Battelle

The Business of Innovation

Carbon Dioxide Capture and Storage a Key Element of a Global Carbon Management Portfolio: Findings from Phase 2 of the Global Energy Technology Strategy Project

Neeraj Gupta, James J Dooley, Gerald M. Stokes
Battelle

July 18, 2006

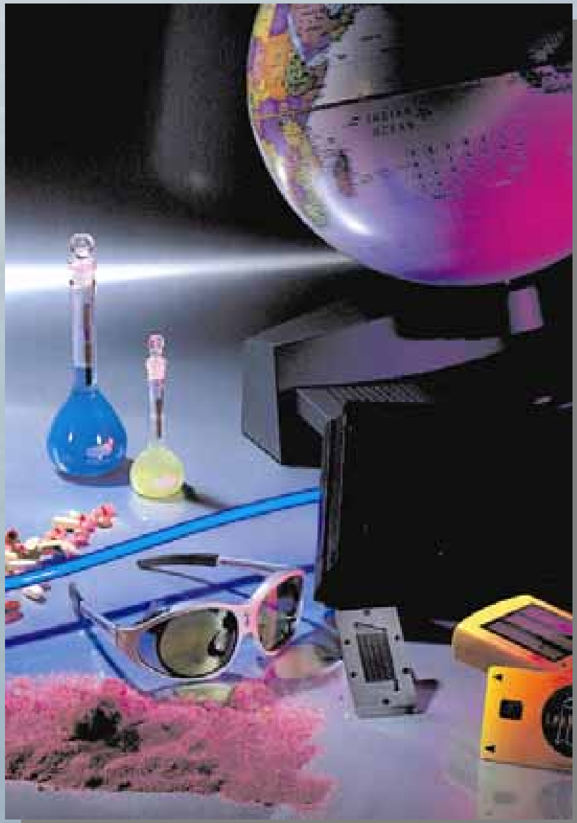
PNWD-SA-7474

Outline

- Battelle and its role in defining real world solutions to climate change
- The Global Energy Technology Strategy and an Overview of what it means “to address climate change”
- The role of Carbon Dioxide Capture and Storage technologies in addressing climate change
- Conclusions

Battelle Memorial Institute
The Business of Innovation

- **World's largest not-for-profit R&D company, established 1928**
- **7,500 staff members, >1,400 industrial clients**
- **$2.7 billion in R&D annually**
- **Principal markets**
  - **Energy**
  - **Agrifood**
  - **Environment**
  - **Chemicals**
  - **Medical Products Pharmaceuticals**
  - **Automotive**
  - **National Security**



Battelle's Major Technology Centers

National Renewable Energy Laboratory
Golden, Colorado

Corporate Headquarters
Columbus, Ohio

Pacific Northwest National Laboratory
Richland, Washington

Oak Ridge National Laboratory
Oak Ridge, Tennessee

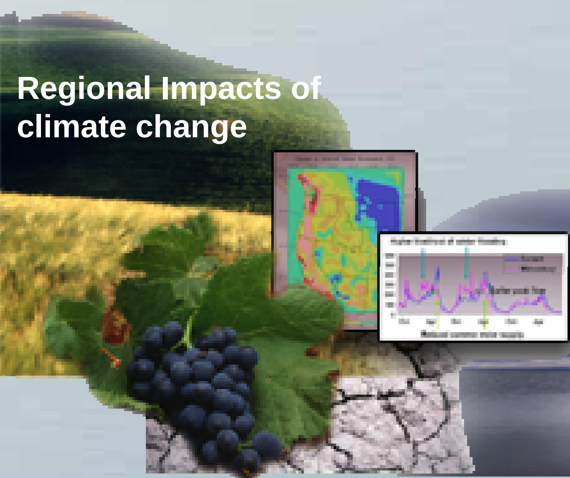
Battelle Europe
Geneva, Switzerland

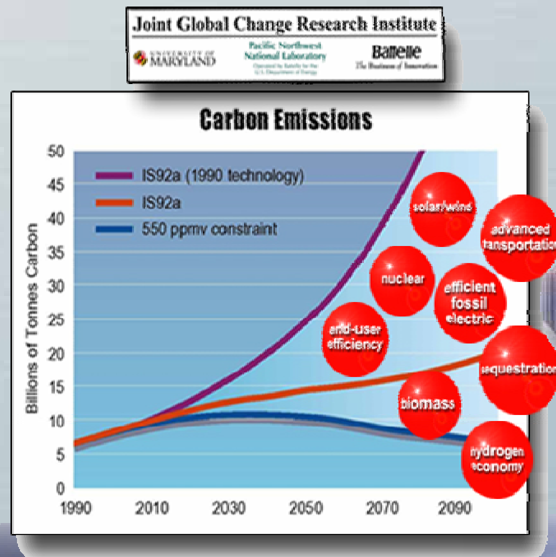
Brookhaven National Laboratory
Long Island, New York

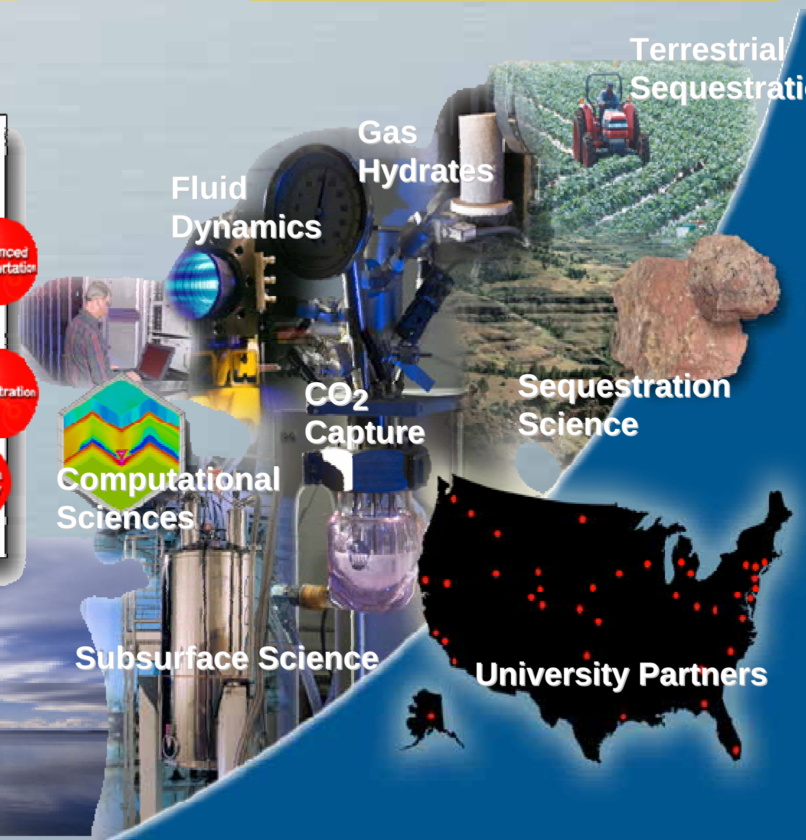
Battelle
The Business of Innovation

Battelle's Signature Contributions to Carbon Management

Understanding of the Problem → **Evaluating Solution Strategies** → **Developing & Deploying Solutions**







The Global Energy Technology Strategy Project

- Unique, multinational, public/private sector research program launched in 1998 to better understand the role of technology in addressing climate change.

- First GTSP summary report released in 2001 at a special session at COP6 in the Hague which articulated the need for a multi-pronged, systematic strategy for addressing climate change that must include four key components:
    - Adaptation
    - (Global) Technology Development and Deployment
    - Emissions Mitigation
    - Resolving the Scientific Uncertainty.

