Geothermal Operational Optimization with Machine Learning

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Geothermal Operational Optimization with Machine Learning

NREL Transforming ENERGY

Upflow

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Tuwharetoa mai Kawerau ki te Tai

contact

ORMAT

FLOW STATE SOLUTIONS

Wairakei Steamfield

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How Engineers See it

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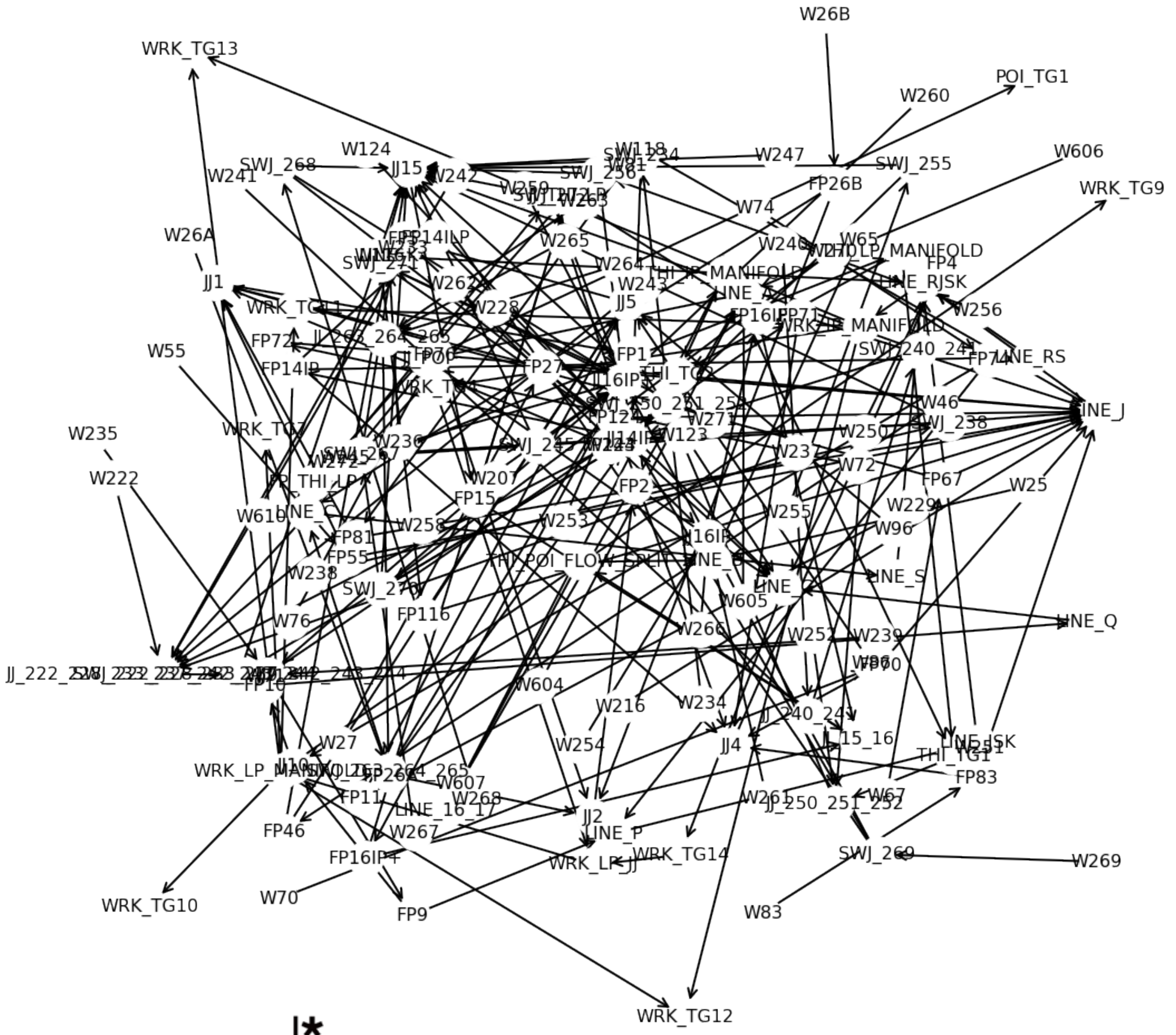
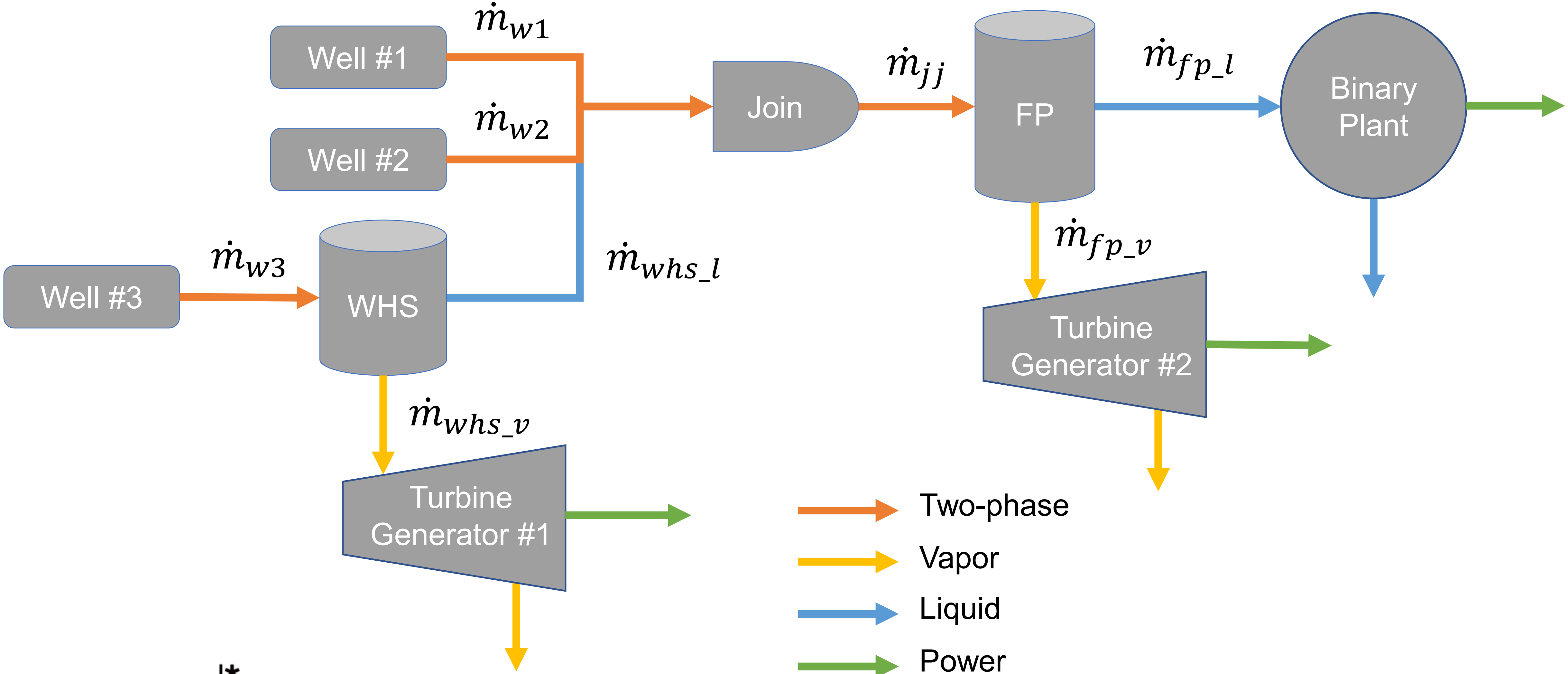
How Python Sees It



