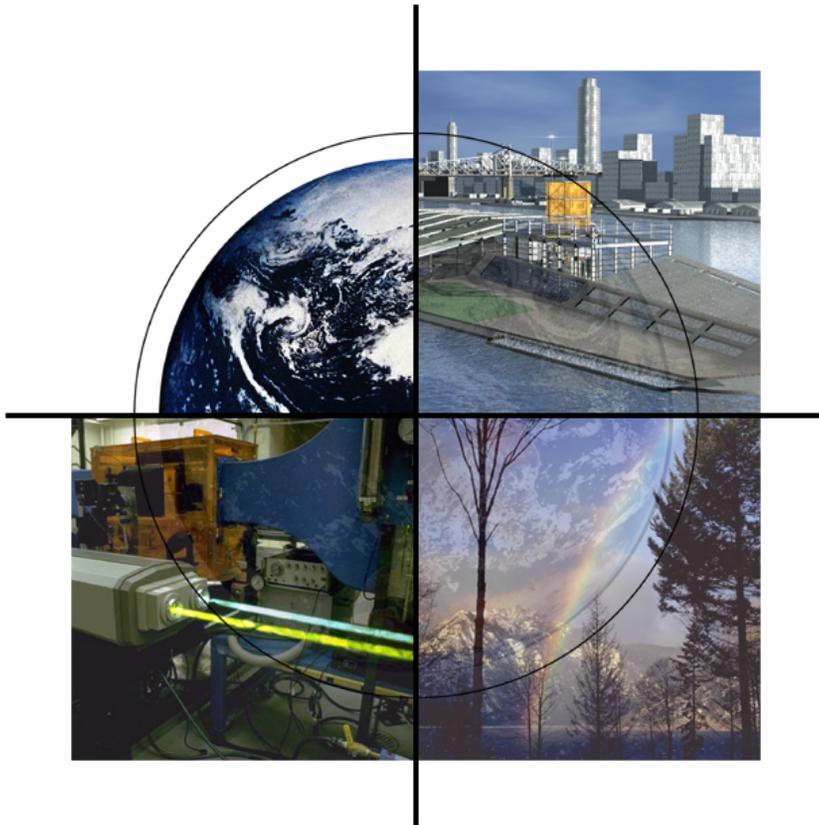


Coal Power Program Roadmap

CCPI Round 2 Planning Workshop

Pittsburgh, PA
August 26, 2003



Kenneth Markel, Jr., Associate Director
National Energy Technology Laboratory



Coal Power Program Roadmap

Approach

- **Review performance & cost targets**
 - CURC, EPRI, DOE product lines, Future energy plants
- **Capture common objectives**
 - NEP
 - Presidential Initiatives
 - State-of-art > 2020
 - Existing fleet
 - New plants
 - Regulations
 - Carbon management
- **Quantify benefits**
 - Benefits vs. RD&D costs
- **Reach consensus**
 - CURC, EPRI



