ESE Benefits Forecast Merit Review

Office of Fossil Energy (FE)

Methodology, Assumptions & Results

Julianne M. Klara
Senior Analyst
Office of Systems, Analysis and Planning

December 20, 2006

National Energy Technology Laboratory

Outline

- **The Office of Fossil Energy’s Research Portfolio**
- **Benefits Methodology**
- **Baseline Forecast**
  - Input assumptions
  - Comparison to AEO2006
- **“With FE R&D” Forecast**
  - Input assumptions
  - Results
- **Sensitivity Analysis: Policy and Market Scenarios**
- **Future Work**

The Office of Fossil Energy's Research Portfolio

FE R&D Addresses Key Energy Issues

- **Goal:**
  - To ensure availability of ultra-clean (“zero” emissions), abundant, low-cost, domestic electricity and energy

- **Two programs:**
  - **Clean Coal**
    - Focus of 2006 benefits analysis and this presentation
  - **Oil and Natural Gas**
    - Benefits not calculated in 2006 (FY2007 funding = 0)
    - Section 999 of Energy Policy Act of 2005 assumed to continue research regardless of FE oversight and participation

FE Research Portfolio

Clean Coal Program Activities (1 of 2)

- ***Innovations for Existing Plants***
  - Pollution control options for current fleet of coal-fired power plants
  - Comply with current and future environmental regulations
  - No major cost burdens to ratepayer
  - Build foundation for entirely new environmental control processes
- ***Advanced Power Systems***
  - New generation of electric power generating “platforms”
  - Advanced coal gasification, turbines capable of burning coal-derived syngas, and novel combustion concepts
  - Core of the “zero” emission coal plant of the future
- ***Carbon Sequestration***
  - New suite of technologies to safely and economically capture and store carbon dioxide from coal-based energy systems
  - Permanent removal of contributors to global climate change
- ***Solid State Energy Conversion Alliance (SECA) Fuel Cells***
  - Revolutionary approaches using solid state technology
  - Electrochemical-based fuel cells that can operate on coal-derived fuels

Clean Coal Program Activities (2 of 2)

- ***Hydrogen-From-Coal***
  - New, affordable methods to extract commercial-grade hydrogen from coal
  - Deliver hydrogen reliably to end-users, especially transportation sector
  - *Not sufficiently modeled in NEMS to estimate benefits*
- ***Clean Coal Power Initiative (CCPI)***
  - Series of competitive solicitations (2002–2012)
  - Encourage industry to identify and cost-share final stages of development for best emerging coal-based power-generating technologies
  - *Not modeled directly in NEMS, contributes to timing of other programs*
- ***FutureGen***
  - Culminating project to build world's first integrated coal-based energy plant
  - Generate electricity, produce hydrogen and sequester greenhouse gases
  - Serve as the proving ground for advanced coal concepts
  - *Not modeled directly in NEMS, contributes to timing of other programs*

Benefits Methodology

Methodology: 3 Step Summary

1. **Craft baseline forecast.** Run NEMS model with technology cost and performance assumptions consistent with cessation of FE funded research

2. **Craft "with FE R&D" forecast.** Re-run NEMS model with technology cost & performance assumptions changed to reflect achievement of FE research portfolio goals

3. **Derive FE benefits.** Analyze differences between the baseline and "with FE" forecasts

Process is repeated for a number of policy/market scenarios (e.g., business as usual, high fuel price, carbon constraint)

Benefits Methodology

Sectors in NEMS Affected by FE Research

- **Utility Sector: Electricity Market Module**
  - Power plant retrofits
  - New central station power plants
  - Utility-owned distributed generation

- **Buildings Sector: Residential and Commercial Demand Modules**
  - Distributed generation systems

Benefits Methodology

Program/NEMS input Crosswalk

FE Program/technology	NEMS Category
IEP Hg Controls for Existing Coal Plants NO_x Controls for Existing Plants	Activated Carbon Injection Low-NO_x Burner and SCR
Advanced Power Gasification, Turbines, Fuel Cells[1]	Advanced Coal Advanced NGCC
Sequestration	Advanced Coal and NG with Sequestration
Fuel Cells (SECA)	Utility: base load and distributed generation Buildings: distributed generation

1. The addition of a fuel cell integrated with an advanced turbine in an IGCC is called an IGCC-Hybrid plant

NETL

Baseline Forecast

Baseline forecast

Baseline Cost & Performance Inputs for FE Technologies Relative to AEO 2006 Ref. Case

- **Unchanged from AEO 2006**
  - Retrofit mercury emissions abatement
  - Retrofit NO_x emissions abatement
  - Fuel cells
  - Distributed generation in building sectors

- **Changed**
  - IGCC
  - IGCC with sequestration
  - Advanced NGCC

Baseline forecast, Inputs

FE Approach to Developing Baseline Inputs

- **2004 study performed by Booz Allen Hamilton (BAH)**
- **Approach was to poll a group of experts**
  - Gather opinions about future technology cost and performance, both with and absent DOE funding
  - Estimate capital cost, heat rate, O&M
  - Engage experts from a range of backgrounds
  - Conduct a series of workshops and iteratively refinement estimates
- **BAH "no R&D" case definition:**
  - Results are a "natural evolution of technologies based on cost and efficiency improvements that are gradual and consistent with historical trends"


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Booz | Allen | Hamilton

Final Report

Coal-Based Integrated Gasification Combined Cycle: Market Penetration Recommendations and Strategies

Produced for the Department of Energy (DOE) National Energy Technology Laboratory (NETL) and the Gasification Technologies Council (GTC)

September 2004

NETL

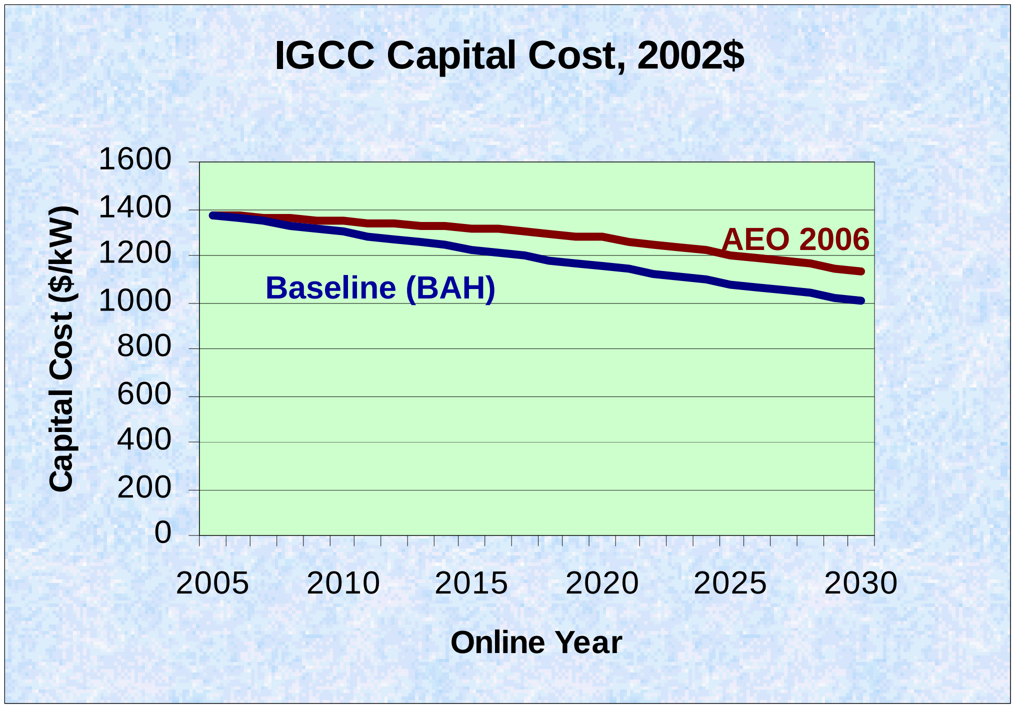
Reference:
Booz, Allen, Hamilton, "Coal-Based Integrated Gasification Combined Cycle: Market Penetration Recommendations and Strategies," DE-AM26-99FT40575, September 3, 2004.

Baseline forecast, Inputs

Inputting Baseline Projections into NEMS

- **Learning and technology advancement factors in NEMS replaced by user-specified 30-year projections**
  - Capital cost, efficiency, and O&M
  - Linear interpolation and extrapolation used in absence of more detailed data
  - Expert opinion used for baseline
- **Attention to details**
  - Contingency
  - Inflation
  - Online year versus decision year

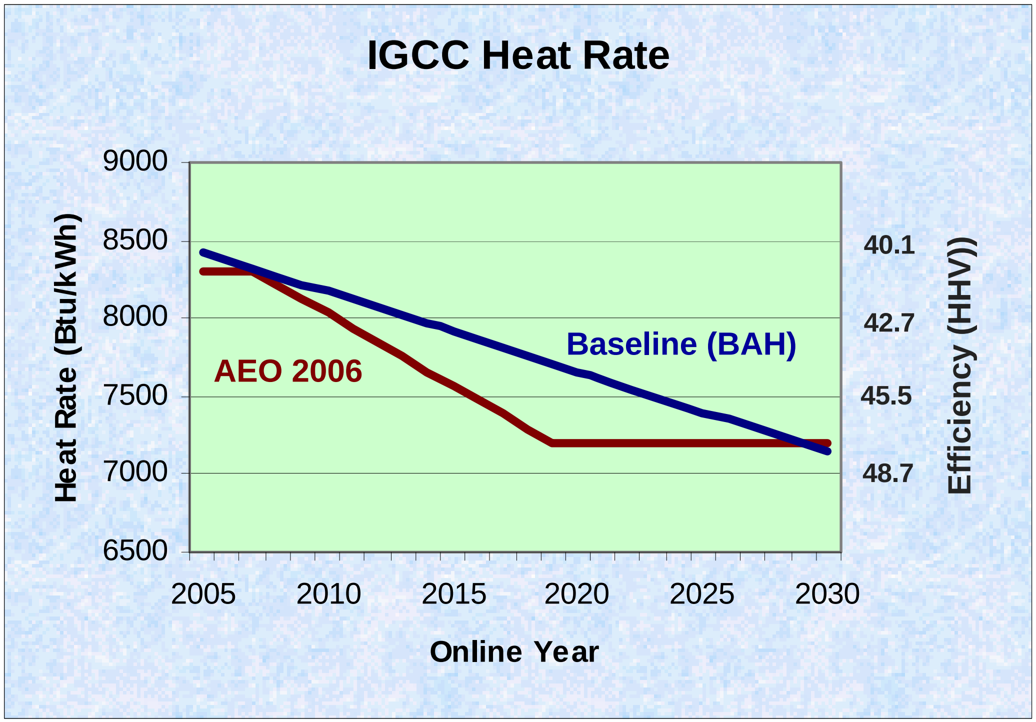
Example: Baseline IGCC inputs versus AEO 2006



- **BAH study predicts IGCC capital costs that are lower than AEO 2006 reference case**
- **BAH estimates available only for 2005 and 2025. Straight-line interpolation / extrapolation used to develop curve.**

