Existing Plants - Fleet Assessment

2019 Annual Project Review Meeting for Crosscutting, Rare Earth Elements, Gasification and Transformative Power Generation

Jeff Hoffmann, Systems Engineering & Analysis Directorate
Briefing Outline

- Coal Fleet Trends
- Diversity in Coal Plant Design and Operation
- Diversity in Electricity Markets
- Coal Plant Retirements
- Closing Thoughts
Recent Trends of the U.S. Coal Fleet

- Decreasing coal-based electricity generation has driven retirement of uneconomic assets

Impact on Coal Fleet

Owners’ Response

Top Right - NETL analysis of EIA data
Bottom Right - EIA, Almost all power plants that retired in the past decade were powered by fossil fuels, https://www.eia.gov/todayinenergy/detail.php?id=34452, 2018 and 2019 updated with current EIA Data (Preliminary Monthly Electric Generator Inventory, January 2019)
Changing Generation Mix

2018 Installed Electricity Generating Capacity

- Coal, 23%, ~270 GW
- Nuclear, 9%, ~110 GW
- NG, 44%, ~520 GW

2018 Annual U.S. Electricity Generation

Operable Utility-Scale Generating Units (as of January 2019)

Credits: Top Left – Adapted from OE Energy Market Snapshot, National – Data through October 2018, FERC Office of Enforcement, November 2018
Bottom Left – NETL analysis of monthly data as provided in EIA’s Electricity Data Browser
Right - EIA, https://www.eia.gov/electricity/data/eia860M/ (Release Date March 26, 2019)
Monthly Data Provide Greater Insight

Source: NETL analysis of monthly data as provided in EIA’s Electricity Data Browser
Coal Relatively Stable Through 2008

Net Generation, Thousand MWh

- Net Generation
- Coal
- Nuclear
- Natural Gas
- All Other
- Conv. Hydro
- Wind
- Solar

Source: NETL analysis of monthly data as provided in EIA’s Electricity Data Browser
Coal Decline Starts 2009 and Continues

Source: NETL analysis of monthly data as provided in EIA’s Electricity Data Browser
Renewable Variability is Interesting

Source: NETL analysis of monthly data as provided in EIA’s Electricity Data Browser
Utilization Trends of the Existing Fleet

Power Plant Operating Profiles

- Baseload
- Predominantly Baseload
- Load Following
- Predominantly Low Load
- Shifting

Impact of unit operating load on heat rate

Average EFOF vs. Age for coal-power plants designed for baseload operating in a cycling regime

Credits:
- Left – Analysis of unit-level hourly output
- Top Right – Adapted from IEA Coal Industry Advisory Board, Power Generation from Coal, 2010
- Bottom Right – Adapted from European Technology Development Ltd, Impacts of Cyclic Operation on Maintenance Programmes
Observations on Coal Plant Performance and Design
Diversity Across the U.S. Coal Fleet

Coal Unit Component Design and Configuration
- Coal Handling
- Boiler Design and Operating Conditions: Including NOx Control
- Five Gas Processing (heat exchange, particulate control, sulfur control, Hg control, CO2, trace species)
- Turbine-Generator Design
- Cooling Technology
- Water Treatment
- Ash Handling
- Residue Treatment
- Instrumentation and use (e.g., performance, predictive maintenance)
- Process Control – equipment and approach

U.S. utility-scale coal-fired electric generating capacity by initial operating year gigawatts

Diversity of coal plants in the Lower 48 states

Credits: Bottom Left, NETL analysis of Ventyx Energy Velocity Suite Database Information
Center: Samarac, C., et al., Characterizing the U.S. Industrial Base for Coal-Powered Electricity, RAND Corporation, 2011
Right Top and Bottom, DOE EIA
## 2016 Fleet Performance Characteristics

