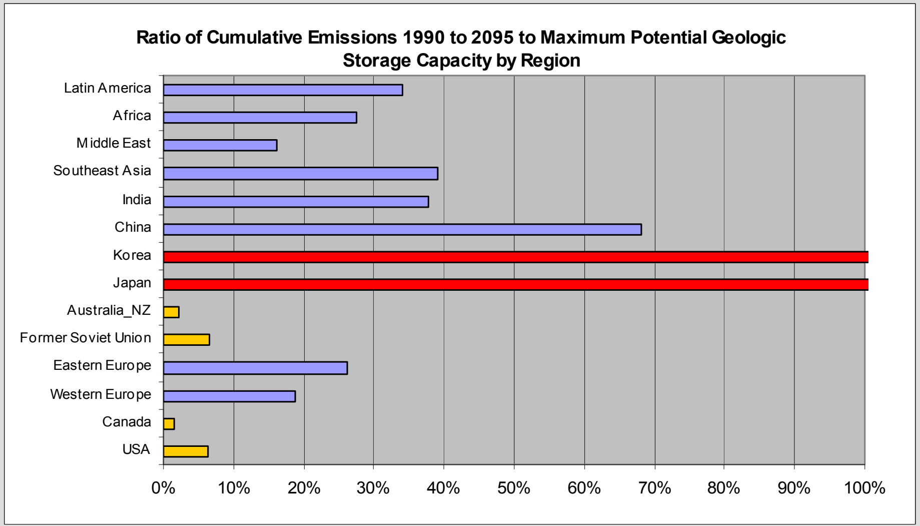


Global CO_2 Storage Capacity: *Abundant, Valuable and Very Heterogeneous Natural Resource*

- There appears to be sufficient global theoretical storage capacity to easily accommodate the demand for CO_2 storage for stabilization scenarios ranging from 450-750ppmv.

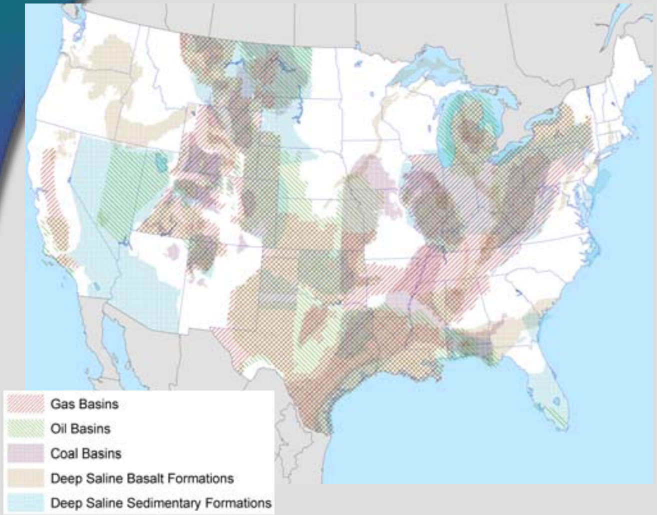


- However, geologic CO_2 storage reservoirs, like many other natural resources, are not homogenous in quality nor in their distribution:
  - Some regions will be able to use CCS for a very long time and likely with fairly constant and possibly declining costs.
  - In other regions, CCS appears to be more of a transition technology.



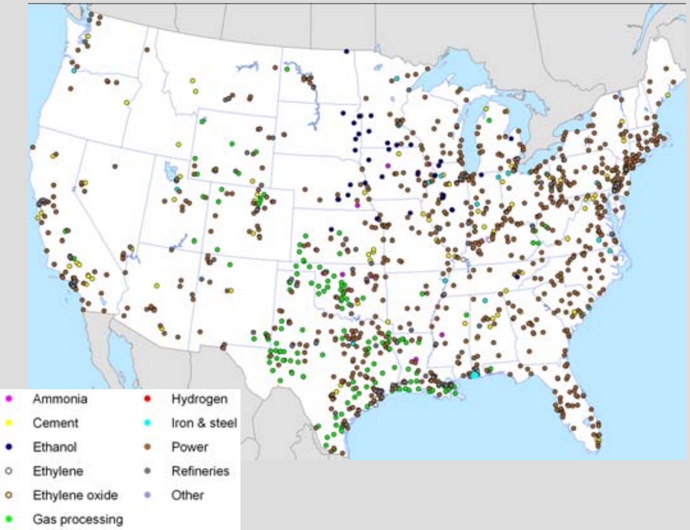
CCS Deployment Across the US Economy

Large 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)

