Climate Change Technology – Perspectives on Future Prospects and Challenges

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National Academy of Sciences -- America's Climate Choices
Panel on Limiting the Magnitude of Future Climate Change
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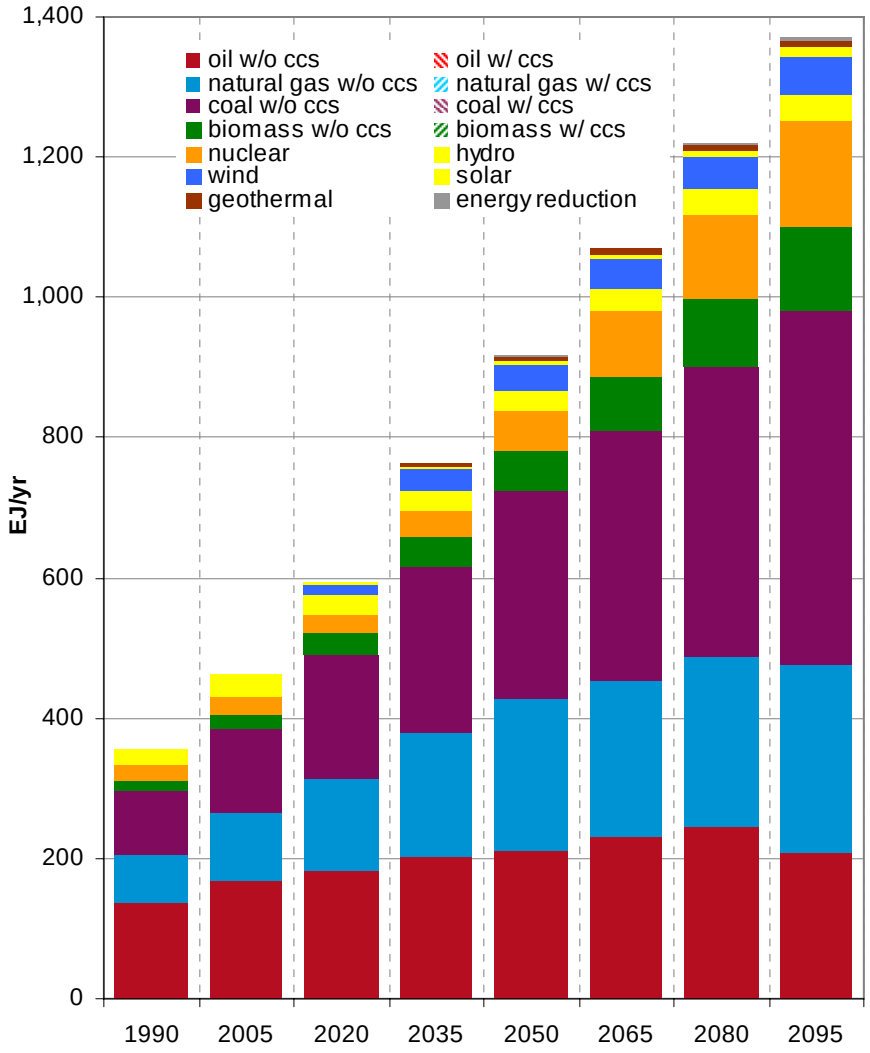
Washington, DC

New Reference Case – U.S. and World

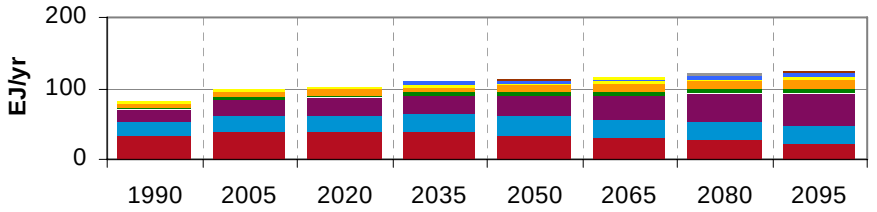
(Primary Energy – No GHG Constraints)

World

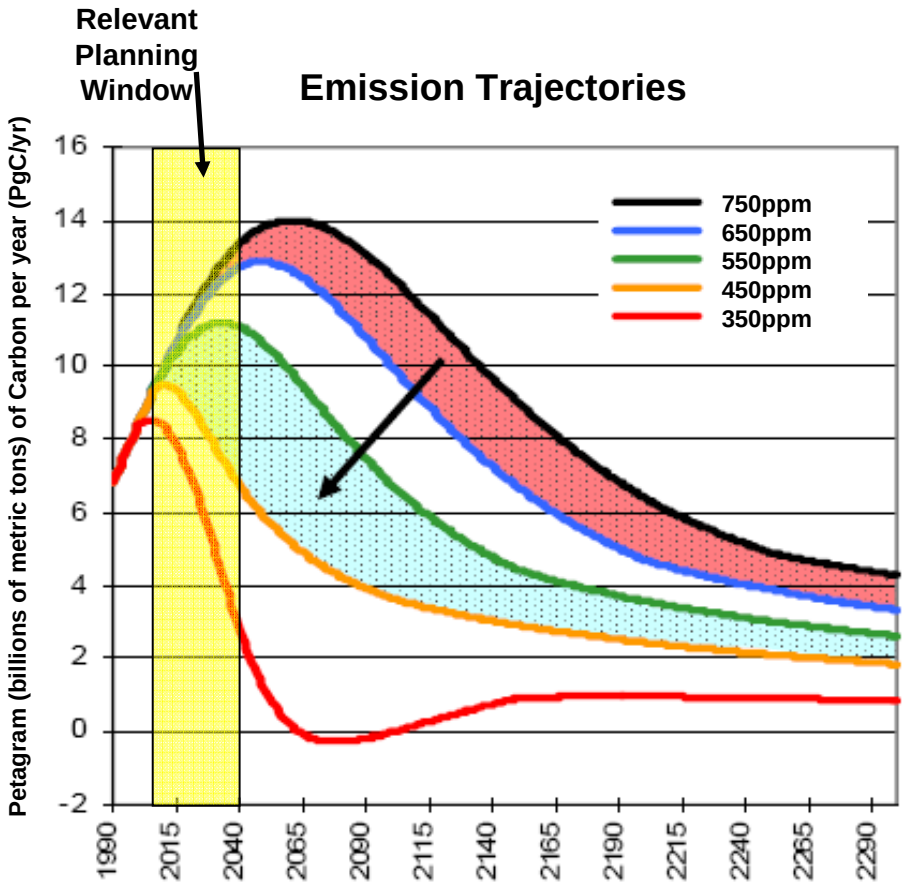


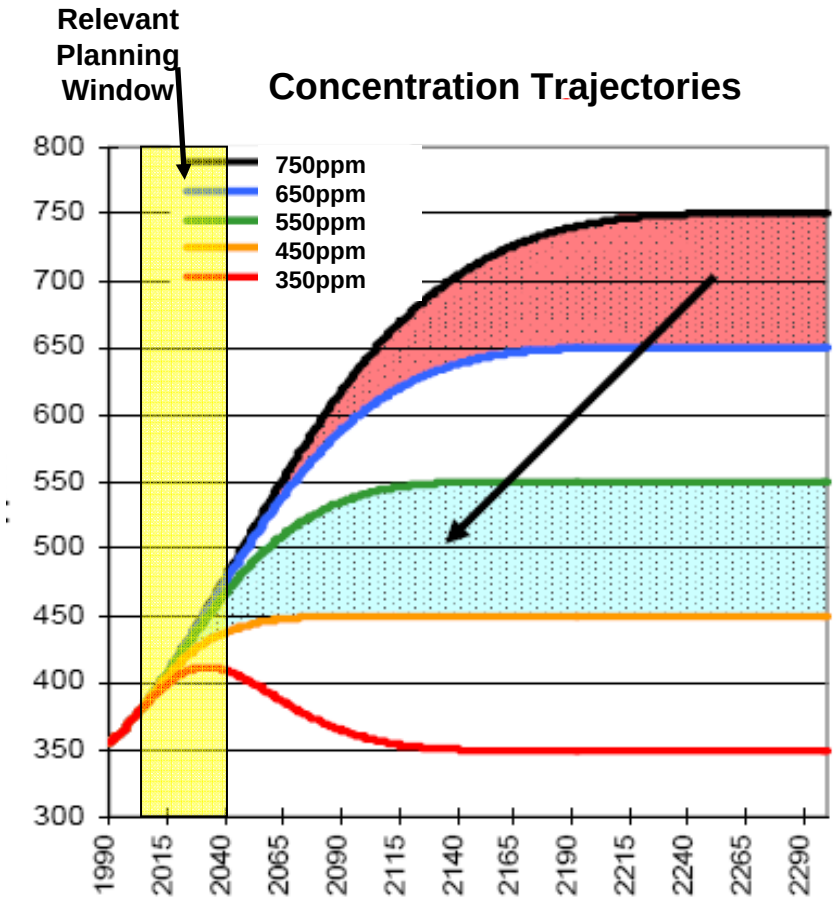
- **World Energy Demand Grows Three-Fold from 2005 to 2100**
- **Reference Case Dominated by Coal, Oil, and Natural Gas**
- **U.S. Energy Demand Slows Relative to Rest of World**
- **<u>Key Insight</u>: Strong World Demand Raises Prices; Encourages Efficiency and Use of Alternatives (Bio, Wind, Nuclear, Hydro, and Solar)**

U.S.



Technical Goals Set In Context of UNFCCC





Emission and concentration trajectories based on level of effort for technology investments

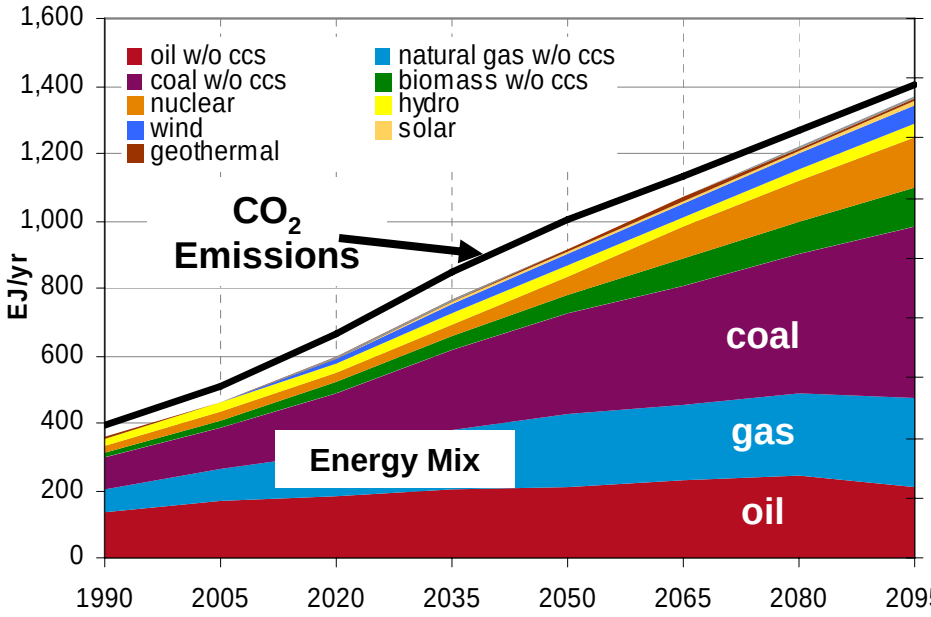
Potential carbon reductions based on more aggressive technology investments

Relevant planning window to influence longer-term outcomes

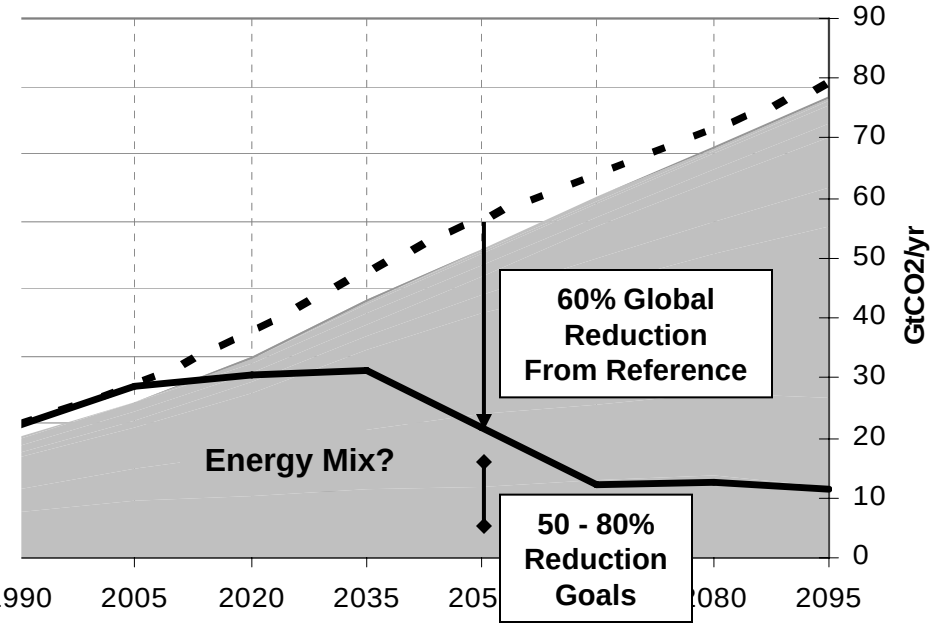
Wigley, Richels, Edmonds, Nature, 1996

Energy and Emissions Futures

Global Reference Case CO_2 Emissions (No Stabilization)



Constrained Global CO2 Emissions for 450 ppm CO_2 Stabilization



Reference Case

- No Reduction in Carbon Intensity of Energy, so Emissions Grow at Same Rate
- Energy System Dominated by Coal, Oil, and Natural Gas

Stabilization Case

- Graph shows reductions consistent with 450 ppm CO2 concentration (~550 ppm CO2-eq.)
- Requires global reductions of 60% below projected emissions in 2050 (25% below 2005 levels)
- Achieving a 50 – 80% reduction is even more aggressive

