Component Level Modeling of Materials Degradation for Insights into Operational Flexibility of Existing Coal Power Plants
Anand Kulkarni, Siemens Corporation
DOE Award: DE-FE-0031831
Acknowledgements

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Outline

Introduction

Project Objective and Team

Project Approach to Meet Technical Targets

Task 2.0 - Collect boiler/steam turbine plant operating data
  o Subtask 2.1 – Boiler/Heat exchanger component down-selection and requirement definition
  o Subtask 3.2 – Steam turbine component down-selection and requirement definition

Task 3.0 – Fireside corrosion/steam oxidation/creep modeling of superheater/reheater tubes

Task 4.0 – Water droplet erosion modeling for low pressure (LP) steam turbine blade

Task 5.0 - Modeling Data Validation and Scale-up Opportunities
  o Subtask 5.1 – Constitutive model/tool validation
  o Subtask 5.2 – Component design/analysis for scale-up opportunities
  o Subtask 5.3 - Techno-economic analysis for model output

Project Schedule and Milestones
Synergistic research for component level modeling for insights into operational flexibility of existing coal power plants

Project information

PI: Anand Kulkarni  
Funder: DOE Office of Fossil Energy (FE) – NETL Crosscutting  
Strategic Partner: Siemens Gas and Power, Cranfield University  
Total Project Funding: $937.5K ($750K Federal/$187.5K Cost share)

Technical Highlights

<table>
<thead>
<tr>
<th>Funding Opportunity Objective</th>
<th>Objective of the Proposed Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced modeling tools for existing power plant issues and mitigation</td>
<td>Component level modeling utilizing computational fluid dynamics for materials degradation for existing coal power plant issues</td>
</tr>
</tbody>
</table>
| Insight into existing coal plant challenges and mitigation solutions | Modeling activities will focus on 1) Creepfired superheater/ re heater boiler/steam pipe oxidation in and 2) steam pipe oxidation in last stage steam pipe oxide scale 
| Materials degradation for operational flexibility | Multidisciplinary models for solid particle impingement/steam pipe oxide scale; evaluation within the boiler tubes and droplet impingement in steam 
| Analytics results from model validated from plant data | Validation of modeling results using service run data (destructive metallurgical analysis) to correlate model and design assumptions to actual power plant performance |

• Generate CFD/FE models for the prediction of deposition/erosion/corrosion around the fireside surfaces of a superheater/reheater boiler/heat exchanger tube.

• Generate CFD/FE models predicting the extent of steam oxidation within a heat exchanger tube or steam pipe, and the impact that plant cyclic operation will have on oxide spallation.

• Generate CFD/FE models for multiphase fluid flow predicting water droplet erosion for last stage low pressure turbine blade.

• Determine the impact of plant operations (fuel/operational flexibility), validated with service feedback data using plant and pilot-scale rig data (where available), on the response/trends of the three component/material CFD/FE models generated.

The proposed innovation is in developing a computational fluid dynamics/finite element (CFD/FE) modeling toolkit for the component level models to tackle multidisciplinary failure mechanisms occurring concurrently for extreme environment materials. Lifetime assessment in such environments also needs to account for the unit-specific analyses, operational history and fuel feedstock; this can only be obtained by destructive analysis of components. This, in turn, enables validation of the model toolkits utilizing service feedback data, improving the probability of time/temperature dependent life prediction.
## Project team and expertise

Anand Kulkarni, Siemens  
Principal Investigator

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Skill and expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principal Investigator:</strong> Anand Kulkarni</td>
<td>Senior Key Expert; 25 years in research and technology in the area of materials/coatings for power systems, 10 years in materials needs for environmental and operational flexibility</td>
</tr>
</tbody>
</table>
| **Siemens Team:**  
Bob Reynolds (BR)  
William McDonald (WM) | **BR:** Staff Scientist; 20 years’ Computational Fluid Dynamics (CFD) experience in industry. Expert in various CFD applications including aerodynamics, conjugate heat transfer, Fluid-Structure Interaction, multiphase, phase change, reacting flow, Lagrangian particle tracking  
**WM:** Senior Engineer, Program Manager, 10 years’ experience with design, service engineering and monitoring of steam turbines |
| **Cranfield Team:**  
Nigel Simms (NS)  
Joy Sumner (JS)  
John Oakey (JO) | **NS:** Professor; 30 years’ experience of power generation systems, Development of advanced higher efficiency and lower emission thermal power systems, Performance of components in conventional and advanced power systems  
**JS:** Senior Lecturer, Expert in degradation of materials in coal and gas-fired power plants  
**JO:** 30 years’ experience of power generation systems, with emphasis on the development of advanced higher efficiency and lower emission thermal power systems |