**Sources:** NETL analysis of Ventyx Energy Velocity Suite Database, Platts 2016 UDI Database

<table>
<thead>
<tr>
<th>Segment Criteria</th>
<th>Sub-population Characteristics</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit Type</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal Type</td>
<td>Capacity (GW)</td>
</tr>
<tr>
<td>Low Pressure Subcritical (1,600 psig and less)</td>
<td>Bit</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Sub</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>0.64</td>
</tr>
<tr>
<td>High Pressure Subcritical (1,800-2,600 psig)</td>
<td>Bit</td>
<td>0.199</td>
</tr>
<tr>
<td></td>
<td>200-499</td>
<td>30.4</td>
</tr>
<tr>
<td></td>
<td>500+</td>
<td>29.8</td>
</tr>
<tr>
<td></td>
<td>Sub</td>
<td>0.199</td>
</tr>
<tr>
<td></td>
<td>200-499</td>
<td>27.3</td>
</tr>
<tr>
<td></td>
<td>500+</td>
<td>66.6</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>8.86</td>
</tr>
<tr>
<td>Supercritical (Over 3334 psig)</td>
<td>Bit</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Sub</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>All</td>
</tr>
<tr>
<td>Fleet</td>
<td>NA</td>
<td>269</td>
</tr>
</tbody>
</table>
Technologies to Improve Performance

• Many plant areas have room for improvement
• Solutions are commercially offered
• Key factors limiting implementation:
  • High cost
  • Inadequate performance improvement
## Sample List of Improvement Opportunities

<table>
<thead>
<tr>
<th>Upgrade Options</th>
<th>Upgrade Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boiler Island</strong></td>
<td><strong>Water Treatment</strong></td>
</tr>
<tr>
<td>Redesign/replace economizer</td>
<td>Cooling tower upgrades</td>
</tr>
<tr>
<td>Boiler tube coatings</td>
<td>FGD waste water treatment</td>
</tr>
<tr>
<td>Fuel delivery upgrades</td>
<td>Instrumentation &amp; Control</td>
</tr>
<tr>
<td>Sootblower upgrades</td>
<td>Digital controls</td>
</tr>
<tr>
<td>Air heater upgrades/lower outlet temp.</td>
<td>Neural network</td>
</tr>
<tr>
<td>Condenser upgrades</td>
<td>Coal Choices</td>
</tr>
<tr>
<td>Ash handling upgrades</td>
<td>Pre-beneficiation</td>
</tr>
<tr>
<td><strong>Turbine Island</strong></td>
<td>Reduce moisture</td>
</tr>
<tr>
<td>Upgrade (e.g., blades, seals, materials, coatings)</td>
<td>Reduce ash</td>
</tr>
<tr>
<td>Boiler feed pump upgrades</td>
<td>Change fuel</td>
</tr>
<tr>
<td>Generator upgrades</td>
<td>CHP Opportunities</td>
</tr>
<tr>
<td><strong>Flue Gas System</strong></td>
<td>Waste heat utilization</td>
</tr>
<tr>
<td>Fan and pump upgrades</td>
<td>Sell low-pressure steam</td>
</tr>
<tr>
<td>Emissions control modifications</td>
<td>Incorporate thermal energy storage</td>
</tr>
</tbody>
</table>

- For any given unit, only a subset will be technically feasible, of which only a few may be economically feasible
- The implication is that there is no practical one-size-fits-all solution
Performance Improvement Opportunity

- **Navajo Generating Station**
  - 3 x ~800 MWe (Nameplate)
  - 1970’s vintage bituminous-fired supercritical units
  - Env. Control - Hot-side ESP (PM), Wet FGD (SO₂) and ACI (Hg)
  - Supplies the WECC Desert Southwest market
  - Online years – 1974-1976, scheduled retirement in 2019

- **Primary drivers for retirement**
  - Changing economic circumstances (low NG prices, low demand)
  - Required future retrofit of SCR on Units 2 & 3 to comply with Regional Haze regulations
  - Other site-specific drivers (site lease, closure requirements)
Case Study – Navajo Generating Station