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

- UNFCCC has nearly 200 signatory countries 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 <u>not</u> Emissions

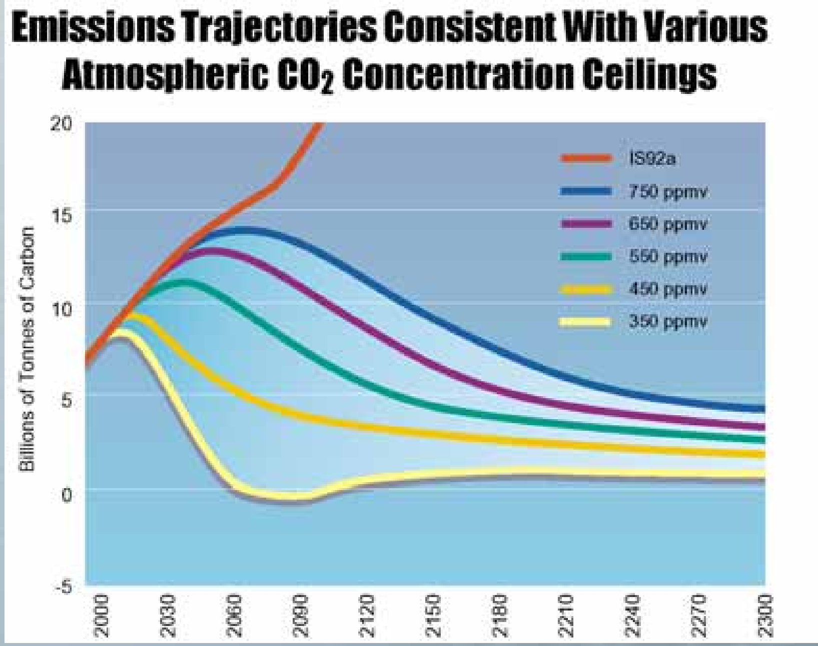
Don’t Know What is Dangerous

Economic Development Matters

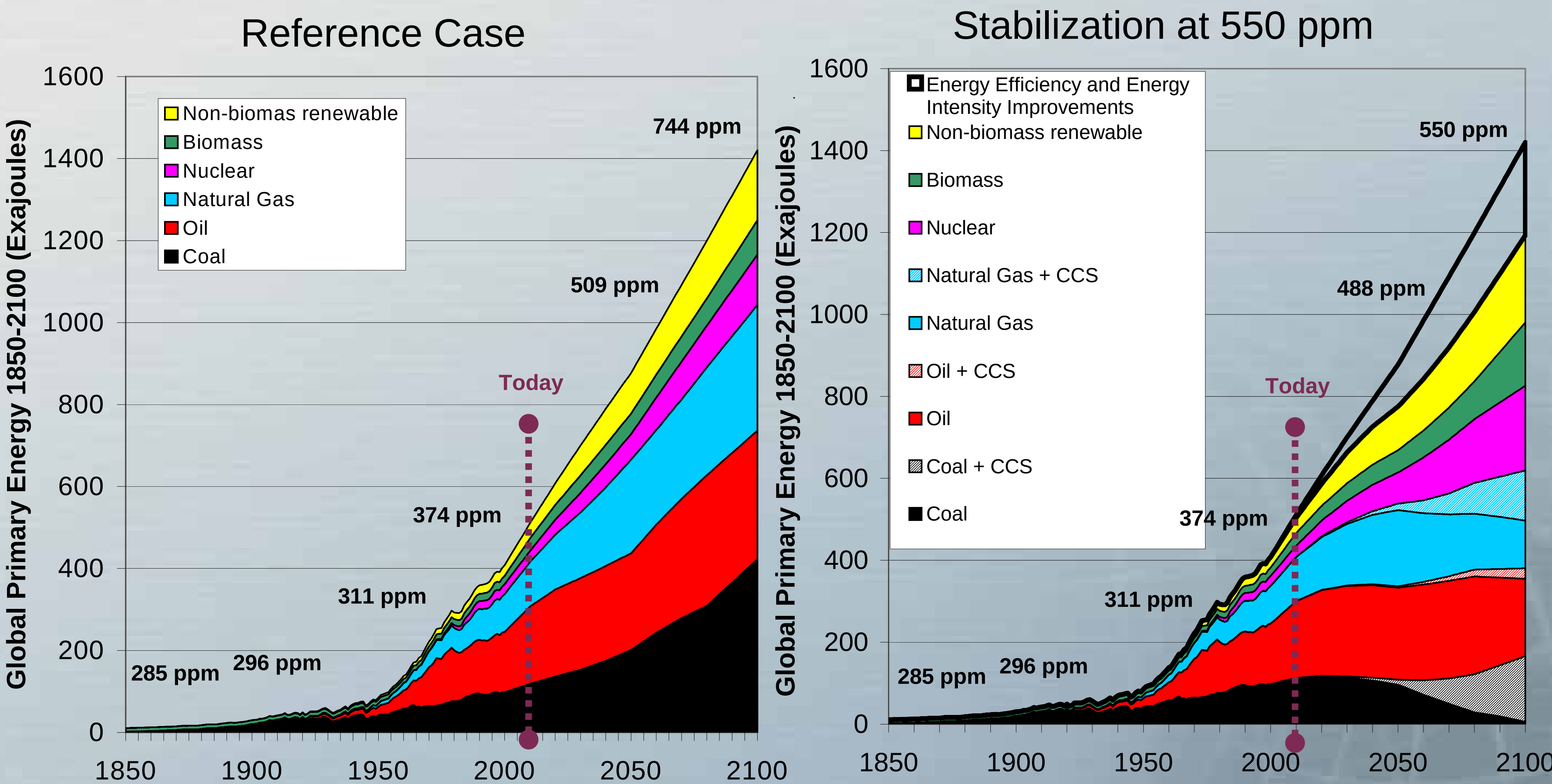
Stabilizing Atmospheric Concentrations and not Annual Emissions Levels is the Goal

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

- Stabilizing atmospheric concentrations of greenhouse gases implies 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.

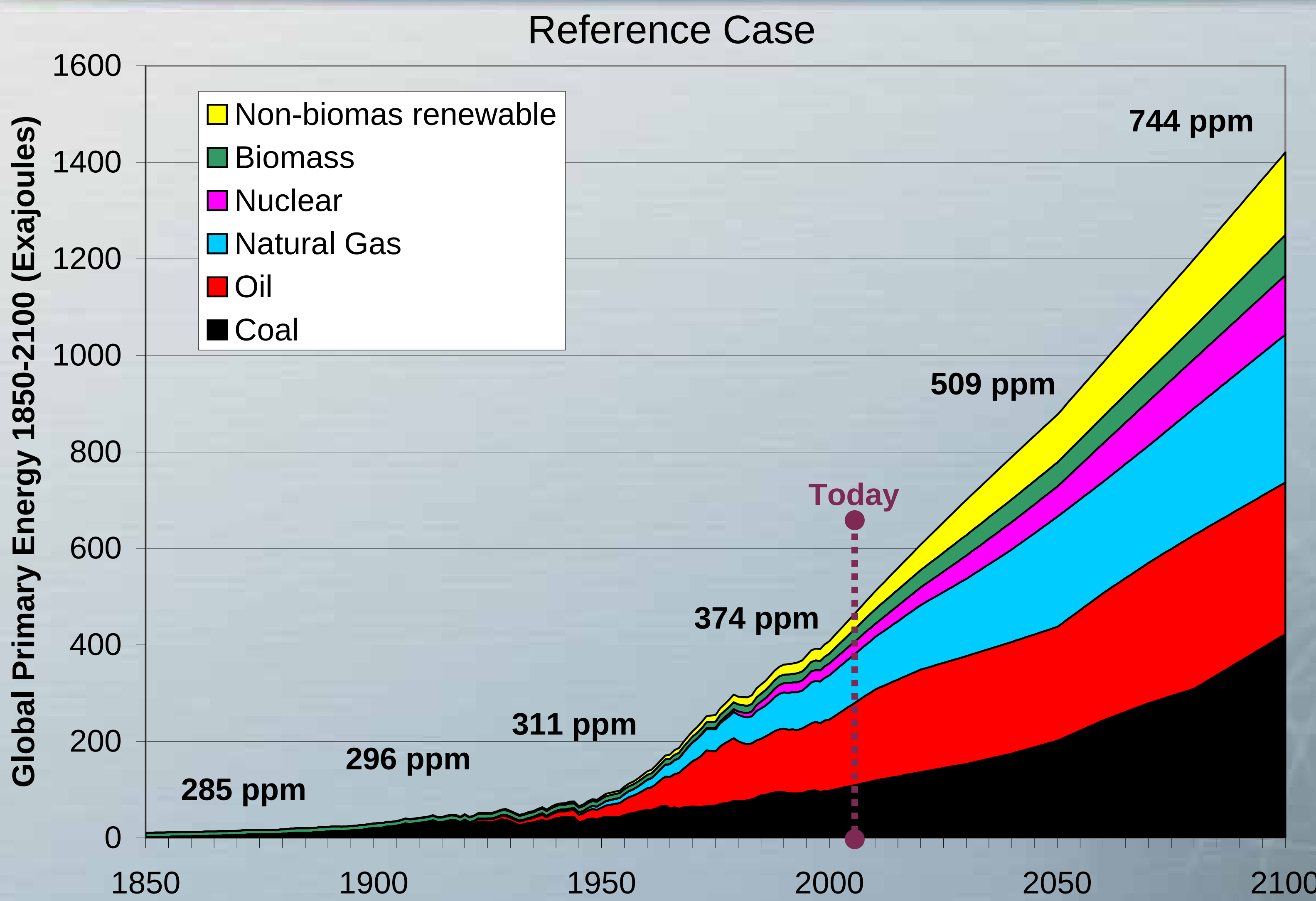


Fundamental transformation of the way in which energy is produced and consumed will be required to stabilize atmospheric concentrations of greenhouse gases