### Materials knowledge, Operational flexibility, Steam Turbines Field Experience, Design and analysis
- Anand Kulkarni, Siemens
- Bob Reynolds, Siemens
- William McDonald, Siemens
- Nigel Simms, Cranfield University
- Joy Sumner, Cranfield University
- John Oakey, Cranfield University

### Contract Administration
- Kevin Go, Siemens
- Kathy Sasala, Siemens
- Contract management

### Financial Management
- Terri Held, Siemens
- Financials, invoicing
- Subcontractor agreements

### Senior Technical Advisors
- Xavier Montesdeoca, Siemens
- Michael Smiarowski, Siemens
- Steam turbine design and modifications
- Boiler design and performance expertise

### Program Management
- Jason Weissman, Siemens
- Risk analysis
- Program management

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The technical team is strong and has been working together for 15+ years
### Project approach for component modeling for existing power plants

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technical Progress</strong>&lt;br&gt;Computational CFD/FE for failure mechanisms observed.&lt;br&gt;Plant operations data for existing power plants as input for computational simulations&lt;br&gt;<strong>Go / No-Go</strong>&lt;br&gt;CFD/FE toolkit framework with plant operations data and component performance and issues</td>
<td><strong>Technical Progress</strong>&lt;br&gt;Model simulation for Multidisciplinary failure mechanisms&lt;br&gt;<strong>Go / No-Go</strong>&lt;br&gt;Develop one stop tool interface for model liking to design data and FEA package for component model analysis</td>
<td><strong>Technical Progress</strong>&lt;br&gt;Heat exchanger and steam Turbine Component model validation with plant data&lt;br&gt;<strong>Program Success</strong>&lt;br&gt;Integrated framework established for robust life prediction assessment for operational flexibility and future plans</td>
</tr>
</tbody>
</table>

- **Technical Progress**
  - Computational CFD/FE for failure mechanisms observed.
  - Plant operations data for existing power plants as input for computational simulations.
  - Go / No-Go: CFD/FE toolkit framework with plant operations data and component performance and issues.

- **Year 1**
  - Computational CFD/FE toolkit Framework

- **Year 2**
  - Model simulation for Multidisciplinary failure mechanisms
  - Go / No-Go: Develop one stop tool interface for model liking to design data and FEA package for component model analysis

- **Year 3**
  - Heat exchanger and steam Turbine Component model validation with plant data
  - Program Success: Integrated framework established for robust life prediction assessment for operational flexibility and future plans
Development approach to advance technology

Simulated domain containing the boiler with super heater and economizers

Temperature profile
Concentration of KCl
Corrosion risk on the SH3 surface

Prediction of ash buildup on SH3 on front side facing flow

Simulation models for corrosion to predict localized high risk corrosion areas – Monitoring, Mitigation and Reduced repair costs/Forced Outages
Task 2.0 - Collect Boiler/Heat exchanger/Steam turbine plant operating data

Part of steam circuit

Simulated air-fired combustion gases

Fouling in heat exchangers
Task 2.0 - Collect boiler/steam turbine plant operating data

- Data gathered on plant component materials degradation to establish CFD/FE model framework
- Data from exposures previously carried out in UK power plants (e.g. Tilbury, Ironbridge, Ratcliffe) for ‘Innovate UK’ projects (ASPECT and ASPIRE), EU NEXTGENPOWER project and earlier superheater/reheater tube monitoring
- Data include fireside corrosion damage measurements from inspections of heat exchanger tubes operated in pulvisered coal fired power plants as well as temperature-controlled probes of materials/components installed in plants for evaluation.
- Datasets gathered includes fuel compositions and operating environments – but every exposure has gathered different sets of exposure parameters
- Datasets allow the range of exposure conditions and alloy/coating fireside corrosion in superheater/reheater tubes in historic coal-fired UK pulverised fuel power stations to be quantified
- These data feed into the development/validation of fireside corrosion model (part of Task 3.2).
Task 3.0 – Fireside corrosion/Steam oxidation/Creep modeling of Superheater/Reheater tubes
Updated - deposition modeling