Baseline forecast, Inputs

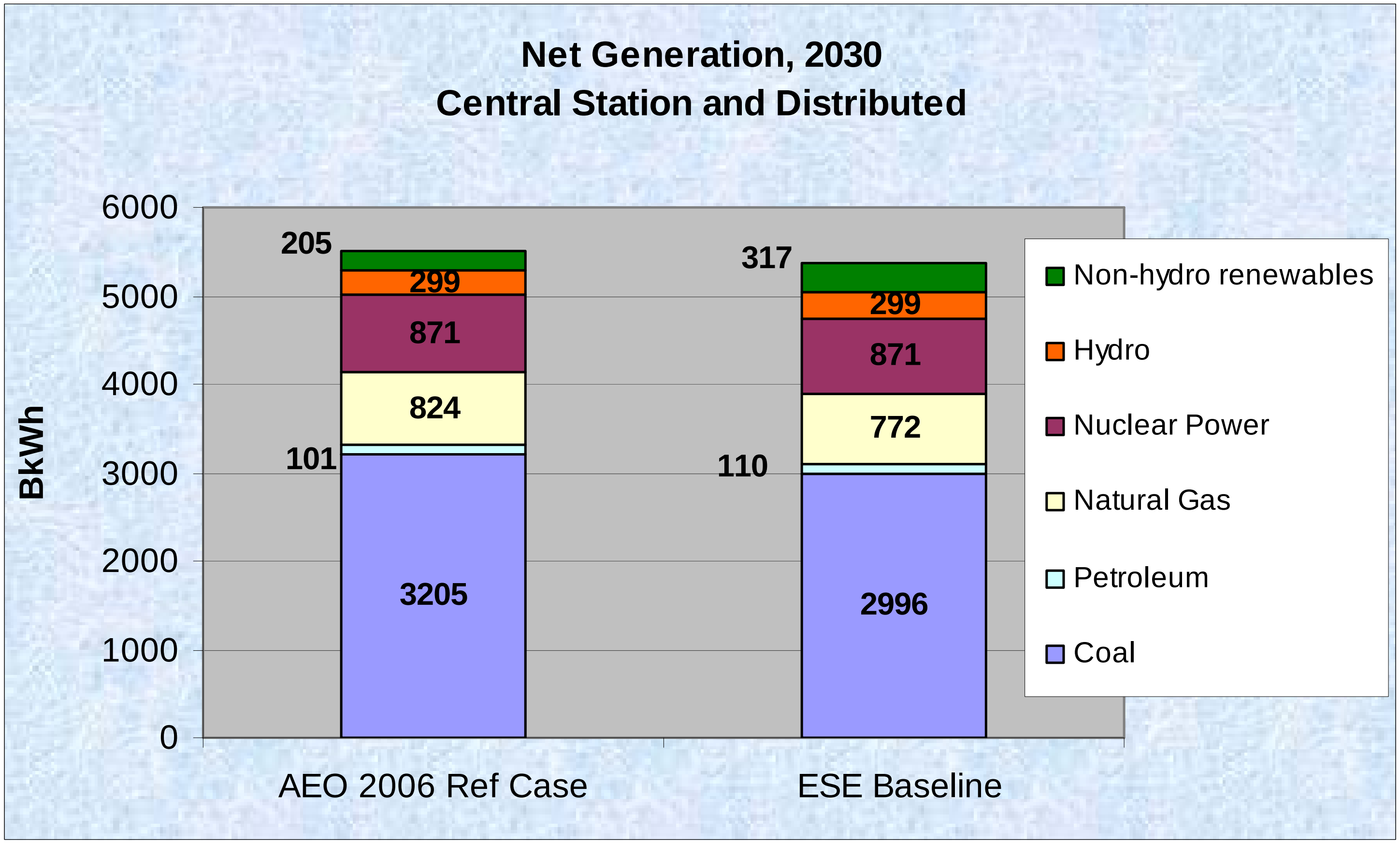
Example: Baseline IGCC inputs versus AEO 2006



- **BAH and AEO 2006 reference case predict IGCC heat rates comparable in long term; AEO 2006 assumes earlier progress**
- **BAH estimates available only for 2005 and 2025. Straight-line interpolation / extrapolation used to develop curve.**

Baseline forecast, Comparison to AEO2006

Impact of Baseline Modifications



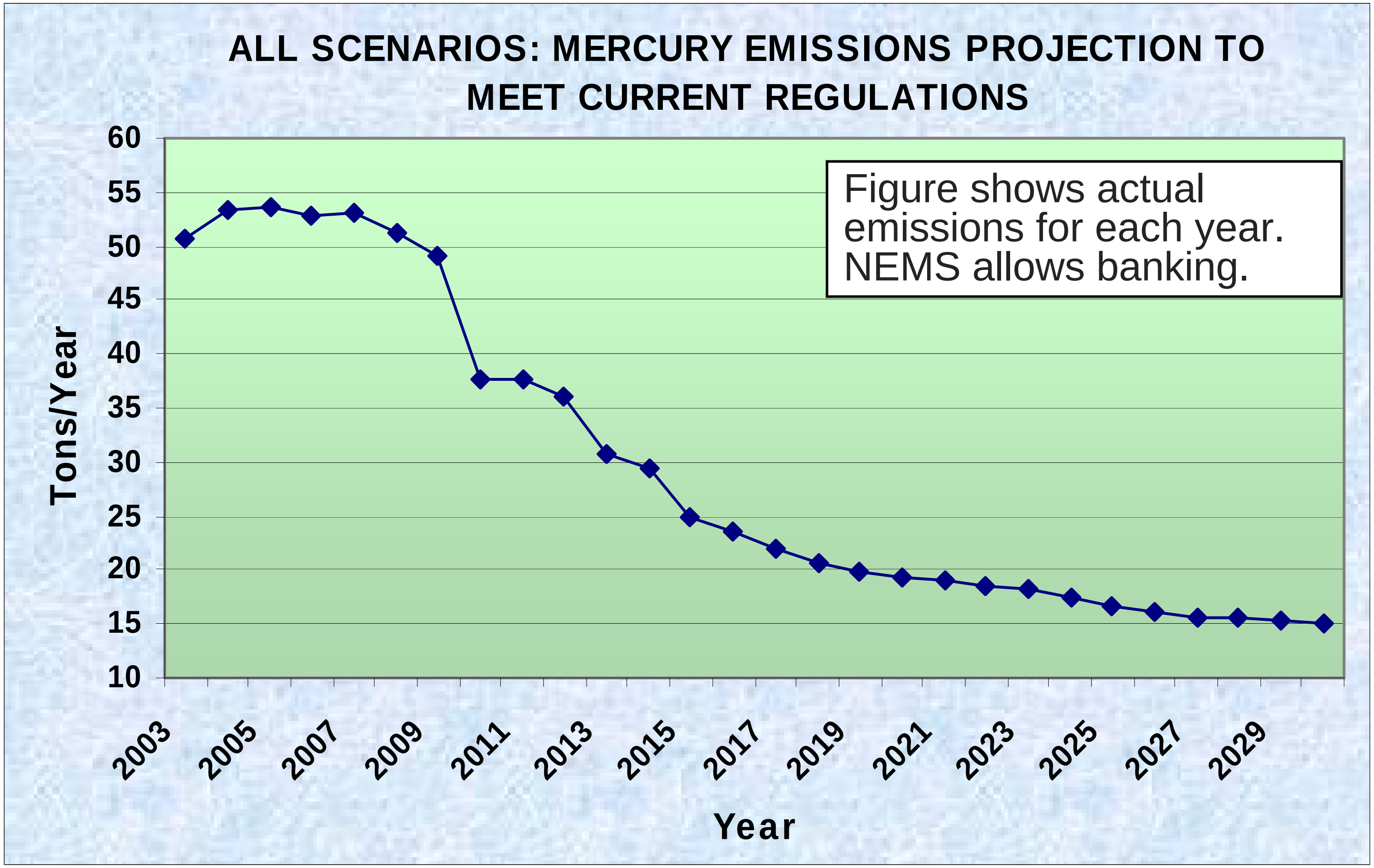
“With FE R&D” Case

Defining “With FE R&D” Case

- **Uses technology cost and performance impacts from FE programs only**
  - All FE programs achieve all goals
  - EERE, NE, OE baseline parameters are unchanged from the ESE baseline
  - A first step towards ESE portfolio evaluation
- **Economic growth, world oil price, and environmental regulations are unchanged from baseline**

