Office of Nuclear Energy Research and Development Benefits Analysis Activities

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Office of Nuclear Energy

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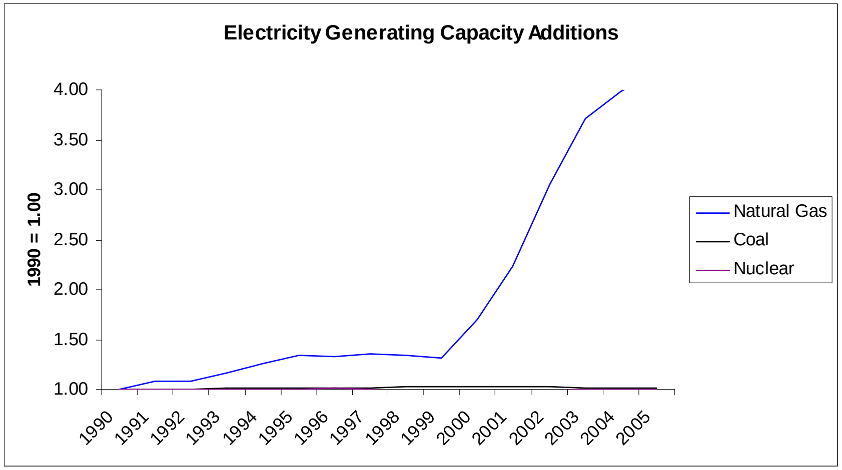
December 20, 2006

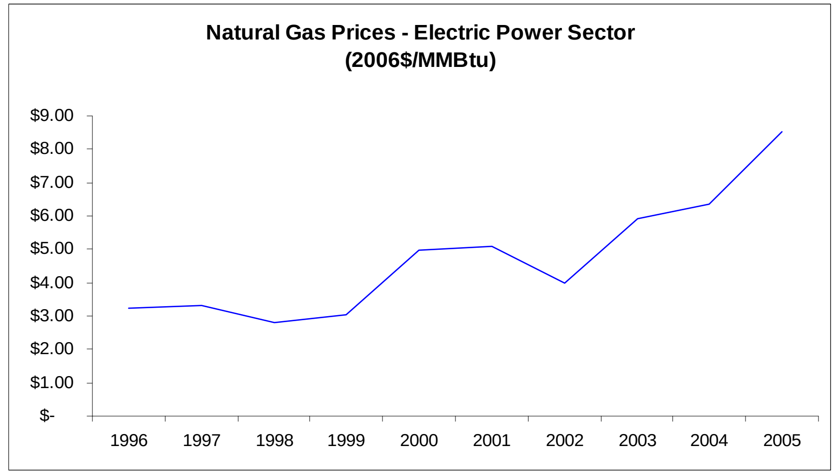
Presentation Outline

- Broad Objectives Governing NE Programs
- NE Program Descriptions & Assumptions
- The Process of Measuring Benefits
- Benefits Under Alternative Scenarios

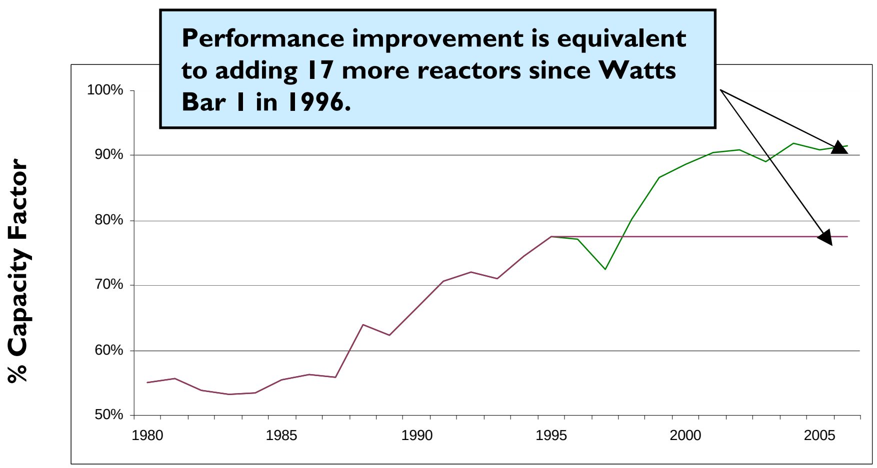
- **Broad Objectives Governing NE Programs**

Why Nuclear Power?

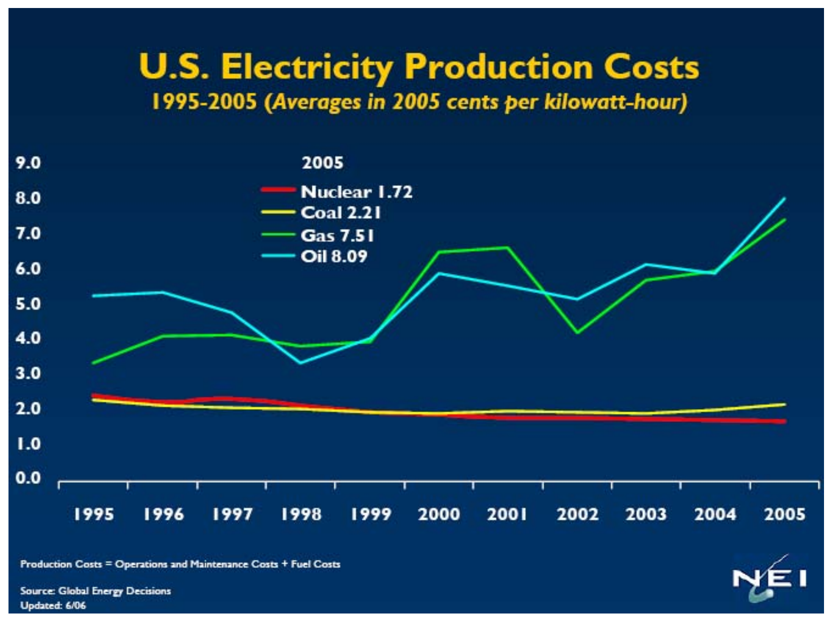




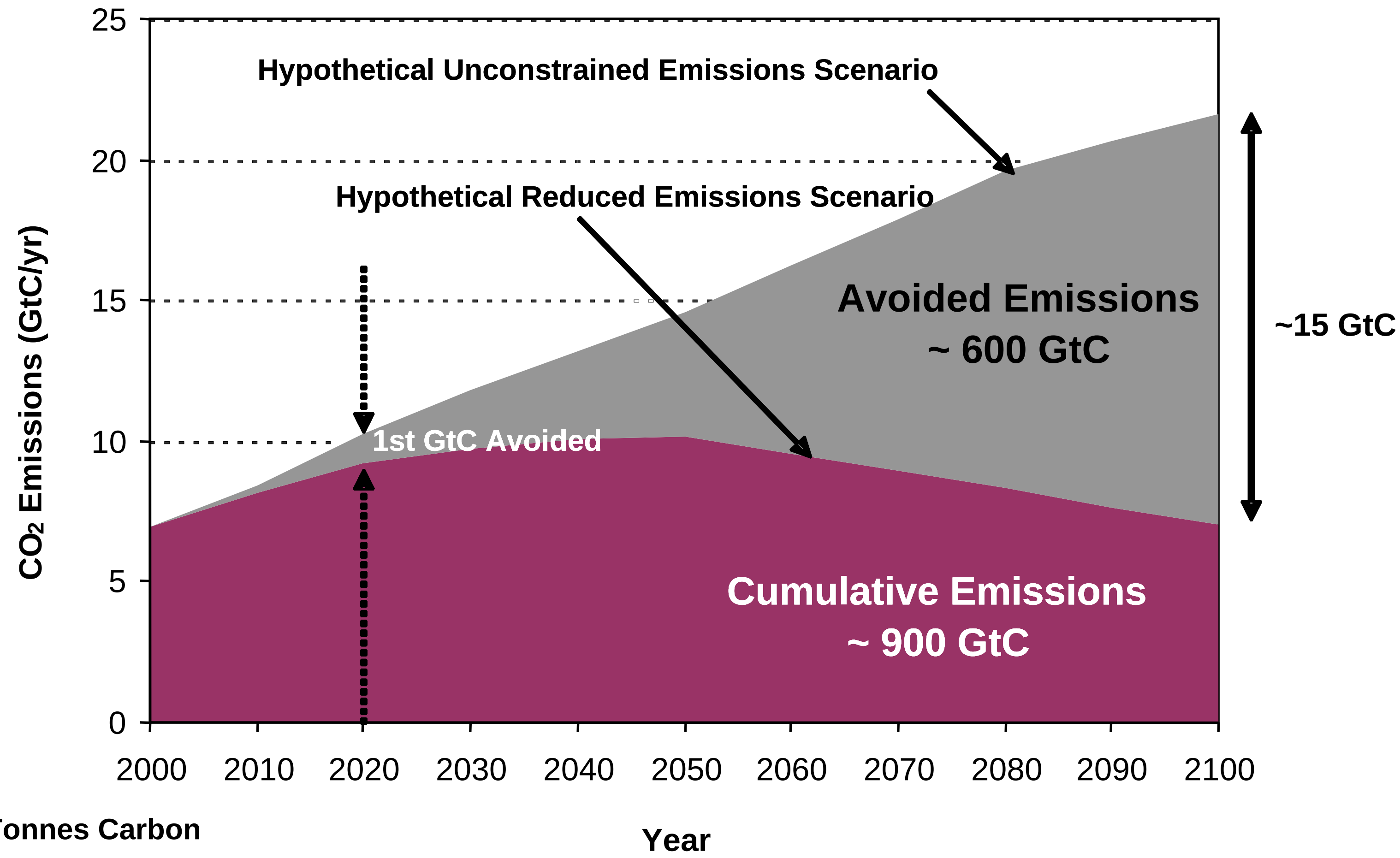
Nuclear Capacity Factor is at an All-Time High



Source: Energy Information Administration data



A CO2 Emissions Scenario



GtC = Giga-Tonnes Carbon

How Big is a "Gigaton" ?

