Overview of Recent Benefits Analyses for the Crosscutting Technology Research Program

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U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

Benefits Division

- **Estimate Technology Deployment Benefits**
  - Design and test methodologies for quantifying benefits of advanced technology deployments
  - Develop representations of advanced technologies in economic models
  - Estimate the economic and environmental benefits of advanced technology deployments across various policy and economic scenarios

- **Provide Program Guidance**
  - Assess R&D program alignment with industry needs
  - Identify opportunities for advanced technologies in various markets
  - Review third-party economic and environmental impact assessments of technology deployments
  - Examine cost and performance necessary for technologies to deploy

Current Benefits Activities for Crosscutting Program

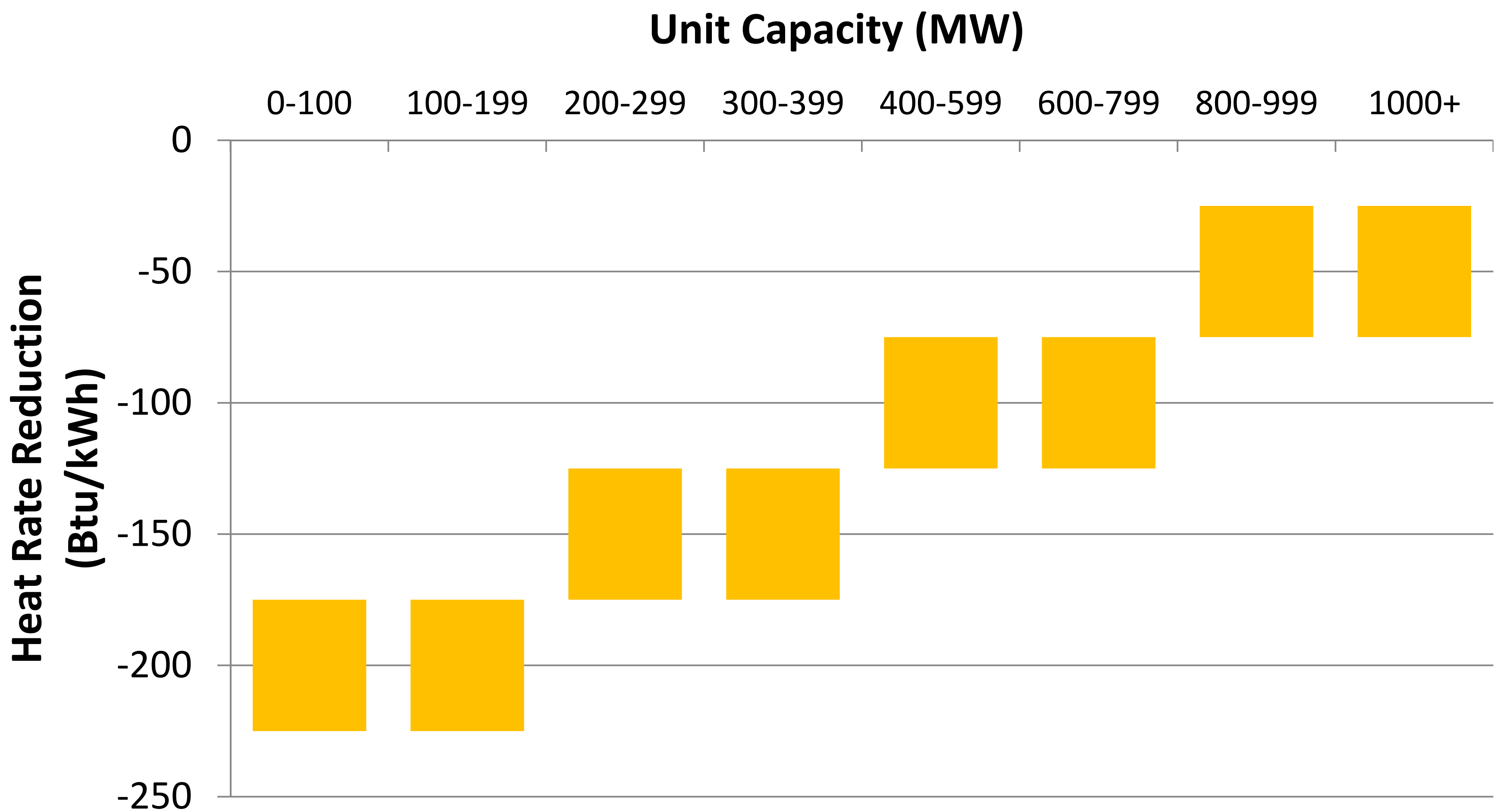
	Report Title	Status
Sensors and Controls	Economic Assessment of Advanced Sensors and Controls for Existing Coal and NGCC Units	*Complete*
Sensors and Controls	Comparison of Sensors and Controls Analysis to Real World Examples	*Complete*
Sensors and Controls / Adv Materials	Potential Use of Sensors & Controls and Materials in Load Following Coal-Fired Units	*Complete*
Adv Materials	Benefits of Advanced Material Use for Boiler Tubes in Coal-fired Power Units	*Complete*
Adv Materials	Advanced Material Export Market Opportunities	*Complete*
Water/Energy	Potential for Solid Oxide Fuel Cells to Minimize Water Use in the Electric Power Sector	*Complete*
Water/Energy	ERCOT Regional Water Use Analysis in the Power Sector	*Planned Completion* May 2015
Water/Energy	Western States Water-Energy Model	*Planned Completion* May 2015

Economic Assessment of Advanced Sensors and Controls for Existing Coal and NGCC Units

