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On the Potential Large-Scale Commercial Deployment of Carbon Dioxide Capture and Storage Technologies:

Findings from Phase 2 of the Global Energy Technology Strategy Project

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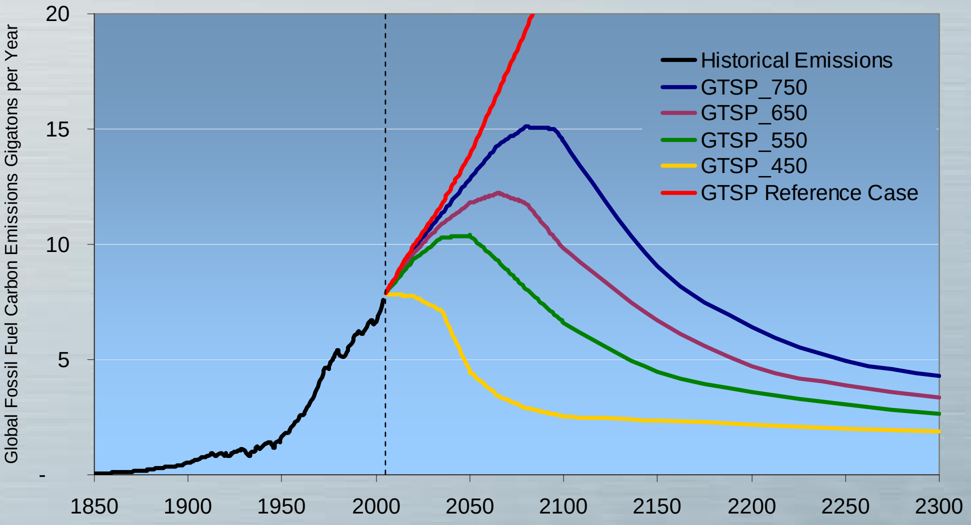
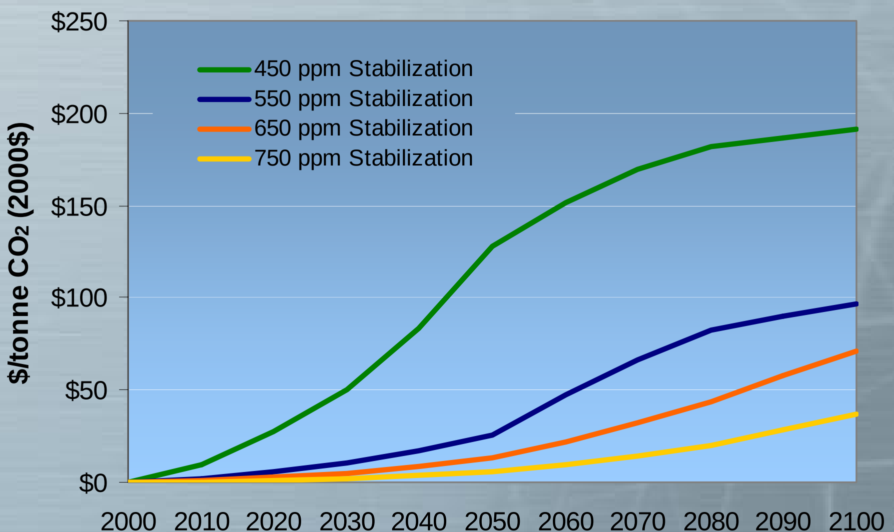
Climate change is a long-term strategic problem with implications for today

- 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.





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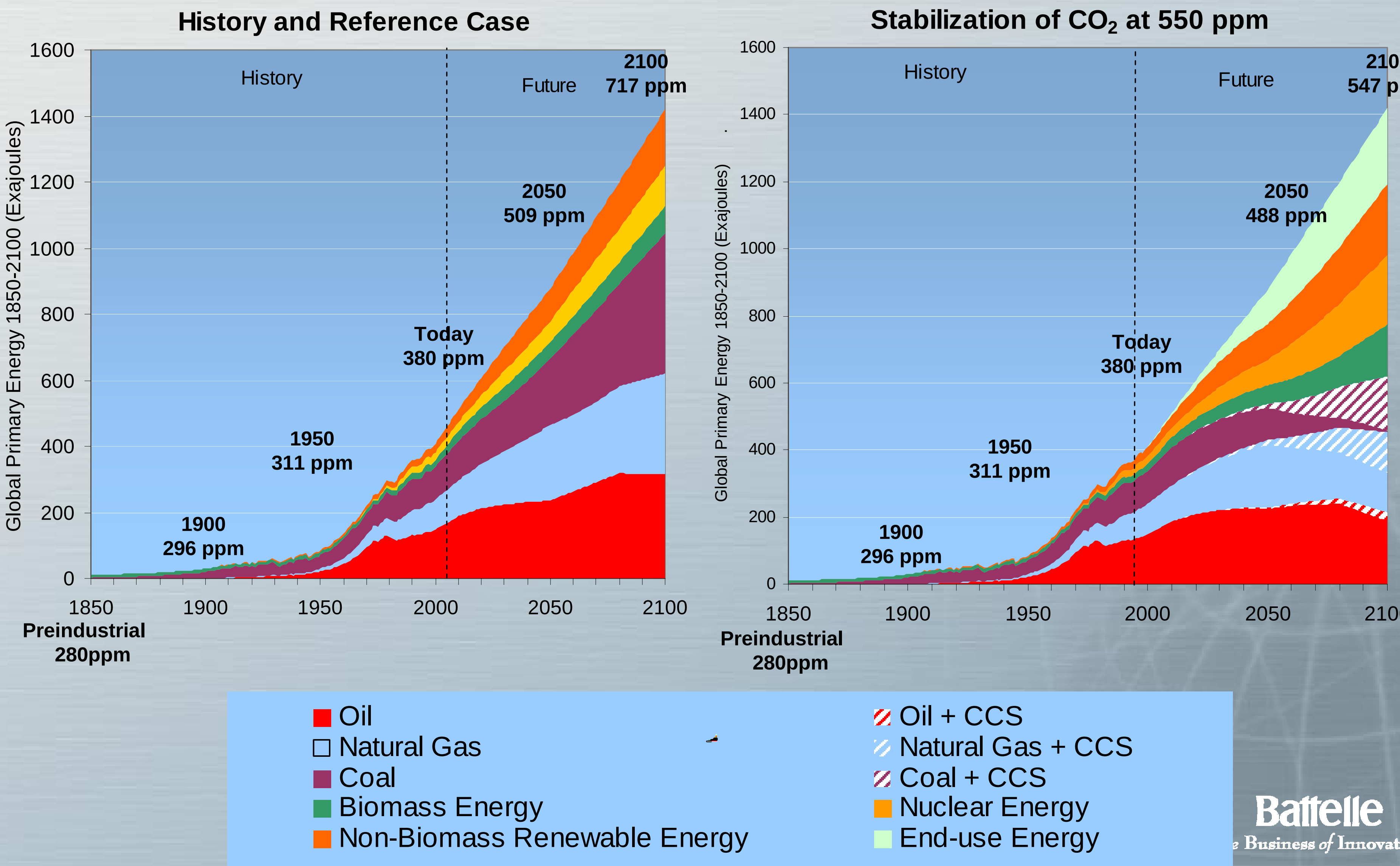
Stabilization of CO_2 concentrations means fundamental change to the global energy system



