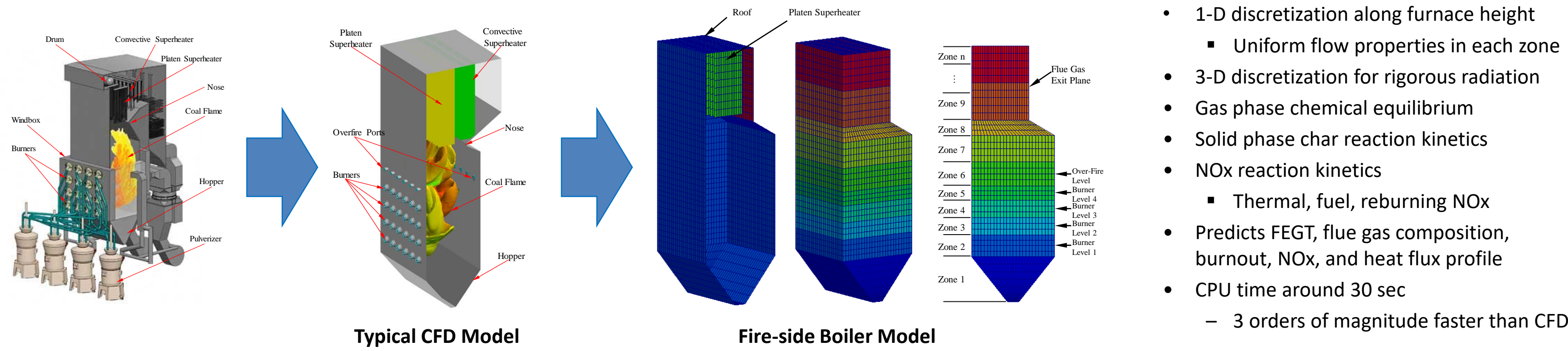


IDAES is developing capabilities to **improve the efficiency and reliability** of the existing fleet of **coal-fired power plants** while accelerating the development of a broad range of advanced fossil energy systems

IDAES tools address several important challenges:

- Enabling **flexible long-term operation** to accommodate highly variable renewable energy resources
- Determining the best **options for retirement or refurbishment** of aging fossil energy assets

