HYBRID ANALYTICS SOLUTION TO IMPROVE COAL POWER PLANT OPERATIONS

DE-FE0031753

2020 Sensors and Controls
Project Review Meeting

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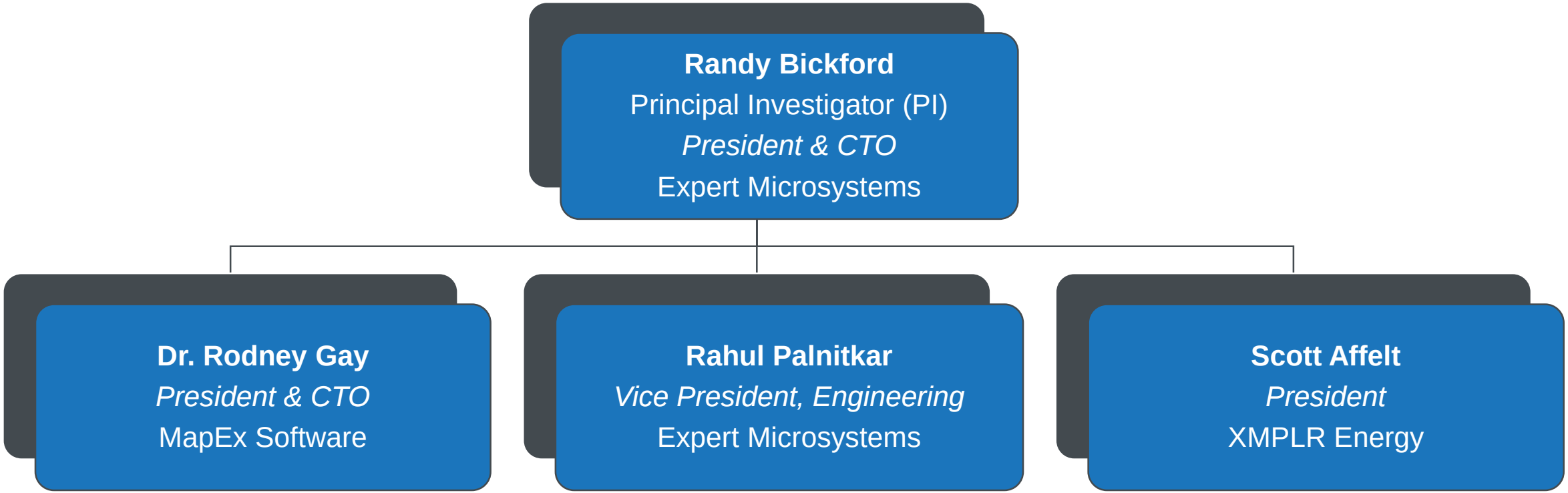
PROJECT TEAM AND COAUTHORS



PROJECT OBJECTIVE & DESCRIPTION

OBJECTIVE

Align with DOE's Fossil Energy Objective to create innovative solutions that integrate physics-based models with data-driven analytics and machine learning techniques to improve coal-fueled power plant operations

(DE-FOA-0001989 Topic 3A)

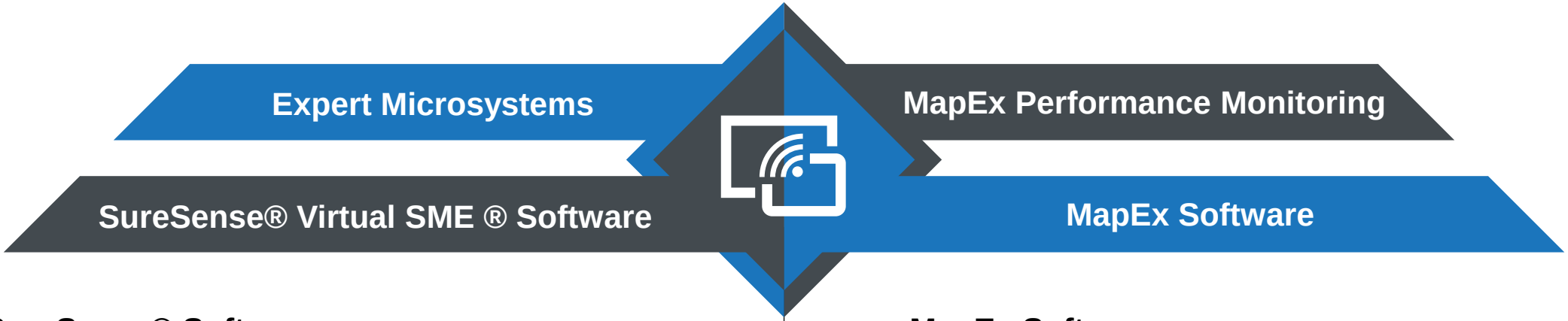
DESCRIPTION

New technology is developed to integrate an existing heat-balance modeling product with an existing advanced pattern recognition, machine learning and artificial intelligence product to create a hybrid online monitoring solution

- Completed solution is demonstrated at a utility-owned coal fired plant
- New Technology Elements are taken from TRL 2 to TRL 7