Using Today's Technology, These Actions Can Cut Emissions by 1 GtC/Year

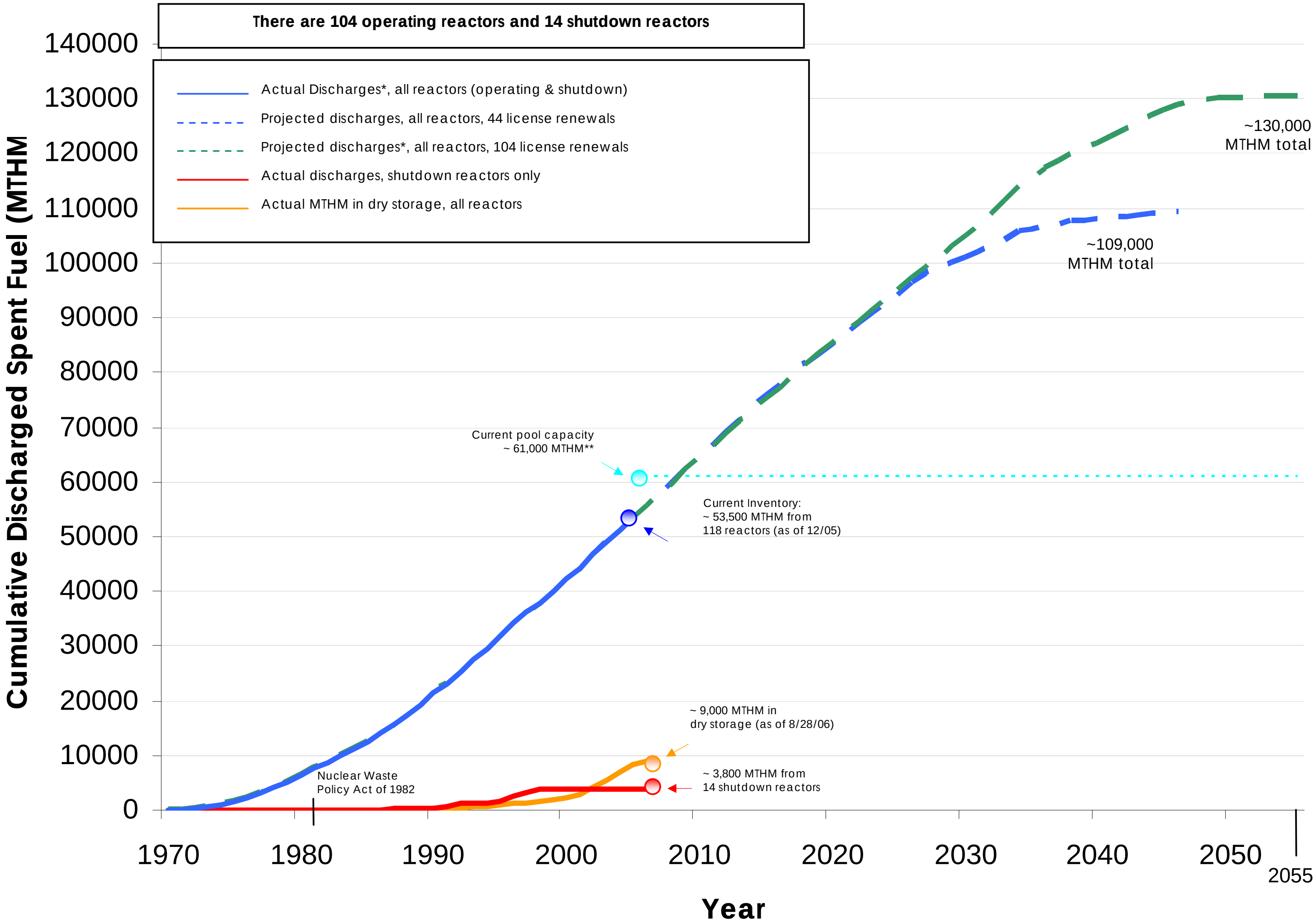
Today's Technology	Actions that Provide 1 Gigaton/Year of Mitigation
Coal-Fired Power Plants	**Build 1,000 "zero-emission" 500-MW coal-fired power plants (in lieu of coal-fired plants without CO_2 capture and storage)**
Geologic Sequestration	**Install 3,700 sequestration sites like Norway's Sliepner 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)**
Efficiency	**Deploy 1 billion new cars at 40 miles per gallon (mpg) instead of 20 mpg**
Wind Energy	**Install capacity to produce 50 times the current global wind generation (in lieu of coal-fired power plants without CO_2 capture and storage)**
Solar Photovoltaics	**Install capacity to produce 1,000 times the current global solar PV generation (in lieu of coal-fired power plants without CO_2 capture and storage)**
Biomass fuels from plantations	**Convert a barren area about 15 times the size of Iowa's farmland (about 30 million acres) to biomass crop production**
CO_2 Storage in New Forest.	**Convert a barren area about 30 times the size of Iowa's farmland to new forest**

Business Case for New Nuclear Power Plants

- **Outlook for nuclear power has improved since 1990:**
  - **A sharp rise in fleet capacity factor (65% in 1990; over 90% now), plus**
  - **Lower marginal cost of power produced relative to competing sources.**
  - **Good safety record and improved public sentiment in several regions.**
- **"Nth" nuclear power plant competitive with other sources.**
- **However, three key barriers could stall new U.S. orders.**
  - **Spent fuel disposal, including transportation.**
  - **Reauthorization of accident indemnification.**
  - **Clarification of NRC licensing processes, particularly for commissioning.**
- **Plus, early-plant capital costs appear to be too high:**
  - **Capital costs (financing included) could be >$1600 / KWe at first, may decline to ~$1200 / KWe for 4th/5th plants, and to ~$1100 / KWe for "Nth".**
  - **Orders of first plants could require government assistance.**
  - **Such assistance may / can more precisely address risks than cost-shared grants / contracts and reduce potential costs to government.**

Source: "Business Case for New Nuclear Power Plants," Scully Capital, June 2002.

Impact of Different Fuel Cycle Strategies on Eventual Repository Needs



NE's Two Overarching Goals

- **Pave the way for industry decisions to build new advanced light water reactors in the United States that will begin operation early in the next decade.**

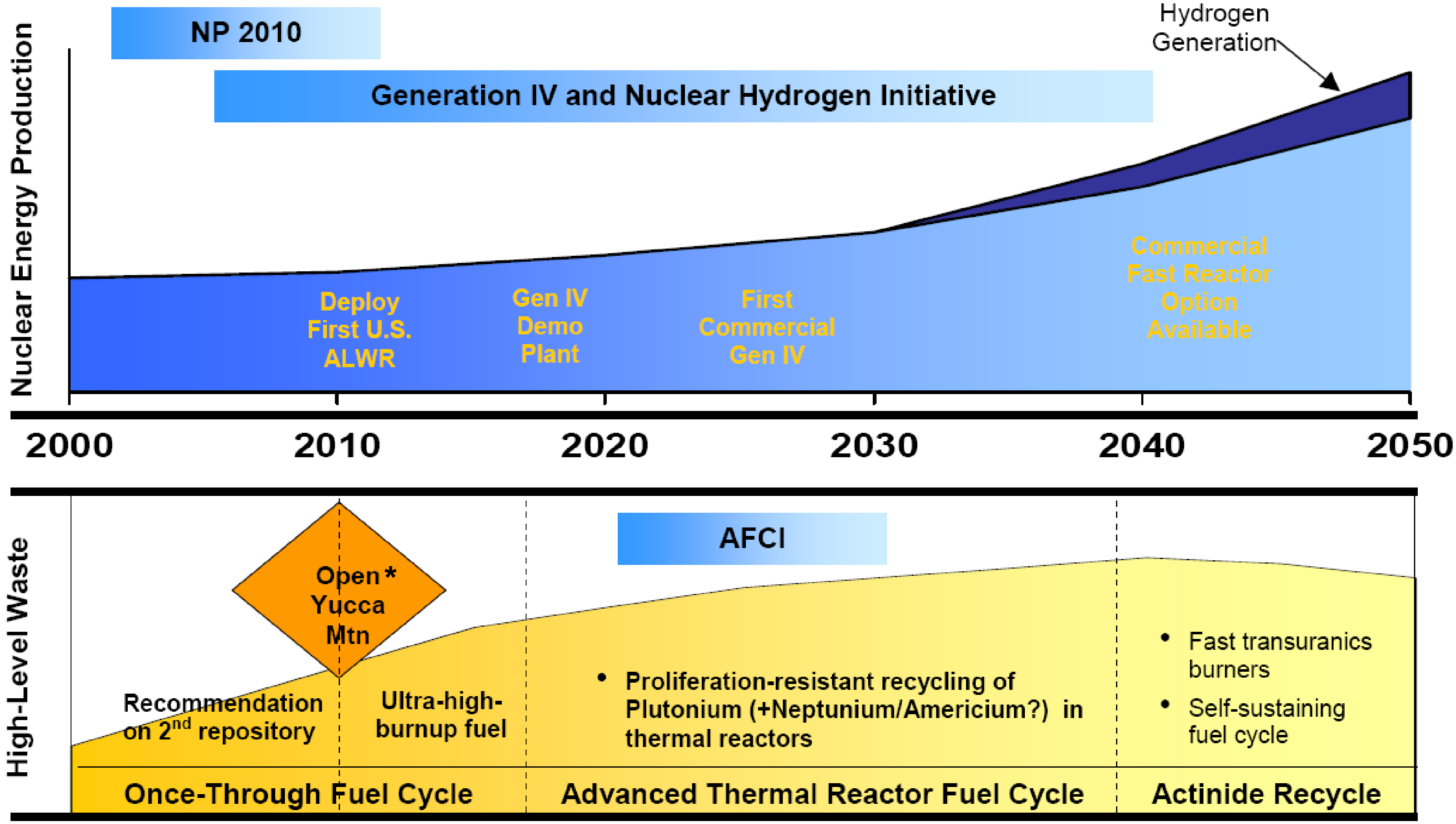
- **Optimize the disposition of spent nuclear fuel.**

- **NE Program Descriptions & Assumptions**

NE Programs

- **Research and Development**
  - Nuclear Power 2010 (NP 2010)
  - Generation IV Nuclear Energy Systems Initiative (Gen IV)
  - Nuclear Hydrogen Initiative (NHI)
  - Advanced Fuel Cycle Initiative (AFCI)
    - Now a part of the Global Nuclear Energy Partnership (GNEP)
- **Non-Research and Development**
  - University Reactor Infrastructure and Education Assistance
  - Radiological Facilities Management
  - Idaho Facilities Management