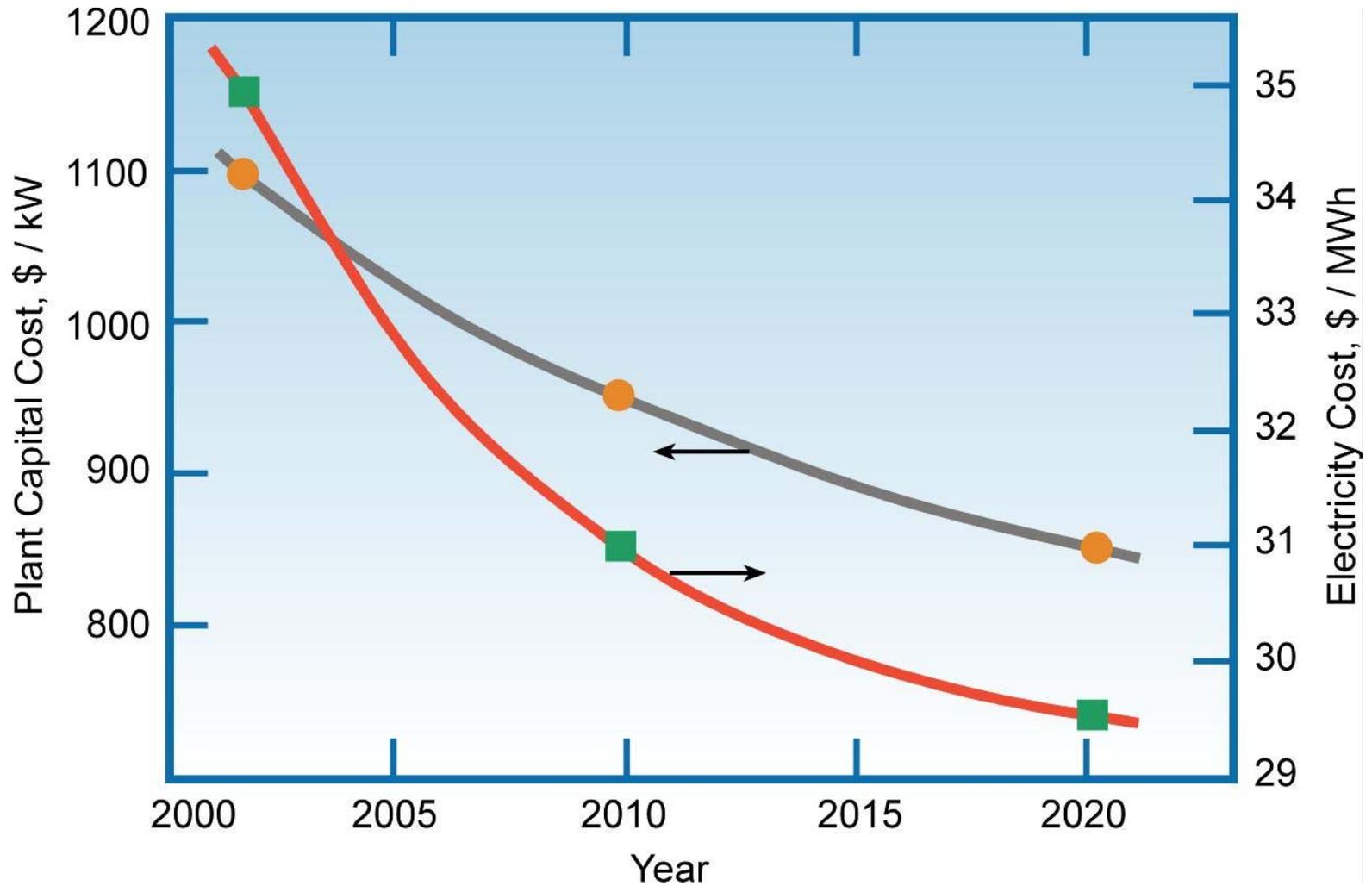
Coal Power Program Roadmap

Key Assumptions

- **Today's technologies**
 - ≠ Near Zero Emission (NZE)
 - ≠ carbon management
 - Incremental improvement ≠ future requirements
 - Adding equipment = complex & costly
 - Need Innovative Integrated Technologies**
- **Today's fleet > Tomorrow's fleet**
 - 60% is 20-40 years old
 - 10 -15 years > new technology
 - Must meet demand
 - Must comply with Regulations
 - Transition critical**



New Power Plant Cost Targets



Coal Power Program Roadmap

Destinations and Critical Technology Needs

- **Integrated Energy Plants**

Destinations

- 2010
 - Power & multi-product
 - w/o CO₂
- 2020
 - NZE & Sequestration-ready

Technology Needs

- Module designs, systems integration, simulation capability, sensors & controls (“smart” plant operation), improved materials



Coal Power Program Roadmap

Destinations and Critical Technology Needs

- **Existing Plants - Emissions Control**

Destinations

– 2010

- Clear Skies, NO_x, PM, Hg, by-product, & fresh water use targets

Technology Needs

- Low-NO_x combustion, low-cost catalysts, improved filtration and electrostatic separation, sorbent systems, multi-pollutant controls, dry cooling systems, sensors



Coal Power Program Roadmap

Destinations and Critical Technology Needs

- **Advanced Combustion**

Destinations

- 2005
 - Fuel flexibility
- 2010
 - Supercritical steam – 1200°F
- 2020
 - Ultra-supercritical steam – 1400°F
 - Nitrogen-free combustion / sequestration-ready

Technology Needs

- Cofiring, CFB scale-up, advanced boiler tube & steam turbine materials, coal-oxygen combustion, oxygen “carriers,” sensors & controls