Annual Operational Statistics 2011-2018

<table>
<thead>
<tr>
<th>Year</th>
<th>Output, MWh</th>
<th>HR, BTU/kWh</th>
<th>CF, %</th>
<th>Unit Level CF, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>16,951,775</td>
<td>10,060</td>
<td>80.2</td>
<td>U1: 69.0 U2: 84.4 U3: 87.4</td>
</tr>
<tr>
<td>2012</td>
<td>15,888,068</td>
<td>10,042</td>
<td>75.3</td>
<td>U1: 75.2 U2: 75.7 U3: 74.8</td>
</tr>
<tr>
<td>2013</td>
<td>17,131,763</td>
<td>10,135</td>
<td>81.2</td>
<td>U1: 82.8 U2: 75.0 U3: 85.3</td>
</tr>
<tr>
<td>2014</td>
<td>17,297,076</td>
<td>10,263</td>
<td>82.0</td>
<td>U1: 79.5 U2: 85.7 U3: 80.6</td>
</tr>
<tr>
<td>2015</td>
<td>13,572,760</td>
<td>10,392</td>
<td>64.3</td>
<td>U1: 71.6 U2: 65.6 U3: 55.6</td>
</tr>
<tr>
<td>2016</td>
<td>12,058,583</td>
<td>10,417</td>
<td>57.1</td>
<td>U1: 59.3 U2: 54.6 U3: 57.4</td>
</tr>
<tr>
<td>2017</td>
<td>13,781,218</td>
<td>10,349</td>
<td>65.3</td>
<td>U1: 61.2 U2: 68.3 U3: 66.3</td>
</tr>
<tr>
<td>2018</td>
<td>13,017,437</td>
<td>10,545</td>
<td>61.7</td>
<td>U1: 61.0 U2: 61.9 U3: 62.0</td>
</tr>
</tbody>
</table>

*Source – EIA Form 923*

- Already showing negative effects
  - Decreasing EAF
  - Increasing EFOR

**Source** – EIA Form 923

**Plant Level (all Net)**

**Unit Level CF, %**

- Gross Load, MW
- U1
- U2
- U3

**Hourly load data source** – https://ampd.epa.gov/ampd/

*Approximate 40% of MCR*

*Approximate 100% of MCR*
Case Study – Navajo Generating Station

• Study Objective
  • Identify and evaluate potentially feasible heat rate improvement (HRI) opportunities
  • Consider only commercially-available, state-of-the-art technologies
  • Focus on technical assessment including magnitude of potential HRI and order of magnitude implementation costs

• Study Findings
  • Twenty three individual HRI opportunities identified and evaluated
    • Individual improvements ranging from very small to ~1.4%
    • Individual implementation costs from negligible to ~$18M/unit (~$24/kW)
    • Individual cost efficiencies ranging from “free” to >$150k per Btu/kWh improvement to unit heat rate
  • Maximum “feasible” HRI ~4.7% at cumulative implementation cost ~$40M/unit (~$55/kW)

• NGS Operator (Salt River Project) Perspective
  • Has “considered many of the options” identified by Black & Veatch
  • Acted on or dismissed options based on “operating and economic factors”

Credits: NETL, Plant Efficiency Evaluation at Navajo Generating Station, DOE/NETL-2018/1891, January 2018
Observations on U.S. Electricity Markets
### Diversity Across U.S. Electricity Markets

