Grand Challenges in Science for Guiding Climate Change Mitigation and Adaptation

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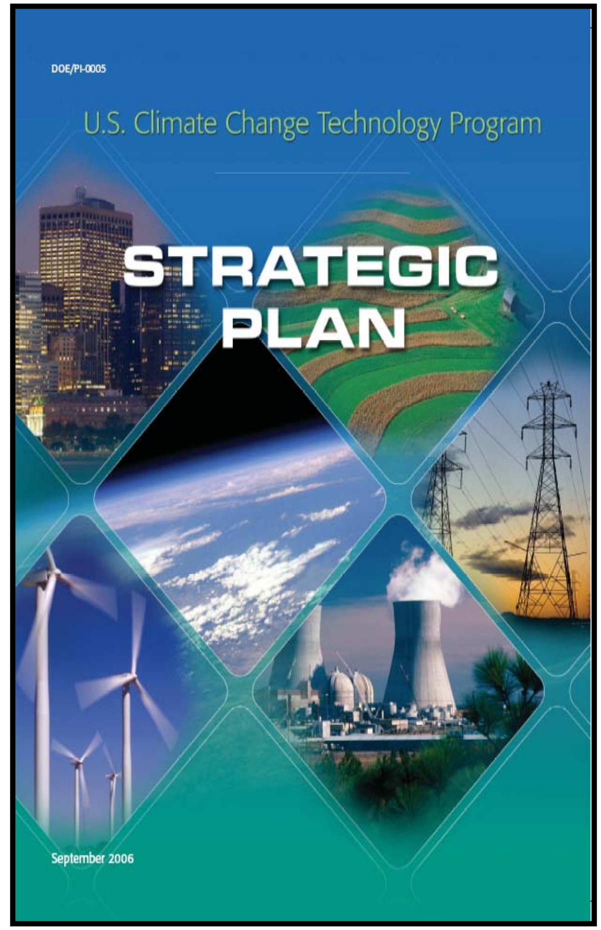
Overview

- U.S. Climate Change Technology Program
- Interfaces Between CCTP and CCSP
- CCTP Grand Challenges
  1. Inform the Pace of Technology Development & Deployment
  2. Illuminate Trade-Offs Among Response Strategies
  3. Inform Decision-Making at Appropriate Levels of Governance
  4. Identify Key Interactions Between Natural and Human Systems
  5. Organize Integrated Systems Architecture for Measurement & Verification
  6. Explore the Means and Consequences of "Back-Stop" Options
- Summary: CCTP Grand Challenges Mapped onto Workshop Breakouts

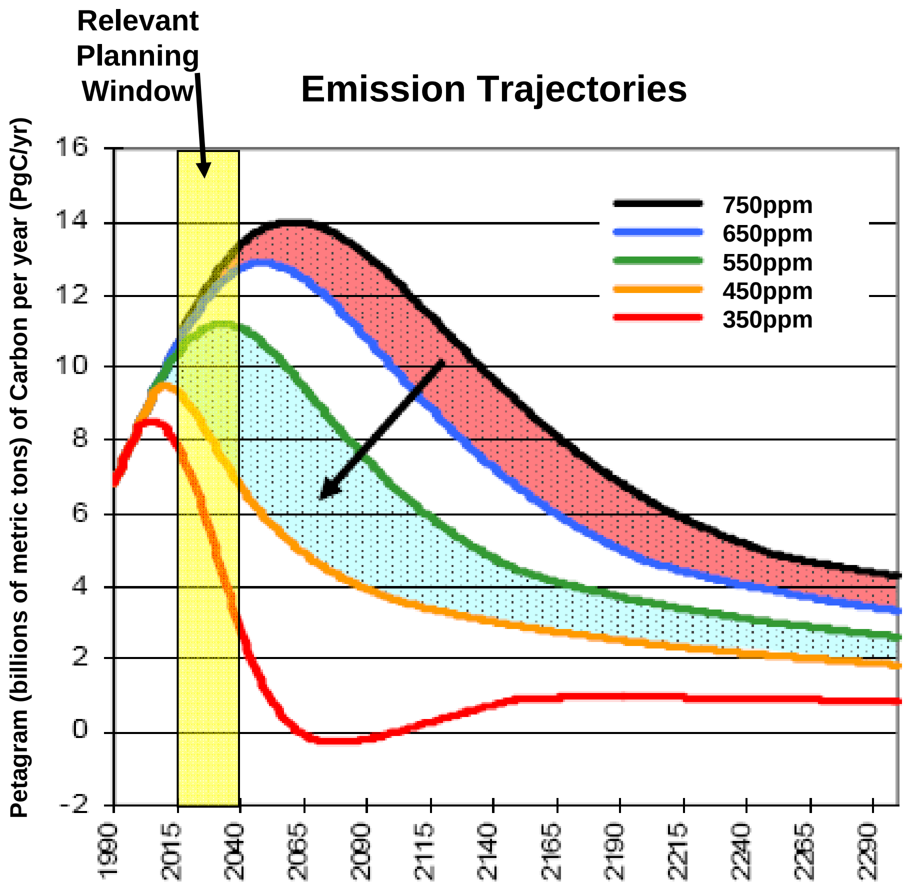
U.S. Climate Change Technology Program

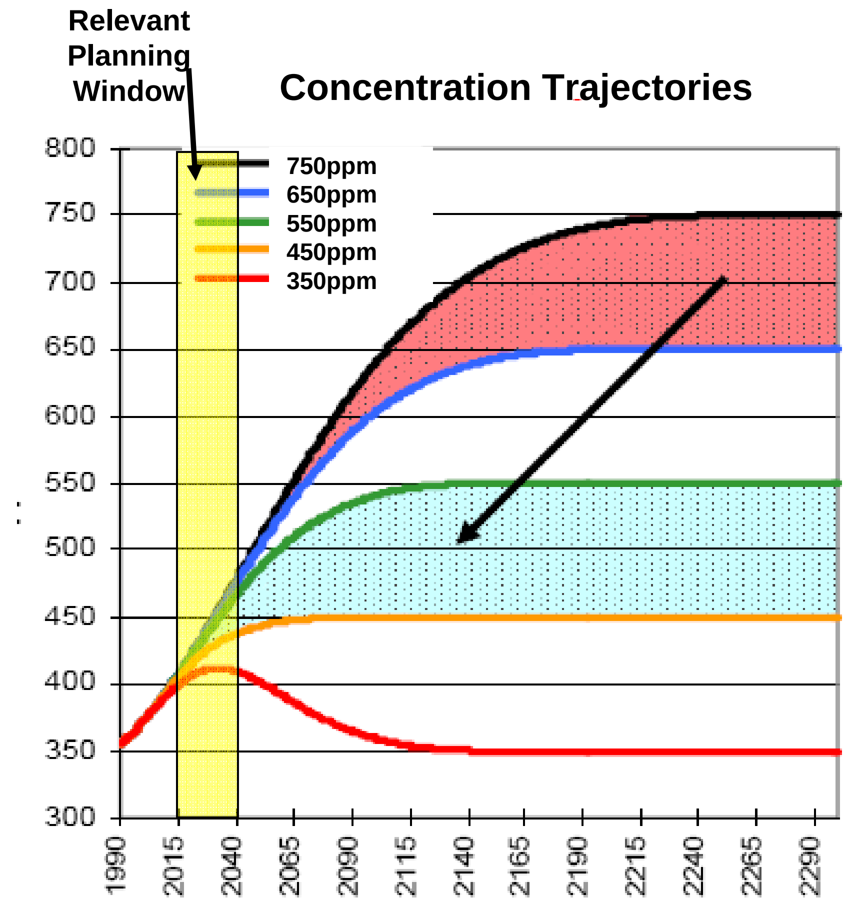
- **U.S. Climate Change Technology Program**
  - Mission – Accelerate RD&D on Adv. CC Techs
  - Scope – Ten Federal R&D Agencies
  - Budget -- $4.4 Billion Requested for FY'09
  - Activities – Coord. RD&D Planning & Budgeting
- **Goals:**
  - Four emissions-related strategic goals:
    - ✓ Reduce emissions from energy end use & infrastructure;
    - ✓ Reduce emissions from energy supply;
    - ✓ capture & sequester CO_2; and
    - ✓ Reduce emissions from non-CO_2 gases.
  - Two cross-cutting, supporting strategic goals:
    - ✓ Improve capabilities to measure & monitor GHGs; and
    - ✓ Bolster basic science and strategic research.
- **CCTP Authorized in *EPAct2005,* Led by DOE**