HYBRID ANALYTICS SOLUTION

INTEGRATION OF TWO PROVEN TECHNOLOGIES

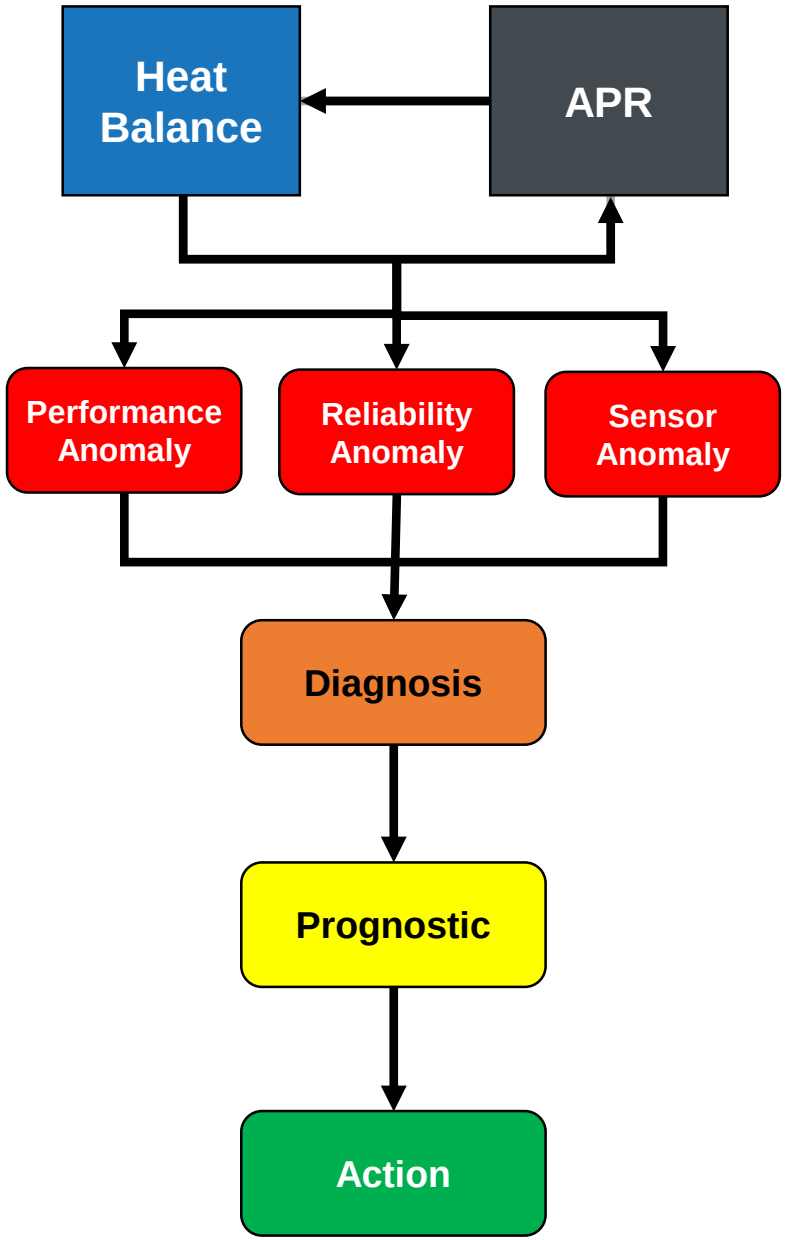


- **SureSense® Software**
  - Leading-edge Advanced Pattern Recognition (APR) software
  - Automated AI diagnostics
  - Online remaining time to act estimates
- **Broad Power Generation User Base**
  - Coal, nuclear, CCGT, hydro & renewables
- **Chemical & Refining User Base**
  - Downstream oil and gas plants
- **Established in 1996**

- **MapEx Software**
  - Heat balance analysis
  - Data reconciliation
  - Equipment performance analysis
- **Led by Dr. Rodney Gay**
  - Original developer of GE GateCycle
    - (acquired by GE in 1999)
  - Author: “Power Plant Performance Monitoring”
- **Installed at more than 25 sites globally**
- **Established in 2011**

HYBRID ANALYTICS SOLUTION

IMPROVING PERFORMANCE & RELIABILITY



- **Heat Balance (HB) Models**
  - Calculates “virtual” sensor information
  - APR models “calibrate” HB models
- **Advanced Pattern Recognition (APR) Models**
  - Uses both measured and calc HB data
  - Compares *Current State* to *Normal State*
- **Comprehensive Anomaly Detection**
  - Early and accurate anomaly detection
- **Diagnostics**
  - Both model-based & rule-based
  - Use symptoms from both HB and APR
  - Considers upstream/downstream info
- **Prognostics**
  - Calculates remaining time to act
  - Automatically updates with new information

IMPROVING POWER PLANT OPERATIONS

ENABLING EARLIER INTERVENTION TO PREVENT PROBLEMS

Improve Equipment Reliability

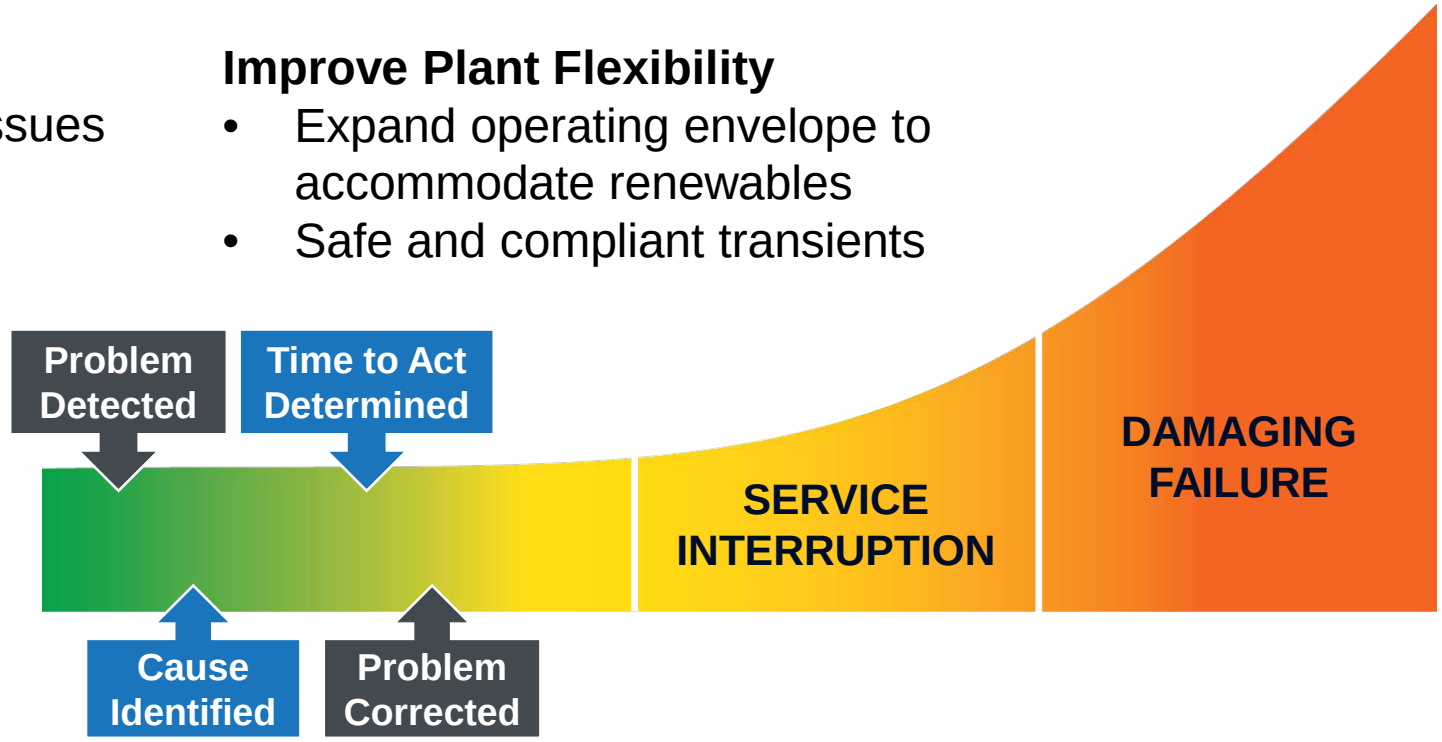
- Early detection of pending equipment issues
- Higher equipment availability
- Insights into issue causes
- Insights into remaining time to act