NE Long-term Goals

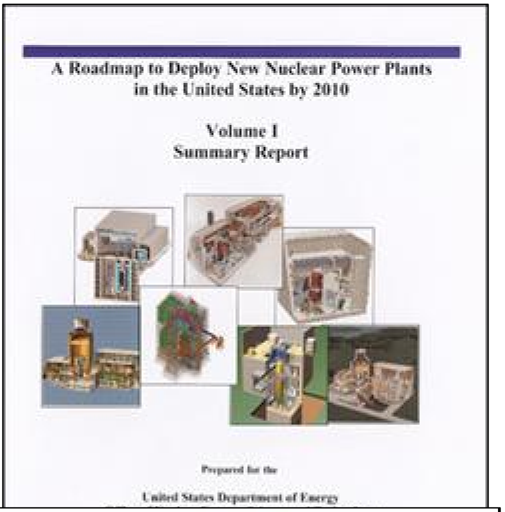


* Currently scheduled for 2017

- **Nuclear Power 2010**
- **(NP 2010)**

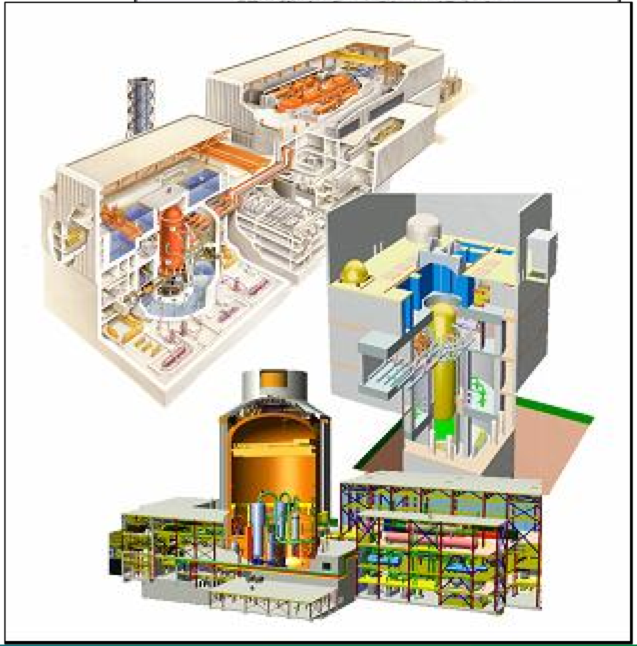
Nuclear Power 2010 Overview … *Working with Industry to Build New Nuclear Plants*

- **Focused on addressing technical, regulatory and institutional challenges**
- **Government/industry cooperative effort**
  - **50-50 cost-shared industry projects**
  - **Market-driven**
- **Testing new, stream-lined regulatory processes**
  - **Early Site Permit (ESP)**
  - **Combined Construction and Operating License (COL)**
- **Developing new light water reactor designs**
  - **Design Certification for new reactors**
  - **First-of-a-kind engineering for new standardized nuclear plant designs**
- **Inputs to Energy Policy Act of 2005 (EPAct)**


A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010

Volume I
Summary Report

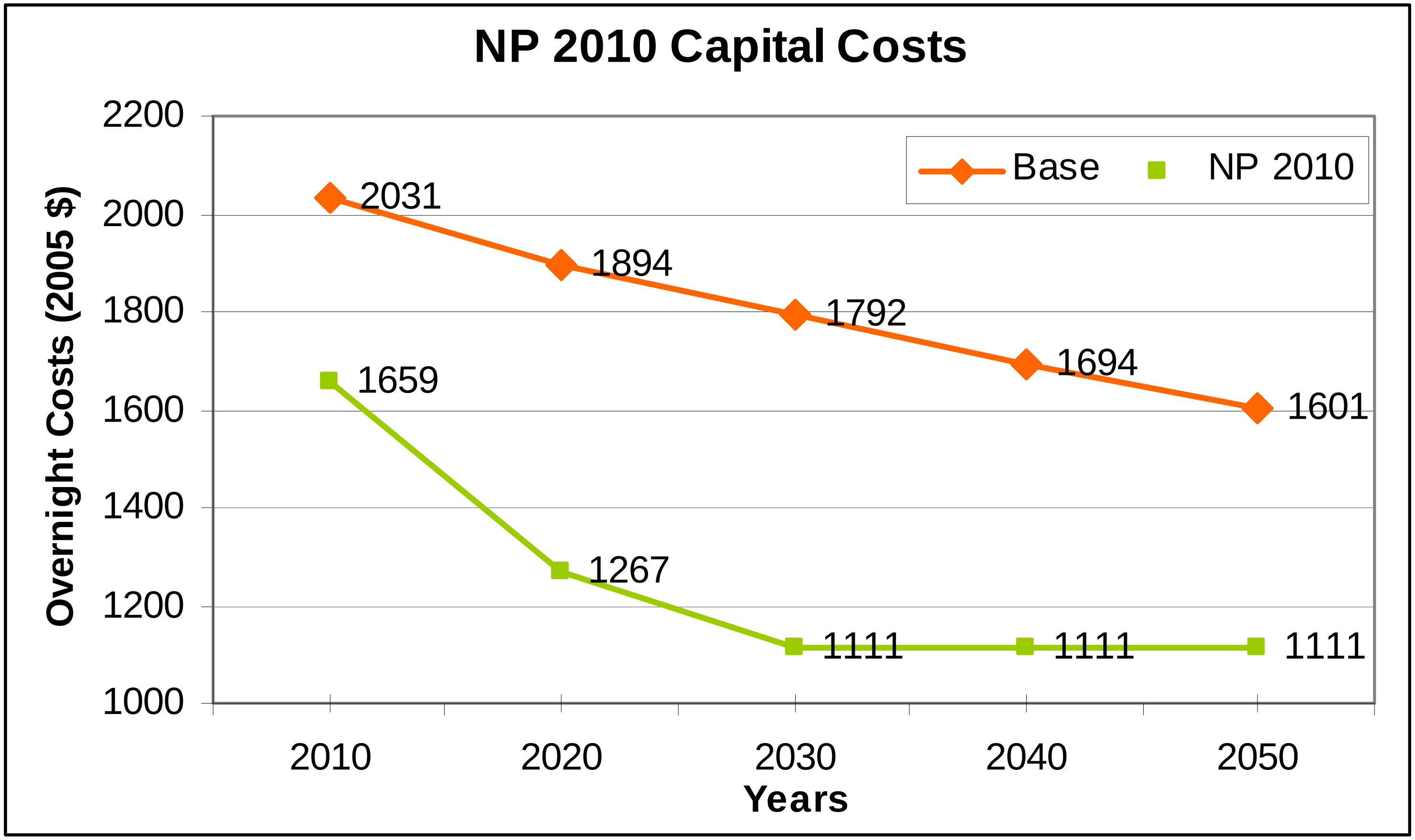
Prepared for the
United States Department of Energy



NP 2010 Technologies

- **NP 2010 Roadmap Selected Seven Technologies;**
  - **ABWR: Advanced Boiling Water Reactor**
  - **SWR 1000: Siemens Developed Advanced BWR**
  - **ESBWR: Economic Simplified Boiling Water Reactor**
  - **AP600/AP1000: Advanced Pressurized Water Reactor**
  - **IRIS: International Reactor Innovative and Secure**
  - **PBMR: Pebble Bed Modular Reactor**
  - **GT-MHR: Gas Turbine Modular Helium Reactor**
- **Currently, ABWR, ESBWR, AP1000 and European Pressurized Water Reactor (EPR) are considered for early deployment.**
- **Due to the uncertainty on technologies selected for actual deployment under NP 2010, a generic generation III+ technology has been considered to indicate program outputs.**

NP 2010 Technology Assumptions



Adjusting the Baseline Case: The World without NE R&D

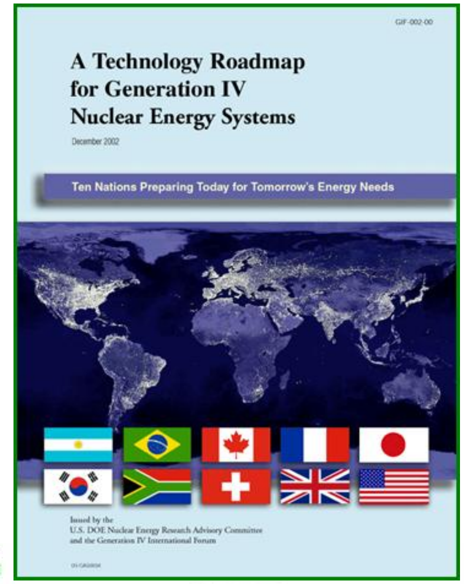
- **Purpose of a common baseline**
  - **Assure same initial forecasts for economic growth, energy prices, and levels of energy demand**
  - **Provide a basis for assessing how well nuclear technologies might be able to compete against future, rather than current, energy technologies**
  - **Assure that underlying improvements in nuclear energy are not counted as part of the benefits of the NE programs**

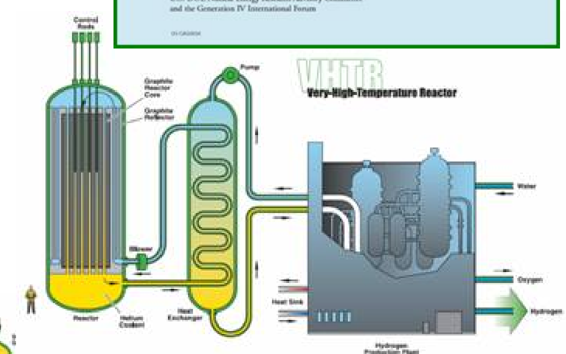
	AEO 2006	GPRA08
Advanced Light Water Reactors	• PTCs bring in 6,000 MWe of new nuclear capacity	• Decided not to adjust—conservatism

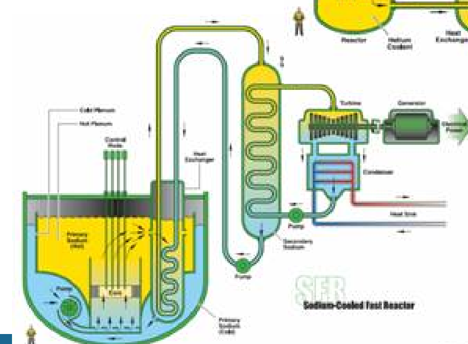
- **Generation IV Nuclear Energy Systems Initiative (Gen IV)**