www.climatetechnology.gov

Long-Term Goals Require Near-Term Actions



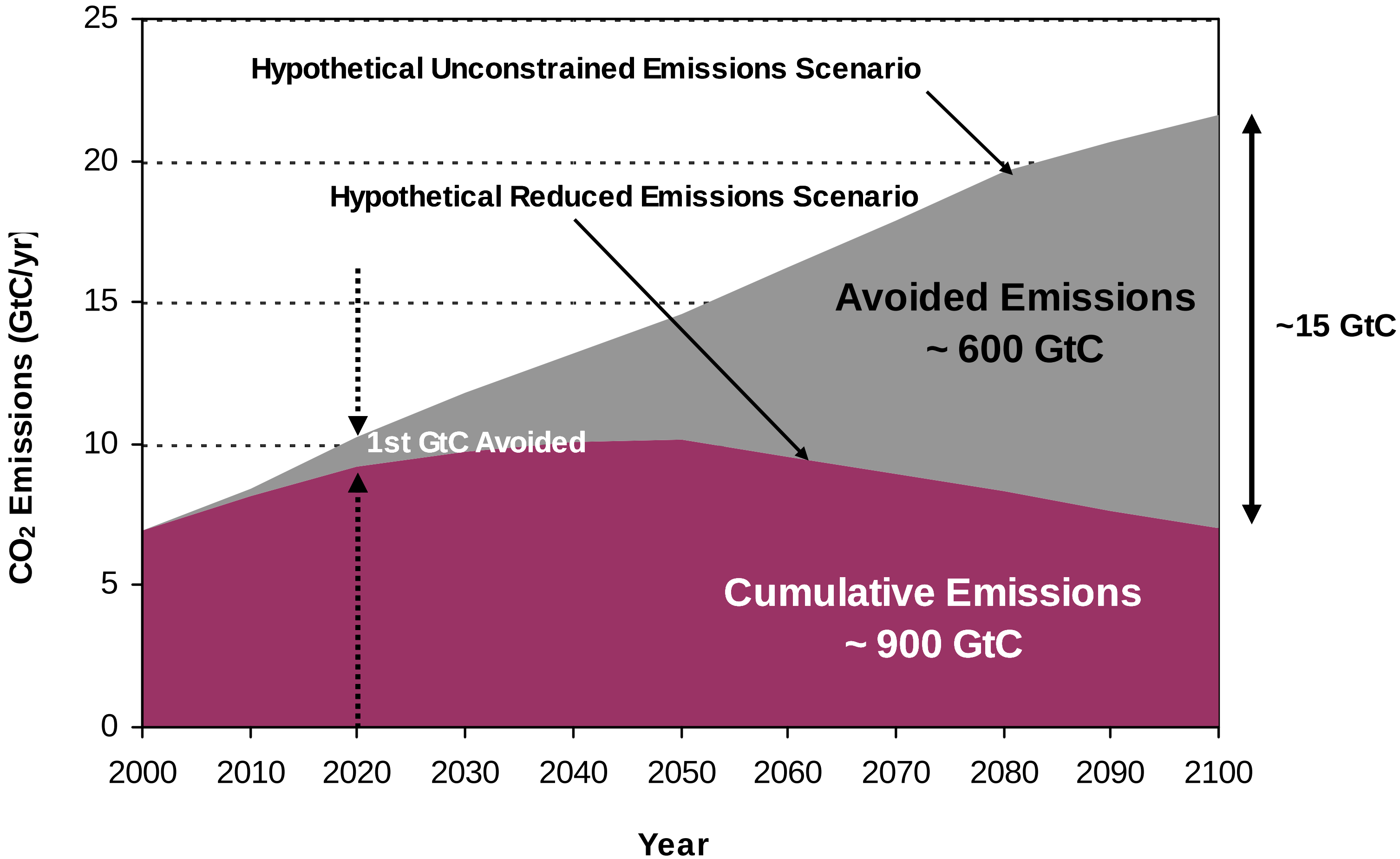


Emission and concentration trajectories based on current funding profile for technology investments

Potential carbon reductions based on proposed technology investments

Action period to influence longer-term outcomes

Mid-Range Example of A Reduced GHG Emissions Future



GtC = Giga-Tonnes Carbon

Giga-Tonne = Billion (10^9) Metric-Tonnes (1000 Kilograms)

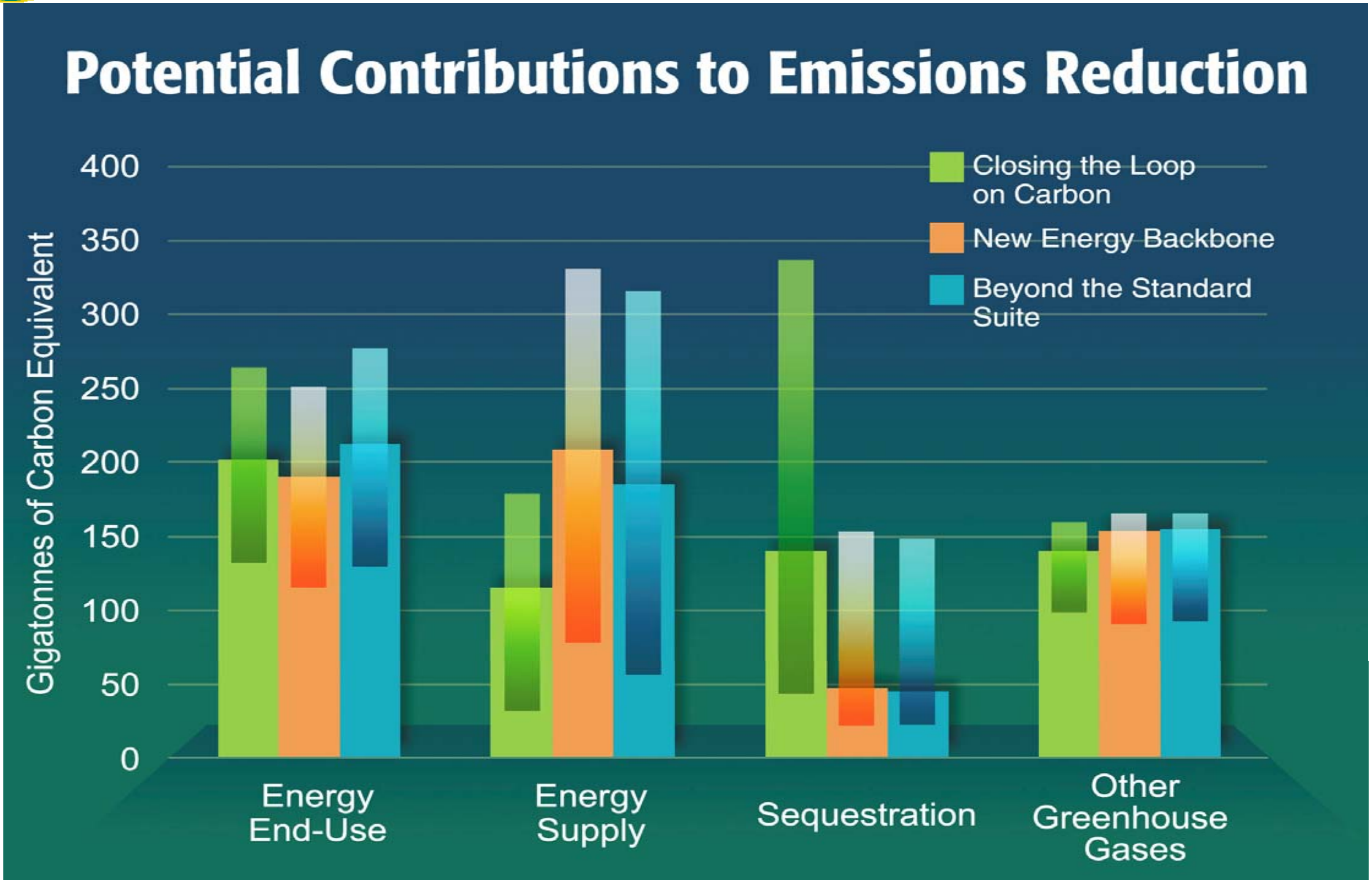
How Big is a Gigaton? Using U.S. Technology,* These Actions Can Cut Emissions by 1 GtC/Year