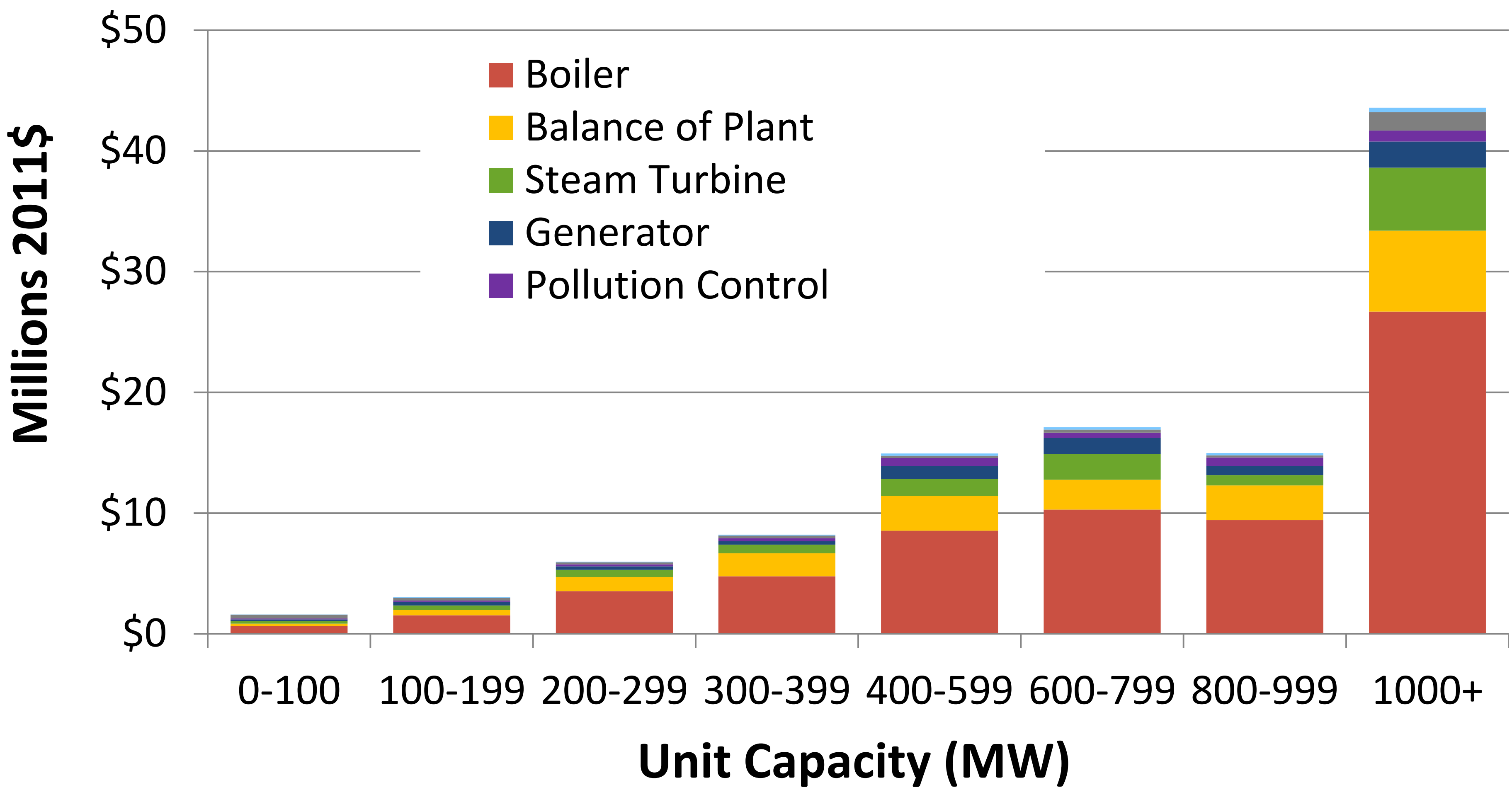
- **Potential economic impact of improvements in efficiency and unit availability from the use of AS&C in both coal-fired and NGCC units**
- **Key Assumptions**
  - Analysis at Unit-level
  - Technology Available in 2020
- **Three analyses performed**
  - Net Present Value Analysis
  - Dispatch Analysis
  - Technology Deployment Analysis

Heat Rate Reductions from AS&C

Efficiency Assumptions

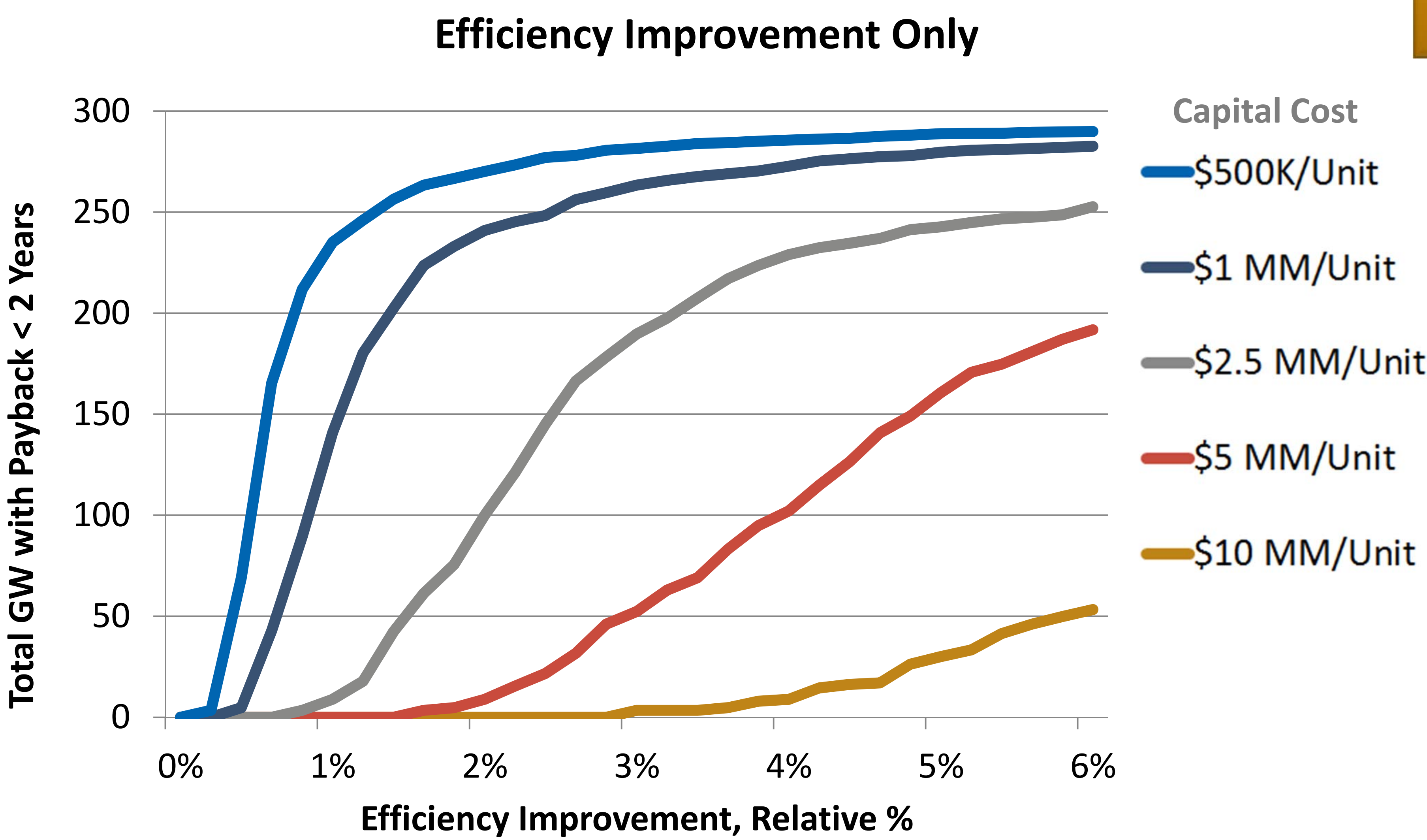


Forced Outage Data Used to Estimate Average Annual Revenue Loss in Coal Power Sector



