



Carbon Management and the Global Energy Technology Challenge

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Joint Global Change Research Institute

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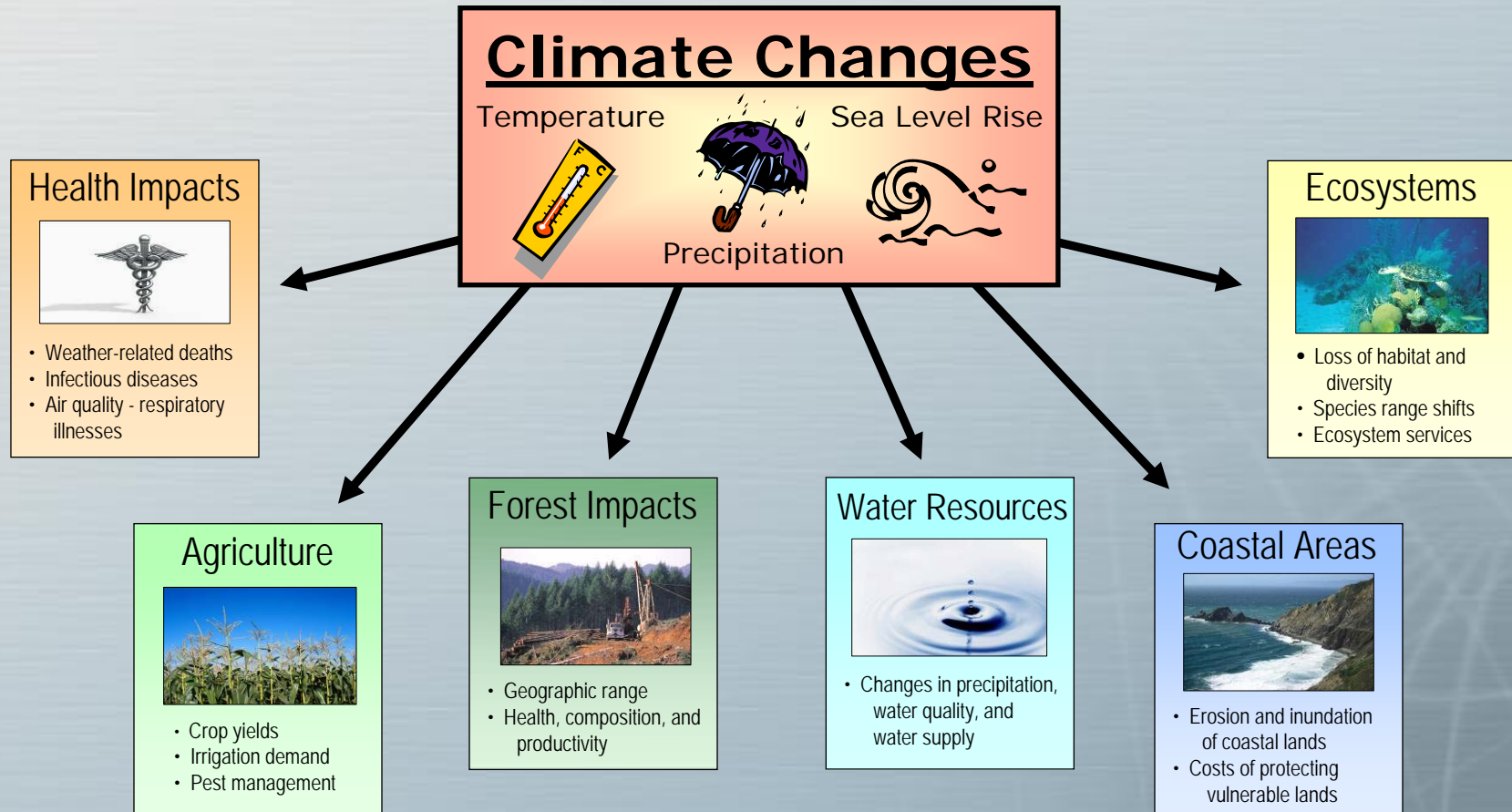
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What are the potential impacts associated with climate change?



Image courtesy of NRDC.

What are the potential impacts associated with climate change?



Carbon Management Problem Statement 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**

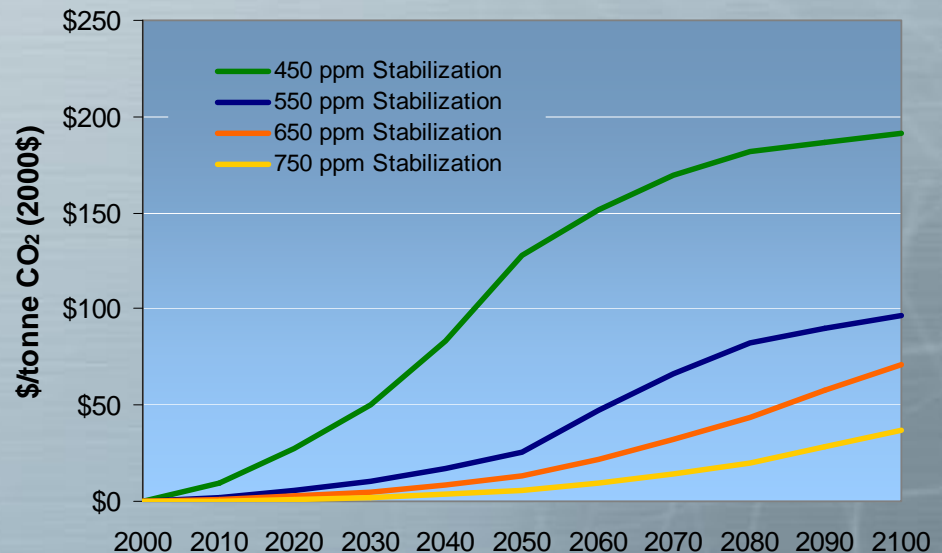
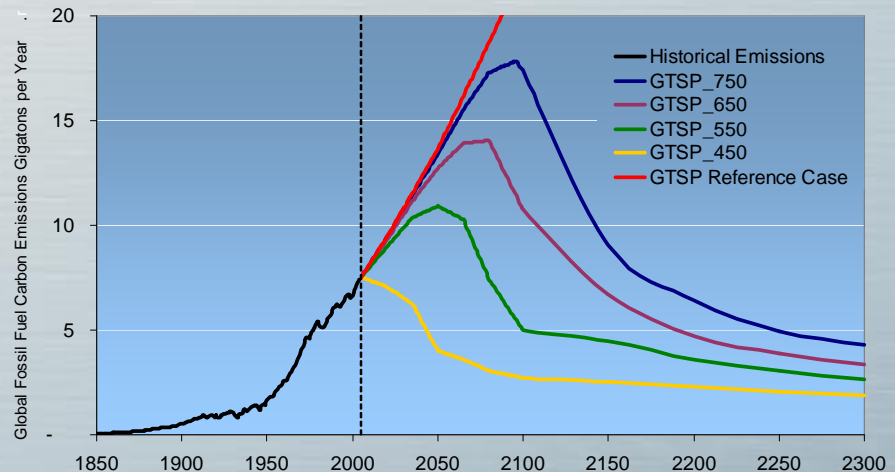