Technology Strategy

Key Technology Elements

- Coal
  - De-Carbonize the Grid
  - Nuclear Power
  - Low-Emission Coal Power
  - Renewable Power
- Cars
  - Transform Vehicles To New Fuels
  - Hybrid & Electric Vehicles
  - Alt. Fuel Vehicles & Bio-Based Fuels
  - Alternatives, including Other Modes
- Efficiency (All Sectors)
- Other GHGs
- Enablers
  - CO2 Capture and Storage
  - Modernized Grid
  - Energy Storage
    - » Large Scale, Utility-Scale
    - » Small Scale, Vehicle-Scale
  - Strategic and Exploratory Research

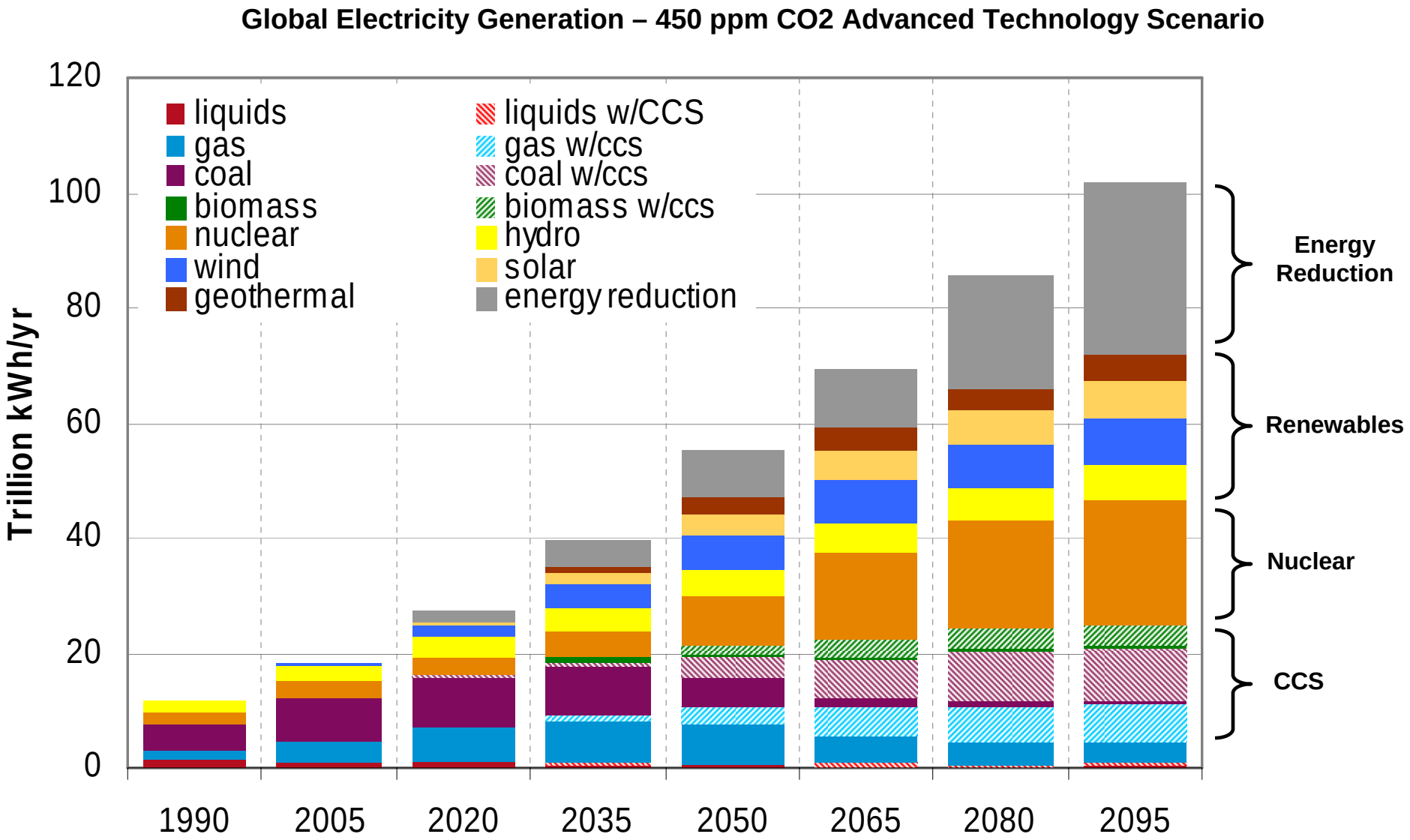
Supporting Policies

- Financial Incentives
  - Value Avoided GHG Emissions
  - Technology Investment Incentives
  - Loan Guarantees to Address Risk
  - Fuel Mandates
  - Codes, Standards, Labeling
  - Transparent Means for Measuring Progress

R&D Strategy

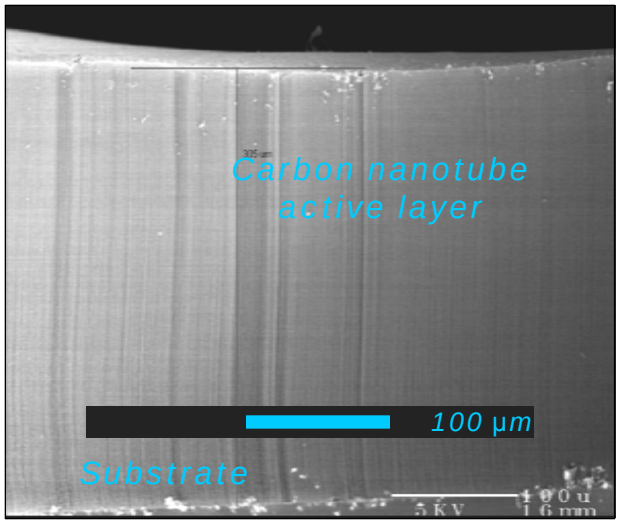
- Via U.S. Climate Change Technology Program
  - Strengthen Federal R&D Portfolio
  - Prioritize Investments
- Via Policy and Cost-Shared Programs
  - Encourage Private Sector R&D
- Expand R&D Cooperation & Collaboration
  - Include non-Federal Entities
  - Encourage International Cooperation
  - G8 Pledge of $10B in R&D per Year

“De-Carbonize” the Electric Grid



"De-Oil" Transportation

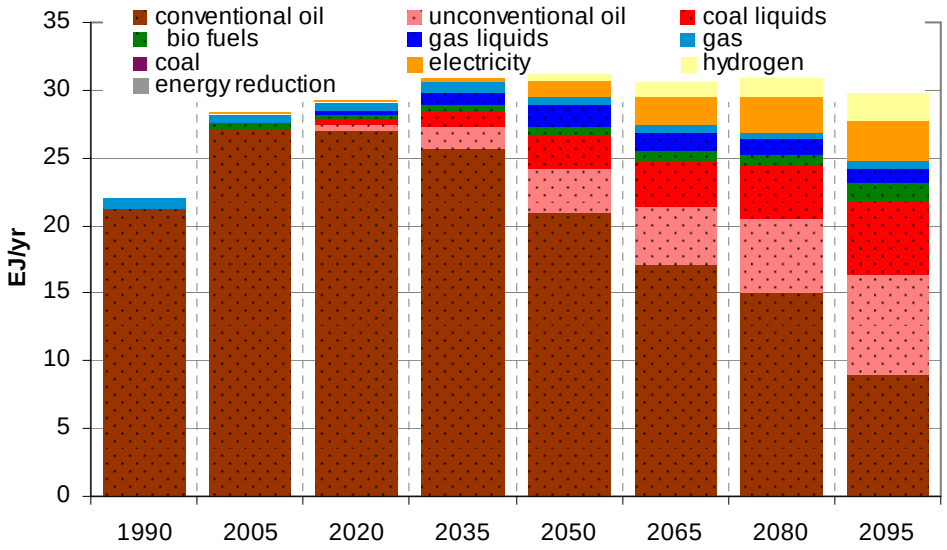
- **Future Transport System**
  - Multi-Modal
  - Regional Choices
  - Coordinated Integrated Land-Use Planning
- **Vehicle Options**
  - Electric Vehicles
  - Hybrid Vehicles
  - Bio-Based Vehicles
  - H2 & Hydrogenated Molecules
  - Oil & Gas Vehicles



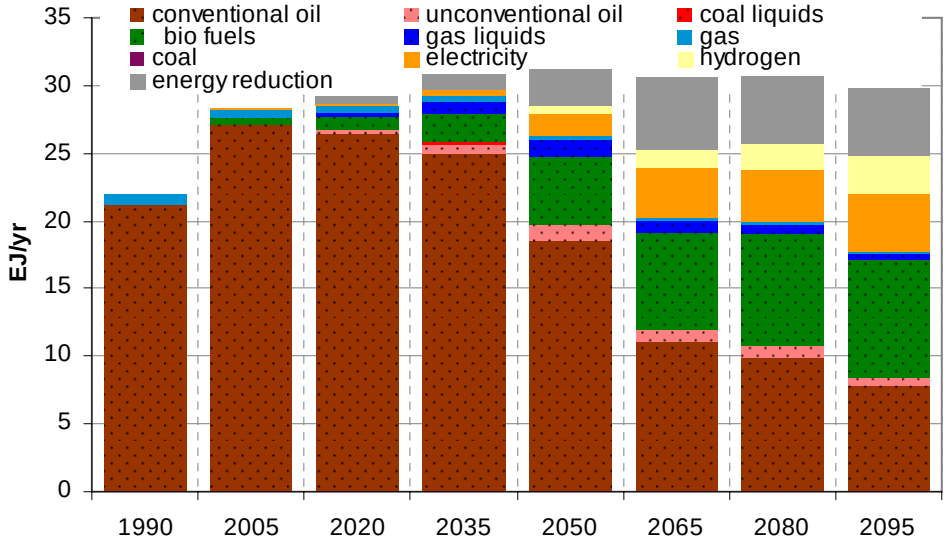
Nanotube-Enhanced Ultracapacitor
[MIT, R. Signorelli – March 2005]

Transportation – What Happens to Oil? (U.S.)

Reference Case (no constraint)

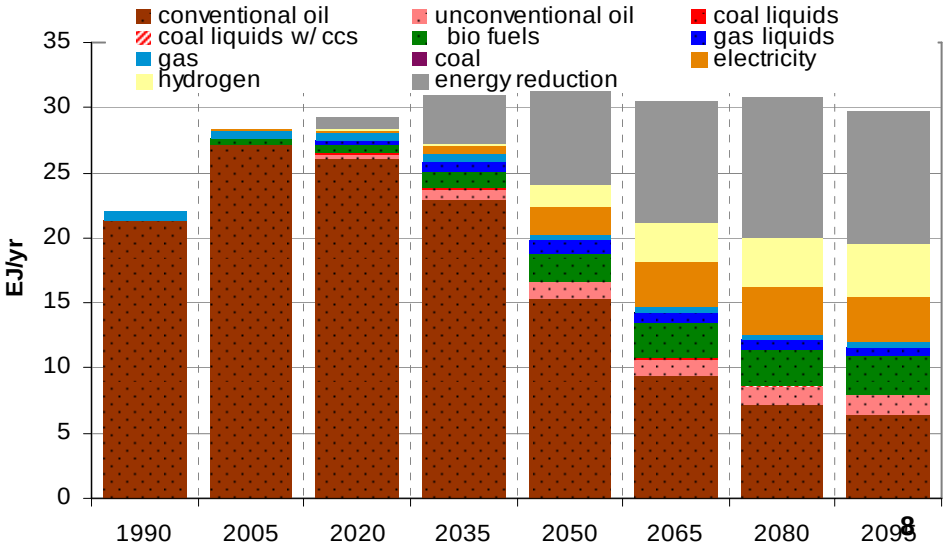


450 Reference

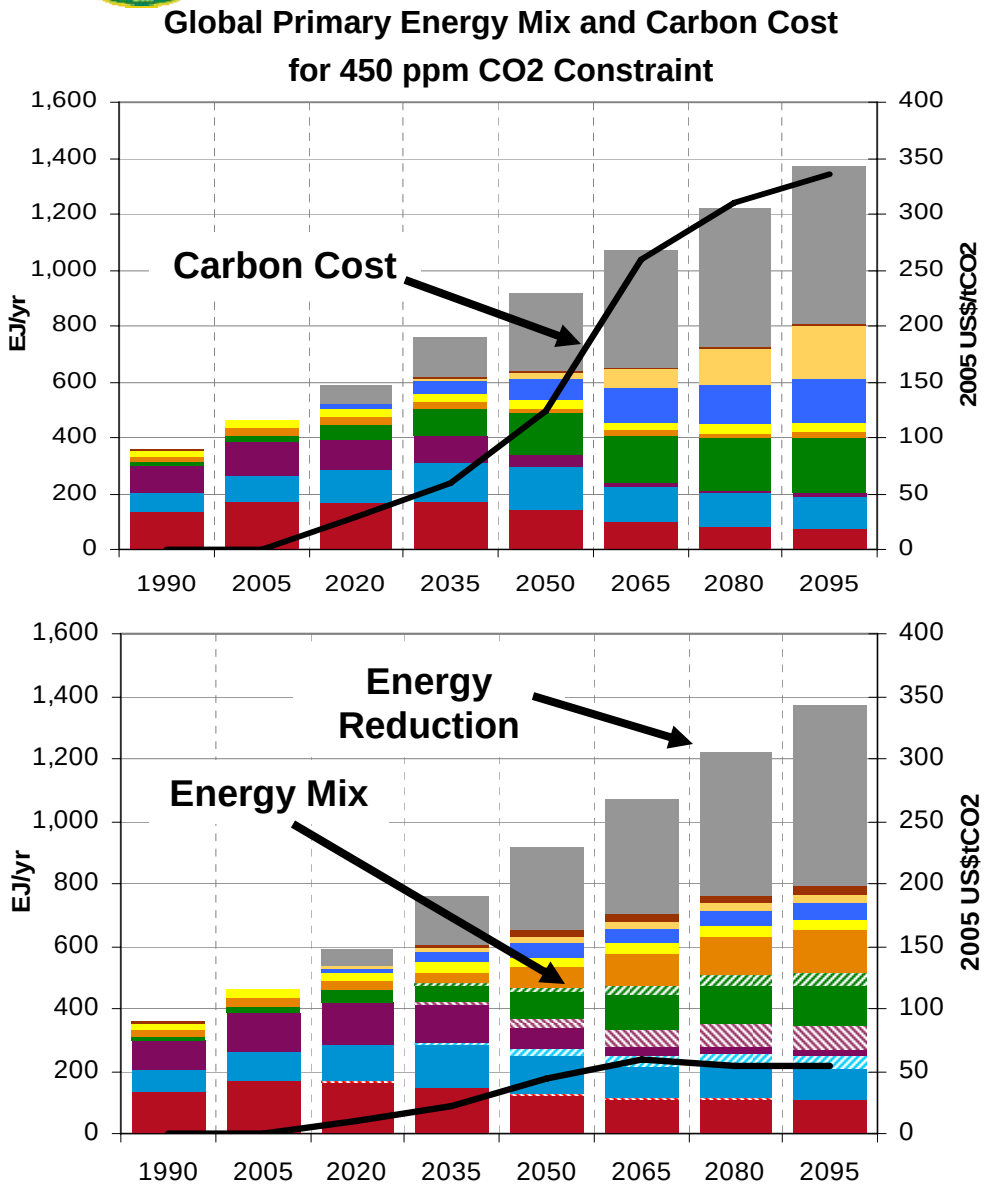


- **Ref. Case – Oil Continues to Dominate, Even in New Forms**
- **Constrained Cases – Oil Share Falls to Less than 1/2 Due to:**
  - **Biofuels**
  - **Electrification**
  - **Hydrogen**
  - **Reduced Demand**
  - **Modal Changes**

