Perspectives from the United States

Using Long-Term Scenarios to Inform R&D Priority Setting

Dr. Robert C. Marlay
Director, Science and Technology Policy
Deputy Director, U.S. Climate Change Technology Program
U.S. Department of Energy
robert.marlay@hq.doe.gov

IEA Energy R&D Experts Group
February 15-16, 2007
Paris, France

R&D Planning and Prioritization System

Steps:

- National Energy and Long-Term Policy Goals *
- Visioning the Roles for Advanced Technology *
- Scenarios Analyses *
- Portfolio Analyses *
- Prioritization and Budgeting *
- High-Level Oversight and Appropriations
- R&D Program Evaluation and Feedback
- Supporting Policies for Int’l Cooperation & Deployment

*** Focus of This Presentation. Other Parts are Necessary for a Complete Process.**

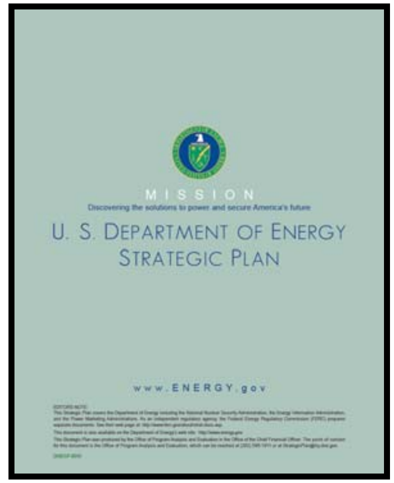
Step 1 --

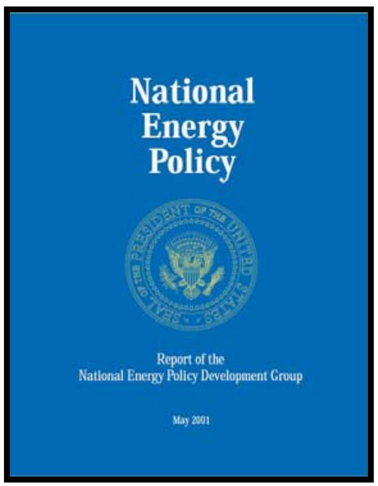
National Energy and Long-Term Policy Goals

National Energy Strategy, Long-Term Policy Goals

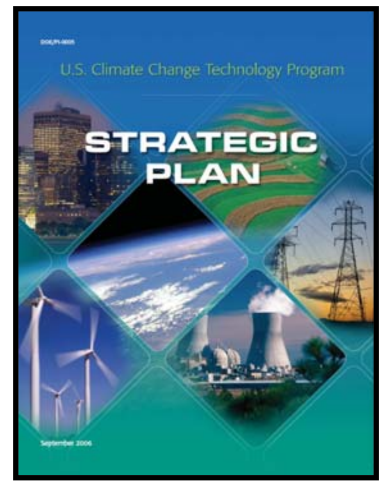
Energy Policy Act of 2005

Enacted: August 8, 2005





- **Economic Prosperity**
- **Energy Security**
- **Environmental Protection**



Visioning the Roles for Advanced Technology

Policy Goals	Technology Goals
• Economic Prosperity	• Reliable, Affordable, Energy Supply • Efficient Energy Use • Efficient & Transparent Markets
• Energy Security	• Alternatives to Oil • Diversify from Insecure Sources • Expand Practical Options • Promote Clean Energy Use
• Environmental Protection	• Minimize Air & Water Pollution • Minimize Impacts Land & Ecosystems • Slow Growth of GHG Emissions • Stabilize GHG Concentrations

Step 2 --

Visioning the Roles for Advanced Technology

Our Analyses Begins with "Innovation Strands" Augmented by Cross-Cutting "System" Assessments

Supply
- Advanced Nuclear
- Zero Emission Fossil Electric Generation
- Renewable Energy
- Fusion Energy
- Alternative Liquid Fuels
- Bioenergy/Chemicals

Distribution
- Electric Grid of the Future
- Hydrogen & Gas Infrastructure
- Fuel Grid of the Future

Use
- Industrial Technologies
- Advanced Building Systems
- Vehicle Technologies

Future Electricity Systems Assessment

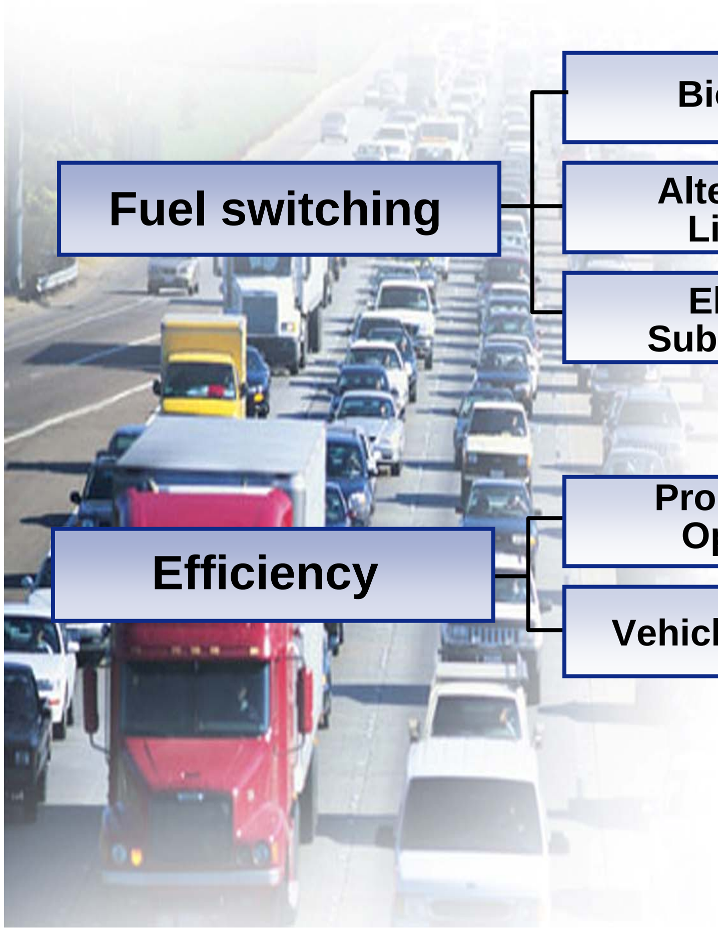
Future Liquid Fuels Systems Assessment

Future Hydrogen & Gaseous Fuels Systems Assessment

Cross-cutting / Enabling Science and Technology Opportunities & Challenges

Energy Security – Focus on Transportation Fuels

Transportation



Fuel switching

- **Biofuels**
  - Ethanol from sugar
  - Cellulosic ethanol
  - Bio-diesel
- **Alternative Liquids**
  - Oil Shales
  - Coal Liquifaction
  - Enhanced oil recovery
  - Heavy crude processing
- **Electric Substitution**
  - Hybridization
  - Electrical energy storage
  - Auxiliary power options

Efficiency

- **Propulsion Options**
  - High Efficiency Diesels
  - Hybridization
  - Plug-in hybrids
- **Vehicle Systems**
  - Lightweight structures / materials
  - Electrification of auxiliaries
  - Efficient conversion systems

Energy Security – Focus on Transportation Fuels

- **Near-Term: Efficiency options build on improved ICE technologies and hybrid drives**
  - **Light duty HE Diesels with NOx control**
  - **Flex-fuel engine management**
  - **Mild hybrid designs utilizing conventional batteries**
- **Near- to Mid-Term: Fuel switching provides a bridging option to offset oil demand**
  - **Current ethanol options can support expanded distribution systems**
  - **Coal to liquids is a viable option for benchmark crude prices over $35-40 / bbl**
- **Longer-Term: Technology options provide a more stable and sustainable energy base for transportation systems**
  - **Cellulosic conversion essential to sustained bio-fuels market penetration**
  - **High density electric storage options are essential to broadening hybrid market penetration (2x improvement)**
  - **Viable CO_2 disposal options essential to mitigating environmental impacts of coal-to liquids and unconventional hydrocarbon production**
  - **Hydrogen requires major technology and infrastructure breakthroughs**

Key Technologies

Near Term Options < 2010

- Conventional, diesel and hybrid propulsion
- Coal to liquids (w/o sequestration)
- Corn starch / sugars to ethanol
- Efficient flexible fuel vehicles

Through 2015

- Coal to liquids (w/ CCS)
- 1st- generation conversion of cellulosic feedstock to biofuels
- Plug-in hybrids

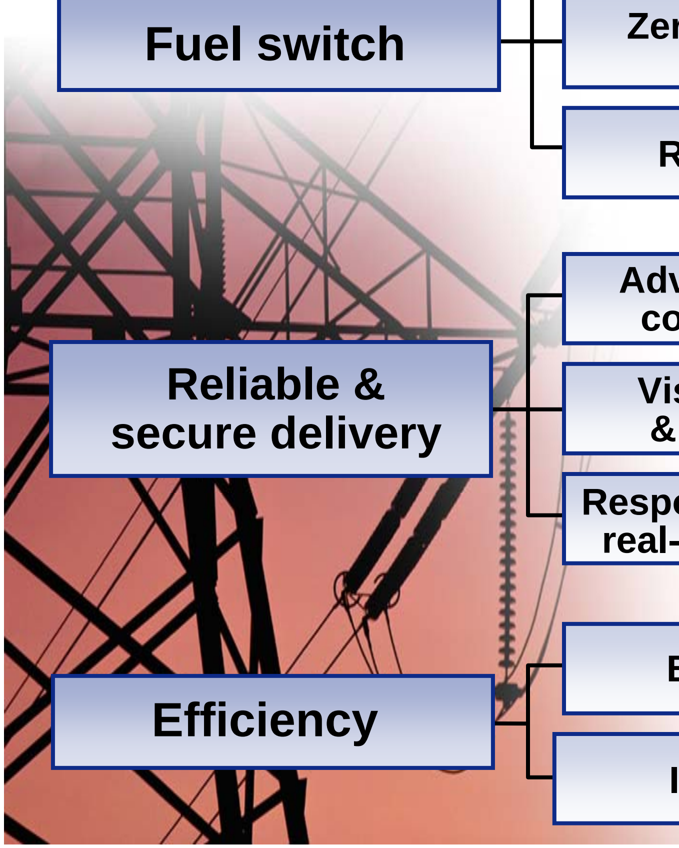
Through 2025 and beyond

- Hydrogen vehicles
- In-situ oil shale production at scale
- Bioengineered energy crops

Supporting S&T

Technology maturation and deployment	Targeted Research And Development	Discovery Research
• High efficiency diesel with effective environmental controls • Improved gas – electric hybrid options • Flexible fuel vehicles • Lower cost corn starch to ethanol conversion • Coal to liquids (without carbon capture and storage)	• Light weight materials for vehicles • High density, on-board electric storage • Fuel cell technology • Power electronics • Combustion modeling and process optimization • Cellulosic biofuels • In-situ oil shale processing • Carbon capture and storage for coal to liquids	• Compact, high capacity, electric energy storage • High density hydrogen storage • Catalysis & control of chemical transformation • Membrane separations • Bioengineering for increased yield and ease of conversion of bio feedstocks • Permeability science & engineering for EOR • Nanoscale materials science