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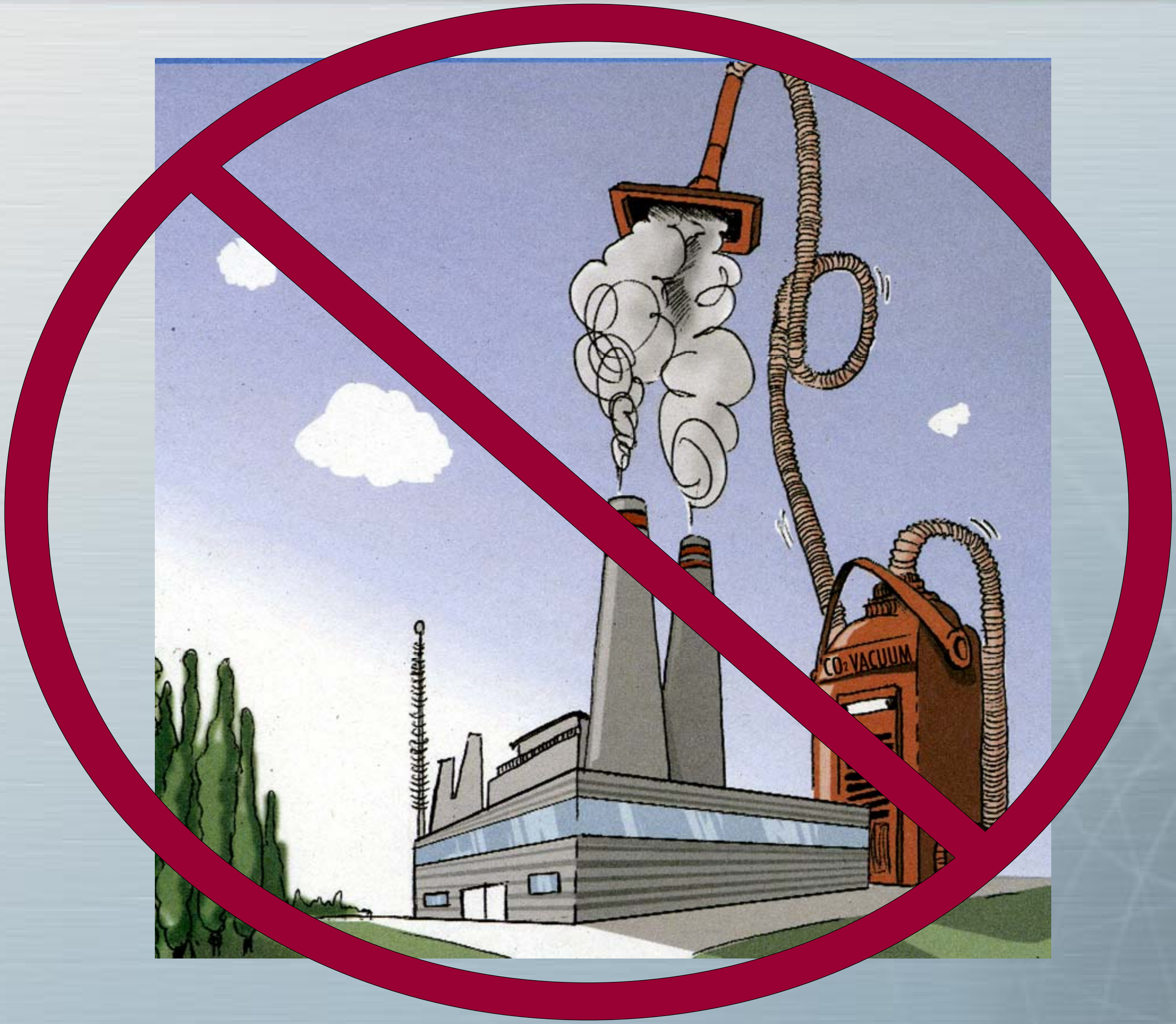
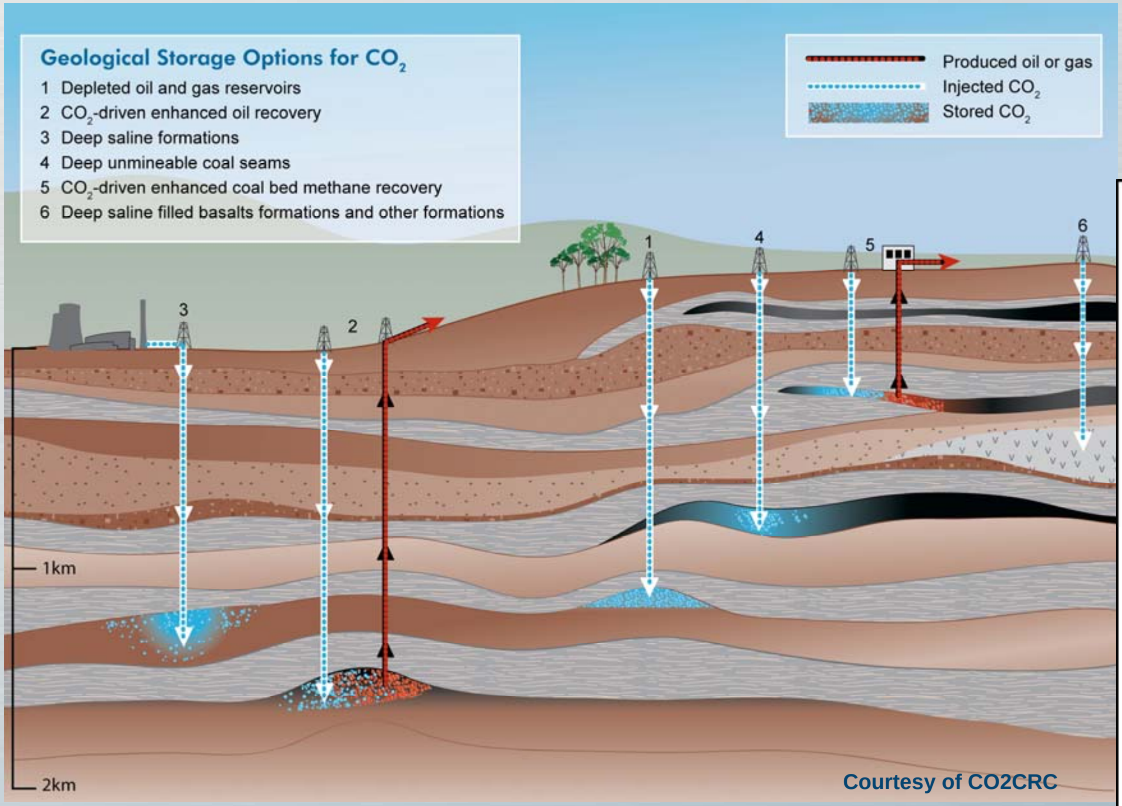
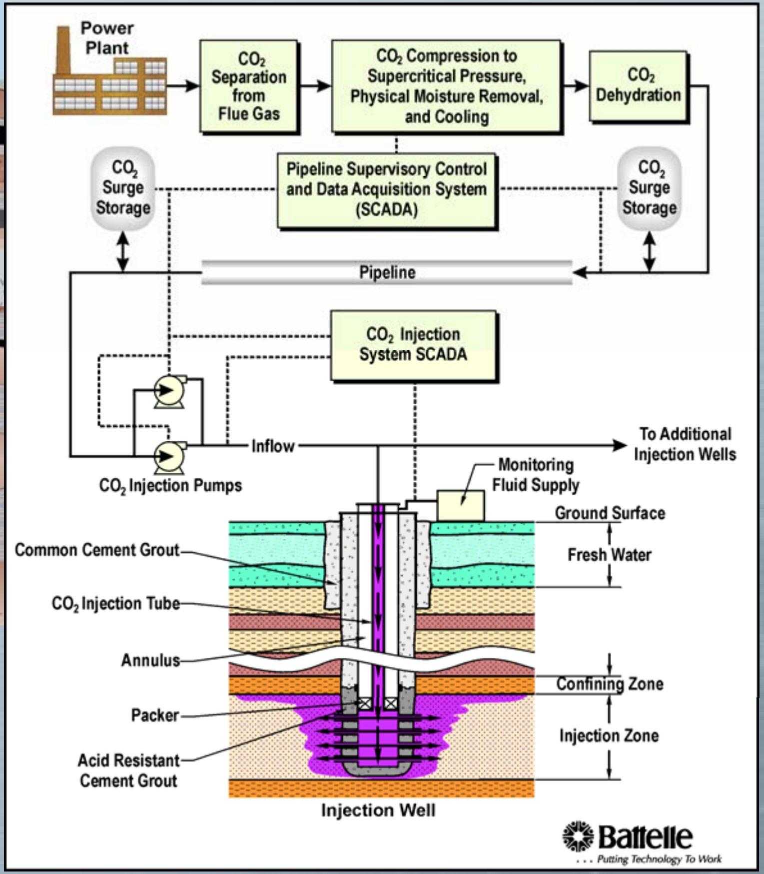
Overview of Carbon Dioxide Capture and Storage (CCS)