450 All-in



Global Constraint Scenarios: Advanced Technologies Make Goal More Affordable



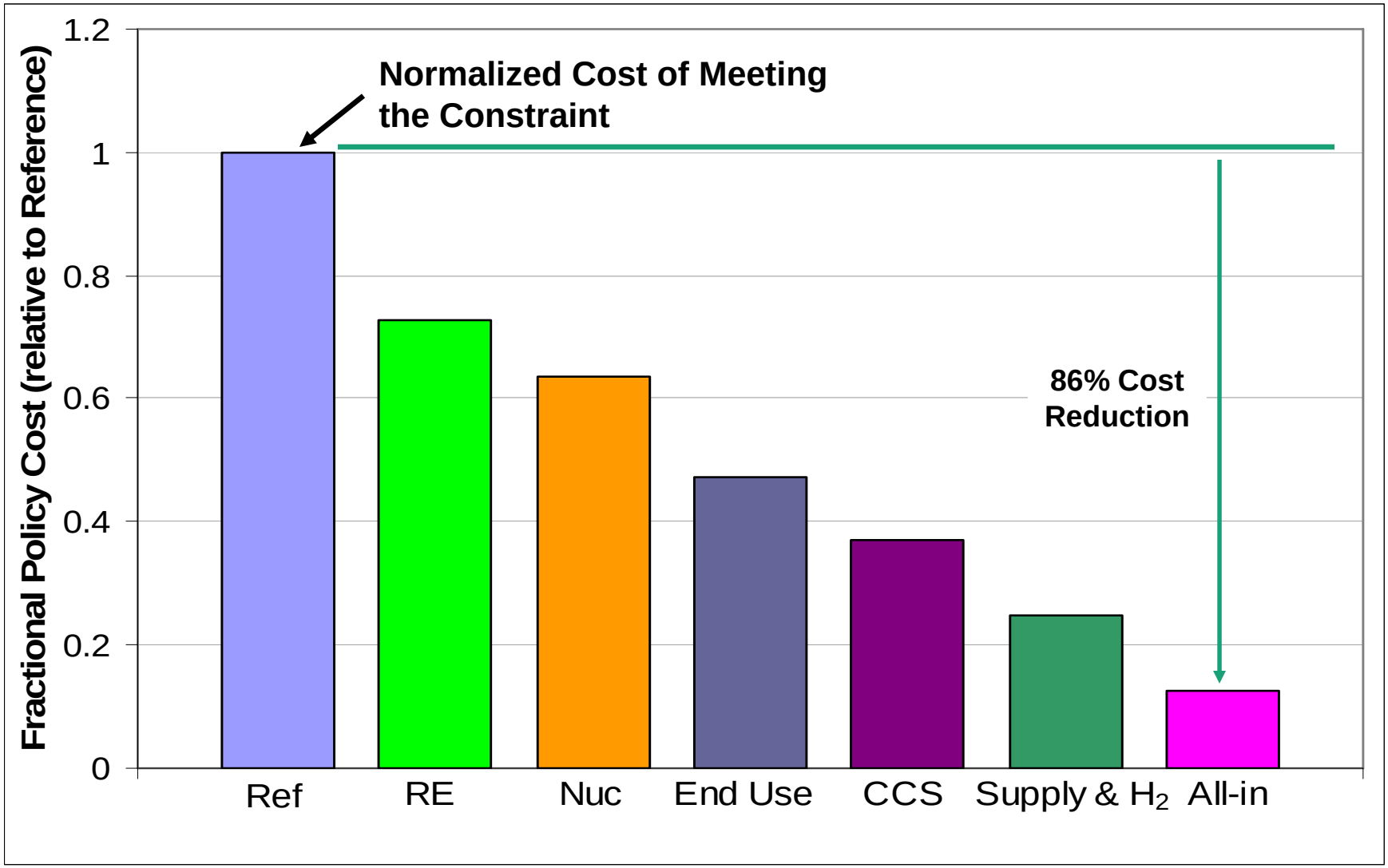
Reference Case Technologies

- No CCS
- No Nuclear Expansion
- BAU Progress on Other Techs
- Coal Virtually Disappears after 2050
- Biomass, Wind and Solar Dominate Mix
- Price-induced Demand Reduction
- Most Expensive Scenario
  - $124/tCO2 in 2050; $335 in 2095
  - Peak costs ~2.5% of global GDP

Advanced Technologies (All-in)

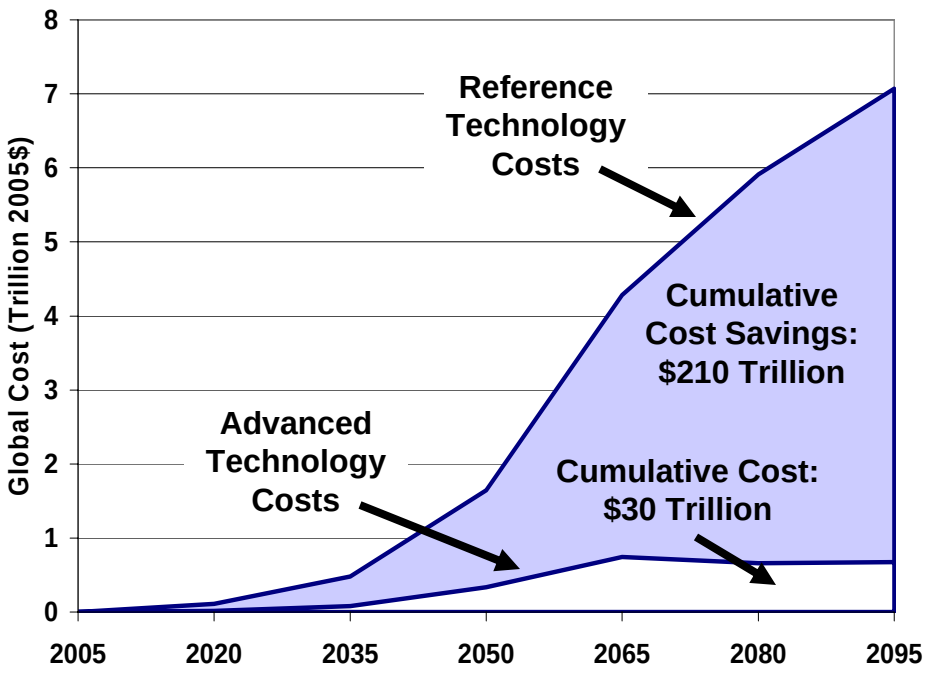
- CCS Deploys
- Nuclear Expands
- Accelerated Progress on Other Techs
- Coal Remains, but with CCS
- Portfolio Balanced Among: CCS, Nuclear, Renewables, Efficiency
- Technology-Induced Demand Reduction
- Least Expensive Scenario
  - $44/tCO2 in 2050; $54 in 2095
  - Peak costs ~0.5% of global GDP

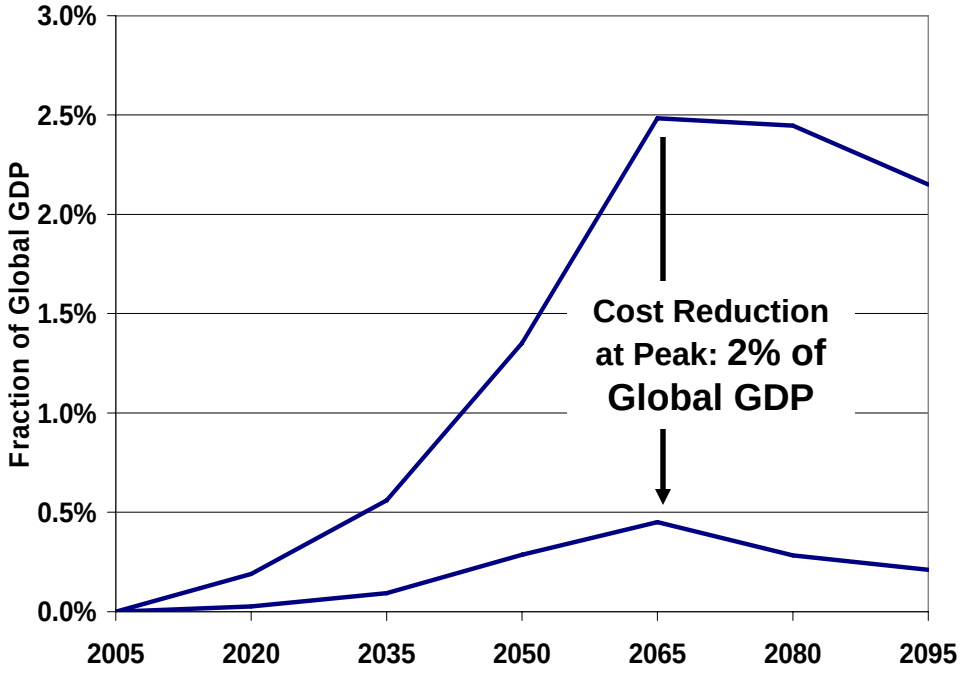
Relative Cost for Main Technologies/Clusters



Costs Are Significant Without Advanced Technology

Global Cost* of Meeting a 450 ppm CO_2 Emissions Constraint





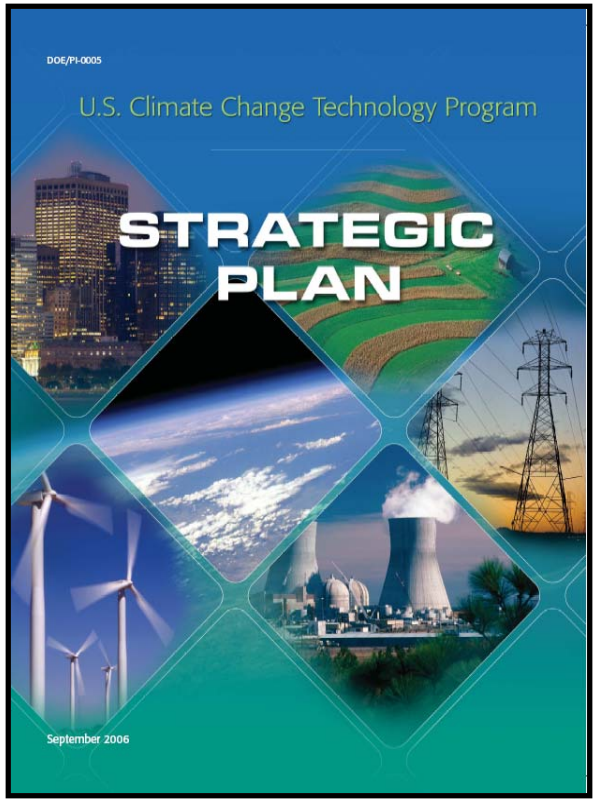
*Undiscounted 2005 US$

- **Results are Optimistic - Actual Costs Would be Higher**
  - **Assumes Uniform Global Action, Starting Now**
  - **Not All Technologies Will Be Successful**
- **Global Costs of 2.5% of GDP May Prevent Action**
- **Development of Advanced Technologies Will Enable More Aggressive Goals**

Federal
Research and Development

U.S. Climate Change Technology Program

- **U.S. Climate Change Technology Program**
  - Mission – Accelerate R&D on Adv. CC Techs
  - Scope – Ten Federal R&D Agencies
  - Budget -- $4.4 Billion Requested for FY'09
  - Activities – Coord. R&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

Roadmap for Climate Change 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)