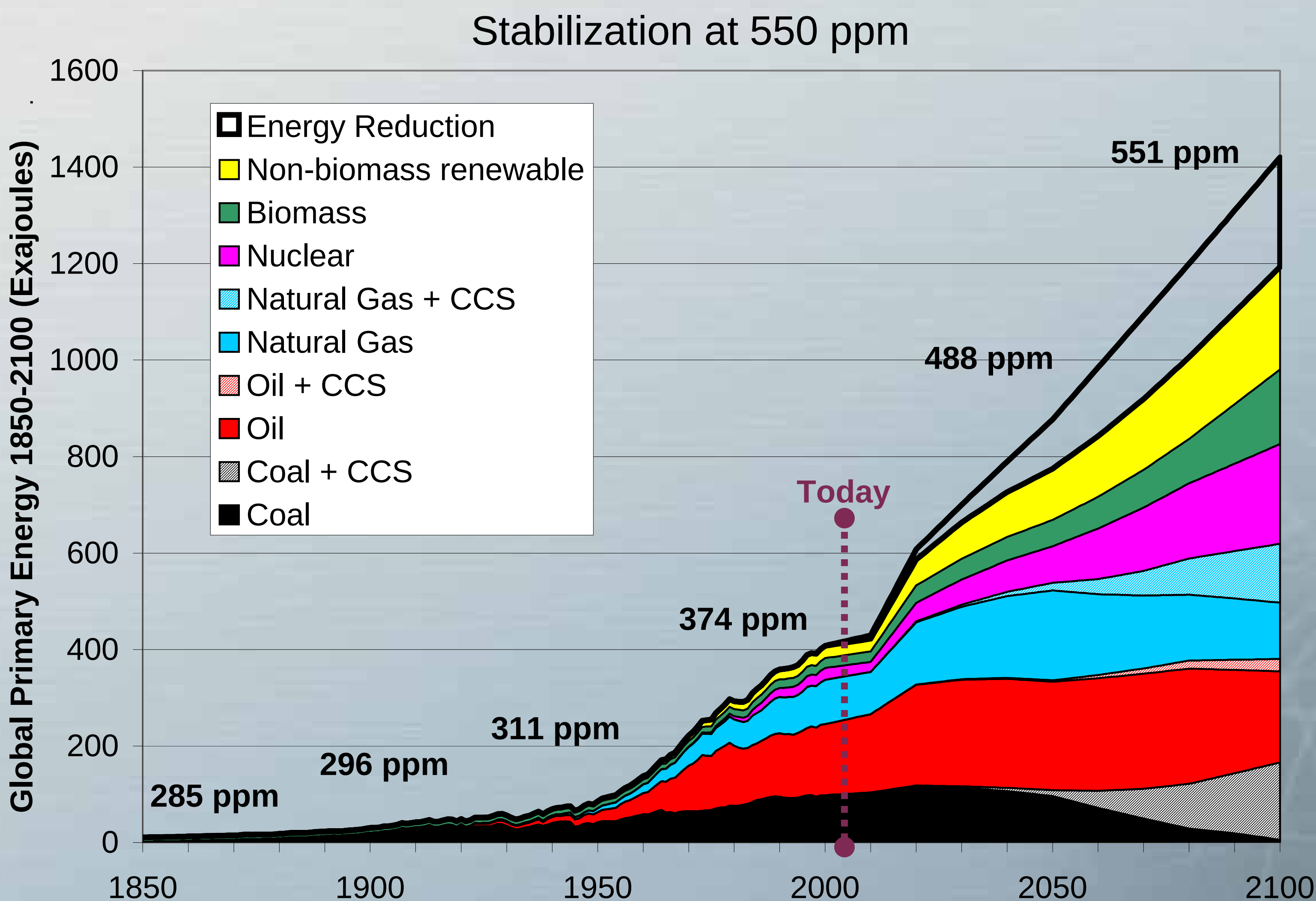


Battelle
The Business of Innovation

Fundamental transformation of the way in which energy is produced and consumed will be required to stabilize atmospheric concentrations of greenhouse gases



Fundamental transformation of the way in which energy is produced and consumed will be required to stabilize atmospheric concentrations of greenhouse gases

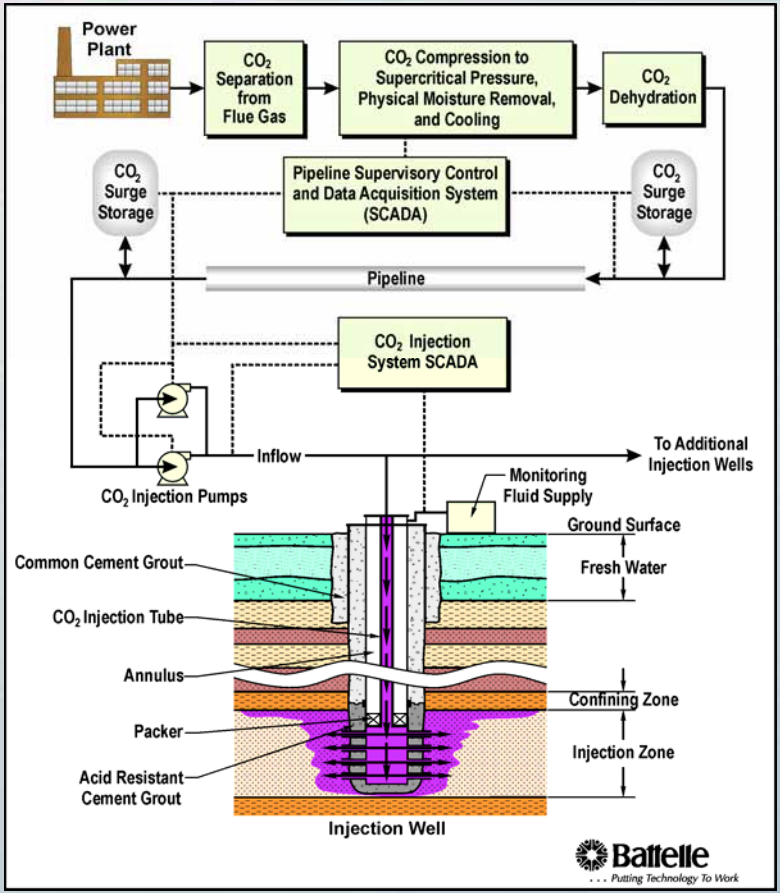


Battelle
The Business of Innovation

Carbon Management Challenge
Take Home Points

- Fundamental changes in the energy system are necessary to stabilize atmospheric concentrations of GHGs.
- Successful development and deployment of new technologies can significantly reduce the cost of achieving any stabilization target.
- Key Carbon Management Technologies that have <u>to be ready for deployment</u> by 2020 include:
  - Commercial Biomass
  - Soil Carbon Sequestration
  - CO_2 Capture and Storage
  - Advanced Gasification
  - Fuel Cells
  - Nuclear Energy
  - Advanced Renewable Energy Technologies
  - Advanced Energy Efficient Technologies
- R&D programs need to be designed to lay the ground work for <u>massive deployment</u>. Near term field demonstrations need to be designed with this in mind.