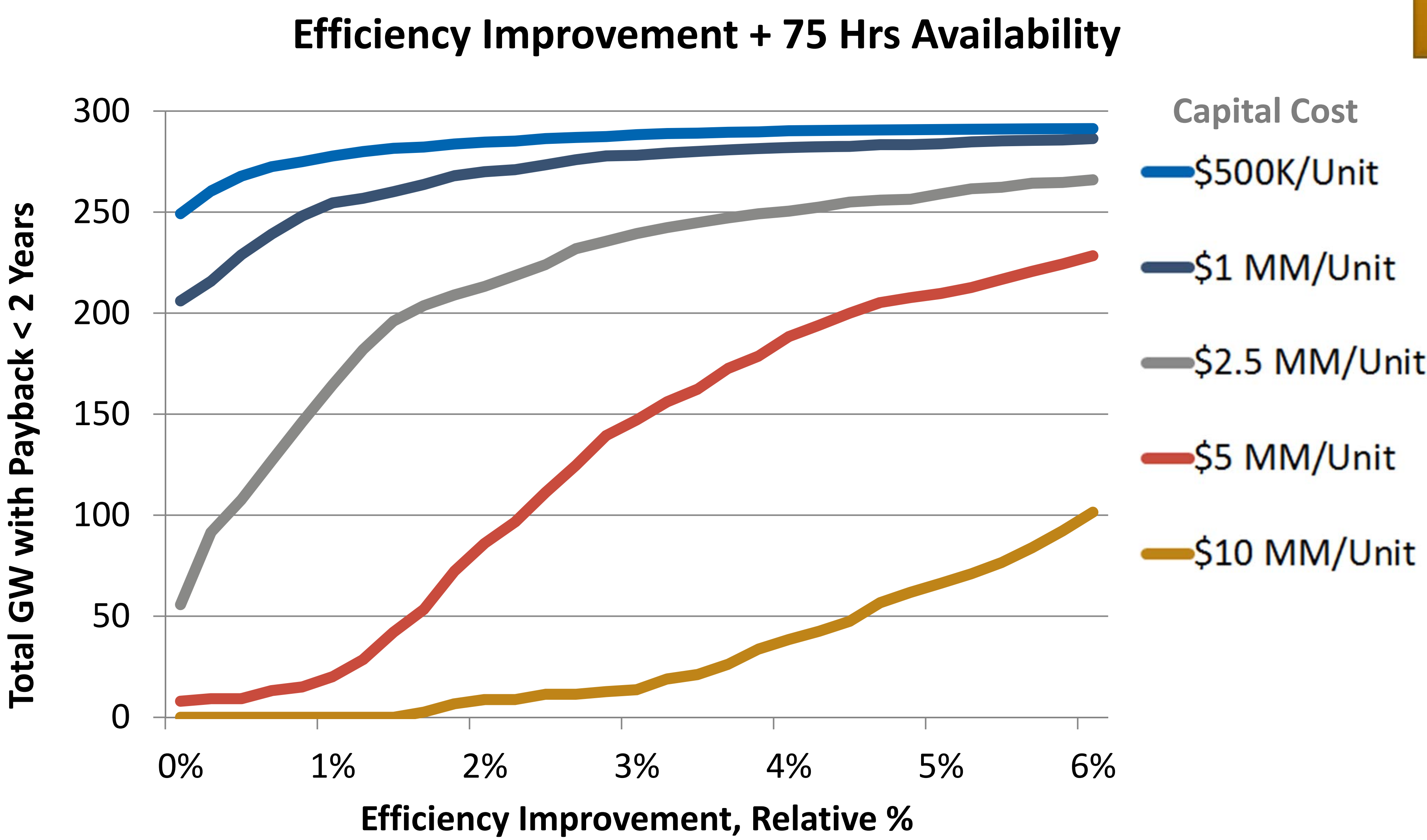
Source: Outage Data - NERC GADS Database 9/19/12 Accessed 1/9/13; Avg. Wholesale Price Data – EIA
http://www.eia.doe.gov/cneaf/electricity/wholesale/wholesale.html Wholesale Market Data, PJM West, NEPOOL, ERCOT Wtg. Avg;

Coal Unit NPV Analysis



Source: Results based on unit by unit discounted cash flow model. Unit level data taken from 2012 Ventyx database. Cost and performance based on NETL survey of previous sensors and controls projects.

Coal Unit NPV Analysis



Source: Results based on unit by unit discounted cash flow model. Unit level data taken from 2012 Ventyx database. Cost and performance based on NETL survey of previous sensors and controls projects.

Coal Unit Dispatch

DynamicMOD Analysis – Unit Level Dispatch

AS&C: 2% efficiency increase, $5/kW, and an additional 75 generating hours

Results	Plant 1 - ERCOT	Plant 2 - ERCOT	Plant 3 – RFC West
	Low Capacity Factor High HR (low Eff.) Dispatches after many gas plants	High Capacity Factor Moderate HR (OK Eff.) Dispatches before most gas plants	Average Capacity Factor Low HR (Good Eff.) Middle of the pack dispatch
Lower Natural Gas Case ($3.40-$3.60/MMBtu)			
Capacity Factor Gain	15.7 % points	5.4 % points	37.8 % points
Profit Gain	$700,000	$2,600,000	$1,200,000
High Natural Gas Case ($5/MMBtu)			
Capacity Factor Gain *	0.9 % points	2.3 % points	18.1 % points
Profit Gain	$1,900,000	$3,500,000	$4,800,000

Capacity Factor Gains: 1% to 38% points

Profit Gains: $700,000 – $4,800,000

**As natural gas price increase (assuming coal price is constant) coal will dispatch sooner*

NEMS Deployment Analysis

Assumptions

- **Based on NPV Model**
- **NEMS Inputs:**
  - Retrofitted in 2020 and after
  - Capital Cost (2011 $) Coal -$600,000/unit NGCC - $250,000/unit
  - Forced Outage Reduction: Coal - 25 hrs per year NGCC - 10 hrs per year
  - Heat rate Improvement (%): Coal - 1% NGCC - 0.3%

Results

- **Technology deployment analysis results in 263 GW of coal and 108 GW of NGCC units implementing AS&C**
- **AS&C can result in CO_2 emissions reductions of 9-14 million tonnes CO_2 equivalent per year**
- **Resulting decreases in electricity end-use prices and electricity expenditure savings suggest a Program Internal Rate Of Return (IRR) of 53% - 70% (assuming current program funding levels through 2020)**