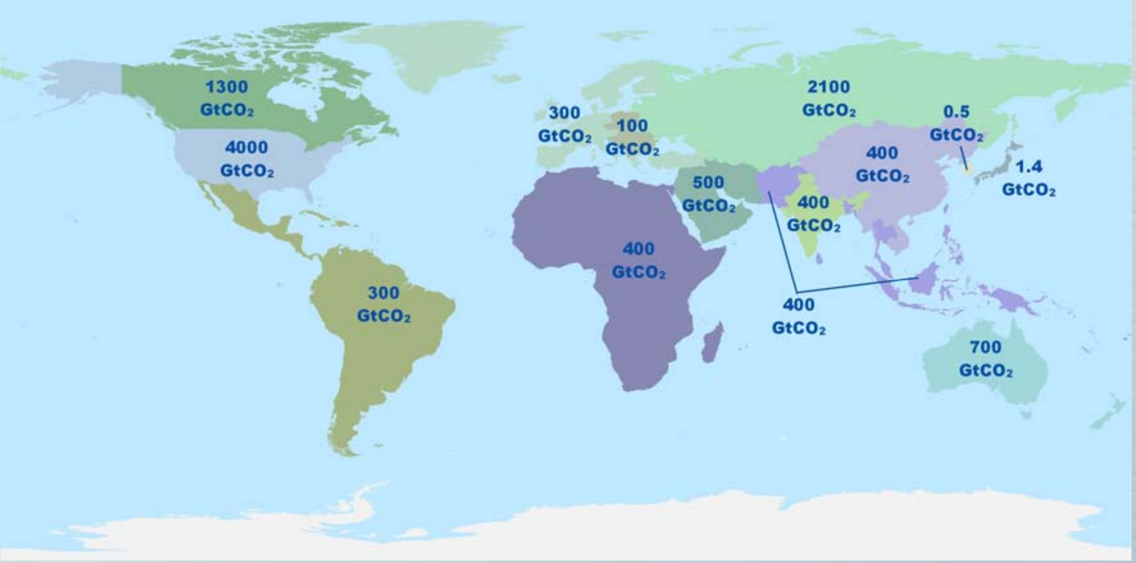
Overview of Carbon Dioxide Capture and Storage (CCS)