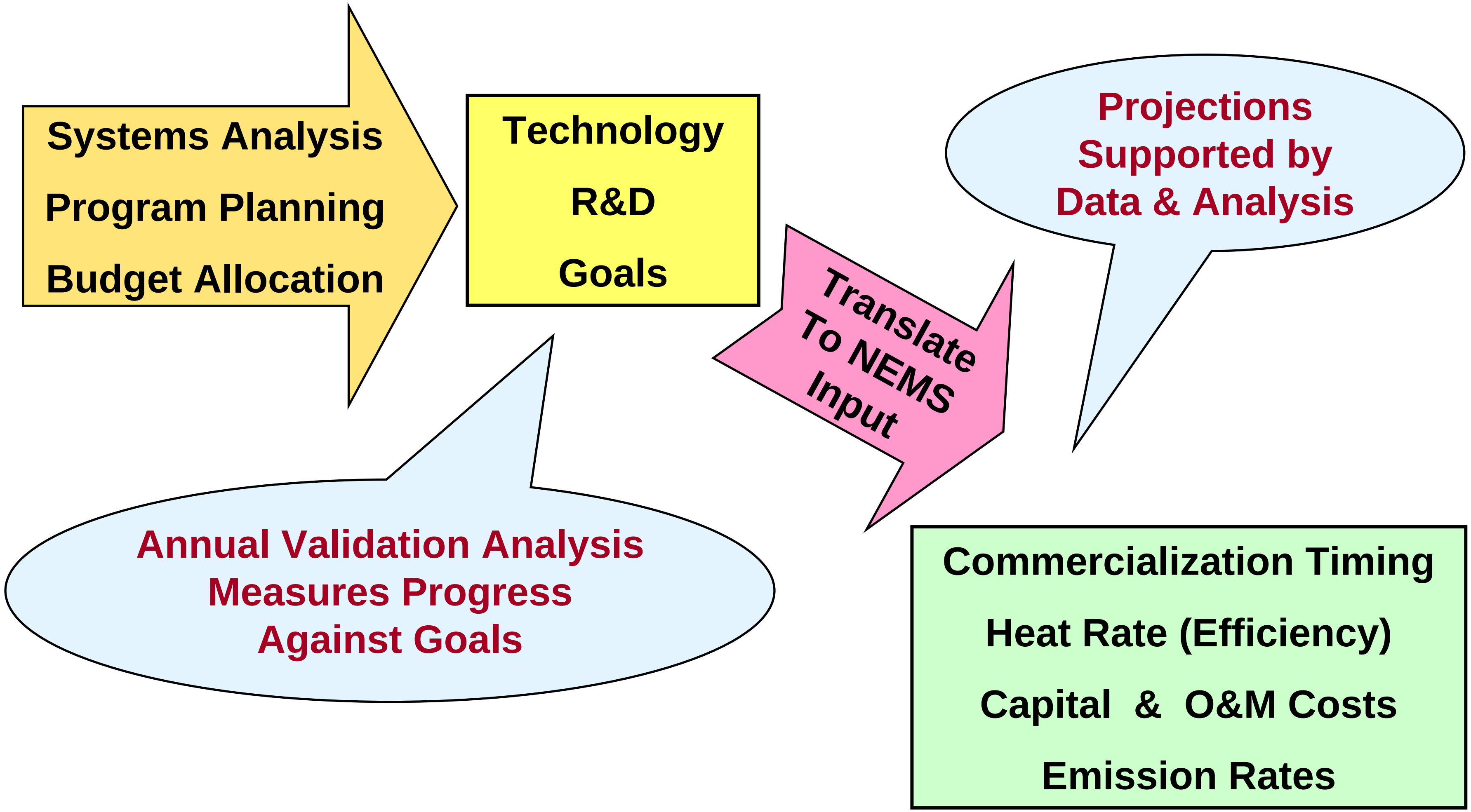
"With FE R&D" Case

Emissions of Regulated Pollutants



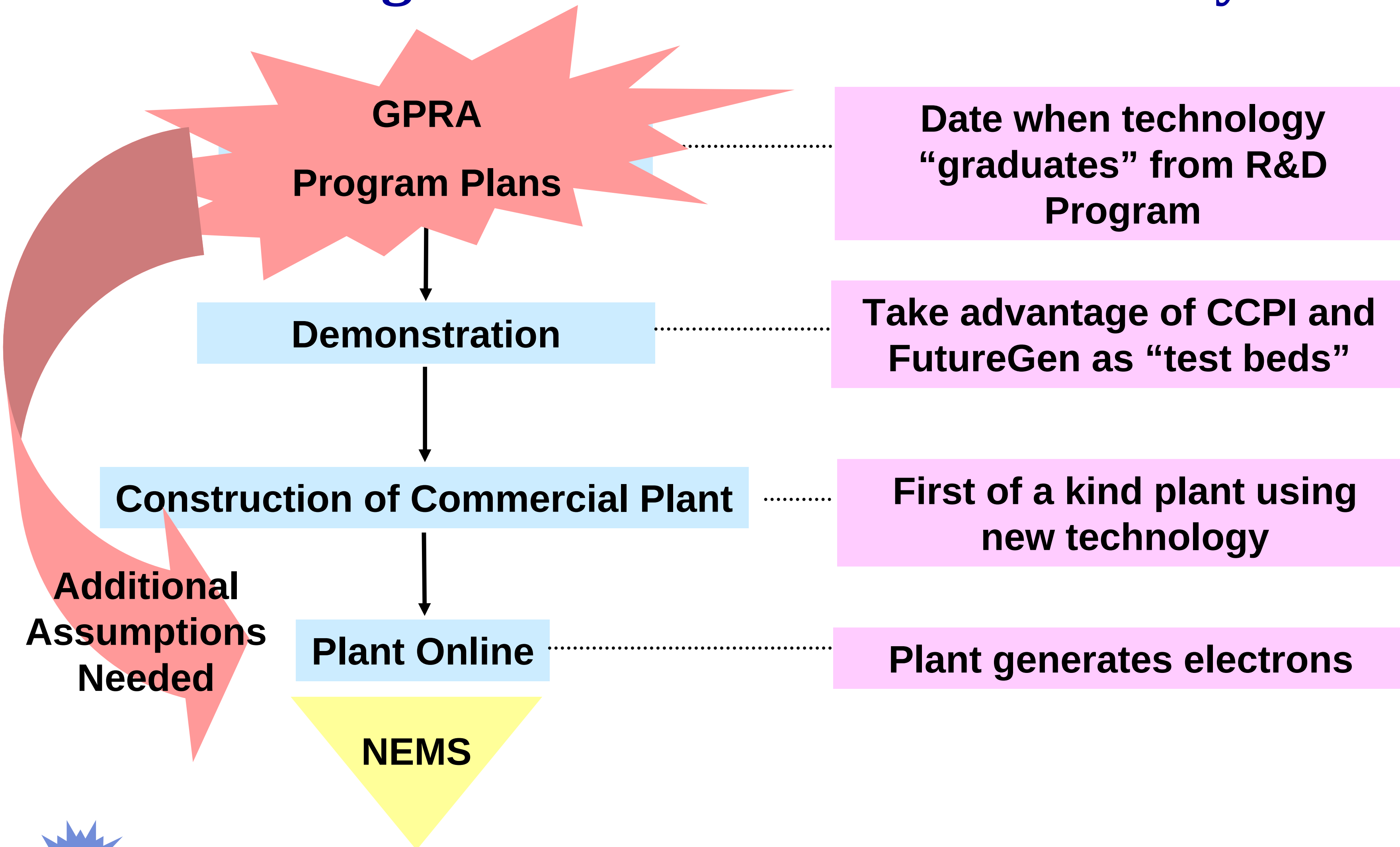
“With FE R&D” Case, Inputs

Developing NEMS Input



"With FE R&D" Case, Inputs

Estimating First Commercial Availability



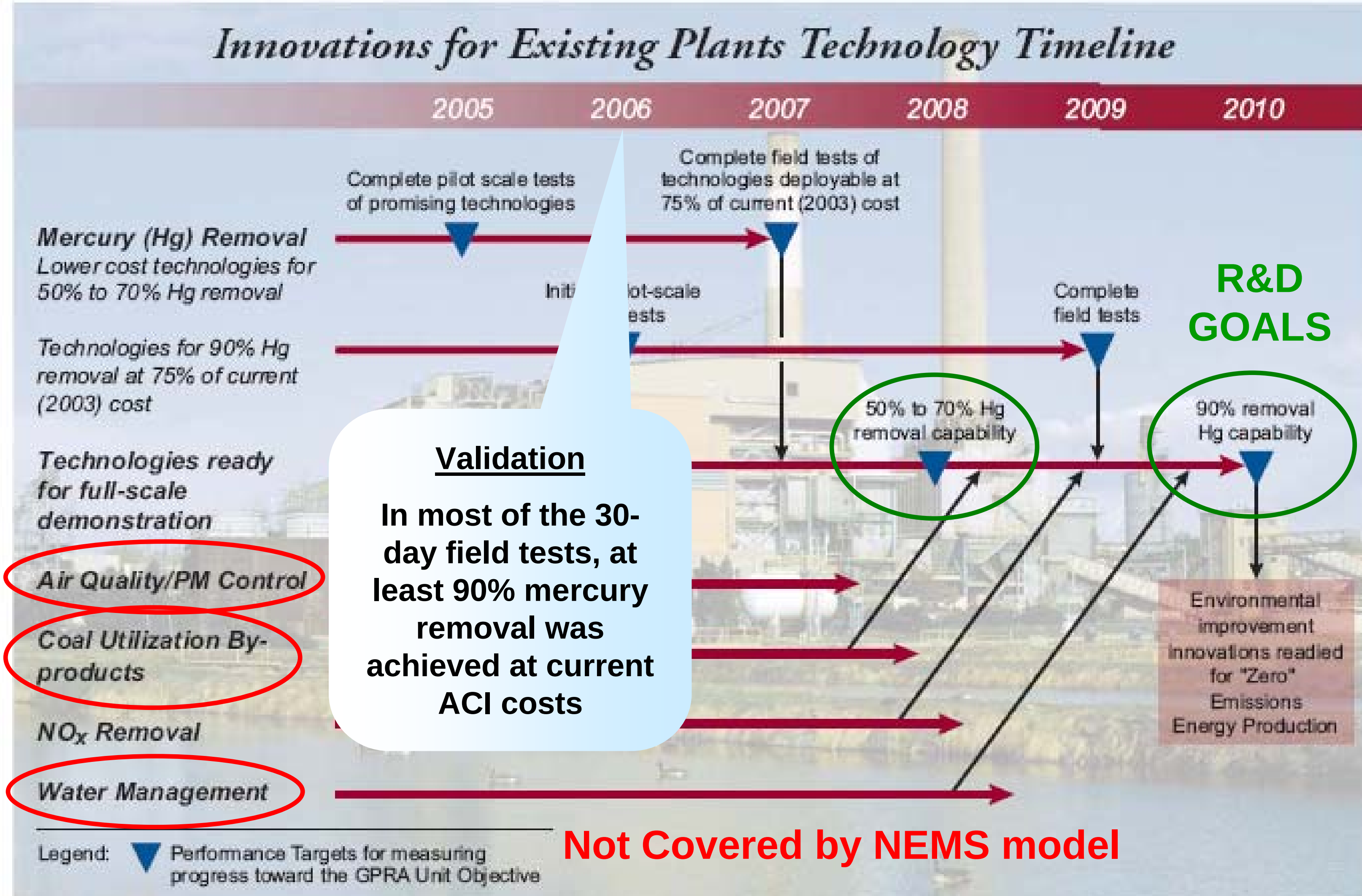
“With FE R&D” Case, Inputs

Input Assumptions & Results by Technology Area

- IEP
- Advanced Power
- Sequestration
- SECA Fuel Cells

"With FE R&D" Case, Inputs, IEP

Innovations for Existing Plants (IEP) Snapshot



"With FE R&D" Case, Inputs, IEP

IEP Major Assumptions

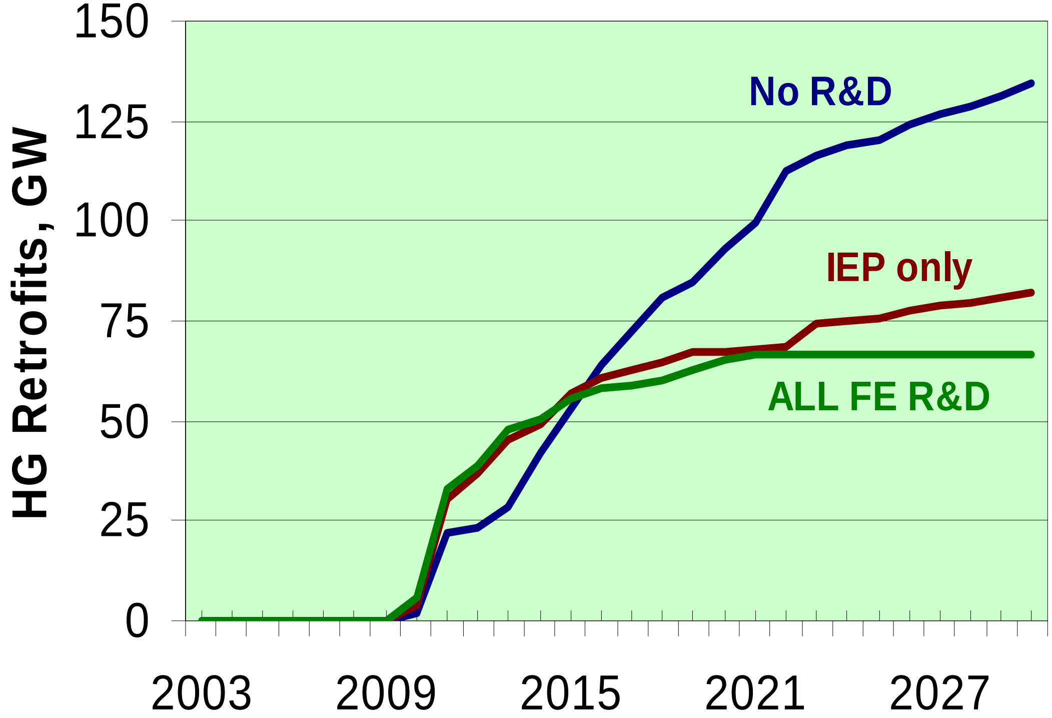
- **Mercury removal costs decline while efficiency improves**
  - Activated carbon injection cost is modified in NEMS
    - 2012: 70% removal at 50% of current ACI cost*
    - 2015: 90% removal at 50% of current ACI cost*

* $50K-70K/lb

- **NO_x removal costs decline as emission rate improves**
  - Cost reduction is applied to low-NOx burner technology option so that it can compete with SCR
    - 2009 .15lb/MMBtu NO_x 75% of SCR ($/ton NOx removed)
    - 2015 .10lb/MMBtu NO_x 75% of SCR
    - 2025 .01lb/MMBtu NO_x 75% of SCR

"With FE R&D" Case, Results, IEP

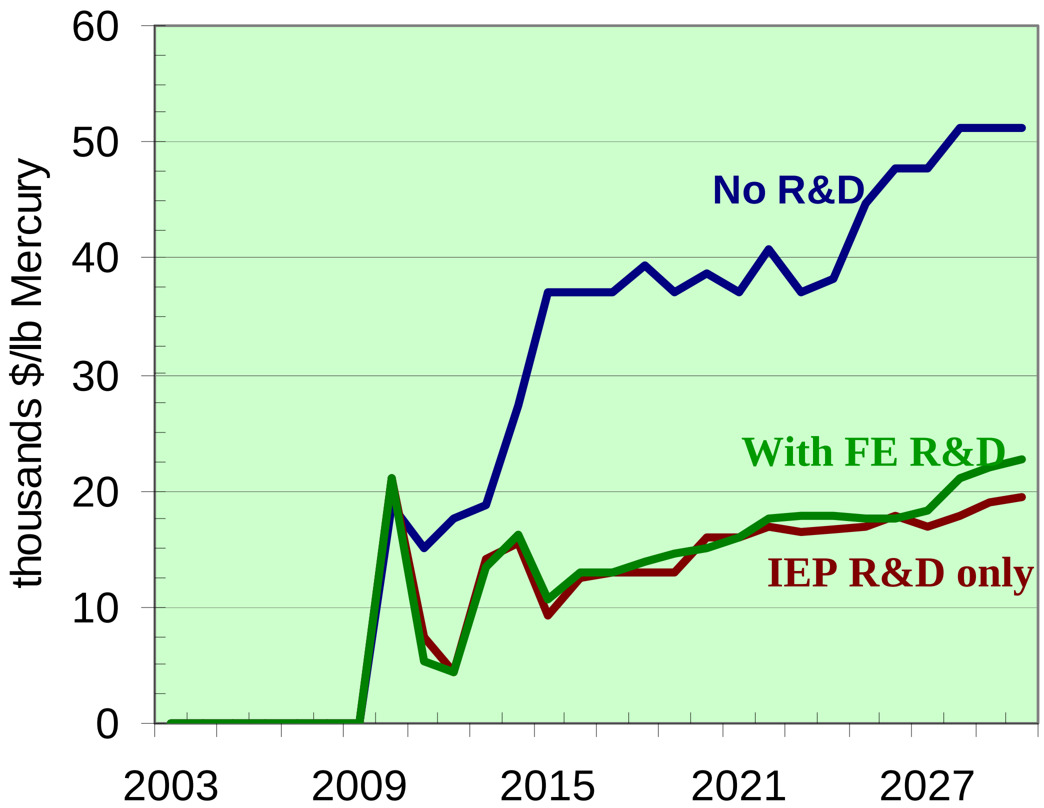
More Effective Mercury Control Retrofits with R&D