Improve Process Performance

- Early detection of performance issues
- Enhance/maintain optimal performance

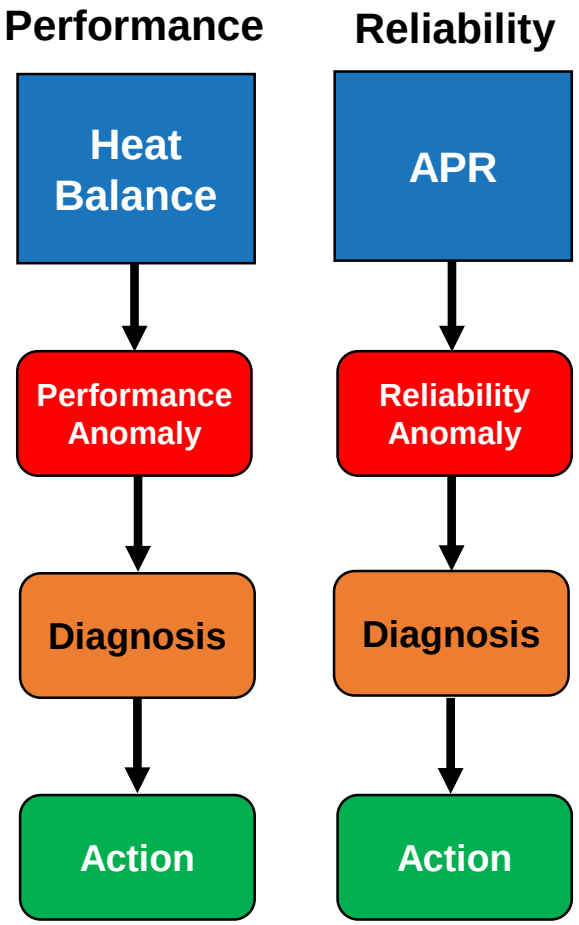
Improve Plant Flexibility

- Expand operating envelope to accommodate renewables
- Safe and compliant transients



TYPICAL UTILITY M&D CONFIGURATION

SEPARATE PERFORMANCE AND RELIABILITY TEAMS / PRODUCTS



First Principles Methods

- Thermal analysis & heat balance models
- Generally focused on performance
- Anomaly detection limited by model fidelity

Advanced Pattern Recognition (APR)

- Generally focused on reliability
- Good at detecting small changes
- Uses mostly measured values

Diagnostics

- 1st principles can provide insight on cause
- Simple IF/THEN rules
- Rarely used even if available

Prognostics

- Generally NO prognostics available
- Single parameter trending (vibration)

PERFORMANCE & RELIABILITY MODEL TYPES

PRIOR STATE OF THE ART

Thermal Performance Models (e.g., OEM, PEPSE, EtaPRO)

- Based on first principle analysis and/or vendor curves
- Inputs: Operating point, component performance curves and/or 1st principle models
- Outputs: Expected values and performance based on design

Heat Balance Models (e.g., MapEx)

- Inputs: Measured values & laws of conservation of mass & energy
- Outputs: Actual performance based on current measurements and conditions
- Calculates values not directly measured (“virtual" sensors)

Advanced Pattern Recognition Models (e.g., SureSense)

- Data-driven models based on machine learning and historical data
- Inputs: Current measured and/or calculated values
- Outputs: Normal or expected value for each input value and residual difference
- Detects anomalies in current vs. normal state for each input

HYBRID HB/APR MODELS

COMBINE ADVANTAGES & REMOVE LIMITATIONS

HEAT BALANCE MODEL

Advantages

- Based on physics of process
- Calculates values not directly measured
- Best to explain cause
- Considers upstream or downstream impacts
- Includes infrequent operating conditions

Limitations

- Difficult to setup & configure
- Long run times
- May not converge for given time step
- Limited anomaly detection
- Considers only current data