All Three Policy Goals (E, E &E) Served by a Modernized Electricity System



Electricity System

Fuel switch

- **Nuclear**
  - ALWR • Closed fuel cycle • International reactor
  - High temperature reactor • LWR
- **Zero emission fossil**
  - Future Gen • Sequestration
  - Advanced gasification • Zero-emission combustion
- **Renewable**
  - Wind – low speed & off-shore • Photovoltaic
  - Concentrating solar • Storage • Bio power

Reliable & secure delivery

- **Advanced T&D components**
  - Energy storage • High temperature superconductivity
  - Power electronics • Fault current limiters
- **Visualization & modeling**
  - Grid monitoring • Computational modeling
  - Real time visualization
- **Responsive loads & real-time controls**
  - DG interconnection • MicroGrids
  - Sensors & real-time controls

Efficiency

- **Buildings**
  - Zero-energy buildings • Solid-state lighting
  - Efficient integrated system
- **Industrial**
  - Recycle & gasification by-product
  - Efficient processing • Novel manufacturing systems
  - Efficient conversion systems

Several Key Technologies Offer the Foundation for Technology Options to Reduce CO_2 Emissions

Near Term Options < 2010

- Advanced Light Water Reactors "First Movers"
- EOR sequestration demo (Weyburn)
- Advanced gasification (w/o CCS)
- Photovoltaics
- Solar water heating
- On-shore wind (class 5+)
- Corn starch to ethanol
- Bio-diesel (<20% blend)
- Integrated building systems
- Efficient Industrial systems

Through 2015

- Advanced Light Water Reactors fleet
- Demonstration of fast reactors
- FutureGen demo in 2012
- SECA/hybrid fuel cell demo
- Low velocity and off-shore wind
- Next generation PV systems
- Concentrating solar power
- Biorefinery plants in operation
- First generation biofuels from lignocellulosic feedstock

Through 2025 and beyond

- First high-temperature reactor for H2 production
- Small modular reactor operational
- Integrated demo of thermal and fast reactors in closed fuel cycle
- Oxycombustion technology
- High power density electric energy storage
- Third generation high performance PV
- "Zero energy" buildings
- Advanced lignocellulosic conversion technologies
- High yield energy crops
- Solid state lighting

CO_2 Reduction Requires an S&T Portfolio Spanning Discovery to Commercial Innovation

Technology Maturation and Deployment

- Terrestrial sequestration options evaluated
- Large scale demonstrations of geologic sequestration
- Exploration and mapping of potential geologic sequestration sites
- Demonstration of sequestration in a range of geologic formations
- Near-term improvements for hydrogen production, delivery, storage and fuel cells
- Single crystal silicon solar cells
- Technology for cellulose-lignin separation
- Smart power electronics for switchable grid connections to enable utility scale renewables

Targeted Research And Development

- 3D seismic mapping and modeling of fluid flow in permeable geologic formations
- High temperature separation of CO, H2 and CO2
- Nanostructured catalyst-membrane composites for high temperature CO, H2, and CO2 separation
- New methods and tools for synthesizing new catalysts
- Efficient processes for production, energy storage and energy conversion
- Photocatalysis
- Interfacial processes
- Thin film organics for PV
- Efficient methods for enzymatic and thermochemical conversion of cellulose to sugars
- Efficient conversion of sugars other than glucose to ethanol
- Charge transport and separation in organic solar cells
- Tuning to the solar spectrum with dye sensitized solar cells

Discovery Research

- Theoretical models for hydrodynamics in permeable media
- Catalysts for mineralization of CO2 to stable carbonates
- Computational models oxy-combustion in turbines
- Photocatalytic processes for water splitting and hydrogen production
- Designer nano-structured catalysts
- Hydrogen storage materials and processes
- Quantum dot photoexcitation
- Theory and modeling of charge excitation and transport in quantum dot arrays
- Bioengineered crops
- Genetically modified photosynthesis
- Understand mechanism of biological cellulose and lignin degradation
- Bioengineer nitrogen fixation
- Bioengineer organisms and synthetic catalysts for cellulose to fuel

Comparative Analysis of Technology Strategies for "Energy" and "Climate Change"

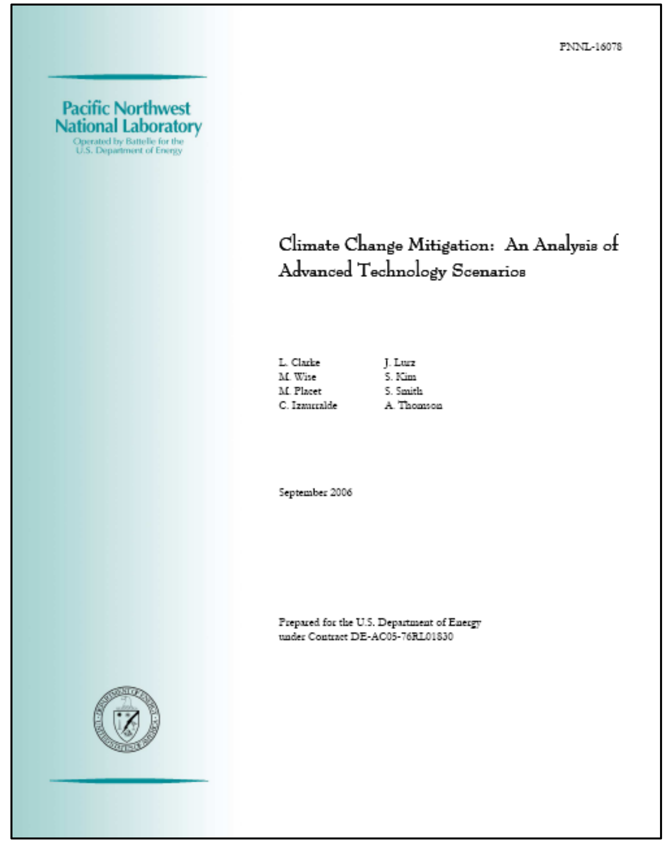
- **Both Technology Strategies are Largely Aligned**
- **Climate Change is Technically More Challenging**
- **If Climate Change Strategy is Pursued Successfully, Energy Security Goals Will Also Be Achieved**
- **Selected Exceptions May Be Dealt with Separately**
  - **Coal to Liquids**
  - **Oil Shale**
  - **Methane Hydrates (in Ocean Continental Shelf)**

Step 3 --

Scenario Analysis

Planning & Analysis Under Conditions of Uncertainty

- **Global Perspective**
- **100-Year Planning Horizon**
- **Uncertainty Across GHG Stabilization Goals**
- **Technology Scenarios**
- **Technology Competitions**
- **Economic Benefits**



PNNL-16078

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Climate Change Mitigation: An Analysis of Advanced Technology Scenarios

L. Clarke, J. Lurz, M. Wise, S. Kim, M. Placet, S. Smith, C. Izaurralde, A. Thomson

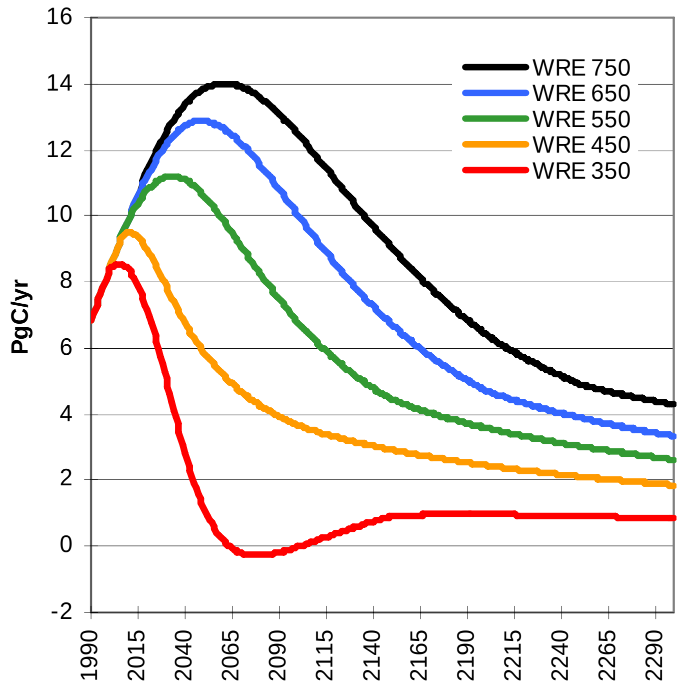
September 2006

Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

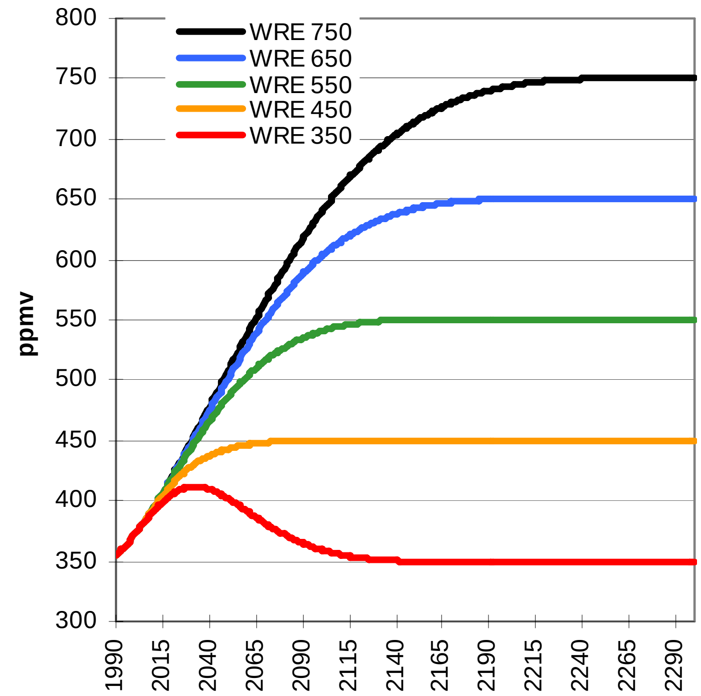
http://www.globalchange.umd.edu/

Planning Under Uncertainty – Alt. Paths to the UNFCCC Goal …

Emission Trajectories



Concentration Trajectories

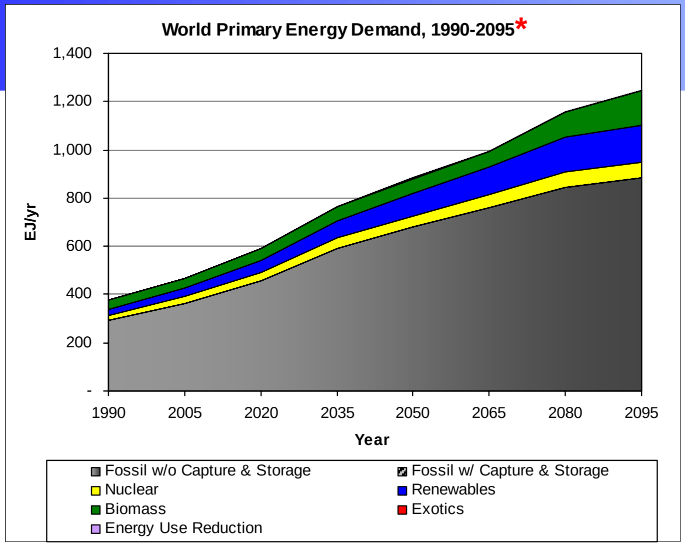


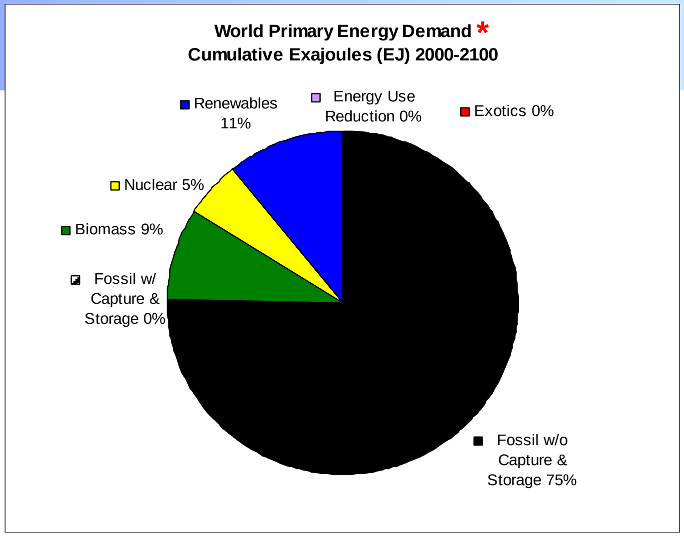
T.M.L. Wigley, R. Richels, & J.A. Edmonds (WRE), Nature, January 18, 1996, “Economic and Environmental Stabilization of Atmospheric Concentrations”