- IEP technology increases Hg reduction from 50% to 90%, need less retrofits to achieve compliance
- IEP technology is deployed even with success in IGCC (67 GW versus 82 GW)

"With FE R&D" Case, Results, IEP

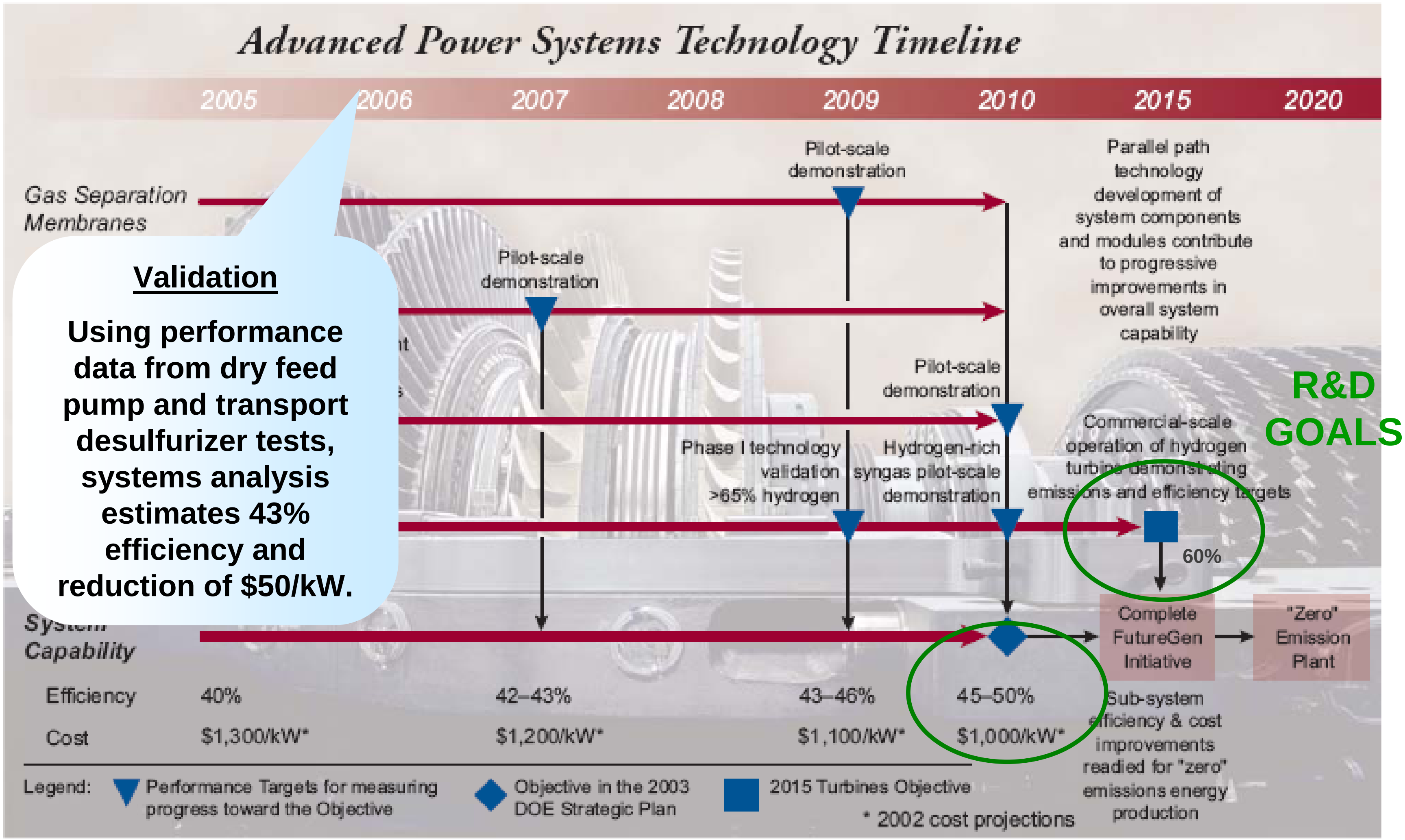
Mercury Allowance Costs Reduced with R&D



- IEP alone and full FE portfolio provide significant reductions in mercury allowance prices
- In 2020 the volume of allowances traded is 19 short tons Hg, giving a benefit of $880 MM/yr
- Post combustion Hg capture also provides a backstop against slip in the IGCC deployment schedule

"With FE R&D" Case, Inputs, Advanced Power

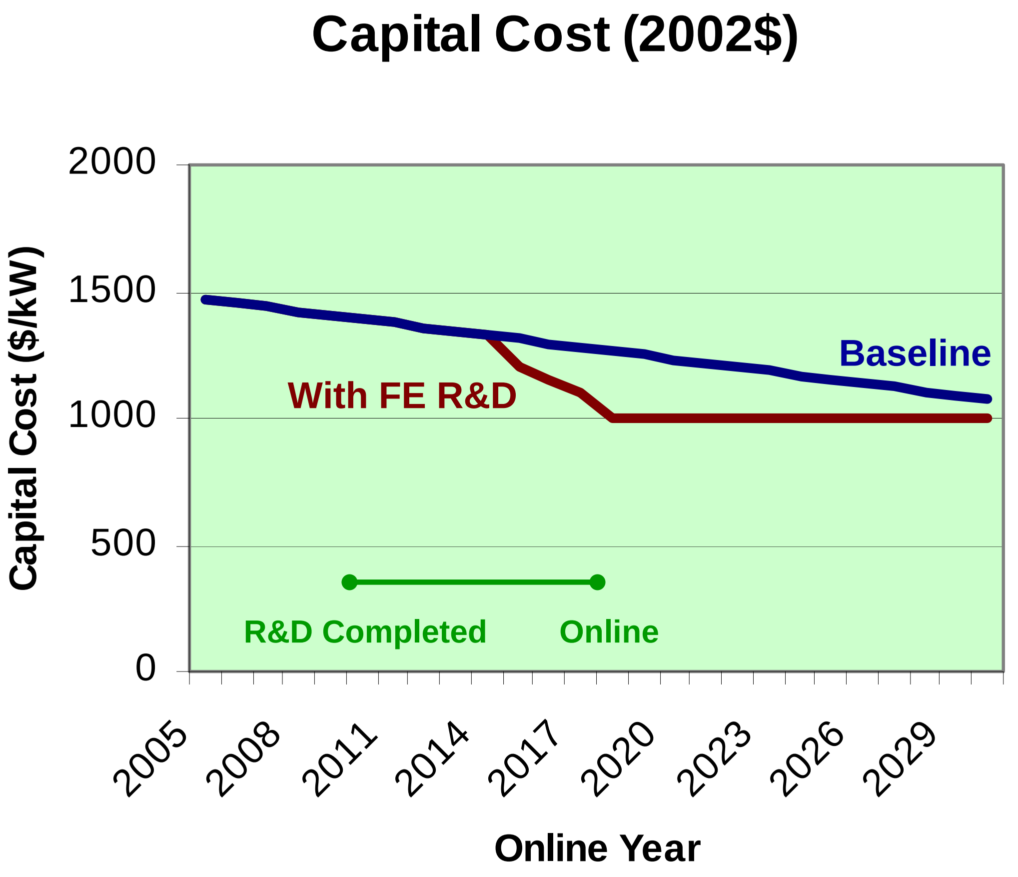
Advanced Power Systems Snapshot



Validation

Using performance data from dry feed pump and transport desulfurizer tests, systems analysis estimates 43% efficiency and reduction of $50/kW.

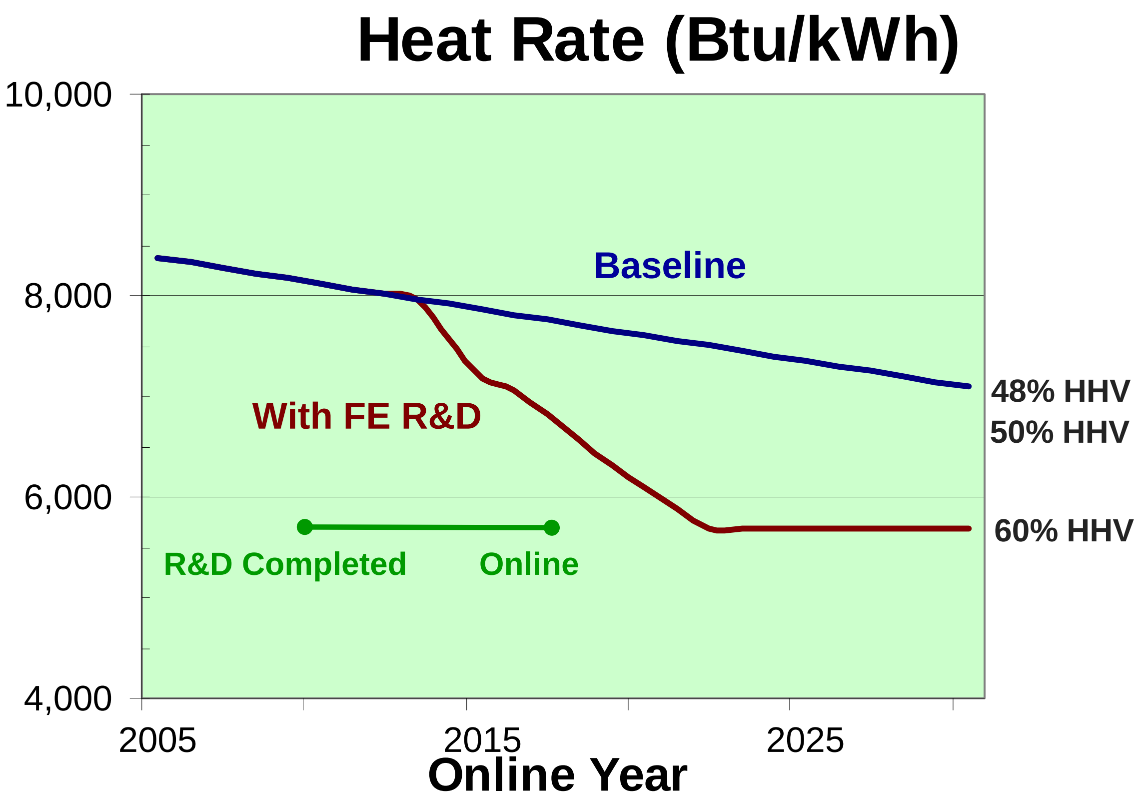
Advanced Power Systems Decrease Capital Costs



- **NETL demonstrates $1000/kW in 2010**
- **Commercial plant with this cost comes online in 2018**
- **Technologies that improve cost:**
  - Dry feed pump
  - Warm gas cleanup
  - Membranes for ASU
  - Syngas turbine
  - SECA fuel cell