What is *Carbon Dioxide Capture and Geologic Storage?*



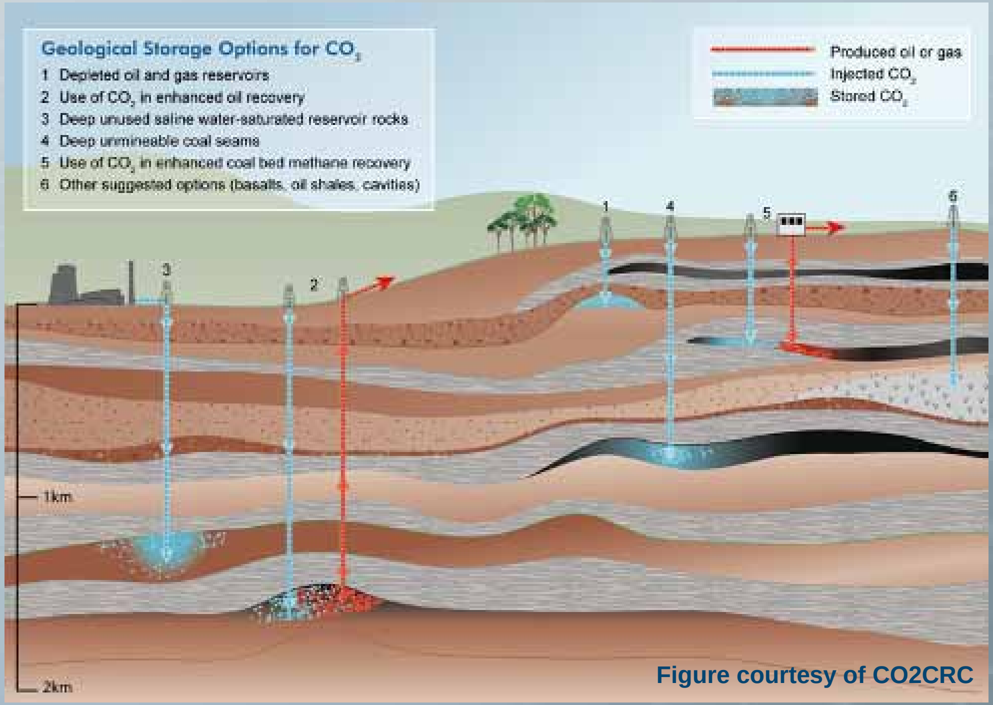
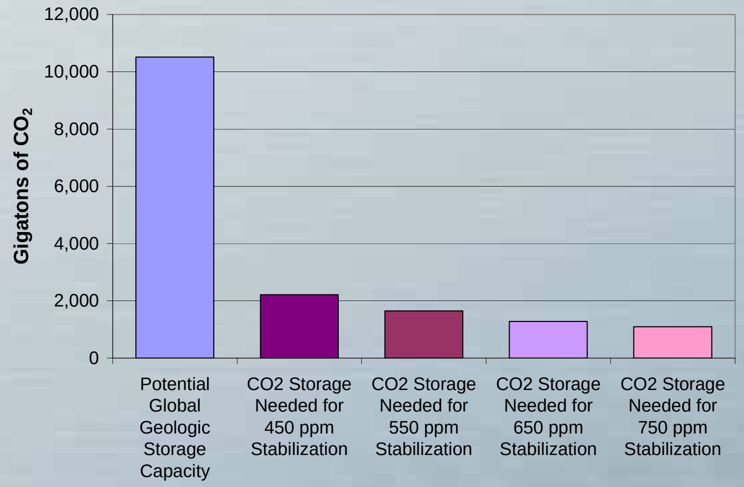


Figure courtesy of CO2CRC

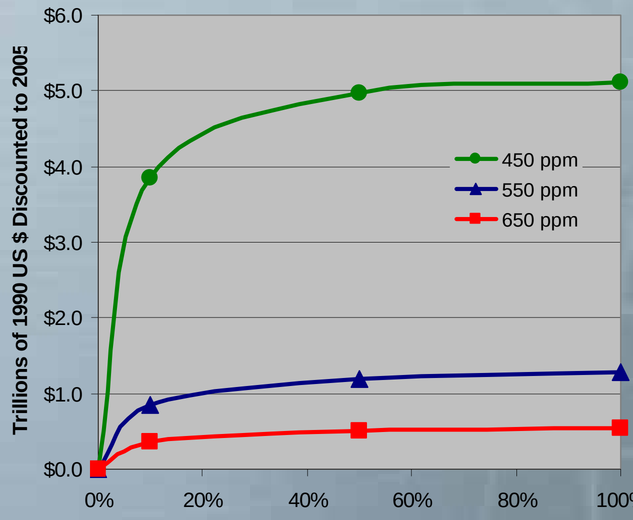
- What is the potential scale of CCS deployment?
- Is there enough geologic storage capacity?
- What’s the value of CCS deployment?

Global CO_2 Storage Capacity:
Abundant and Potentially Valuable Natural Resource

- Assuming that society has a broad portfolio of carbon management options at its disposal:
  - 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.

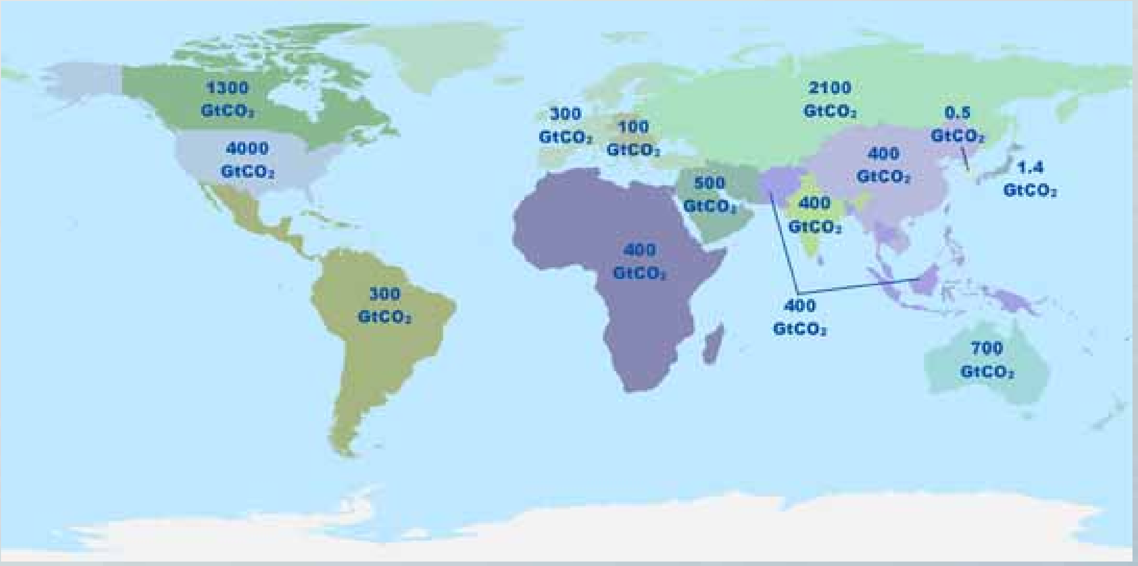


- Even though there is no definitive answer as to what the total global theoretical capacity is and what fraction is viable:
  - CCS still has potentially huge value to society even if only a fraction of current estimates of potential global geologic CO_2 storage capacity is available.