APR (DATA-DRIVEN) MODEL

Advantages

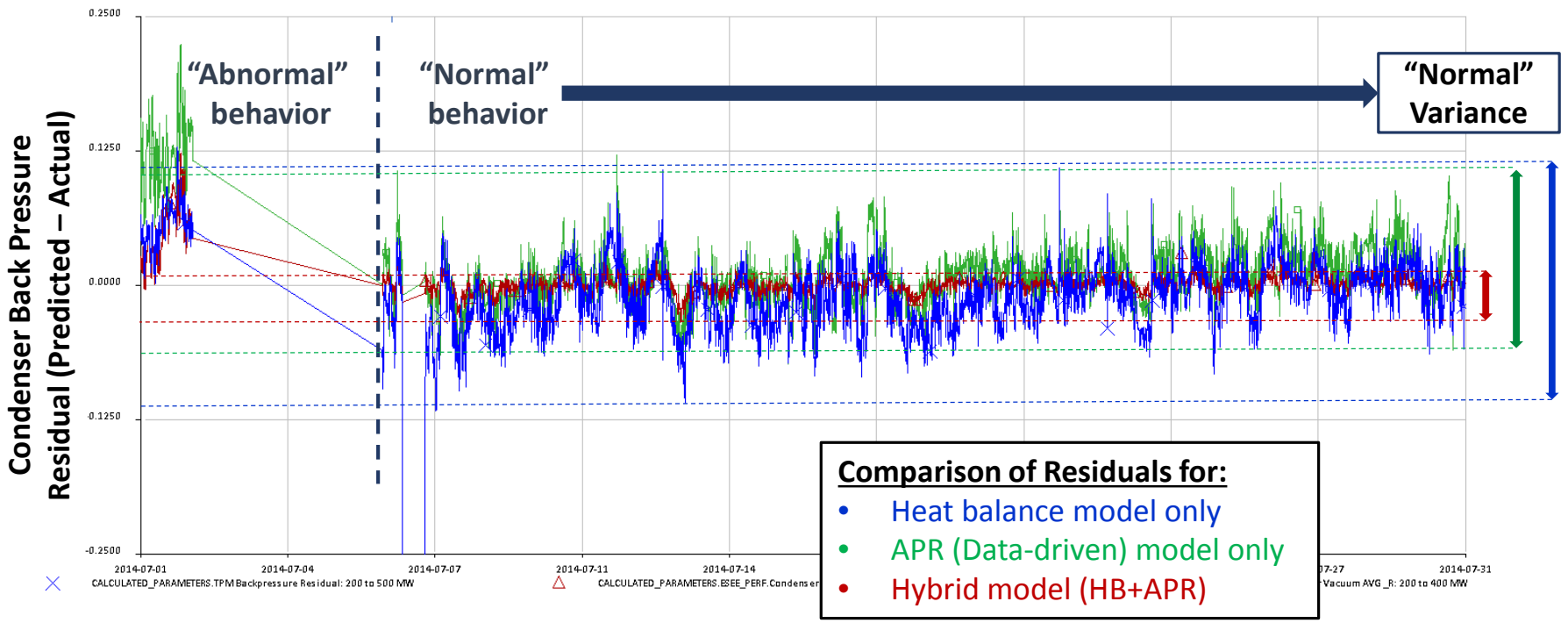
- Easy to setup & configure
- More accurate predictions
- Highly sensitive anomaly detection
- Detects Abnormal states
- Considers historical relationships between data

Limitations

- Normal state defined by training dataset (operating envelope)
- No inherent basis to explain cause
- No consideration of upstream or downstream impacts

HYBRID MODELS DETECT PROBLEMS SOONER

MODEL RESIDUALS ARE MINIMIZED FOR NORMAL BEHAVIOR



Comparison of Residuals for:

- Heat balance model only
- APR (Data-driven) model only
- Hybrid model (HB+APR)

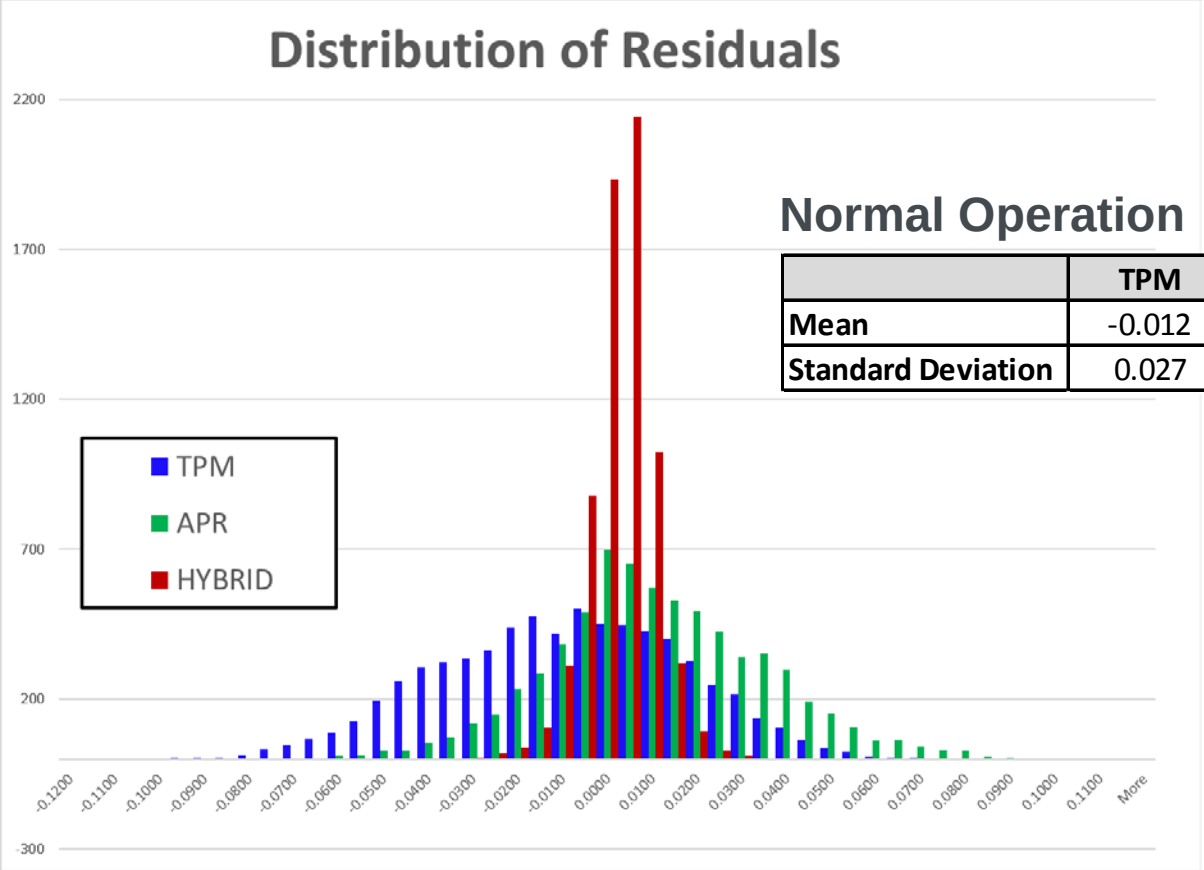
Heat balance models have modeling error/noise that makes it difficult to clearly detect an anomaly through the "normal" noise or variance.