Today's Technology	Actions that Provide 1 Gigaton / Year of Mitigation
Coal-Fired Power Plants	Build 1,200 "zero-emission" 500-MW coal-fired power plants (in lieu of coal-fired plants without CO_2 capture and storage) (73% CF)
Geologic Sequestration	Install 3,700 sequestration sites like Norway's Sliepner project (0.27 MtC/year)
Nuclear	Build 500 new nuclear power plants, each 1 GW in size (in lieu of new coal-fired power plants without CO_2 capture and storage) (90% CF)
Electricity from Landfill Gas Projects	Install 28,000 "typical" landfill gas electricity projects (3 MW projects at non-regulated landfills) that collect landfill methane emissions and use them as fuel for electric generation.
Efficiency	Deploy 1 billion new cars at 40 miles per gallon (mpg), instead of new cars at 20 mpg (assume 12,000 miles per year per car)
Wind Energy	Install 650,000 wind turbines (1.5 MW each, operating at 0.45 capacity factor) in lieu of coal-fired power plants without CO_2 capture and storage.
Solar Photovoltaics	Install 6 million acres of solar photovoltaics to supplant coal-fired power plants without CO_2 capture and storage (10% cell DC eff'cy; 1700 kWh/m2 solar radiance; 90% DC-AC conv. eff'cy).
Biomass fuels from plantations	Convert to biomass crop production a barren area about 20 times the total land area of Iowa (about 700 million acres)
CO_2 Storage in New Forest.	Convert to new forest a barren area about 9 times the total land area of the State of Washington (nearly 400 million acres) (Assumes Douglas Fir on Pacific Coast)

Giga-Tonne = Billion ($10^{9)}$ Metric-Tonnes (1000 Kilograms)

* Based on U.S. Data and Current Technology

Integrated Results



Source: Placet M; Humphreys, KK; Mahasenan, NM. Climate Change Technology Scenarios: Energy, Emissions and Economic Implications. Pacific Northwest Nation Laboratory, PNL-14800, August 2004. Available at: http://www.pnl.gov/energy/climatetechnology.stm.
Image updated: April 2006

Roadmap for CC Technology Development

	NEAR-TERM	MID-TERM	LONG-TERM
GOAL #1 Energy End-Use & Infrastructure	• Hybrid & Plug-In Hybrid Electric Vehicles • Engineered Urban Designs • High-Performance Integrated Homes • High Efficiency Appliances • High Efficiency Boilers & Combustion Systems • High-Temperature Superconductivity Demonstrations	• Fuel Cell Vehicles and H_2 Fuels • Low Emission Aircraft • Solid-State Lighting • Ultra-Efficient HVACR • "Smart" Buildings • Transformational Technologies for Energy-Intensive Industries • Energy Storage for Load Leveling	• Widespread Use of Engineered Urban Designs & Regional Planning • Energy Managed Communities • Integration of Industrial Heat, Power, Process, and Techniques • Superconducting Transmission and Equipment
GOAL #2 Energy Supply	• IGCC Commercialization • Stationary H_2 Fuel Cells • Cost-Competitive Solar PV • Demonstrations of Cellulosic Ethanol • Distributed Electric Generation • Advanced Fission Reactor and Fuel Cycle Technology	• FutureGen Scale-Up • H_2 Co-Production from Coal/Biomass • Low Wind Speed Turbines • Advanced Biorefineries • Community-Scale Solar • Gen IV Nuclear Plants • Fusion Pilot Plant Demonstration	• Zero-Emission Fossil Energy • H_2 & Electric Economy • Widespread Renewable Energy • Bio-Inspired Energy & Fuels • Widespread Nuclear Power • Fusion Power Plants
GOAL #3 Capture, Storage & Sequestration	• CSLF & CSRP • Post Combustion Capture • Oxy-Fuel Combustion • Enhanced Hydrocarbon Recovery • Geologic Reservoir Characterization • Soils Conservation • Dilution of Direct Injected CO_2	• Geologic Storage Proven Safe • CO_2 Transport Infrastructure • Soils Uptake & Land Use • Ocean CO_2 Biological Impacts Addressed	• Track Record of Successful CO_2 Storage Experience • Large-Scale Sequestration • Carbon & CO_2 Based Products & Materials • Safe Long-Term Ocean Storage
GOAL #4 Other Gases	• Methane to Markets • Precision Agriculture • Advanced Refrigeration Technologies • PM Control Technologies for Vehicles	• Advanced Landfill Gas Utilization • Soil Microbial Processes • Substitutes for SF_6 • Catalysts That Reduce N_2O to Elemental Nitrogen in Diesel Engines	• Integrated Waste Management System with Automated Sorting, Processing & Recycle • Zero-Emission Agriculture • Solid-State Refrigeration/AC Systems
GOAL #5 Measure & Monitor	• Low-Cost Sensors and Communications	• Large Scale, Secure Data Storage System • Direct Measurement to Replace Proxies and Estimators	• Fully Operational Integrated MM Systems Architecture (Sensors, Indicators, Data Visualization and Storage, Models)

Interfaces Between CCTP and CCSP

Interface Between CCTP and CCSP

- **CCTP-CCSP Issues Intersect**
  - Informing the Pace of Technology Development
  - Linking GHG Emission Rates to the Timing of Impacts & Vulnerabilities
  - Identifying Effects of Climate Variability and Change on Energy Production and Use
  - Science of Carbon Sequestration Options
  - Integrated Systems Architecture for Measuring, Reporting, and Verification
  - Characterizing Regional Impacts in the U.S.
  - Adaptation/Infrastructure Planning
  - Ecological and Environmental Impacts of Mitigation & Adaptation Technologies
  - Ocean Acidification
  - Geo-Engineering
- **Support Joint Mechanism to Aid Coordination Between CCTP & CCSP**

Effects of Climate Change on Energy Production and Use in the United States*

- **End-Use (Effects Differ by Region)**
  - Reductions in Energy Demand for Space Heating in Buildings
  - Increases in Energy Demand for Space Cooling in Buildings
  - Lower net Energy Requirements for Buildings in net Heating Areas
  - Higher net Energy Requirements for Buildings in net Cooling Areas
- **Production and Supply (Effects Differ by Region)**
  - Changes in Water Availability will Affect Power Plants
  - Temperature Increases will decrease Overall Generation Efficiency
  - Energy Production and Delivery are Vulnerable to Effects of sea Level Rise and Extreme Weather Events

Effects of Climate Change on Energy Production And Use in the United States

U.S. Climate Change Science Program
Synthesis and Assessment Product 4.5

October 2007

http://www.climatescience.gov/Library/sap/sap4-5/final-report/default.htm

* Synthesis and Assessment Product 4.5, Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, October 2007

Grand Challenge #1 --

Inform the Pace of Technology Development & Deployment

Technology Strategy

"Energy security and climate change are two of the great challenges of our time. These challenges share a common solution: technology."

