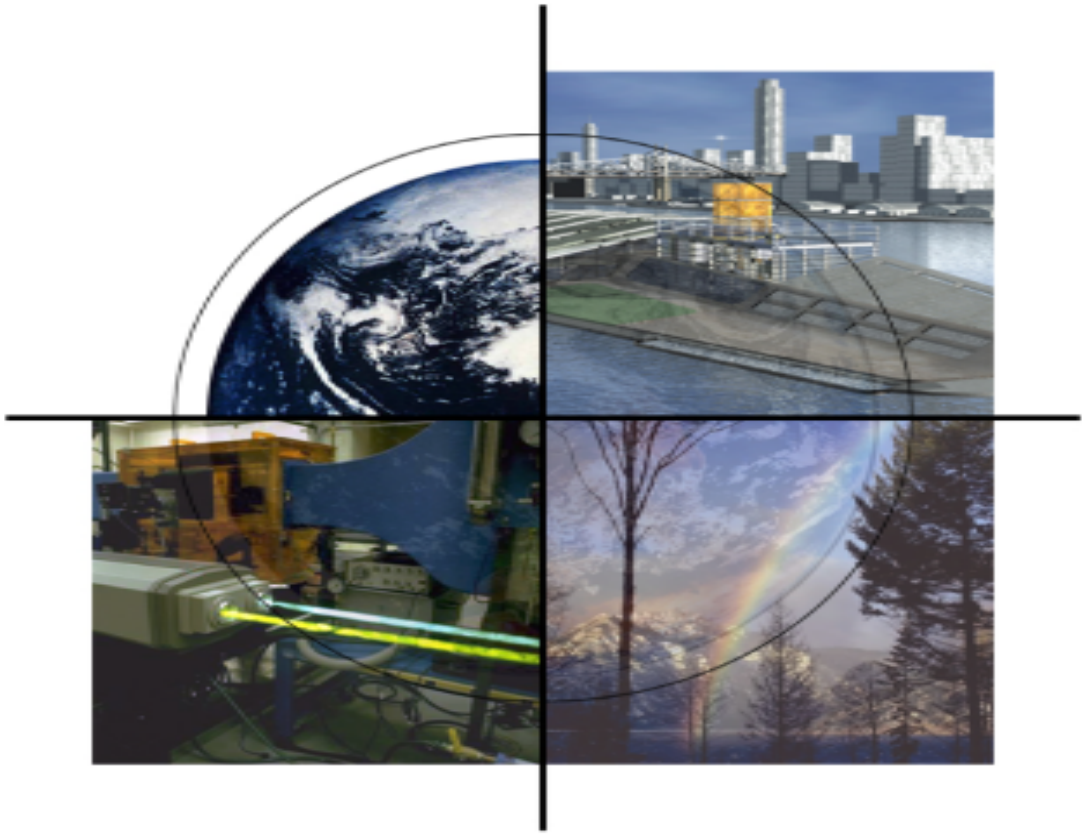
Clean Coal Technology Roadmap
"CURC/EPRI/DOE Consensus Roadmap"



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http://www.netl.doe.gov/coalpower/ccpi/pubs/CCT-Roadmap.pdf

Roadmap Goals

- **Develop unified coal program roadmap**
  - Integrate CURC, EPRI, DOE roadmaps
  - Support NEP & Presidential Initiatives
- **Maintain high-level approach**
  - Set performance/cost targets
  - Specify destinations & critical technology needs
  - Save details for NETL technology roadmaps
- **Quantify coal program benefits**
  - Economic, environmental, security

Roadmap Approach

- **Review current DOE & industry performance & cost targets**
  - CURC; EPRI; DOE technology areas
- **Assess targets and develop unified roadmap to capture common objectives**
  - Span today's state-of-the-art through 2020
  - Incorporate current & emerging regulations
  - Address existing fleet improvements & new plants
  - Address fuels production
  - Address CO_2 management
- **Estimate program benefits**
  - Apply clear, consistent assumptions
  - Compare benefits with RD&D investment costs