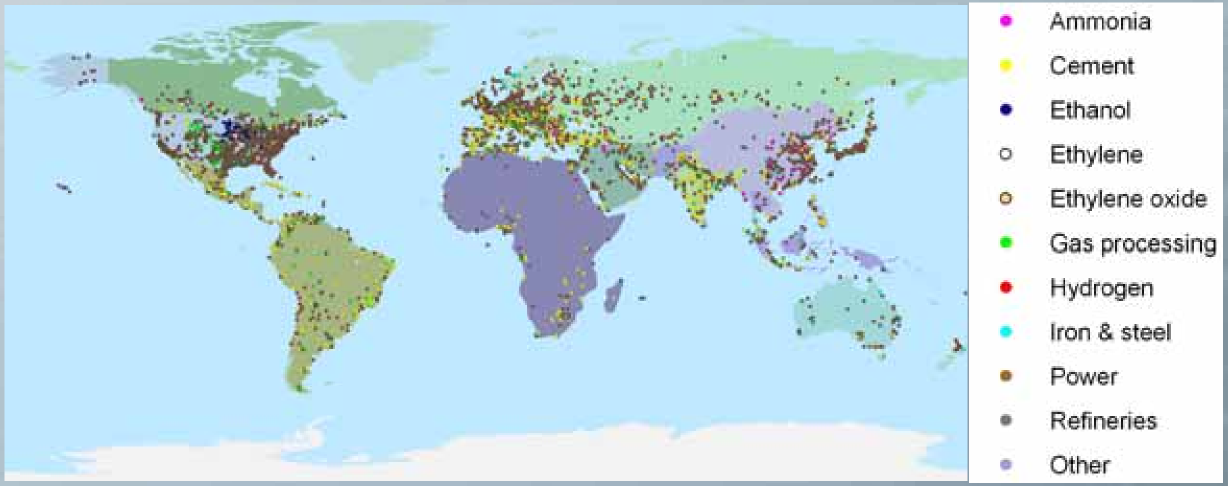
Battelle
The Business of Innovation

Global CO_2 Storage Capacity
A 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**

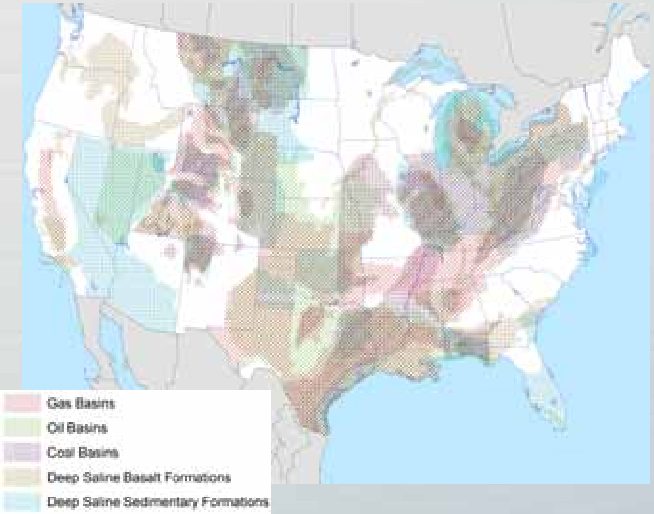


How will CCS deploy across the U.S. economy?

How will CCS work within the U.S. electric utility industry?

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

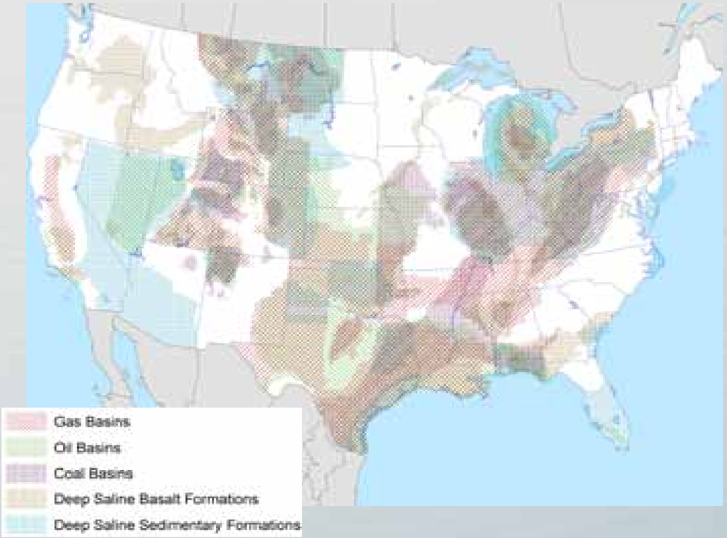
- 2,730 $GtCO_2$ in deep saline formations (DSF) with perhaps close to another 900 $GtCO_2$ in offshore DSFs
- 240 Gt CO_2 in on-shore saline filled basalt formations
- 35 $GtCO_2$ in depleted gas fields
- 30 $GtCO_2$ in deep unmineable coal seams with potential for enhanced coalbed methane (ECBM) recovery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

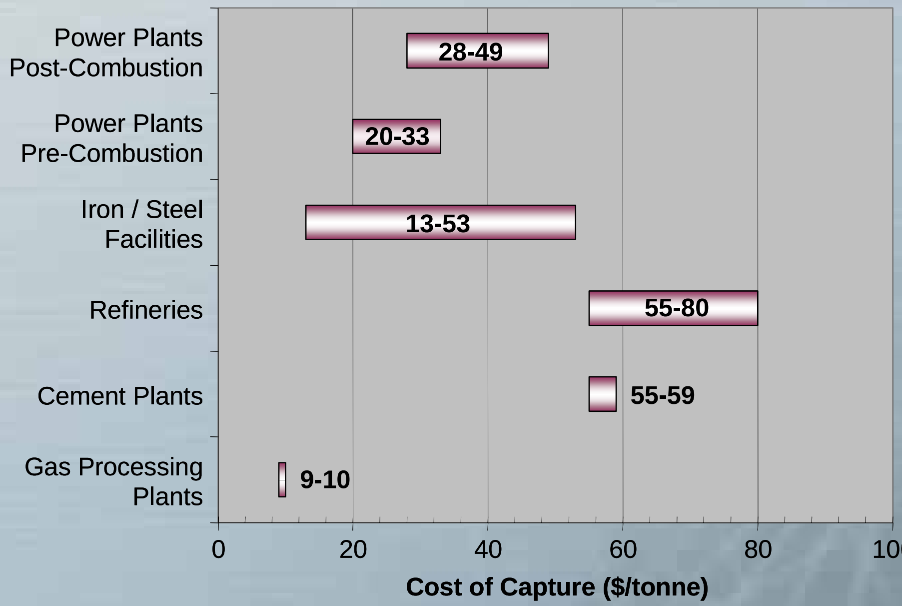
1,715 Large Sources (100+ $ktCO_2$/yr) with Total Annual Emissions = 2.9 $GtCO_2$

- 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.