- 20+ component models
  - wells, turbines, weir boxes, join junctions, flash plants, wellhead separators, etc…
- 3 system frameworks
  - historical, forecast, and uncertainty
- 175 interconnected components in the Wairakei model:
  - 67 wells
  - 29 flash plants
  - 11 turbine-generators
  - 68 junctions / manifolds

Simplified System Network



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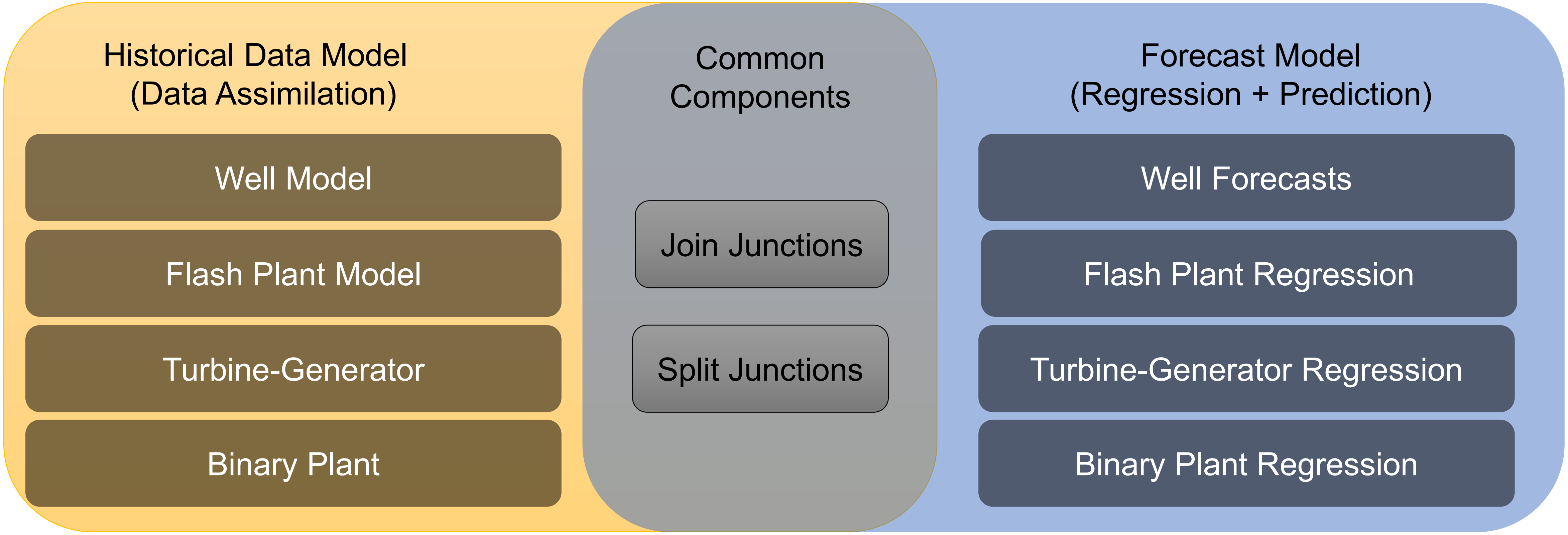
Model Development and Architecture

GOOML component models fall into two system frameworks:



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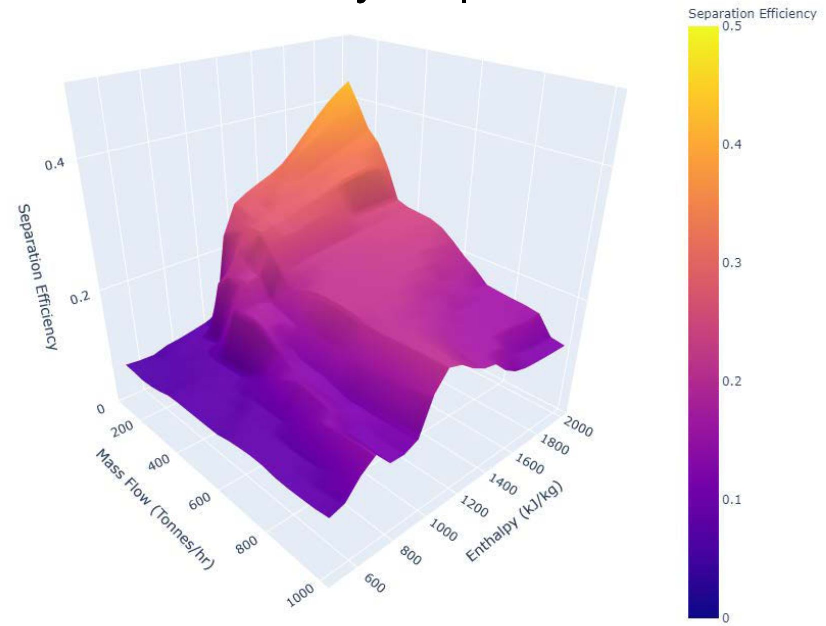
Flash Plant Modeling