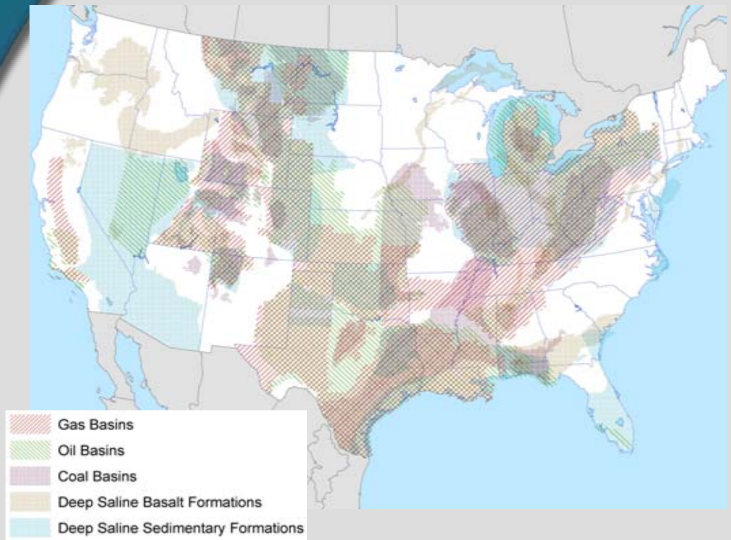


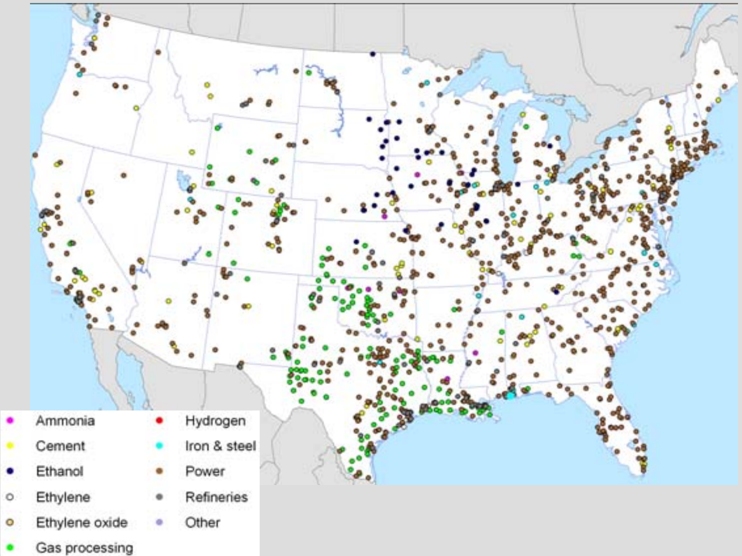
1,715 Large Sources (100+ $ktCO_2$/yr) with Total Annual Emissions = 2.9 $GtCO_2$

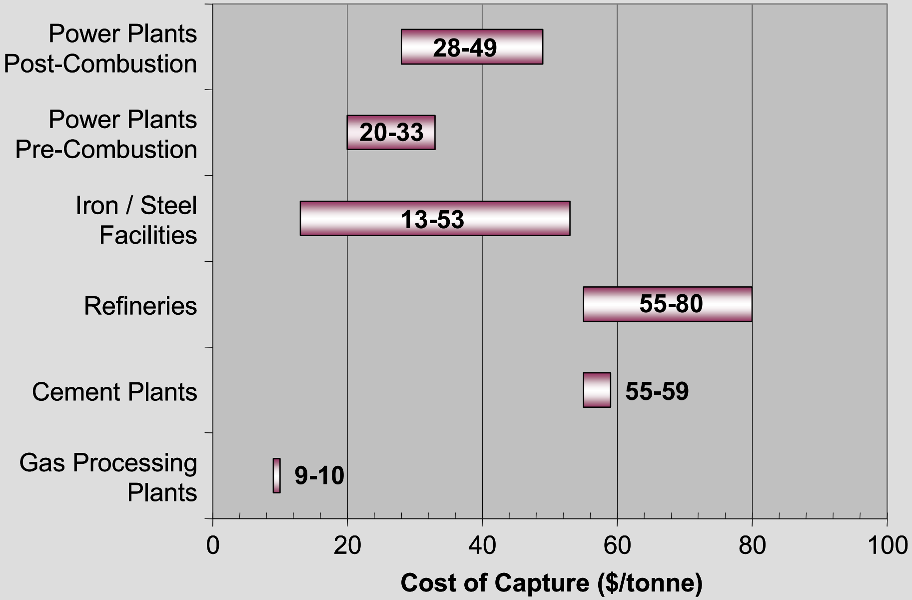
- 1,053 electric power plants
- 259 natural gas processing facilities
- 126 petroleum refineries
- 44 iron & steel foundries
- 105 cement kilns
- 38 ethylene plants
- 30 hydrogen production
- 19 ammonia refineries
- 34 ethanol production plants
- 7 ethylene oxide plants