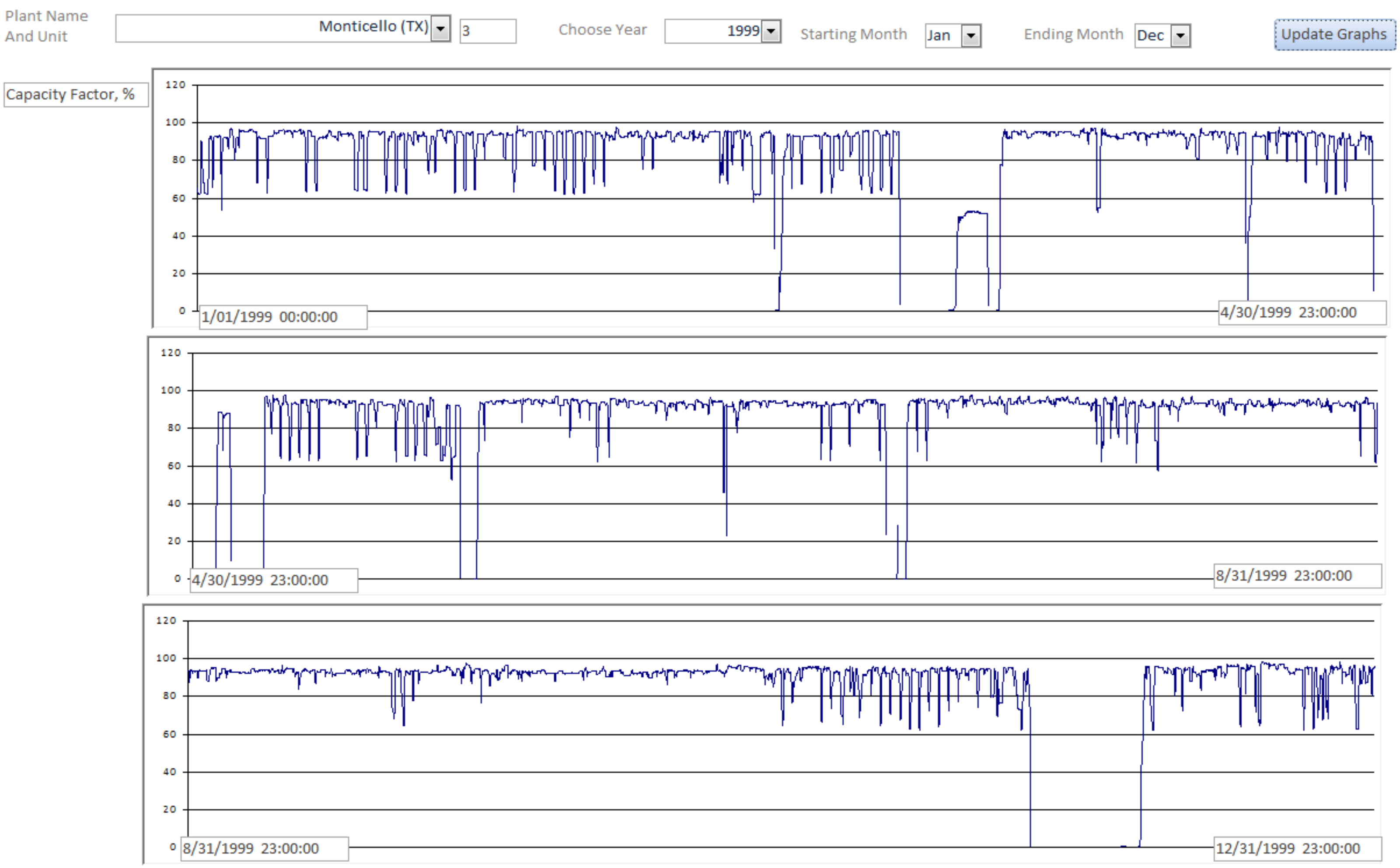
Comparison of Sensors and Controls Analysis to Real World Examples

- **Input Provided from Three Utilities**
  - Represented Sub-critical PC, Super-Critical PC & NGCC Units
  - Input based on experience with six projects
- **Existing experience with Sensors and Controls retrofits**
  - Installation costs ranged from $0.50 to $12.50 /kW
  - Installation outage time ranged from 1 to 8 weeks
- **Compare Feedback with Benefits Analysis**
  - Cost assumptions were reasonable
  - Availability is extremely important
  - Efficiency was less important than availability

Comments from Respondents

- **Philosophy was different depending if in a regulated or unregulated region**
- **Advanced Pattern Recognition and other technologies that enable better prediction of equipment performance and maintenance requirements significantly reduce costs by reducing power purchases to meet bid generation commitments**
- **Most would apply advanced technologies on trial basis**
- **Wireless sensors are not used for control**
- **Improve wireless sensor reliability - Improve battery life to allow for increased recording frequency and use for control**
- **Generally will install advanced materials if proven and available**
  - Have had previous experience with advanced materials
  - Additional cost generally not a major factor
- **No specific advanced S&C or Material experience with NGCC units**

Potential of Sensors and Controls to Mitigate Adverse Impacts from Load Following



Source: Ventyx Database

Study Approach

Adv Materials
Sensors and Controls

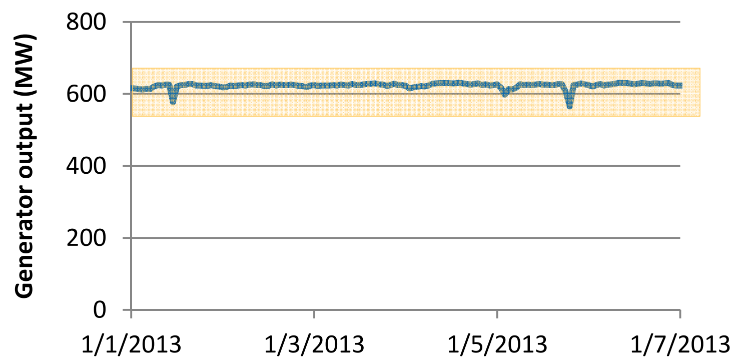
1. **Develop load following analysis tools for detailed identification of load following plants**
   - Three tools developed to identify load following behavior and display results in an easy-to-use format
2. **Use tools developed to analyze load following behavior**
   - Show how load following has changed over time
   - Potential determinants: renewable generation, economic factors, fuel prices, etc.
   - Correlation analysis to suggest the main determinants of load following
   - Qualitatively describe how load following may change in the future
3. **Identify the key problems that a load following coal unit may face and how NETL research can help**
   - General consequences of load following and how NETL research can help
   - Detailed analysis of component issues and key problem areas
   - Identify potential advanced sensors, controls, and materials solutions for key problem areas