#### Electric Power Markets: National Overview

#### 2016 Nameplate Capacity, MW

<table>
<thead>
<tr>
<th>Region</th>
<th>Capacity</th>
<th>Coal</th>
<th>Gas</th>
<th>Int</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAISO</td>
<td>82,379</td>
<td>0%</td>
<td>53%</td>
<td>23%</td>
</tr>
<tr>
<td>MISO</td>
<td>184,427</td>
<td>38%</td>
<td>43%</td>
<td>11%</td>
</tr>
<tr>
<td>ISO-NE</td>
<td>31,798</td>
<td>3%</td>
<td>52%</td>
<td>8%</td>
</tr>
<tr>
<td>NYISO</td>
<td>41,646</td>
<td>3%</td>
<td>53%</td>
<td>5%</td>
</tr>
<tr>
<td>Northwest</td>
<td>81,494</td>
<td>15%</td>
<td>25%</td>
<td>16%</td>
</tr>
<tr>
<td>PJM</td>
<td>200,440</td>
<td>32%</td>
<td>38%</td>
<td>6%</td>
</tr>
<tr>
<td>Southeast</td>
<td>232,614</td>
<td>28%</td>
<td>49%</td>
<td>3%</td>
</tr>
<tr>
<td>Southwest</td>
<td>59,070</td>
<td>29%</td>
<td>47%</td>
<td>17%</td>
</tr>
<tr>
<td>SPP</td>
<td>87,255</td>
<td>30%</td>
<td>39%</td>
<td>12%</td>
</tr>
<tr>
<td>ERCOT</td>
<td>107,569</td>
<td>17%</td>
<td>59%</td>
<td>22%</td>
</tr>
<tr>
<td>Total</td>
<td>1,108,691</td>
<td>25%</td>
<td>45%</td>
<td>12%</td>
</tr>
</tbody>
</table>

#### Market Characteristics

<table>
<thead>
<tr>
<th>Region</th>
<th>Access to electricity markets across eight western states; CO2 constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAISO</td>
<td>Access to shale gas and wind; a number of state utilities continue to be vertically integrated monopolies; seasonal (i.e., winter) challenges for flexibility and reliability, capacity market and ancillary service opportunities; power import/export with Canada</td>
</tr>
<tr>
<td>MISO</td>
<td>Increasing NG capacity; NG infrastructure challenge; power import/export with Canada</td>
</tr>
<tr>
<td>ISO-NE</td>
<td>Declining electricity demand and aging infrastructure; increasing NG and wind with coal &amp; oil declining; hydro &amp; nuclear (mostly) constant; changing demand profile due to efforts focused on energy efficiency and other behind-the-meter opportunities; power import/export with Canada</td>
</tr>
<tr>
<td>NYISO</td>
<td>Heavy reliance on hydro; legacy state-regulated, vertically integrated, monopoly markets; significant Federal presence (Bonneville Power); power import/export with Canada</td>
</tr>
<tr>
<td>Northwest</td>
<td>Declining electricity demand and aging infrastructure; changing demand profile due to efforts focused on energy efficiency; large legacy generation disproportionate in some states; capacity market and ancillary service opportunity</td>
</tr>
<tr>
<td>PJM</td>
<td>Legacy state-regulated, vertically integrated, monopoly markets</td>
</tr>
<tr>
<td>Southeast</td>
<td>Legacy state-regulated, vertically integrated, monopoly markets</td>
</tr>
<tr>
<td>Southwest</td>
<td>Legacy state-regulated, vertically integrated, monopoly markets</td>
</tr>
<tr>
<td>SPP</td>
<td>Increasing NG capacity, wind generation, ancillary service opportunity</td>
</tr>
<tr>
<td>ERCOT</td>
<td>Excess capacity, increasing wind growth</td>
</tr>
</tbody>
</table>

1. % Intermittent includes wind and solar; does not include geothermal, landfill gas, MSW, black liquor, biomass or hydro

Credits: Ventyx Energy Velocity Suite Database (data); EIA, FERC (graphics)
Market Variability - Capacity Mix

Generation Capacity Mix – Continental United States
Operating or Standby Status, June 2018

% of Installed MW

Credits: Adapted from OE Energy Market Snapshot, National – Data through October 2018, FERC Office of Enforcement, November 2018
Wind & Solar split based on FERC-cited data source (EIA Form 860M, June 2016)
Comparison of Market Components Across Competitive Electricity Markets (as of 2015-2016)