**Don't
Know What is
Dangerous**

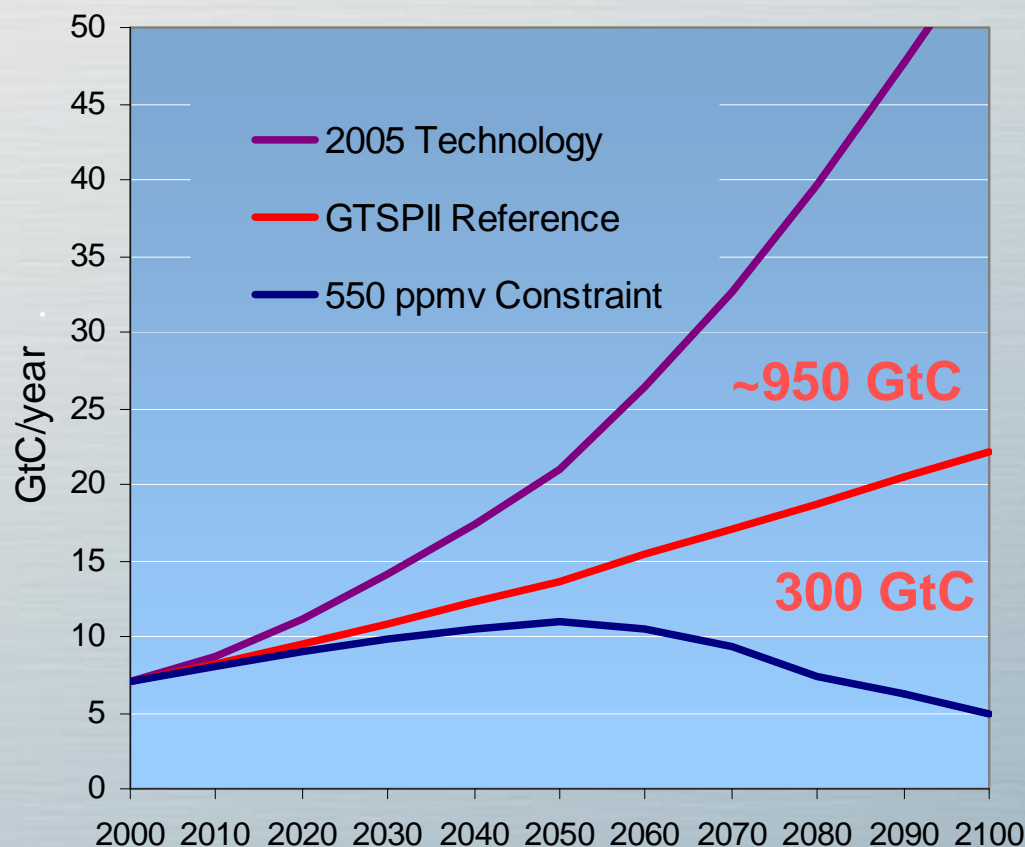
**Economic
Development
Matters**

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 CO₂ 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.



Technology will continue to improve but Business as Usual going to be enough



← ***Today's Technology***



← ***"Business As Usual"***



← ***Stabilization at 550ppmv***

Carbon Management Challenge

A gigaton is...

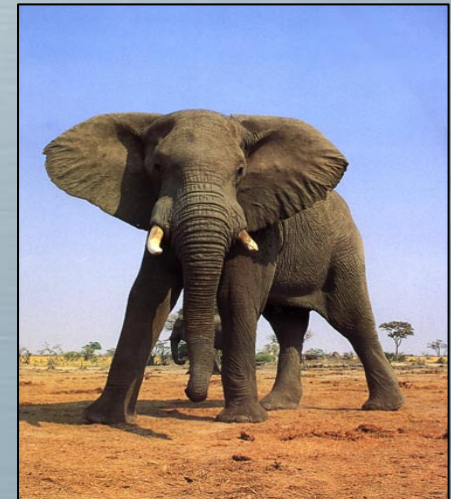
1,240 Golden Gate Bridges



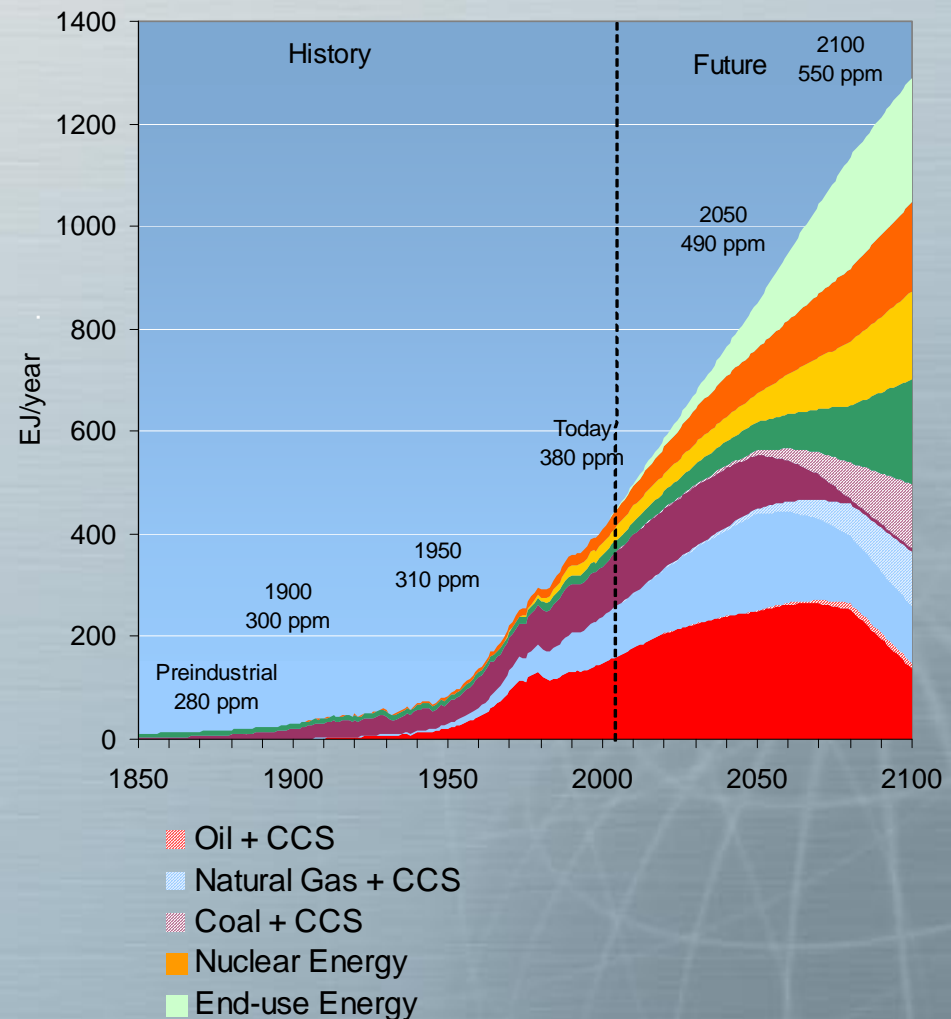
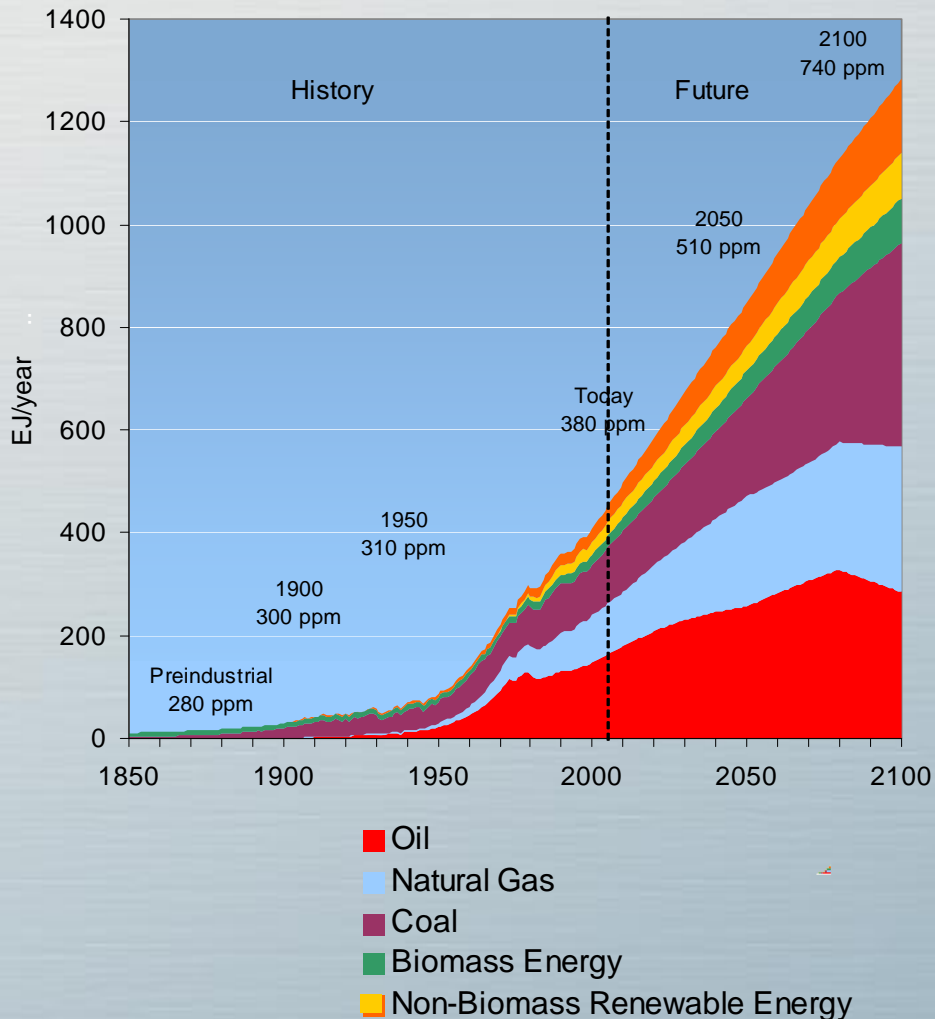
2740 Empire State Buildings