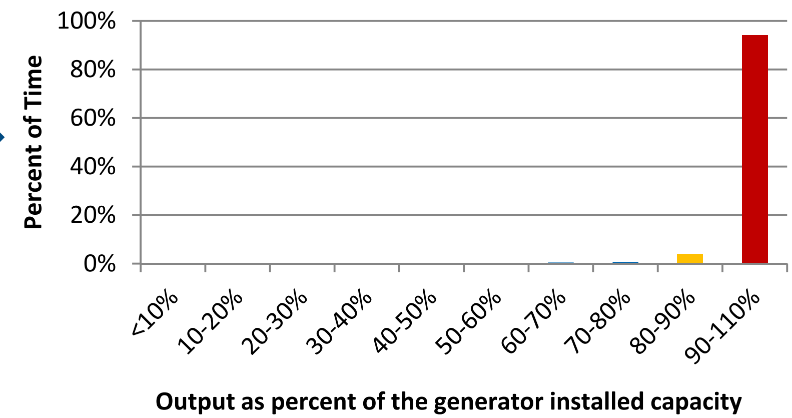
Adv Materials | Sensors and Controls

Tools and Analysis

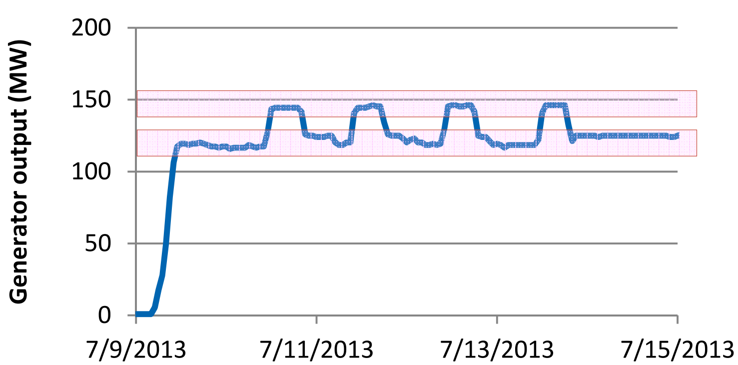
Profile Construction Tool

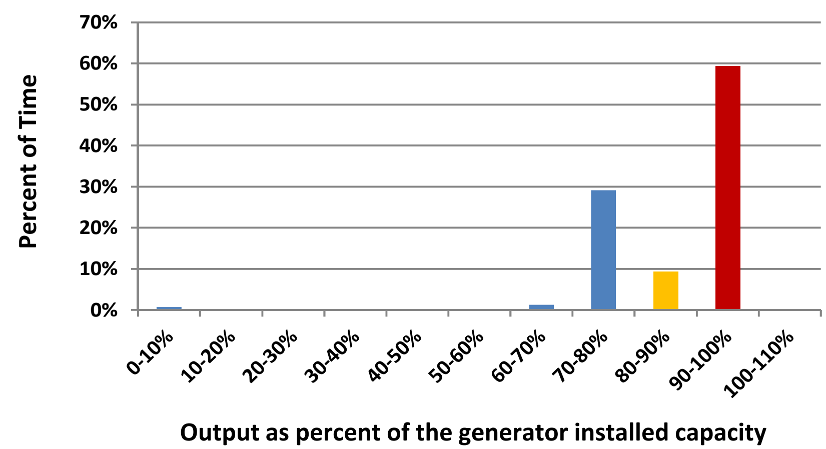
Baseload: Operates around a set point 24/7