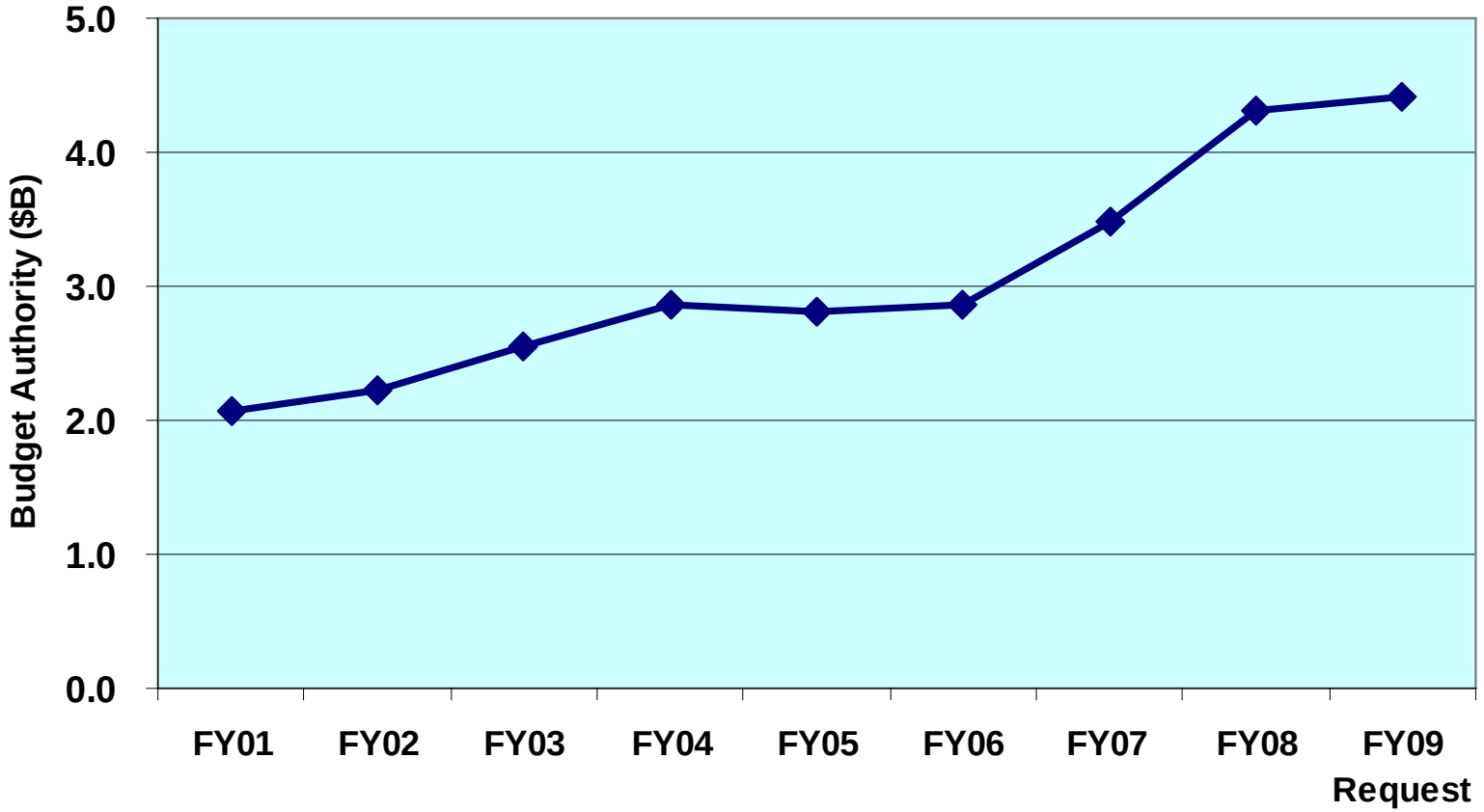
Federal Agency Participation in CCTP

Agency	Selected Examples of Climate Change-Related Technology R&D Activities
DOC	Instrumentation, Standards, Ocean Sequestration, Decision Support Tools
DoD	Aircraft, Engines, Fuels, Trucks, Equipment, Power, Fuel Cells, Lasers, Energy Management, Basic Research
DOE	Energy Efficiency, Renewable Energy, Nuclear Fission and Fusion, Fossil Fuels and Power, Carbon Sequestration, Basic Energy Sciences, Hydrogen, Bio-Fuels, Electric Grid and Infrastructure
DOI	Land, Forest, and Prairie Management, Mining, Sequestration, Geothermal, Terrestrial Sequestration Technology Development
DOS*	International Science and Technology Cooperation, Oceans, Environment
DOT	Aviation, Highways, Rail, Freight, Maritime, Urban Mass Transit, Transportation Systems, Efficiency and Safety
EPA	Mitigation of CO2 and Non-CO2 GHG Emissions through Voluntary Partnership Programs, including Energy STAR, Climate Leaders, Green Power, Combined Heat and Power, State and Local Clean Energy, Methane and High-GWP Gases, and Transportation; GHG Emissions Inventory
HHS*	Environmental Sciences, Biotechnology, Genome Sequencing, Health Effects
NASA	Earth Observations, Measuring, Monitoring, Aviation Equipment, Operations and Infrastructure Efficiency
NSF	Geosciences, Oceans, Nanoscale Science and Engineering Computational Sciences
USAID*	International Assistance, Technology Deployment, Land Use, Human Impacts
USDA	Carbon Fluxes in Soils, Forests and Other Vegetation, Carbon Sequestration, Nutrient Management, Cropping Systems, Forest and Forest Products Management, Livestock, and Waste Management, Biomass Energy and Bio-based Products Development

*** CCTP-related funding for the indicated agencies is not included in the totals for CCTP in the budget tables of Appendix A of the Strategic Plan. However, the agencies participate in CCTP R&D planning and coordination as members of CCTP's Working Groups.**

Historical Perspective on CCTP Funding*

CCTP Budget History



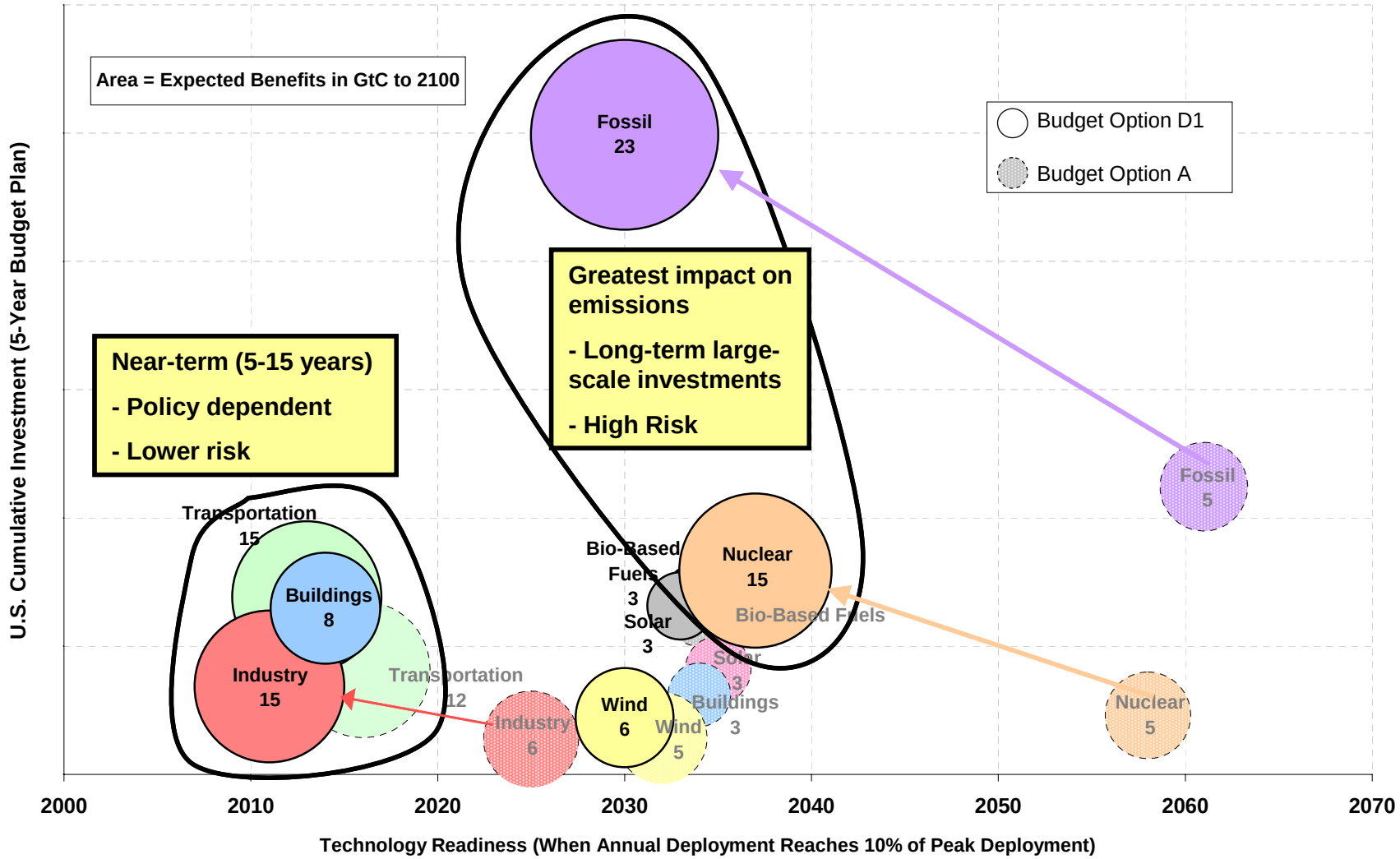
*Does not Include CCTP related Funding from STATE ($36M) and USAID deployment activities ($189M).

CCTP RD&D "Dashboard"

CCTP Strategic Goal		Key Element of Strategy	CCTP Strategic Plan -- Corresponding Technologies in Scenarios Analysis	Lead	Most Challenging Technical Scenario	Units	Scenarios Years & Quantities -- U.S. Only					Likelihood of CCTP Goal Attainment*				
							2020	2030	2040	2050	2100	Very Unlikely	Unlikely	Maybe	Likely	Very Likely
1 Reducing Emissions from Energy End-Use and Infrastructure	1.1	Transportation	Primary Energy Reduction	EE	BSS 450	$MtCO_2/yr$	371	530	687	858	1,247					
	1.2	Buildings	Primary Energy Reduction	EE	BSS 450	$MtCO_2/yr$	157	275	388	501	543					
	1.3	Industry	Primary Energy Reduction	EE	BSS 450	$MtCO_2/yr$	443	641	775	878	652					
	1.4	Electric Grid and Infrastructure	Enabling Technology, U.S. Grid Demand	OE	NEB 450	Trillion kWh/yr	6.67	7.35	7.92	8.38	9.49					
2 Reducing Emissions from Energy Supply	2.1	Low-Emission, Fossil-Based Fuels and Power	Electricity: Coal w/CCS	FE	CLC 450	$MtCO_2/yr$	69	192	401	689	1,208					
			Electricity: Natural Gas w/CCS	FE	CLC 450	$MtCO_2/yr$	60	148	311	541	954					
	2.2	Hydrogen	Hydrogen Production	EE	CLC 450	Quads	2.40	3.10	4.00	5.10	7.40					
	2.3	Renewable Energy and Fuels	Electricity: Solar Power	EE	NEB 450	$MtCO_2/yr$	0	9	59	164	216					
			Electricity: Wind Power	EE	NEB 450	$MtCO_2/yr$	11	89	237	421	476					
			Bio-Based Fuels	EE	BSS 450	$MtCO_2/yr$	0	8	56	168	214					
	2.4	Nuclear Fission	Electricity: Gen III Reactors	NE	NEB 450	$MtCO_2/yr$	33	183	472	864	1,339					
			Electricity: Gen IV Reactors	NE	NEB 450	$MtCO_2/yr$	0	14	77	207	556					
			Electricity: International Tech. --GNEP	NE	NEB 450-W	Trillion kWh/yr	0.01	0.01	0.02	21.94	39.06					
	2.5	Fusion Energy	Electricity: Fusion Energy, Others	SC	BSS 450	$MtCO_2/yr$	0	0	44	163	1,287					
3 Capturing and Sequestering Carbon Dioxide	3.1	Carbon Capture	(Embedded in 2.1)	FE	N/A	N/A	TBD									
	3.2	Geological Storage	Carbon Storage	FE	CLC 450	$MtCO_2/yr$	130	341	726	1,285	2,237					
	3.3	Terrestrial Sequestration	TBD	USDA	TBD	$MtCO_2/yr$	TBD									
	3.4	Ocean Sequestration	Not Applicable This Round	DOE	N/A	N/A	TBD									
4 Reducing Emissions of Non-CO_2 Greenhouse Gasses	4.1	Methane Emissions from Energy and Waste	CH_4 in CO_2-Equivalence	DOE/EPA	CLC 450	$MtCO_2$-Eq/yr	TBD									
	4.2	Methane and Nitrous Oxide Emissions from Agriculture	TBD--CH_4 (Part)	USDA	CLC 450	$MtCO_2$-Eq/yr	TBD									
			TBD--N_2O (Part)	USDA	CLC 450	$MtCO_2$-Eq/yr	TBD									
	4.3	Emissions of High Global-Warming Potential Gases	Short-Lived F-Gases in CO_2-Equivalence	EPA	CLC 450	$MtCO_2$-Eq/yr	TBD									
			Long-Lived F-Gases in CO_2-Equivalence	EPA	CLC 450	$MtCO_2$-Eq/yr	TBD									
	4.4	Nitrous Oxide Emissions from Combustion and Industrial Sources	N_2O in CO_2-Equivalence	EPA	CLC 450	$MtCO_2$-Eq/yr	TBD									
	4.5	Emissions of Tropospheric Ozone Precursors and Black Carbon	TBD	EPA	TBD	$MtCO_2$-Eq/yr	TBD									
5 Enhancing Capabilities to Measure and Monitor Greenhouse Gasses	5.2	MM -- Energy Production and Efficiency	N/A	DOE			Refer to Strategic Plan, Chapter 8									
	5.3	MM -- CO_2 Capture and Sequestration	N/A	DOE			Refer to Strategic Plan, Chapter 8									
	5.4	MM -- Other Greenhouse Gases	N/A	EPA			Refer to Strategic Plan, Chapter 8									
	5.5	MM -- Integrated Systems Architecture	N/A	SC			Refer to Strategic Plan, Chapter 8									
6 Bolster Basic Science Contributions to Technology Development	6.1	Strategic Research	N/A	SC			Refer to Strategic Plan, Chapter 9									
	6.2	Fundamental Science	N/A	SC			Refer to Strategic Plan, Chapter 9									
	6.3	Exploratory Research	N/A	SC			Refer to Strategic Plan, Chapter 9									

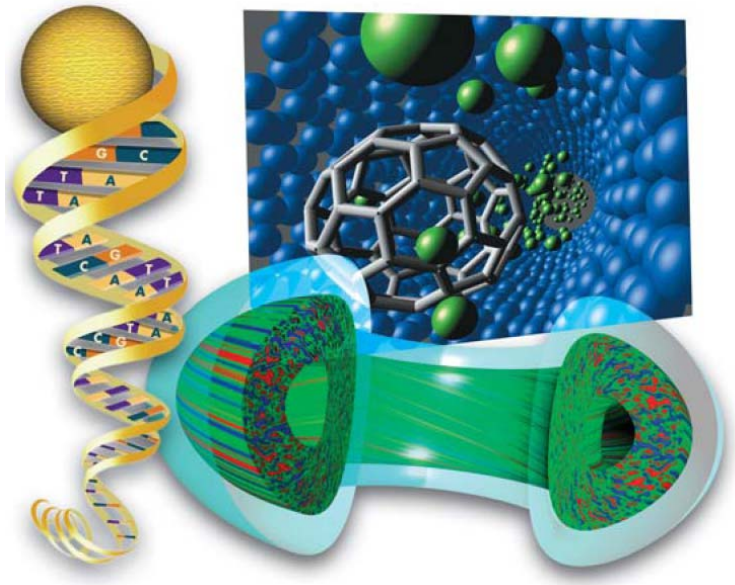
Federal RD&D Investment on High Return Areas

5-Year RD&D Investment, Technology Readiness Acceleration, and Expected Climate Change Benefits
(CCTP Goals & Risk Factors; to 2100)



Basic Science Research

- **Fundamental Science:**
  - **Fundamental science is basic research that provides the underlying foundation of scientific knowledge that can lead to fundamental new discoveries.**
- **Strategic Research:**
  - **Strategic research is basic research that is inspired by technical challenges in the applied research and development programs.**
- **Exploratory Research:**
  - **Exploratory research is basic research, or early and exploratory study of application-inspired concepts, undertaken in the pursuit of high-risk, novel, emergent, integrative or enabling approaches, not elsewhere covered.**



Fundamental science is critically important in the creation of new knowledge and improved understanding of technological innovation.