CCS Deployment Across the US Economy

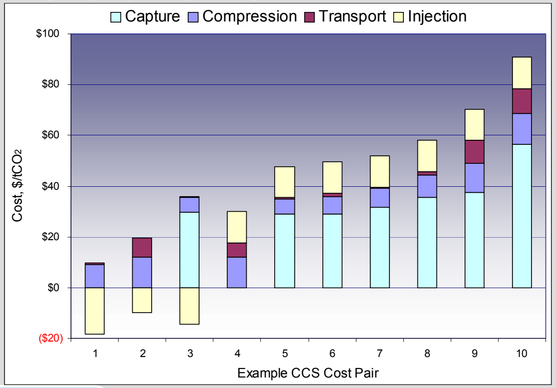
No uniform "CCS" technology. No homogenous market.



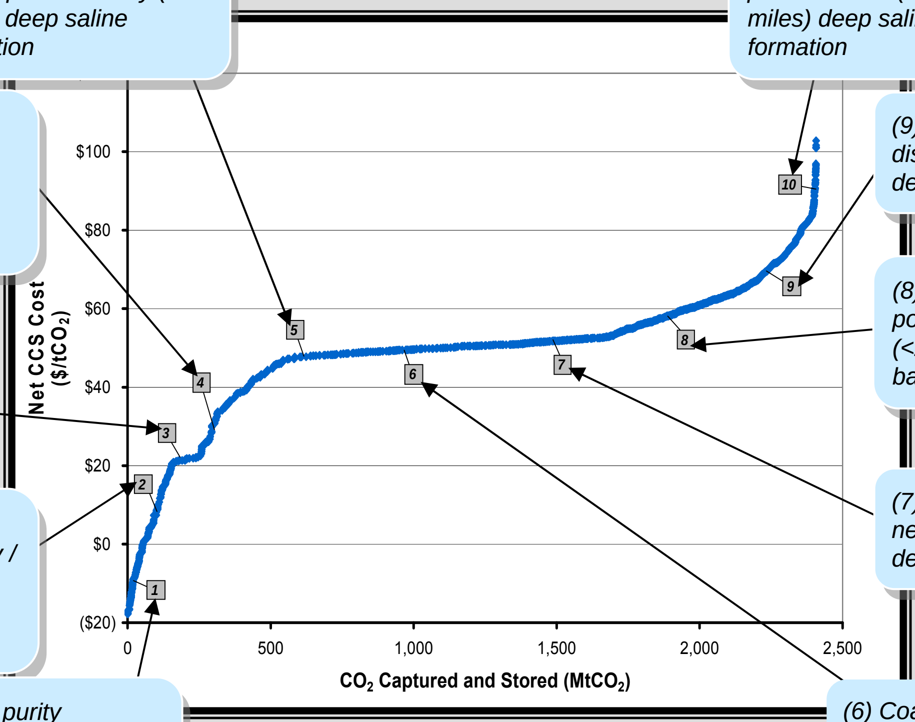




CCS Deployment Across the US Economy: *Differentiated CCS Adoption Across Economic Sectors*



The Net Cost of Employing CCS within the United States - Current Sources and Technology



(1) High purity ammonia plant / nearby (<10 miles) EOR opportunity

(2) High purity natural gas processing facility / moderately distant (~50 miles) EOR opportunity

(3) Large, coal-fired power plant / nearby (<10 miles) ECBM opportunity

(4) High purity hydrogen production facility / nearby (<25 miles) depleted gas field

(5) Large, coal-fired power plant / nearby (<25 miles) deep saline formation

(6) Coal-fired power plant / moderately distant (<50 miles) depleted gas field

(7) Iron & steel plant / nearby (<10 miles) deep saline formation

(8) Smaller coal-fired power plant / nearby (<25 miles) deep saline basalt formation