Generation IV Technologies: *Design Objectives*

- **Sustainable**
  - **Reduced waste production**
  - **Burn existing waste**
  - **Environmentally friendly—no GHGs emitted**
- **Economically Competitive**
  - **Capital costs < $1000/kW**
  - **Operating cost < $0.015/kW-hr**
- **Safe and Reliable**
  - **Increased use of inherent safety features**
  - **Eliminate use of off-site response to emergency plant events**
- **Proliferation Resistance and Physical Protection**
  - **Plutonium never handled as pure element; always mixed with actinides**


A Technology Roadmap for Generation IV Nuclear Energy Systems
December 2002
Ten Nations Preparing Today for Tomorrow's Energy Needs
Issued by the U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum

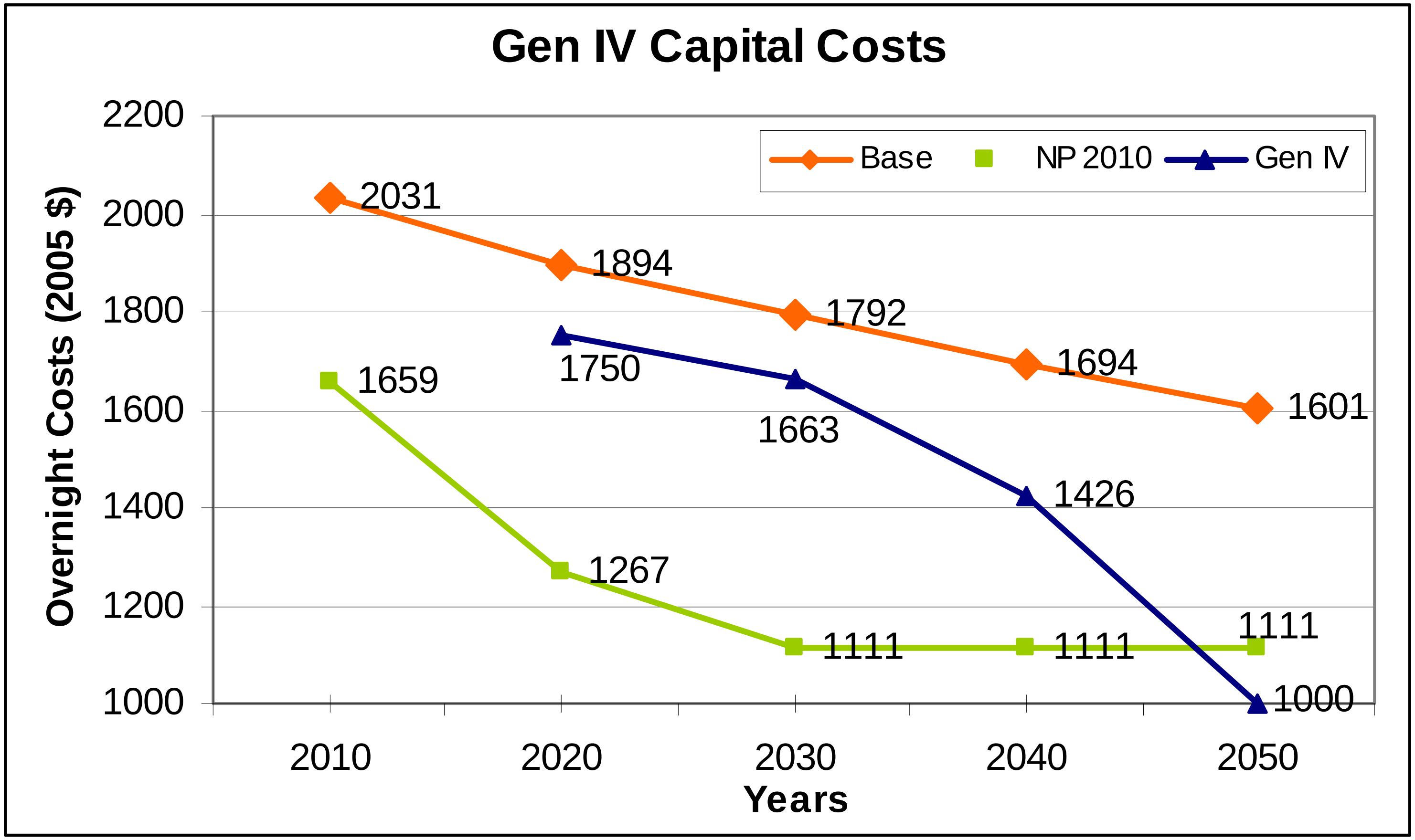




Generation IV Technologies

- Gen IV Technologies Covered by the Roadmap:
  - GFR: Gas-cooled Fast Reactor
  - LFR: Lead-cooled Fast Reactor
  - SFR: Sodium-cooled Fast Reactor
  - MSR: Molten Salt Reactor
  - SCWR: Supercritical Water-cooled Reactor
  - VHTR: Very High Temperature Reactor
- Currently, VHTR and SFR are considered for early deployment.
- Due to the uncertainty on technologies selected for actual deployment under Gen IV, a generic Generation VI technology has been considered to indicate program outputs.

Gen IV Technology Assumptions

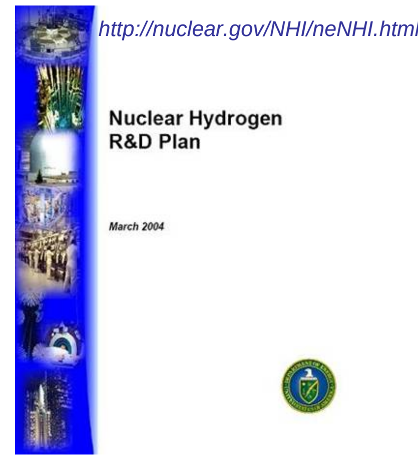


- **Nuclear Hydrogen Initiative (NHI)**

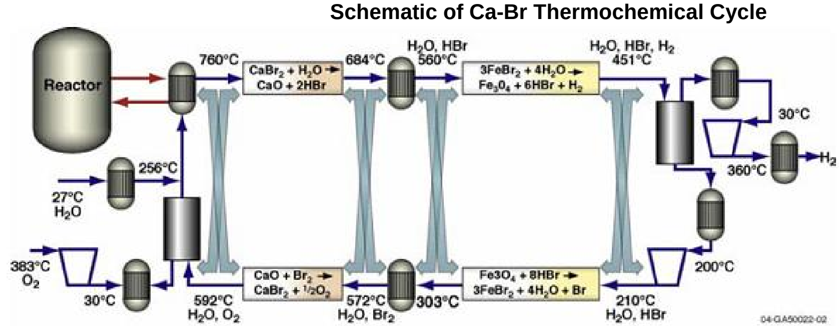
Nuclear Hydrogen Initiative

- **Goal: Demonstrate the economic, commercial-scale production of hydrogen using nuclear energy**
- **Use high-temperature heat and/or electricity from next generation and advanced nuclear system to a hydrogen-producing**
  - **Thermochemical (sulfur family and calciumbromine) plant; or**
  - **High-temperature electrolysis plant**
- **Direct NHI benefits are hard to measure in absence of H2 demand technologies in NE portfolio**

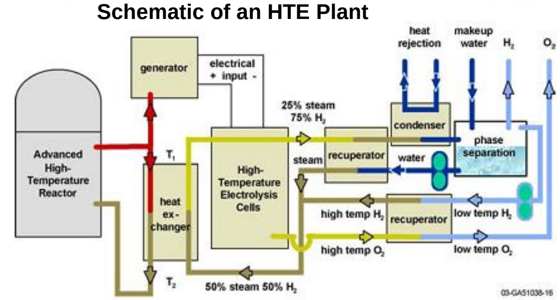
http://nuclear.gov/NHI/neNHI.html



Schematic of Ca-Br Thermochemical Cycle



Schematic of an HTE Plant



NHI Technology Assumptions

(in 2005 $)

Technology Parameter	Time Independent Data	2020	2030	2040	2050
Thermochemical (Sulfur-Iodine) Production of Hydrogen					
Capital Cost (Overnight, $/kWth)		1200	1000	800	650
Fixed O&M Cost ($/kWth)		175	60	50	40
Variable O&M Cost ($/kg of H_2)		0.90	0.60	0.45	0.40
Capacity Factor (%)	-	55%	75%	87.5%	90%
Thermal to H_2 Energy Efficiency (%)		35	42.5	47.5	50
Availability Date (Year)	2020				
Plant Life (Years)	40				
Estimated Technology Maturity Date	2030				
High-Temperature Electrolysis (HTE)					
Capital Cost (Overnight, $/kWth)		1250	950	900	800
Fixed O&M Cost ($/kWth)		200	55	47.5	40
Variable O&M Cost ($/kg of H_2)		0.7	0.45	0.375	0.30
Capacity Factor (%)		72.5%	77.5%	87.5%	90%
Thermal to H_2 Energy Efficiency (%)		40	42.5	43.5	45
Availability Date (Year)	2020				
Plant Life (Years)	40				
Estimated Technology Maturity Date	2030				