<table>
<thead>
<tr>
<th></th>
<th>ISO-NE</th>
<th>NYISO</th>
<th>PJM</th>
<th>MISO</th>
<th>SPP</th>
<th>ERCOT</th>
<th>CAISO</th>
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</thead>
<tbody>
<tr>
<td>Ancillary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regulation</td>
<td>RT</td>
<td>DA/RT</td>
<td>RT</td>
<td>DA/RT</td>
<td>DA/RT</td>
<td>DA/RT</td>
<td>DA</td>
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<tr>
<td>Reserves¹</td>
<td>FP/RT</td>
<td>DA/RT</td>
<td>DA/RT</td>
<td>DA/RT</td>
<td>DA/RT</td>
<td>DA/RT</td>
<td>DA/RT</td>
</tr>
<tr>
<td>Voltage Support</td>
<td>Yes²</td>
<td>Yes²</td>
<td>Yes²</td>
<td>Yes²</td>
<td>Yes²</td>
<td>Yes²</td>
<td>Yes²</td>
</tr>
<tr>
<td>Black Start</td>
<td>Yes²</td>
<td>Yes²</td>
<td>Yes²</td>
<td>Yes²</td>
<td>Yes²</td>
<td>No</td>
<td>Yes²</td>
</tr>
<tr>
<td>Transmission</td>
<td>FTR</td>
<td>TCC</td>
<td>FTR</td>
<td>FTR</td>
<td>TCR</td>
<td>CRR</td>
<td>CRR</td>
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<tr>
<td>Capacity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes:
1. Reserves include one or more of the following services: Spinning, Non-Spinning, 30-minute, Supplemental
2. Voltage support and black start ancillary services are compensated through cost-based mechanisms and are not a “competed” component of the market structure.

Table Abbreviations:
- DA – Day Ahead
- RT – Real Time
- FP – Forward Planning (pre-DA)
- FTR – Financial Transmission Rights
- TCC – Transmission Congestion Contracts
- TCR – Transmission Congestion Rights
- CRR – Congestion Revenue Rights

Bulk Power Grid of the Continental United States

Credits: Left – EIA, U.S. electric system is made up of interconnections and balancing authorities, July 2016, Online at: https://www.eia.gov/todayinenergy/detail.php?id=277528
Market Variability – Power Pricing

2018 Spot Power Prices ($/MWh)

- Mid-Columbia: $34 (32%)
- Indiana Hub: $38 (8.5%)
- Mass Hub: $48 (38.9%)
- NP 15: $40 (4%)
- Palo Verde: $40 (18.1%)
- SPP North: $29 (15.5%)
- PJM West: $42 (26.2%)
- NYISO ZJ: $46 (23.2%)
- ERCOT North: $42 (56%)
- Into Southern: $31 (3%)

$ = Average YTD 2018 monthly day-ahead on-peak price
% = Percent increase from 2017 YTD
Source: RTO/ISO data and SNL Day-ahead Prices

Credit: OE Energy Market Snapshot, National – Data through October 2018, FERC Office of Enforcement, November 2018
Observations on Coal Plant Retirements
A Significant Decade for Coal Retirements

Source – NETL analysis of EIA data, augmented with information from ABB Energy Velocity Database

~2 GW more than identified by EIA
Attributes of Retired and Operating Units

Coal Retirements According to Heat Rate and Environmental Controls

Coal Plant Status - Environmental Controls and Fuel Type

Right – NETL analyses of EIA unit-level data
U.S. Coal Fleet Through 2030

Legend
- All coal units
  - Size By Nameplate Capacity (MW)
    - 500 to 1300
    - 250 to 500
    - 0.4 to 250
- All coal units
  - Color By Status
    - Announced Retirement
    - Operating
    - Retired
    - NERC_Regions

Source: NETL analysis
Why do coal plants retire?