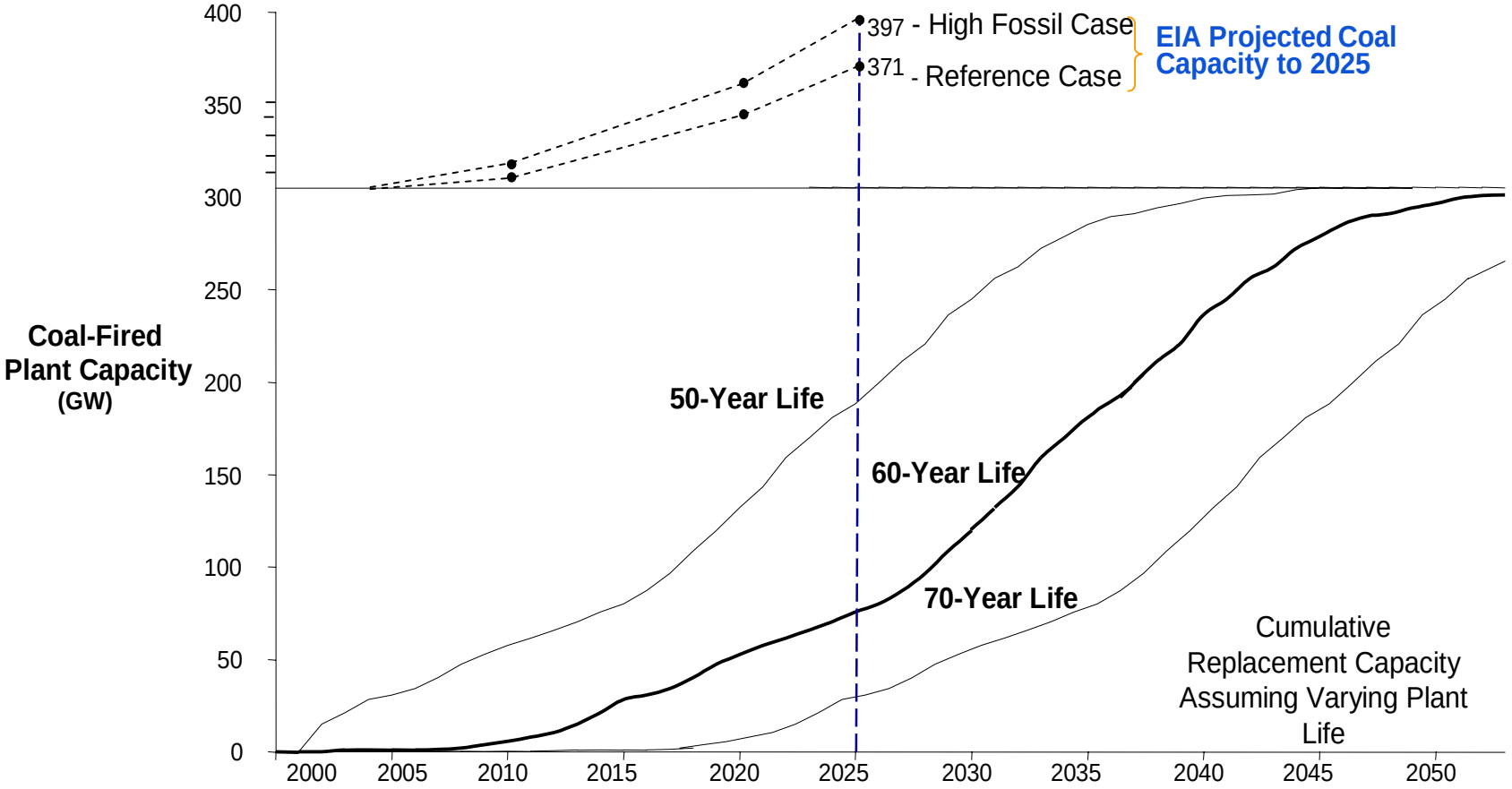
Roadmap Supports Presidential Initiatives

- **Clear Skies**
  - Meets existing & emerging SO_2, NO_x, Hg regulations
- **Clean Coal Power**
  - Provides emerging near-zero emission technologies for demonstration
- **Climate Change**
  - Supports research to reduce CO_2 emissions at acceptable costs
- **Homeland Security**
  - Keeps low-cost, abundant domestic coal competitive energy resource for the future

Key Assumptions

- EIA coal power capacity forecasts are used as reference
- Time period: today to 2020
- Goal: ‘near-zero’ emission coal plants
- Goal: carbon capture and sequestration capability
- Roadmap destinations represent commercially available ‘products’ but not yet in wide-spread use
- 2020 environmental objectives/targets represent best achievable performance
- Innovative, new technologies needed to achieve new plant targets at costs competitive with alternative options having comparable environmental performance
- Technology applied to existing plants:
  - improve environmental performance
  - maintain competitive cost of electricity