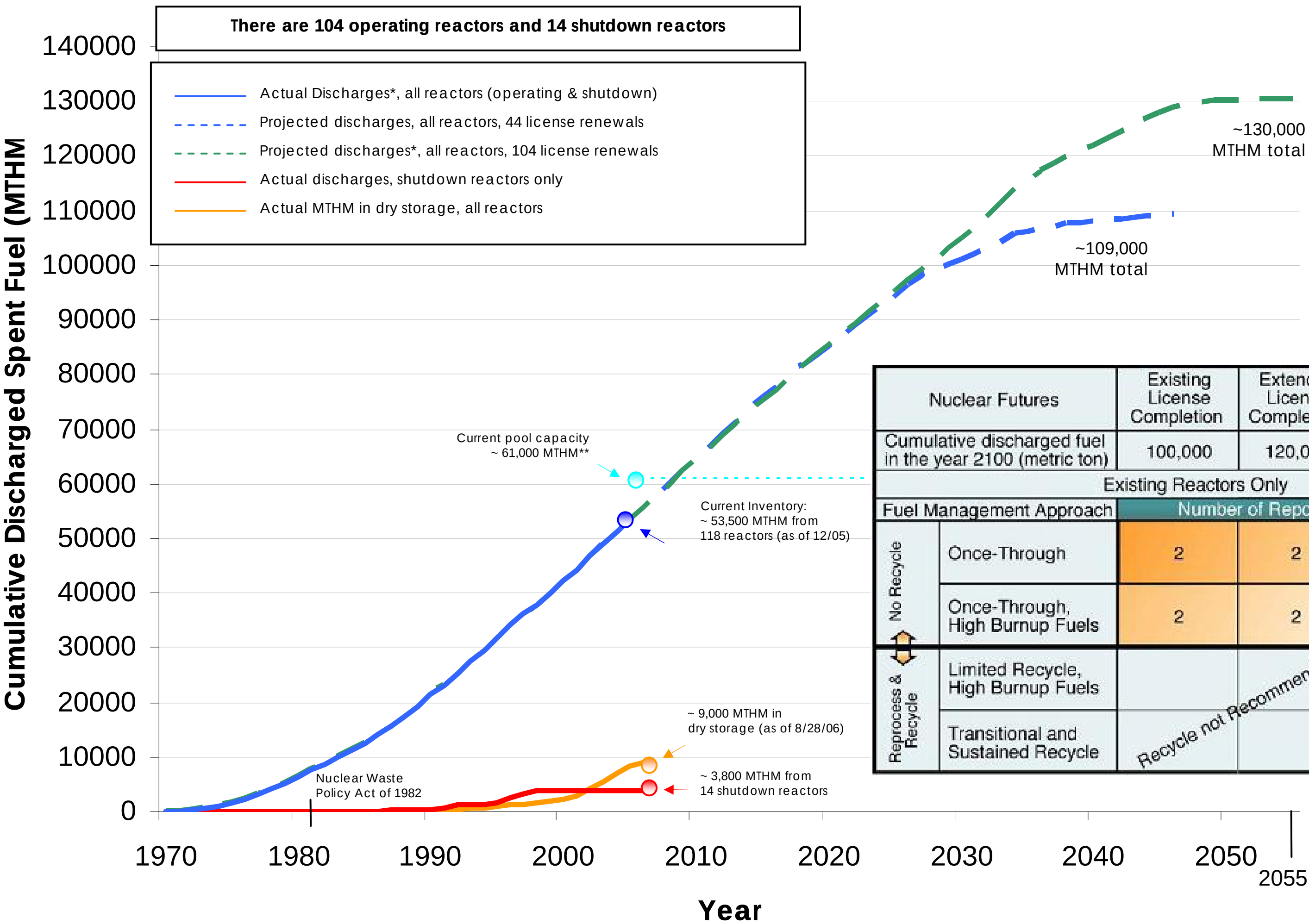
– **Global Nuclear Energy Partnership**

– **(GNEP)**

– **Incorporates…**

– **Advanced Fuel Cycle Initiative (AFCI)**

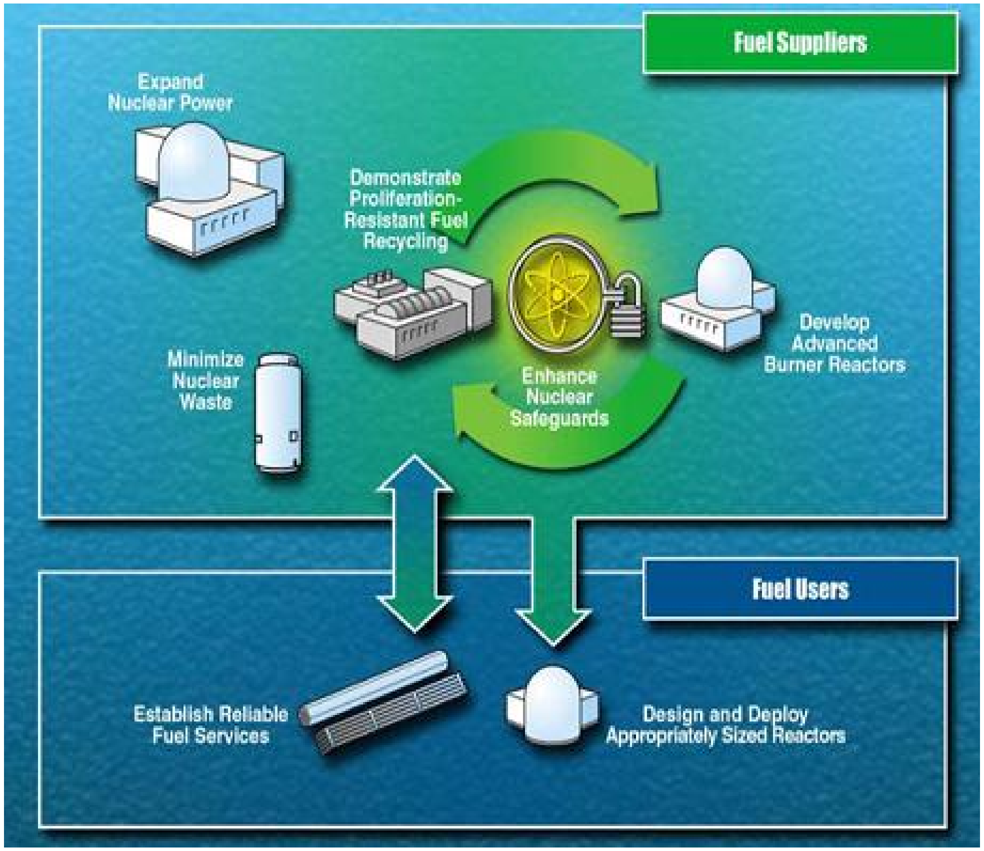
Impact of Different Fuel Cycle Strategies on Eventual Repository Needs



	Nuclear Futures	Existing License Completion	Extended License Completion	Continuing Level Energy Generation	Continuing Market Share Generation	Growing Market Share Generation
	Cumulative discharged fuel in the year 2100 (metric ton)	100,000	120,000	250,000	600,000	1,400,000
		Existing Reactors Only		Existing and New Reactors		
	Fuel Management Approach	Number of Repositories Needed at 70,000 Metric Ton Each				
No Recycle	Once-Through	2	2	4	9	20
No Recycle	Once-Through, High Burnup Fuels	2	2	3	7	17
Reprocess & Recycle	Limited Recycle, High Burnup Fuels	Recycle not Recommended		2	5	10
Reprocess & Recycle	Transitional and Sustained Recycle			1	1	1

Global Nuclear Energy Partnership: Goal

- *Enable the expanded worldwide use of economical, environmentally responsible nuclear energy to meet growing electricity demand, while virtually eliminating the risk of nuclear material misuse.*

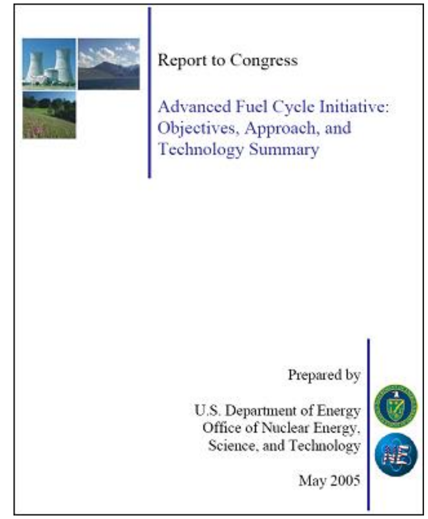


Program Elements:

- **Expand use of nuclear power**
- **Minimize nuclear waste**
- **Demonstrate recycle technology**
- **Develop Advanced Burner Reactors**
- **Establish reliable fuel services**
- **Enhance nuclear safeguards technology**
- **Demonstrate grid-appropriate, exportable reactors**
- **Apply world-leading advanced computing**

AFCI Objectives

- **Reduce the long-term environmental burden of nuclear energy through more efficient disposal of waste materials.**
- **Enhance overall nuclear fuel cycle proliferation resistance via improved technologies for spent fuel management.**
- **Enhance energy security by extracting energy recoverable in spent fuel and depleted uranium, ensuring that uranium resources do not become a limiting resource for nuclear power.**
- **Improve fuel cycle management, while continuing competitive fuel cycle economics and excellent safety performance of the entire nuclear fuel cycle system.**

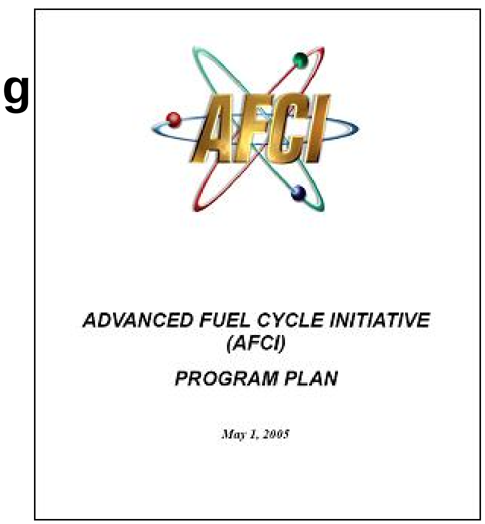

Report to Congress

Advanced Fuel Cycle Initiative: Objectives, Approach, and Technology Summary

Prepared by

U.S. Department of Energy
Office of Nuclear Energy,
Science, and Technology

May 2005



ADVANCED FUEL CYCLE INITIATIVE (AFCI)