142,857,142 African elephants



Stabilization of CO₂ concentrations means fundamental change to the global energy system



No “Silver Bullet” for addressing climate change

- The atmosphere is indifferent as to what kinds of processes and where any given ton of CO₂ is released from. CO₂ released from any of these has the same effect on the climate



CO₂ from a power plant in China



CO₂ from automobiles in Southern California



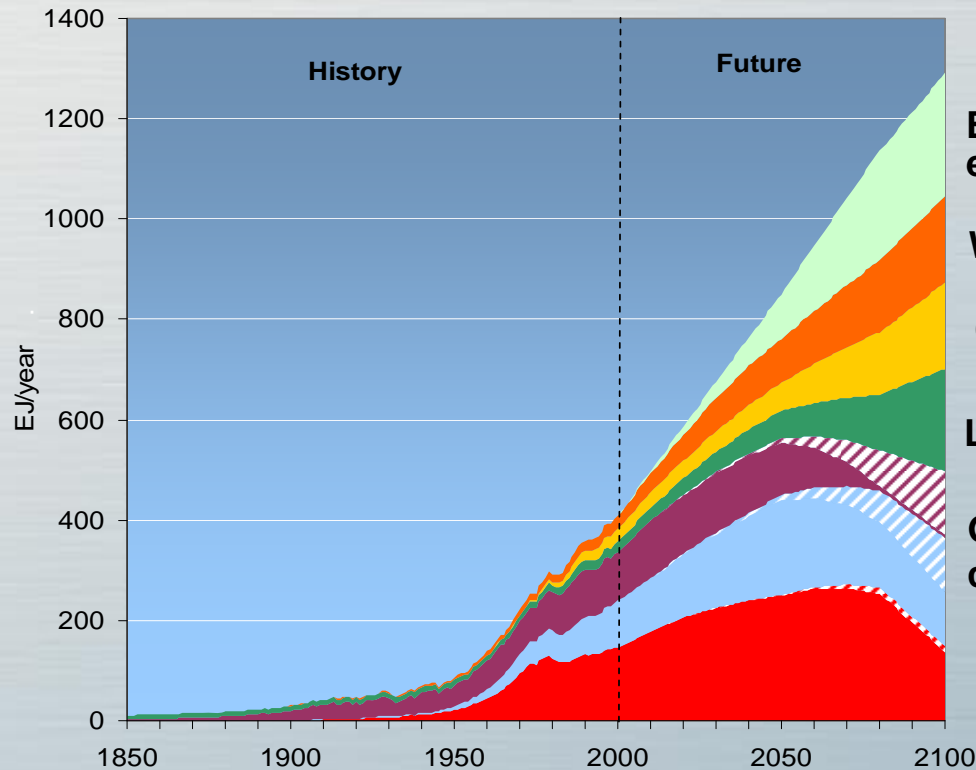
CO₂ from natural gas fired hot water heaters in European homes



CO₂ released deforestation in the Amazon

- However the global economy, firms, consumers and governments do care – and care a great deal – how we go about reducing greenhouse gas emissions as the cost of abating these emissions varies dramatically across various aspects of the global economy.

Stabilization of CO₂ concentrations means fundamental change to the global energy system...



Expanded deployment of advanced energy efficiency technologies

Wind & solar accelerate their expansion

Continued expansion of nuclear energy

Large-scale bio energy crop production

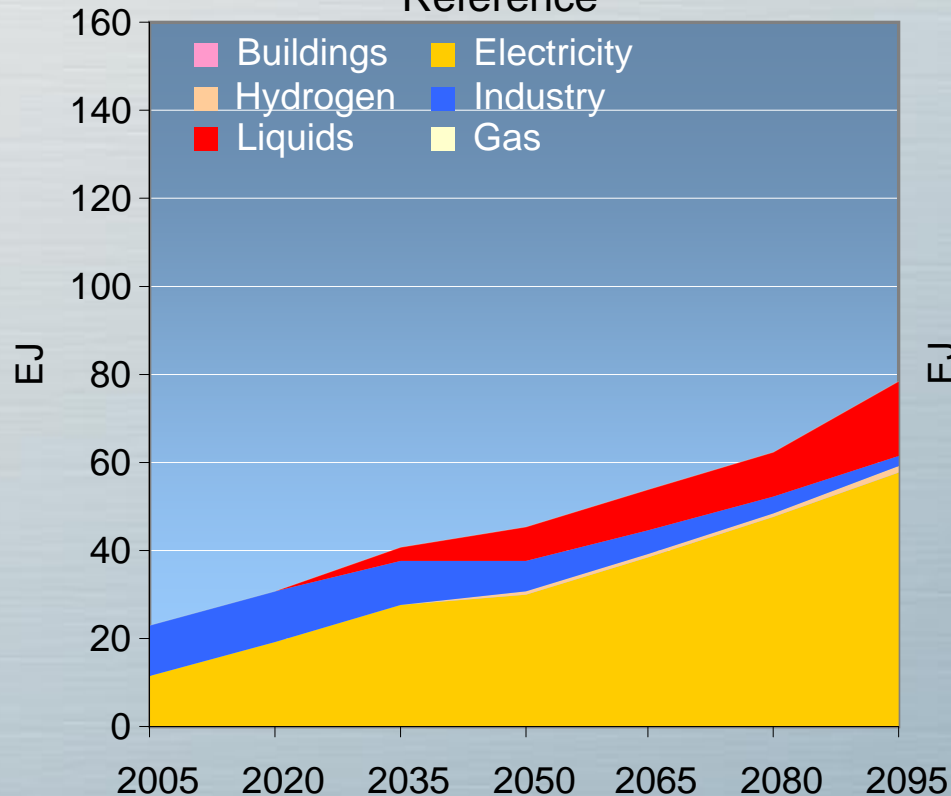
Global commercial deployment of CO₂ capture and storage (CCS)

It is simply inconceivable that there is one silver bullet technology that can deliver transportation services, electricity, heat and power in industry, lighting and cooling in buildings, ... today and for the rest of the century.