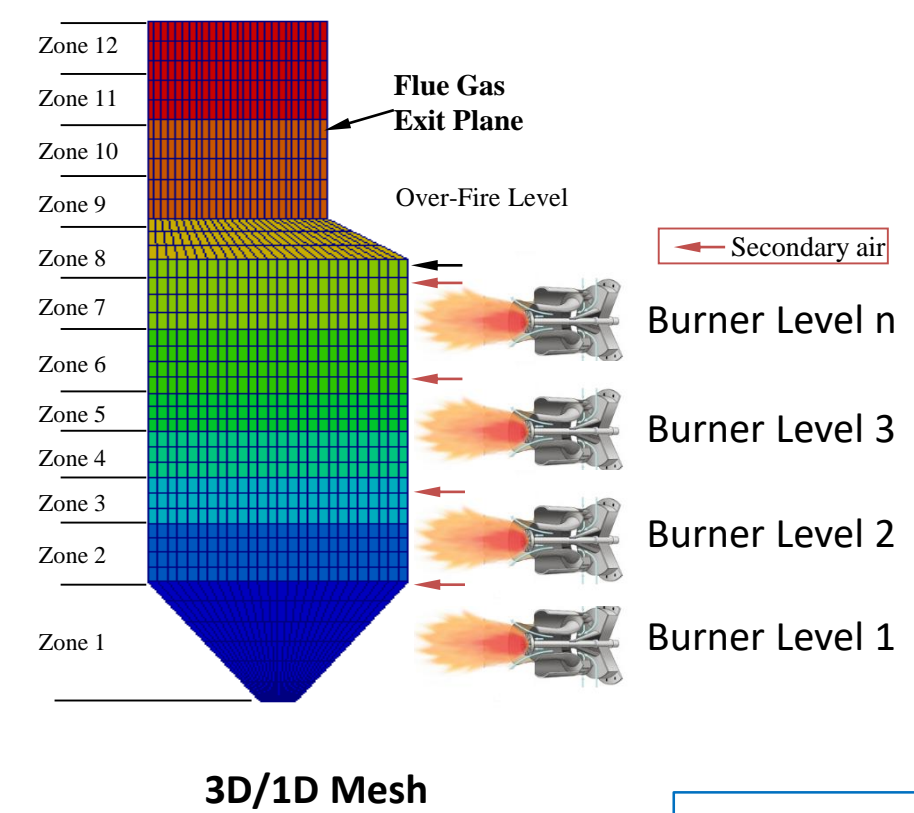
Overview of Fire-side Boiler Model



Fire Side: Highly Accurate Algebraic Surrogate Models

Inputs, Latin hypercube sampling

- Wall temperature (each zone)
 - 400 - 1100 K
- Fuel flow rate
 - 10 - 45 kg/s
- Stoichiometric ratio
 - 1.1-1.2 calc O₂/real O₂
 - Air splits calculated
 - Primary Air
 - Secondary Air
 - Over-Fire Air
- Secondary air temperature
 - 550 - 650 K
- Burners operation
 - Full load (i.e. n burners)
 - Mid load (i.e. 3 burners)
 - Low load (i.e. 2 burners)