Source: Chapter 9, U.S. Climate Change Technology Program *Strategic Plan* (September 2006); www.climatetechnology.gov

Basic Science Underpins all Goals

Matrix for Integration of Applied and Basic Research Needs

	A strategic research area that is <u>central to advancing</u> the technology approach
	A strategic research area that is <u>expected to contribute significantly</u> to the technology approach
	A strategic research area that has the <u>potential to contribute significantly</u> to the technology approach
	A strategic research area that is <u>not expected to contribute significantly</u> to the technology approach

Goal 6: Basic Research		Goal 1: Energy End Use				Goal 2: Energy Supply					Goal 3: Capture & Sequestration			Goal 4	Goal 5
Fundamental Research Area	**Strategic Research Area**	Transportation	Buildings	Industry	Grid	Fossil	Hydrogen	Renewable	Nuclear	Fusion	Capture	Geo-Storage	Terrestrial Sequestration	Non-CO_2 Gases	Measurement and Monitoring
Physical Sciences	Materials: High Temperature														
	Materials: Tailored Mechanical Chemical Properties														
	Materials: Tailored Electrical Magnetic Properties														
	Heat Transfer & Fluid Dynamics														
	Combustion														
	Chemistry (Electro, Thermo)														
	Chemistry (Photo, Radiation)														
	Membranes & Separations														
	Condensed Matter Physics														
	Nanosciences														
	Geosciences & Hydrology														
	Chemical Catalysis														
Biological Sciences	Bio-Catalysis														
	Plant and Microbial Genomics (Biotechnology)														
	Bio-Based & Bio Inspired Processing														
Environmental Sciences	Environmental Science														
	Atmospheric Science														
Advanced Scientific Computing	Computational Sciences (Models & Simulations)														
Fusion Sciences	Plasma Sciences														
Enabling Research	Strategic Research for Sensors & Instrumentation														

Science to Technology Workshops

Basic Research Needs from 2005 CCTP Portfolio Review:

- Electric grid challenges – system architecture, control systems, and power electronics
- Thermoelectrics by application (e.g., refrigeration, power generation)
- Solid state lighting
- Bio-X – combination of nanoscience and genomics
- Plant genetic engineering
- Measuring and monitoring of climate change mitigation – international focus
- Sensors, controls, communication
- Energy storage – basic science and requirements of integrated systems
- Batteries – power & energy (basic chemistry)
- Heat Transfer – material insulation, cryogenics, thermal conducting coolants
- Ocean sequestration & methane hydrates

BES/BER "BRN" Workshops To Date:

- **Catalysis for Energy**
  August 6-8, 2007
- **Electric Energy Storage**
  April 2-4, 2007
- **Clean and Efficient Combustion of 21st Century Transportation Fuels**
  October 29–November 1, 2006
- **Advanced Nuclear Energy Systems**
  July 31 - August 3, 2006
- **Solid-State Lighting**
  May 22 - 24, 2006
- **Superconductivity**
  May 8-11, 2006
- **Breaking the Biological Barriers to Cellulosic Ethanol**
  December 2005
- **Genomics: GTL Roadmap**
  August 2005
- **The Path to Sustainable Nuclear Energy**
  September 2005
- **Solar Energy Utilization**
  April 18-21, 2005
- **Advanced Computational Materials Science: Application to Fusion and Generation IV Fission Reactors**
  March 31-April 2, 2004
- **Nanoscience Research for Energy Needs**
  March 16-18, 2004
- **Hydrogen Economy**
  May 13-15, 2003
- **Assure a Secure Energy Future**
  October 21-25, 2002
- **Opportunities for Catalysis**
  2002

BRN = Basic Research Needs

Energy Frontier Research Centers

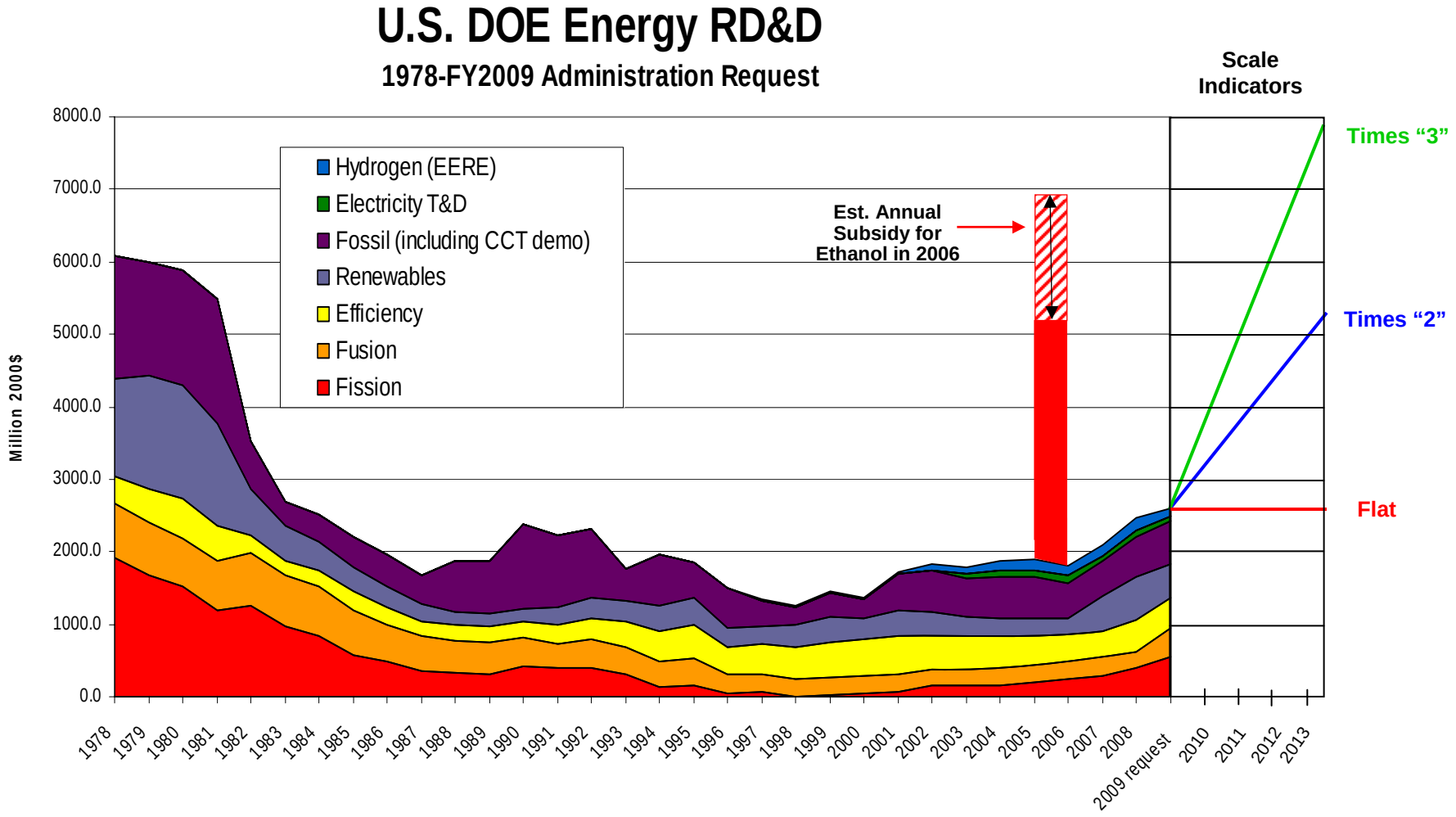
- **A New Era for Science --**
  - ***Innovative Basic Research to Accelerate Scientific Breakthroughs Needed to Create Advanced Energy Technologies for the 21st Century Awards to be $2M - $5M per Year for an Initial 5-Year Period (~$100M/Yr)***

- **Centers Will Pursue Fundamental Basic Research in Areas Such as:**
  - **Solar Energy Utilization**
  - **Catalysis for Energy**
  - **Electrical Energy Storage**
  - **Solid State Lighting**
  - **Superconductivity**
  - **Geosciences for Nuclear Waste and CO2 Storage**
  - **Advanced Nuclear Energy Systems**
  - **Combustion of 21st Century Transportation Fuels**
  - **Hydrogen Production, Storage, and Use**
  - **Materials Under Extreme Environments**

- **FY 2009 Budget Proposal --**
  - ***The Office of Science seeks to engage the Nation's intellectual and creative talent to tackle the scientific grand challenges associated with determining how nature works, leading the scientific community to direct and control matter at the quantum, atomic, and molecular levels, and harness this new knowledge and capability for some of our most critical real-world challenges.***

- **U.S. Universities, DOE Laboratories, and Other Institutions are Eligible**

Historical Perspective on DOE Spending



Gallager, K.S., Energy Technology Innovation Project, Belfer Center for Science & International Affairs, Kennedy School of Government, Harvard University, Cambridge, MA. File downloaded at: http://belfercenter.ksg.harvard.edu/publication/18152/doe_budget_authority_for_energy_research_development_and_demonstration_database.html

Commercialization and Deployment

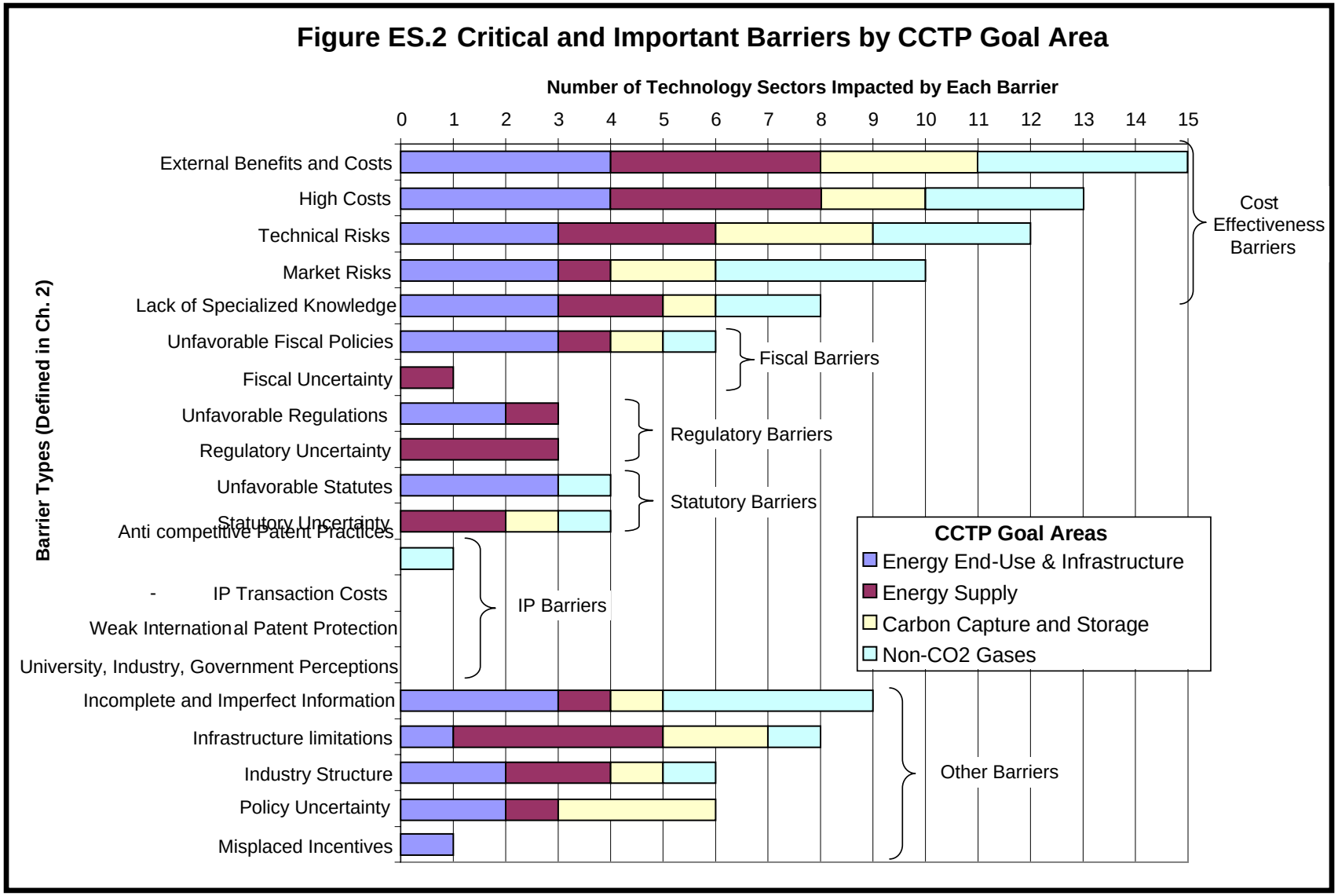
Barriers Typology

Cost Effectiveness	Fiscal Barriers	Regulatory Barriers	Statutory Barriers	Intellectual Property Barriers	Other Barriers
High Costs	Unfavorable Fiscal	Unfavorable Regulations	Unfavorable Statutes	IP Transaction Costs	Incomplete and Imperfect Information
Technical Risks	Fiscal Uncertainty	Regulatory Uncertainty	Statutory Uncertainty	Anti-competitive Patent Practices	Infrastructure limitations
Market Risks	Unfavorable tariffs			Weak International Patent Protection	Industry Structure
External Benefits and Costs				University, Industry, Government Perceptions	Misplaced Incentives
Lack of Specialized Knowledge					Policy Uncertainty

6 Barrier Categories
21 Barriers
~50 Detailed Barriers

Barriers are organized into six categories consistent with EPAct 2005 Title XVI.