PROGRAM PLAN

May 1, 2005

Performance Measures of AFCI Technologies-1

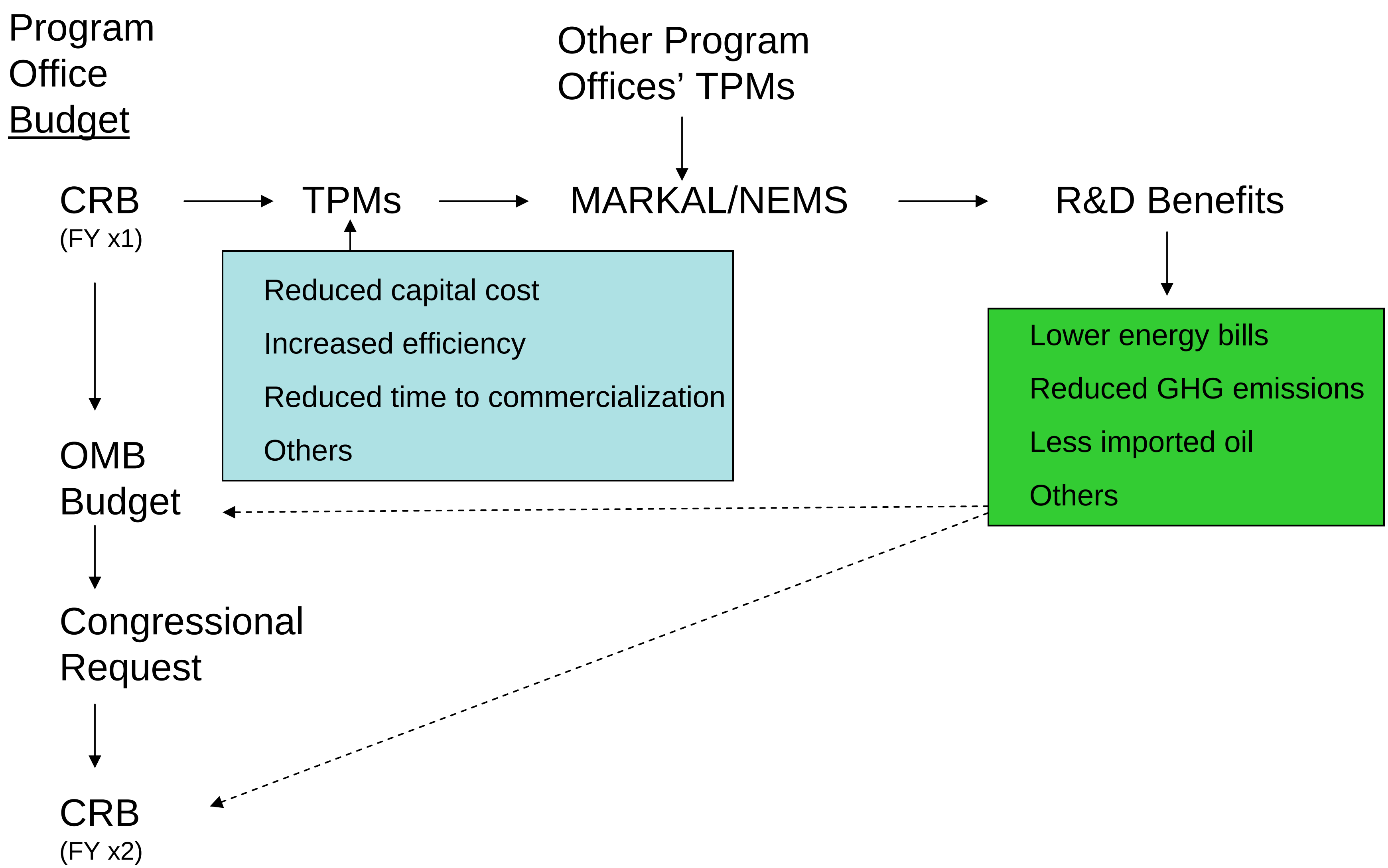
Technology Parameter	Time Independent Data	2020	2030	2040	2050
UREX+ Process for Light Water Reactor Spent Fuel (2,500 Mt/year plant)					
Capital Cost (Overnight, M$)		7500			
O&M Cost (M$ per year)		625	600	600	600
Capacity Factor (%)		77.5	87.5	97.5	97.5
HLW, m^3 per Mt SNF processed		0.12	0.09	0.09	0.05
TRU losses to HLW per Mt SNF processed		<0.1%	<0.1%	<0.1%	<0.1%
Secondary Wastes, m^3 per Mt SNF processed		0.13	0.13	0.1	0.1
Availability Date (Year)	2025				
Plant Lifetime (Years)	45				
Estimated Technology Maturity Date	2025				
Innovative Aqueous Process for Light Water Reactor Spent Fuel (2,500 Mt/yr plant)					
Capital Cost (Overnight, M$)				5000	5000
O&M Cost (M$ per year)				350	350
Capacity Factor (%)				87.5	97.5
HLW per Mt SNF processed				0.05	0.05
TRU losses to HLW per Mt SNF processed				<0.1%	<0.1%
Secondary Wastes per Mt SNF processed				0.13	0.1
Availability Date (Year)	2040				
Plant Lifetime (Years)	45				
Estimated Technology Maturity Date	2045				

Performance Measures of AFCI Technologies-2

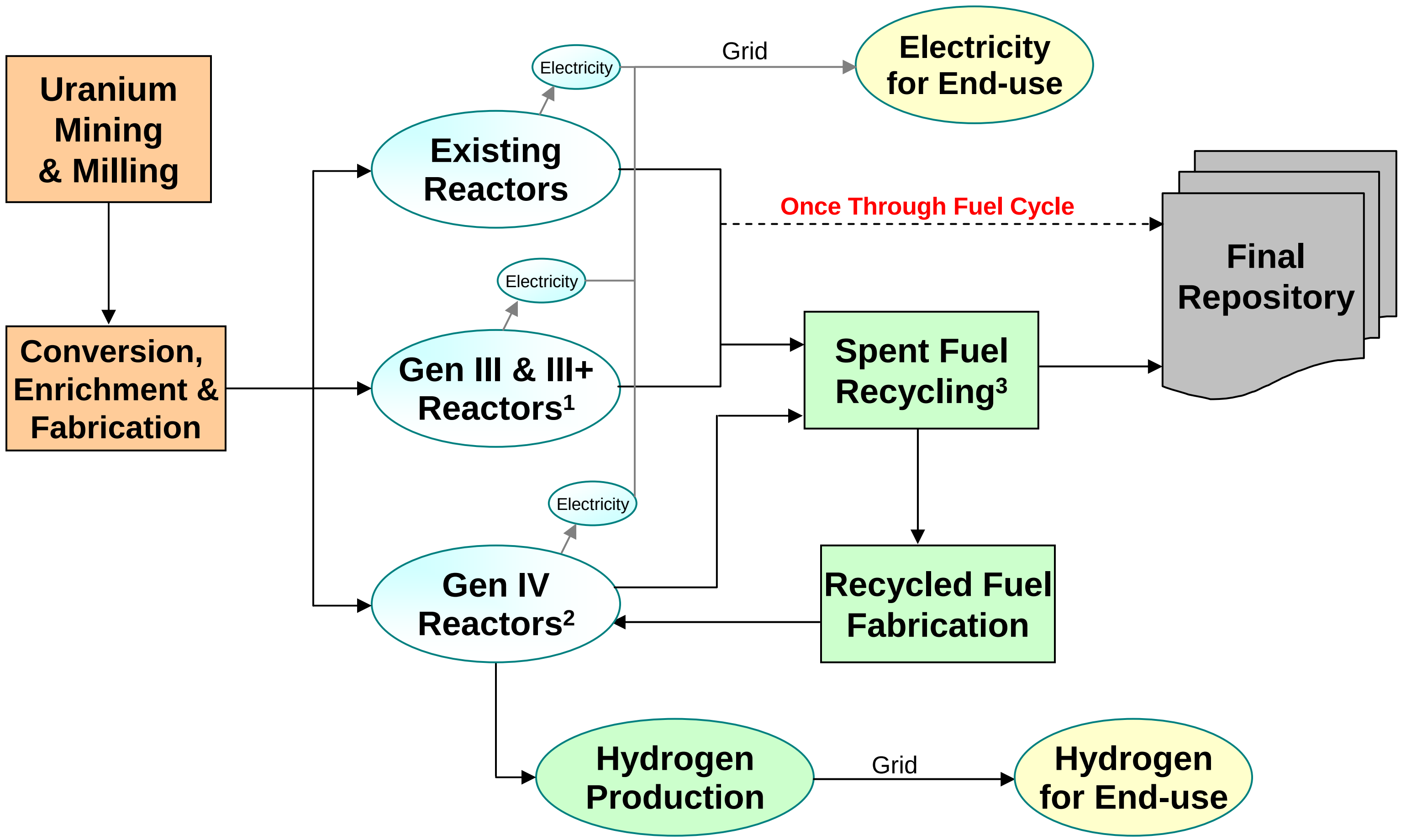
Technology Parameter	Time Indep-endent Data	2020	2030	2040	2050
Pyrochemical Process for Fast Reactor Spent Fuel (co-located with reactor park, 5 Mt/yr plant)					
Capital Cost (Overnight, M$)			525	525	525
O&M Cost (M$ per year)			100	100	100
Capacity Factor (%)			65	75	80
HLW, m^3 per Mt SNF processed			0.67	0.505	0.505
TRU losses to HLW per Mt SNF processed			<0.3%	<0.3%	<0.3%
Secondary Wastes, m^3 per Mt SNF processed			0.25	0.25	0.25
Availability Date (Year)	2035				
Plant Lifetime (Years)	45				
Estimated Technology Maturity Date	2040				

- **The Process of Measuring Benefits**

The Process


Program Office Budget
Other Program Offices' TPMs
CRB
(FY x1)
TPMs
MARKAL/NEMS
R&D Benefits
Reduced capital cost
Increased efficiency
Reduced time to commercialization
Others
Lower energy bills
Reduced GHG emissions
Less imported oil
Others
OMB Budget
Congressional Request
CRB
(FY x2)