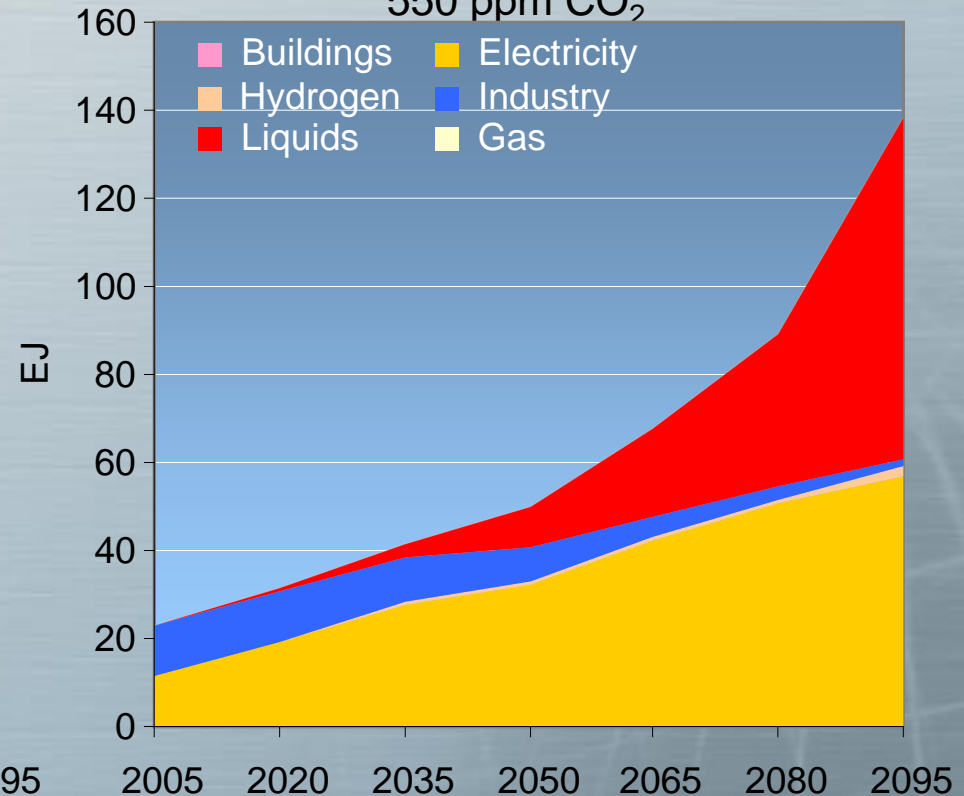
No Silver Bullet: Bioenergy

For most of the century, the largest market for bioenergy crops is electricity generation however a climate policy expands overall bioenergy use and substantially increases its deployment in the transportation sector.

**Global Commercial Biomass
Reference**



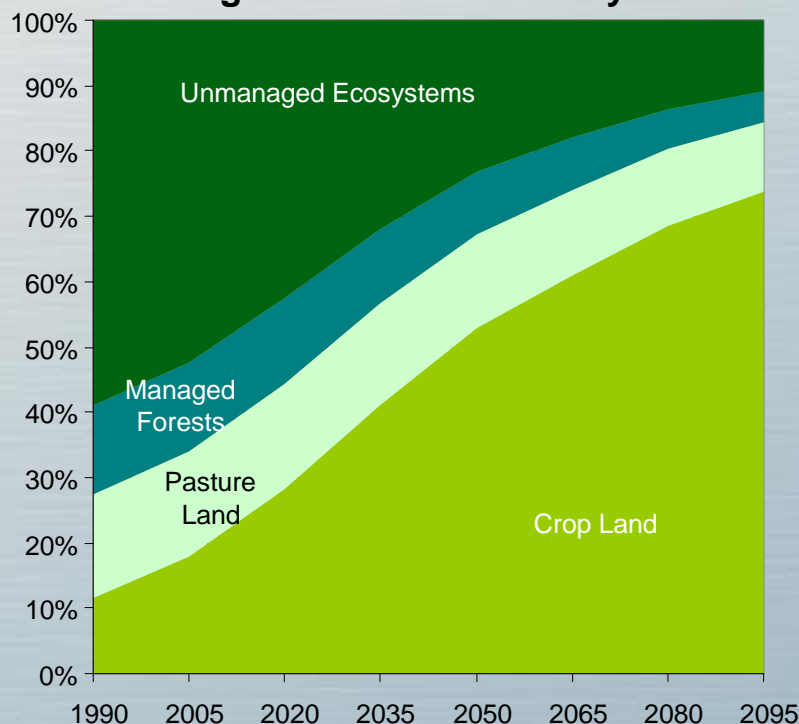
**Global Commercial Biomass
550 ppm CO₂**



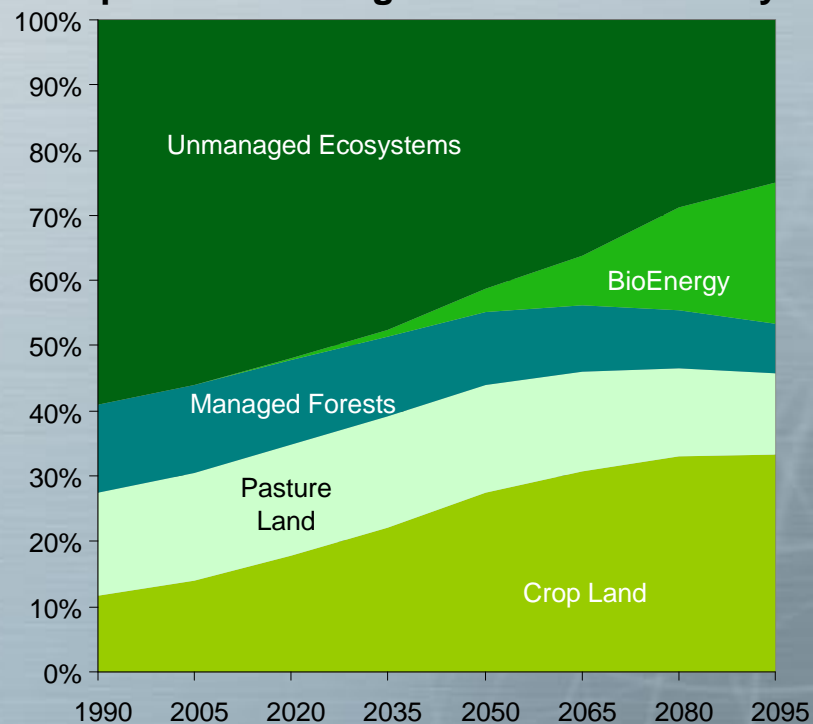
No Silver Bullet: Bioenergy

The successful deployment of bioenergy in a climate-constrained world depends as much on continued productivity advances for food crops as on advancements for energy crops.