(9) Cement plant / distant (>50 miles) deep saline formation

(10) Gas-fired power plant / distant (>50 miles) deep saline formation

In the near-term, CCS ≠ IGCC+CCS

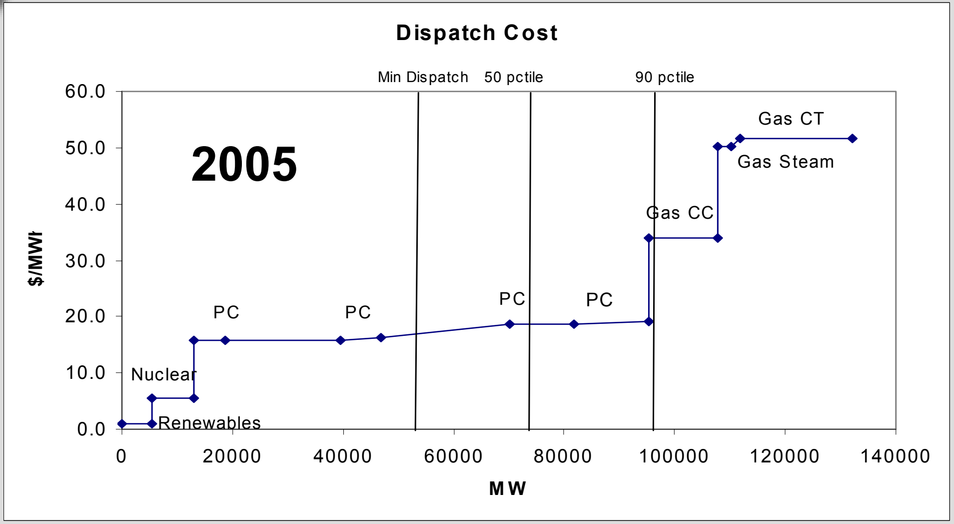
- The deployment of carbon dioxide capture and storage technologies will be driven by efforts to explicitly regulate greenhouse gas emissions.

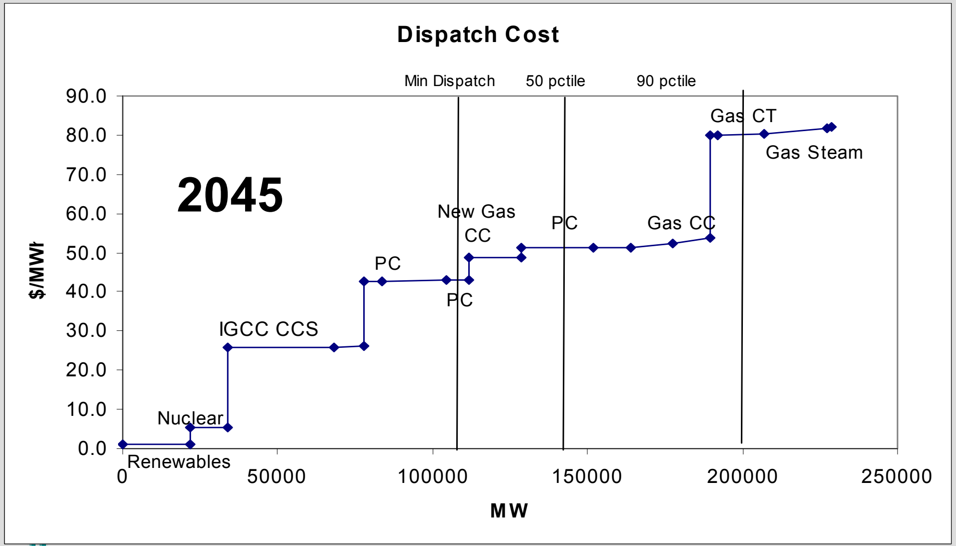
- The CCS technical literature is clear on a couple of key points:
  - The potential deployment of CCS could be very large.
  - The large scale deployment of CCS will require the presence of a significant disincentive on the free venting of greenhouse gas emissions (e.g., >\$25/tonCO_2).
  - The majority of CCS deployment and deep geologic CO_2 storage will occur in the second half of this century.

- This is often misinterpreted as implying that CCS deployment – and perhaps significant deployment -- will not take place for many years to come.