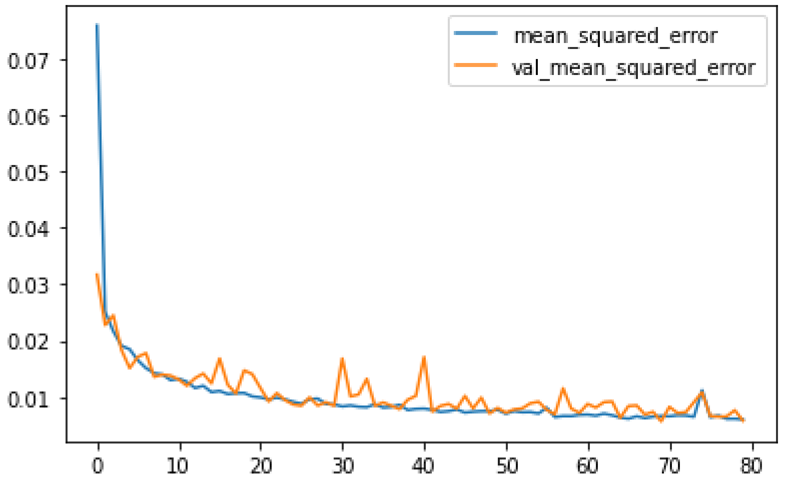
Flash Plant Modeling

- Based on a TensorFlow feed-forward neural network
- Physics-informed features using “traditional” semi-empiric relations:
  - Pressure drop
  - Residence time
  - Cyclone design number
  - Theoretical flash fraction
  - etc…

Saliency Map



Training Loss



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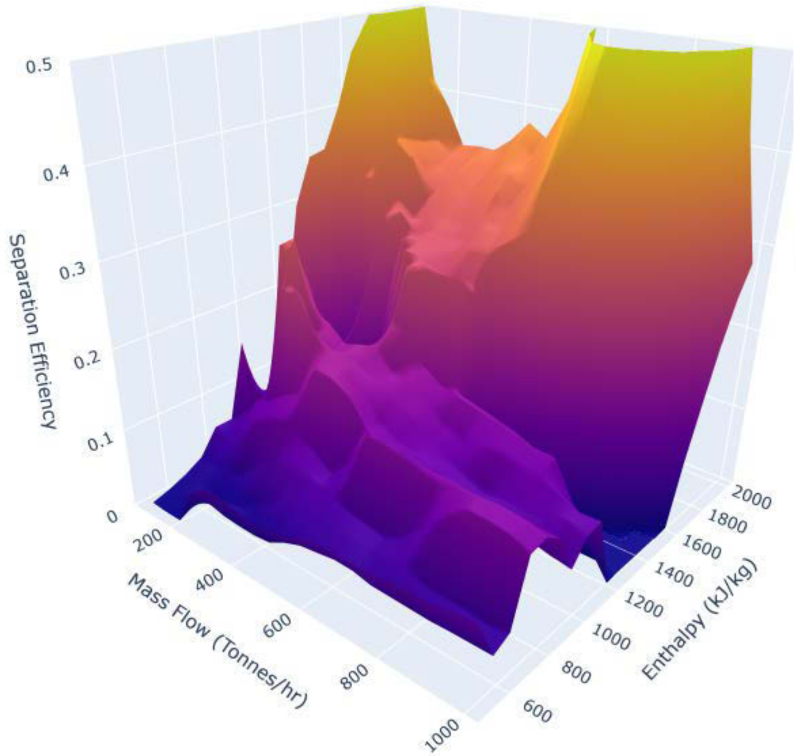
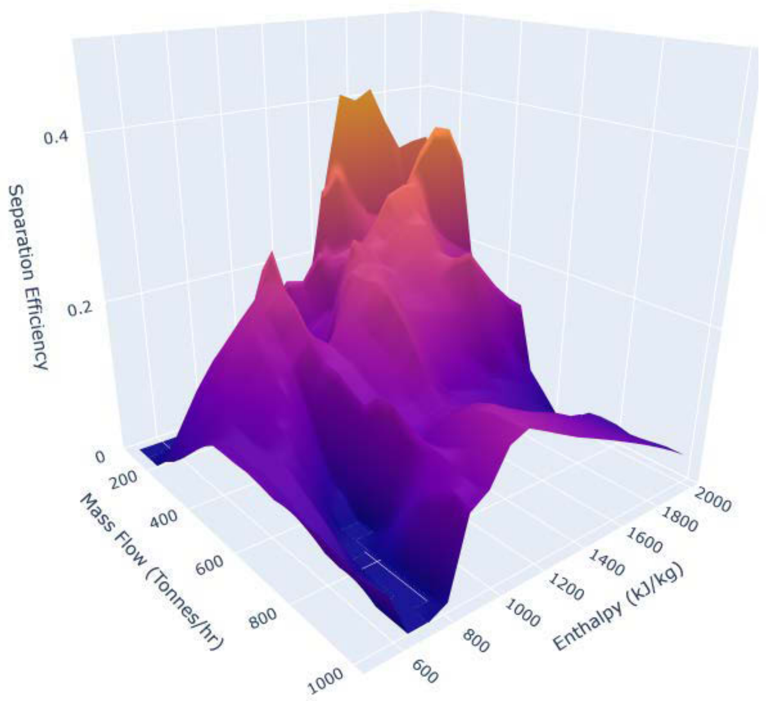
Flash Plant Modeling