President George W. Bush
Major Economies Meeting
September 28, 2007

- **Key Technology Elements**
  - Coal -- De-Carbonize the Grid
    - Nuclear Power
    - Low-Emission Coal Power
    - Renewable Power
  - Cars -- Transform Cars/Trucks Toward New Fuels
    - Hybrid & Electric Vehicles
    - Alternative Fuel Vehicles & Bio-Based Fuels
    - Alternatives, including Other Modes
  - Efficiency (All Sectors)
  - Other GHGs
  - Enablers
    - CO_2 Capture and Storage
    - Modernized Grid
    - Energy Storage, Large and Small Scale
    - Strategic and Exploratory Research
- **Supporting Policies to Promote Deployment**
  - Financial Incentives
  - Fuel Mandates
  - Codes, Standards, Labeling
  - Transparent System for Measuring Progress
- **Via U.S. Climate Change Technology Program**
  - Strengthen Federal R&D Portfolio
  - Prioritize Investments
- **Expand R&D Cooperation with non-Federal Entities**

Timing

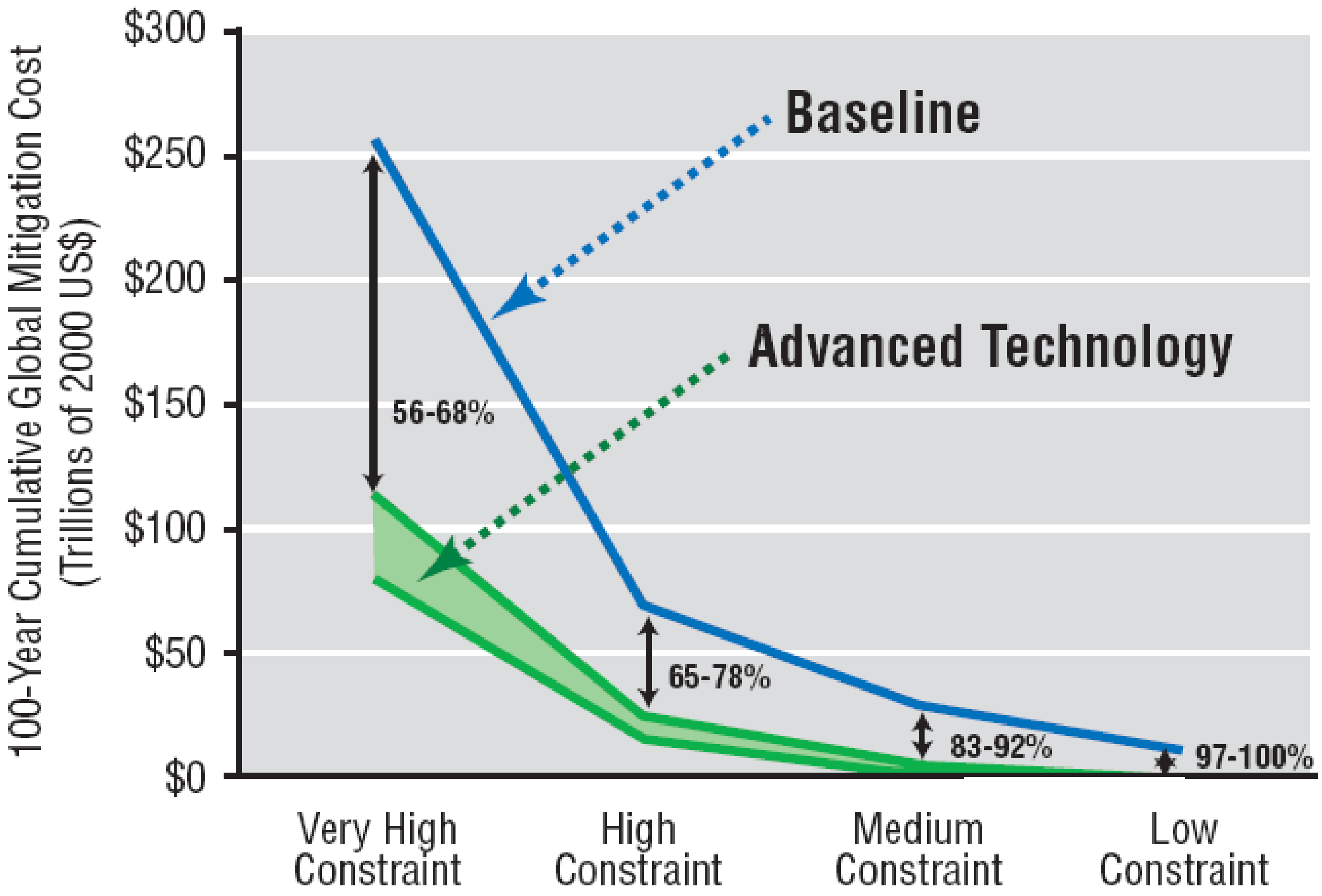
CCTP Strategic Goal	Very High Constraint	High Constraint	Medium Constraint	Low Constraint
Goal #1: **Reduce Emissions from Energy End Use and Infrastructure**	2010 - 2020	2030 - 2040	2030 - 2050	2040 - 2060
Goal #2: **Reduce Emissions from Energy Supply**	2020 - 2040	2040 - 2060	2050 - 2070	2060 – 2100
Goal #3: **Capture and Sequester Carbon Dioxide**	2020 - 2050	2040 or Later	2060 or Later	Beyond 2100
Goal #4: **Reduce Emissions of Non-CO_2 GHGs**	2020 - 2030	2050 - 2060	2050 - 2060	2070 - 2080

Estimated timing of advanced technology market penetrations, as indicated by the first GtC-eq./year of incremental emissions mitigation, by strategic goal, across a range of hypothesized GHG emissions constraints.

Source:: Clarke, L., M. Wise, M. Placet, C. Izaurralde, J. Lurz, S. Kim, S. Smith, and A. Thomson. 2006. Climate Change Mitigation: An Analysis of Advanced Technology Scenarios. Richland, WA: Pacific Northwest National Laboratory.