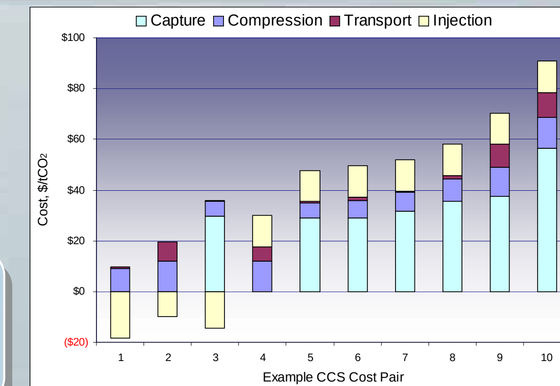




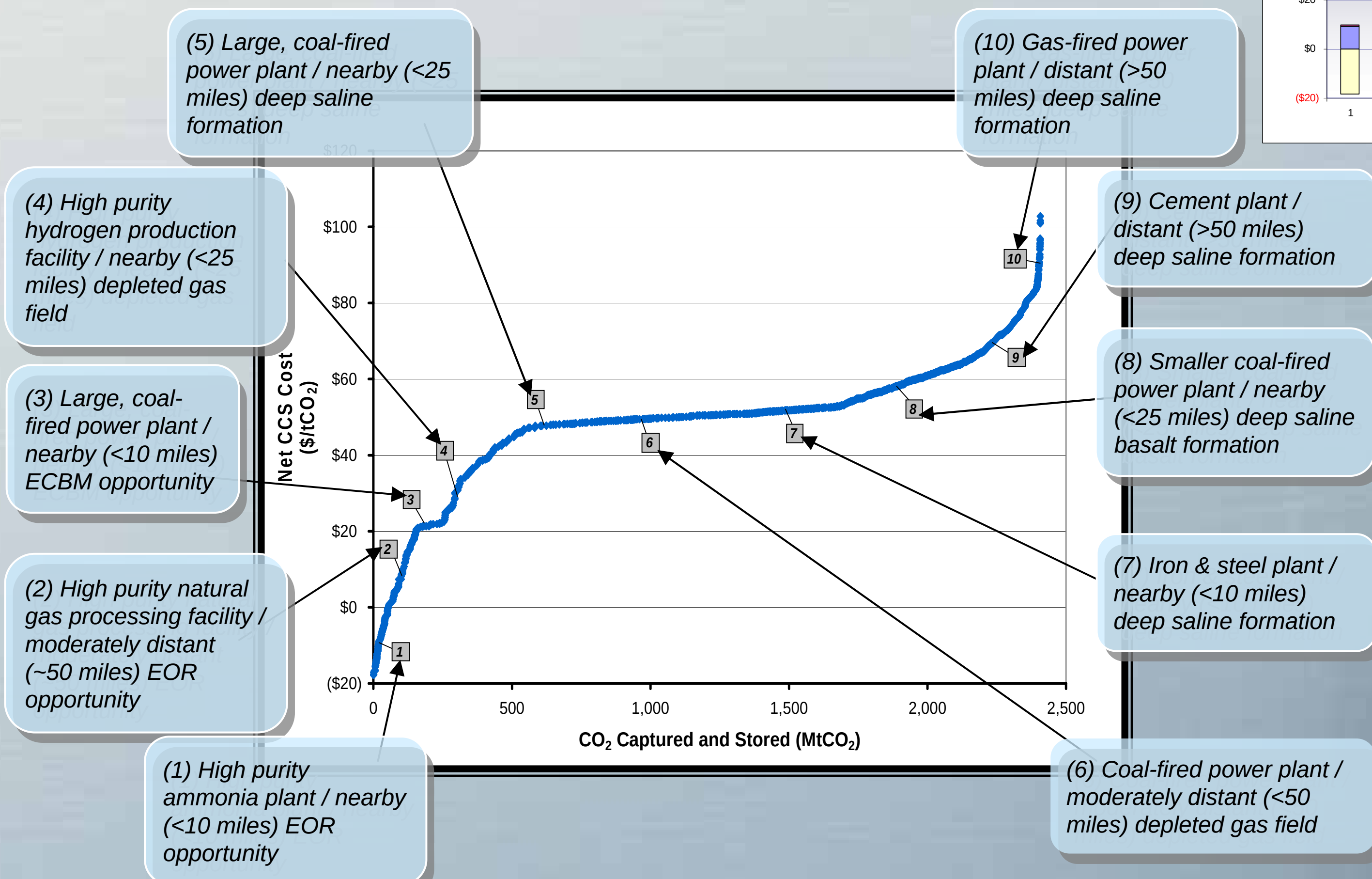
Battelle
The Business of Innovation

CCS Deployment Across the US Economy

Differentiated CCS Adoption Across Economic Sectors

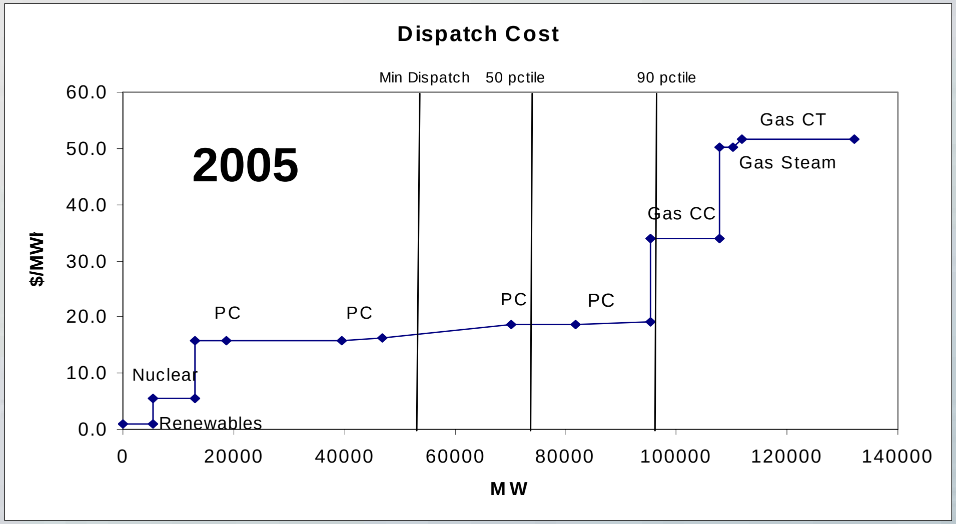


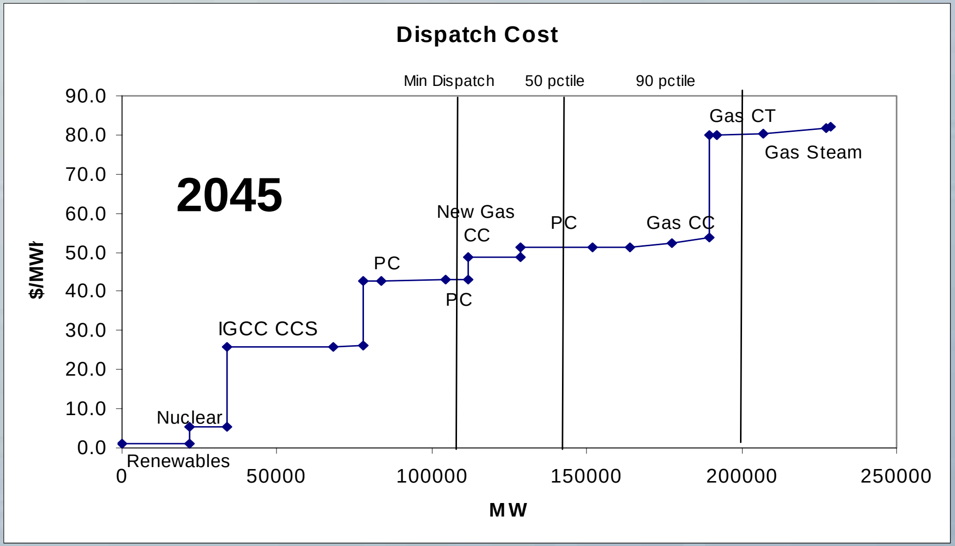
The Net Cost of Employing CCS within the United States - Current Sources and Technology



Battelle
The Business of Innovation

CCS Deployment by Electric Utilities
IGCC+CCS and Nuclear Are Keys to Decarbonizing Baseload Power

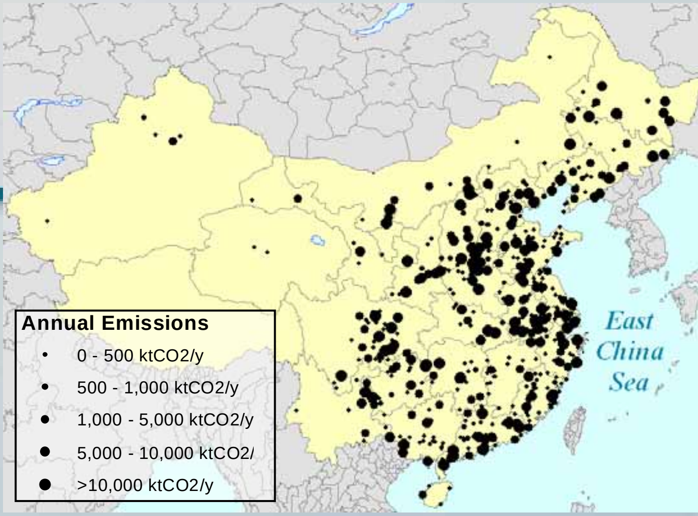




- In 2005, conventional fossil-fired power plants were the predominant means of generating competitively priced electricity.
- However, given today's and (likely) tomorrow's higher natural gas prices and the imposition of a hypothetical binding greenhouse gas control policy,
  - IGCC+CCS and nuclear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

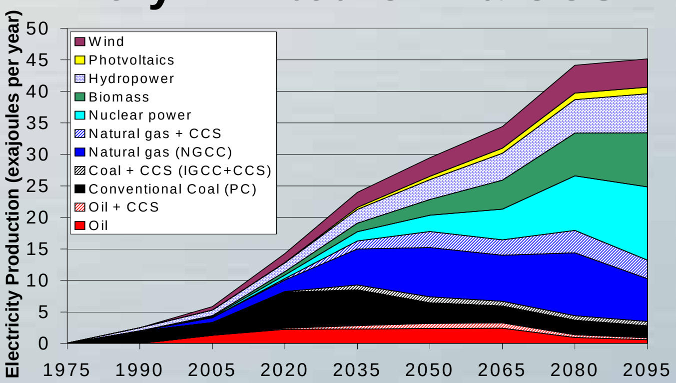
What role will CCS play for nations that do not have abundant domestic geologic CO_2 storage reservoirs?