CCS Deployment by Electric Utilities

IGCC+CCS and Nuclear Are Keys to Decarbonizing Baseload Power

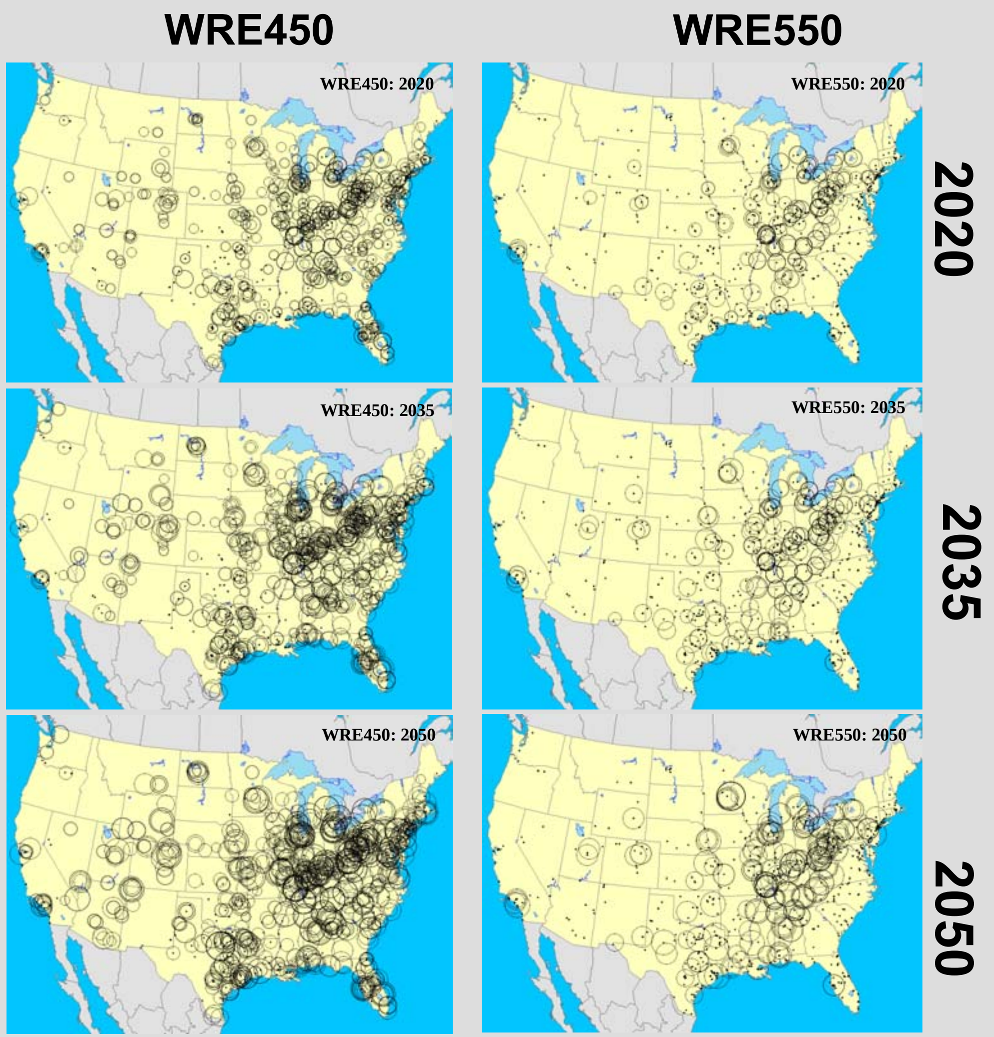




- In 2005, conventional fossil-fired power plants were the predominant means of generating competitively priced electricity.
- However, given today’s and (likely) tomorrow’s higher natural gas prices and the imposition of a hypothetical binding greenhouse gas control policy,
  - While renewables are 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.

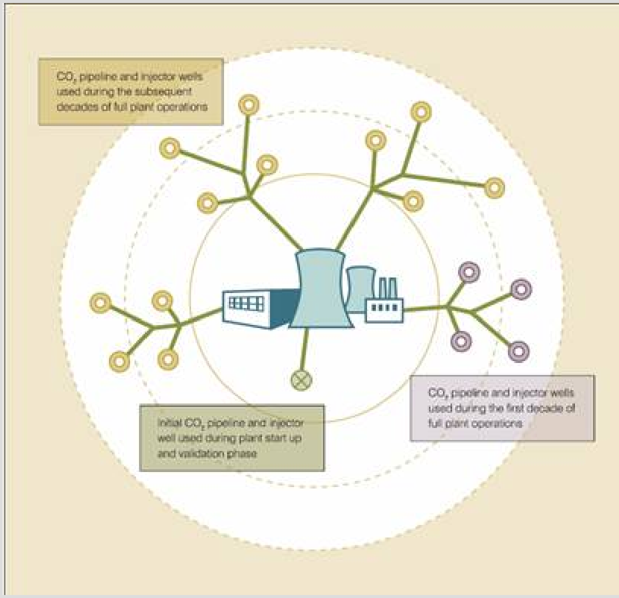
It is important to realize that we are in the *earliest stages* of the deployment of CCS technologies.