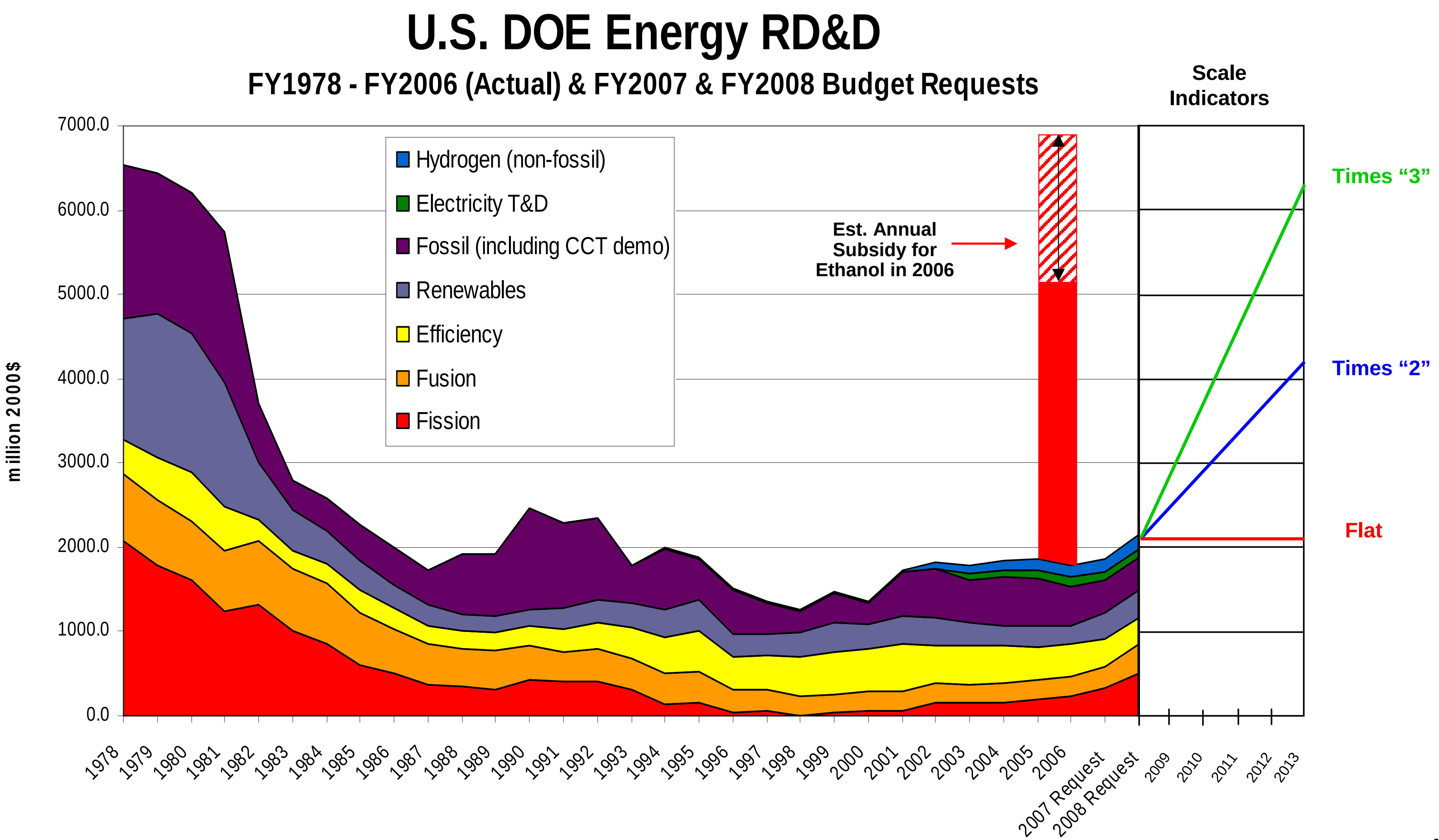
Cost – 100-Year Reductions

Comparative Analysis of Estimated Cumulative Costs Over the 21st Century of GHG Mitigation, With and Without Advanced Technology, Across a Range of Hypothesized GHG Emissions Constraints.



March 25, 2008

Historical Perspective on DOE Spending



Grand Challenge #2 --

Illuminate the Trade-Offs Among Response Strategies

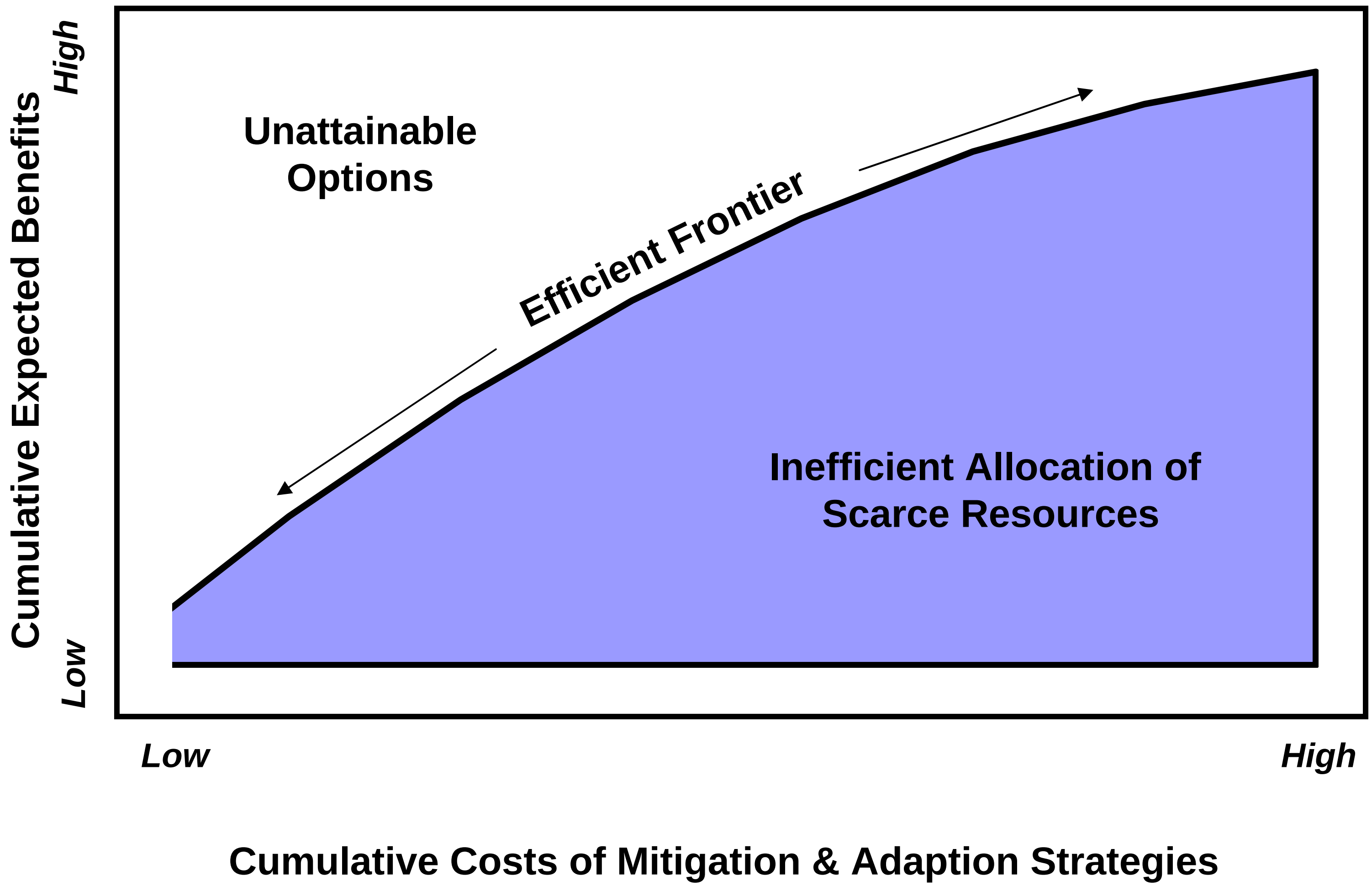
Response Strategies -- Cost-Benefit Trade-Offs

Cost of Mitigation & Adaptation

Cost of Impacts & Vulnerabilities *

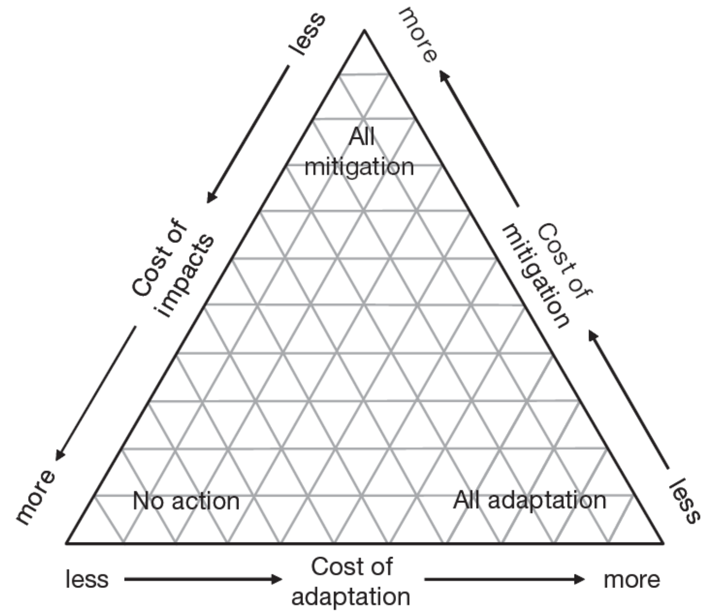
*** Benefits of Damage Avoidance and/or Risk Reduction**

Framework for Assessing Marginal Benefits of Damage Avoidance or Risk Reduction



Response Strategies

- Mitigation[1]
- Adaptation[2]
- Impacts -- Some Suffer; Some Benefit
- Trade-Offs Among These Options are Poorly Informed by Science, Economics or Analysis
- Grand Challenge: Illuminating the Efficacies and Trade-Offs Among Mitigation, Adaptation and Impacts
- Need Work on Framework for Assessing Marginal Benefits of Damage Avoidance[3]



A schematic overview of inter-relationships between adaptation, mitigation and impacts, based on Holdridge's life-zone classification scheme (Holdridge, 1947, 1967; M.L. Parry, personal communication)

[1] Mitigation: An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2001a)

[2] Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001a

[3] See Chapter 18, Working Group II, IPCC Fourth Assessment Report

Grand Challenge #3 --

Inform Decision-Making at Appropriate Levels of Governance

Governance Levels

Response Strategy	Participation	Effects*	Costs
Mitigation	Global	Global	Local
Adaptation	Local	Local	Local
No Action	Local	Local	Local

Global: International agreements and ensuing National public policy, possibly complemented by unilateral and/or voluntary actions at regional, State or local levels

Local: Private actions of affected entities Including individual households, farmers and private firms, and public arrangements of local, state, and regionally impacted communities possibly complemented by National policies.