Barriers – Summary of Findings



Financial Incentives

Existing Incentives

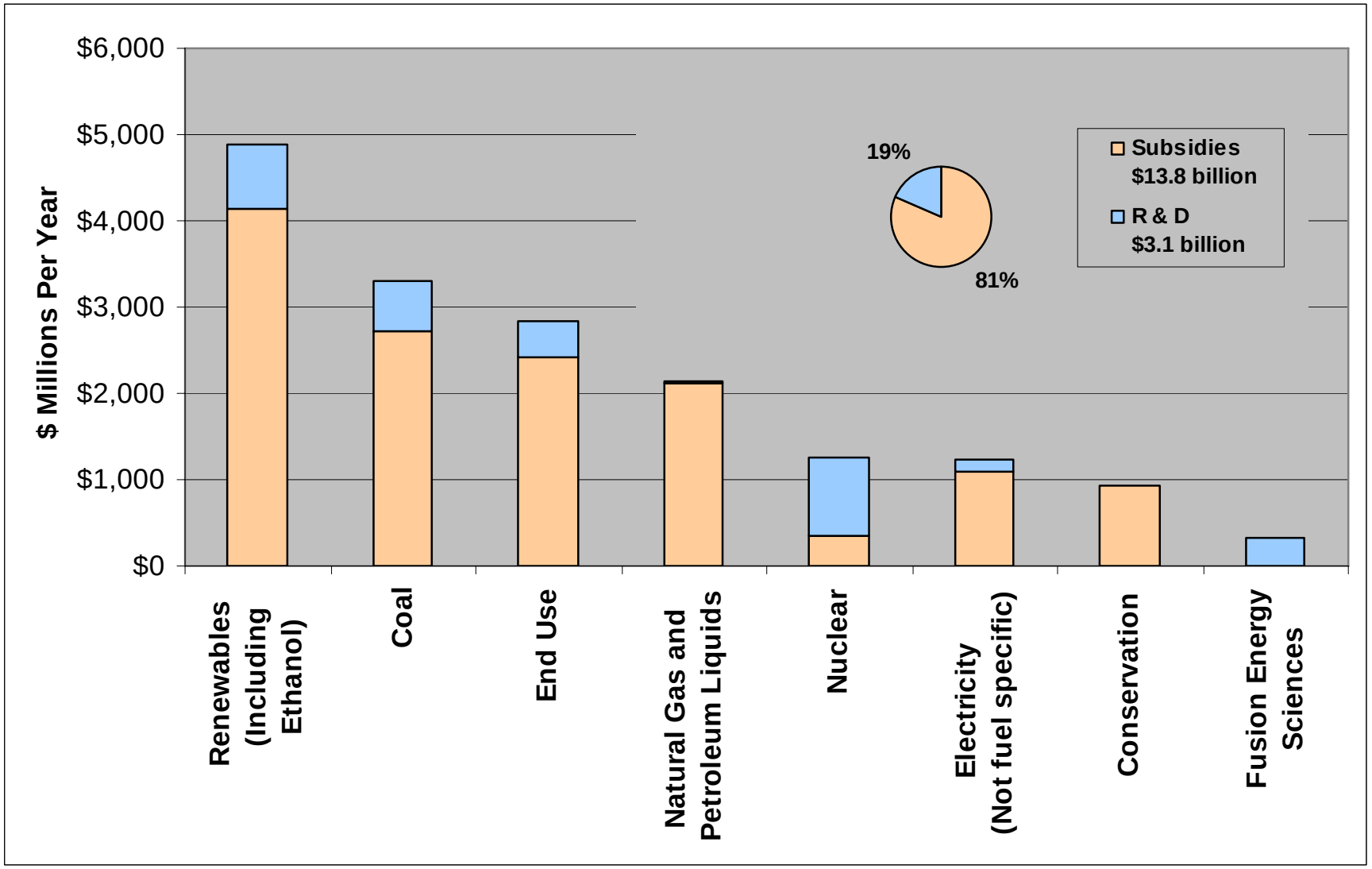
- **Efficiency & Transportation**
  - Hybrid and Fuel Cell Vehicles (Tax Credit)
  - Clean Fuel Cars, Truck and Refueling Stations
  - Tax Credits for Energy Efficient Building Improvements (Residential and Commercial)
  - Tax Credits for Construction of Energy Efficient Homes
  - Exclusion of Utility Conservation Subsidies
- **Renewable Energy**
  - Renewable Energy Production Credits
  - Residential Solar Energy (Tax Credits)
  - Investment Tax Credits for Solar, Geothermal
  - Hydroelectric, Biomass Elec. (Excl. of Interest on Bonds)
  - Biomass Ethanol (Exemption from Excise Taxes)
- **Low-Carbon Fossil**
  - Coal Bed Methane (Production Credit)
- **Other and Crosscutting**
  - Industry Tax Credits for Landfill Gas and Combined Heat and Power

Recent Additions*

- **Efficiency & Transportation**
  - Conservation and Energy Efficiency
  - Tax Credit for Efficient Vehicles
  - Loans for Manufacture of Adv. Technology Vehicles
- **Renewable Energy**
  - Extend Renewable Electricity Production Credit (e.g., Home Solar)
  - Renewable Energy Bonds
  - Ethanol and Biodiesel Tax Credits
- **Low-Carbon Fossil**
  - Clean Coal Investment Tax Credit
- **Nuclear**
  - Production Credit for Advanced Nuclear,
  - Nuclear Decommissioning,
  - Risk Insurance
- **Other and Crosscutting**
  - Energy Infrastructure (Transmission)
  - Loan Guarantees for Power and Fuels

*EPAct05, EISA07, Omnibus FY08 Appropriation, Emergency Economic Stabilization Act of 2008, & FY-2009 CR

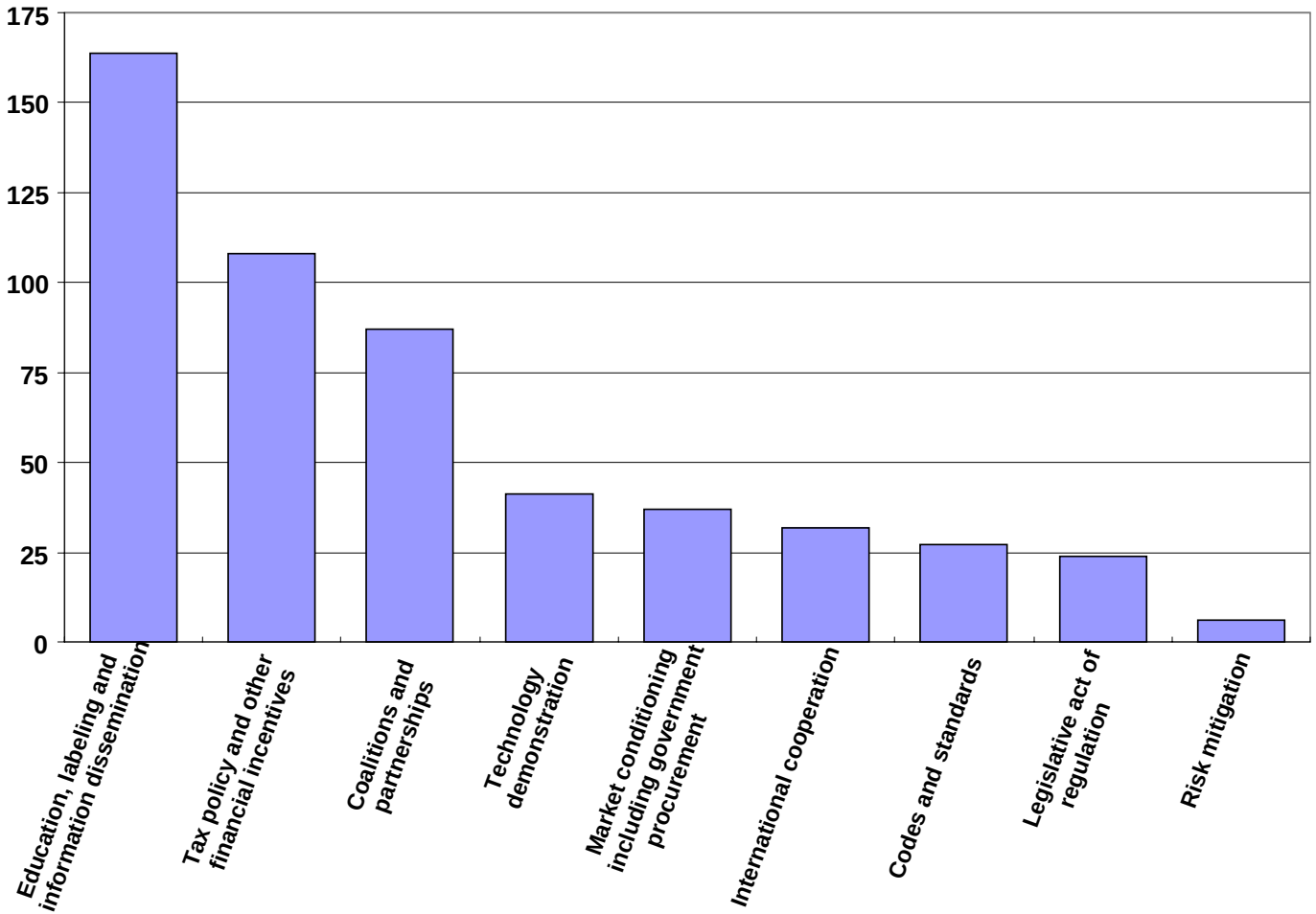
Federal Financial Interventions and Subsidies in Energy Markets FY 2007



Source: Energy Information Administration "Federal Financial Interventions and Subsidies in Energy Markets 2007, SR/CNEAF/2008-01, April 2008"

Commercialization & Deployment Activities, by Category or Genre

Number of Government Commercialization and Deployment Activities by Type of Policy and Measure



Policy Process Underway
Some Policy Options, by Technology Area

Technology Areas	Tax Policy and Financial Incentives	Legislative Acts and/or Regulation
Coal w/CCS	Loan Guarantees; Tax Incentives; Cost-Shared Partnerships	CO_2 Storage – Siting & Permitting; Monitoring and Verification; Liability Indemnification; New Source Review Revisions; Access to Public Lands; Property Rights for Subsurface Areas
Nuclear Fission	Loan Guarantees; Production Tax Credit; Standby Support for Certain Delays	Liability Indemnification; Standard Design Certifications; Early Site Permits; Combined Construction & Operating License; Waste and Fuel Management and Storage
Electric Grid and Infrastructure	Loan Guarantee Program, Waste Energy Recovery Incentive Grants*; SmartGrid Investments Matching Grants*; Additional Incentives for Investments (including Cost Recovery Mechanisms)	Public Utilities Regulatory Policies; Renewable and Distributed Generation Code and Standards; Transmission Pricing (Rate Structures); National Transmission Corridors; SmartGrid Code and Standards*; Utility Energy Efficiency Programs*; Standard Net Metering and Interconnection Policies; Siting Access Rights; Access to Meter and Other Data;
Transportation	Tax Credit; Manufacturing Credit; Consumer Incentives, Manufacturing Incentives*	National Regulatory Policies; Urban and Land Use Planning; CAFÉ*; Federal Fleet*
Hydrogen	Loan Guarantees; Alternative Motor Vehicle and Alternative Fuel Infrastructure Tax Credits; Investor Incentives; Insurance	Safety, Codes & Standards; Stationary Fuel Cell Permitting
Bio-Based Fuels	Credit for installing alternative fuel refueling; Loan Guarantees; Production Tax Credit; Development Grants*	Stable Financial Incentives; National Regulatory Policies; Biofuels Tariff; Federal Fleet*, Standard specifications for fuels*
Wind Power	Loan Guarantees; Production Tax Credit; Clean Renewable Energy Bonds; Development Grants*;	Manufacturing Partnerships*; Stable Financial Incentives; Mandated Federal Procurement of Wind Power;
Industry	Loan Guarantees; Efficiency Tax Credits; Sector Specific Tax Credits	Equipment Standards; Emissions Regulations; Informational Partnerships (e.g.; Manufacturing Extension Partnership), Energy-intensive industries program*
Buildings	Manufacturer and Consumer Efficiency Tax Credits, Tax Deductions for Commercial Buildings; Accelerated Depreciation	Federal appliance and equipment standards; Building Codes*; Government Procurement, Federal Buildings Standards*
Solar Power	Loan Guarantees; Business Energy Tax Credit; Residential & Business Solar Investment Tax Credit; Clean Renewable Energy Bonds; Development Grants*; Production Tax Credit	Manufacturing Partnerships*; Stable Financial Incentives; Access to Public Lands (for concentrating solar power installations); Mandated Federal Procurement of Solar Power