"With FE R&D" Case, Inputs, Advanced Power

Advanced Power Systems Improve Efficiency



- **NETL demonstrates 60% efficiency in 2015**
- **Commercial plant with 60% efficiency online in 2023**
- **Technologies that improve efficiency:**
  - Dry feed pump
  - Warm gas cleanup
  - Membranes for ASU
  - Syngas turbines
  - SECA fuel cells

Advanced Power (IGCC) Is Cheapest Option through 2020

Levelized Electricity Costs for New Plants, 2020

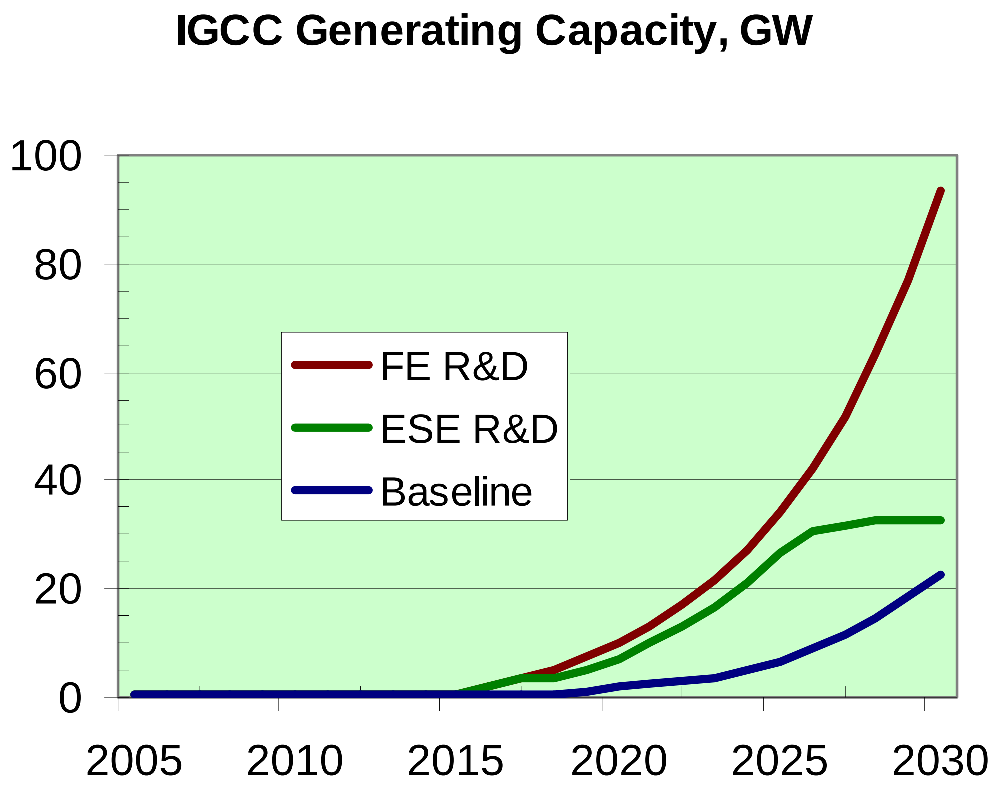
BAU Scenario

2004 mills per kilowatt-hour

	No DOE R&D	All DOE R&D
IGCC	53.5	44.0
Nuclear	59.6	45.2
NGCC	55.0	48.3
Wind	57.4	49.4

“With FE R&D” Case, Results, Advanced Power

R&D Significantly Increases IGCC Deployment



- Prior to 2025, FE R&D provides roughly 20 GW of additional IGCC capacity under both FE only and ESE wide cases
- Post 2025, some of the advanced technologies in EERE and NE push out IGCCs
- With FE R&D, IGCC deployments are adequate to provide an option in case other goals are not achieved.

"With FE R&D" Case, Results, BAU Scenario

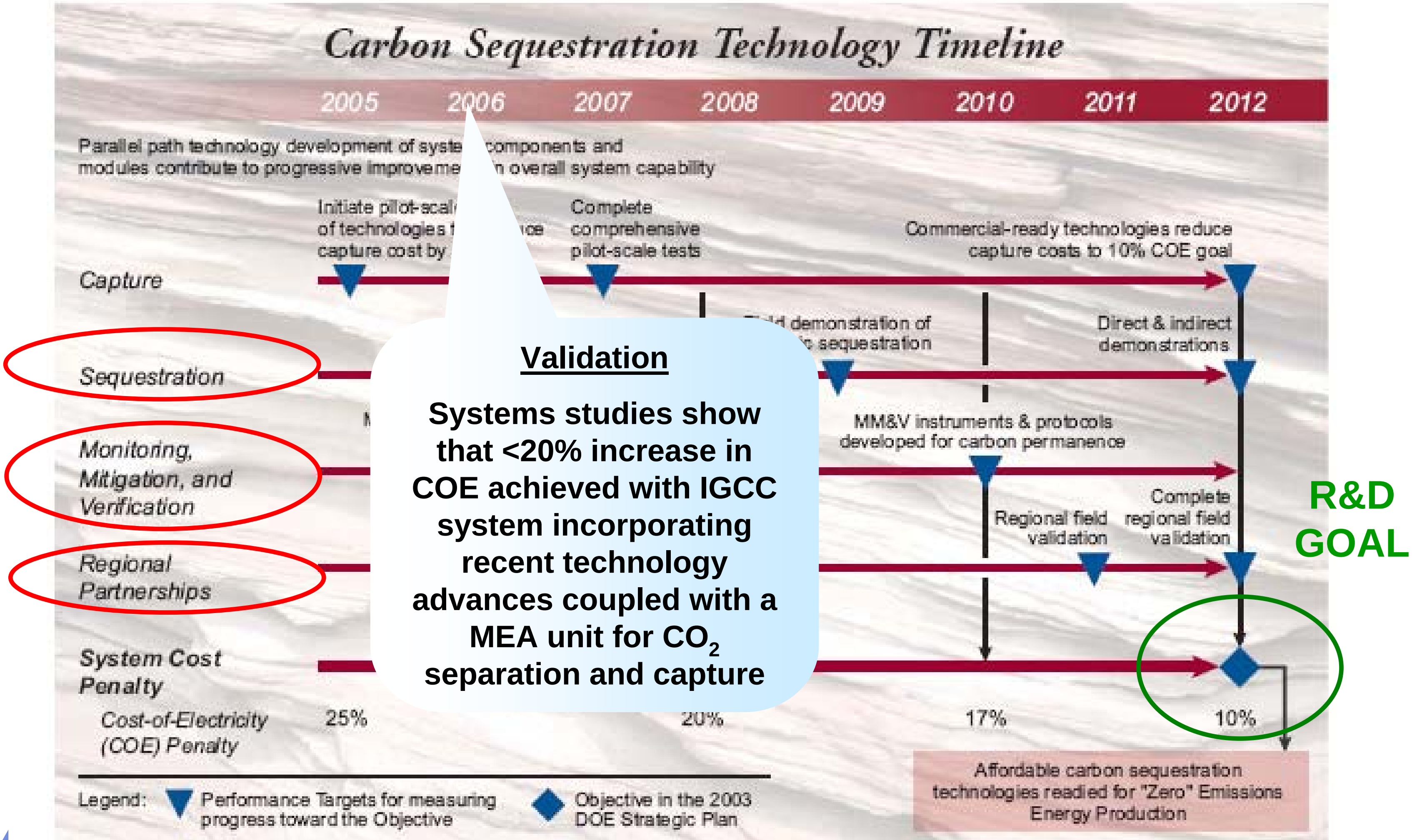
R&D Reduces Consumer Electricity Expenditures

Electricity Savings, Discounted, FE R&D only Billion dollars		
	Annual	Cumulative
2020	3.1	13
2030	5.4	42

Electricity savings equals the difference in consumer expenditures on electricity in all sectors in the ESE baseline NEMS run and the "FE Only" NEMS run. Cumulative savings are discounted using a 3% rate.

"With FE R&D" Case, Inputs, Sequestration

Sequestration Snapshot



Validation

Systems studies show that <20% increase in COE achieved with IGCC system incorporating recent technology advances coupled with a MEA unit for CO_2 separation and capture

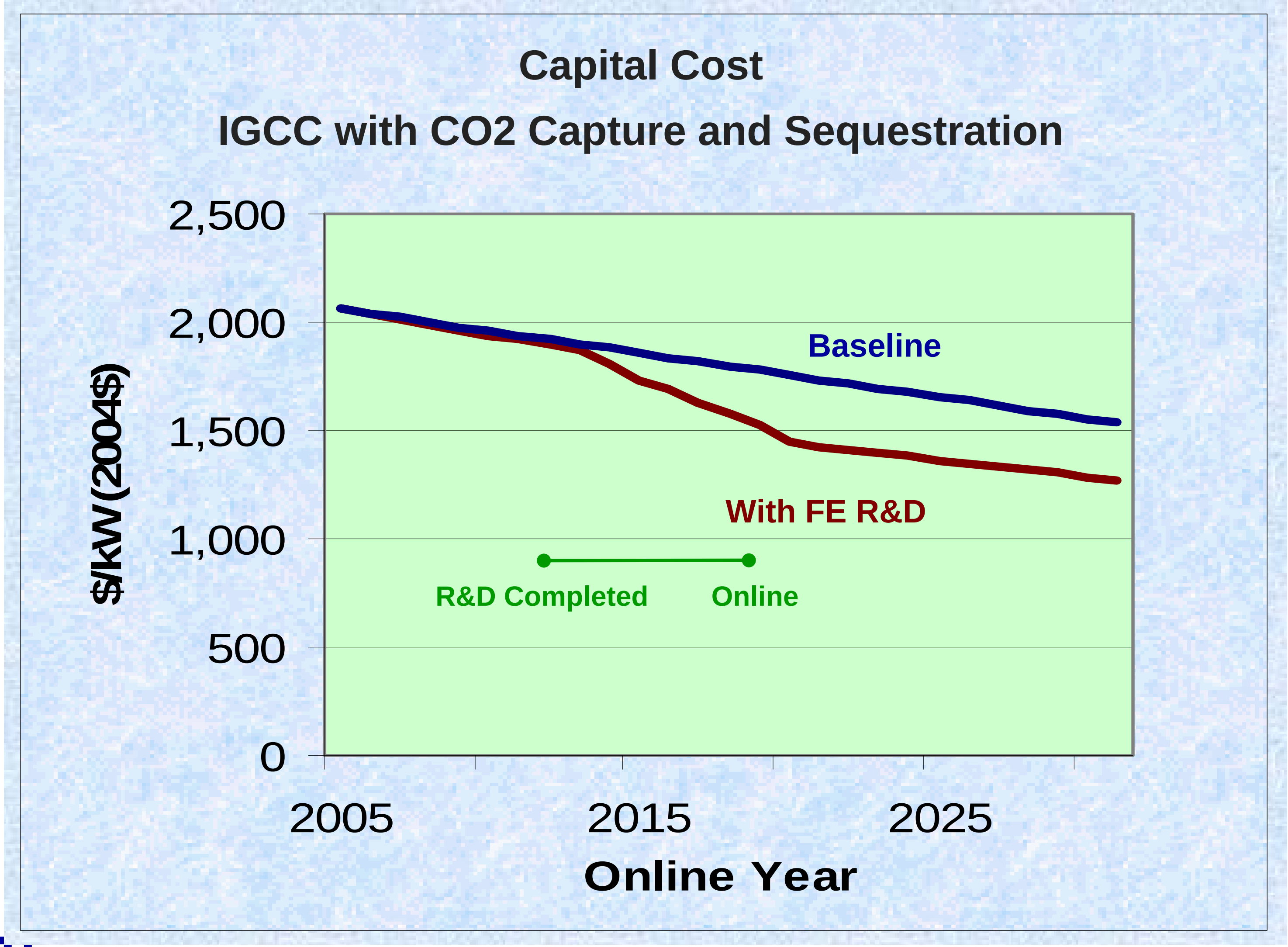
Activities that enable deployments and timing of goals.