Data-based APR models have lower "normal" residuals & therefore can detect anomalies easier & earlier.

Hybrid models (APR+Heat Balance) have the lowest residuals and most accurate anomaly detection

RESIDUAL DISTRIBUTION COMPARISON

HYBRID MODEL HAS BEST RESIDUAL DISTRIBUTION



Normal Operation

	TPM	APR	HYBRID
Mean	-0.012	0.009	0.000
Standard Deviation	0.027	0.024	0.007

HYBRID MODEL

- Less Bias (lower mean)
- Lower Standard Deviation

BENEFITS

- Tighter Thresholds
- More Sensitivity
- Earlier Detection
- Fewer False Alarms

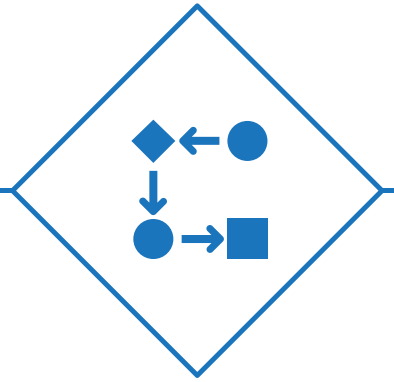
CURRENT STATUS OF PROJECT

FOUR TECHNICAL TASKS (MONTH 10 OF 24)

Develop & Integrate Physics-based Models

- MapEx HB modeling engine rewritten as SureSense plug-in
- MapEx user interface plugin for SureSense in progress

Develop & Integrate Hybrid-Analytics Framework

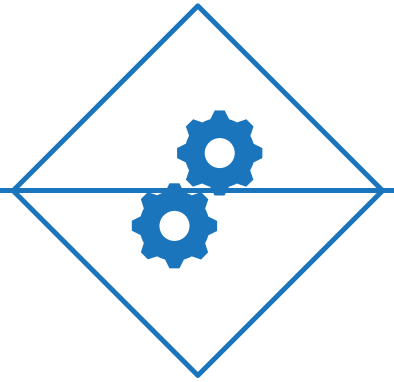


- First generation MapEx HB modeling engine integrated
- Iterative analytics framework completed

Verify Hybrid-Analytics Solution

- Agile development and test sprints ongoing
- Framework elements deployed at customer sites for user feedback