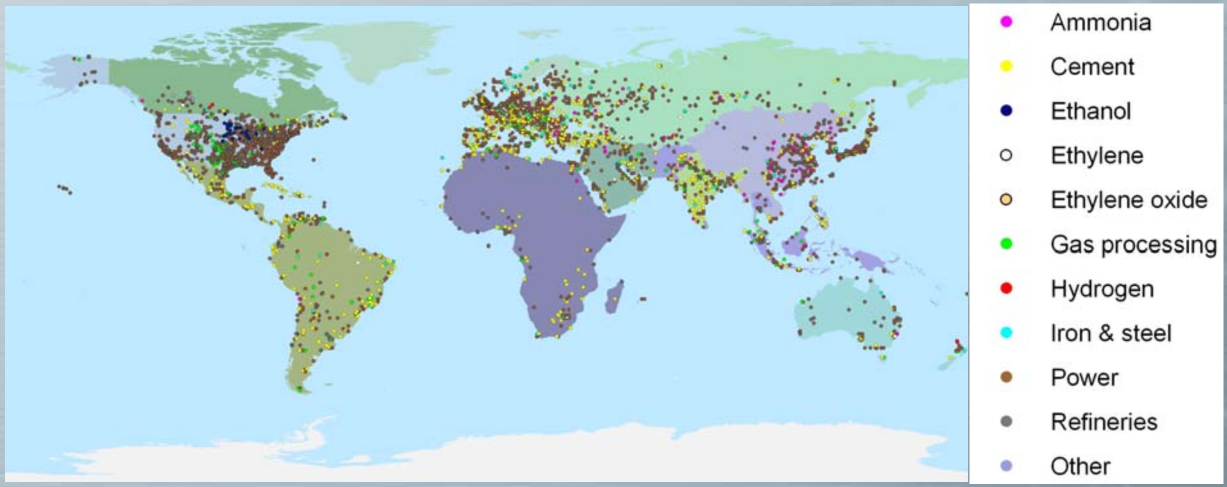
Global CO_2 Storage Capacity:

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



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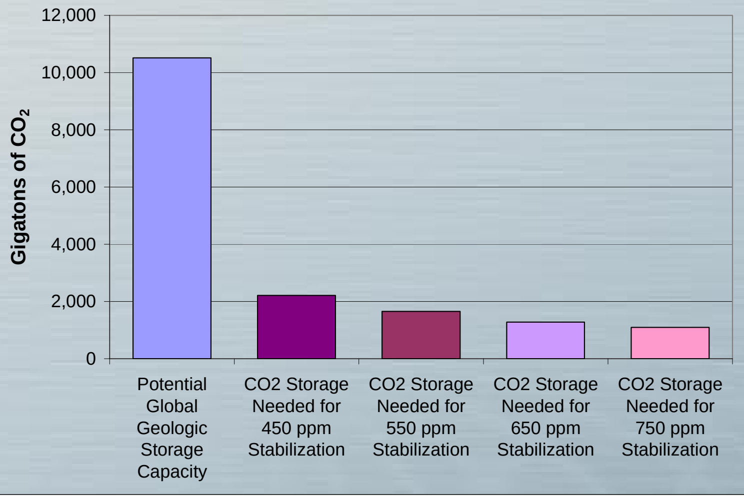
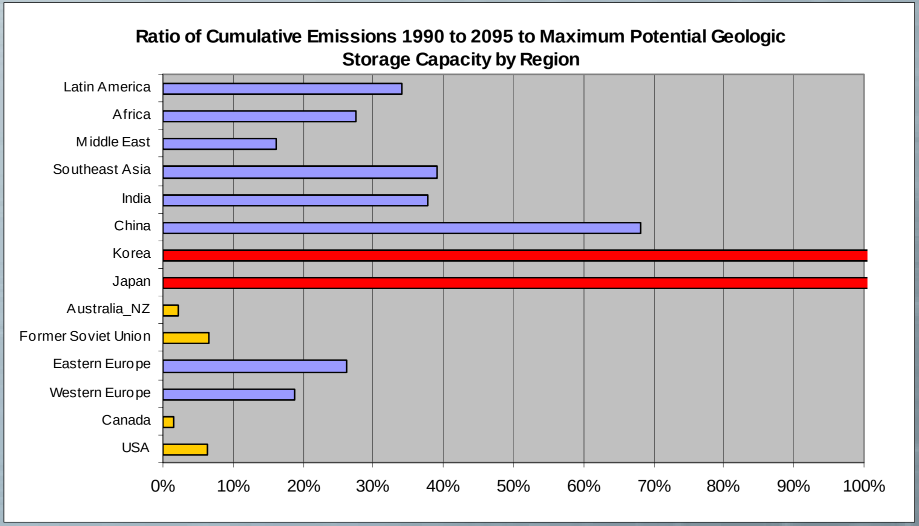
Global CO_2 Storage Capacity:

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.



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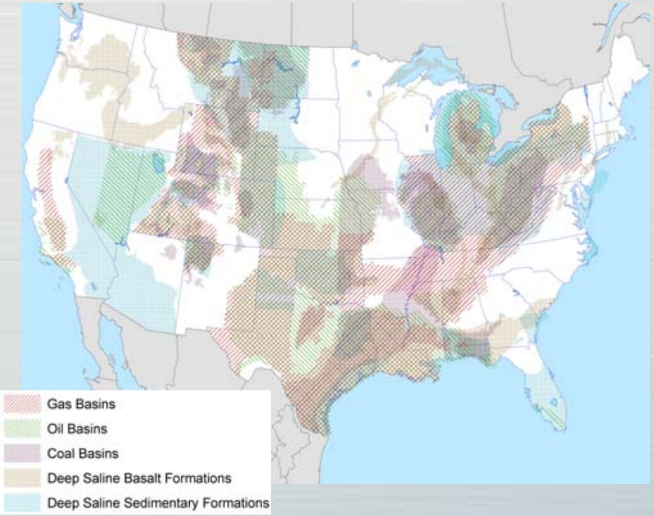
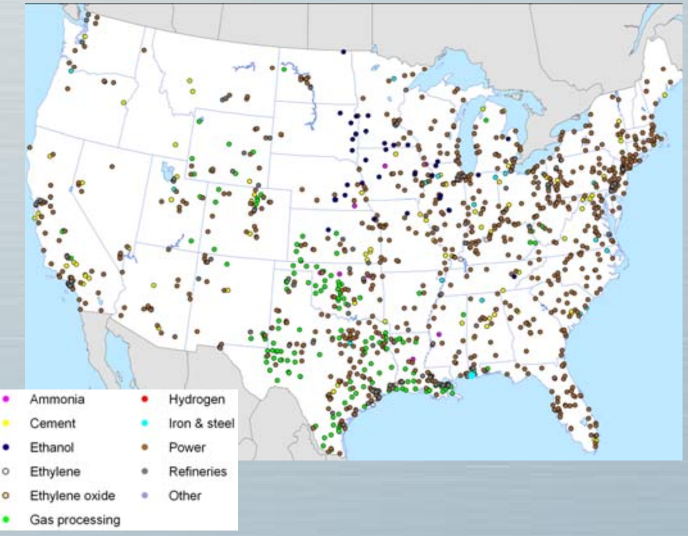
CCS Deployment Across the US Economy