Coal Power Program Roadmap

Destinations and Critical Technology Needs

- **Advanced Gasifier System**

Destinations

– 2010

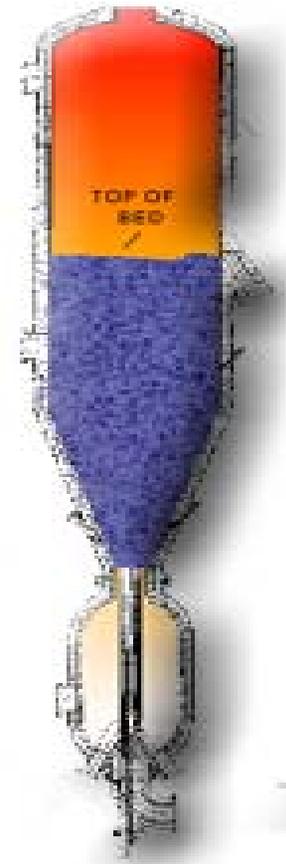
- Lower cost, increased efficiency, higher availability
- Low-cost air separation
- Dry solids feed/fuel flexible

– 2020

- Lower cost, increased efficiency, higher availability

Technology Needs

- More efficient, lower cost gasifier designs (transport & others), improved refractory materials, air separation, more efficient & reliable feed systems



Coal Power Program Roadmap

Destinations and Critical Technology Needs

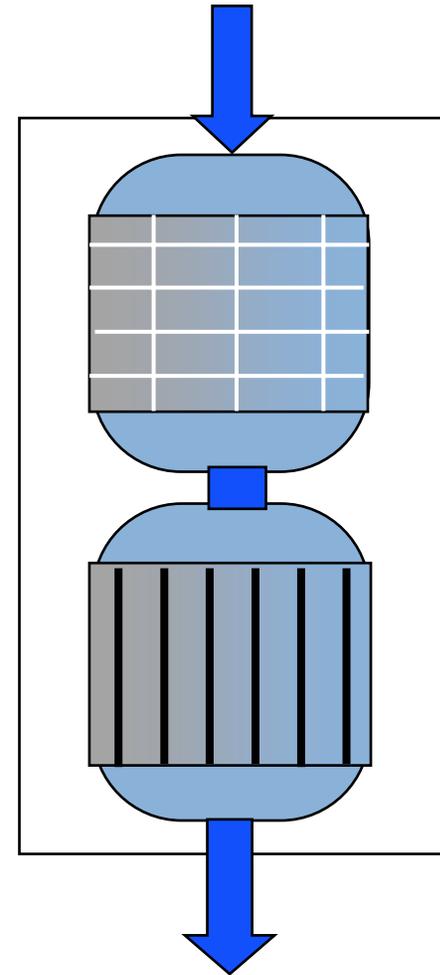
- **Gas Cleaning**

Destination

- 2010 - Meet environmental & process requirements
 - Optimal temperature & pressure
 - Oxidizing & reducing environments

Technology Needs

- Multi-pollutant control, filter materials & systems, regenerable sorbents, sensors & instrumentation



Coal Power Program Roadmap

Destinations and Critical Technology Needs

- **Syngas**

Destinations

- 2010
 - Clean fuels
 - Increased efficiency
 - Power
 - Fuels
 - Reduced combustions emissions
- 2020
 - Co-production > electricity & hydrogen
 - Hydrogen/air & natural gas/oxygen turbines
 - SOFC @100 MW scale
 - Advanced hydrogen separation



Technology Needs

- Fuels synthesis reactors, syngas combustion, fuel cells, fuel-flexible turbines, hybrid fuel cell-turbine systems, hydrogen combustion, air separation, hydrogen separation



Coal Power Program Roadmap

Destinations and Critical Technology Needs

- **CO₂ Capture & Sequestration**

Destinations

- 2010
 - MW-scale capture demonstrations
 - Field sequestration demonstrations
- 2020
 - Integrated capture/sequestration meeting program cost goal

Technology Needs

- Solid sorbents, CO₂ hydrates, membranes, liquid absorption, O₂ combustion
- Direct & indirect sequestration concepts; value-added concepts; geologic, ocean, soil eco-system performance & modeling capability



Coal Power Program Benefits

Assumptions

- **2002 dollars**
- **No credit for prior DOE technology investments**
- **State-of-art coal plant = baseline**
- **2010 benefits primarily from existing plants**
- **2010- 2020 benefits primarily from new plants**
- **2020 added capacity includes**
 - replacement of >60-year old plants (53 GW)
 - new capacity (31-64 GW)
- **Emissions trading not considered**



Coal Power Program Benefits

Savings Category	Basis
Fuel Cost	Higher Efficiency
Capital Cost (New Plants)	Lower capital cost
Control Technology Cost (Existing Plants)	Lower capital and operating cost
Avoided Environmental Costs	Estimated credit (health, infrastructure, agriculture)¹
Technology Export	Foreign U.S. technology sales increase 10-15%
Absence of NZE plants	1-2 ¢/kWh increase in COE