Starting point: 2D Fluent deposition model
- Tube numbers increased from 3 to 12
- Model reconfigured from 2D to 3D geometry
- Alkali vapour condensation model updated with new parameters
- User defined functions (UDFs) updated and operations verified for both 2D and 3D cases
- Fluent code now on High Performance Computer (HPC)
- Siemens STAR-CCM+ software on desktop computer to investigate equivalent simulations compared to the Fluent
Effect of increased vapour condensation on deposition flux profiles: 
U= 2 m/s, Na$_2$SO$_4$ = 1 ppm or 10 ppm

Mean Deposition Flux (mg/cm$^2$-hr), 
U=2 m/s

Particle Diameter Distribution (for Na$_2$SO$_4$ = 10 ppm)
L0 Titanium blade trailing edge erosion

Background

Trailing Edge Erosion

Observed on the convex surface of the airfoil on all current styles of last row titanium blades on some units.

The erosion observed has varied, but in some cases has extended from the portion of the airfoil trailing edge just above the blade platform to as high as the mid-height interlock.

Blade airfoil cracks have been observed to initiate in the lower third of the airfoil.

Cracks originating in a heavily eroded region of the trailing edge have led to blade separation events on some units.
Exhaust Recirculation

- Recirculation can occur during low load or part load operation and is influenced by elevated backpressures.
- Figure to right illustrates general relationship between steam turbine flow, condenser backpressure, and exhaust recirculation.

In general, as backpressure increases for a given load, the potential for flow recirculation increases.
Titanium blade trailing edge erosion contributors

Downstream Moisture

- The layout and operation of the condenser, including the steam bypass system and the associated condenser spray systems, have been identified as factors in the amount of downstream moisture available to be recirculated back toward the turbine.

- These spray systems, depending on their orientation and location in a particular unit, can provide the moisture necessary for erosion to occur.

Example Moisture Sources in Condenser
Model of curtain spray for water droplet studies

- Diffuser with struts
- Two Condensers
- Dilution pipes with inlets

8A (massflow inlet)
8B (massflow inlet)
Turbine (stator) inlet
(total pressure distr.
flow angles / velocity comp.)
Rotor blades, no snubber
no shroud – blade without gap
7B (massflow inlet)
7A (massflow inlet)
Outlet (pressure)
Condenser outlet (80-90 %)
Const massflow + pressure loss
Preliminary results

View from upstream side of the rotor, the droplets from the inlet mainly impact on the leading edge and close to the hub, while some droplets from the diffuser can be brought back to the turbine and impact the rotor blades close to the hub, no droplets from the curtain spray can be observed from this view.
Physics models for erosion

- **Erosion rate**
  The erosion rate is defined as the mass of wall material eroded per unit area per unit time. It is calculated on wall, baffle, and contact boundary faces by accumulating the damage that each particle impact does on the face.

- **Oka correlation for erosion ratio**

  \[ e_r = e_{90} g(\alpha) \left( \frac{v_{rel}}{v_{ref}} \right)^{k_2} \left( \frac{D_p}{D_{ref}} \right)^{k_3} \]

  where:
  - The angle function \( g(\alpha) \) is defined as:
    \[ g(\alpha) = (\sin \alpha)^{n_1} (1 + H_y (1 - \sin \alpha))^{n_2} \]
  with \( n_1, n_2, \) and \( H_y \) user-specified constants. Oka and others identify the value of \( H_y \) as the Vickers hardness of the eroded material in units of GPa.
  - \( v_{rel} \) is the magnitude of the relative velocity of the particle with respect to the wall.
  - \( v_{ref} \) is the user-specified reference velocity.
  - \( D_{ref} \) is the user-specified reference diameter.
  - \( k_2 \) and \( k_3 \) are user-specified exponents.

- Comparing with other erosion correlation models, Oka correlation has the advantage of accounting for both droplets’ velocity and diameter.
- The erosion rate \( e_r \) has the dimension of kg/m\(^2\)-s.
- Revised erosion model parameters are needed for the materials systems.
- Current, data digging for results of erosion testing for input into the model.
Erosion data for model calculations

Table 2
Mechanical properties of specimen (at 313 K; standard testing conditions).