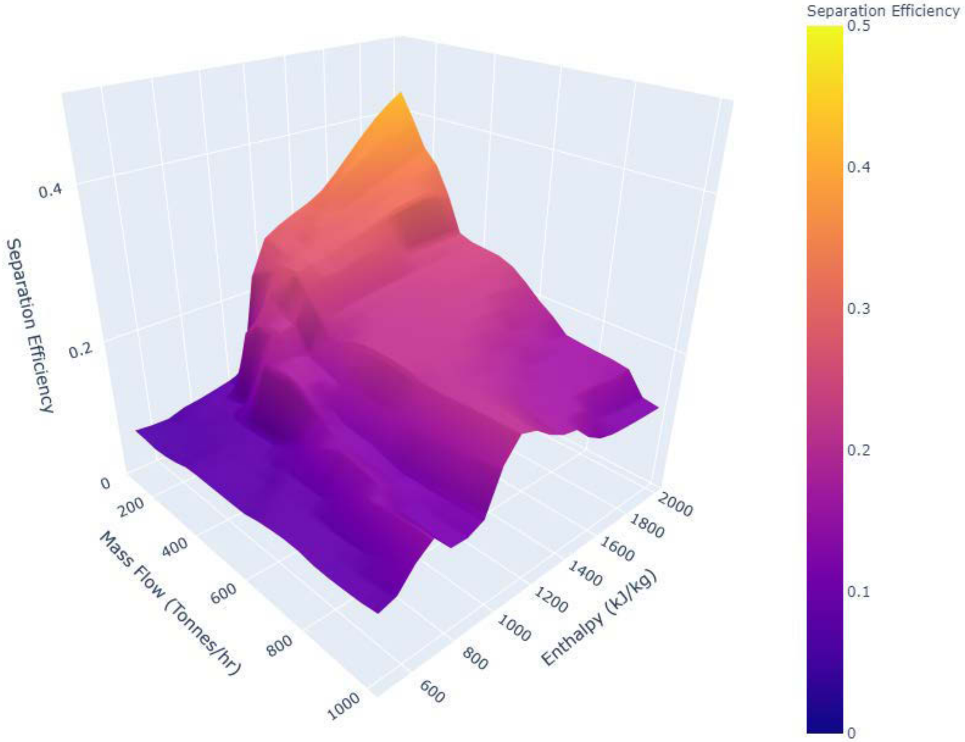
- Saliency maps show how the model architecture affects overfitting