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)

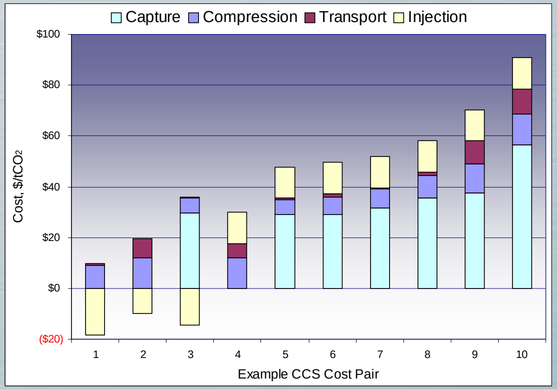


1,715 Large Sources (100+ ktCO_2/yr) with Total Annual Emissions = 2.9 GtCO_2

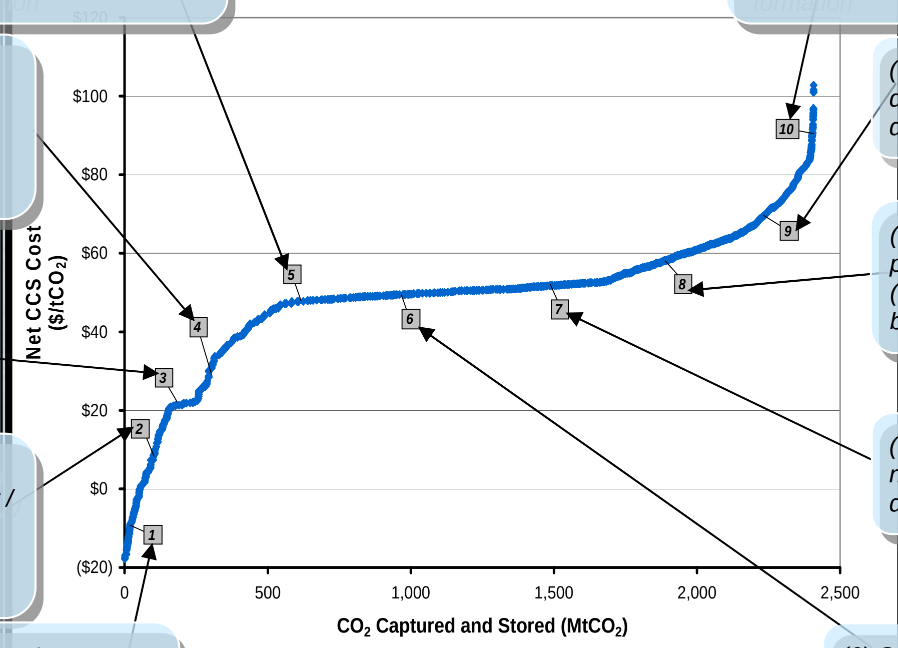
- 1,053 electric power plants
- 259 natural gas processing facilities
- 126 petroleum refineries
- 44 iron & steel foundries
- 105 cement kilns
- 38 ethylene plants
- 30 hydrogen production
- 19 ammonia refineries
- 34 ethanol production plants
- 7 ethylene oxide plants

CCS Deployment Across the US Economy

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

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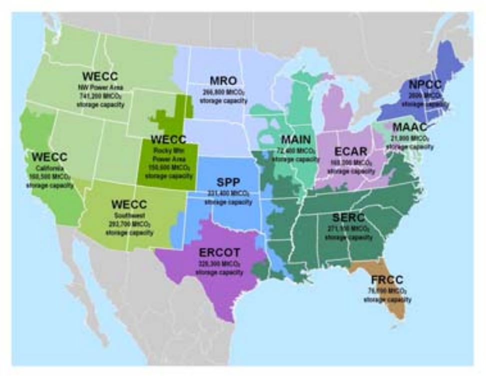
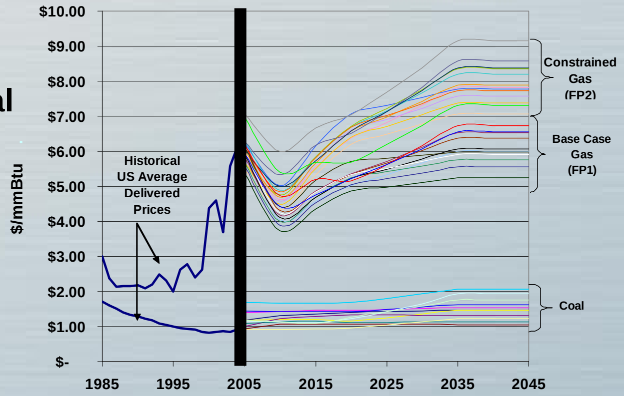
Assuming CCS technologies can deploy if needed, a “valley of death” scenario for coal usage in the United States is difficult to envision

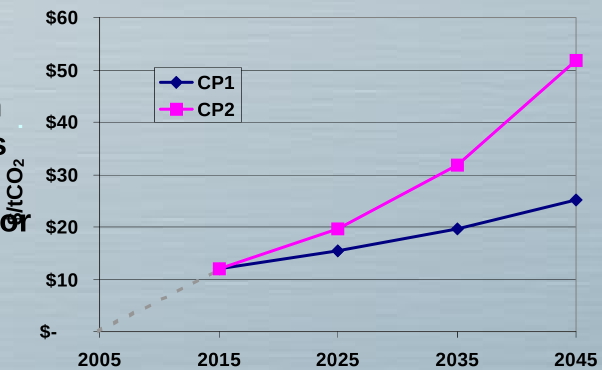
Most NERC Regions have significant CO_2 storage potential