Two-shifting: Operates around two set points



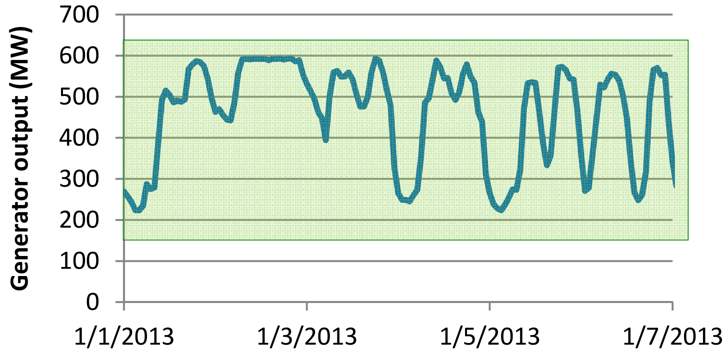


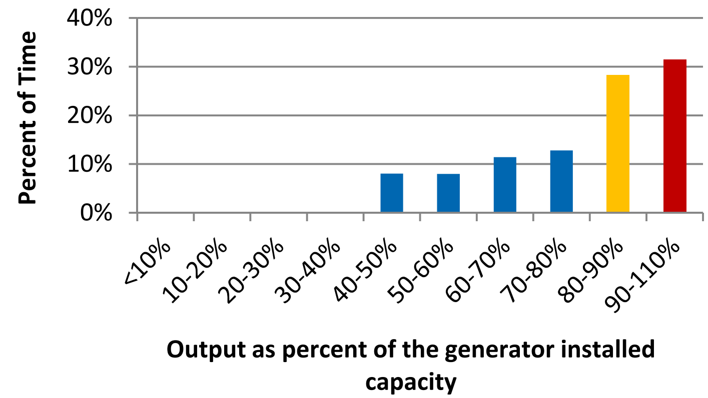
Source: Ventyx Database

Tools and Analysis

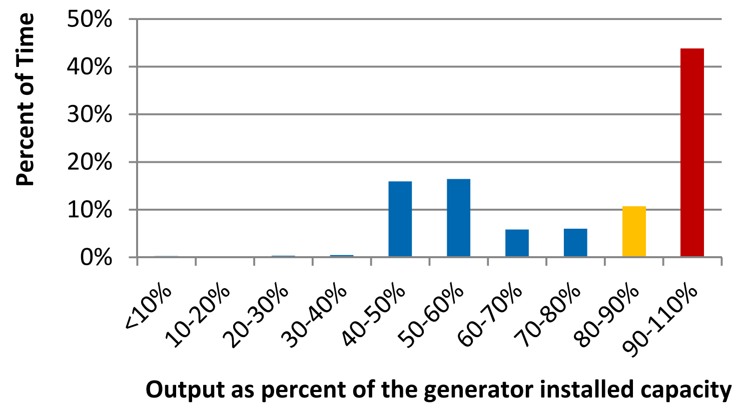
Profile Construction Tool

Load following: Operates across a wide range





OR

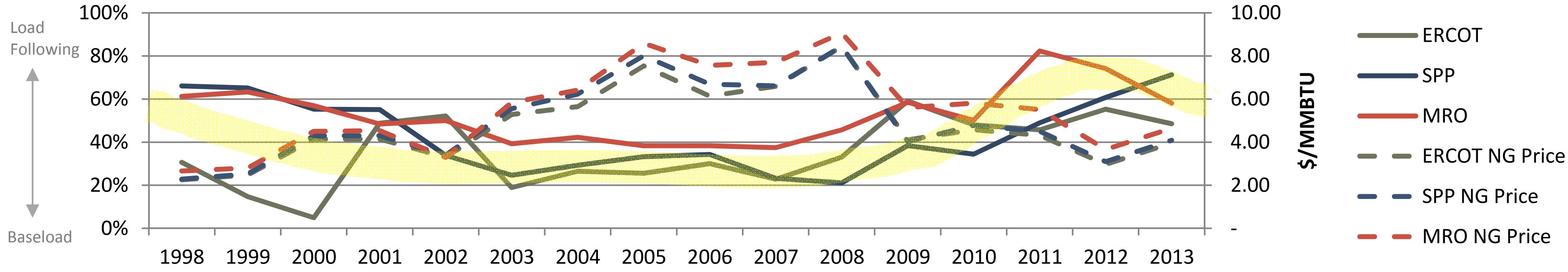


Source: Ventyx Database

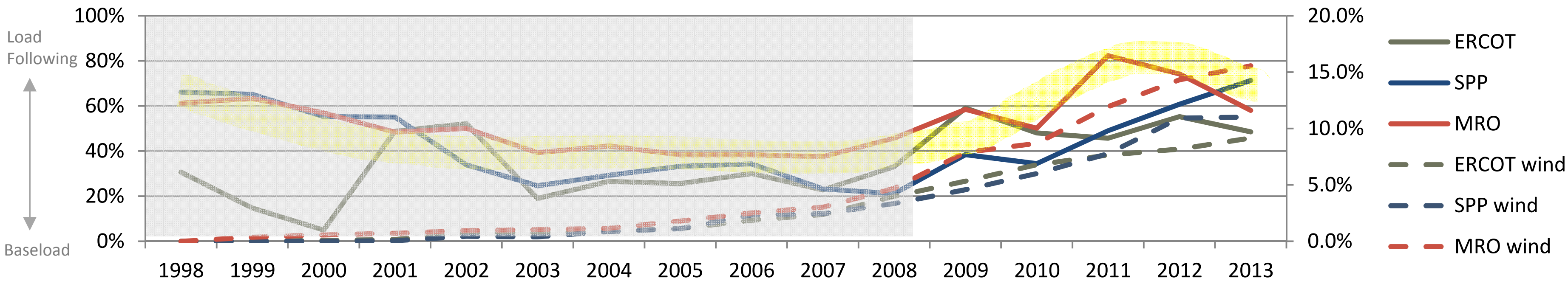
Trend Analysis

Load Following from 1998-2013

Load Following Capacity as a Percentage of Total Coal Capacity and Weighted Average Natural Gas Price



Load Following Capacity as a Percentage of Total Coal Capacity and Wind Generation as a Percentage of Load



EIA forecasts increased wind deployment with continued low natural gas prices = Increase in load following

Source: Ventyx Database

10 Key Problem Areas – Coal Units

Identified as opportunities for advanced sensors, controls, and/or materials

Adv Materials
Sensors and Controls

KPA	Solution/Area	Research Area
Pressure Control in Boiler	Sliding Pressure – boiler	Advanced Controls
Pulverizer Control	Pulverizer - coal feed	Advanced Controls
Boiler Burner	Burner Management – boiler	Advanced Controls
Soot Blowing	Intelligent Soot Blowing - boiler	Advanced Sensors and Controls
Superheater Life	Materials - Boiler	Advanced Materials
Turbine Life	Materials - Turbine	Advanced Materials
Turbine Life	Monitoring – Turbine	Advanced Sensors
FGD Life	Materials – FDG	Advanced Materials
Corrosive water	Automated Water treatment – BOP	Advanced Sensors and Controls
Motors	Variable Frequency Drives - BOP	Advanced Controls

Summary

Potential Use of Sensors & Controls and Materials in Load Following Coal-Fired Units

Adv Materials
Sensors and Controls

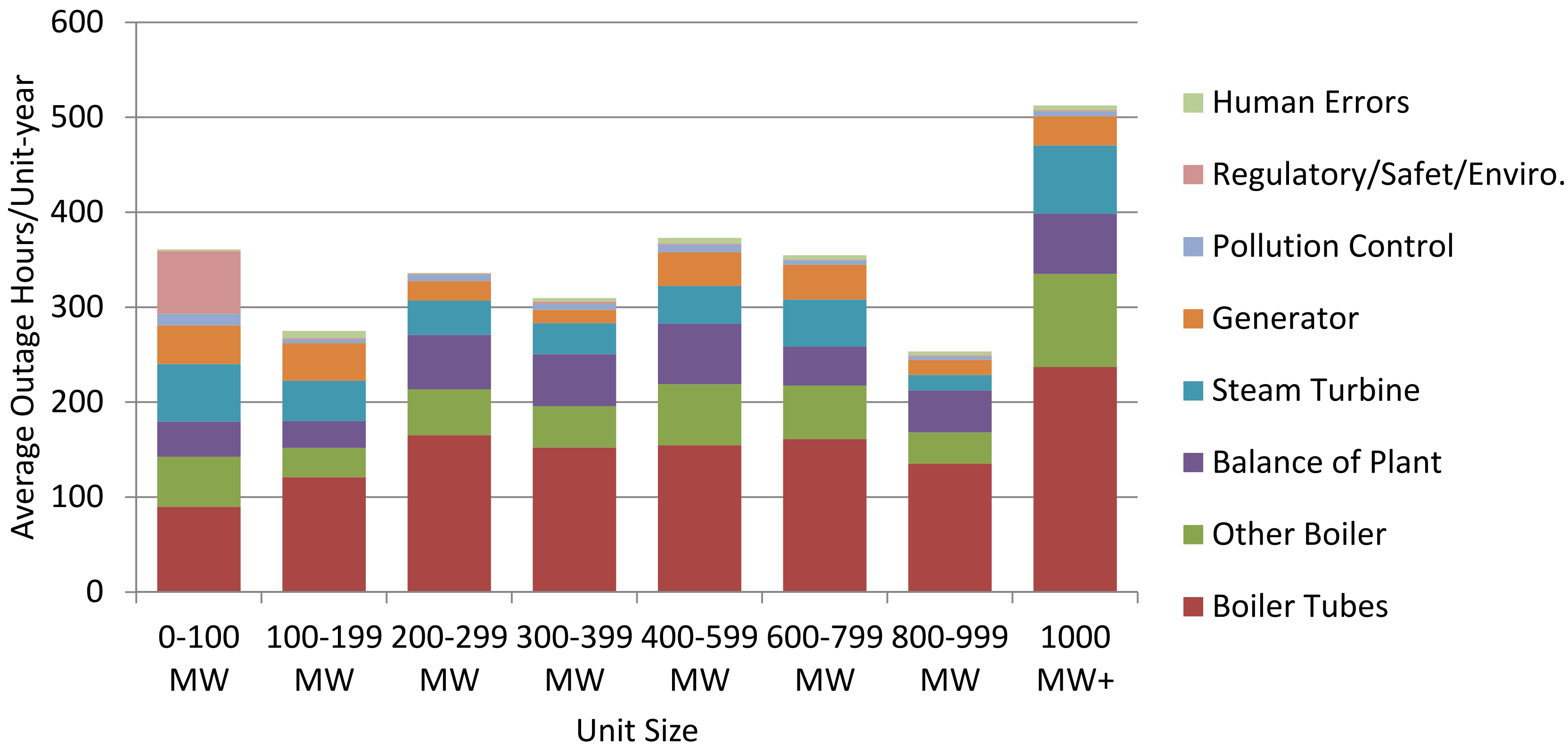
- **Developed tools to identify operating behaviors in the fleet**
- **Most coal plants were not designed to operate as load following units but many are increasingly operating as load followers**
  - 75% of subcritical units showed an increase in load following in the last 10 years
  - This behavior is often associated with increased generation from renewables as well as changes in coal and natural gas prices
- **Load following can lead to increased repair and maintenance costs**
  - A result of creep and fatigue issues that arise when plants operate outside of their design parameters
- **Advanced sensors, controls, and materials can help alleviate many of the issues experienced by load following coal-fired power plants**
- **Identified Key Problem areas and listed solutions where Advance Technologies can help**