550 ppm Stabilization: No Improvement in Agricultural Productivity

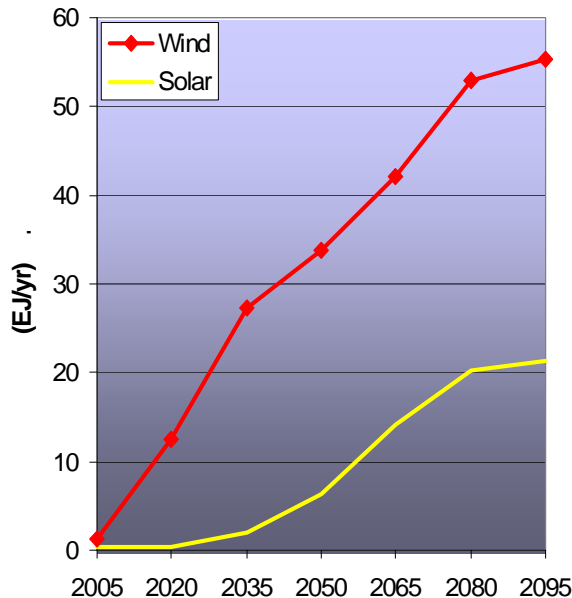


550 ppm Stabilization: 0.5% per Year Improvement in Agricultural Productivity

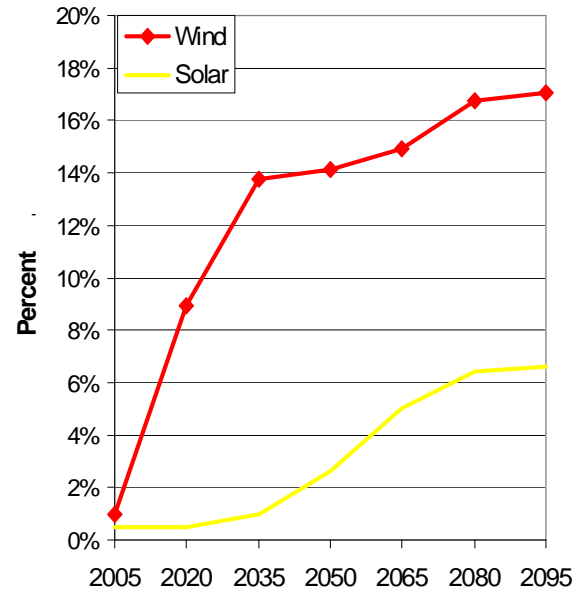


No Silver Bullet: Wind and solar power

Global Electricity Production

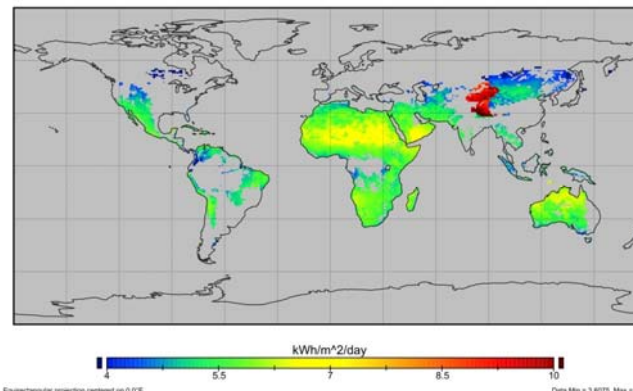


Percent of Global Electricity Production



- Wind and solar power will continue to grow in absolute and relative terms and the imposition of a climate policy acts to accelerate this growth.
- Intermittency and the cost of reliable large-scale energy back up are lesser although still significant constraints.
- However, the principal constraint on wind and solar power deployment is likely deteriorating cost competitiveness as it becomes necessary to tap poorer grades or more distant wind/solar resources.

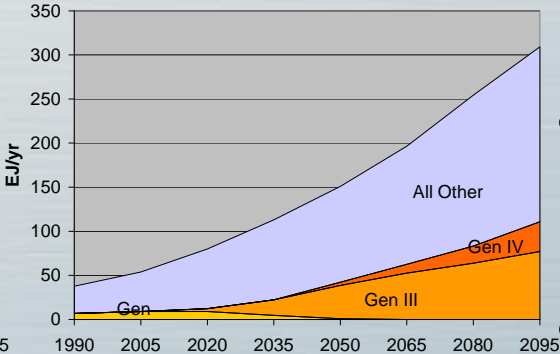
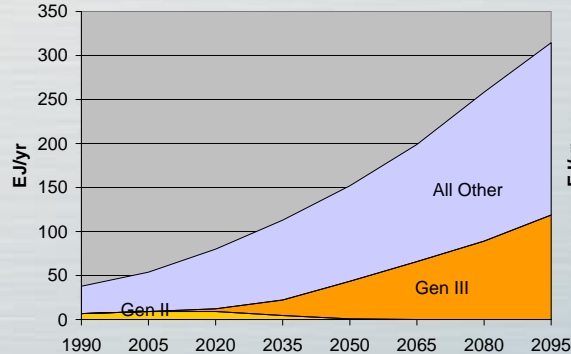
Direct Solar Radiation