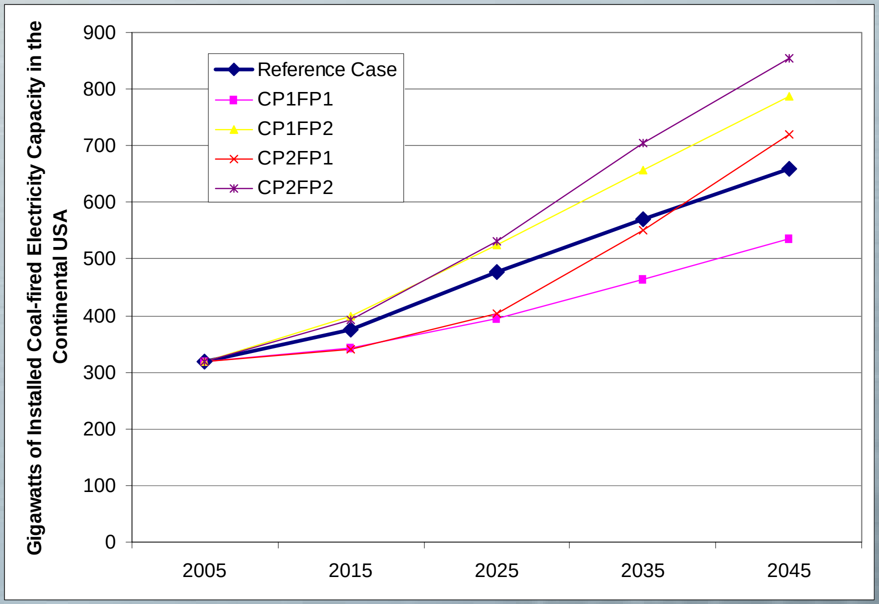
Current and projected natural gas prices have fundamentally altered dispatch economics



The possible imposition of constraints on CO_2 emissions represents an additional factor that will fundamentally alter dispatch



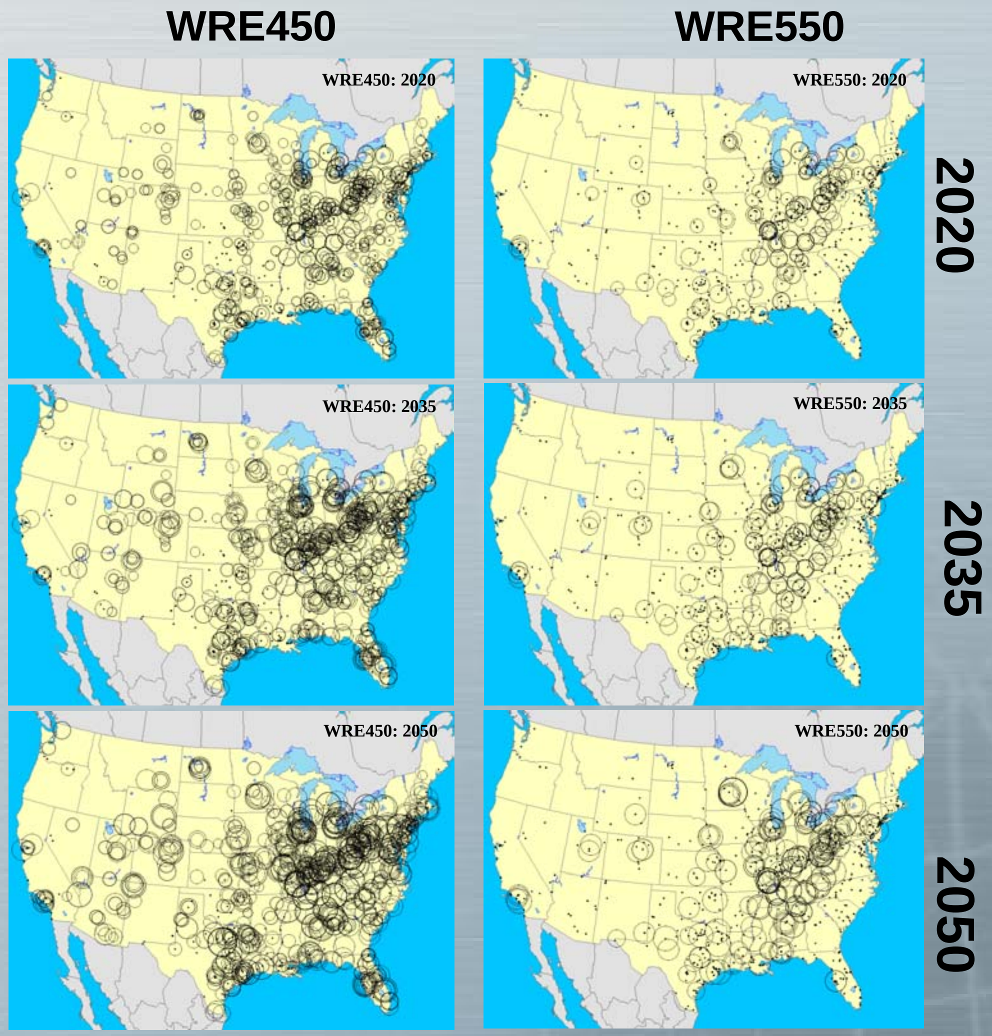
Coal-fired electricity capacity could even expand beyond the no climate policy reference case