5 Layers x 128 Nodes x 0.0 Dropout



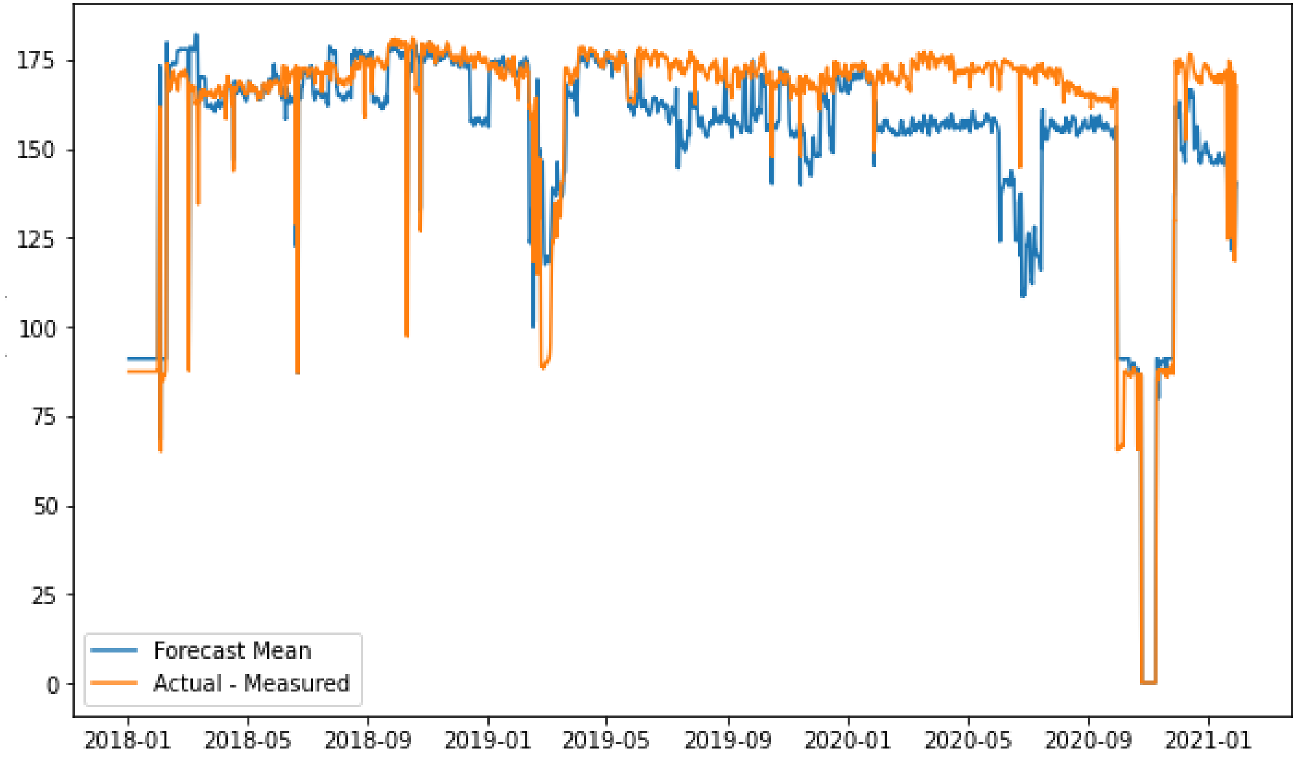
3 Layers x 64 Nodes x 0.0 Dropout



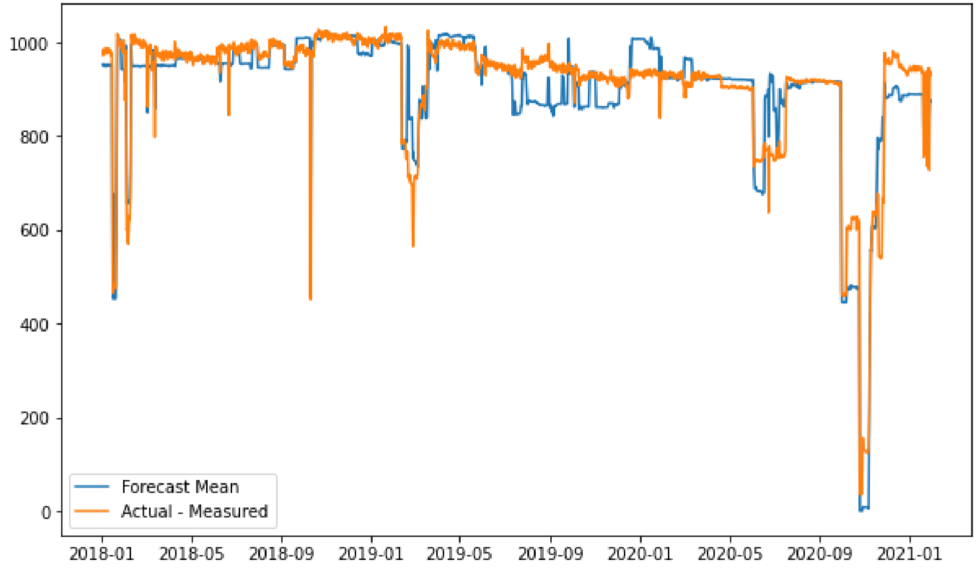
3 Layers x 128 Nodes x 0.5 Dropout

Hindcast Validation

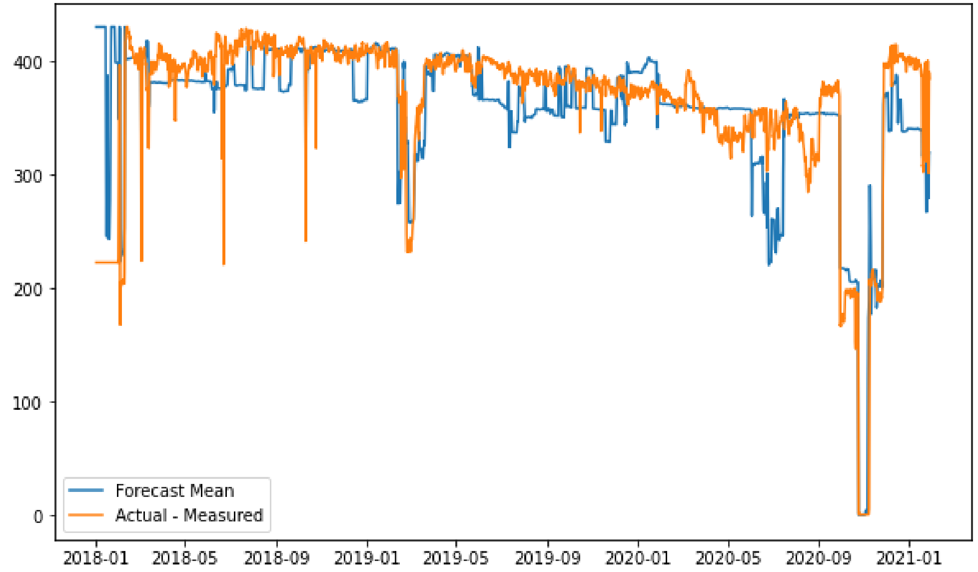
Power Generation



Intermediate-Pressure Steam



Low-Pressure Steam



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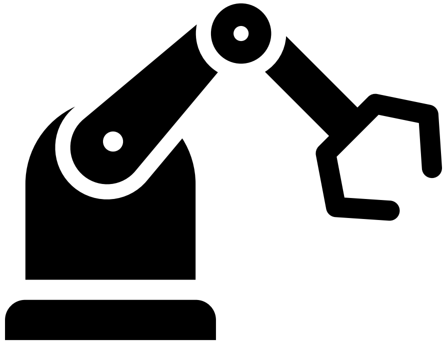
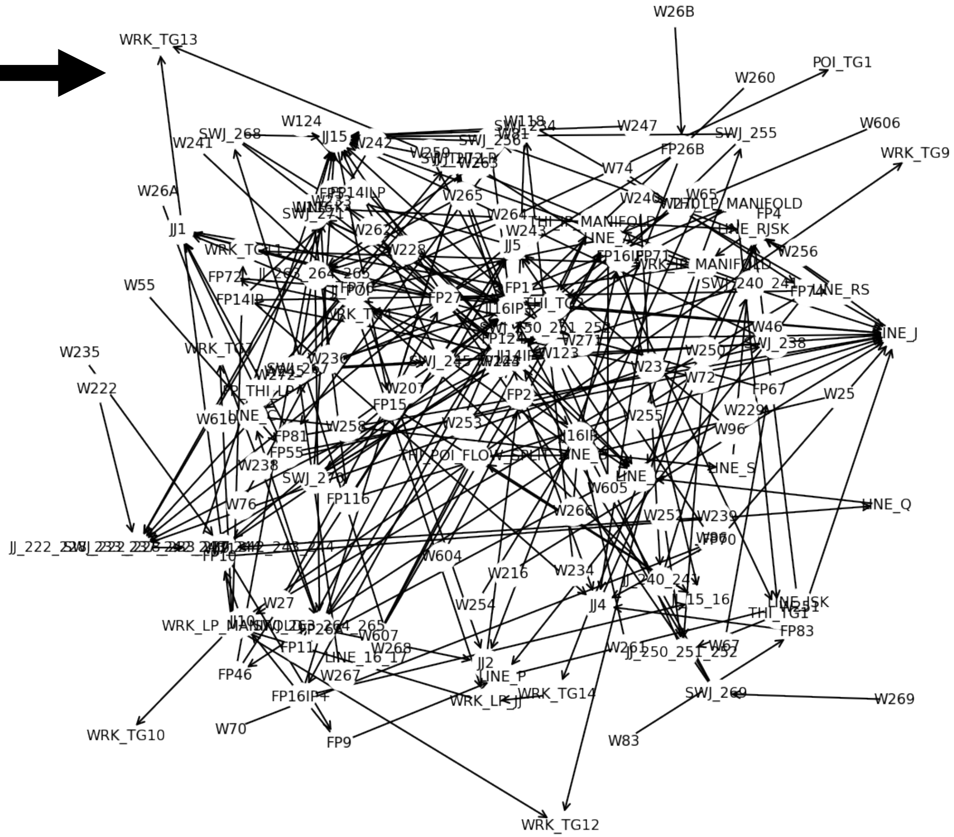
System-Level Reinforcement Learning