- **Revenue insufficient to cover cost of ownership**
  - “Routine” increased costs associated with aging and normal use of plant equipment
  - “Non-routine” increased costs due to accelerated wear from non-baseload operations
  - Decreased capacity utilization

- **Factors that influence decision**
  - Competition with lower-cost alternatives (e.g., natural gas, renewables)
  - Changing market conditions, largely unfavorable to coal (e.g., decreasing demand, market incentives for renewables, inadequate or non-existent compensation mechanisms)
  - Increasing corporate/investor focus on “clean” energy options
  - Public policies (e.g., renewable portfolio standards, state and federal regulations)
  - Societal concerns (e.g., “customer choice” for renewables, active opposition resulting in protracted permitting efforts, uncertainty in future public policy)
Retirement Example (Retired in 2018)

• Sandow Power Plant
  • Unit 5 – 692 MWe Lignite-fired fluidized bed combustor
  • Full-load efficiency – 35%
  • Full suite of environmental controls
  • Supplied the competitive wholesale ERCOT market
  • Online year – 2010, retired in 2018

• Primary drivers for retirement
  • Low wholesale power prices due to oversupply of generation, largely due to:
    • Recent and continued addition of wind and solar generation
    • Sustained low natural gas prices

Bottom, NETL modification of Google Earth imagery.
• Intermountain Generating Station
  • Units 1 & 2 – 1,775 MWe Bituminous-fired pulverized coal
  • Full-load efficiency – 35.2% (Unit 1), 35.9% (Unit 2)
  • Full suite of environmental controls
  • Supplied multiple customers in Utah and California
  • Online year – 1986 (Unit 1), 1987 (Unit 2), both scheduled for retirement in 2025

• Primary drivers for retirement
  • LADWP (plant operator and purchaser of 48.6% of generation) will not renew power purchase agreement, in part due to CA limitations on CO₂ emissions
  • New NGCC planned for site of existing coal units
Closing Thoughts
• Solutions relevant to the existing fleet are needed in the near-term
• Must bring meaningful improvements to targeted attribute (e.g., efficiency, flexibility, reliability)
• Must be low cost, rapid return on investment
• Must be low risk in all aspects
  • Performance – must function as intended
  • Reliability – must not negatively impact the existing plant
  • Cost – must have high cost certainty, minimal “collateral costs” (i.e., costly investments in other parts of the plant for system integration, life extension, etc.)
  • Integration – must be easily “absorbed” by existing plant infrastructure (including workforce)
  • Execution – predictable implementation, acceptable impact to short- and long-term operations

Time is of the Essence
## Opportunities for Targeted R&D

<table>
<thead>
<tr>
<th>R&amp;D Focus</th>
<th>Benefit to Owner/Operator</th>
<th>Benefit to System and Society</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved Efficiency</td>
<td>• Increased capacity utilization via higher unit dispatch</td>
<td>• Lower electricity cost to the consumer</td>
</tr>
<tr>
<td></td>
<td>• lower cost of generation</td>
<td>• Decrease in environmental emissions from coal-fired electricity production</td>
</tr>
<tr>
<td>Increased Flexibility</td>
<td>• Greater agility to respond to rapid changes in electricity supply and demand</td>
<td>• Improved system capability to handle increased penetration of VERs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lower system cost due to decreased need for replacement generation capacity</td>
</tr>
<tr>
<td>Enhanced Reliability</td>
<td>• Decreased maintenance costs</td>
<td>• Improved energy security supported through higher system reliability</td>
</tr>
<tr>
<td></td>
<td>• Fewer and shorter unplanned outages</td>
<td>• Lower cost to consumer through decreased need to source higher cost replacement power</td>
</tr>
<tr>
<td></td>
<td></td>
<td>when unplanned outages occur</td>
</tr>
</tbody>
</table>
Thank You

Jeff Hoffmann

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