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

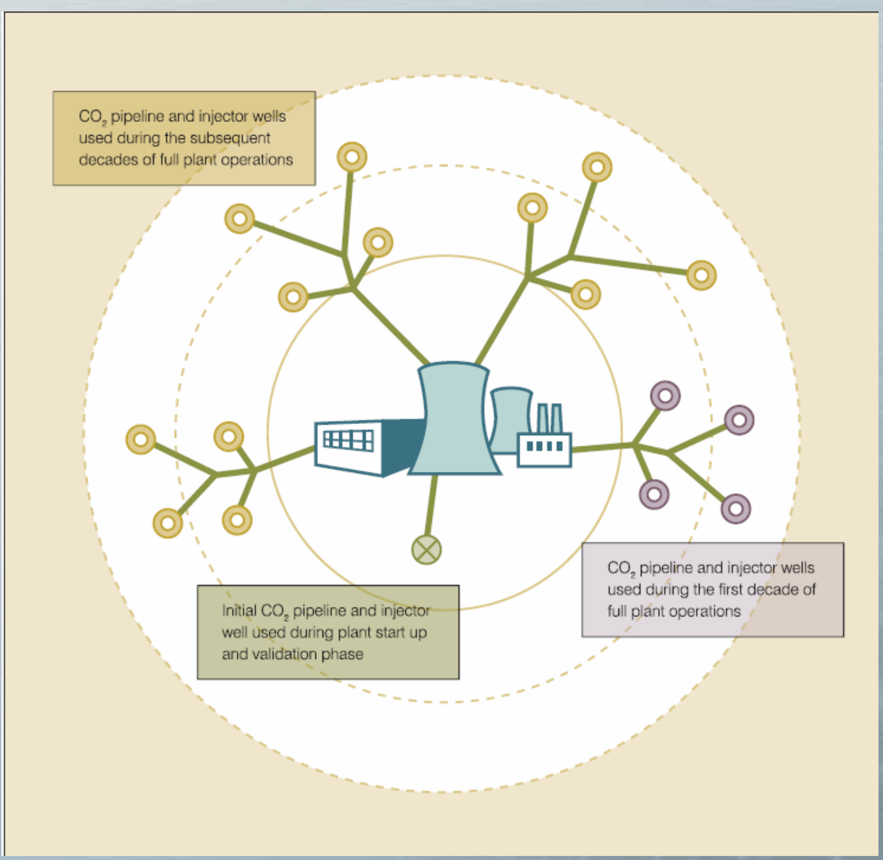
- The potential deployment of CCS technologies could be truly massive. The potential deployment of CCS in the US could entail:
  - 1,000s of power plants and industrial facilities capturing CO_2, 24-7-365.
  - 1,000s of miles of dedicated CO_2 pipelines.
  - 100s of millions of tons of CO_2 being injected into the subsurface annually.

- The deployment across the rest of the world could be at least another order of magnitude.

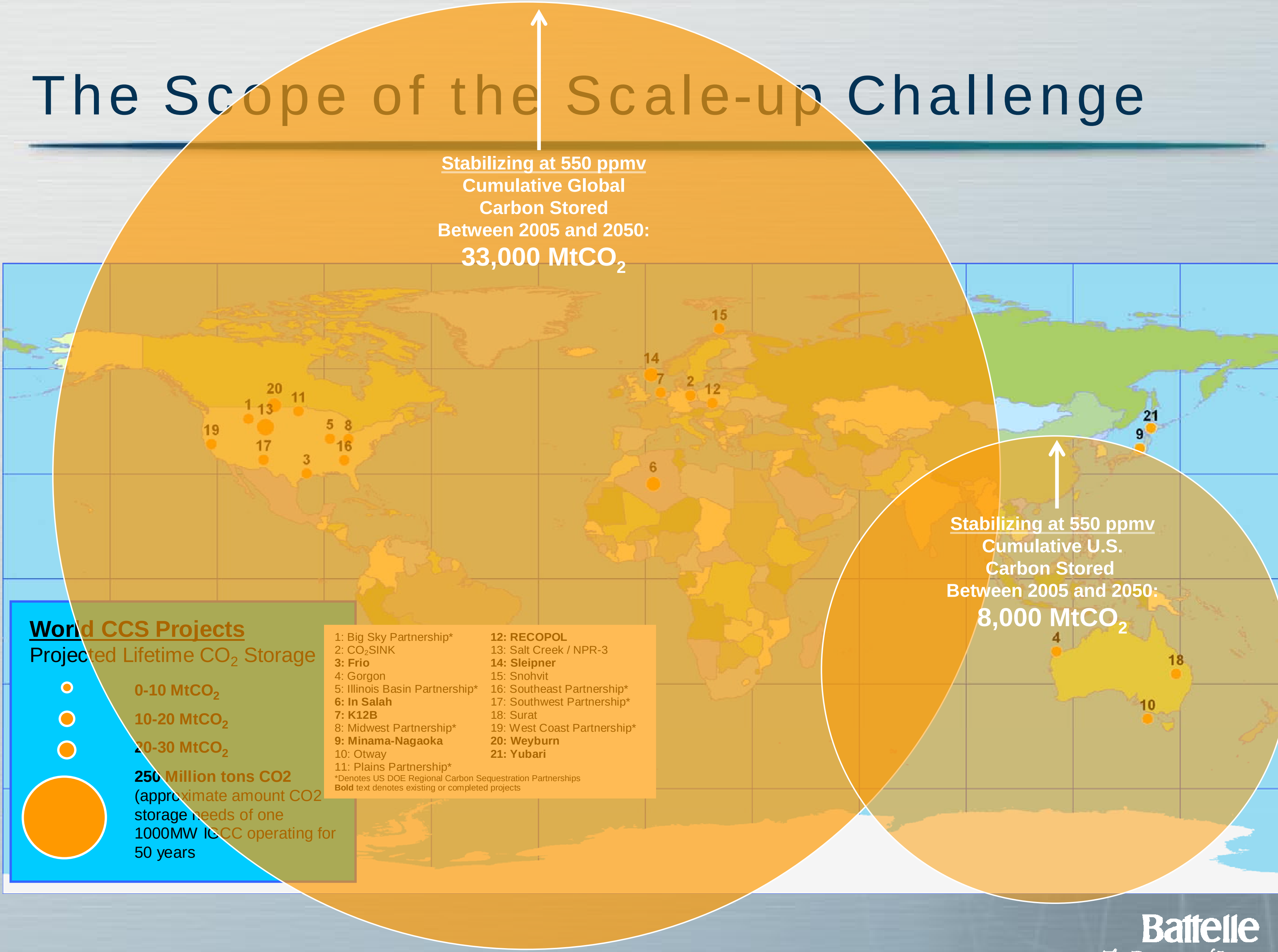


Much work needs to be done to ensure that the potential large and rapid scale-up in CCS deployment will be safe and successful.