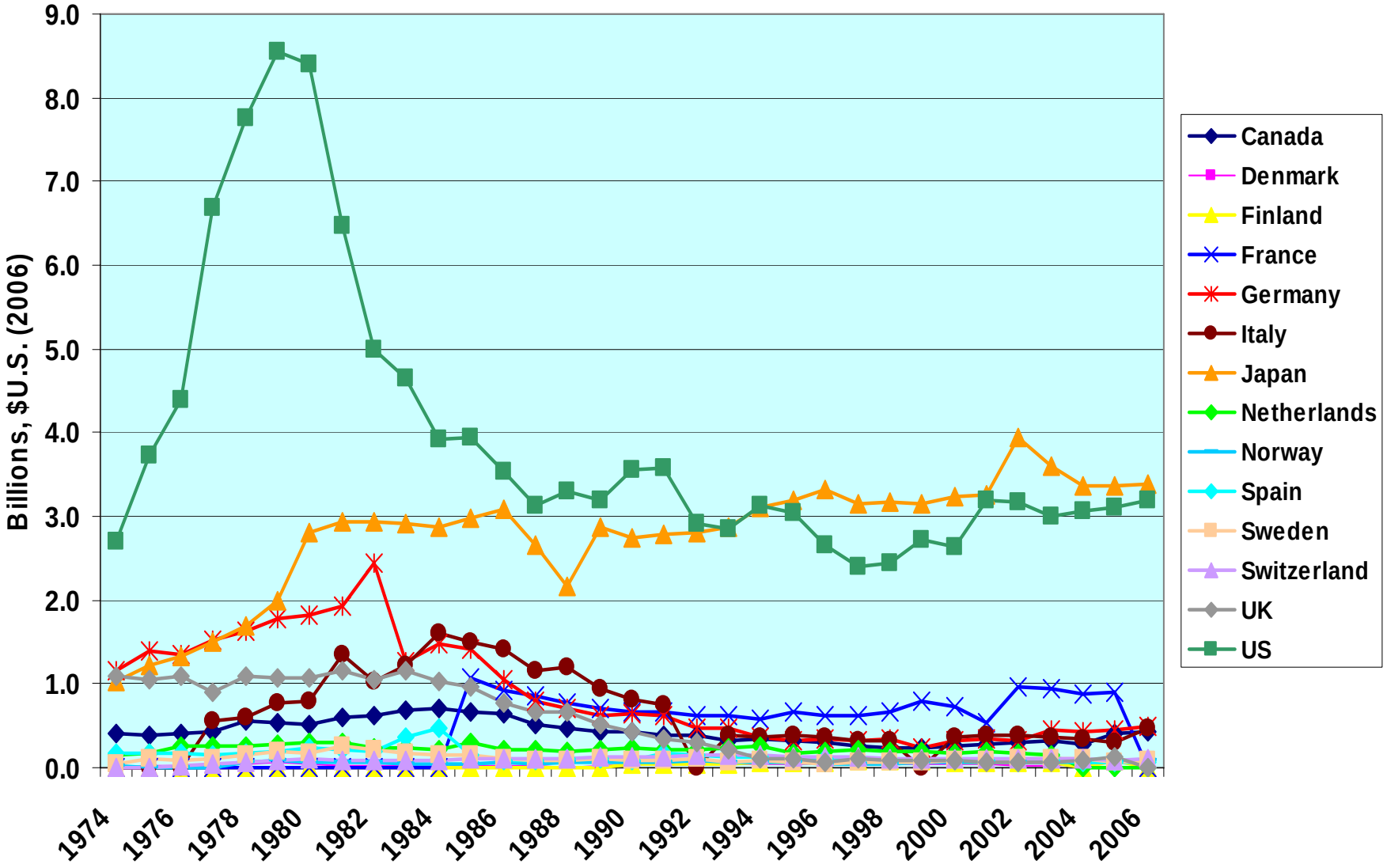
Green: Existing Policies
Red: Policy Options

International R&D Cooperation

International Planning Context

- U.S. is Signatory to the UNFCCC
- U.S. is Committed to Bali Roadmap for a Post-2012 Agreement
  - Emphasis is on Technology and an Outcome that is Both:
    - » Environmentally Effective – Measurable, Reportable, and Verifiable Actions by the World's Largest Emitters
    - » Economically Sustainable – Uphold Hopes for Economic Growth, Energy Security, and Improved Quality of Life
- Mechanisms for Progress Include:
  - Major Economies Process to Engage Largest Emitters
  - Financial Assistance to Developing Countries – MDBs , GEF, CTF
  - Cooperative Partnerships to Engage the Private Sector (e.g., APP)
  - Global Tech. to Lower Costs and Speed Deployment
    - » U.S. Joined Other G8 Members in Committing to Increased Clean Energy Technology R&D -- $10 B Pledged So Far
    - » Numerous Cooperative Mechanisms
- Agreement Must be Something the Senate Would Ratify

History of Int'l Energy R&D



International Energy Agency: Statistics: R&D Investments

International Cooperation

Benefits

- Raise Overall Global Level of Effort
- Accelerate Technology Development
- Pool Technical Resources
- Gain Access to Privileged Facilities
- Broaden Knowledge Base
- Facilitate Exchange of Information
- Enable Multi-Path Approaches
- Harmonize Technical Standards
- Reduce Partner Costs & Risks
- Increase Likelihood of Success

Challenges

- Diverse National R&D Funding Motivations, Schemes and Priorities
- Lack of Common, Shared Vision
- Heterogeneous Program Designs
- Patents & Intellectual Property Issues
- Other Barriers (e.g., National Security)
- Administrative Complexity and Cost
- Travel and Coordination Costs
- Management & Accountability Issues
- Technical Support (e.g. IPCC/TSU)
- Need for Strong Central Leadership

Key Technologies & International Cooperation

Key Technologies

- Advanced Lighting
- Building & Home Construction
- Advanced Transportation
- Grid (Power Electronics)
- Clean Coal
- Advanced IGCC
- Geothermal
- Hydro/Wind/Solar Power
- Rural/Village Energy Systems
- Bioenergy
- Civilian Nuclear Power
- Methane Capture/Use
- Agriculture/Forestry

International Cooperation

- Carbon Capture and Storage
  (22 Nations)
- Future Gen Coal (5 Nations)
- Hydrogen (17 Nations)
- Global Nuclear Energy Partnership
  (21 Nations)
- Gen IV Nuclear (13 Nations)
- Fusion Energy - ITER (7 Nations)
- Global Earth Observation (73 Nations)
  - Recommended by National Academy of Sciences
- Clean Energy Technology Fund
  - US, UK and Japan, World Bank
- Asia Pacific Partnership (6 Nations)

Potential Areas for Int'l Collaboration

Energy End-Use Technologies	Energy Supply Technologies	Capture CO_2 Directly from Atmosphere
Zero-Emission Vehicle Systems	Stationary Fuel Cells	Geologic Storage: Safety, Health, and Environmental Risk Assessment
Multi-Modal Intercity & Freight Transport	Zero-Emission Fossil Energy	Geologic Storage: Large-Scale Demonstration
Engineered Urban Designs & Regional Planning	Hydrogen Zero-Emission Fossil Energy	Terrestrial Sequestration: Reforestation
Low Aviation Emissions	Low-Cost H_2 Storage & Delivery	Terrestrial Sequestration: Soils Conservation
Ultra-Efficient HVACR	Cost-Competitive Solar PV	Carbon & CO_2 Based Products & Materials
Intelligent Building Systems	Cellulosic Biofuels	Ocean CO_2 Biological Impacts Addressed
Energy Managed Communities	Photolytic Water Splitting	**Non CO_2 GHGs**
C&CO_2 Managed Industries	Advanced Fission Reactor and Fuel Cycle Technology	Precision Agriculture
Water and Energy System Optimization	Proliferation-Resistant Fuel Cycles	Zero-Emission Agriculture
Industrial Heat, Power, Processes	Advanced Concepts for Waste Reduction	Solid-State Refrigeration/AC Systems
High-Efficiency, All-Electric Manufacturing	Demonstration of Burning Plasmas	Catalytic Reduction of N_2O
Closed-Cycle Products & Materials	Fusion Power Plants	**M&M**
Energy Storage for Load Leveling	**CCS**	Fully Operational Sensor and Satellite Networks
Advanced Controls and Power Electronics	Post Combustion Capture	Low-Cost Sensors and Communications
Wireless Transmission	Oxygen Separation Technologies	MM Systems Architecture

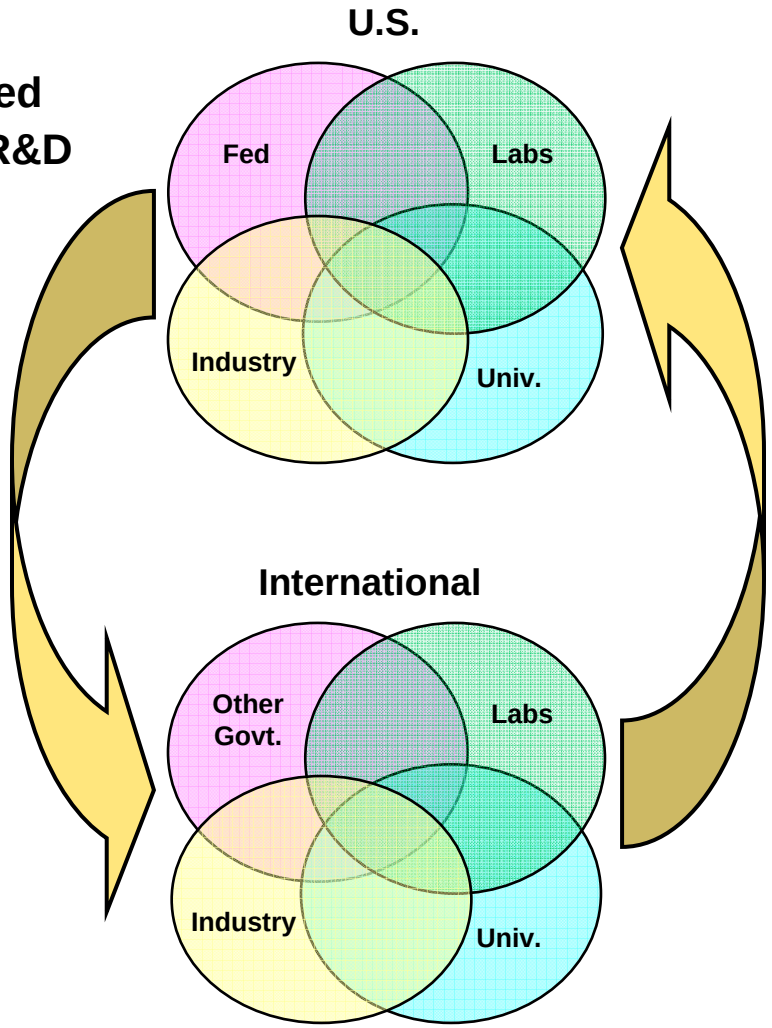
Thoughts
for Discussion

Additional Technology Perspectives

- **Known Next Steps for U.S. Domestic Action**
  - **Continue to Carry-Out More than 300 Federal Polices & Measures**
  - **Implement New or Strengthened Climate Change-related Provisions of Recent Legislation – EPAct'05, EISA'07, Omnibus Appropriations for FY'08, Continuing Resolution for FY'09, and the Emergency Economic Stabilization Act of '08.**
- **Selected Highlights:**
  - **More Aggressive Phase-Out of Ozone Depleting Substances That Have High Global Warming Potential**
  - **Land Use Incentives in the Farm Bill**
  - **Increased Auto Fuel Efficiency Standards**
  - **Renewable Fuel Standards**
  - **Nation-Wide Lighting Standards**
  - **Building and Appliance Standards**
  - **Support $42.5 B in Loan Guarantees for Spurring Investment of Early-Adopters in Climate Technologies – Renewables, Nuclear, Clean Coal**
  - **Address the Pending Environmental Regulatory Agenda of EPA**
  - **Mandatory GHG Emissions Reporting; Rules for CCS**
- **Others ?**