Benefits of Advanced Material Use for Boiler Tubes in Coal-fired Power Units

Two analyses performed

- Net Present Value Analysis
- Technology Deployment Analysis

Average Annual Forced Outage Hours for Coal-fired Units (2007-2011)



- **For 300MW – 1GW+ coal units, boiler tube failures account for an average of:**
  - 168 hours of downtime per year
  - $3 million to $15 million of annual revenue losses

Adv Materials

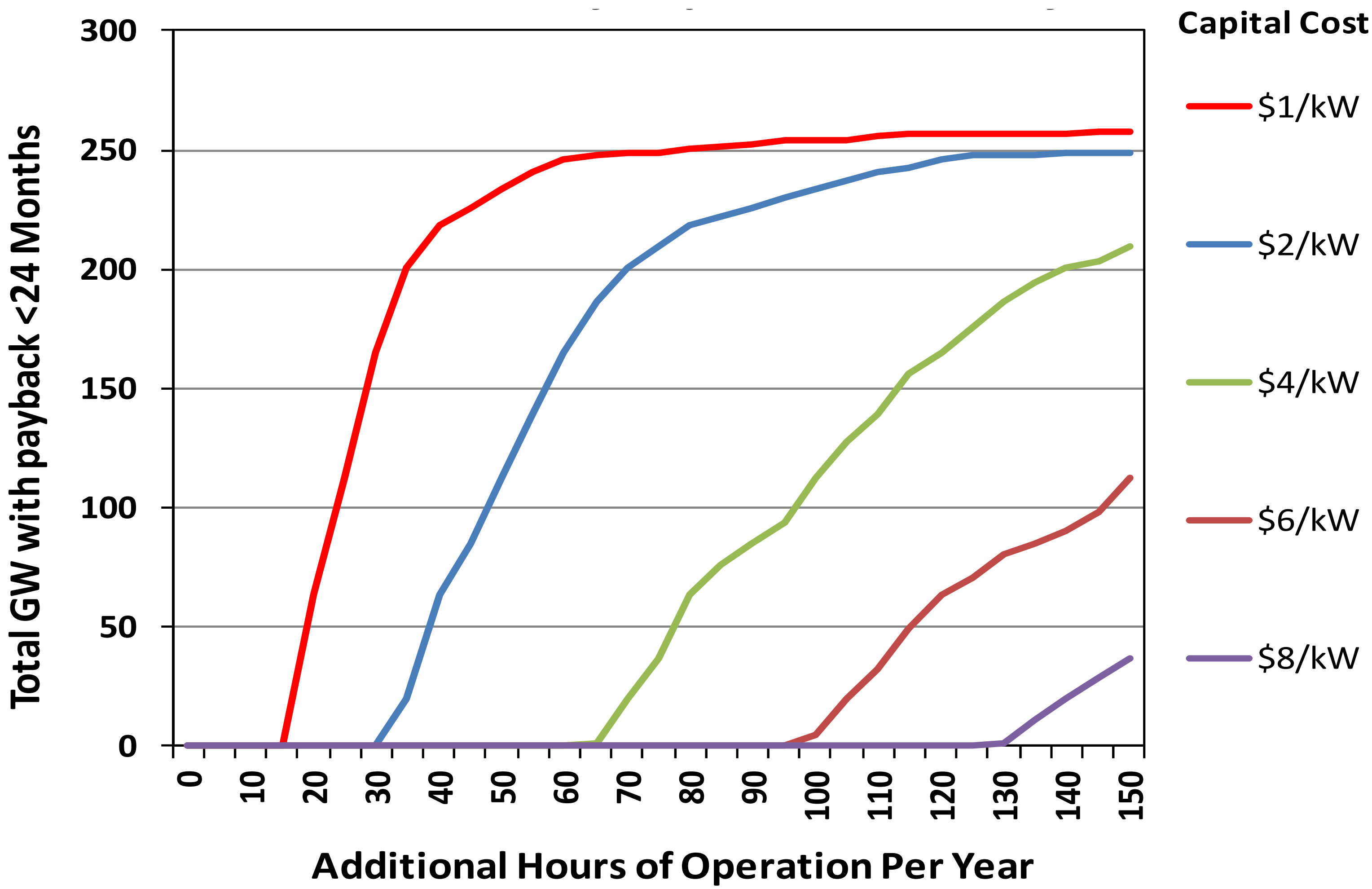
Source: DOE/NETL, NERC GADS Database

Net Present Value Analysis

- **Calculates the NPV of cash flows that occur after the installation of the new advanced materials and the payback period**
  - Advanced materials refurbishments occur in 2020
  - Full debt financing

- **257 GW total capacity are represented in the NPV analysis**
  - Exclusions include:
    - Coal-fired units put into service after 1990
    - Coal-fired units scheduled to retire before 2020
    - Coal-fired units smaller than 50 MW capacity

Coal Unit NPV Analysis



Source: Results based on unit by unit discounted cash flow model. Unit level data taken from 2012 Ventyx database.

NEMS Analysis

Adv Materials

Assumptions

- **Advanced materials are used in only the most problematic boiler areas**
  - Accounting for 10% of the total boiler tubes

- **Advanced material refurbishment option for NEMS:**
  - Based on results from EUCG survey and NPV model
  - Available to coal-fired power plants in 2020
  - Cost: $6/kW
  - Forced Outage Reduction: 80 hours per year

Results

- **193 GW of coal-fired units choose the advanced materials refurbishment option**
  - More than suggested by the NPV model
  - Units do not have the constraint of a payback hurdle

NETL

Summary

Benefits of Advanced Material Use for Boiler Tubes in Coal-fired Power Units

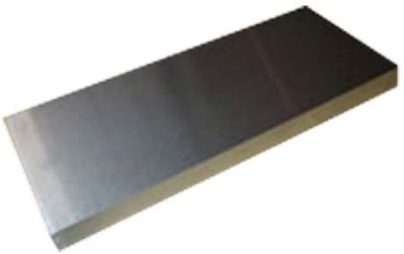
- **Advanced materials R&D at NETL is focused on attributes that address common boiler tube failure mechanisms:**
  – High temperature alloys
  – Materials with better corrosion resistance
  – Materials with better high temperature creep strength