China: Is There Enough CO_2 Storage Capacity?



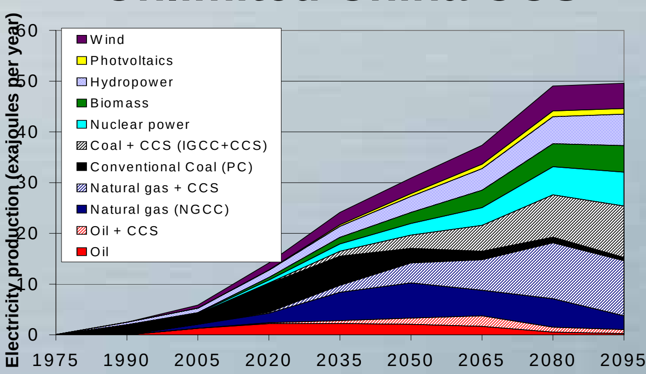
China's Reliance on Nuclear Power and the Price of Energy Are Tied to How Much CO_2 Storage Capacity is Available

Very Limited China CCS



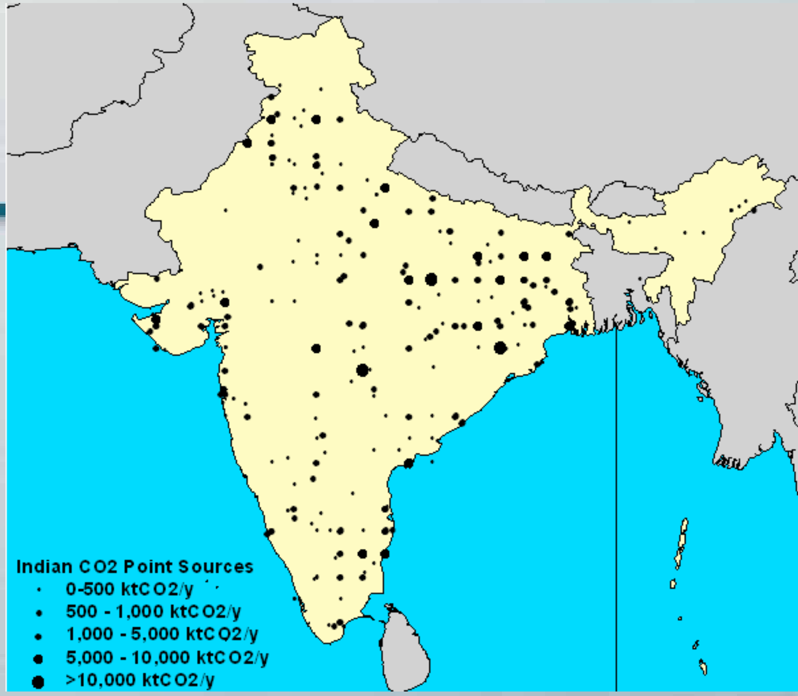
- The use of fossil fuels is severely curtailed in carbon-constrained world
- Nuclear power and biomass must be pushed, beyond cost-effective limits to meet energy demand
- High energy prices result

Unlimited China CCS

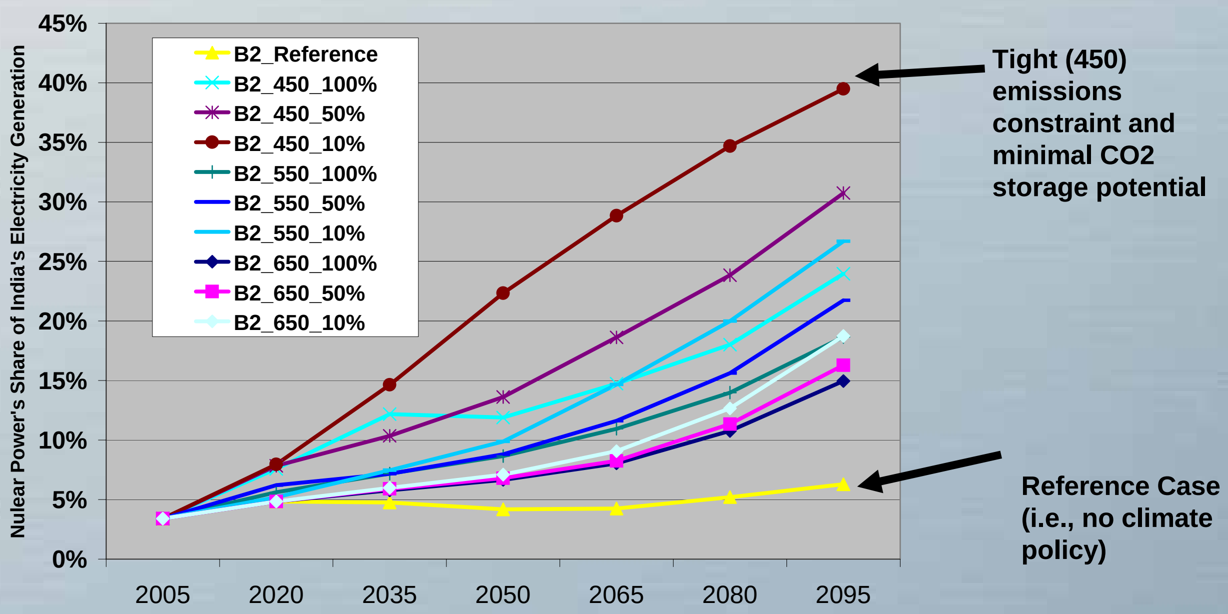


- Fossil fuel use increases while emissions are curtailed
- Balanced, stable electricity generation portfolio is maintained
- Lower energy prices
- $100s of billions to a $1 trillion in economic benefits

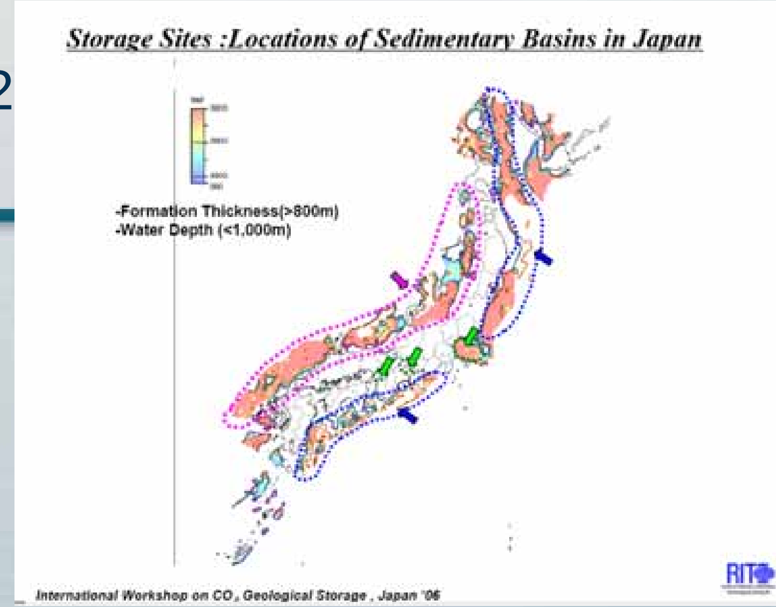
India: Is There Enough CO_2 Storage Capacity?