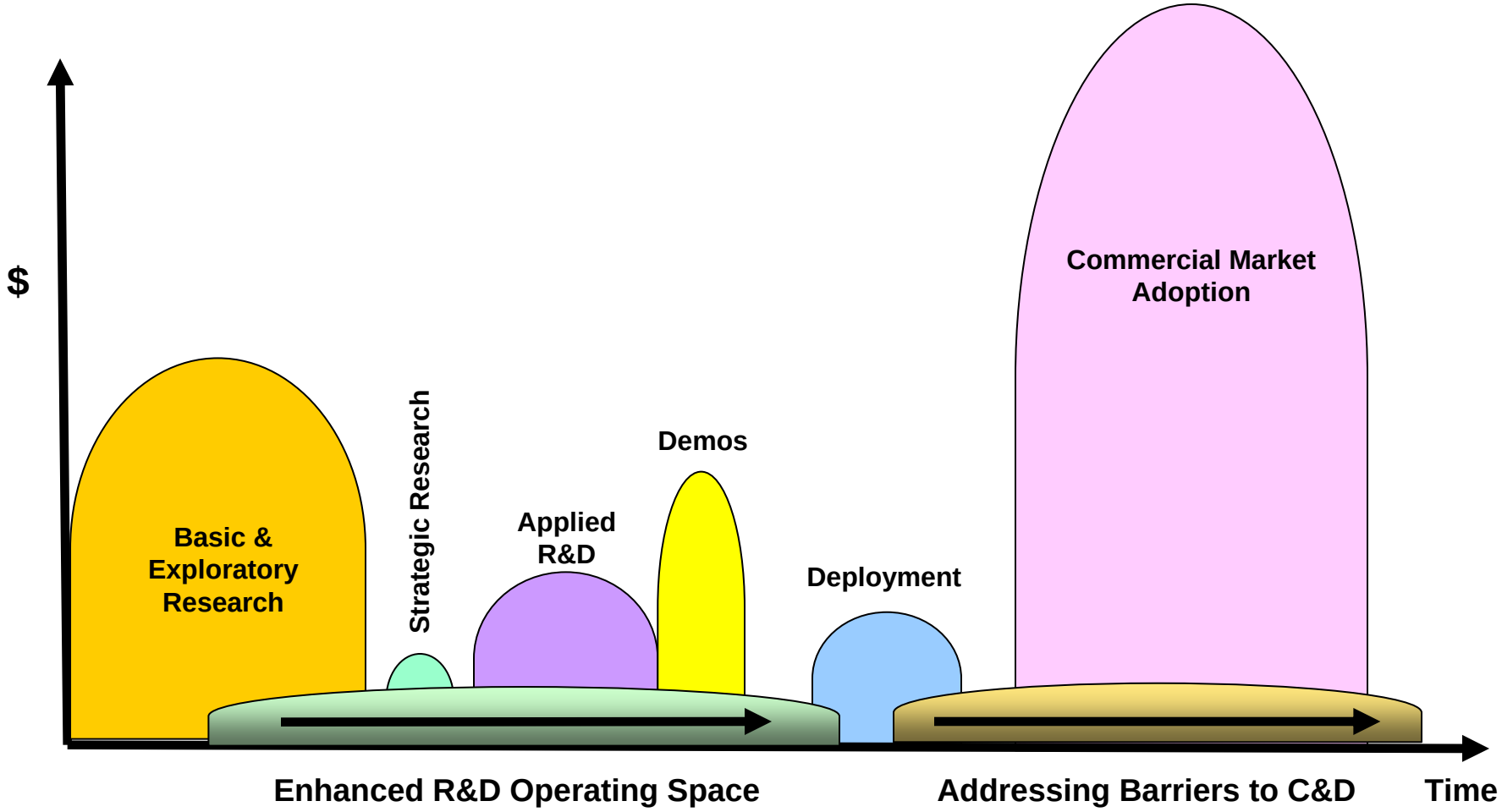
Accelerated Technology Development

- **Level of Global R&D Investment -- Too Low**
  - **Pace of Progress Too Slow**
  - **U.S. Federal R&D is Increasing, but Constrained**
  - **Two Countries Account for 80 Percent of CC R&D**
  - **Other Governments' R&D Decreasing**
- **How to Lift Global Effort?**
  - **More U.S. R&D ?**
  - **More International R&D ?**
  - **More Private Sector R&D ?**
  - **Technology Push vs. Technology Pull ?**
  - **New Models for Incentivizing R&D ?**
- **Potential Areas for Enhancement**
  - **Coord., Integrated, Global R&D Strategy**
  - **Better Access to Under-Utilized Assets**
  - **More R&D Collaboration**
  - **Division of Labor on Key Tech. Initiatives**
  - **Enhanced S&T Cooperation**
  - **Addressing Non-Technical Barriers**
  - **Experimenting with New R&D Models**



Do We Need New R&D Management Constructs?

- **Are Existing R&D Management Structures Sufficient to Speed Progress and Address Key Barriers?**

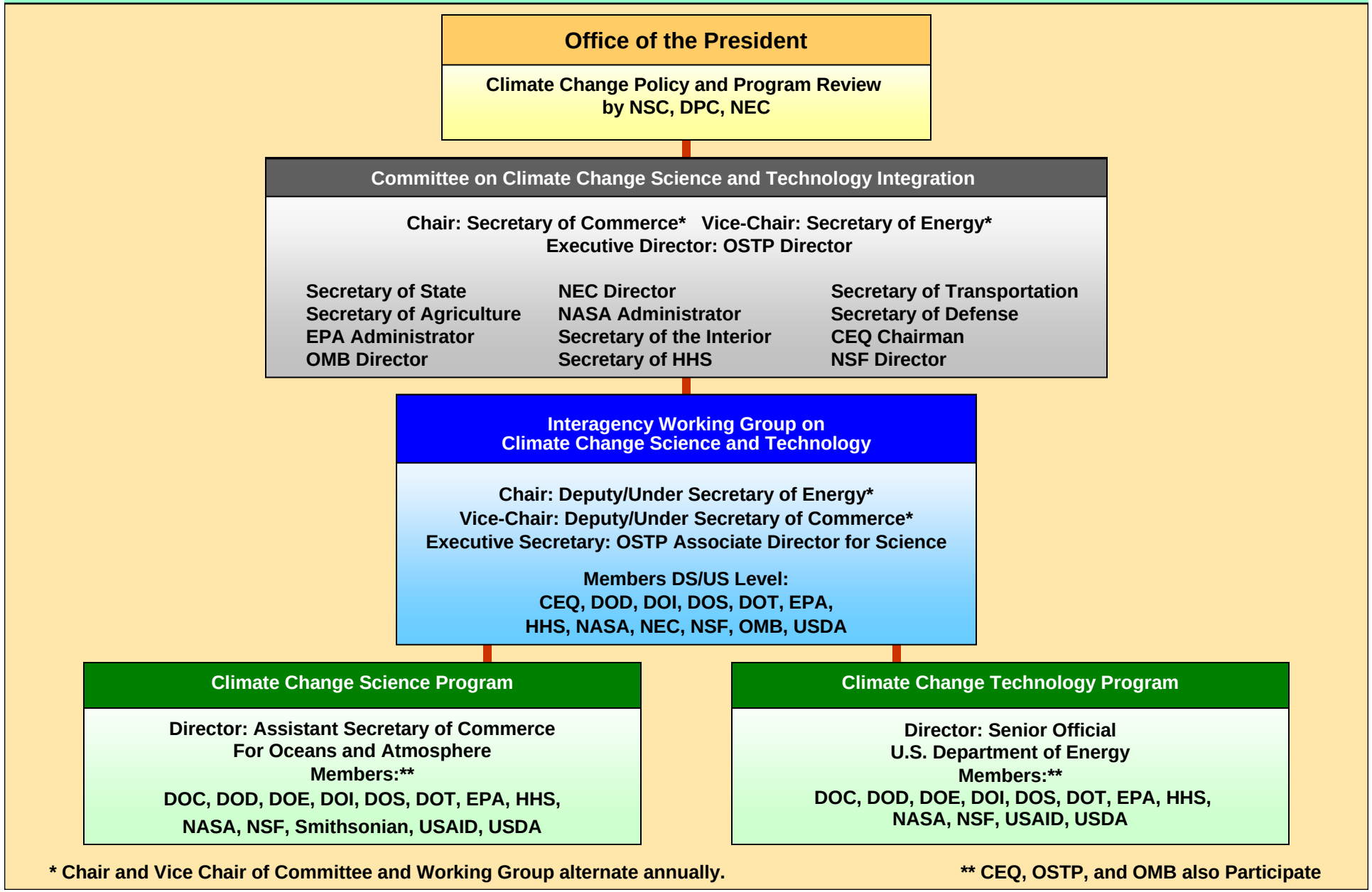


Summary Theme -- Multi-Goal Convergence

- **Global Community Aspires to Attain Multiple Goals:**
  - **Economic Growth and Prosperity**
  - **Quality of Life, Health and Respect for the Environment**
  - **Secure, Reliable, Affordable, Clean Energy Supply**
  - **National Security and Global Stability**
  - **Climate Protection**
- **Such Goals Are Inextricably Intertwined**
  - **They Can Be, But Are Not Fundamentally, in Conflict**
- **The "Long-Pole" in the Tent is Climate Change**
- **If Society Were to Transform Itself to Meet the UNFCCC's Ultimate Goal Using Appropriate Technology, It Would . . .**
  - **Meet the Criteria of "Environmentally Effective" and "Economically Sustainable"**
  - **See "Convergence" of Progress Toward All Goals**
  - **Achieve Affordable Climate Protection**
- **Advanced Technology is the Key Enabler**

Back-Up Slides

Cabinet-Level Engagement



* Chair and Vice Chair of Committee and Working Group alternate annually.

** CEQ, OSTP, and OMB also Participate

CCTP Working Groups and Subgroups

8 January 2009

Climate Change Technology Program
Director: Steve Eule
Deputy Director: Robert Marlay
DOC, DOD, DOE, DOI, DOS, DOT, EPA, HHS, NASA, NSF, OMB, OSTP, USAID, USDA

Energy Supply
(DOE/NE)

- Hydrogen Production
- Renewable & Low Carbon Fuels
- Renewable Power
- Nuclear Fission Power
- Fusion Energy
- Low Emissions Fossil-Based Power

Energy End Use
(DOE/EE)
(DOC/NIST)

- Hydrogen End-Use
- Transportation
- Buildings
- Industry
- Electric Grid & Infrastructure

Other Gases
(EPA)

- Energy & Waste -Methane
- Agric. Methane & Other Gases
- High GWP Gases
- Nitrous Oxide
- Ozone Precursors & Black Carbon

Sequestration
(USDA)
(DOE/FE)

- Carbon Capture
- Geologic Storage
- Terrestrial Sequestration
- Ocean Storage
- Products/Materials

Basic Research
(DOE/SC)
(NSF)

- Fundamental Research
- Strategic Research
- Exploratory Research
- Integrative R&D Planning

Measurement & Monitoring
(NASA) (DOC/NOAA)

- Application Areas
- Integrated Systems

International Frameworks

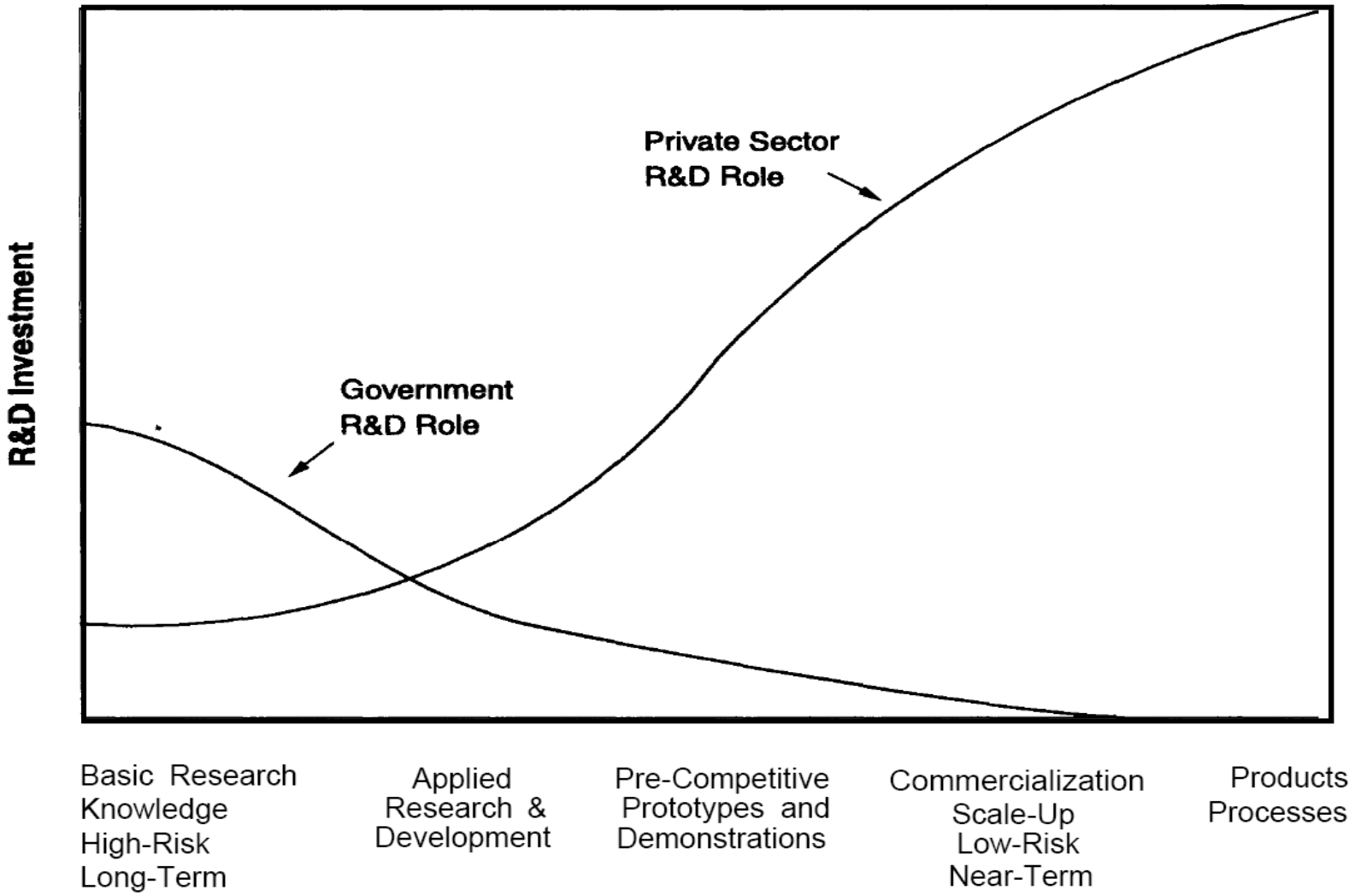
Global Action Programs

- Asia-Pacific Partnership (7 Nations)
  - Accounts for 50% of emissions
  - Nearly 100 actions
- G-8 Dialogue (13-20 Nations)
  - More than 40 programs
- Methane to Markets (20 Nations)
  - 180+ million tons reduced by 2015
- Renewable Energy and Efficiency (17 Nations)
- 12+ Bilateral Agreements on Technology and Lower Emissions
- Tropical Forest Conservation
- Stopping Illegal Logging
- Major Economies Process (17 Nations, Including EU)

Technology Advancement

- Carbon Capture and Storage (22 Nations)
- Future Gen Coal (5 Nations)
- Hydrogen (17 Nations)
- Global Nuclear Energy Partnership (19 Nations)
- Gen IV Nuclear (10 Nations)
- Fusion Energy - ITER (7 Nations)
- Global Earth Observation (71 Nations)
  - Recommended by National Academy of Sciences
- Clean Energy Technology Fund (US, UK and Japan, World Bank)

Innovation Process



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**

Grand Challenges in CC Science

- 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