* Benefits of Avoided Damage of Reduced Risks & Other Effects

Risk Management *

- **Historical Approach:**
  - **Past as a Guide for the Future**
- **Approach Needed to Address Climate Change Impacts**
  - **Future will no Longer Resemble the Past**
  - **New Strategies for Developing Resilience to Climate Variability and Extreme Weather Events Needed**
  - **Well-Considered Assumptions About Regional Conditions Should be Incorporated into Regional Planning**
  - **Studying Different Regions with Different Conditions will Provide Insights and Methods for Assessing Other Regions**
- **Need to Inform Local Decision-Making**
- **Need for Capacity to Provide Technical Assistance to States, and Local, Regional, and Intergovernmental Organizations**

*** "Regional Impacts of Climate Change," Pew Center on Climate Change, December 2007**

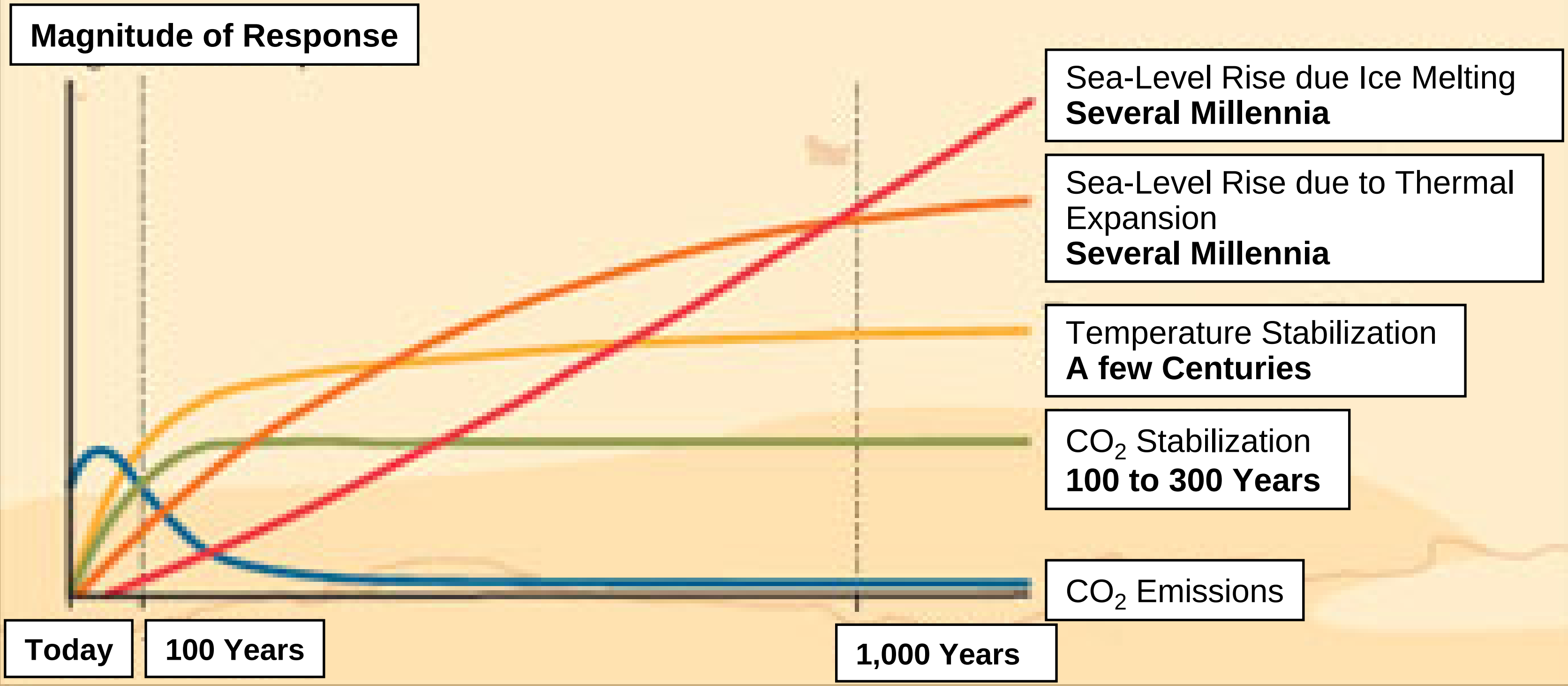
Grand Challenge #4 --

Identify Key Interactions Between Natural and Human Systems

Time to Equilibrium

Time to Equilibrium

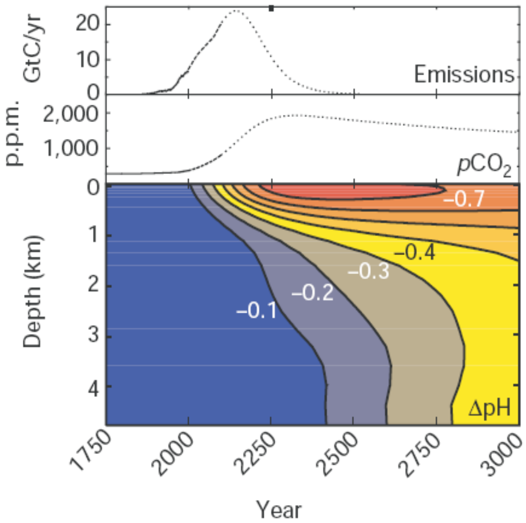
Climate-change experts predict that even when GHG emissions are curtailed, their effects on the environment will continue to be felt for hundreds, if not thousands, of years.



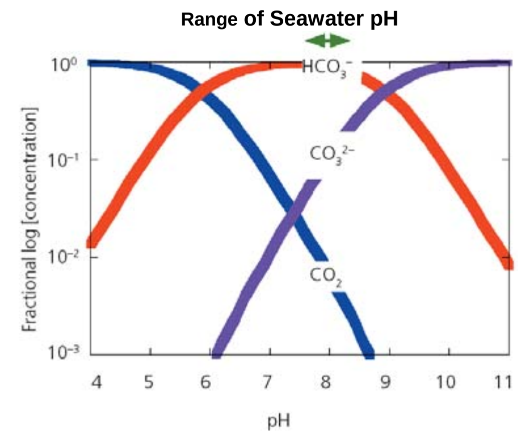
Jones-Thompson, Maryanne, "Engineering Climate", *Technology Review*, MIT, March 2005

Ecosystem Interface -- Ocean Acidification as one Example

- **Authoritative Works Indicate:**
  - **Oceans are Absorbing CO_2 Produced From Human Activities and Causing Chemical Changes Which Make Them More Acidic**
  - **Reduction in Ocean pH will Negatively Impact Marine Organisms and Ecosystems and Associated Food Chains That Depend Upon Them**
  - **Chemical Effects of CO_2 on The Marine Environment may be as Great a Cause for Concern as Radiative Effects of CO_2 on Earth's Climate and Surface Environment**
  - **At This Time Reducing the Scale of Future Changes to the Chemistry and Acidity of the Oceans is Only Possible by Preventing the Accumulation of CO_2 In Atmosphere.**
  - **Ocean Acidification is a Compelling Reason, in Addition to Climate Change, for Reducing Global CO_2 Emissions.**
- **What Other "Compelling" Reasons are Most Important for Consideration ?**