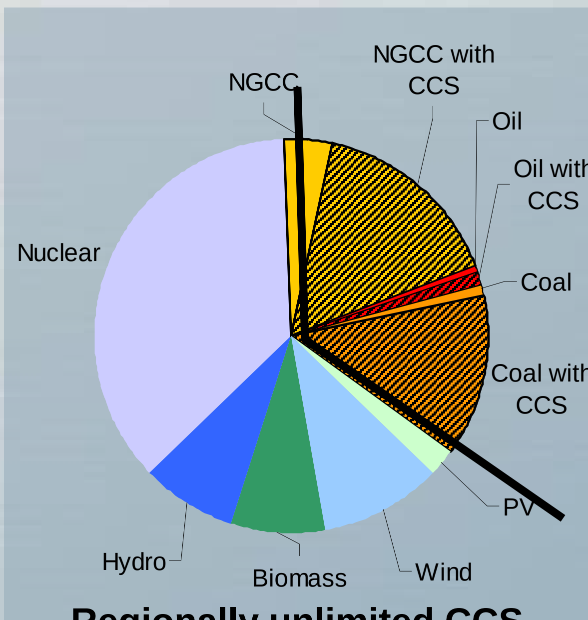
Without Suitable Geologic CO_2 Storage Formations India's Reliance on Nuclear Power Grows Substantially in Face of CO_2 Emissions Constraints



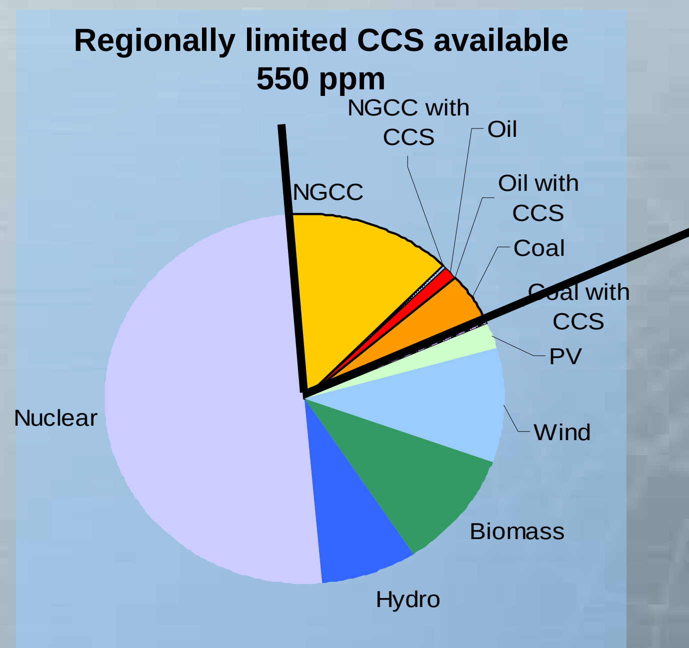
Japan: Is There Enough CO_2 Storage Capacity?



Composition of Power Generation in Japan, 2095



Regionally unlimited CCS assumed available, 550 ppm

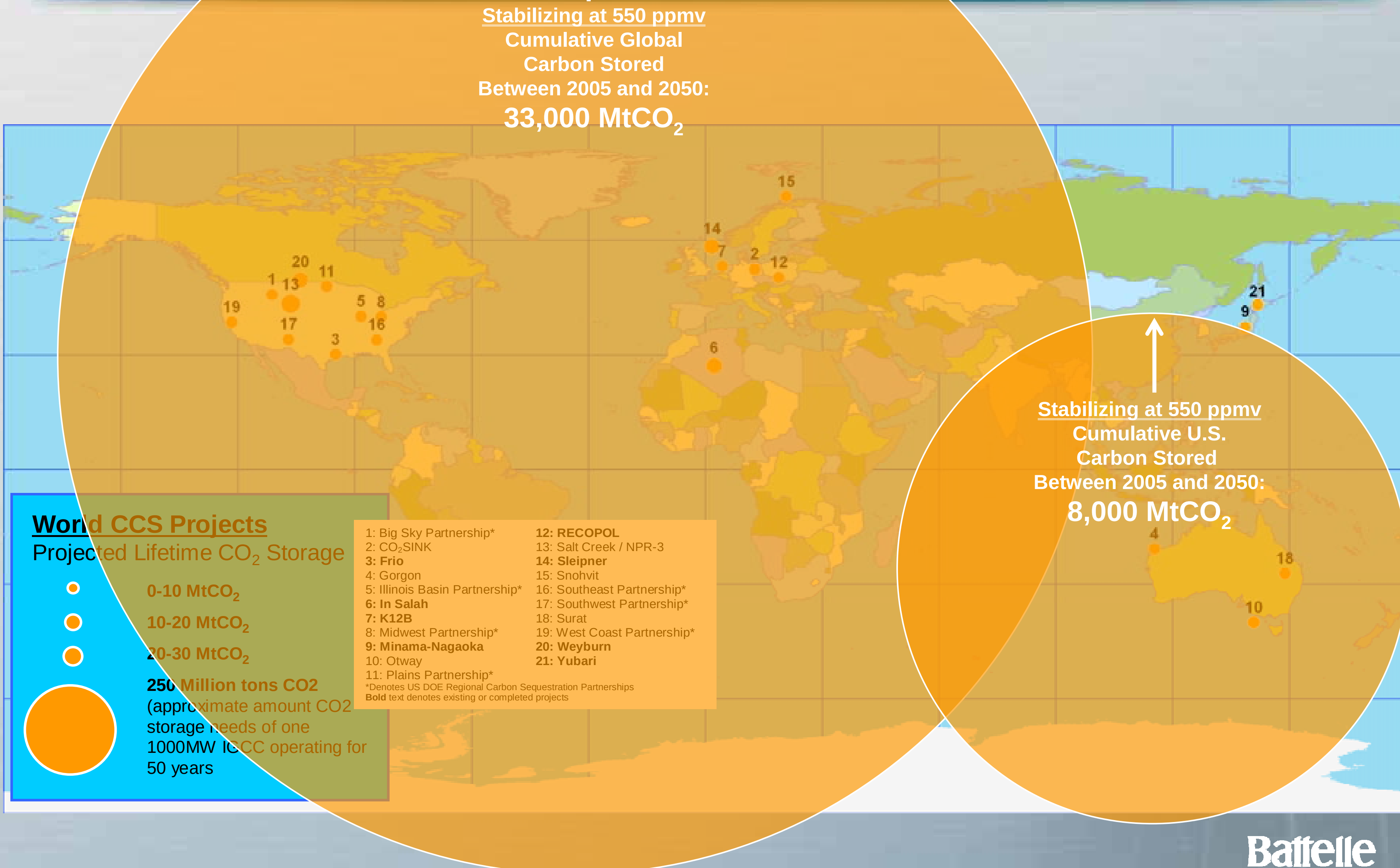


- Taiwan: Is There Enough CO_2 Storage Capacity?

Global CO_2 Storage Capacity: *Take Home Messages*

- Geologic CO_2 storage reservoirs, like many other natural resources, are heterogeneous in quality or distribution.
  - Some regions have the potential 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.
  - Simply knowing whether a given region has more theoretical CO_2 storage capacity or more "value-added" CO_2 storage potential is not a significant predictor of the extent to which CCS technologies will be deployed as a central means of reducing CO_2 emissions.
  - On the other hand, *a priori* knowledge of a lack of or severely constrained CO_2 storage potential in a region likely does suggest fewer options for reducing CO_2 emissions.
- A near-term high-priority research task is to survey candidate CO_2 storage reservoirs in the U.S. and in other key nations (e.g., China and India) as the availability of this resource directly impacts the likely evolution of a region's future energy infrastructure.

The Scope of the Scale-up Challenge



Global CCS Deployment:
Take Home Messages

- 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"
- Deep saline formations will be the workhorse for the USA and many other countries.
- Within the utility sector, CCS is most economically deployed for base load.
- CCS must be integrated with large coal-fired electricity and H_2 production to make a large contribution to addressing climate change.
- Multiple large-scale field experiments, in different sinks and from different sources, need to go forward now (FutureGen is just ONE and not enough).
- It is important to realize that we are in the *earliest stages* of the deployment of CCS technologies. Much hard work remains to fulfill the potential promise of CCS technologies for addressing climate change.

Global CCS Deployment:
Take Home Messages

- 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 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?

- Regulatory Issues:
  - Who will assume the liability for the stored CO_2?
  - How will CO_2 injection wells be permitted (Class I, Class V, New Class)?
  - Rights of way for CO_2 transport: How will these be regulated?

Battelle
The Business of Innovation

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.