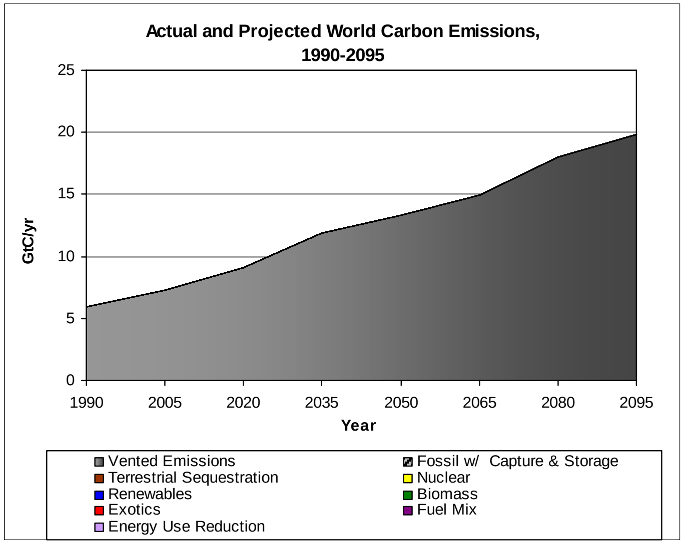
Reference Case

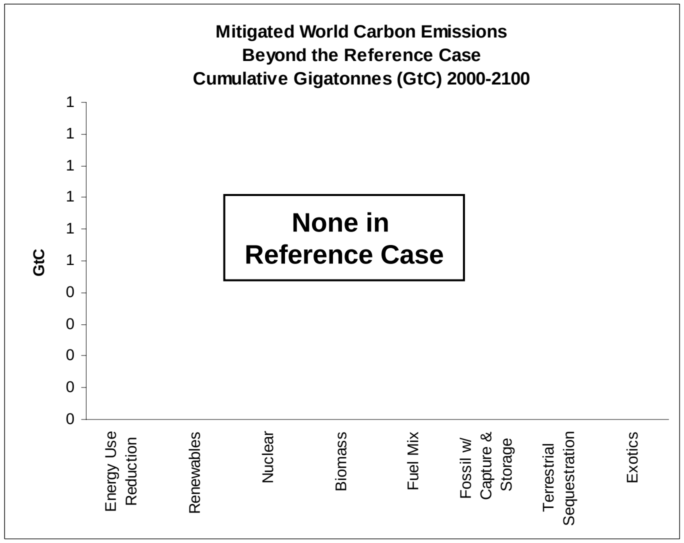
11 February 2007

(Including "Reference Case" Assumptions About Advancing Technology)







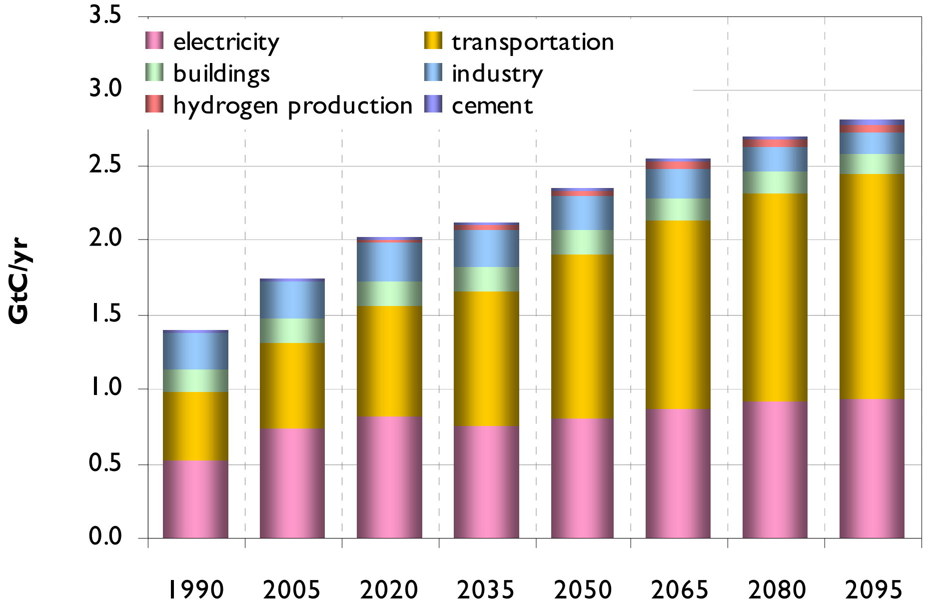


*** Reference Case includes energy efficiency improvements (i.e., improvements in energy use per unit of economic output) at a an rate of change that is consistent with long-term historical rates.**

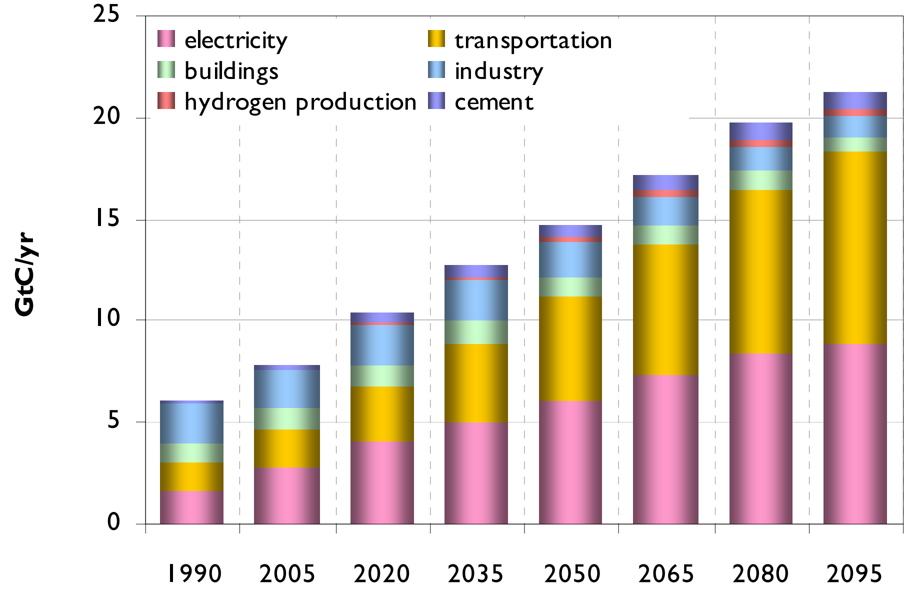
19

Reference Case CO_2 Emissions, by sector

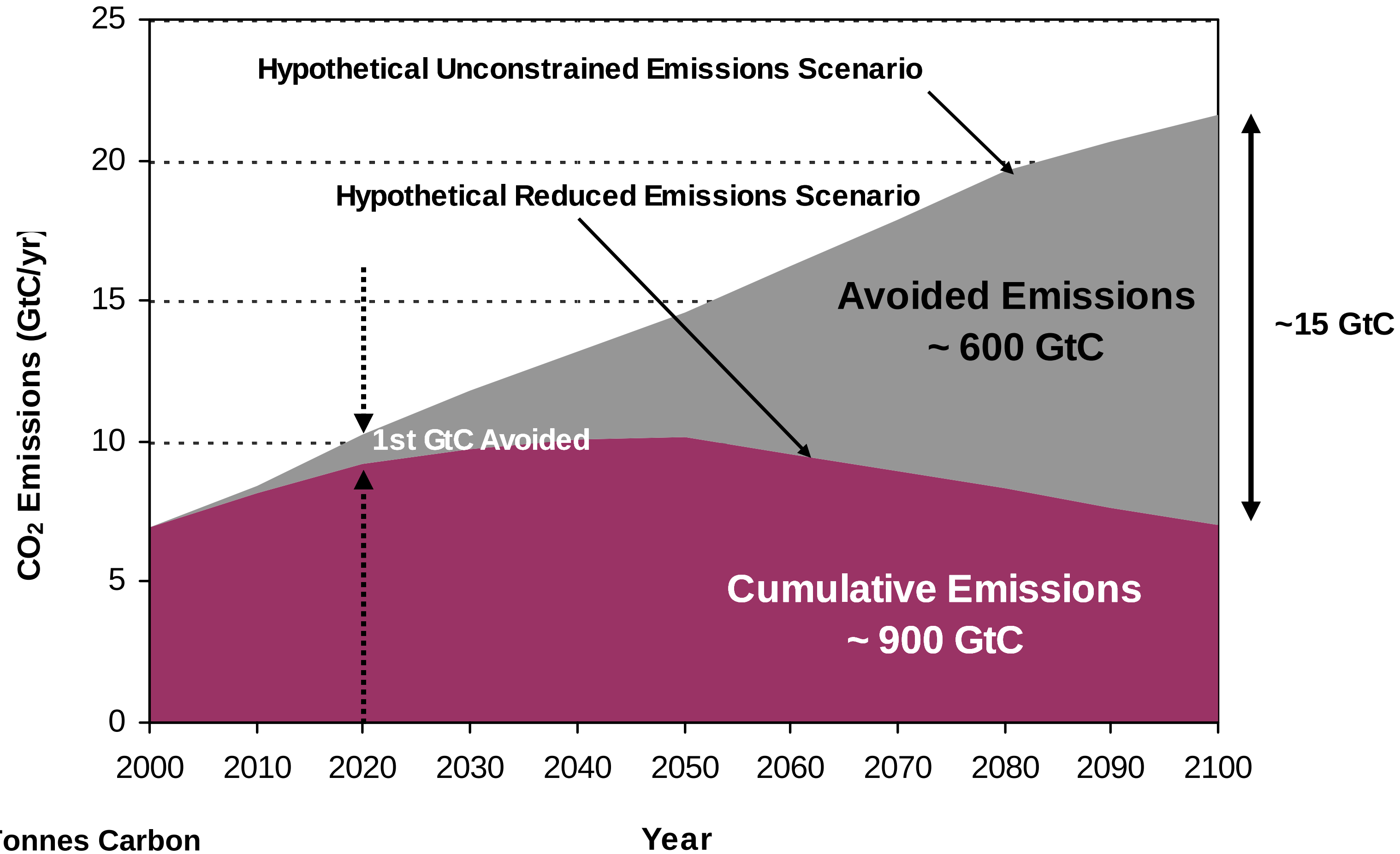
United States



The World



Mid-Range Example of A Reduced GHG Emissions Future



GtC = Giga-Tonnes Carbon

How Big is One Gigaton Per Year Of GHG Reduction?