Market for New Coal Power Plant Technology



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Coal Power Plant Performance Criteria

- Air Emissions
  - SO_2
  - NO_x
  - Particulate
  - Hg
- CO_2 Management
- By-Product Utilization
- Water Use and Discharge
- Plant Efficiency
- Reliability/Availability
- Capital and Product Cost

  (power and fuels production)

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Roadmap Performance Targets

(Represents best integrated plant technology capability)

	Reference Plant*	2010	2020
Air Emissions	98% SO_2 removal	99%	>99%
	0.15 lb/10^6 Btu NOx	0.05 lb/10^6 Btu(1)	<0.01 lb/10^6 Btu
	0.01 lb/10^6 Btu Particulate Matter	0.005 lb/10^6 Btu(2)	0.002 lb/10^6 Btu
	Mercury (Hg)(3)	90% removal(4)	95% removal
By-Product Utilization	30%(5)	50%(6)	near 100%(6)

*Reference plant has performance typical of today's technology;
Improved performance achievable with cost/efficiency tradeoffs.

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Footnotes for Performance Targets

(1) For existing plants, reduce cost for achieving <0.10 lb/10^6 Btu using combustion control by 25% compared to SCR by 2010; same cost reduction for 0.15 lb/10^6 Btu by 2005

(2) Achieve PM targets for existing plants in 2010: 99.99% capture of 0.1-10 micron particles

(3) Some Hg reduction is being achieved as a co-benefit with existing environmental control technologies

(4) 2005 objective to achieve 50-70% Hg removal to less than 75% of the cost of activated carbon injection

(5) Represents average for existing plant locations

(6) Target represents technically achievable for new or existing plants; economics are site specific

Roadmap Performance Targets(1)

(Represents best integrated new plant technology capability)

	Reference Plant	2010	2020
Plant Efficiency (HHV)(2)	**40%**	**45-50%**	**50-60%**
Availability(3)	**>80%**	**>85%**	**≥90%**
Plant Capital Cost(2) $/kW	**1000 – 1300**	**900 – 1000**	**800 – 900**
Cost of Electricity(4) ¢/kWh	**3.5**	**3.0-3.2**	**<3.0**

(1) Targets are w/o carbon capture and sequestration and reflect current cooling tower technology for water use

(2) Range reflects performance projected for different plant technologies that will achieve environmental performance and energy cost targets

(3) Percent of time capable of generating power (ref. North American Electric Reliability Council)

(4) Bus-bar cost-of-electricity in today's dollars; Reference plant based on $1000/kW capital cost, $1.20/$10^6$ Btu coal cost

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Addressing Future Concerns - Water

- **An important initiative that considers:**
  - Emerging policy responses to societal concerns
  - Technology choices
- **Focus on defining technology program**
  - Help formulate policy based on good scien
  - Respond to policy
  - Address water use, water quality, and cost of electricity from coal
- **Performance milestones**
  - Reduced fresh water use (% reduction target for 2010 under study)
  - Economic near-zero cooling water use plant option (by 2020)

CO_2 Management

- **Carbon management applicable for all carbon-based fuels; direct and indirect sequestration**
- **Coal Program Roadmap Goals**
  - <10% increase in cost of electricity for >90% removal of CO_2 (including sequestration)
  - Near-zero emission power and multi-product plants capable of CO_2 capture and sequestration - cost goal to be determined
- **Milestones to meet goals**
  - Field demonstration(s) of capture; field demonstration(s) of sequestration (2010)
  - Demonstrate energy plants integrated with capture/sequestration meeting program cost goal (2020)

Performance Targets: Coal-to-Fuel

	2010	2020 Vision 21
Plant Efficiency[1]	**45 - 65%**	**60 - 75%**
Plant Capital Cost[2]	**$35,000/bpd**	**<$25,000/bpd liq. $3-7/scfd H_2**
Product Cost - Liquids - Hydrogen[3]	**$30/bbl --**	**<$30/bbl $3-5/$10^6$ Btu**

(1) Efficiency depends on ratio of H_2 to electricity
(2) Capital cost of H_2 plant depends on ratio of H_2 to electricity
(3) H_2 cost depends on ratio of H_2 to electricity