Carbon Sequestration, NEMS inputs

- **NEMS inputs capture synergy between reductions in CO_2 capture parasitic load and improvements in base power plant efficiency**
- **Revenues from sale of captured CO_2 for use in EOR/EGR is not considered**
- **Only IGCC and NGCC is modeled in NEMS with capture – PC retrofit not available**

"With FE R&D" Case, Inputs, Sequestration

Sequestration R&D Impacts Power System Cost



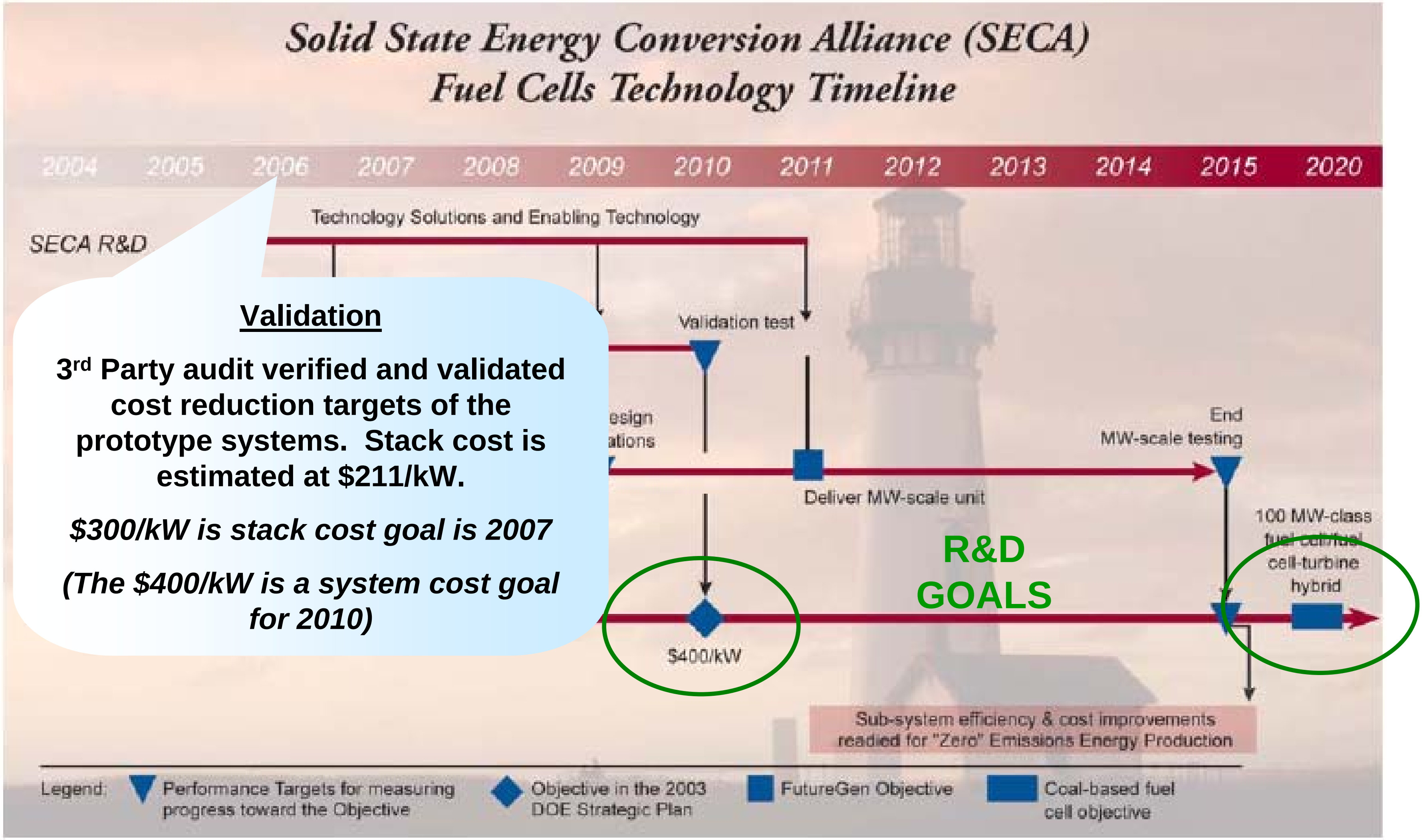
"With FE R&D" Case, Results, Carbon Constraint Scenario

Sequestration Keeps Coal Competitive

Levelized Electricity Costs for New Plants, 2020 2004 mills per kilowatthour			
	No DOE R&D	FE R&D	All DOE R&D
Nuclear	58.8	58.7	45.3
IGCC w/ Seq.	68.0	59.0	57.3
NGCC	67.9	64.7	57.5
Wind	75.1	68.7	59.3
IGCC	83.5	68.9	63.3
Carbon Tax (2004 dollars per mtco2e)	35.5	32.5	27.5

“With FE R&D” Case, Input, SECA

SECA Fuel Cells Snapshot



Validation

3rd Party audit verified and validated cost reduction targets of the prototype systems. Stack cost is estimated at $211/kW.

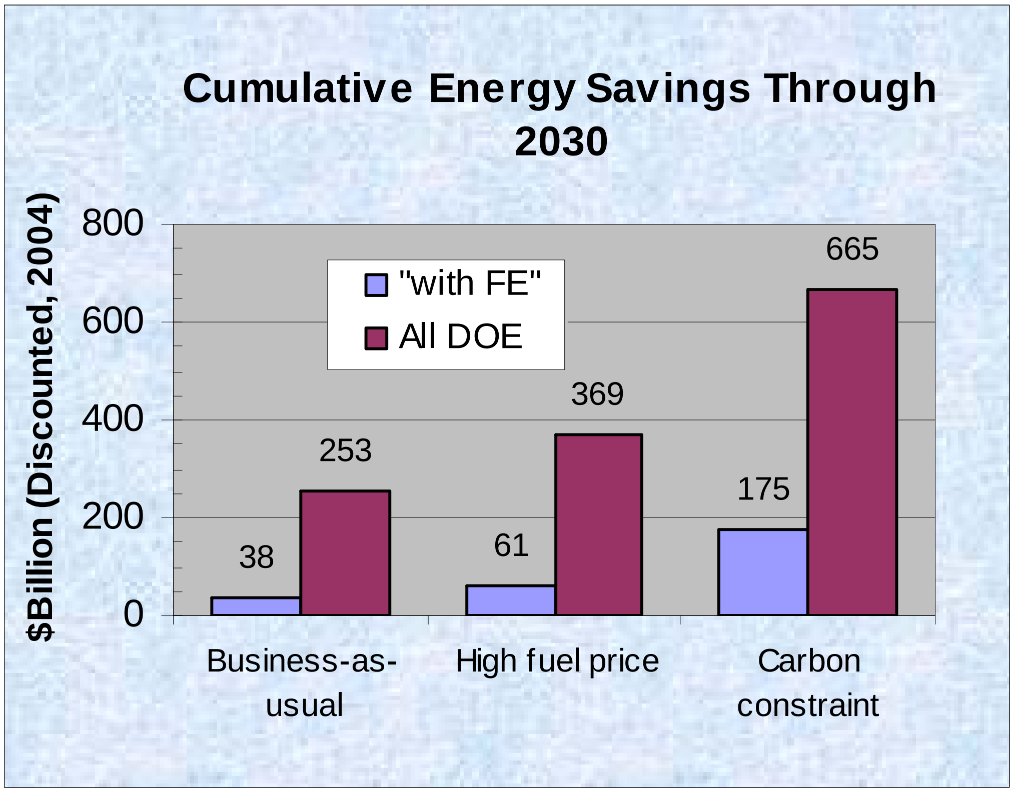
$300/kW is stack cost goal is 2007

(The $400/kW is a system cost goal for 2010)

Sensitivity Analysis:
Policy and Market Scenarios

FE Benefits Sensitivity

Reduced Cost of Energy by Policy Scenario



"Energy savings"
The difference between consumer cost for electricity and natural gas in the respective DOE research case and the baseline.

- FE benefits go up under the high fuel price and carbon constraint scenarios due to increased demand for efficiency and emissions control

Future Work (2007)

- **Incremental improvements**
  - More detailed support for program goals
  - More precise estimate for lag time between pilot-scale validation and commercial availability
  - Improved representation of R&D post 2030
- **New thrusts**
  - Work with EIA to integrate hydrogen and liquid fuels from coal into the NEMS model such that benefits can be estimated
  - Quantify ESE benefits metrics not taken directly from NEMS (e.g. water impacts, land impacts)
  - Work within ESE to incorporate technology risk into the benefits methodology
  - Review the decision algorithm for retirement / repowering of existing coal-fired power plants
  - Evaluate the derivation of net benefits (consumer + producer surplus) from NEMS Electricity Supply output

Additional Slides

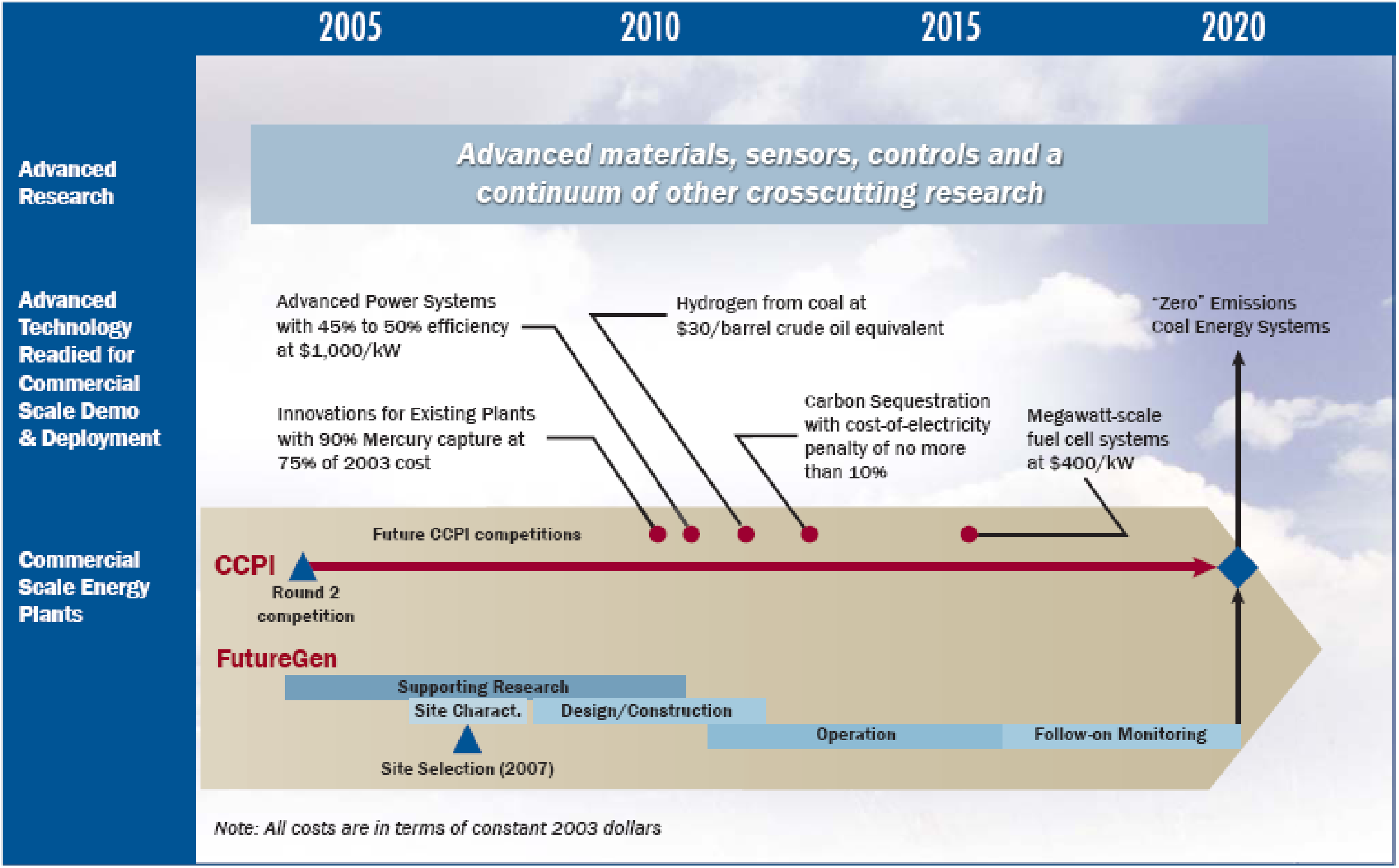
Benefits Methodology

Why use NEMS?