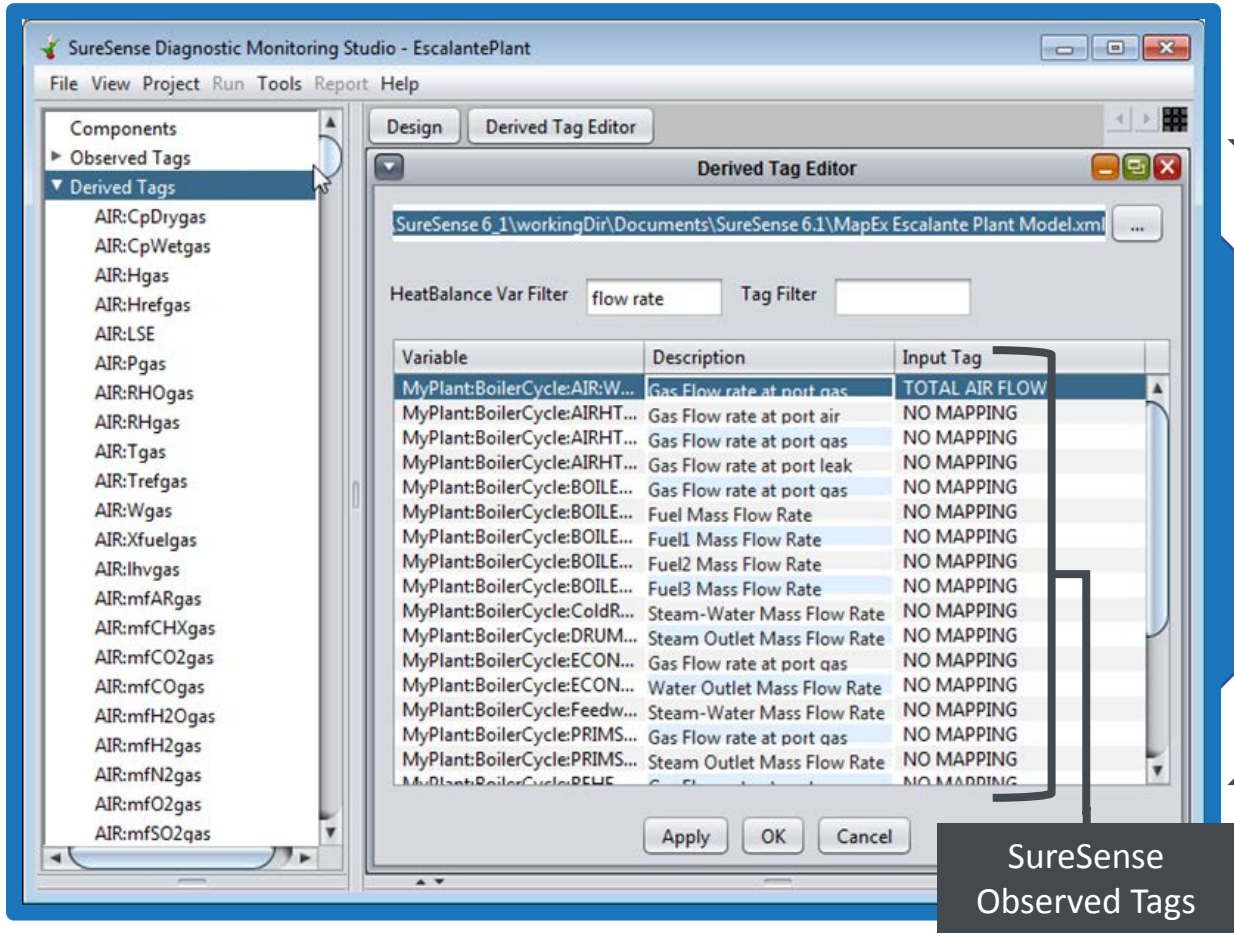
Demonstrate Hybrid Analytics Solution



- Coal-fired boiler and steam system heat balance model in progress for utility site demonstration testing

COAL-FIRED PLANT HEAT BALANCE MODEL

INPUT – OUTPUT MAPPING EDITOR



Connect real-time plant data to the MapEx model plugin

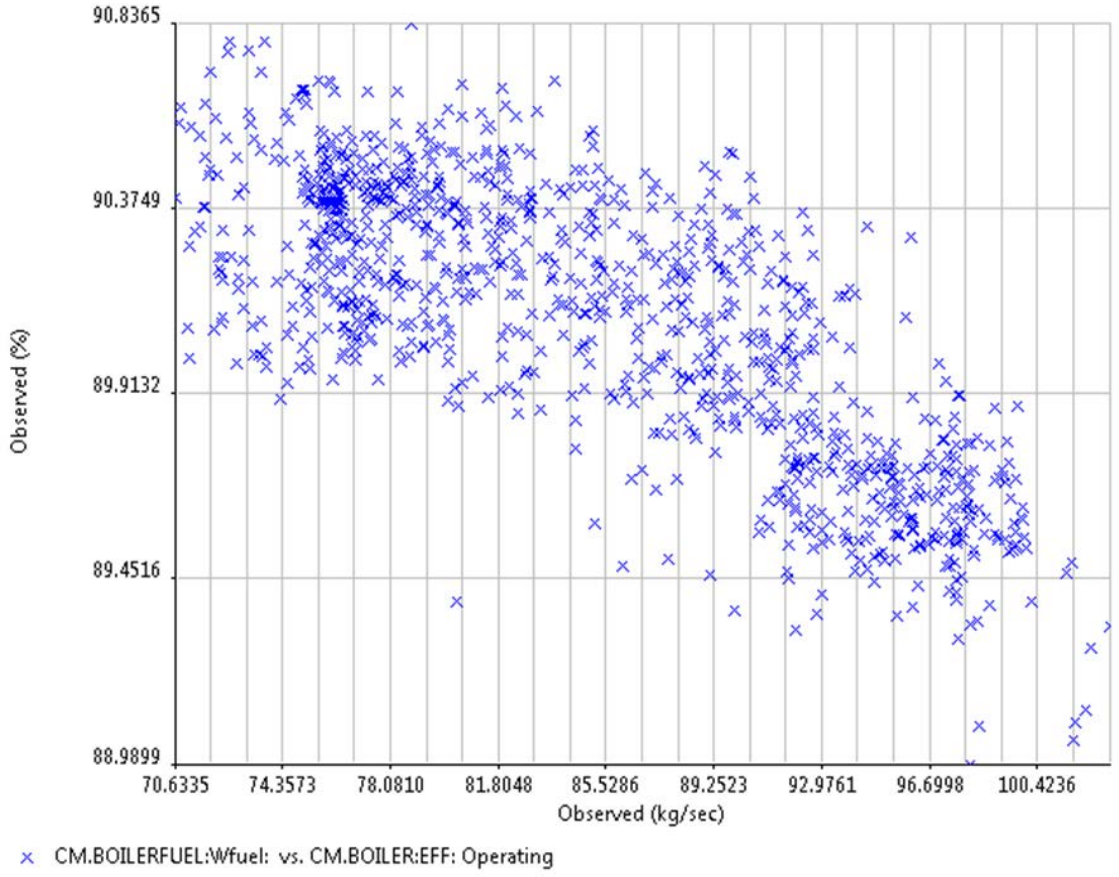
Model adjusts to use the available input tags