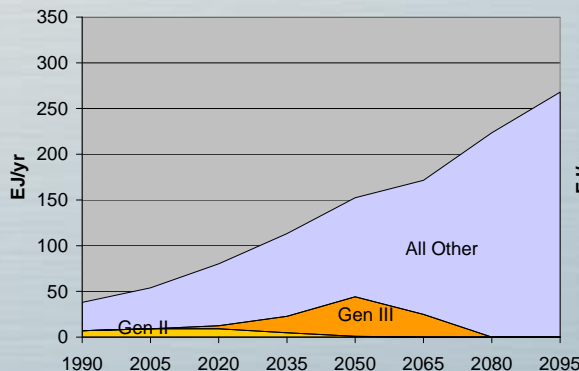
No Silver Bullet: Nuclear power

**Global Electricity Generation
WRE 550 Case**

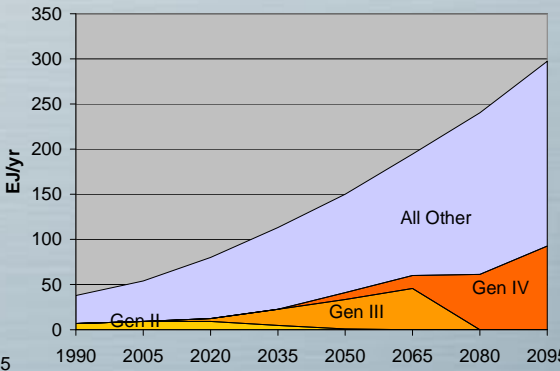
Uranium Available
Beyond 11 MTU



Uranium Limited
to 11 MTU



Only Gen III Reactors
are Deployed



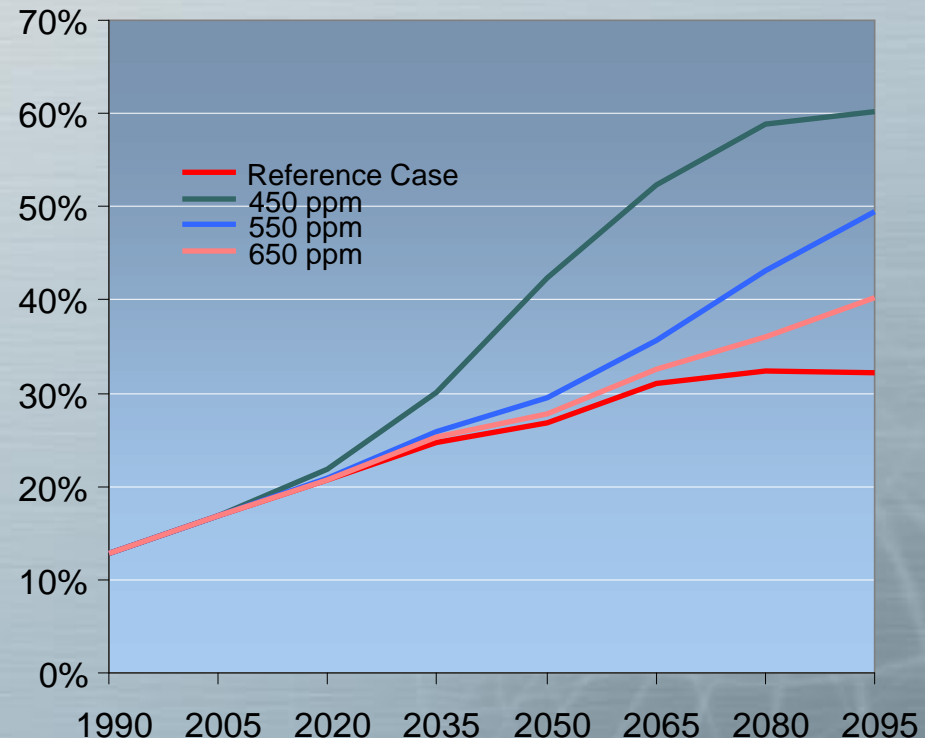
Gen III & Gen IV Reactors
are Deployed

- Outside the U.S., nuclear power remains a growing part of the world's energy supply.
- A climate policy tends to accelerate the deployment of nuclear power.
- The long-term deployment of nuclear energy will be driven by key factors such as:
 - the availability and cost of uranium,
 - an acceptable solution to long-term waste disposal, and
 - Public acceptance of new nuclear power plants
 - the performance of next generation nuclear reactor technologies.

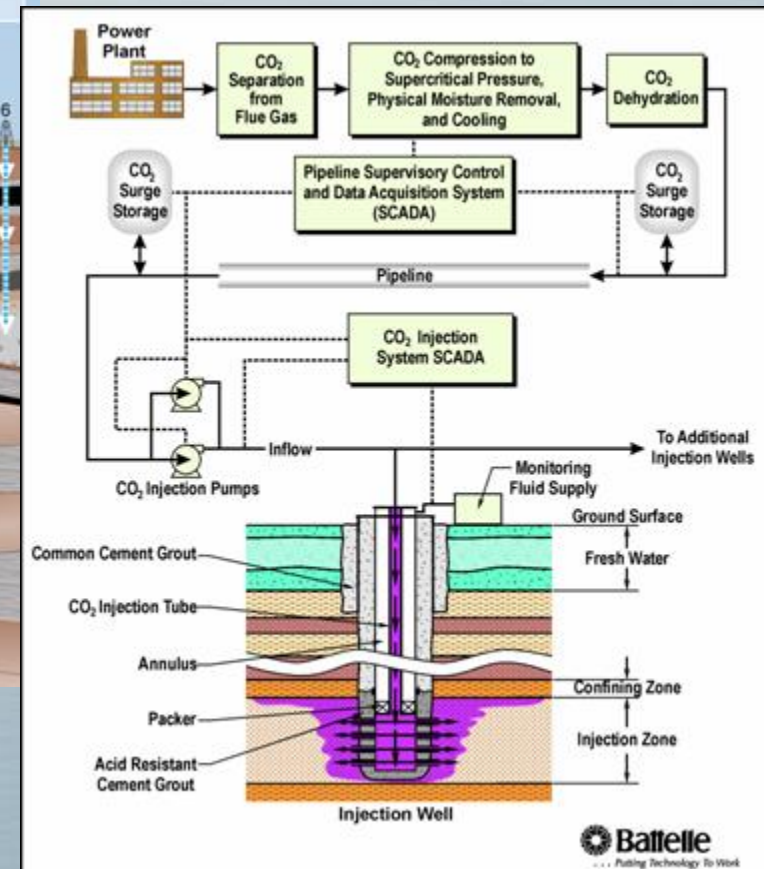
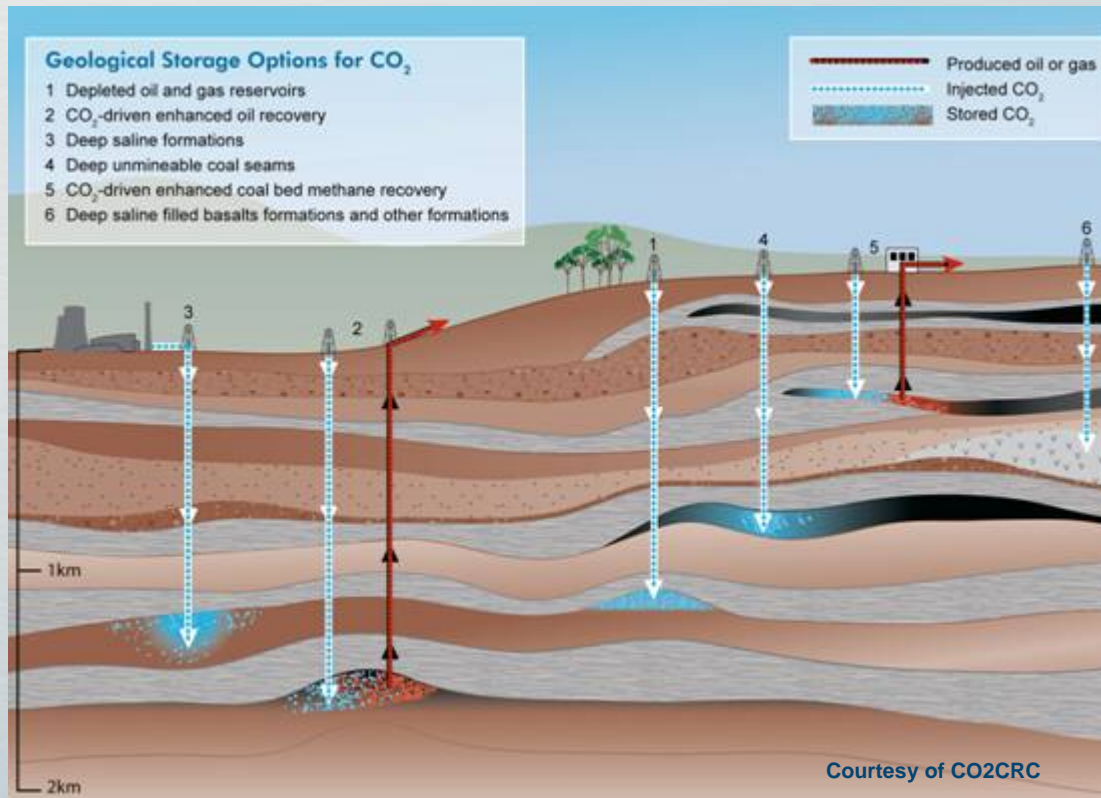
No Silver Bullet: Advanced Energy Efficient Technologies

- Climate policy works to accelerate the on-going electrification of the global economy
- This increases the overall market and therefore increases the greenhouse gas emissions reduction potential of a large number of energy efficient technologies.
- Increased end-use energy efficiency has a "multiplier" effect on total energy consumption as it avoids the conversion and transmission losses associated with getting primary energy to the end-use.