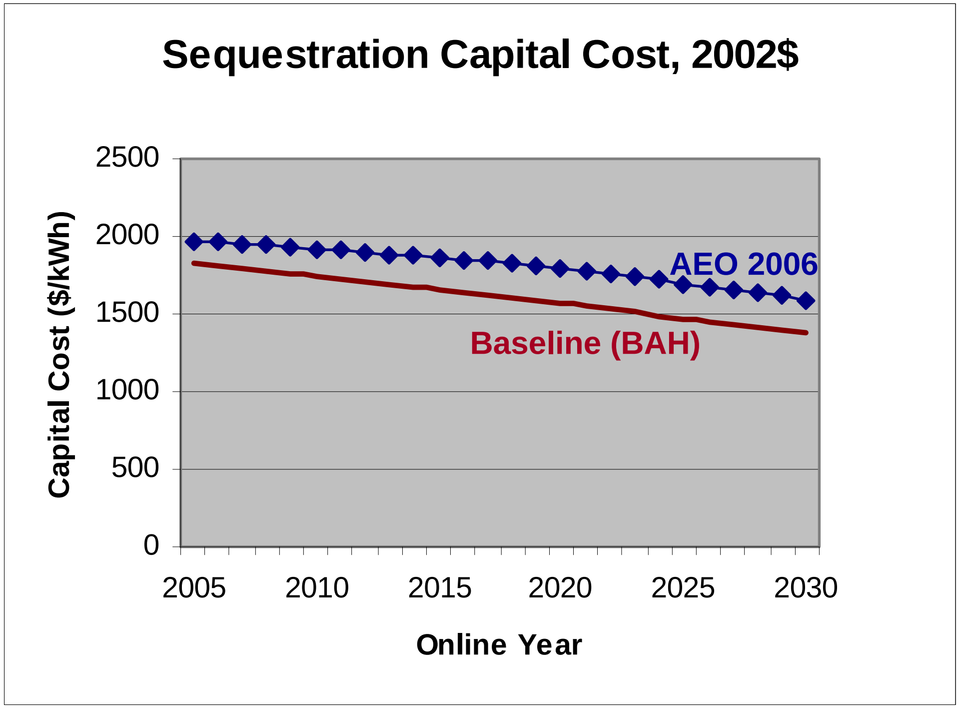
- **Picture of FE technologies in the market place**
  - Capital stock life/turnover
  - Competition with other technology options
  - Elasticity of demand and supply for energy services
- **Enables rigorous, objective thinking of issues**
  - Economic growth
  - Environmental regulations
  - Commodity market pricing
- **External recognition and acceptance**
  - Arguably the most complete model of U.S. energy markets
  - "Official" DOE forecasts
  - Transparent, documented and can be validated

FE Research Portfolio

Clean Coal R&D Program At-A-Glance

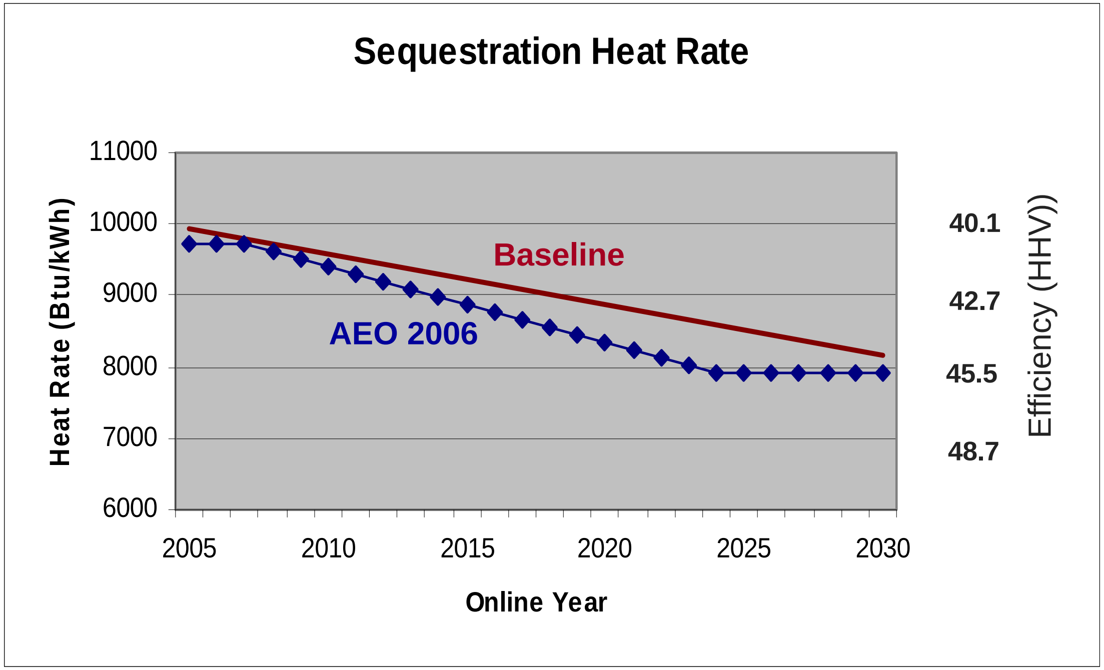


Baseline Sequestration Inputs versus AEO 2006 (1 of 2)



- **Similar trend as IGCC**
  - **BAH study predicts a capital cost for IGCC w/ sequestration that is <u>lower</u> than AEO 2006 reference case**
- **Straight-line interpolation and extrapolation used for baseline values**

Baseline Sequestration Inputs versus AEO 2006 (2 of 2)



- **Similar trend to IGCC**
  - **BAH study predicts IGCC heat rate comparable in long term to AEO 2006**
  - **AEO 2006 assumes more progress earlier**
- **Straight-line interpolation and extrapolation used for baseline values**

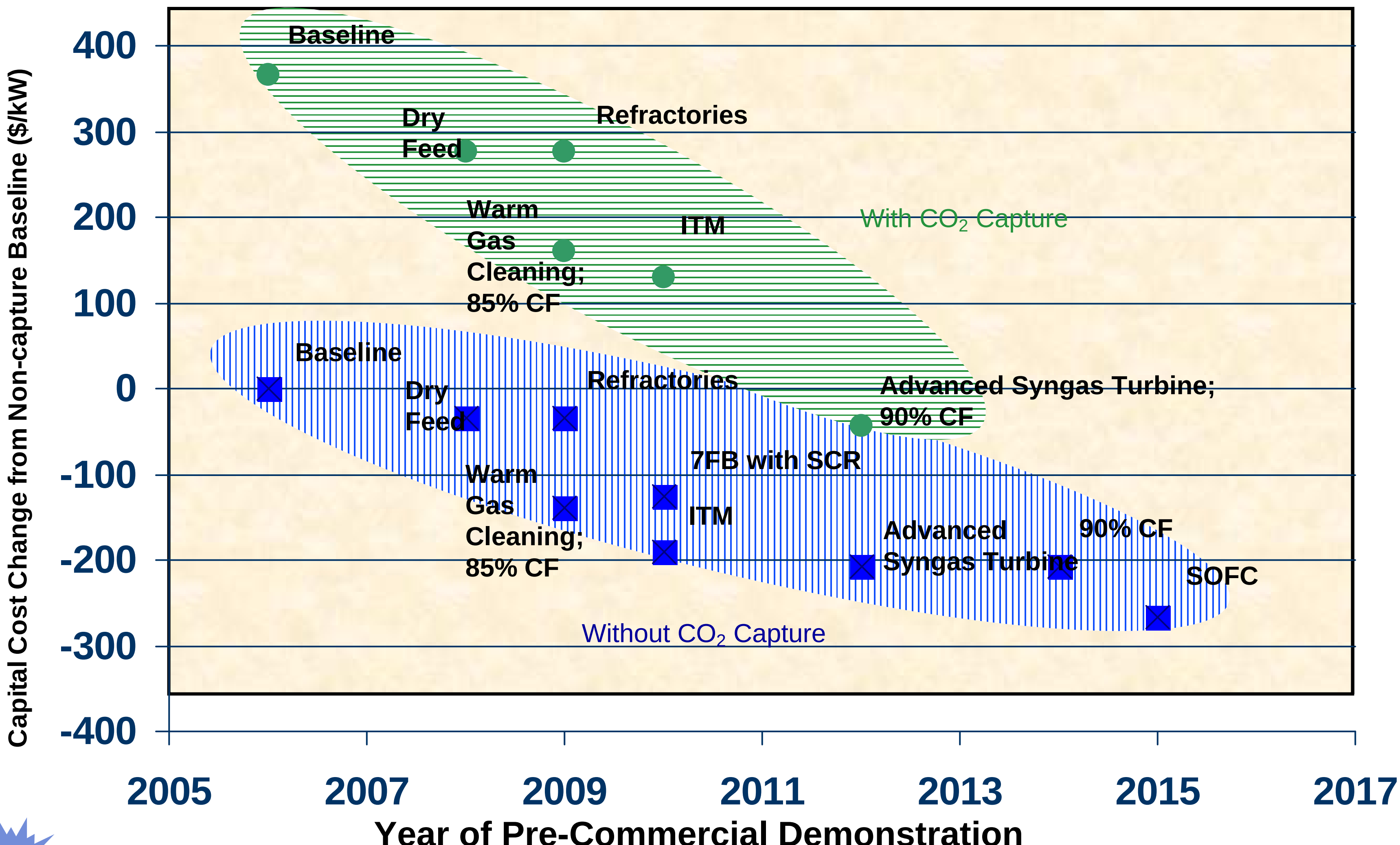
Baseline forecast, Inputs

Translating R&D Goals to NEMS Input

FE R&D Program Area	Delay between GPRA pilot-scale performance demonstration and first commercial unit online
NOx abatement	2 yrs for 2007 goal 5 yrs for 2010, 2020 goals
Mercury abatement	5 yrs
IGCC system	8 yrs
IGCC with Sequestration	8 yrs
SECA	8 yrs