- 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.
  - 1,000s of miles of dedicated CO_2 pipelines.
  - 100s of millions of tons of CO_2 being injected into the subsurface annually.
- The overwhelming criteria for siting a CCS-enabled power plant will relate to things like injectivities and total reservoir capacity and not whether there is “buyer for CO_2”

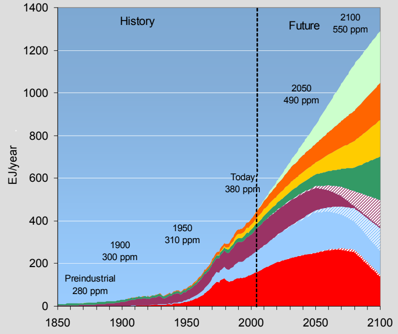


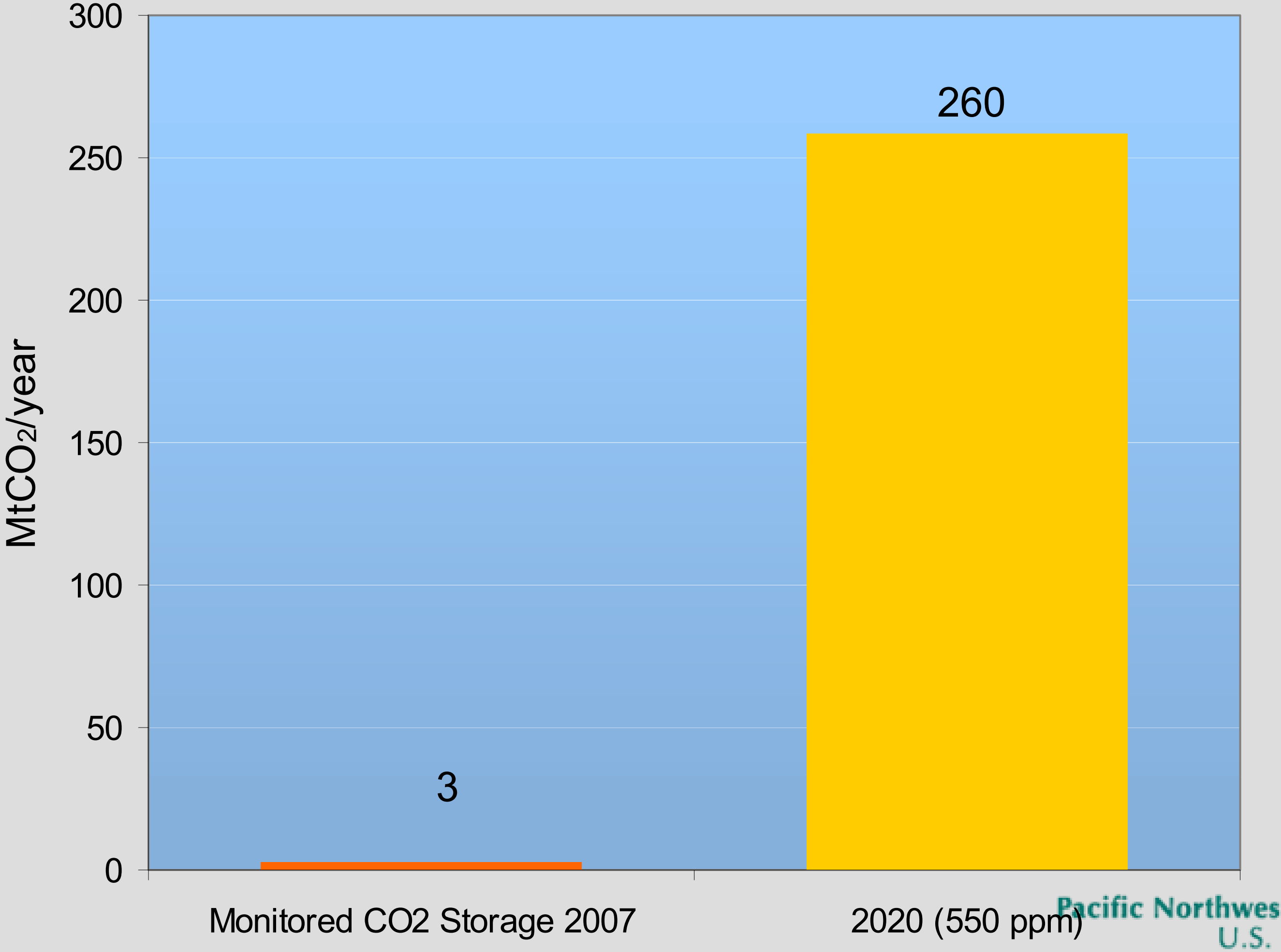
Geologic CO_2 Storage: Selected Basic Engineering and Operational Issues

- 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:
  - How many injector wells will be needed? How close can they be to each other?
  - 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 fore 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?