GOOML Environment

Action

Agent(s)





Reward +
Observation

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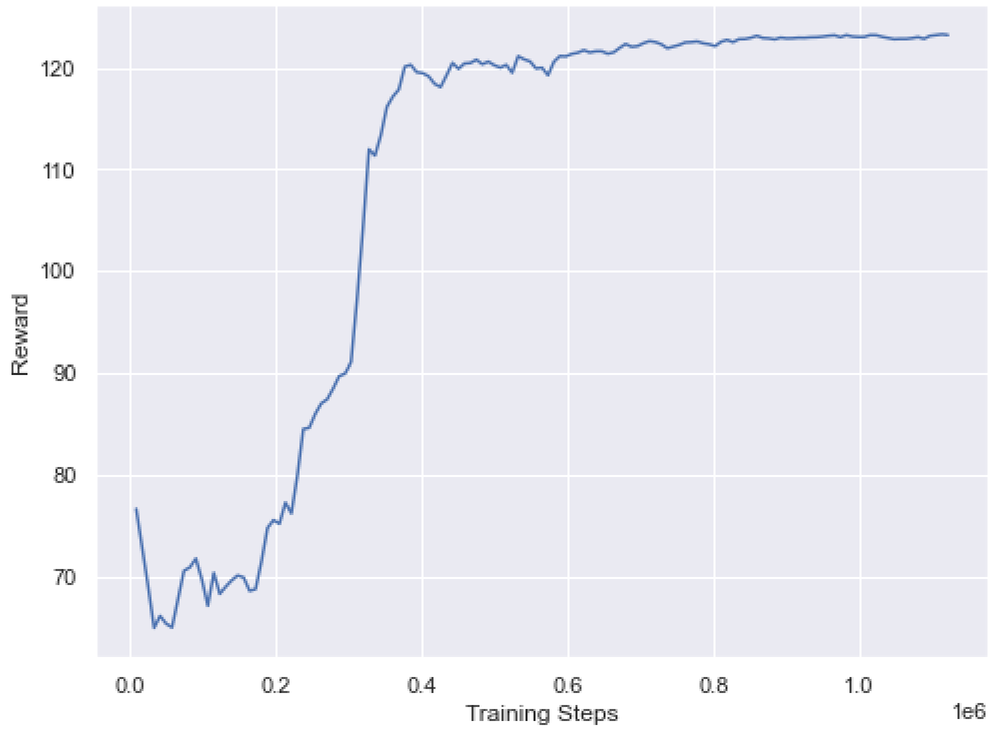
Reinforcement Learning Experiment

- Agent Controls:
  - IP Pressure (+/- 2 bar)
  - LP Pressure (+/- 1 bar)
  - Control Well Pressure (+/- 2 bar)
- Reward:
  - Based on power
  - Relative to the “baseline” scenario
- Results:
  - Added 20 MWe* to the system!
    - *could be pushing the environment to un-acceptable operating conditions.