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Roadmap Destinations

- **Integrated Plants**
  - **2010** Demonstrated power and multi-product plants w/o CO_2 capture meeting 2010 performance targets
  - **2020** Demonstrated near-zero emission power and multi-product plants that are capture and sequestration capable
- **Emissions Control - Existing Plants**
  - **2010** Meet air emissions; by-product use; water use and quality targets

Roadmap Destinations

- **Advanced Combustion**
  - **2010** Increased capacity, capacity factor, and efficiency; ultra supercritical steam - 1250 F
  - **2020** Ultra supercritical steam - 1400 F; Oxygen-coal combustion
- **Advanced Gasifier System**
  - **2010** Advanced air separation; slurry and pressurized dry solids feed; fuel flexible; improved performance at lower cost
  - **2020** Lower cost; increased efficiency; higher availability

Roadmap Destinations

- **Gas Cleaning**
  - **2010** Oxidizing & reducing; meet environmental and process requirements at optimal temperature and pressure

- **Syngas Utilization for Power, Fuels**
  - **2010** Increased efficiency, reduced emissions for syngas combustion with advanced turbines; Advanced syngas-to-liquid synthesis
  - **2020** Hydrogen gas separation; hydrogen turbine; 100 MW scale fuel cell systems

Carbon Management Roadmap Destinations

Technology Path	Technology Development	Demonstration
Separate & Capture - Gasification - Nitrogen-free combustion - post-combustion	2002-2012	2005-2012
Sequestration - Direct CO_2 storage - Natural sinks - Measure / verify	2002-2014	2006-2015

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Critical Technology Needs

Integrated Plants	Module designs, systems integration, high temperature materials, plant simulation capability, sensors & controls, intelligent plant operation (RAM – high reliability/availability, efficient and low cost operation)

Critical Technology Needs

Emissions Control	Gas separation, combustion, multi-pollutant control, cooling system design, sensors
Advanced Combustion	Materials for supercritical and ultra supercritical steam – boiler and steam turbine, CFB scale-up, O_2-combustion, heat & O_2-carrier concepts, sensors, control
Advanced Gasifier System	Gasifier design / scale-up, air separation, solids feed
Gas Cleaning	Multi-pollutant control, filter materials, regenerable sorbents

Critical Technology Needs

Syngas Utilization for Power, Fuels	Syngas combustion, synthesis reactor design, fuel cell systems, hybrid fuel cell-turbine systems, hydrogen gas separation, hydrogen turbine, storage and infrastructure for hydrogen economy

Critical Technology Needs

CO_2 Capture	Solid sorbents, CO_2 hydrates, membranes, liquid absorption
CO_2 Sequestration	Direct and indirect sequestration concepts; 'value-added' concepts; geologic, ocean, soil eco-system affects and modeling capability

Roadmap Benefits: Key Assumptions

- Economic benefits are constant 2002 $'s
- No credit taken for prior DOE investments in technology currently used (e.g., benefits from FGD)
- Cost savings are relative to 2000 PC plant
- Added capacity in 2020 includes replacement of >60-year old plants (53GW) plus new capacity (31-64 GW)
- Benefits from emissions trading cost credits not considered

Roadmap Benefits

- Provides competitive near-zero emission coal-based plants
- $100 billion projected direct economic benefit through 2020 (fuel cost, capital cost, technology export)
- $500 billion to $1 trillion additional benefit projected through 2050[1]
  - Assumes loss of coal option projected to force use of alternative technology with 1-2 ¢/kWh increase in COE
- Security benefits include:
  - maintaining diversity of energy resources
  - retains domestic manufacturing capabilities
  - reduced dependence on imported oil (transportation fuel production capability)