- The cost of capturing CO_2 is **not** the single biggest obstacle standing in the way of CCS deployment.
- No one has ever attempted to determine what it means to store 100% of a large power plant's emissions for 50+ years.
  - 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?
  - 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?
  - Who will regulate CO_2 storage on a day-to-day basis? What criteria and metrics will this regulator use?



The Scope of the Scale-up Challenge



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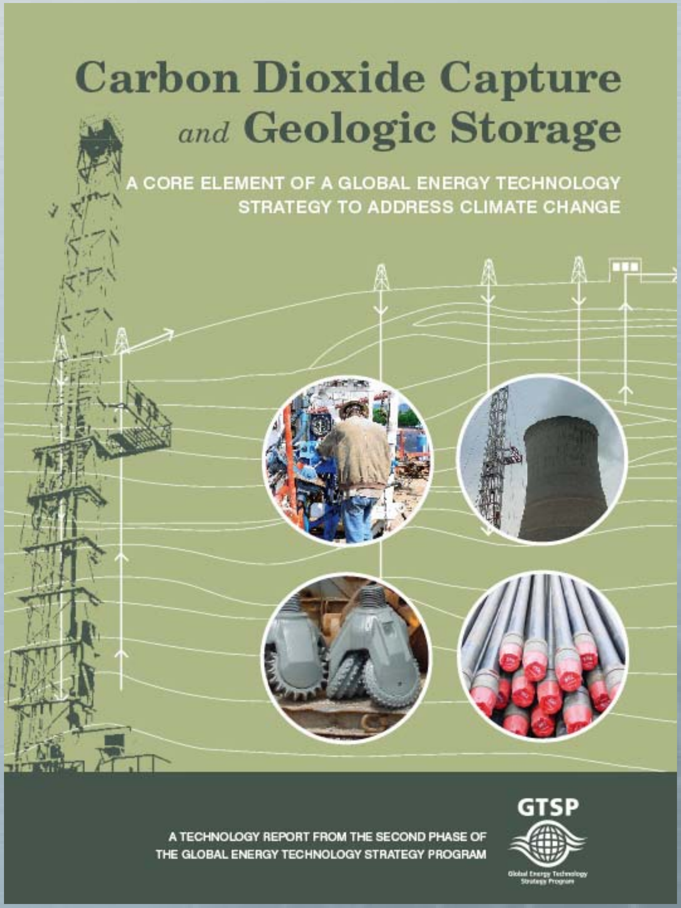
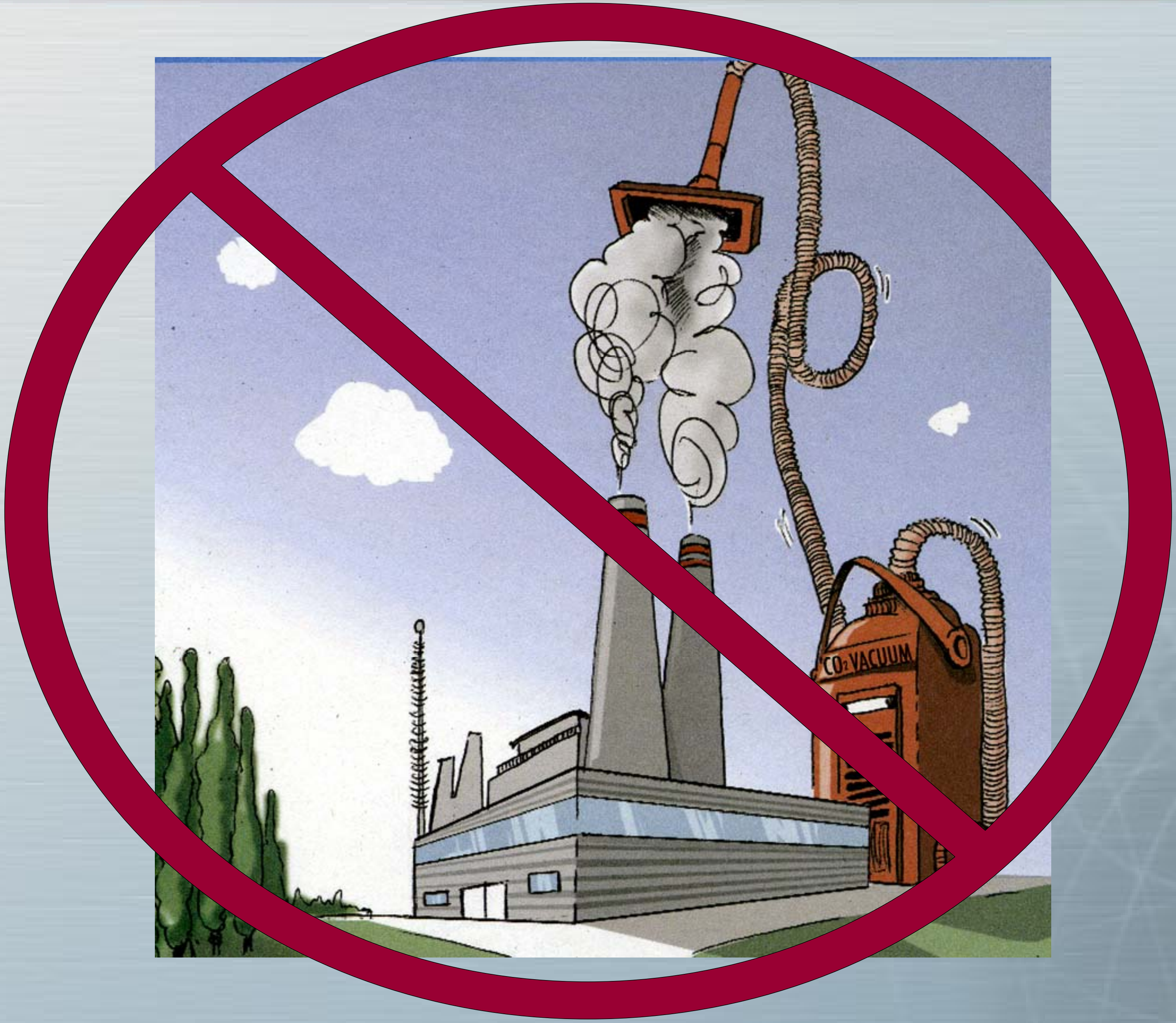
GTSP Phase II Capstone Report on Carbon Dioxide Capture and Storage

- 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.




CO2 VACUUM