Actions that provide 1 gigaton per year of carbon-equivalent mitigation for the duration of their existence:

- **Coal-Fired Power Plants**. Build 1,000 "zero-emission" 500-MW coal-fired power plants to supplant coal-fired power plants without CO_2 capture and storage. (Current global installed generating capacity is about 2 million MW.)
- **Geologic Storage**. Install 3,700 carbon storage sites like Norway's Sliepner project (0.27 MtC/year).
- **Nuclear**. Build 500 new nuclear power plants, each 1 GW in size, to supplant an equal capacity of coal-fired power plants without CO_2 capture and storage. This would more than double the current number of nuclear plants worldwide.
- **Electricity from Landfill Gas Projects**. Install 7,874 "typical" landfill gas electricity projects (typical size being 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 20 mpg
- **Wind Energy**. Install 650,000 wind turbines (1.5 MW each, operating at 0.45 capacity factor) to supplant 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 (assuming 10% cell DC efficiency, 1700 kWhr/m2 solar radiance, and 90% DC-AC conversion efficiency).
- **Biomass Fuels from Plantations**. Convert a barren area about 15 times the size of Iowa's farmland (about 33 million acres) to biomass crop production.
- **CO_2 Storage in New Forest**. Convert a barren area about 40 times the size of Iowa's farmland to new forest.

Note: SRES (IPCC 2000) scenarios assume that all of these technologies will be used extensively prior to 2100.

Technology Scenarios Explore the Future

Technology Scenario #1: “Closing the Loop on Carbon”

Advanced Coal, Gasification, Carbon Capture, Sequestration, and Hydrogen Technologies Augment the Standard Suite of Technologies

Technology Scenario #2: “A New Energy Backbone”

Technological Advances in Renewable Energy and Nuclear Power Give Rise New Competitive Realities, Reducing Dominant Role of Fossil Fuels

Technology Scenario #3: “Beyond the Standard Suite”

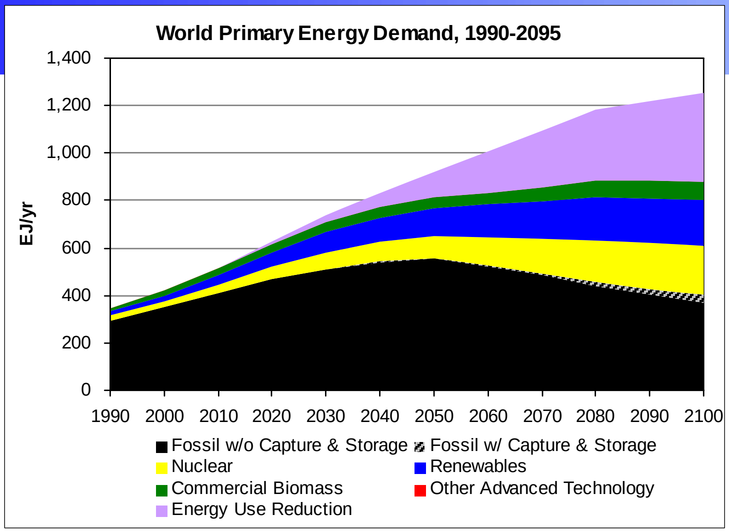
Novel and Advanced Technologies (e.g., Fusion, Large Scale Solar, and Bio-X) Emerge to Play Major Roles, Complementing the Standard Suite.

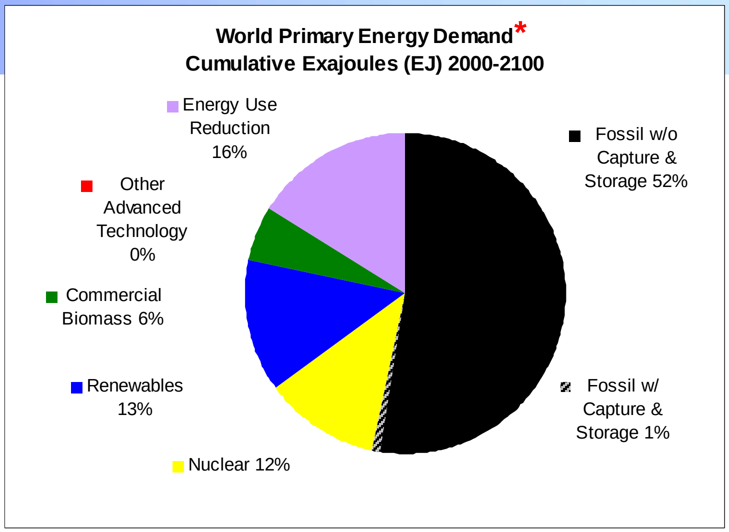
Common Characteristics Across Scenarios:

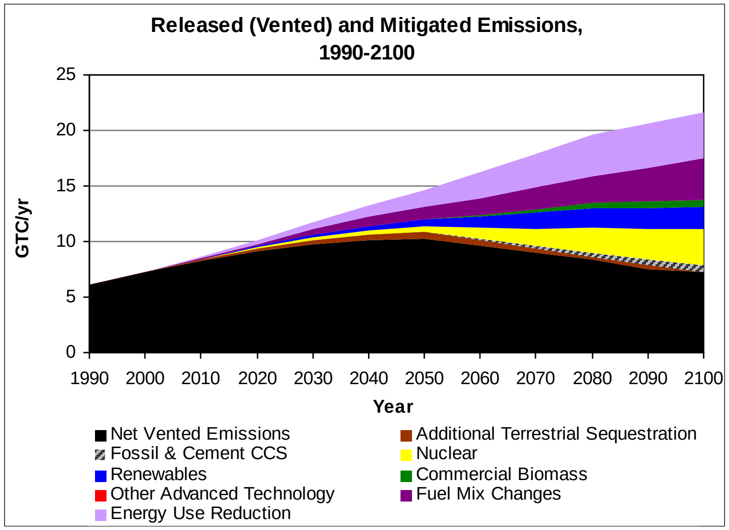
- ✓ *Hydrogen and Liquid Biofuels Become Significant Energy Carriers*
- ✓ *The Full Potential of Conventional Oil & Gas is Realized*
- ✓ *Dramatic Gains in Energy Efficiency Occur*
- ✓ *Successful Management of other GHGs*
- ✓ *Early Market Penetration of Low-Cost Terrestrial Sequestration*

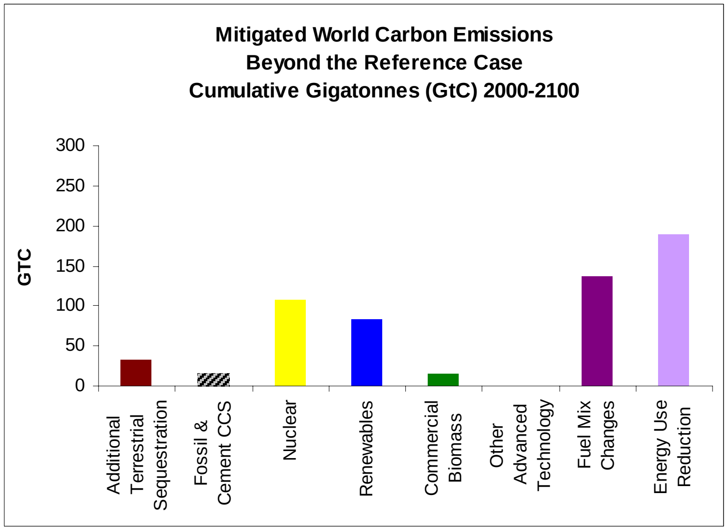
New Energy Backbone for High Emissions Constraint

(At approximately the 550 ppm level of stabilized concentrations)



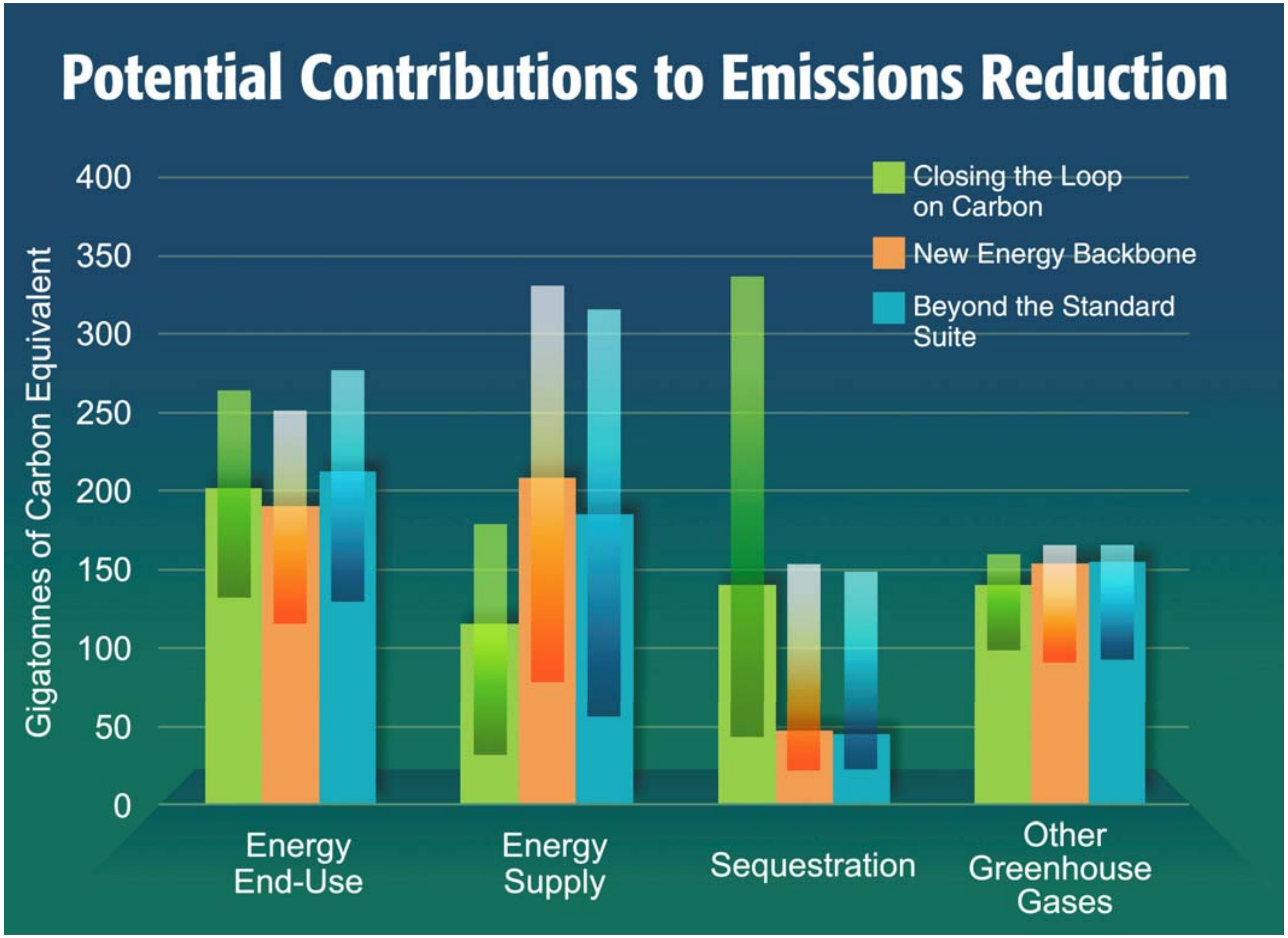






*** Reference Case includes efficiency improvements (i.e., improvements in energy use per unit of economic output) at an annual rate of change that is consistent with long-term historical rates. Shaded areas for "Energy Use Reduction" indicate accelerated improvements, demand reductions, and other economic substitutions.**

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

Quantities – Potential 100-Year Reductions

CCTP Strategic Goal	Very High Constraint	High Constraint	Medium Constraint	Low Constraint
Goal #1: Reduce Emissions from Energy End Use and Infrastructure	250 - 270	190 - 210	150 - 170	110 - 140
Goal #2: Reduce Emissions from Energy Supply	180 - 330	110 - 210	80 - 140	30 - 80
Goal #3: Capture and Sequester Carbon Dioxide	150 - 330	50 - 140	30 - 70	20 - 40
Goal #4: Reduce Emissions of Non-CO_2 GHGs	160 - 170	140 - 150	120 - 130	90 - 100

Estimated cumulative GHG emissions mitigation (GtC) from accelerated adoption of advanced technologies over the 21st century, 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.