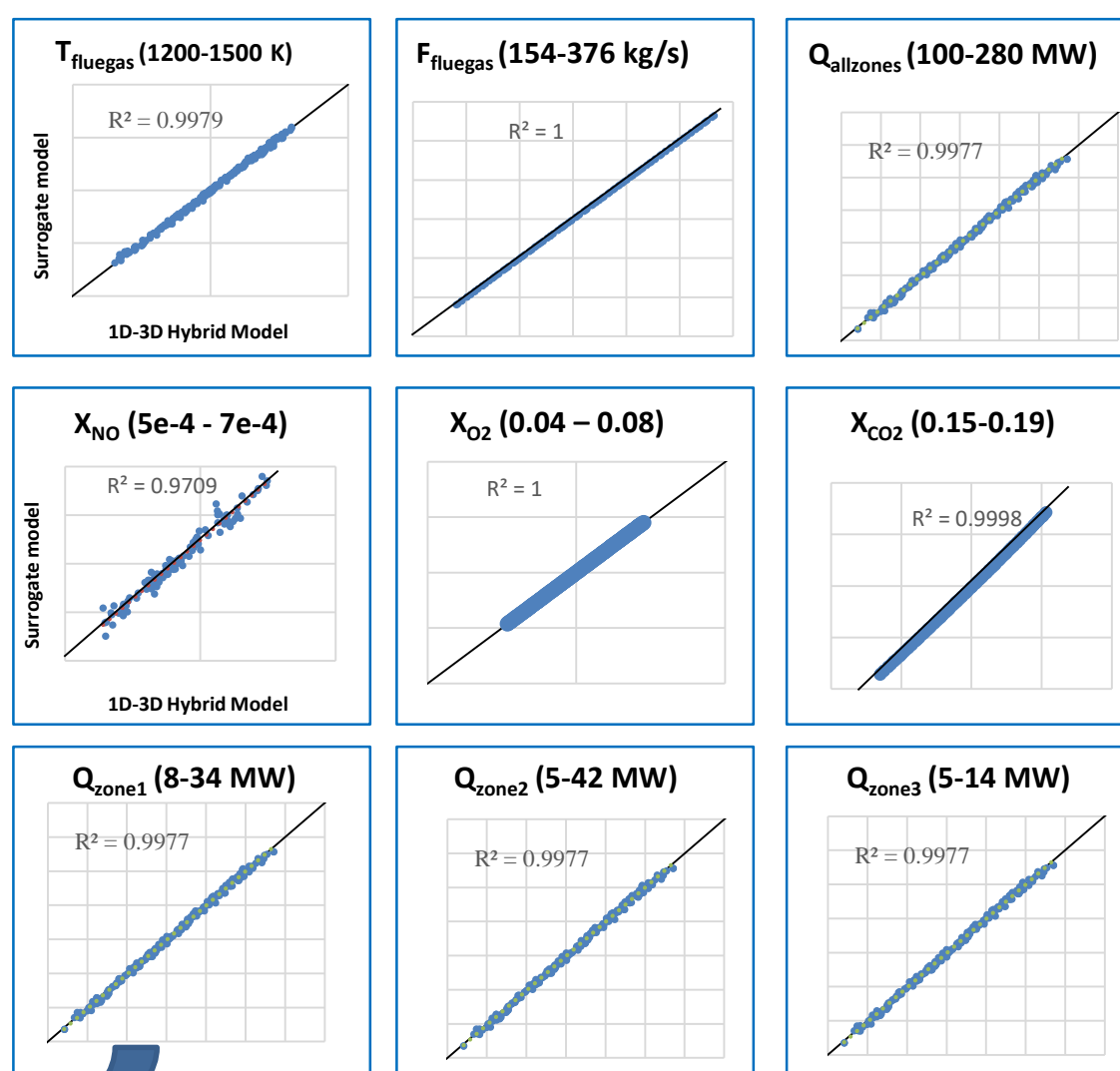
Outputs

- Heat transfer rate (each zone)
- Flue gas composition
 - X_{CO2}
 - X_{H2O}
 - X_{O2}
 - X_{NOx}
 - X_{SOx}
- Flue gas exit temperature
- Unburned carbon

Surrogate model example:

$$q_1 = \alpha_1 F_F + \alpha_2 2ndAirT - \alpha_3 T_{W1} + \alpha_4 T_{W2} + \alpha_5 T_{W7} + \alpha_6 T_{W7} + \log(2ndAirT) - \log(F_F)$$

Outputs



Boiler Model: Integration Fire Side and Water Wall

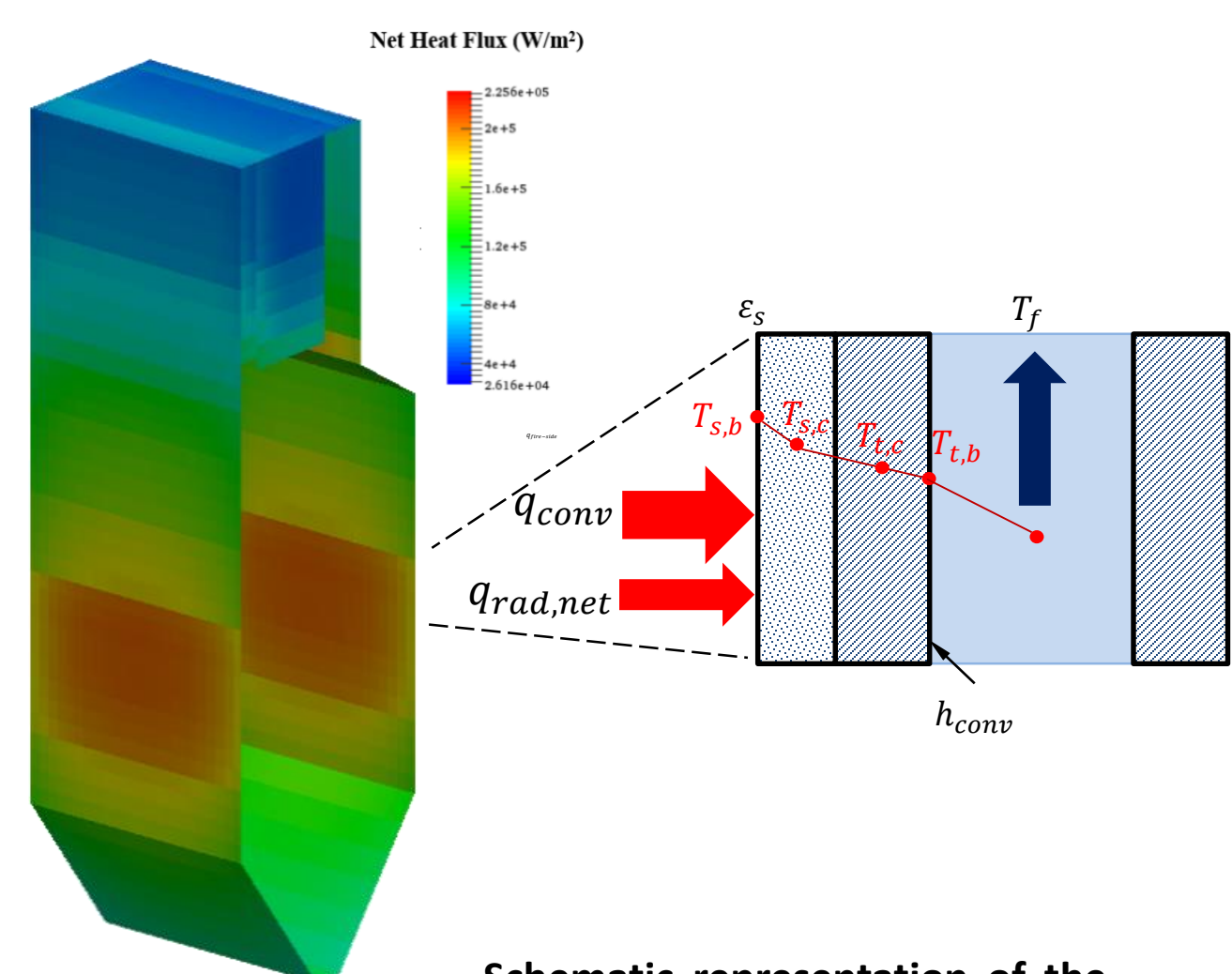
Fire Side:

Inputs:

- Furnace geometry
- Fuel properties, PSD
- Fuel/Air flow rates
- Wall Temperatures

Outputs:

- Heat transfer rates
- Flue Gas:
 - Flow rate
 - Temperature
 - Mole fractions (NO_x)
 - Unburned carbon



Schematic representation of the integration of the fire side 1D/3D model and Water side model

Water Side:

Inputs:

- Tube Geometry (i.e. tube diameter)
- Inlet water/steam
 - Flow rate
 - P, h (or T, x)

Outputs:

- Slag wall temperature
- Outlet water/steam
 - Flow rate
 - P, h (or, T, x)

Tube Side Model:

$$Q + Fh_{in} = Fh_{out}$$

$$Q = \frac{A(T_{s,b} - T_f)}{\frac{1}{h_{conv}} + \frac{1}{h_{tube}} + \frac{1}{h_{slag}}}$$

$$h_{conv} = Eh_l + Sh_{pool} \text{ (two phase flow)}$$

$$h_l \text{ Liquid only heat transfer coef.}$$

$$h_{pool}: \text{Pool boiler heat transfer coef.}$$

$$h_{tube} = \frac{C_{shape,tube} k_{tube}}{\delta_{tube}}$$

$$h_{slag} = \frac{C_{shape,slag} k_{slag}}{\delta_{slag}}$$

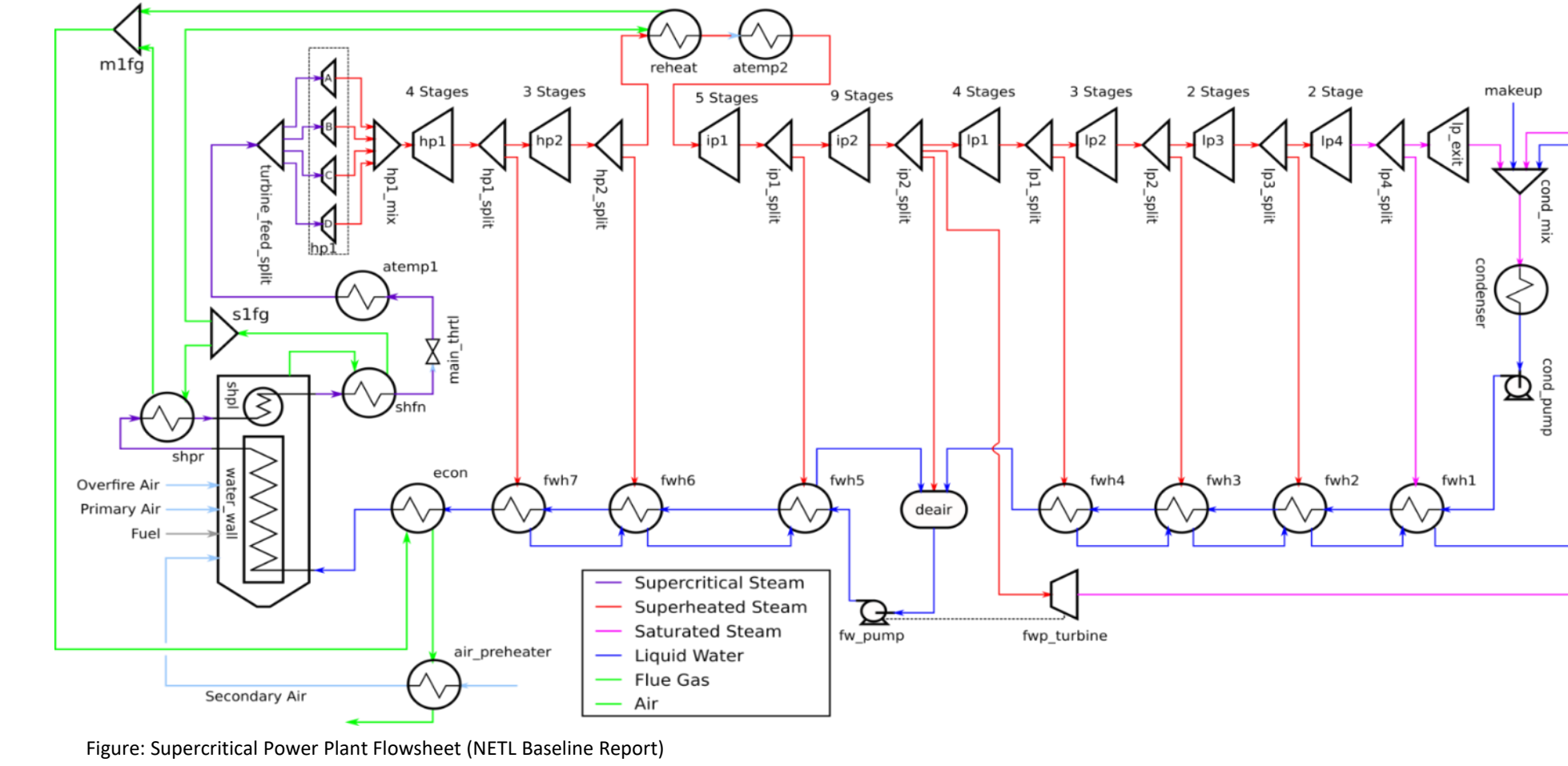
Steam quality in boiler zones at various operations:

| Zone | Vapor Fraction | | |
|------|----------------|--------|-----------|
| | Low Load | Medium | High Load |
| 12 | 0.056 | 0.058 | 0.065 |
| 11 | 0.052 | 0.053 | 0.060 |
| 10 | 0.045 | 0.047 | 0.053 |
| 9 | 0.034 | 0.035 | 0.040 |
| 8 | 0.019 | 0.020 | 0.023 |
| 7 | 0.016 | 0.016 | 0.019 |
| 6 | 0.012 | 0.012 | 0.014 |
| 5 | 0.007 | 0.007 | 0.009 |
| 4 | 0.002 | 0.002 | 0.004 |
| 3 | 0.000 | 0.000 | 0.000 |
| 2 | 0.000 | 0.000 | 0.000 |
| 1 | 0.000 | 0.000 | 0.000 |