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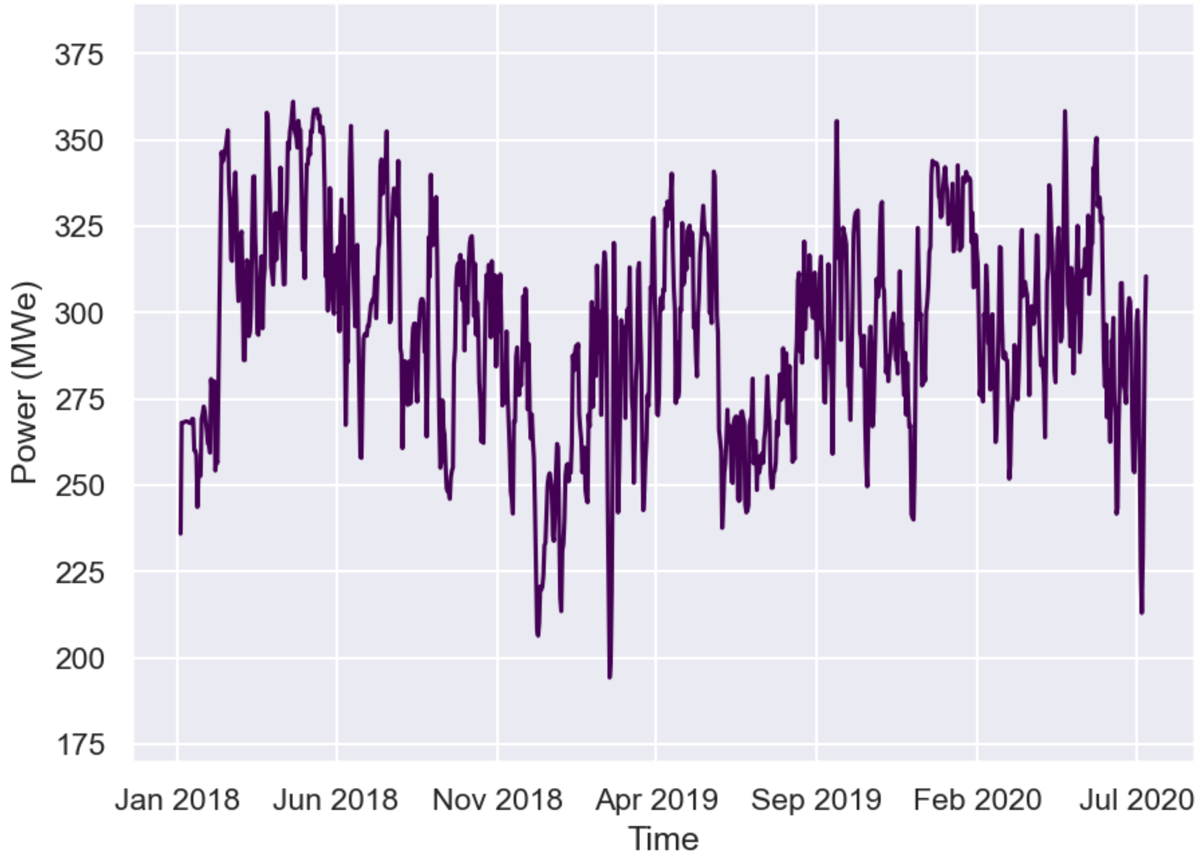
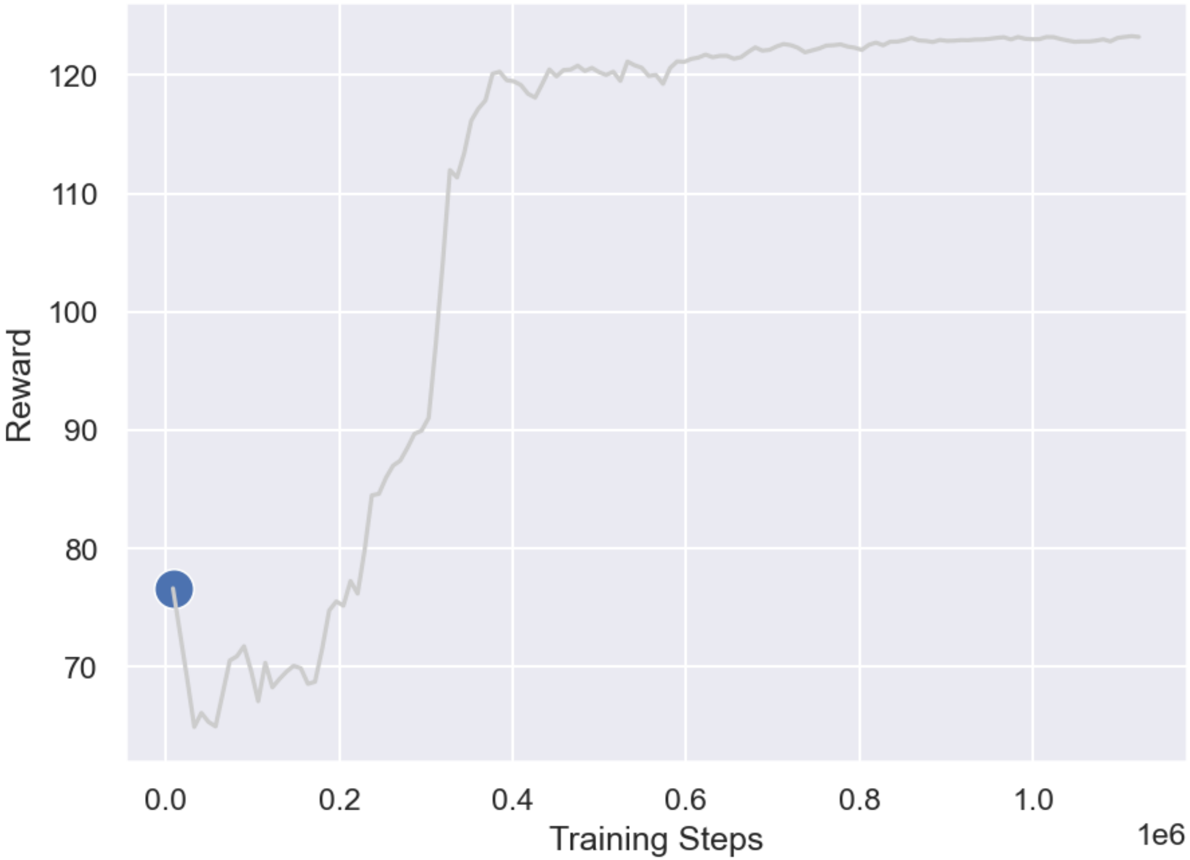
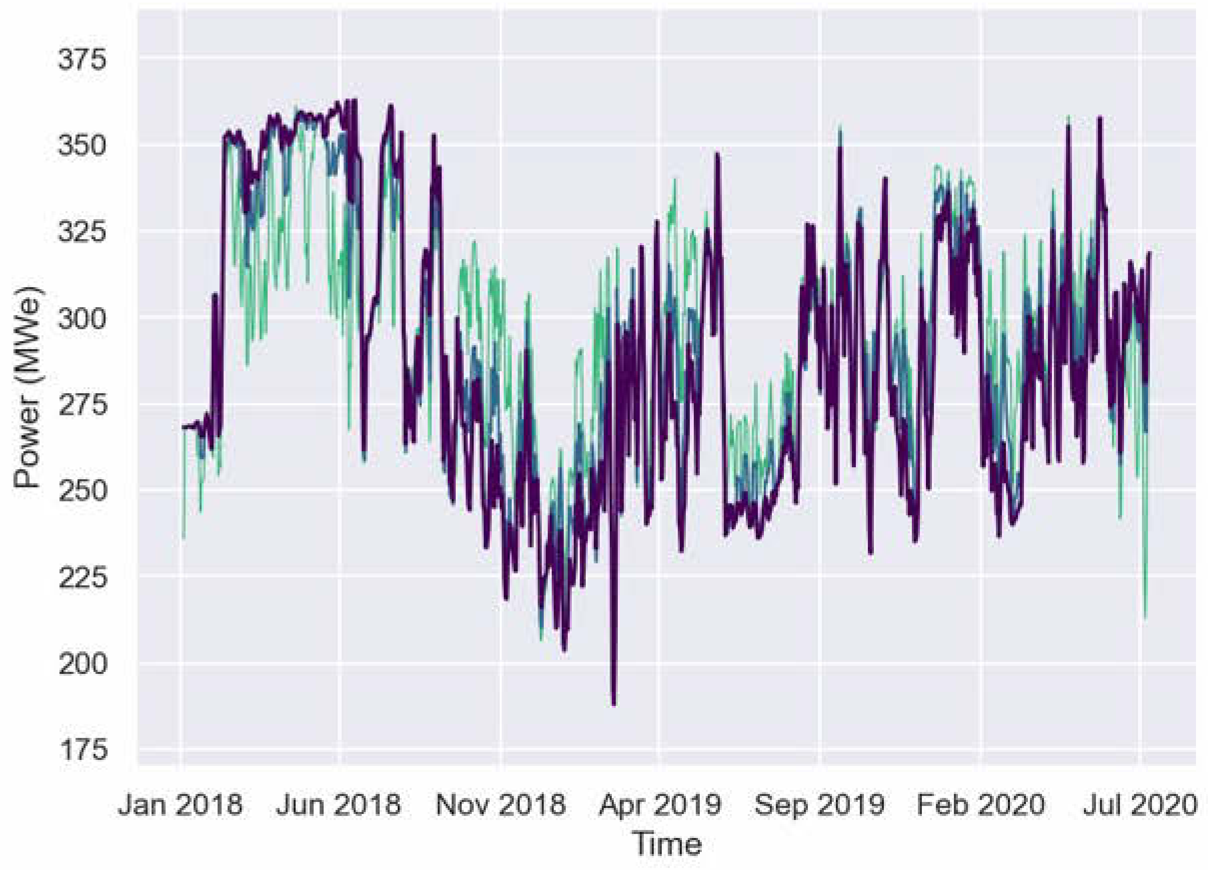
Reinforcement Learning Experiment