Timing

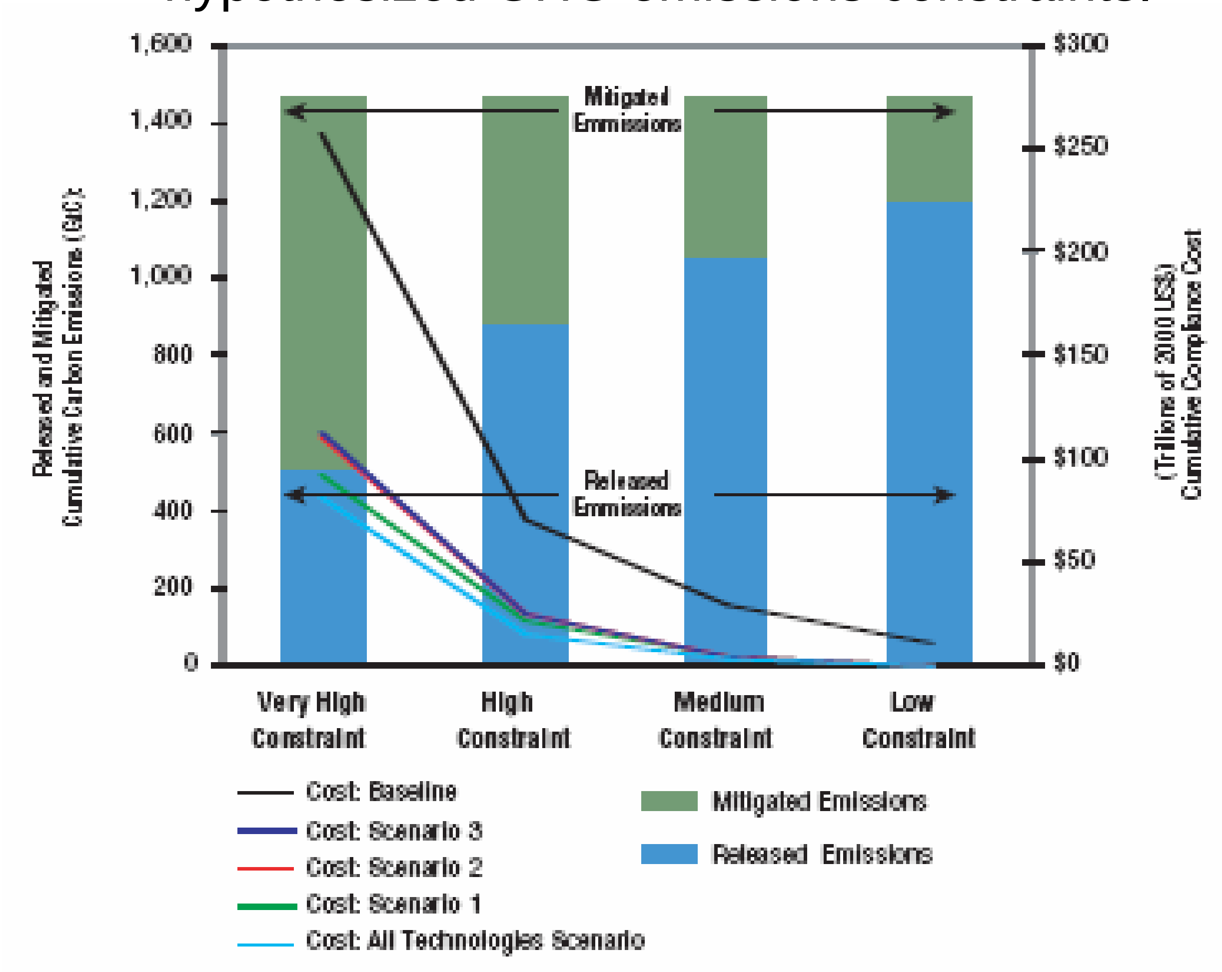
CCTP Strategic Goal	Very High Constraint	High Constraint	Medium Constraint	Low Constraint
Goal #1: **Reduce Emissions from Energy End Use and Infrastructure**	2010 - 2020	2030 - 2040	2030 - 2050	2040 - 2060
Goal #2: **Reduce Emissions from Energy Supply**	2020 - 2040	2040 - 2060	2050 - 2070	2060 – 2100
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.

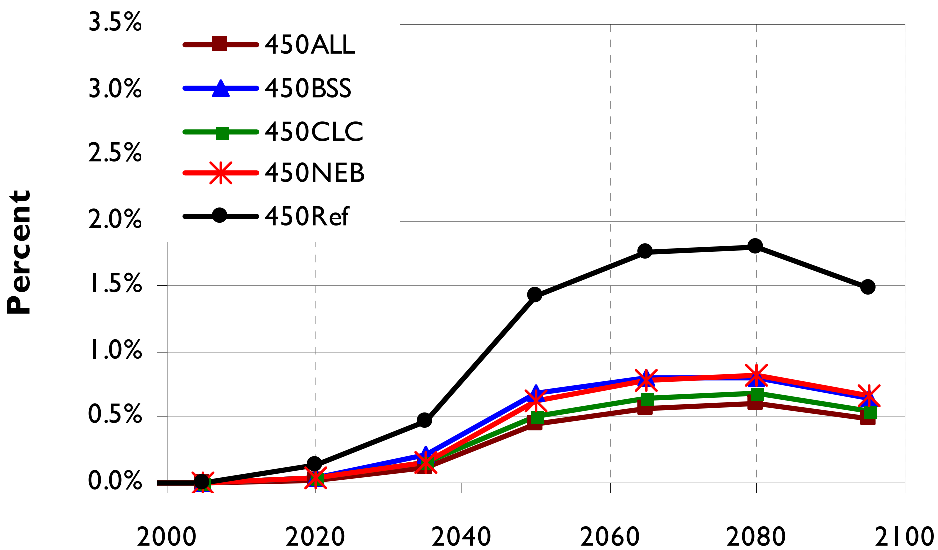
Potential Cost Reductions to 2100

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.