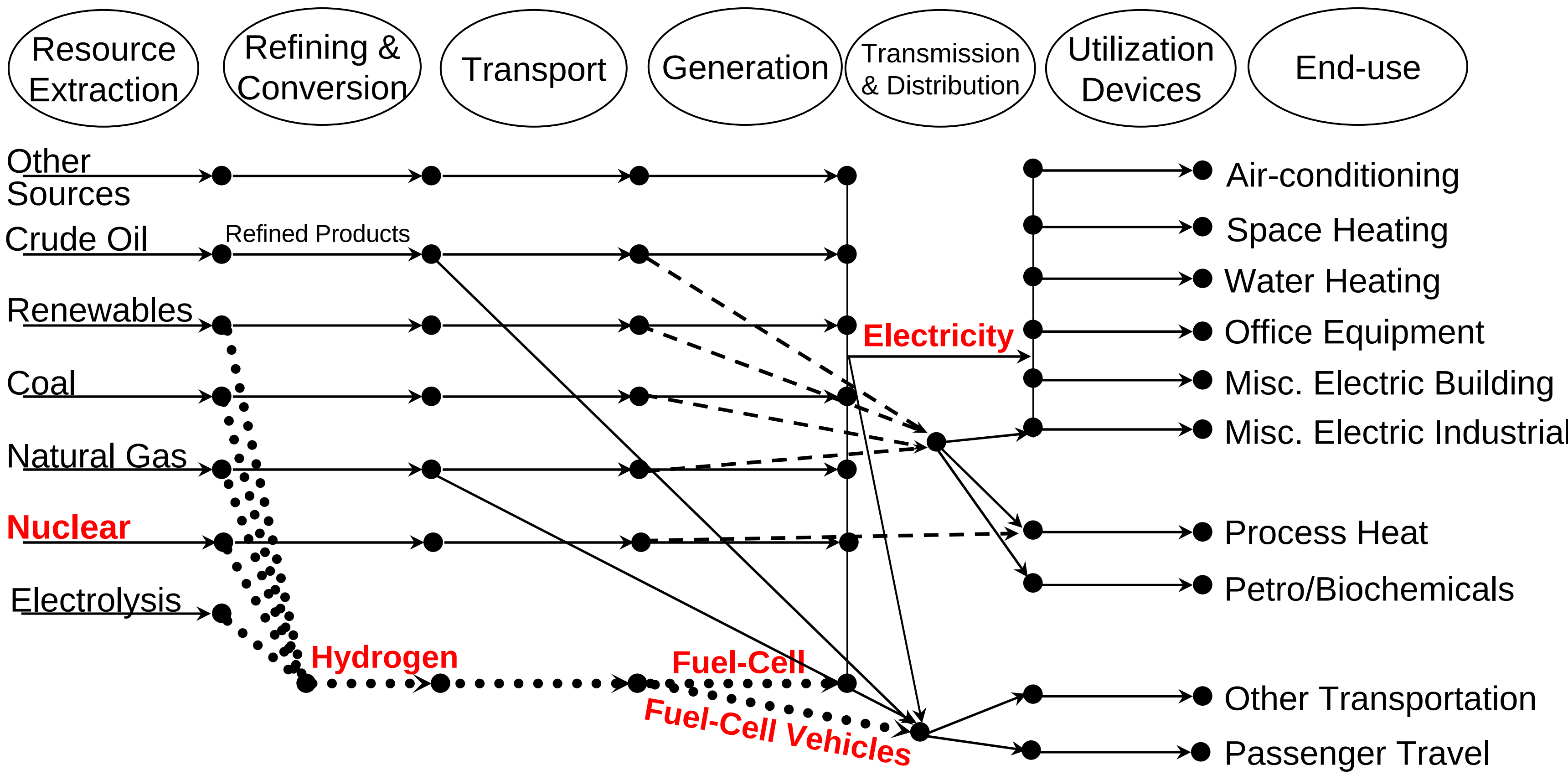
Modeling Nuclear Energy in US MARKAL: System Integration



Notes:
1. Gen III & III+ Technologies Covered: ABWR, EPR, ESBWR, AP600, AP1000, IRIS, PBMR and GT-MHR
2. Gen IV Technologies Covered: SFR, VHTR, GFR, MSR, SCWR, and LFR
3. AFCI Technologies Covered: UREX+, UREX/PYRO, PYROX, and Advanced Aqueous Process with ACP/UREX+

Sources: Based on AFCI Comparison Report, 2003 and 2004.

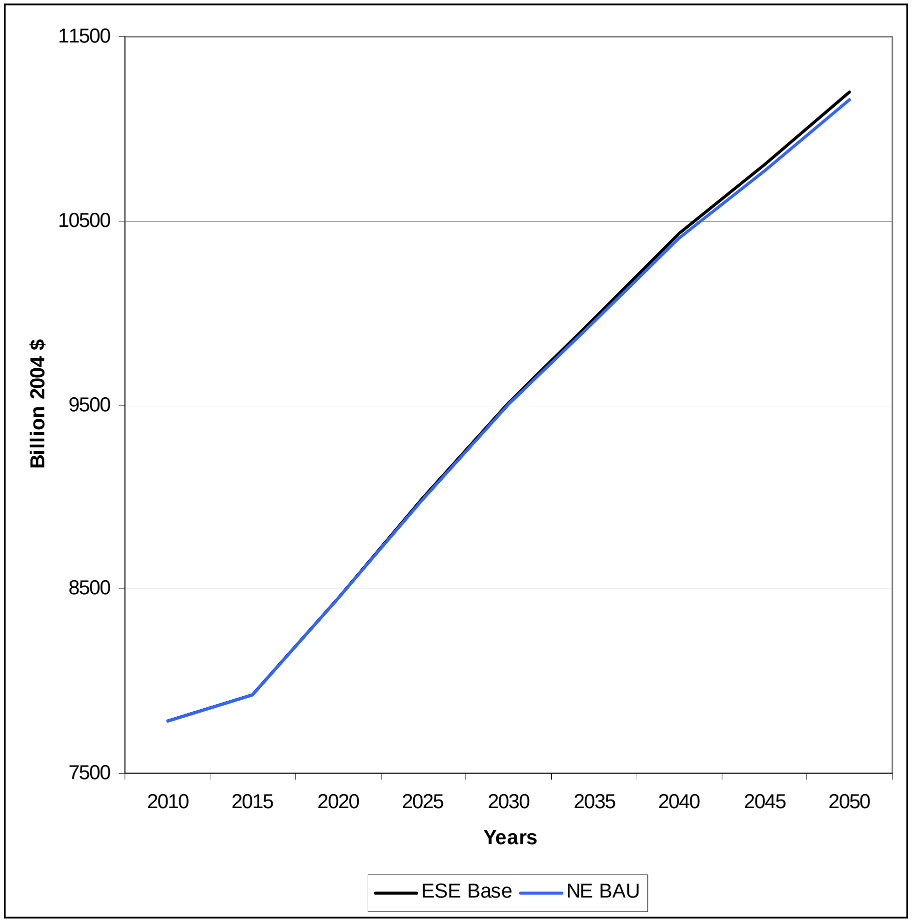
Modeling Nuclear Energy in US MARKAL: Simplified Reference Energy System



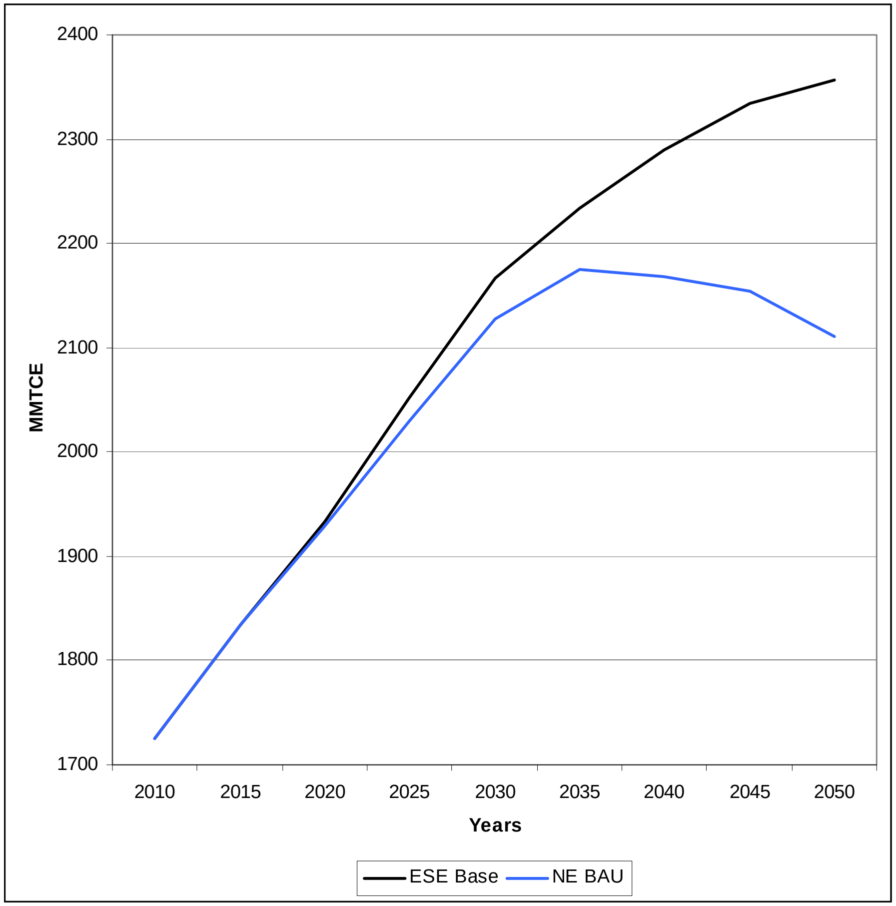
- **Benefits Under Alternative Scenarios**