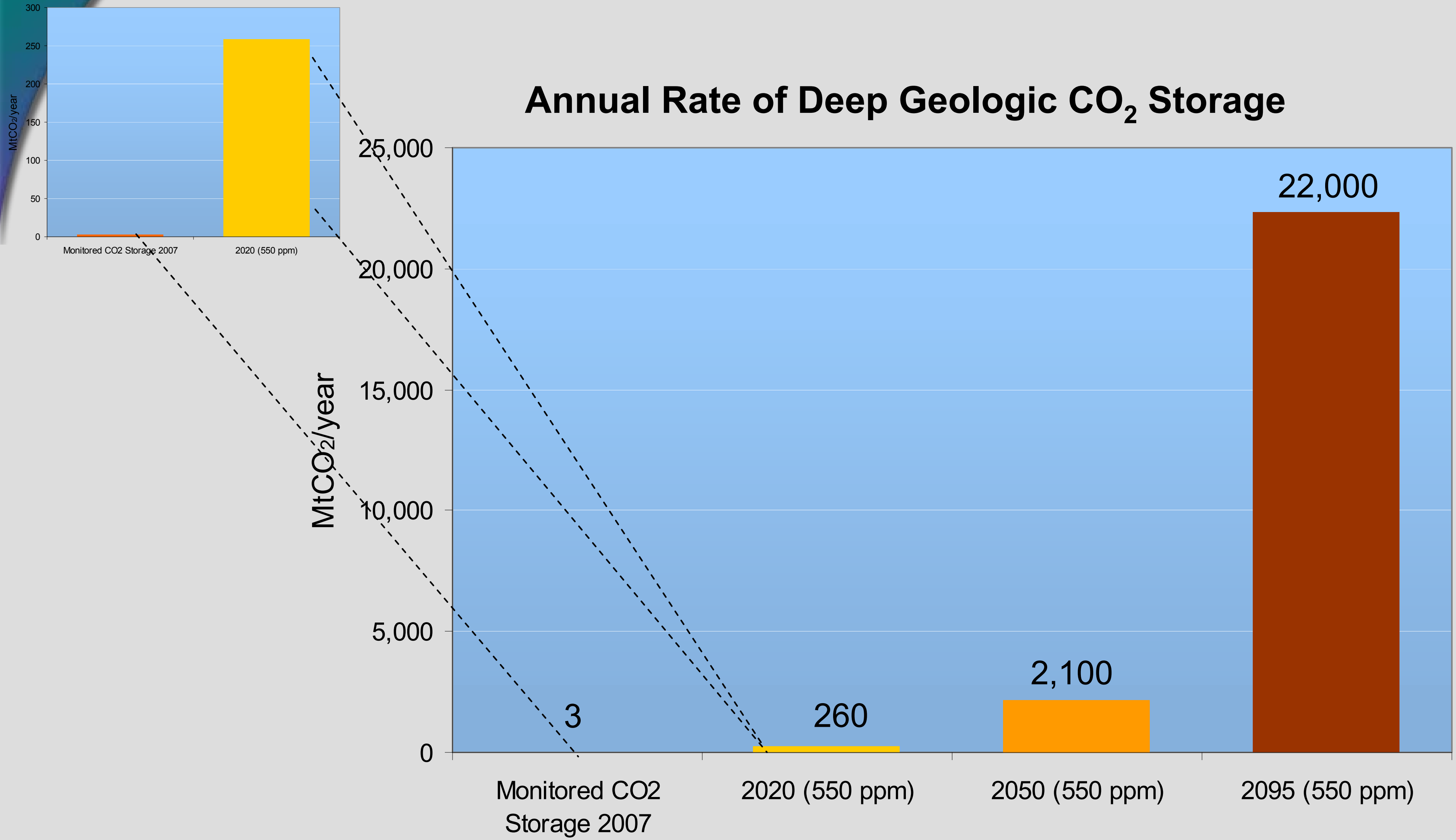


The Challenge of Scale Grows with Time — the near term




Annual Rate of Deep Geologic CO_2 Storage

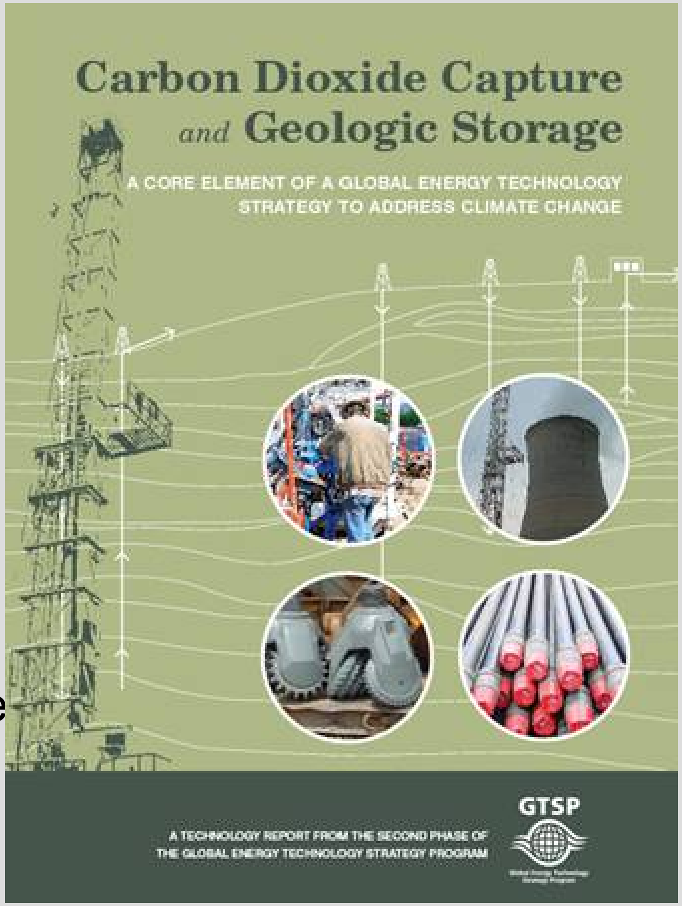
The Challenge of Scale Grows with Time — the mid to long term



Annual Rate of Deep Geologic CO_2 Storage

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.



Carbon Dioxide Capture
and Geologic Storage

A CORE ELEMENT OF A GLOBAL ENERGY TECHNOLOGY STRATEGY TO ADDRESS CLIMATE CHANGE

A TECHNOLOGY REPORT FROM THE SECOND PHASE OF THE GLOBAL ENERGY TECHNOLOGY STRATEGY PROGRAM

GTSP

Selected References

- Dooley, JJ, CL Davidson, RT Dahowski, MA Wise, N Gupta, SH Kim, EL Malone, "Carbon Dioxide Capture and Geologic Storage: A Key Component of a Global Energy Technology Strategy to Address Climate Change." Joint Global Change Research Institute, Battelle Pacific Northwest Division. May 2006. PNWD-3602. College Park, MD.
- Edmonds, J.A., M.A. Wise, J.J. Dooley, S.H. Kim, S.J. Smith, P.J. Runci, L.E. Clarke, E.L. Malone, and G.M. Stokes. 2007. *Global Energy Technology Strategy Addressing Climate Change: Phase 2 Findings from an International Public-Private Sponsored Research Program.* Joint Global Change Research Institute, College Park, MD.