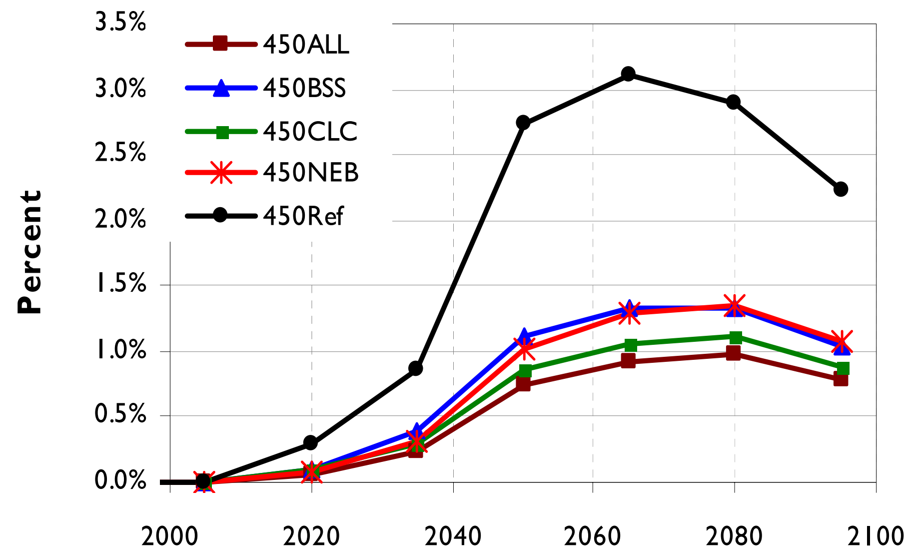


GDP Losses in CCTP scenarios

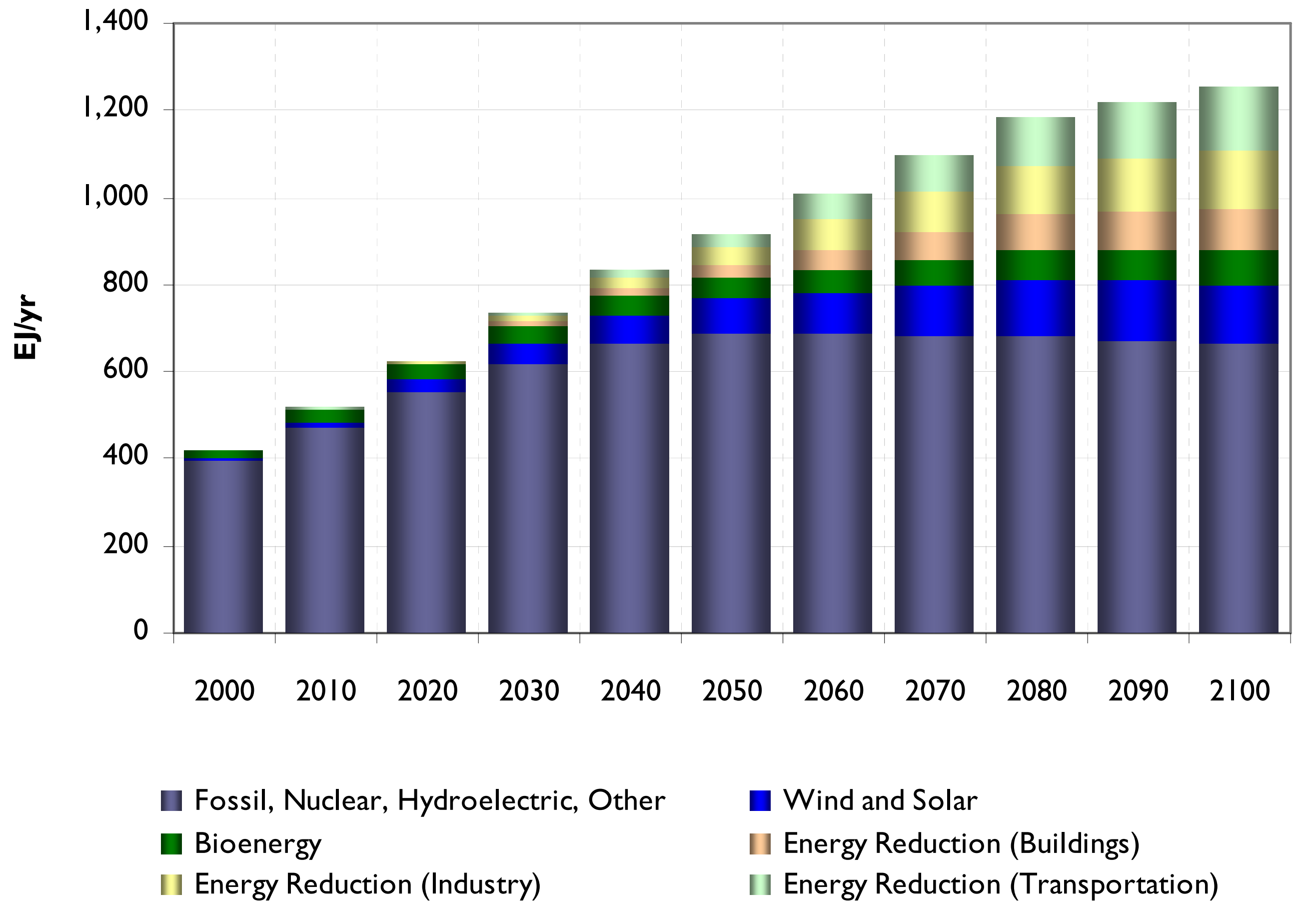
United States



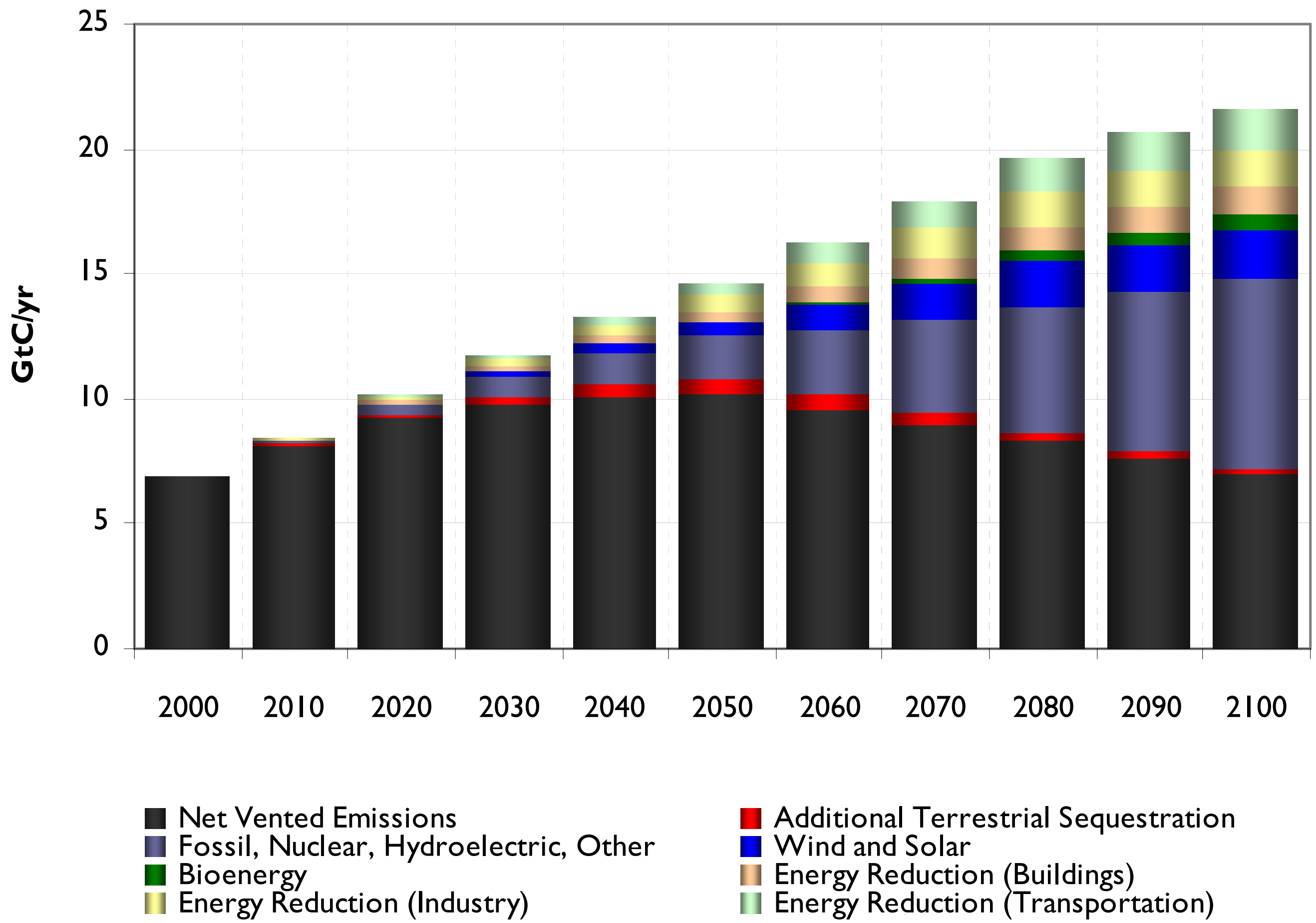
The World



High Constraint NEB: Annual Energy Shares



High Constraint NEB: Annual Emissions, Vented and Mitigated



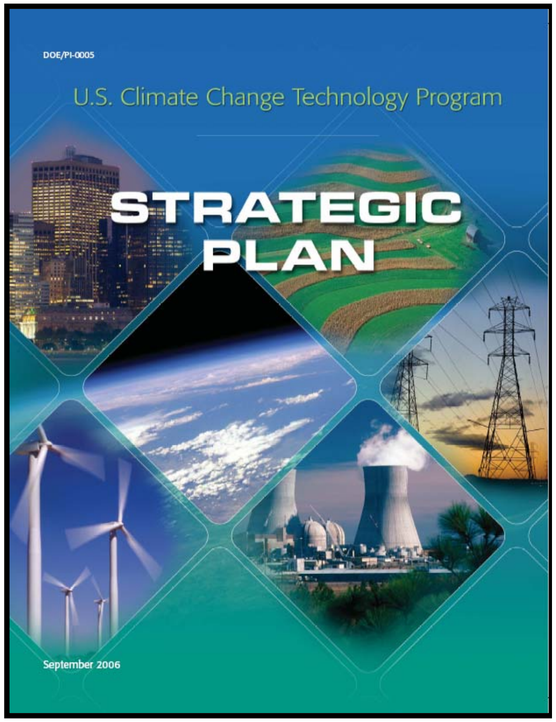
Step 4 --

Portfolio Analysis

Climate Change Technology Strategy

Strategic Goals:

1. Reduce Emissions From Energy End Use & Infrastructure
2. Reduce Emissions From Energy Supply
3. Capture & Sequester CO_2
4. Reduce Emissions From Non-CO_2 Gases
5. Improve Capabilities to Measure & Monitor GHG
6. Bolster Basic Science



www.climatetechnology.gov

Technologies That Will Make A Difference

	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)

CCTP Sponsored R&D Portfolio Reviews

- **For Each CCTP Strategic Goal:**
  - **Assess Adequacy of the R&D Portfolio to Make Progress Towards 6 CCTP Goals**
  - **Identify Strengths, Weaknesses, Gaps & Opportunities**
  - **Prioritize Gaps & Opportunities**
  - **Make Selective Recommendations**

"Results of a Technical Review of the U.S. Climate Change Technology Program's R&D Portfolio," May 2006
www.climatetechnology.gov

Technologies for Goal #1:
Reduce Emissions from End Use and Infrastructure

	NEAR-TERM	MID-TERM	LONG-TERM
Transportation	• Hybrid & Plug-In Hybrid Electric Vehicles • Clean Diesel Vehicles • Alternative and Fuel-Flexible Vehicles • Improved Batteries, Energy Storage • Power Electronics • Engineered Urban Designs • Reduction of Vehicle Miles Traveled • Improved Air Space Operations	• Fuel Cell Vehicles and H_2 Fuels • Efficient, Clean Heavy Trucks • Cellulosic Ethanol Vehicles • Intelligent Transport Systems • Integrated Regional Planning • Low-Emission Aircraft • Intercity Transport Systems	• Zero-Emission Vehicle Systems • Optimized Multi-Modal Intercity & Freight Transport • Widespread Use of Engineered Urban Designs & Regional Planning • Very Low Aviation Emissions (all GHGs)
Buildings	• High-Performance, Integrated Homes • Energy-Efficient Building Materials • High-Efficiency Appliances • Solar Control Windows	• "Smart" Buildings • Solid-State Lighting • Ultra-Efficient HVACR • Intelligent Building Systems • Neural Net Building Controls	• Energy Managed Communities • Low-Power Sensors with Wireless Communications
Industry	• Improved Processes in Energy-Intensive Industries • High-Efficiency Boilers and Combustion Systems • Greater Waste Heat Utilization • Improved Recyclability and Greater Use of Byproducts • Bio-Based Feedstocks	• Transformational Technologies for Energy-Intensive Industries • C&CO_2 Managed Industries • Superconducting Electric Motors • Efficient Thermoelectric Systems • Advanced Separation Technologies • Low-Emission Cement Alternatives • Water and Energy System Optimization	• Integration of Industrial Heat, Power, Processes and Techniques • High-Efficiency, All-Electric Manufacturing • Widespread Use of Bio-Feedstocks • Closed-Cycle Products & Materials
Electric Grid & Infrastructure	• Distributed Generation • Smart Metering & Controls for Peak Shaving • Long-Distance DC Transmission • High-Temperature Superconductivity Demonstrations • Power Electronics • Composite Conductor Cables	• Energy Storage for Load Leveling • Neural Net Grid Systems • Advanced Controls and Power Electronics	• Superconducting Transmission and Equipment • Standardized Power Electronics • Wireless Transmission

Results for Goal #1 - Energy End-Use

Goal Sub-Area	Current Portfolio Strengths	Gaps & Opportunities
Transportation (SP- 4.1)	• Light Vehicles/Hybrids • Heavy Vehicles • Alternative Fuel Vehicles • Intelligent Transport Systems • Aviation Fuel Efficiency	• Plug-in Hybrid Electric Vehicles • Advanced Thermoelectric Concepts to Convert Temperature Differentials • Studies of Advanced Urban-Engineering Concepts to Reduce VMT • Advanced Freight and Low-Emission Aviation Systems • New Combustion Regimes with Fuel Flexibility, Near-Zero Regulated Emissions
Buildings (SP- 4.2)	• Building Envelope • Building Equipment • Integrated Design/Operation • Albedo/Urban Heat Island (EPA)	• Advanced Sensors, Communications and Controls for Smart Buildings • Smart Roofs, Walls and Insulation • Integration of Distributed Energy/Renewables • Ultra-Efficient HVACR
Industry (SP- 4.3)	• Energy Conversion & Utilization • Resource Recovery & Utilization • Industrial Process Efficiency • Enabling Technologies	• Advanced Applications of Biotechnology • Substitutes for Steel, Cement, Limestone, and Other High-GHG Products • Industrial Waste Heat Reduction • Computational Modeling and Process Simulation for System Optimization • Water and Energy System Optimization • Life-Cycle Analysis for GHG Emissions
Infrastructure (SP- 4.4)	• High Temperature Superconductivity • Transmission & Distribution • Distributed Generation • Energy Storage • Sensors/Controls • Power Electronics	• Large-Scale Energy Storage to Solve Intermittency Issues • Materials Science for Efficient AC/DC Conversion • Nanotechnology for Efficient Transmission of Energy • Real-Time Observability, Monitoring and Control of Electric System Conditions