- **NPV analysis indicates:**
  – Market potential for advanced materials boiler tube refurbishments depends on capital cost and availability improvements
  – Could be substantial within reasonable ranges

- **NEMS analysis indicates:**
  – At a cost of $6/kW for 80 additional hours of annual operation:
    - 193 GW of coal would refurbish with advanced materials
    - Coal dispatch would increase

Advanced Material Export Market Opportunities

- **Global Advanced Materials Market Assessment**
  - **Advanced Ultra Supercritical Power Plants**
  - **Market Outside of Coal Power Sector**



A-USC Market for Advanced Materials

- **Regions that will be likely export markets for U.S. advanced materials for A-USC plants include:**
  - European Union, China, India, Japan

- **Impacts will depend on the penetration of A-USC technology around the world and on how much of each market the U.S. penetrates to provide advanced materials parts and engineering expertise:**
  - If 20% of global new builds are A-USC (84 GW, 2025-2035*) and the U.S. penetrates 50% of that market:

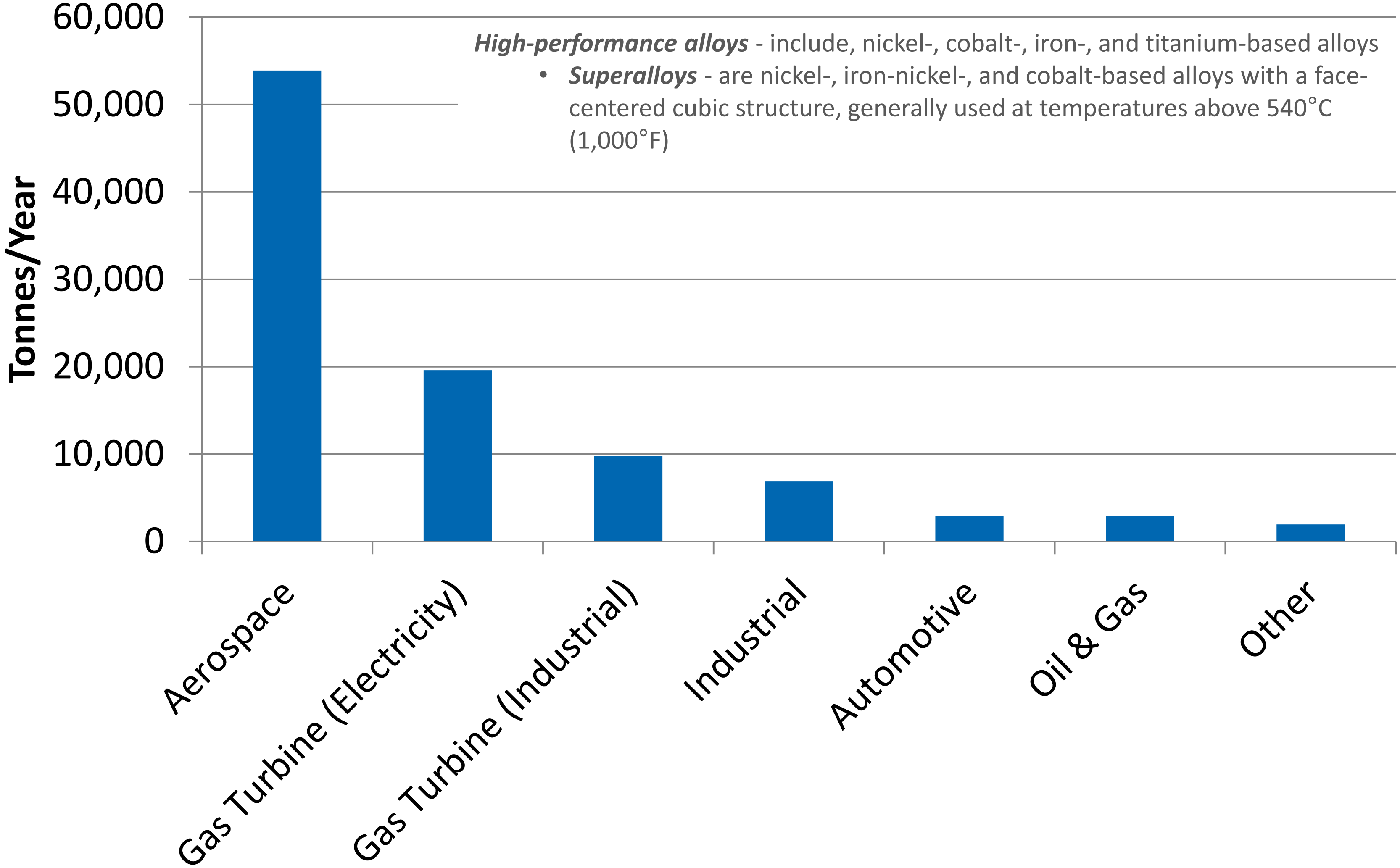
	Adv. Material Value Case	Full Value Case
Average annual exported products and services	$4.5 Billion	$24 Billion
Employment Impact⁺	42,000 job-years	228,000 job-years
Income Impact⁺	$2.6 Billion	$14 Billion
GDP Impact⁺	$4 Billion	$23 Billion

**IEA WEO*
⁺NETL-WVU Econometric Input-Output Model

Superalloy Global Market Distribution

High-performance alloys - include, nickel-, cobalt-, iron-, and titanium-based alloys

- ***Superalloys*** - are nickel-, iron-nickel-, and cobalt-based alloys with a face-centered cubic structure, generally used at temperatures above 540°C (1,000°F)



Into the Melting Pot: The Superalloy and its Impact on Minor Metals, Roskill Information Services Ltd., Presented Feb. 28, 2013 at Minor Metals Conference, Accessed 12/5/13 www.roskill.com

Aerospace Market for Advanced Materials

- **Regions that will be likely export markets for U.S. advanced materials for aerospace include:**
  - Europe & Asia
- **Impacts will depend on the penetration of U.S. aerospace parts for aircraft and rocket assembly around the world and on the actual growth pattern of the global air fleet:**
  - If U.S. exports match the assumed growth rate of 5%* across sectors of interest and any growth after 2024 is assumed to be attributable to NETL research in advanced materials:

	Adv. Material Value Case	Full Value Case
Average annual exported products and services	$18 Billion	$230 Billion
Employment Impact+	170,000 job-years	2,000,000 job-years
Income Impact+	$11 Billion	$143 Billion
GDP Impact+	$29 Billion	$367 Billion

Into the Melting Pot: The Superalloy and its Impact on Minor Metals, Roskill Information Services Ltd., Presented Feb. 28, 2013 at Minor Metals Conference and the Boeing Current Market Outlook

+*NETL-WVU Econometric Input-Output Model*

Thank you

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