Electricity Relative to Total Primary Energy

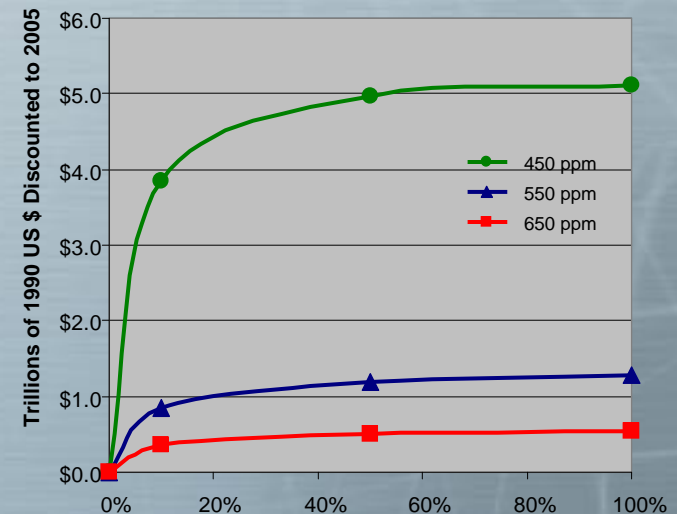
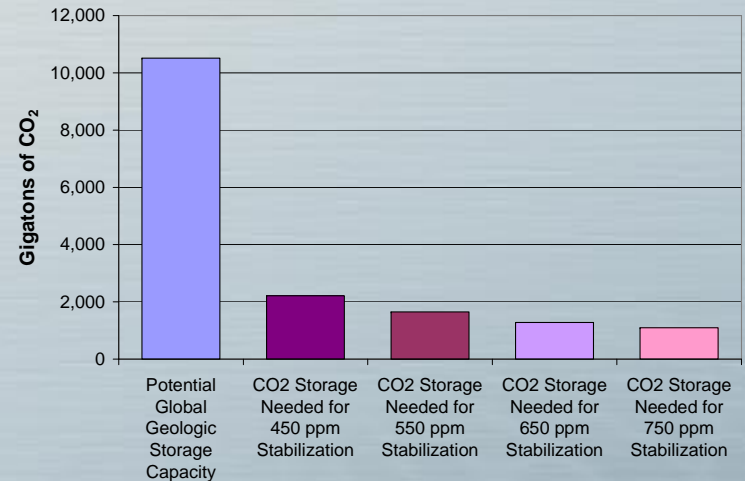


No Silver Bullet: Carbon Dioxide Capture and Storage (CCS)

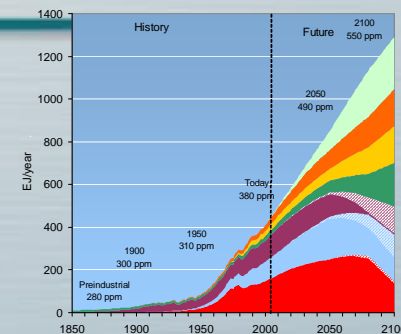
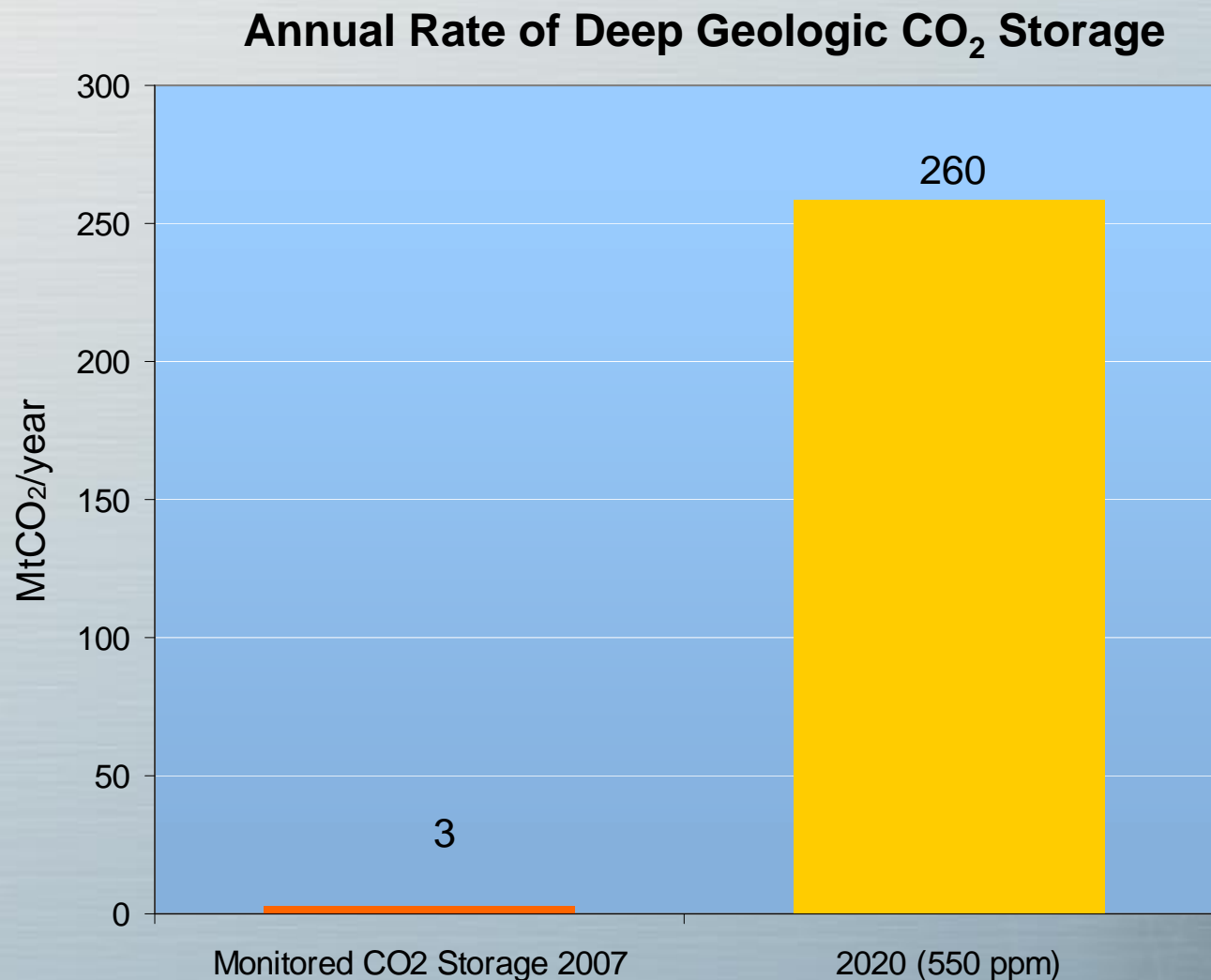