"Anthropogenic carbon and ocean pH"
Caldeira and Wickett, LLNL, "Nature," 2003



"Ocean acidification due to increasing atmospheric carbon dioxide," The Royal Society, London, UK, 2005

Grand Challenge #5 --

Organize Integrated Systems Architecture for Measurement & Verification

Enhancing Capabilities to Measure and Monitor Greenhouse Gases

- **Measurement and Monitoring (M&M) Systems Will Be Needed to:**
  - Assess Efficacy and Sustainability of Important Strategies
  - Guide Future Research and Enhancements
  - Lend Confidence to Implementing Agreements and Commitments
- **Such Systems Can Provide:**
  - Accurate Characterizations Of GHG Emissions From Both Existing and Advanced Technologies
  - Enable Increased Understanding Of Performance
  - Guide Further Research
  - Reduce Costs and
  - Improve Effectiveness
- **Research and Development of These Systems Is Required To:**
  - Increase Capabilities
  - Make Best Use of Data
  - Provide Integrated Insights
  - Facilitate Progress on Decision-Making Tools
  - Accelerate Adoption of Mitigation and Adaption Strategies

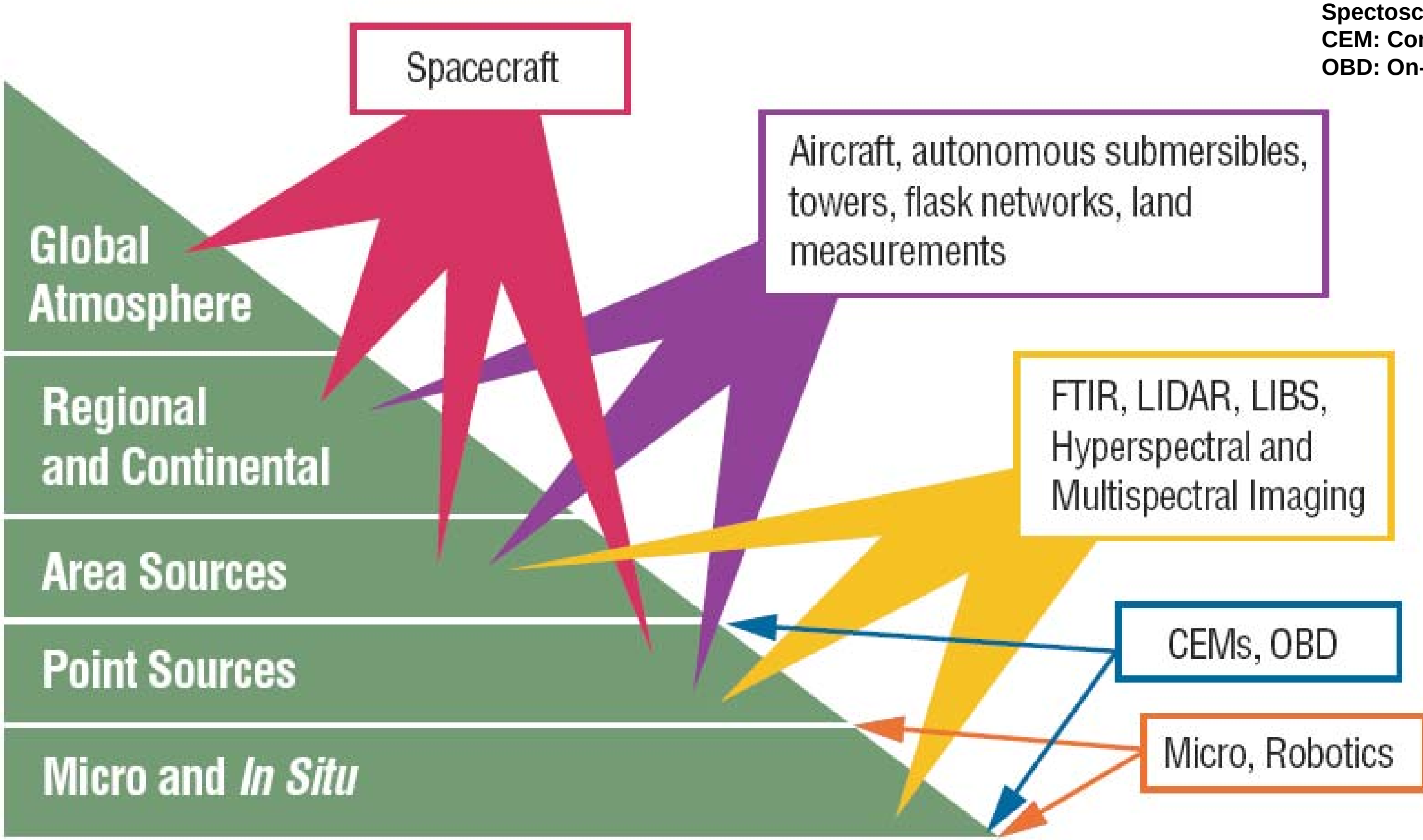
Technologies for Goal #5: Improve Capabilities to Measure and Monitor GHG Emissions

	NEAR-TERM	MID-TERM	LONG-TERM
Energy Production & Efficiency Technologies	• M&M Specifications and Performance Standards • Low-Cost Sensors and Communications • Samplings, Inventories, & Estimates	• Sensor Networks • Remote Sensing Prototype • Direct Measurement to Replace Proxies and Estimates	• Fully Operational Sensor and Satellite Networks that Feed the Integrated Architecture
Carbon Capture, Storage, & Sequestration	• M&M Specifications and Performance Standards • Low-Cost Sensors and Communications • Samplings, Inventories, & Estimates • Ability to Assess the Integrity of Geologic Reservoirs • Improved Leak Detection from Capture and Pipelines	• Sensor Networks • Remote Sensing Prototype	• Fully Operational Sensor and Satellite Networks that Feed the Integrated Architecture
Other GHGs	• M&M Specifications and Performance Standards • Low-Cost Sensors and Communications • Samplings, Inventories, & Estimates	• Sensor Networks • Remote Sensing Prototype • M&M Techniques for Agricultural Sources	• Fully Operational Sensor and Satellite Networks that Feed the Integrated Architecture
Integrated M&M Systems Architecture	• Identification of Metrics, Criteria, Sources, and Requirements for Measurements • Comprehensive Vision of Integrated Systems Architecture and Technology Needs	• Model and Data Specification • Large Scale, Secure Data Storage System • Data Visualization Tools • M&M Processes Incorporated into Design of Climate Change Technologies	• Fully Operational Integrated MM Systems Architecture (Sensors, Indicators, Data Visualization and Storage, Models)

Measurement and Monitoring

Hierarchical Inter-Temperal Layers of Spatial Observation Technologies and Capabilities Unified by GIS Interface

FTIR: Fourier Infared Spectrometer
LIDAR: Light Detection And Ranging
LIBS: Laser Induced Breakdown Spectoscopy
CEM: Continuous Emission Monitors
OBD: On-Board Diagnostics Vehicles



Near-Term Opportunities

1. Incorporating Transportation M&M Sensors into the Onboard Diagnostic and Control Systems of Production Vehicles;
2. Preparing Geologic Sequestration M&M Technologies for Deployment with Planned Demonstration Projects;
3. Exploiting Observations and Measurements from Current and Planned Earth Observing Systems to Measure Atmospheric Concentrations and Profiles of GHGs from Planned Satellites;
4. Undertaking Designs and Deploying the Foundation Components for a National, Multi-Tiered Monitoring System with Optimized Measuring, Monitoring, and Verification Systems;
5. Deploying Sounding Instruments, Biological and Chemical Markers (Either Isotopic or Fluorescence), and Ocean Sensors on a Global Basis to Monitor Changes in Ocean Chemistry;
6. Maintaining In-Situ Observing Systems to Characterize Local-Scale Dynamics of the Carbon Cycle Under Changing Climatic Conditions; and
7. Maintaining In-Situ Observing Systems to Monitor the Effectiveness and Stability of CO_2 Sequestration Activities.