Heat Balance outputs are available as SureSense derived tags

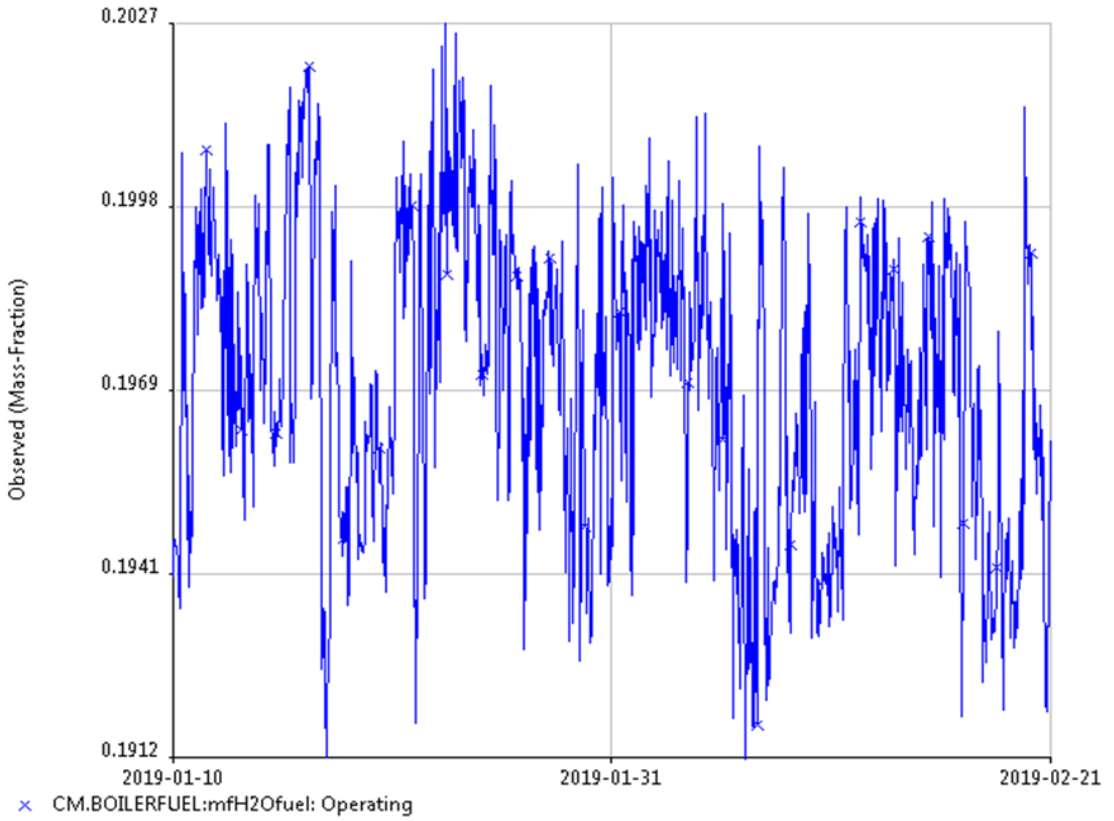
Available for use in data-driven models, diagnostics & prognostics

EXAMPLE RESULTS FOR A COAL-FIRED PLANT

Boiler Efficiency vs. Fuel Flow



Calculated Fuel Moisture Content



FUTURE GOALS AND OPPORTUNITIES

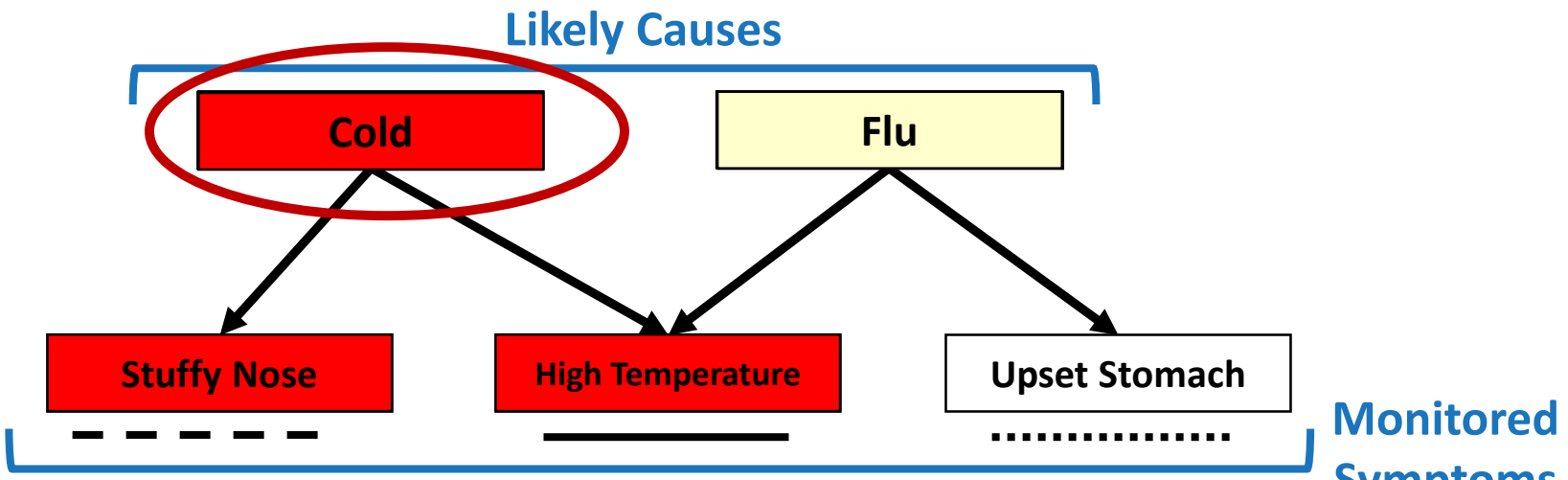
- **The Hybrid Analytics Platform** offers an unprecedented opportunity to implement comprehensive automated online diagnostics and remaining life prognostics for all types of power generation equipment