NE BAU Compared to ESE Base Case

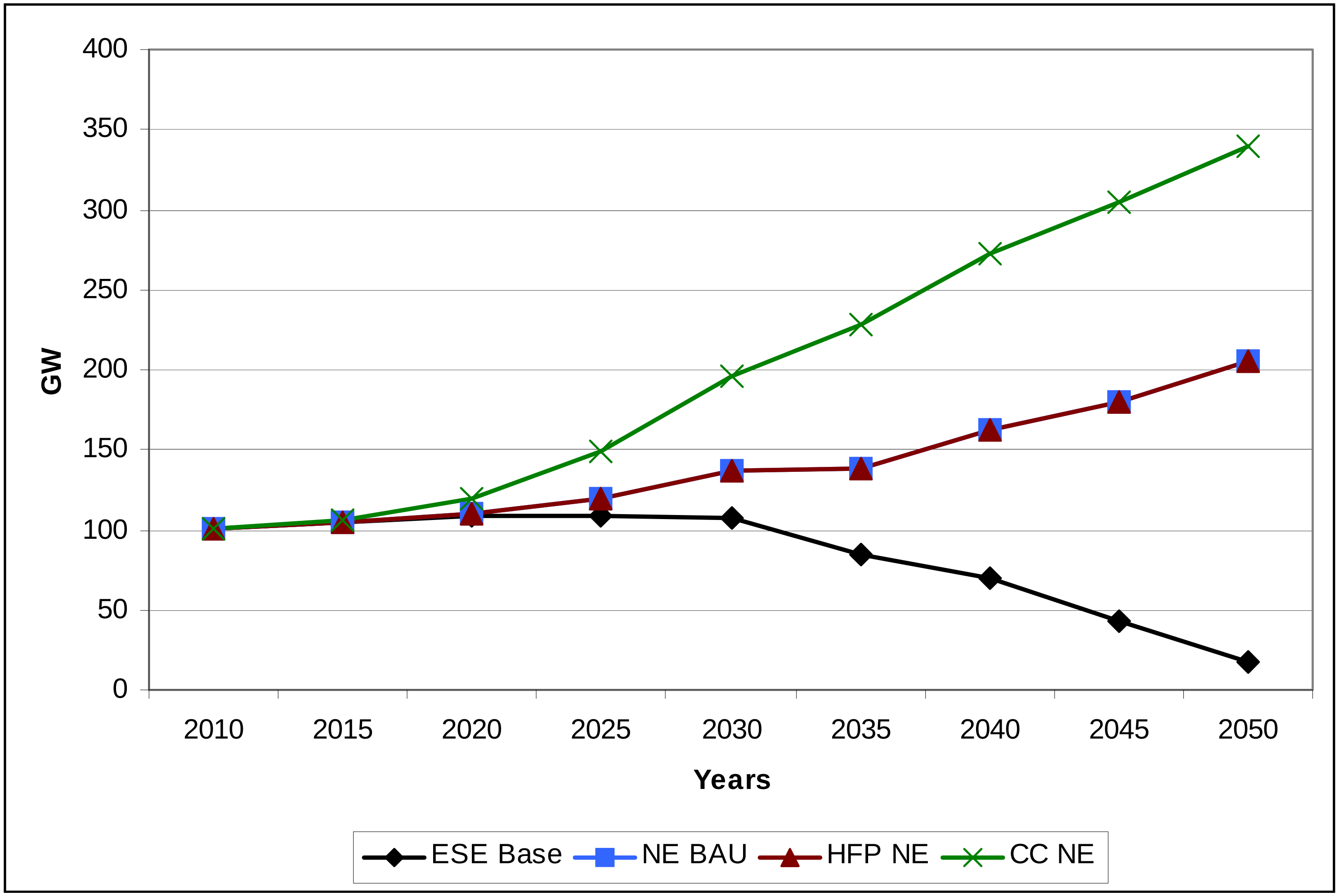
Energy System Cost



Annual GHG Emissions



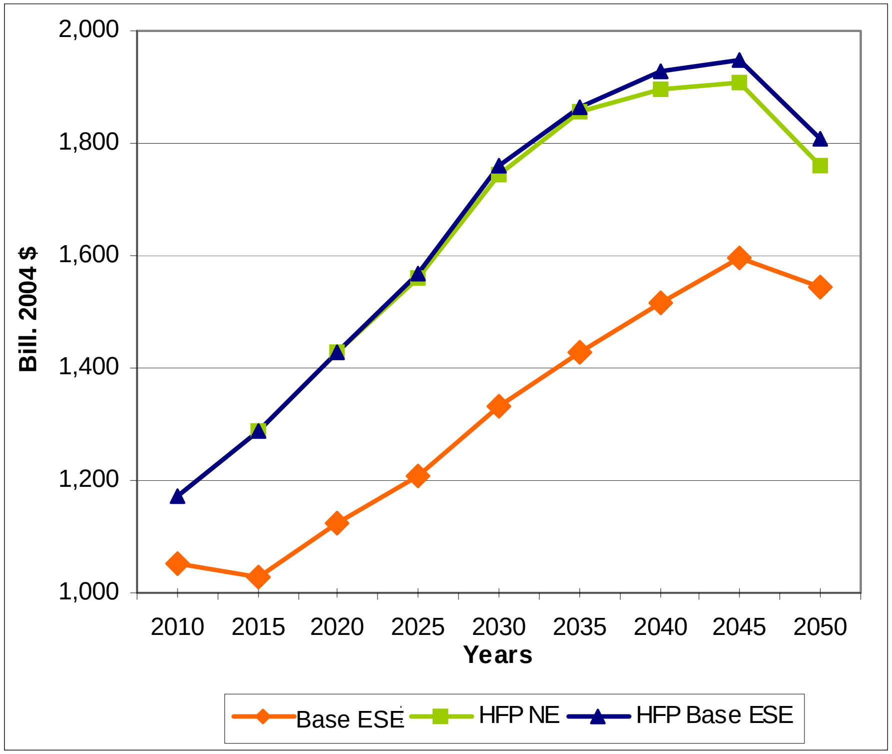
Penetration of NE Technologies



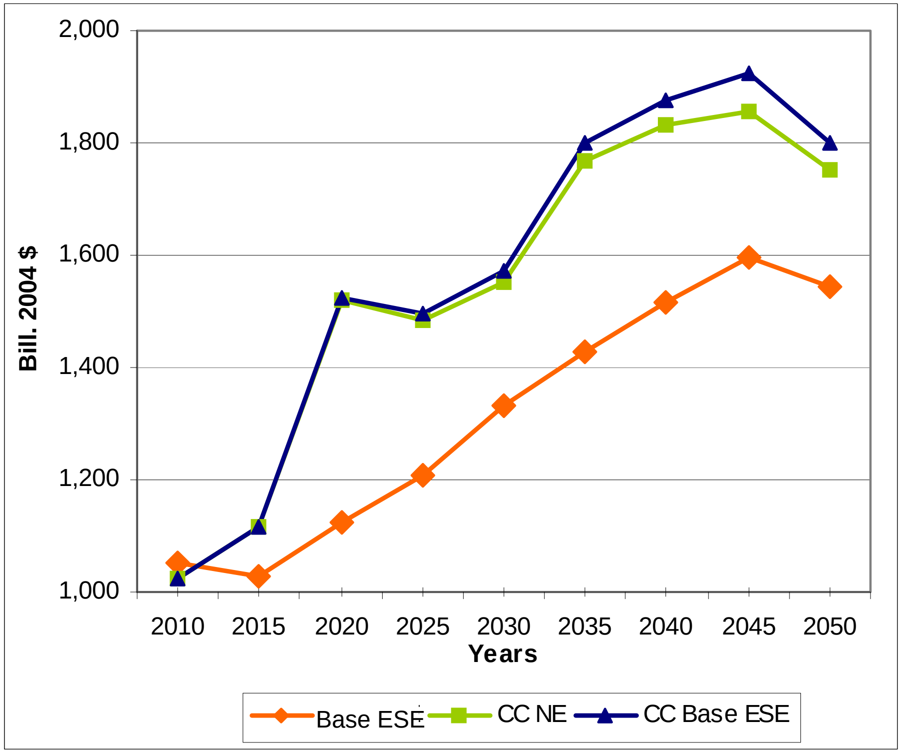
Economic Benefits – Consumer Spending

- **Mitigating impacts of High Fuel Price and Carbon scenarios on consumers**

High Fuels Price

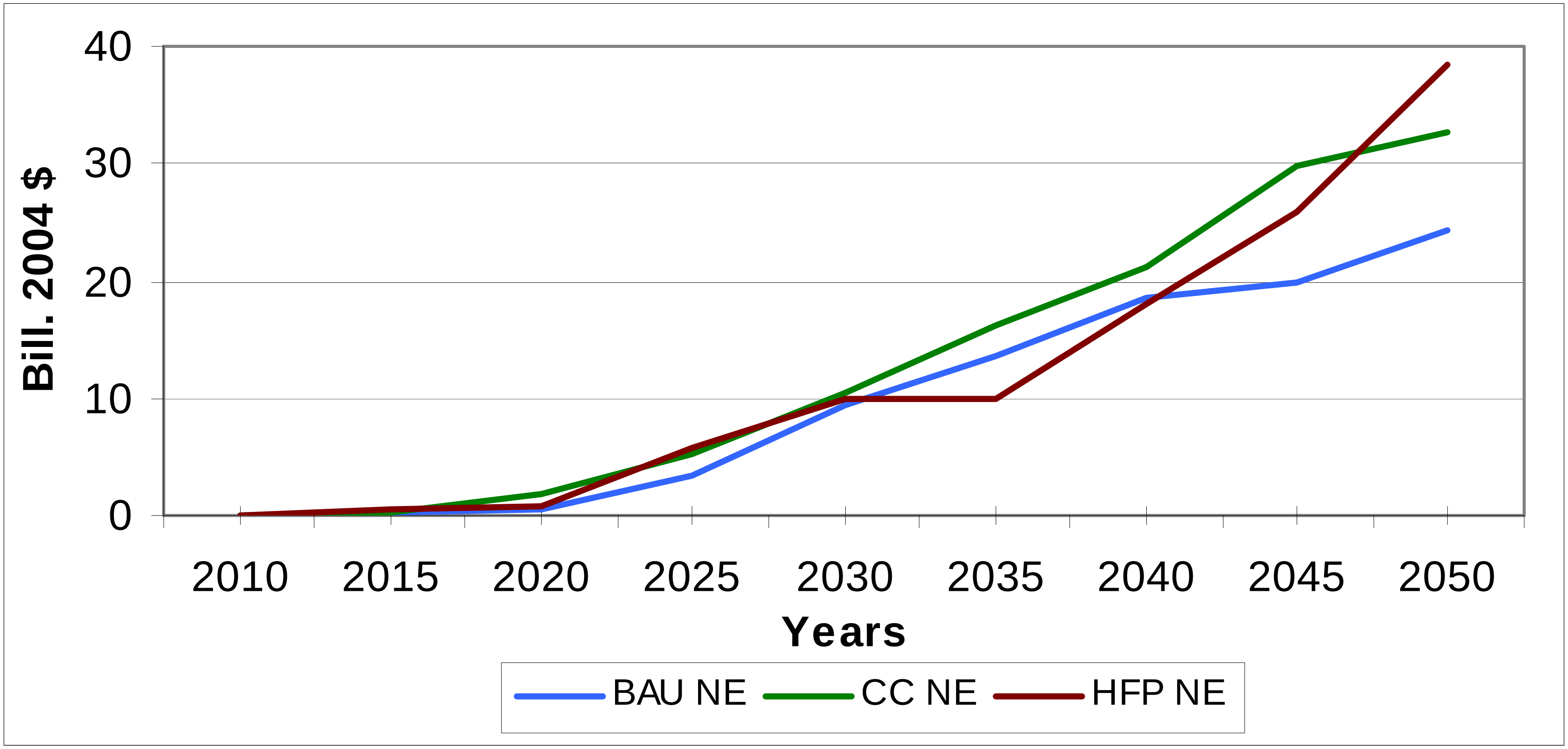


Carbon Constraint



Economic Benefits – Electric Power Industry Savings

- **Greater impacts under Carbon Constraint scenario**



For the Future

- **Improve identification and characterization of risks associated with benefits analysis**
  - o **Technological Risks (e.g., demonstration of technologies)**
  - o **Market Risks (e.g., manufacturing constraints and regulatory barriers)**
- **Achieve further integration among the Department's applied R&D technologies to enhance the uniformity of modeling assumptions**
- **Improve methodology for allocating benefits from the Department's applied R&D portfolio**
- **Investigate additional metrics for measuring NE Program benefits (i.e., proliferation resistance, reduction in spent nuclear fuel, need for future repositories)**