<table>
<thead>
<tr>
<th>Material</th>
<th>Density [kg/m³]</th>
<th>Surface hardness [HV–10]</th>
<th>Young’s modulus E [GPa]</th>
<th>Modulus of resilience $U_r/U_{r,X20Cr13}$</th>
<th>Erosion resistance $R_{E,50}/R_{E,50,X20Cr13}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>X20Cr13</td>
<td>7.710</td>
<td>271</td>
<td>216</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>X5CrNiCuNb 16-4</td>
<td>7.760</td>
<td>328</td>
<td>200</td>
<td>2.61</td>
<td>1.17</td>
</tr>
<tr>
<td>X5CrNiCuNb 16-4, laser treated</td>
<td>7.760</td>
<td>420</td>
<td>200</td>
<td>4.28*</td>
<td>2.58</td>
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<tr>
<td>X5CrNiMoCuNb 14-5-eq</td>
<td>7.750</td>
<td>373</td>
<td>200</td>
<td>3.38*</td>
<td>1.78</td>
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<tr>
<td>Ti6Al4V</td>
<td>4.420</td>
<td>334</td>
<td>110</td>
<td>3.95</td>
<td>3.23</td>
</tr>
</tbody>
</table>
Boilers/Heat Exchangers

Deposition/corrosion around a heat exchanger tube

Flow (particulate/liquid) or droplet impingement/assisted erosion for Casings, Compressor components/HRSG/Boiler tubes/Steam turbines/Piping

Model efforts of interest for Power Plant Upgrades (e.g. Fuel flexibility)

Model validation

Developed CFD models to predict deposition in Cranfield combustion rig

Experimental investigation of deposition on heat exchangers in pilot scale testing