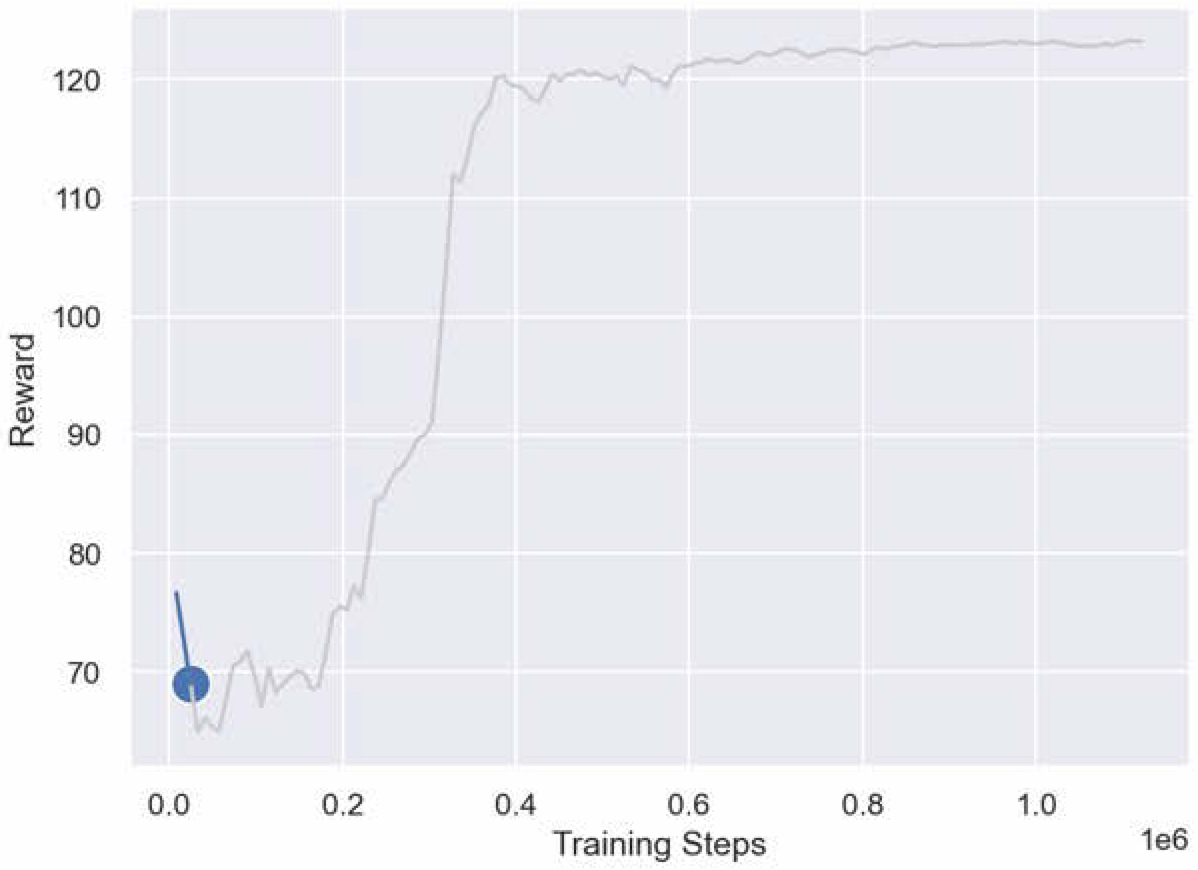




https://app.box.com/s/mpnffv3uwwqsn1g2tbf7di800e0eci83

Reinforcement Learning Experiment





High Level Conclusions *

The GOOML framework is a powerful tool for geothermal analysis

- Forecasts:
  - The GOOML system can forecast future operational scenarios
- Operations:
  - Reinforcement learning agents can act as operation suggestion engines

Looking Forward

- Additional research:
  - Steamfield design optimization
  - Reinforcement learning validation

- Additional steam field models:
  - NTGA Kawerau (model built, being validated)
  - ORMAT McGinness Hills (model built, being validated)

- Open-source software
  - Coming soon!


Good
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to you all!
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