¹Based on EPA and Resources for the Future data



Coal Power Program – Economic Benefits

Savings Categories	Cumulative Benefits (\$ billions, today – 2020)
Fuel Cost ¹	10
Capital Cost (New Plants) ²	12
Control Technology Cost (Existing Plants) ³	32
Avoided Environmental Costs ⁴	10
Technology Export ⁵	36
Total Benefit	100

Other Benefits

- **Estimated increased jobs from technology export –**
 - **75,000 in 2010**
 - **200,000 in 2020**
- **\$500 billion to \$1 trillion additional savings thru 2050**
 - **loss of coal option = 1-2 ¢/kWh increase in COE**



Coal Power Program Roadmap

Summary

- **Integrated roadmap available for first time**
 - Unified performance goals for DOE & industry
 - Goals consistent, quantitative, verifiable
- **Substantial benefits projected**
 - Thru 2020 Benefit/investment = 10 (conservative)
 - Thru 2050 Benefit/investment = 25-50 (+\$0.5-1.0 trillion saved)
 - Lower coal electricity cost
- **Major technological improvements needed to realize benefits**
 - Coal Power Program
 - near-term, transitional, & future
 - Core R&D program providing innovative technology for use through 2050 & beyond



Background Slides for Information



Coal Power Program Roadmap Addresses Short- and Long-Term Needs

- **Short-term: existing fleet**
 - regulations
- **Long-term: future plants**
 - Near-zero (NZE) emissions
 - clean fuels
 - CO₂ management capable



Coal Power Program Roadmap

Issues

- **Requirements different**
 - Existing plants > meet regulations at lowest cost
 - Future plants >: NZE
 - Approach: separate targets for existing & new plants
- **Technologies not equal**
 - Performance
 - Application
 - Approach: Best performance



Coal Power Program Roadmap

New Plant Performance Targets

(Represents best integrated plant technology capability)

	Reference Plant	2010	2020 Vision 21
Air Emissions	98% SO₂ removal	99%	>99%
	0.15 lb/10⁶ Btu NO_x	0.05 lb/10⁶ Btu	<0.01 lb/10⁶ Btu
	0.01 lb/10⁶ Btu Particulate Matter	0.005 lb/10⁶ Btu	0.002 lb/10⁶ Btu
	Mercury (Hg)	90% removal	95% removal
By-Product Utilization	30%	50%	near 100%
Plant Efficiency (HHV)	40%	45-50%	50-60%



Coal Power Program Roadmap

Targets: Coal → Power ⁽¹⁾

(Best integrated capability)

	Reference Plant	2010	2020 Vision 21
Plant Efficiency (HHV)⁽²⁾	40%	45-50%	50-60%
Availability⁽³⁾	>80%	>85%	≥90%
Plant Capital Cost⁽²⁾ \$/kW	900 – 1300	900 – 1000	800 – 900
Cost of Electricity⁽⁴⁾ ¢/kWh	3.5	3.1	<3.0

(1) w/o carbon capture and sequestration & cooling tower technology

(2) Range = different technologies achieving performance and energy cost targets

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

(4) Bus-bar COE - 2003 dollars; Reference plant = \$1000/kW capital cost, \$1.20/10⁶ Btu coal cost



Coal Power Program Roadmap

Targets: Coal→Fuel

	2010	2020 Vision 21
Plant Efficiency⁽¹⁾	45 - 65%	60 - 75%
Plant Capital Cost	\$35,000/BPD	<\$25,000/BPD liq. <\$10,000/SCFD H₂
Fuel Cost - Liquids - Hydrogen	\$30/bbl --	<\$30/bbl \$3-5/10⁶ Btu

(1) Range is for co-production plants



Coal Power Program

Notes for Economic Benefits Table

- 1 Current fuel cost for U.S. coal-fired generation: \$25-30 billion/year
- 2 Based on \$100/kW and \$200/kW savings for new plants in 2010 and 2020 respectively
- 3 Purchase of coal plant control technology currently \$6-10 billion/year (\$5-6 billion/year for SO₂, NO_x, and PM; estimates for Hg control \$1-4 billion/year)
- 4 Avoided costs estimated for health, infrastructure, and agriculture; avoided costs resulting from DOE service and knowledge products to analyze operating plants not included
- 5 Power generating machinery and equipment exports currently \$30-35 billion/year (U.S. Bureau of Census); increased export benefit based on projections for world coal fired generating capacity; assumes clean coal technology will increase U.S. market penetration by 10-15% for coal plant sales – primarily in developing countries