Model boundary conditions
Techno-economic analysis
Project schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Predecessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Component level modeling of materials degradation for insights into operational flexibility of Existing Coal Power Plants</td>
<td>784 days</td>
<td>Tue 1/10/20</td>
<td>Fri 9/30/22</td>
<td>Predecessors</td>
</tr>
<tr>
<td>2</td>
<td>Task 1: Program Management and Planning</td>
<td>784 days</td>
<td>Tue 1/10/20</td>
<td>Fri 9/30/22</td>
<td>Predecessors</td>
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<tr>
<td>3</td>
<td>Update SIPO</td>
<td>30 days</td>
<td>Mon 11/11/19</td>
<td>Mon 11/11/19</td>
<td>Predecessors</td>
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<tr>
<td>4</td>
<td>Kick-off Meeting</td>
<td>30 days</td>
<td>Tue 1/10/20</td>
<td>Mon 11/11/19</td>
<td>Predecessors</td>
</tr>
<tr>
<td>5</td>
<td>Project Management</td>
<td>784 days</td>
<td>Tue 1/10/20</td>
<td>Fri 9/30/22</td>
<td>Predecessors</td>
</tr>
<tr>
<td>6</td>
<td>Contract Administration and Cost Reporting</td>
<td>784 days</td>
<td>Tue 1/10/20</td>
<td>Fri 9/30/22</td>
<td>Predecessors</td>
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<tr>
<td>7</td>
<td>Technical Reporting</td>
<td>784 days</td>
<td>Tue 1/10/20</td>
<td>Fri 9/30/22</td>
<td>Predecessors</td>
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<tr>
<td>8</td>
<td>Progress Reports</td>
<td>784 days</td>
<td>Tue 1/10/20</td>
<td>Fri 9/30/22</td>
<td>Predecessors</td>
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<tr>
<td>9</td>
<td>Task 2: Collect boiler/steam turbine plant operating data</td>
<td>207 days</td>
<td>Tue 1/10/20</td>
<td>Wed 7/15/20</td>
<td>Predecessors</td>
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<tr>
<td>10</td>
<td>Task 3.1: Boiler/Heat exchanger component down-selection and requirement definition</td>
<td>206 days</td>
<td>Tue 1/10/20</td>
<td>Tue 7/14/20</td>
<td>Predecessors</td>
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<tr>
<td>11</td>
<td>Component performance requirements and design constraints</td>
<td>100 days</td>
<td>Mon 1/11/19</td>
<td>Mon 2/17/20</td>
<td>Predecessors</td>
</tr>
<tr>
<td>12</td>
<td>Define design/manufacturing/physical constraints for observed failure</td>
<td>106 days</td>
<td>Tue 2/18/20</td>
<td>Tue 7/14/20</td>
<td>Predecessors</td>
</tr>
<tr>
<td>13</td>
<td>Task 2.2: Steam turbine component down-selection and requirement definition</td>
<td>207 days</td>
<td>Tue 1/10/20</td>
<td>Wed 7/15/20</td>
<td>Predecessors</td>
</tr>
<tr>
<td>14</td>
<td>Component performance requirements and design constraints</td>
<td>100 days</td>
<td>Mon 1/11/19</td>
<td>Mon 2/17/20</td>
<td>Predecessors</td>
</tr>
<tr>
<td>15</td>
<td>Define design/manufacturing/physical constraints for observed failure</td>
<td>106 days</td>
<td>Tue 2/18/20</td>
<td>Tue 7/14/20</td>
<td>Predecessors</td>
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<tr>
<td>16</td>
<td>Further data on plant component materials degradation to establish CFD/FE model</td>
<td>3 days</td>
<td>Wed 7/15/20</td>
<td>Wed 7/15/20</td>
<td>Predecessors</td>
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<tr>
<td>17</td>
<td>Task 3.0: Fireside corrosion/steam oxidation/corrosion of superheater/reheater tubes</td>
<td>547 days</td>
<td>Tue 11/12/19</td>
<td>Wed 12/15/21</td>
<td>Predecessors</td>
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<tr>
<td>18</td>
<td>Task 3.1: Definition of heat exchanger</td>
<td>100 days</td>
<td>Mon 11/12/19</td>
<td>Mon 3/20/20</td>
<td>Predecessors</td>
</tr>
<tr>
<td>19</td>
<td>Evaluation of design conditions and operational data for heat exchanger</td>
<td>50 days</td>
<td>Tue 11/12/19</td>
<td>Wed 1/20/20</td>
<td>Predecessors</td>
</tr>
<tr>
<td>20</td>
<td>Compilation of materials matrix/properties and available experimental data</td>
<td>50 days</td>
<td>Mon 1/11/19</td>
<td>Mon 3/20/20</td>
<td>Predecessors</td>
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<tr>
<td>21</td>
<td>Task 3.2: Fireside degradation model</td>
<td>200 days</td>
<td>Tue 3/31/20</td>
<td>Mon 1/24/21</td>
<td>Predecessors</td>
</tr>
<tr>
<td>22</td>
<td>Data analytics toolkit for deposits/erosion/failure mechanisms</td>
<td>100 days</td>
<td>Mon 3/31/20</td>
<td>Mon 8/17/20</td>
<td>Predecessors</td>
</tr>
<tr>
<td>23</td>
<td>Task 3.3: Steam oxidation and formation model</td>
<td>200 days</td>
<td>Tue 3/31/20</td>
<td>Mon 1/24/21</td>
<td>Predecessors</td>
</tr>
<tr>
<td>24</td>
<td>Data analytics toolkit for deposits/erosion/failure mechanisms</td>
<td>100 days</td>
<td>Mon 3/31/20</td>
<td>Mon 8/17/20</td>
<td>Predecessors</td>
</tr>
<tr>
<td>25</td>
<td>Part damage model development for key components correlated to design/materials analysis</td>
<td>100 days</td>
<td>Mon 8/17/20</td>
<td>Mon 1/24/21</td>
<td>Predecessors</td>
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<tr>
<td>26</td>
<td>Task 3.4: Creep model</td>
<td>93 days</td>
<td>Tue 1/5/21</td>
<td>Thu 5/13/21</td>
<td>Predecessors</td>
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<td>27</td>
<td>Data analytics toolkit for multidisciplinary failure mechanisms run for cyclic loading</td>
<td>93 days</td>
<td>Tue 1/5/21</td>
<td>Thu 5/13/21</td>
<td>Predecessors</td>
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<tr>
<td>28</td>
<td>Deposition / Fireside corrosion / erosion / steam oxidation materials degradation model analysis for heat exchanger tubes for metal loss predictions</td>
<td>1 day</td>
<td>Fri 5/14/21</td>
<td>Fri 5/14/21</td>
<td>Predecessors</td>
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<tr>
<td>29</td>
<td>Robust life prediction approach demonstrated with utilizing materials tested in lab</td>
<td>153 days</td>
<td>Fri 5/14/21</td>
<td>Tue 12/14/21</td>
<td>Predecessors</td>
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<tr>
<td>30</td>
<td>Comparison of materials degradation models for heat exchanger tubes with plant / experimental data</td>
<td>1 day</td>
<td>Wed 12/15/21</td>
<td>Wed 12/15/21</td>
<td>Predecessors</td>
</tr>
</tbody>
</table>