Long-Term Goals

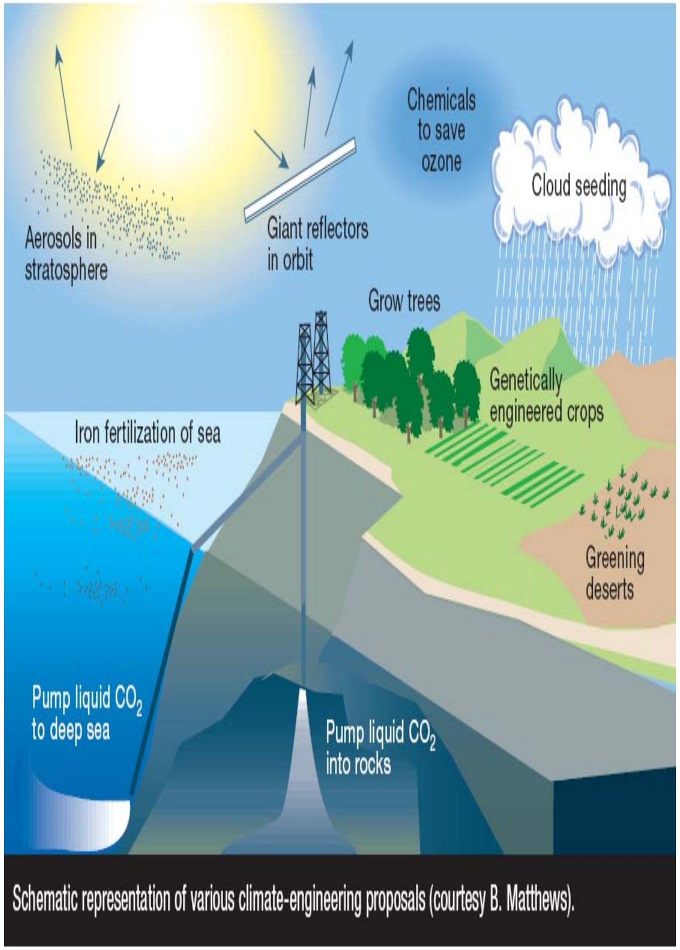
1. Enhance Ability to Model Emissions Based on a Dynamic Combination of Human Activity Patterns, Source Procedures, Energy Sources, and Chemical Processing;
2. Develop Process-Based Models that Reproduce the Atmospheric Physical and Chemical Processes (Including Transport and Transformation Pathways) that Lead to The Observed Vertical Profiles of GHG Concentrations due to Surface Emissions;
3. Determine to what Degree Natural Exchanges with the Surface Affect the net National Emissions of GHGs;
4. Develop a Combination of Space-Borne, Airborne, and Surface-Based Scanning and Remote-Sensing Technologies to Produce 3D, Real-Time Mapping of Atmospheric GHG Concentrations;
5. Develop Specific Technologies for Sensing of Global Methane “Surface” Emissions with Resolution of 10 Km;
6. Develop Remote-Sensing Methods to Determine Spatially Resolved Vertical GHG Profiles, Rather than Column-Averaged Profiles; and
7. Develop Space-Borne and Airborne Monitoring for Soil Moisture at Resolutions Suitable for M&M Activities.

Grand Challenge #6 --

Explore the Means and Consequences of "Back-Stop" Options

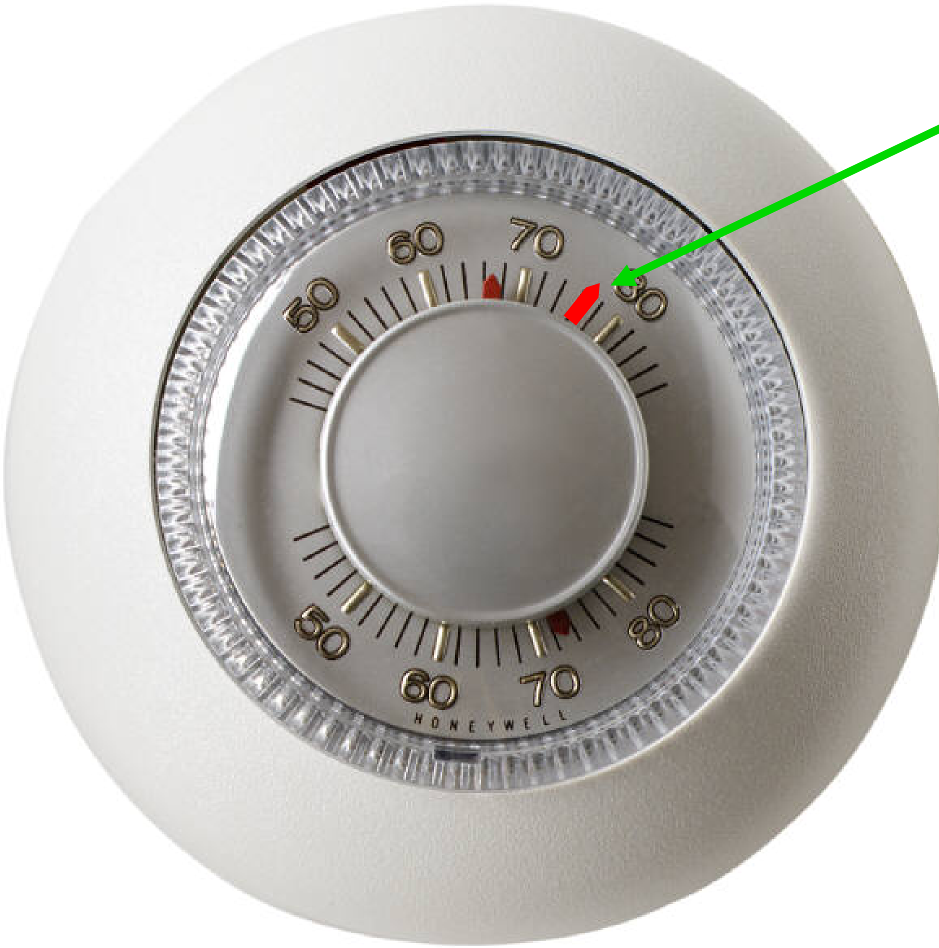
Back-Stop Options -- One Example: Geo-Engineering

- **Geo-Engineering**
  - **Technical Options**
    - » **Space-Based Reflectors**
      - **Lagrange Points Reflectors**
      - **Orbiting Small Reflectors**
    - » **Aerosols in Stratosphere**
      - **Northern Latitude Dispersion**
  - **Potential Benefits:**
    - » **Slow or Reverse Run-Away Temperature Increase**
    - » **2 or 3 Orders of Magnitude Cheaper ($1-3 B/year)**
  - **Risks:**
    - » **Unknown Consequences of Potentially Global Scale**
    - » **Potentially Un-manageable Socio-Political Reverberations**
- **Other Back-Stop Options (See Figure)**
- **Grand-Challenge: Explore the Means and Consequences of Back-Stop Options**



D. Keith, Insight Feature: Geo-engineering, Nature 409, 420 (18 January 2001)

Geo-Engineering Thermostat



What Temperature To Dial-in?

Summary

Mapping CCTP GC's Onto Workshop Breakouts

	CCTP Grand Challenge	Variability & Forcing	Projections	Ecosystems	Observations to Improve Models
1	Informing the Pace of Tech. Development & Deployment		X		X
2	Illuminate Trade-Offs Among Response Strategies	X	X	X	X
3	Inform Decision-Making at Appropriate Levels of Governance		X		X
4	Identify Key Interactions Between Natural and Human Systems		X	X	X
5	Organize Integrated Systems Architecture for Measurement & Verification	X	X	X	X
6	Explore "Back-Stop" Options	X	X	X	