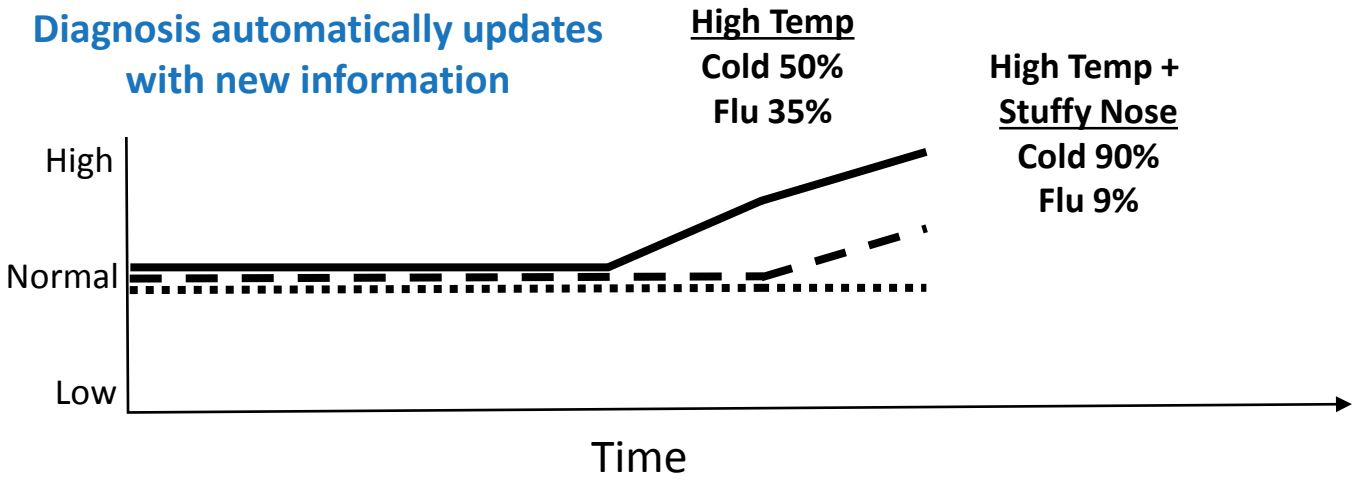
- **Model-Based AI Methods** (e.g., Bayesian Belief Networks) can learn complex data relationships and capture subject matter expertise

  - Probability-based decision tree
  - Ideal for complex & multi-symptom failure modes
  - Uses performance AND reliability symptoms for holistic diagnosis
  - Uses upstream and downstream symptoms for diagnosis
  - Can be combined with simple rules when applicable

MODEL-BASED DIAGNOSTIC MODEL

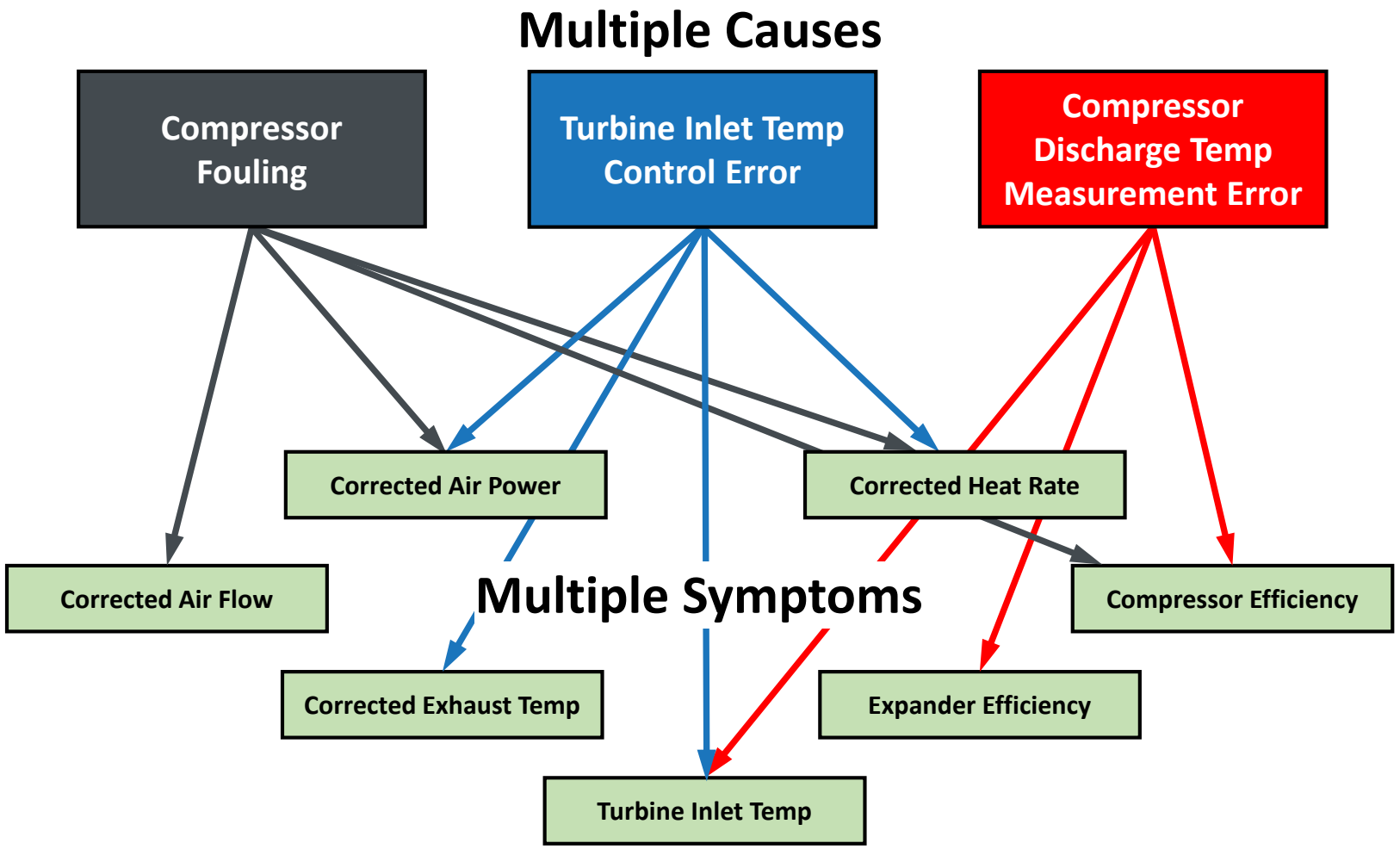
SIMPLE EXAMPLE





MODEL-BASED DIAGNOSTIC MODEL

COMPLEX EXAMPLE



The Diagnostic Model manages the relationships between multiple symptoms & causes

Q&A

DEPARTMENT OF ENERGY

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