**Task 4.0: Water droplet erosion modeling for LP steam turbine blade**

- 482 days | Tue 11/12/19 | Wed 9/15/21
- 165 days | Tue 11/12/19 | Mon 6/29/20
- 80 days | Tue 11/12/19 | Mon 3/2/20
- 150 days | Tue 11/12/19 | Mon 6/29/20

**Task 4.1: Definition of steam turbine blade**

- 150 days | Tue 11/12/19 | Mon 6/29/20
- 80 days | Tue 11/12/19 | Mon 3/2/20

**Evaluation of design conditions and operational data for steam turbine blades**

- 80 days | Tue 11/12/19 | Mon 3/2/20

**Compilation of materials matrix/properties and available experimental data**

- 80 days | Tue 11/12/19 | Mon 3/2/20

**Definition of Steam turbine detailed blade geometry and operating conditions**

- 80 days | Tue 11/12/19 | Mon 3/2/20

**Task 4.2: Water droplet erosion model**

- 150 days | Tue 11/12/19 | Mon 6/29/20
- 80 days | Tue 11/12/19 | Mon 3/2/20

**Data analytics toolkit for water droplet erosion failure mechanisms**

- 80 days | Tue 11/12/19 | Mon 3/2/20

**Part damage model development for key components correlated to design/materials analysis**

- 80 days | Tue 11/12/19 | Mon 3/2/20

**Comparison of steam droplet erosion materials degradation models with plant / experimental data**

- 1 day | Wed 9/15/21
- 1 day | Fri 9/30/22
- 1 day | Fri 10/1/20

**Task 5.0: Modeling Data Validation and Scale-up Opportunities**

- 1305 days | Mon 10/2/17
- 1305 days | Fri 11/27/20
- 140 days | Tue 11/12/19
- 140 days | Tue 11/12/19

**Task 5.1: Constitutive Model/Tool Development**

- 140 days | Tue 11/12/19
- 140 days | Tue 11/12/19
- 5/25/20

**Develop a data analytics framework capable of housing probabilistic design/materials analysis**

- 5/25/20
- 5/25/20

**Part damage model development for key components correlated to design/materials analysis**

- 5/2/20
- 5/2/20

**Deployment of an integrated interface utilizing plant operational data and CFD/FE to predict remaining life of components for improved design/materials analysis**

- 5/26/20
- 5/26/20
- 5/26/20

**Component level models for heat exchanger tubes and steam turbine blades**

- 1 day | Mon 11/30/20
- 1 day | Mon 11/30/20
- 1 day | Mon 11/30/20

**Task 5.2: Component design analysis for scale-up opportunities**

- 784 days | Mon 10/2/17
- 359 days | Mon 11/30/20
- 359 days | Thu 4/14/22

**Fracture mechanics/heat transfer and CFD analysis demonstrated for multiple stages of components for boilers and steam turbines**

- 359 days | Mon 11/30/20
- 359 days | Thu 4/14/22

**Validation of model toolbox for heat exchanger metal loss for baseload and cyclic operations**

- 1 day | Fri 4/15/22
- 1 day | Fri 4/15/22

**Validation of model toolbox for steam turbine erosion and impact on fatigue life**

- 1 day | Fri 4/15/22
- 1 day | Fri 4/15/22

**Demonstrate component model for optimization of design and service maintenance**

- 1 day | Wed 8/31/22
- 1 day | Wed 8/31/22

**Validation of component level modeling for heat exchanger and steam turbine blade with existing plant data**

- 1 day | Wed 8/31/22
- 1 day | Wed 8/31/22

**Final Technical report detailing Improved materials/operational flexibility for improved power plant component**

- 23 days | Wed 8/31/22
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Conclusions

- Efforts are underway to develop component level simulation model to predict localized high-risk areas for mitigations.
- Scale up and validation of fireside corrosion model to industrial systems, based on fundamental understanding of materials behavior and failure mechanisms.
- The CFD/FE framework will enable simulations for varied fuel compositions and operating environments of Boiler/HRSG tubes for risk mitigations and operational flexibility.
- CFD/FE framework for L0 stage/exhaust area established for steam turbines with accurate steam droplet velocity and size distribution at the turbine inlet to improve the erosion prediction.
- Extend model to include the full final row of turbine stage in order to include more accurate water droplet transport models up into final turbine stage (Lagrangian particle tracking and wall impingement).