Modeling and Optimization of the Existing Fleet

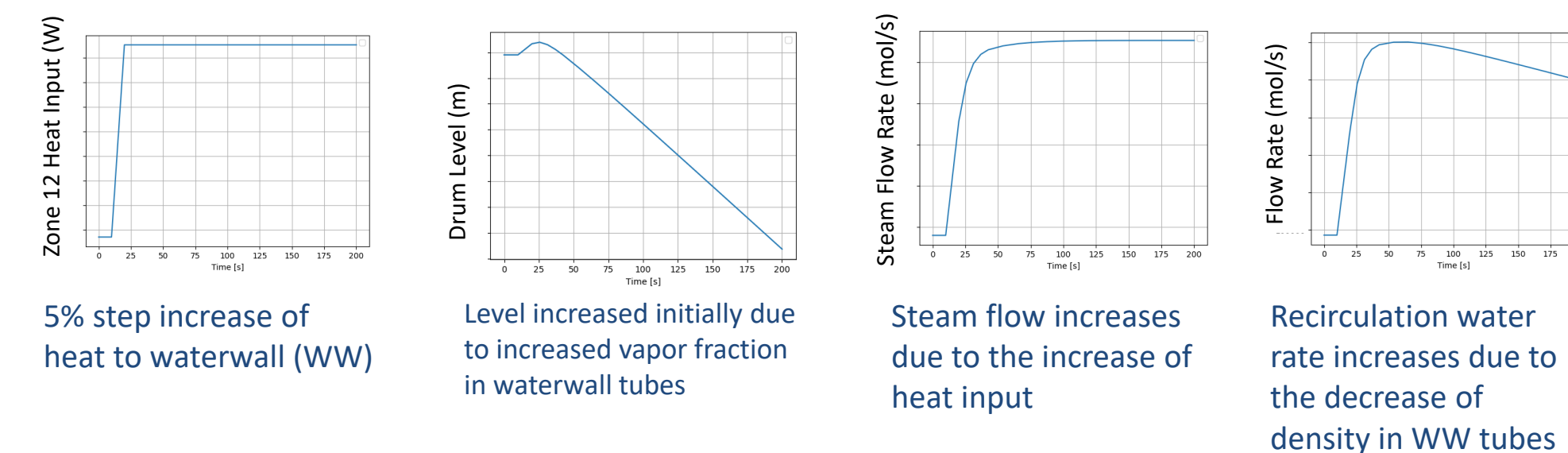
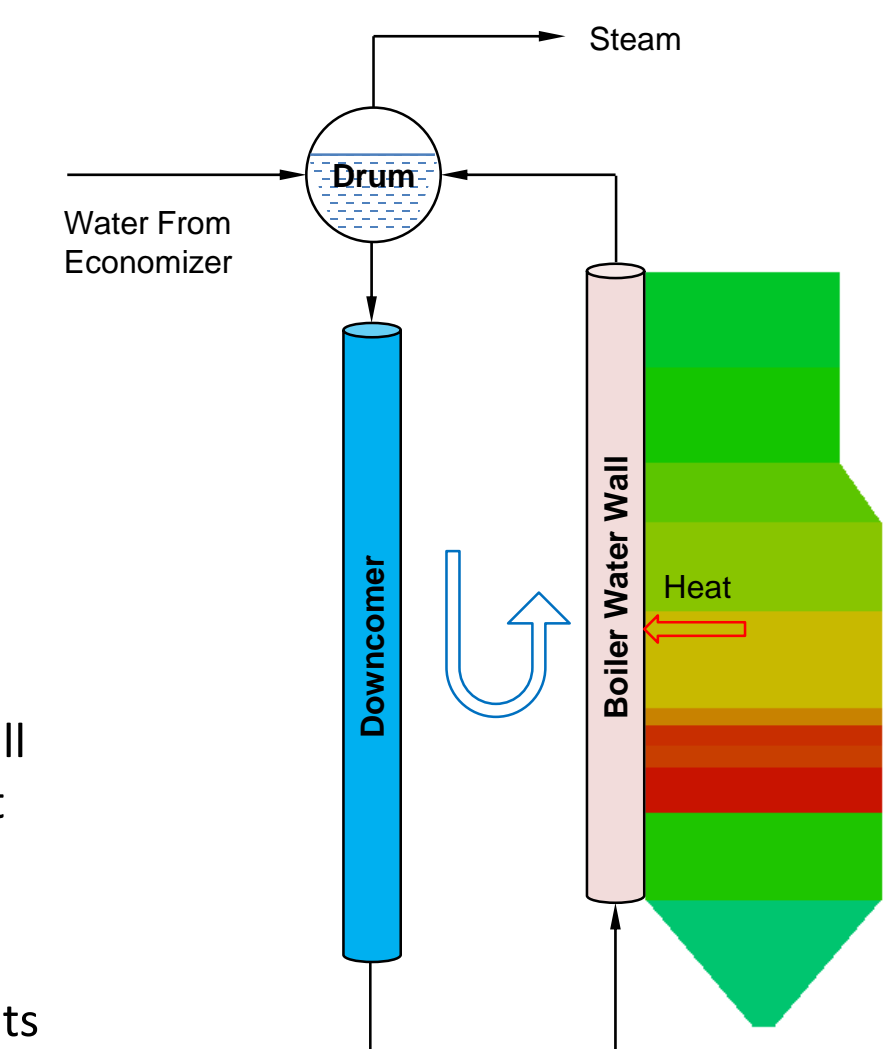
General Power Plant Modeling Library:

- Hybrid Boiler Model (integration of fire and water side)
 - Customizable (coal type, furnace geometry, and materials)
 - Reliable predictions of unburned carbon, Sox, NOx, excess O₂
- Customized heat exchanger model
 - Co-current, counter-current, cross-flow
 - Rigorous heat transfer correlations:
 - Convective heat transfer (single phase or two phase)
 - Ash layer and tube thickness (wall conduction model)
- Rigorous turbine model
 - Customizable (turbine type, materials, # stages, extraction points)
 - Efficiency penalties for off-design conditions



Dynamic Modeling and Optimization

- Fixed Inputs:
 - Drum pressure
 - Feed water flow
 - Feed water state (p, T, h)
- Initial Condition:
 - Steady-state
 - Drum level at 0.89 m from bottom
- Step Change:
 - Heat from fireside to waterwall increased by 5% in all zones at 20 sec
- Duration:
 - 200 sec, 20 discretization points



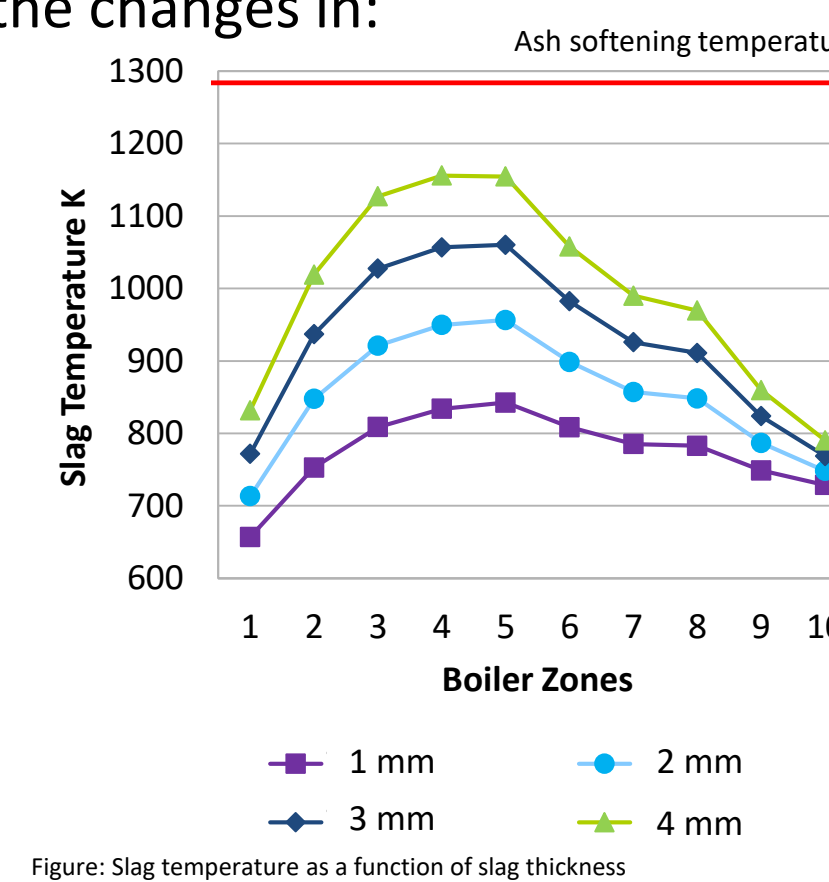
Sensitivity Study: Slag Layer Thickness

The models were used to simulate different cases (slag thickness from 1 to 4 mm) to quantify the changes in:

- Heat transfer coefficients
- Wall temperature
- Slag temperature
- Heat transfer
- Flue gas outlet temperature

Remarks: the slag layer can reach very high temperatures; need to:

- Prevent liquid ash formation
- Avoid ash accumulation in the superheater and reheater

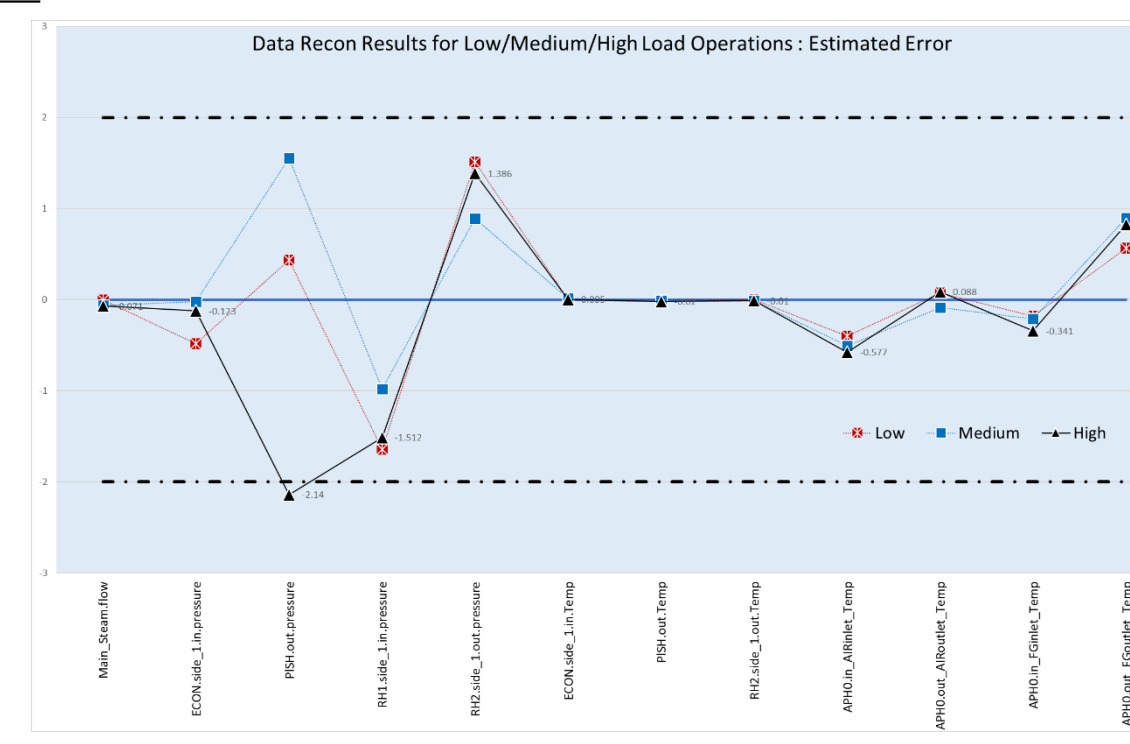


Data Reconciliation Framework

$$\text{Minimize } \sum_{\text{data}} (error_{meas})^2$$

subject to

- Flowsheet connectivity
- Mass and energy balances
- Physical property calculations



IDAES Supports:

- Advanced modeling and machine learning techniques for multi-scale energy systems
- Integration of high fidelity models and surrogate models (i.e. boiler fire side and water wall model)
- Advanced optimization tools for optimal operation of subcritical and supercritical coal-fired power plants.
 - Steady State and Dynamic Optimization
 - Data Reconciliation Framework
 - Parameter Estimation Framework
- Rigorous glass box models can be leveraged to incorporate health models and analyze the impact of cycling in coal-fired power plant operations.

Contact

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