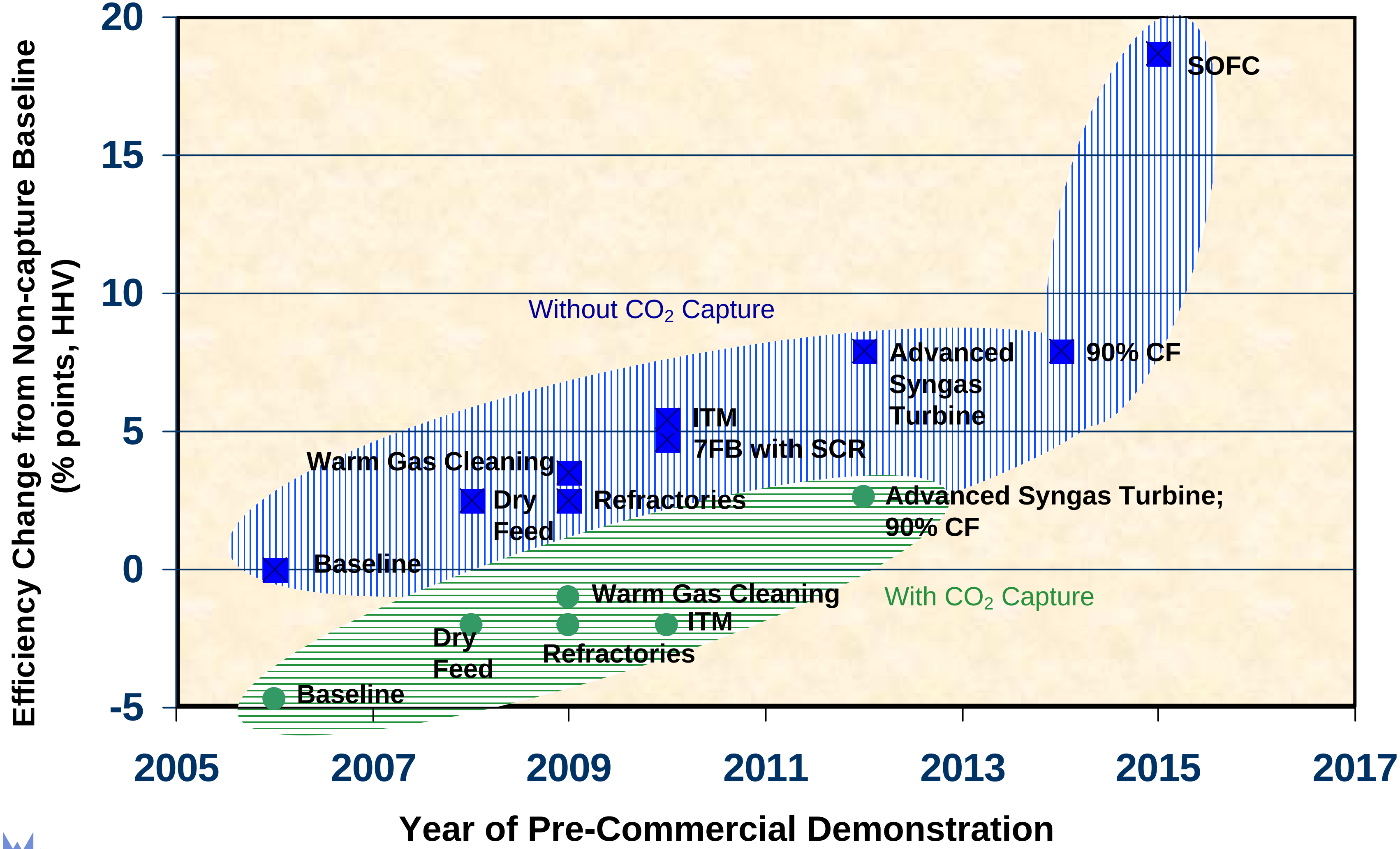
"With FE R&D" Case, Inputs, Advanced Power

System Analysis of IGCC Capital Cost



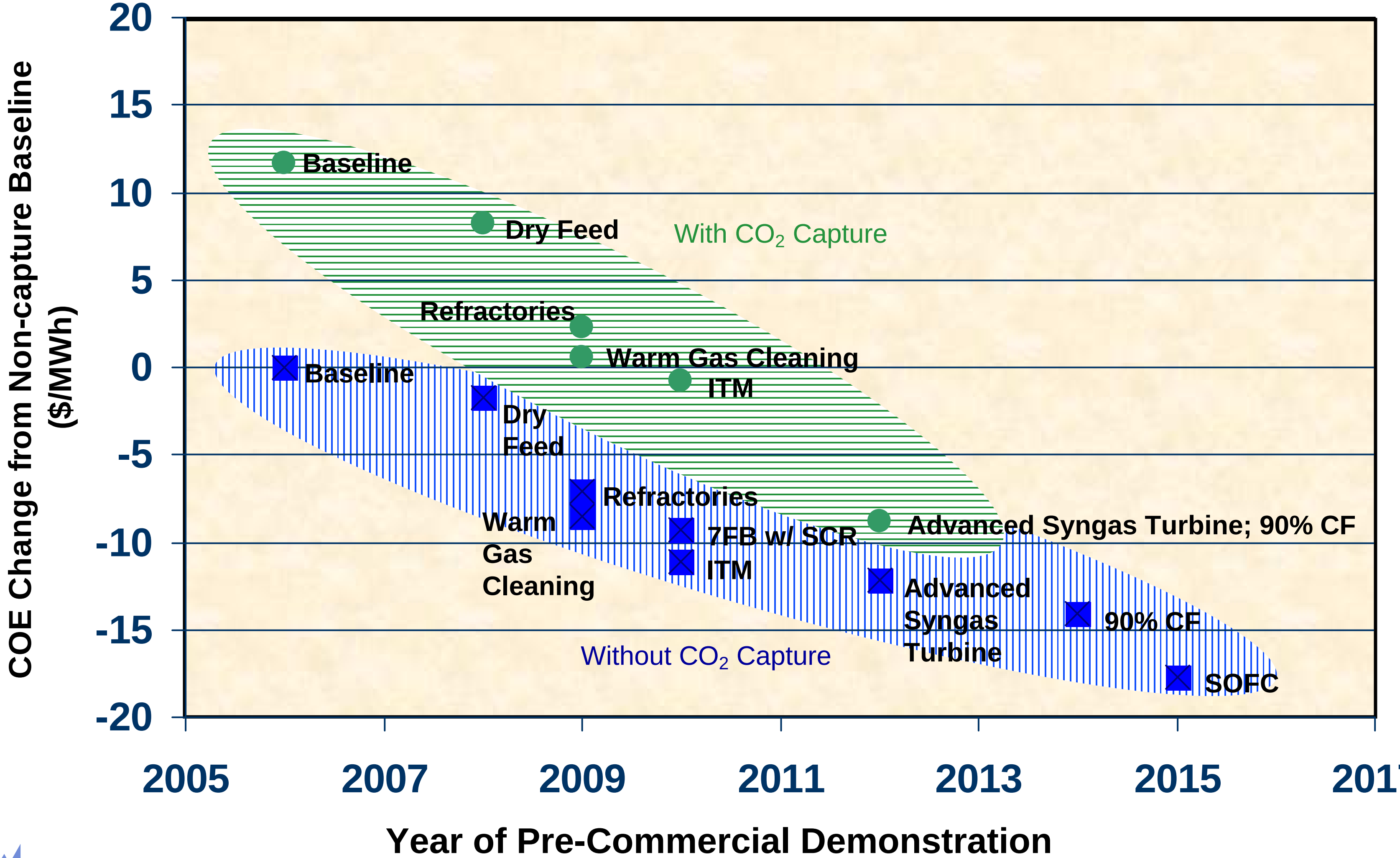
"With FE R&D" Case, Inputs, Advanced Power

System Analysis of IGCC Efficiency



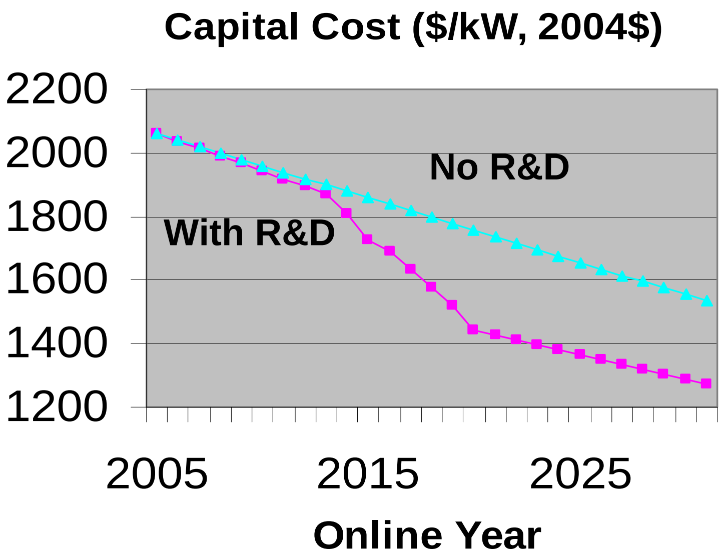
“With FE R&D” Case, Inputs, Advanced Power

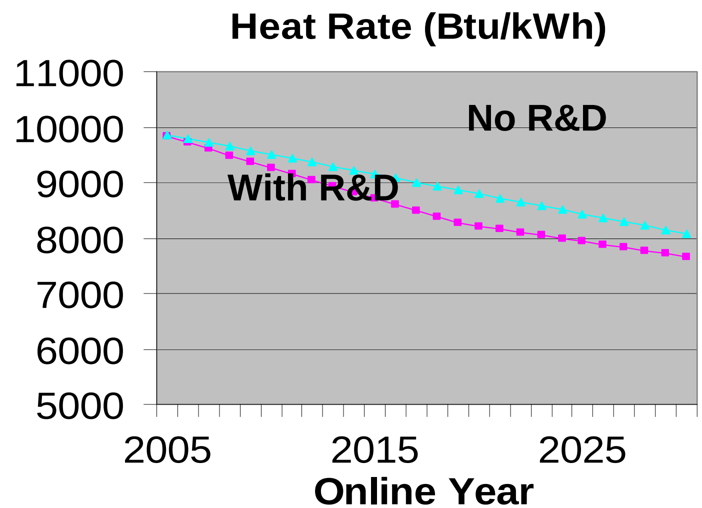
System Analysis of IGCC COE

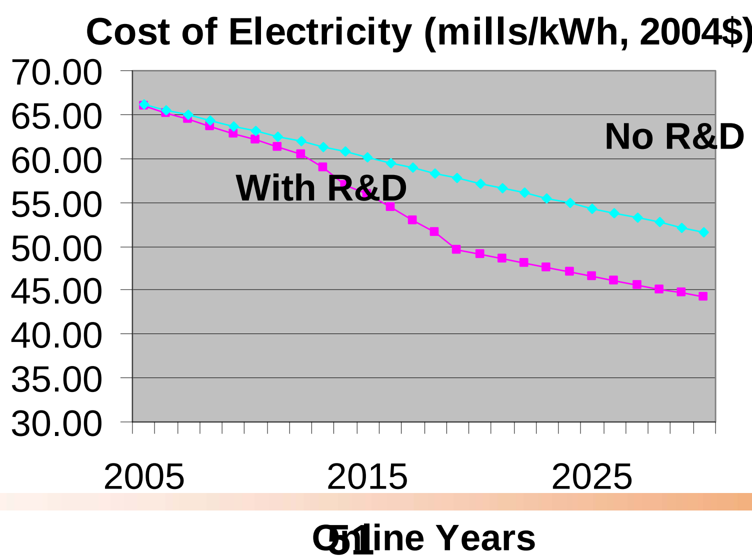


"With FE R&D" Case, Input, Sequestration

Sequestration Input Assumptions







“With FE R&D” Case, Input, SECA

Utility Sector SECA Fuel Cells Major Assumptions

Online Year	Utility FC (NEMS Category = FC)				Utility DG (NEMS Category = DG)			
	Capital Cost $/kW ($2004)		Heat Rate (Btu/kWh)		Capital Cost $/kW ($2004)		Heat Rate (Btu/kWh)	
	Without R&D	With R&D	Without R&D	With R&D	Without R&D	With R&D	Without R&D	With R&D
2005	4374	4374	7930	7930	831	831	9650	9650
2012	4112	880	7588	7335	806	800	8900	8554
2013	4068	798	7531	7025	802	725	8900	8209
2014	4024	743	7474	6715	798	675	8900	7863
2015	3980	660	7417	6405	794	600	8900	7517
2016	3937	550	7359	6095	789	500	8900	7172
2017	3893	400	7302	5785	785	400	8900	6826
2020	3762	400	7131	5785	773	400	8900	6826
2030	3324	400	6960	5785	731	400	8900	6826

"With FE R&D" Case, Input, SECA

Buildings Sector SECA Fuel Cells Major Assumptions

Residential Distributed Generation

Online Year	Electrical Efficiency (LHV)	Overall Efficiency (HHV)	Captial Cost \$/kW (\$2004)
2005	0.300	0.787	AEO2006
2010	0.320	0.795	AEO2006
2012	0.399	0.760	800
2013	0.416	0.766	725
2014	0.434	0.774	675
2015	0.454	0.782	600
2016	0.476	0.790	500
2017	**0.500**	0.800	**400**

Waste heat recovery = 60%

Commercial Distributed Generation

Online Year	Electrical Efficiency (LHV)	Overall Efficiency (HHV)	Captial Cost \$/kW (\$2004)
2005	0.300	0.787	AEO2006
2010	0.320	0.795	AEO2006
2012	0.399	0.729	800
1013	0.416	0.737	725
2014	0.434	0.745	675
2015	0.454	0.754	600
2016	0.476	0.764	500
2017	**0.500**	0.775	**400**

Waste heat recovery = 55%