Technologies for Goal #2:
Reducing Emissions from Energy Supply

	NEAR-TERM	MID-TERM	LONG-TERM
Fossil Power	• IGCC Commercialization • FutureGen Demonstration • Solid Oxide Fuel Cells • More Efficient, Lower-Cost, Cleaner Coal Plants	• Pre-Combustion Technology for Cleaner Coal-Based Electricity Generation • Zero-Emission Coal Plants (FutureGen) • H_2 Co-Production from Coal/Biomass	• Zero-Emission Fossil Energy
Hydrogen	• Integrated Stationary Fuel Cell System • Codes & Standards • Demonstrations of Renewable Hydrogen Production	• Low-Cost H_2 Storage & Delivery • H_2 Production from Nuclear • H_2 Production from Renewables • Renewable-H_2-Powered Fuel Cell Vehicles	• H_2 & Electric Economy
Renewables	• Lower-Cost Wind Power • Biodiesel, Demos of Cellulosic Ethanol • Photovoltaics on Buildings • Cost-Competitive Solar PV • 1st Generation Biorefinery • Distributed Generation Systems	• Low-Wind-Speed Turbines • Advanced Biorefineries • Cellulosic Biofuels • Community-Scale Solar • Photolytic Water Splitting • Energy Storage Options	• Widespread Renewable Energy • Bio-Engineered Biomass • Bio-Inspired Energy & Fuels
Nuclear Fission	• Advanced Fission Reactor and Fuel Cycle Technology • New Fuel Forms and Materials	• GenIV Nuclear Plants • Closed Proliferation-Resistant Fuel Cycles • Minimization of Wastes Requiring Geological Disposal	• Widespread Nuclear Power • Advanced Concepts for Waste Reduction
Fusion Power	• Greater Understanding of Plasmas • Demonstration of Burning Plasmas (ITER) • Identification of Technology Options • Understand Potential of High-Energy-Density Physics Research	• Fusion Pilot Plant Demonstration	• Fusion Power Plants

Results for Goal #2 - Energy Supply

Goal Sub-Area	Current Portfolio Strengths	Gaps & Opportunities
Low-Emissions Fossil-Based Power & Fuels (SP- 5.1)	• Advanced Power Systems • Distributed Generation – Fuel Cells • Co-Production Hydrogen	• Integration with Carbon Capture and Storage • Methane Hydrates
Hydrogen (SP- 5.2)	• Hydrogen From Fission/Fusion • Hydrogen From Fossil/Alternative • Hydrogen Storage & Use • Systems Technology Validation • Hydrogen Infrastructure/Safety	• Integration of Electricity and H_2 Transportation Sectors • Advanced Concepts in Hydrogen Storage • Hydrogen Co-Production and Integration with CO_2 Capture
Renewable Energy & Fuels (SP- 5.3)	• Wind Energy • Photovoltaics, Photoconversion • Solar, Concentrating • Bio-Fuels/Biomass	• Biomass Genomics and Alternative Fuels, Materials, and Chemicals • Systems Approach to Waste Management, Including Waste-to-Energy • Solar Fuels (Artificial Photosynthesis) • Advanced Solid-State Thermoelectrics • Wave Energy and Tidal Dams
Nuclear Fission (SP- 5.4)	• Nuclear: Near-Term Deployment • GenIV • AFCI (GNEP)	• Advanced Fuel Resources and Fuel Cycles for Fission (Including Thorium) • Nano-Engineered Materials and Heat Transfer Technology • Next-Generation Nuclear Reactors Including Dry Cycle Nuclear Plants • Long-Term Nuclear Computations
Fusion Energy (SP- 5.5)	• Fusion Sciences • ITER	• High-Voltage Power Electronics for Fusion Energy Systems • Advanced Sensors for Measurement of Plasma and Optical Parameters • Inertial Fusion Energy • High-Temperature Superconducting Magnets • Nano-Engineered Materials for Fusion Systems

Technologies for Goal #3: CO_2 Capture, Storage, and Sequestration

	NEAR-TERM	MID-TERM	LONG-TERM
Carbon Capture	• CSLF and CSRP • Post Combustion Capture • Pre-Combustion Technologies • Oxy-Fuel Combustion • Oxygen Separation Technologies	• Capability to Capture Most CO_2 Emissions • Novel Capture Technologies • Low-Cost Oxygen • Biomass Coupled with CCS	• Novel In-Situ CO_2 Conversion • Capture CO_2 Directly from Atmosphere
Geologic	• Reservoir Characterization • Safety, Health, and Environmental Risk Assessment • Understand Underground CO_2 Reactions & Microbial Processes • Enhanced Hydrocarbon Recovery • Enhanced Coal-Bed Methane • Large-Scale Demonstration • CO_2 Transport Network Design	• Geologic Storage Proven Safe • Well Sealing Techniques Demonstrated • Mineralization: Solid Carbonates • Reliable and Accurate Inventory Monitoring • Well-Established CO_2 Transport Infrastructure	• Sufficient CO_2 Storage Capacity • Track Record of Successful CO_2 Storage Experience
Terrestrial	• Reforestation • Soils Conservation • Vegetation in Urban Settings	• Soils Uptake & Land Use • Inter-relationship among CO_2, CH_4 & N_2O • Sequestration Decision Support Tools • M&M Tools to Validate Terrestrial Sequestration • Bio-Based & Recycled Products	• Biological Sequestration • Large-Scale Sequestration • Minimal Deforestation • Carbon & CO_2 Based Products & Materials
Ocean	• Effective Dilution of Direct Injected CO_2	• Ocean CO_2 Biological Impacts Addressed • Carbonate Dissolution / Alkalinity Addition	• Safe Long-Term Ocean Storage

Results for Goal #3 - Carbon Capture and Storage

Goal Sub-Area	Current Portfolio Strengths	Gaps & Opportunities
Carbon Capture (SP- 6.1)	• Carbon Capture • CO_2 Separation	• Advanced Materials for CO_2 Separations, Transport and Storage • Integrated Modeling Framework to Evaluate CCS Technologies • Technologies that Capture CO_2 Directly from Atmosphere • Ionize CO_2 to Enable Separation via Electric Field • Oxygen Separation Technologies: Oxyfuels
Geologic Storage (SP- 6.2)	• Knowledge Base for CO_2 Storage • Novel Sequestration Systems • Health, Safety & Environment • Regional Partnerships • International Partnerships	• Understand CO_2 Movement in Hydrocarbon-Bearing Formations • Understand Underground CO_2 Geochemical and Microbial Processes • CO_2 Geologic Storage Engineering (Pore Size, Mineral Trapping, Leak Detection) • Large-Scale Demonstration of CO_2 Storage • Combine CO_2 Storage, In-Situ Refining, Gasification, Power Generation, etc
Terrestrial Sequestration (SP- 6.3)	• Land Management • Biotechnology (Soil Carbon) • Improved M&M	• Systems Approach across Sectors and Gases (Energy Crops, Seq., Nitrogen) • Potential from Land-Use Mgt (e.g., Sustainable Forestry vs. Deforestation) • Optimize Biomass Genomics for Fuels, Materials, Chemicals, & CO_2 Storage • Vegetation in Urban Settings (Sequestration and Heat Island Effect)
Ocean Sequestration (SP- 6.4)	• None	• Basic Research in Ocean Chemistry and Bio-Cycles • Ocean Acidification Issues • Ocean Direct Injection

Technologies for Goal #4: Reduce Emissions of Other Gases

	NEAR-TERM	MID-TERM	LONG-TERM
Methane from Energy & Waste	• Bioreactor Landfill Technology • Methane to Markets • New Drilling Techniques for Recovery of Coal bed Methane • Leak Detection, Measurement, and Mitigation Technologies for Oil & Natural Gas Systems	• Advanced Landfill Gas Utilization (e.g., Fuel Cells, Microturbines), Cover, and Collection Technologies • Ventilation Air Methane Technology • Advanced End-Use Technologies to Use Methane at Remote Well Sites	• Integrated Waste Management System with Automated Sorting, Processing & Recycle • Automated Coal Mining to Eliminate Methane Emissions • Smart Pipes and Self-Repairing Pipelines
Methane & N_2O from Agriculture	• Anaerobic Digesters that Produce Heat and Electricity • Precision Agriculture • Improved Livestock Production Efficiency	• Better Understand Relationship among CH_4, CO_2, N_2O, N_2 & C in Agriculture • Soil Microbial Processes • Prescription Release of Nutrients and Chemicals for Crops • Genetically Designed Forages and Bacteria to Improve Digestion Efficiency	• Zero-Emission Agriculture
High GWP Gases	• Advanced Refrigeration Technologies (Distributed and Secondary-Loop) • Advanced Abatement, Recovery, and Recycling Technologies • Advanced Aluminum Smelting Processes to Reduce Anode Effect	• Alternative Refrigeration Fluids (Non-GHG) • Substitutes for SF_6 in High-Voltage Applications and Magnesium Production • Inert Anode to Eliminate PFC Emissions in Aluminum Production	• Solid-State Refrigeration/AC Systems • New Equipment and Process Designs that do not Require High-GWP Gases
N_2O from Combustion	• Catalytic Reduction of N_2O in Nitric Oxide Plants • Better Understand N_2O Emissions from Vehicles	• Catalysts That Reduce N_2O to Elemental Nitrogen in Diesel Engines • Understand Role of N Compounds from Combustion with Soils and N_2O	• Advanced Vehicles and Non-Carbon Based Fuels
Ozone Precursors & Black Carbon	• Particulate Matter Control Technologies for Vehicles • Reflective Roofs to Reduce Heat Island Effects • Better Understand Effects of Ozone Precursors & Black Carbon	• Model Linkages Between Air Pollution and Climate Change • Jet Fuel Additives to Minimize Black Carbon and Soot	

Results for Goal # 4 - Other Gases

Goal Sub-Area	Current Portfolio Strengths	Gaps & Opportunities
Methane Emissions From Energy & Waste (SP- 7.1)	• Landfill Gas Programs (EPA +) • Coal Mine/Bed Methane (EPA +) • Methane to Markets (EPA +)	• Automated Mining Systems that Eliminate Methane Emissions • Tagging and Sorting Technologies to Convert Waste to Useful Products • Distributed Waste Management Systems: Waste to Fuels or Electricity • Improved Combustion in Natural Gas Flaring • Bioreactor Landfills Using Genetically Engineered Organisms • Self-Repairing, Leak-Free Gas Pipelines and LNG Conversion Systems
Methane and N_2O Emissions from Agriculture (SP- 7.2)	• Advanced AG – N_2O Reduction • Manure Management • Enteric Emissions Reductions	• Precision Agriculture and Biosensors • Improved Understanding of Rumen Microbial Processes and Nutrient Needs • Improved Separation Processes and Stabilization & New Types of Digestors • Improved Understanding of Specific Soil Microbial Processes
Emissions of High GWP Gases (SP- 7.3)	• Substitutes for High GWP Gases • Substitutes for SF_6 • Refrigeration - HFC Reduction	• Alternatives to SF_6 in HV Electric Transformers, Circuit Breakers, etc • Eliminate GHG-Emitting Working Fluids in Refrigeration and Air-Conditioning • Alternatives to SF_6 & PFCs in Chem. Vapor Deposition, Cleaning, Etching, etc • Alternative Cover Gases to Replace SF_6 for Magnesium Melt Protection • New Technologies & Controls to Reduce Aluminum Smelting PFC Emissions
N_2O Emissions from Combustion & Industry (SP- 7.4)	• N_2O Abatement – Nitric Acid • N_2O Abatement – Transportation	• Understanding of Formation and Life of Nitrous Oxides from Combustion • Advanced Catalytic Reduction of N_20 from Combustion Sources
Tropospheric Ozone Precursors & Black Carbon (SP- 7.5)	• Abatement – TOPs & BC	• Analysis of Role of Black & Organic Carbon and Tropospheric Ozone Precursors • Retrofit Designs for NO_x and Particulate Control for Diesel Engines • Reduce NO_x Emissions from On-Road Heavy-Duty Diesel Engines • Jet Fuel Additives • Computational Models of Soot Formation