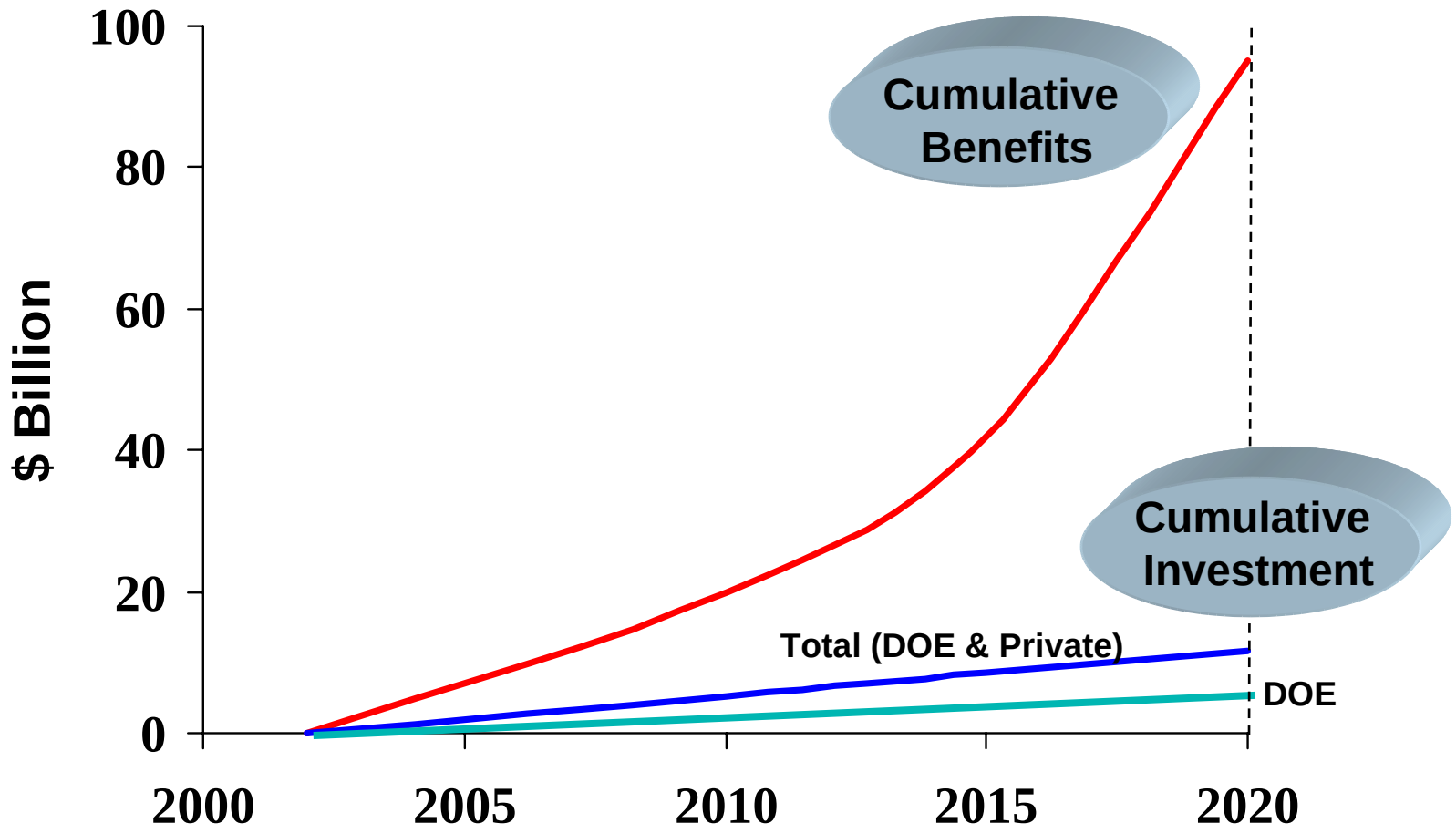
1. Consistent with May 2002 EPRI Market Based Valuation of Coal study that projects $0.3 to 1.3 trillion payoff from coal R&D

Roadmap - Benefits/Investment ($ million)

	Cumulative (today – 2020)
Investment[1,2]	
R&D	**5,300**
Demonstration	**5,400**
Total	**10,700**
Economic Benefit[3]	**100,000**
Benefit/Investment Ratio	**~10**

1 Current year $; Includes DOE + private sector investment
2 Investment does not include carbon sequestration; sequestration investment and benefits are applicable to coal program and other processes using carbon-based fuels; cumulative anticipated investment to 2020 is ~$4 billion
3 Assumes existing plant improvements dominate from today-2010 and new plant benefits dominate from 2010-2020

Roadmap - Benefits/Investment



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Coal Roadmap Benefits: Security Considerations

- **Reduces dependence on imported oil**
  - Co-production of power and environmentally attractive fuels (e.g. F-T liquids, hydrogen)
- **Maintains diversity of energy resource options**
  - Avoids over reliance on gas for central station power
  - Encourages economical use of gas in other sectors
  - Reduces energy price volatility and supply uncertainty
- **Retains domestic manufacturing capabilities & U.S. energy technology leadership**
  - Enhances economic growth and security
- **Provides technology to permit international use of coal resources resulting in higher standards of living and increased social/economic stability**