No Silver Bullet: CCS

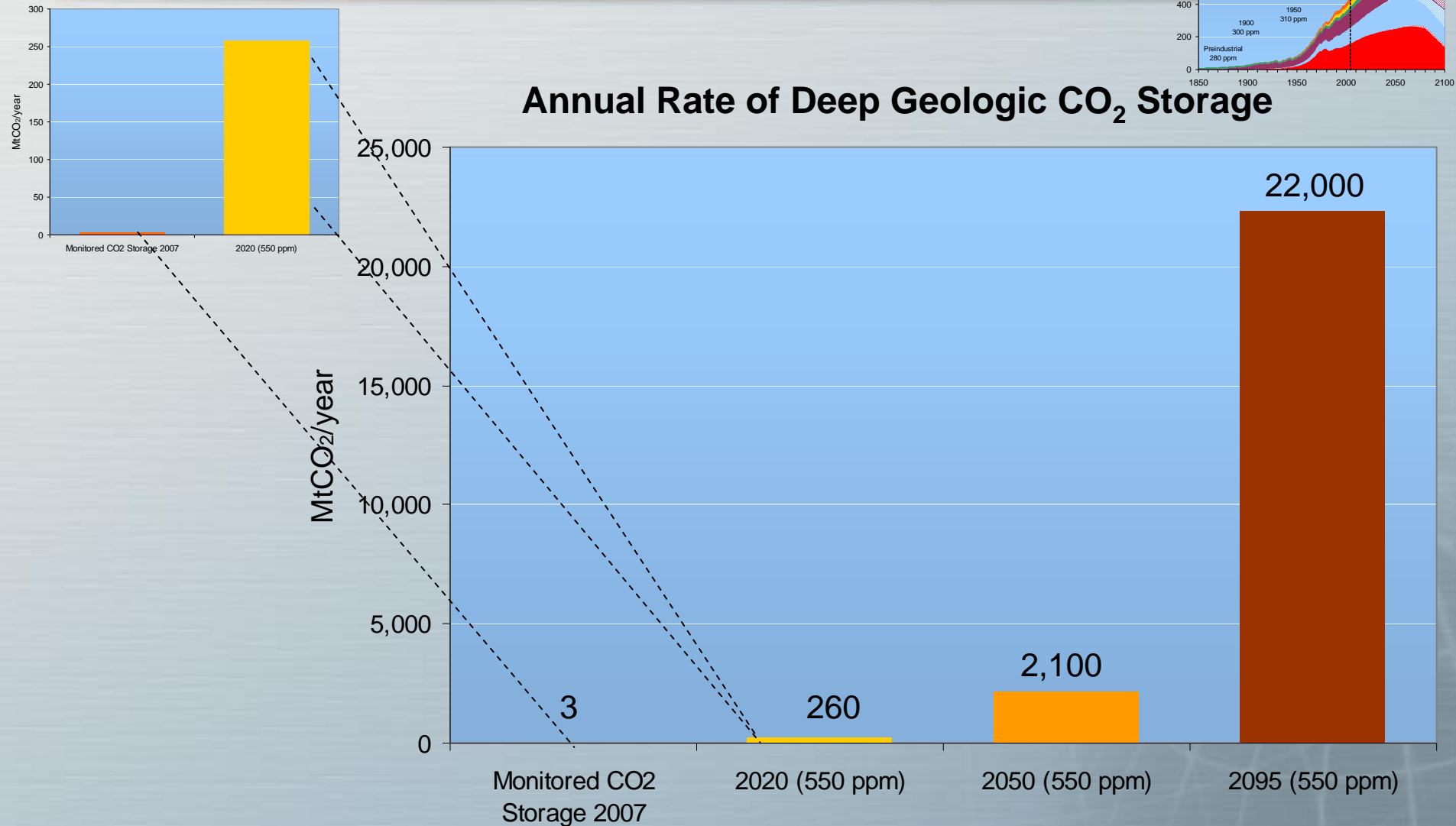
- Assuming that society has a broad portfolio of carbon management options at its disposal:
 - There appears to be sufficient global theoretical storage capacity to easily accommodate the demand for CO₂ storage for stabilization scenarios ranging from 450-750ppmv.
- Even though there is no definitive 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 CO₂ storage capacity is available.



The Challenge of Scale Grows with Time — the near term

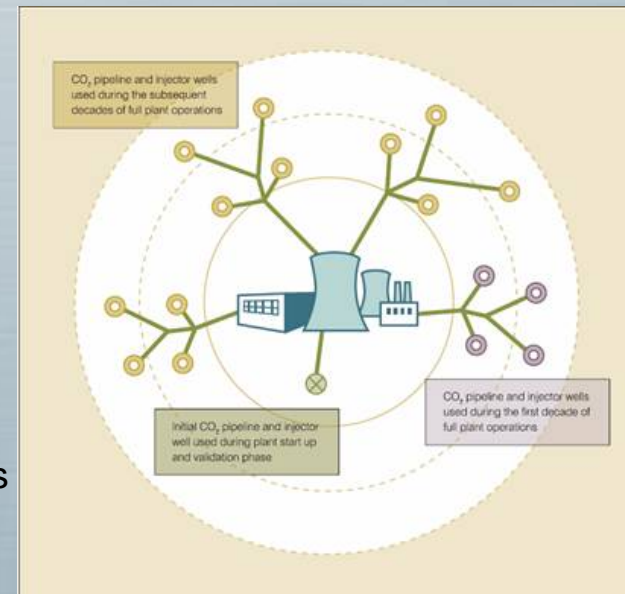


The Challenge of Scale Grows with Time the mid to long term



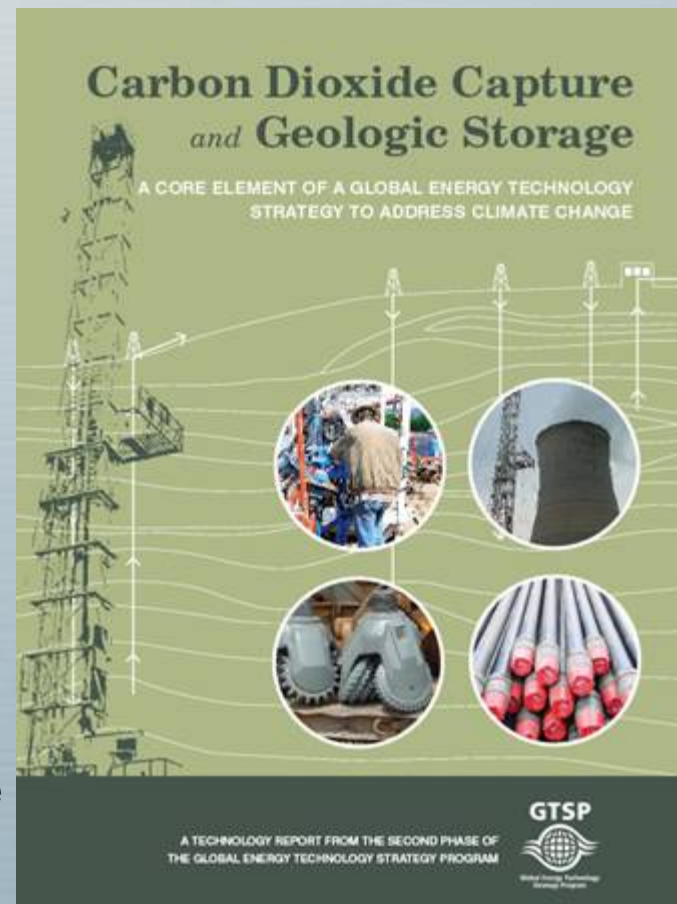
No Silver Bullet: CCS

- The cost of capturing CO₂ 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 that are likely only to be 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 CO₂-driven enhanced oil recovery similar to the demands placed upon deep geologic formation that is being used to isolate large quantities of CO₂ 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 CO₂ storage on a day-to-day basis? What criteria and metrics will this regulator use?



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.



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

- Climate change is a long-term, century scale, problem that ultimately implies a fundamental transformation of the global energy and economic system but that also has implications for today.
- 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 are many strategies for managing the risks posed by climate change. It is collectively up to us to put the best possible strategy on the table.