Technologies for Goal #5:
Measure and Monitor 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)

Results for Goal # 5 - Measurement and Monitoring

Goal Sub-Area	Current Portfolio Strengths	Gaps & Opportunities
Energy Production/ Efficiency (SP- 8.2)	• M&M for Energy Efficiency	• Protocols for Multiple Assessments of Performance of Energy End Uses • Improvements in Temporal and Spatial Resolution Measurements • Satellite-Based Sensors for Direct Measurement of CO_2 and Other Gases • Wireless Micro-Sensor Networks for Migration, Uptake, and Distribution of GHGs
CO_2 Capture & Sequestration (SP- 8.3.1)	• M&M for Geologic Storage	• Remote Subsurface/Near Surface CO_2 Monitoring • Improvements in Leak Detection from Separation and Capture and Pipeline Systems
Terrestrial Sequestration (SP- 8.3.2)	• M&M for Terrestrial Seq.	• Global Network Monitoring and Measurement of Terrestrial Carbon
Oceanic Sequestration (SP- 8.3.4)	• None	• Measurement and Tracking of Injected CO_2
Other Gases (SP- 8.4)	• M&M for Other Gases	• Space-Based Technologies for Long-Term Monitoring of GHGs and Aerosols • N_2O Measurement Techniques for Emerging Gasoline and Diesel Engines • Advanced, Real-Time Measurement for Fine Particulate Matter and Soot • Nanosensors for Pipeline Leak Detection
Integrated M&M System Architecture (SP- 8.5)	M&M Observation System	• Integrated M&M System Architecture • Wide Area Networks that Provide Robust (sensor to Sensor) Communications • Platforms for Spatial Scales and Measurement Layers (Ground, Air, & Space) • Rapid Prototyping and Benchmarking of Existing Integrated System Components • Integrated M&M Field Experiment

Step 5 –

Prioritization & Budgeting

Three Broad Portfolio Planning Principles

1. **The Whole of the Individual R&D Investments Should Constitute a Balanced and Diversified Portfolio**
   - No Single Technology Will Likely Meet the Challenge Alone
   - Investing in R&D in Advanced Technologies Involves Risk
   - Diverse Array of Technology Options can Hedge Against Risk and Provide Flexibility in the Future
2. **Ensure That Factors Affecting Market Acceptance are Addressed**
   - Each Technology Must be Integrated Within a Larger Technical System and Infrastructure
   - Market Acceptance of Technologies is Influenced by a Myriad of Social and Economic Factors
   - CCTP's Portfolio Planning Process Must be:
     - Informed by, and Benefit From, Private Sector and Other Non-federal Inputs,
     - Examine the Lessons of Historical Analogues for Technology Acceptance, and
     - Apply Them as a Means To Anticipate Issues and Inform R&D Planning
3. **The Anticipated Timing Regarding the Commercial Readiness of the Advanced Technology Options is Important**
   - Energy Infrastructure has a Long Lifetime – Change in Capital Stock Occurs Slowly
   - Some Technologies May Need to be Available and Moving Into the Marketplace Decades Before Their Maximum Market Penetration is Achieved

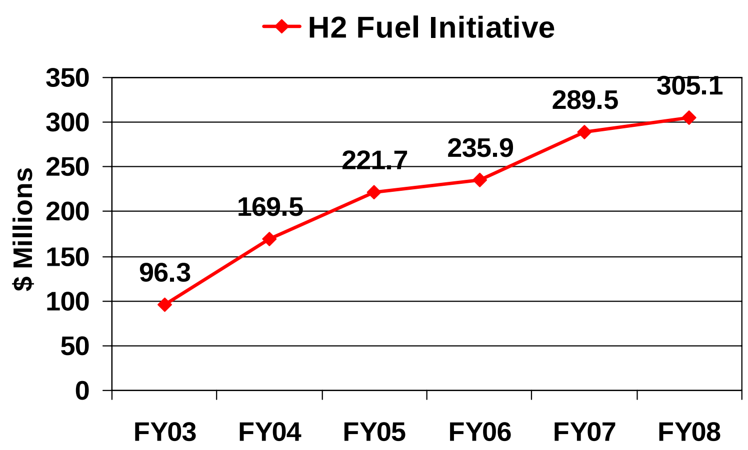
Portfolio Planning and Investment Criteria

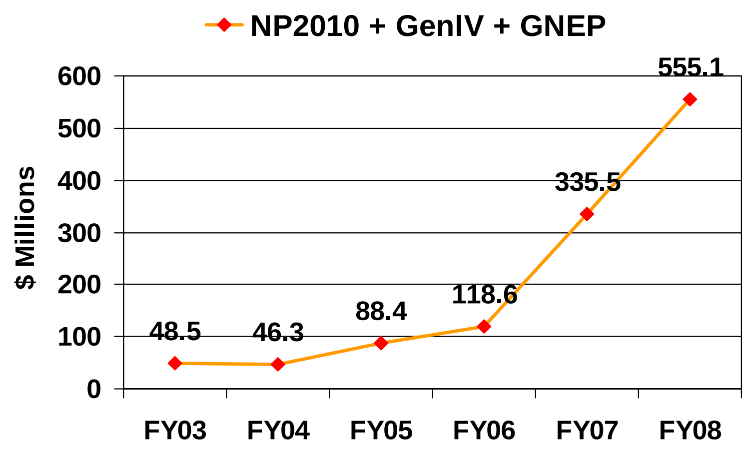
- Maximizing Expected Return on Investment
  - Expected Contributions to the Attainment of Goals
  - Cost-Effectiveness, Improved Productivity
- Acknowledging the Proper and Distinct Roles for the Public and Private Sectors
  - Consideration of Time to Deployment
- Focusing on Technology with Large-Scale Potential
  - Every Technology Option has Limits
  - Adaptable on a Global Scale and Result in Large Mitigation Contributions
- Sequencing R&D Investments in a Logical, Developmental Order
  - Times When Different Technologies Need to be Available and Cost-Effective
  - Early Resolution of Critical Uncertainties
  - Demonstrate Early Success or Feasibility if Needed for Other Technologies

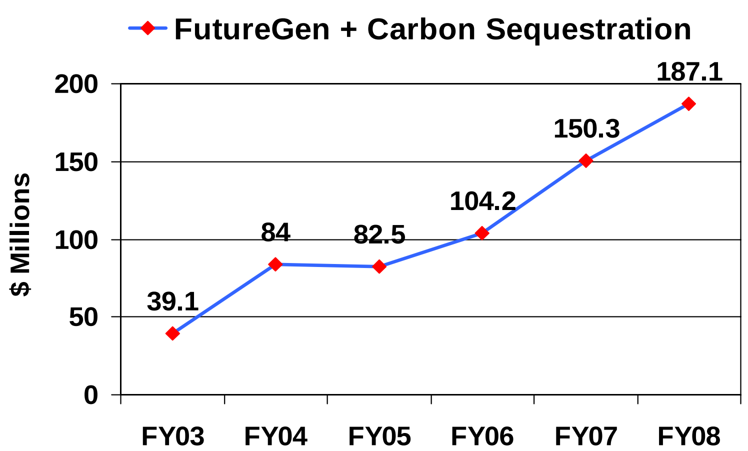
Priorities for FY 2008

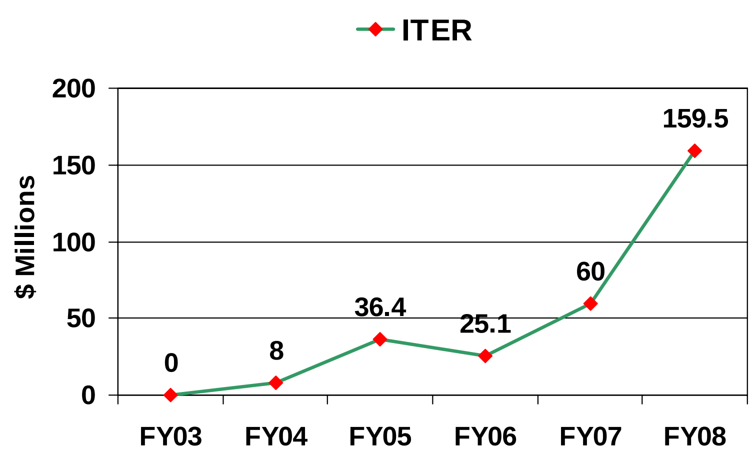
Efficiency	• Vehicle Technology • Buildings • Industry
Supply	• NP2010, GenIV, GNEP • Clean Coal and FutureGen • H_2 & Fuel Cells • Biomass/Biofuels • ITER • Solar
CO_2 CCS	• CO_2 Capture and Sequestration • Terrestrial Sequestration
Other Gases	• Methane to Markets (M2M) • USDA and EPA Programs

FY 2008 Budget Request – Key Initiatives









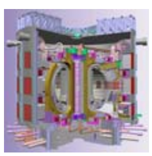
Innovative International Partnerships

Group on Earth Observations: 65 governments and 40+ organizations members; designing and implementing a new Global Earth Observation System of Systems .

Carbon Sequestration Leadership Forum: 22 members; focused on CO_2 capture & storage.

International Partnership for the Hydrogen Economy: 17 members; organizes, coordinates, and leverages hydrogen RD&D programs.

Generation IV International Forum: 10 members; devoted to R&D on next generation of nuclear systems.



ITER: 7 members; project to develop fusion as a commercial energy source.

Methane to Markets: 17 members; recovery and use of methane from landfills, mines, oil & gas systems, and agriculture.

Asia-Pacific Partnership on Clean Development & Climate: 6 members; focuses on accelerating deployment of technologies to address energy security, air pollution, and climate change.

Conclusions

- A Coherent Priority-Setting System Has Multiple Steps
- Guided by L.T. Policy Goals & Creative Visioning
- Scenarios Analysis is One Tool for:
  - Informing Options, Scale, Timing, & Costs
  - Motivating Investment in R&D
  - Providing Feedbacks to Technology Goal-Setting
- Must Be Complemented by:
  - Portfolio Analysis, with Expert Input (S, W, G, and O)
  - Portfolio Development Principles & Investment Criteria
- High-Level Oversight
- Independent R&D Evaluations & Feedback
- Policies Promoting Int’l Cooperation & Deployment