- Edmonds, J., J. Dooley, S. Kim, S. Friedman, and M. Wise. *Technology in an Integrated Assessment Model: The Potential Regional Deployment of Carbon Capture and Storage in the Context of Global CO_2 Stabilization.* (In) Human-induced Climate Change: An Interdisciplinary Assessment, ed. Michael Schlesinger, Haroon Kheshgi, Joel Smith, Francisco de la Chesnaye, John M. Reilly, Tom Wilson and Charles Kolstad. Published by Cambridge University Press. Cambridge University Press 2007. pp. 181-197.
- MA Wise and JJ Dooley. “The Value of Post-Combustion Carbon Dioxide Capture and Storage Technologies in a World with Uncertain Greenhouse Gas Emissions Constraints.” Joint Global Change Research Institute. Pacific Northwest National Laboratory. September 2007. PNNL-16936.
- Wise MA, JJ Dooley, RT Dahowski, and CL Davidson (2007). “Modeling the impacts of climate policy on the deployment of carbon dioxide capture and geologic storage across electric power regions in the United States." International Journal of Greenhouse Gas Control. Volume 1, Issue 2, April 2007, Pages 261-270.
- JJ Dooley. *Public Perception in Relation to the Potential Large-Scale Commercial Deployment of Carbon Dioxide Capture and Storage Technologies.* A Joint Workshop of the International Energy Agency’s Coal Industry Advisory Board and The Royal Society and The Royal Academy of Engineering. Paris. November 8, 2007. PNWD-SA-8021.