

Eavor-Lite Update After Four Years of Operation

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ABSTRACT

Eavor-Lite™ is a full-scale demonstration project of a multilateral closed-loop geothermal system which has been in operation since 2019. The project is located near Sylvan Lake, Alberta, Canada and consists of two 1.7 km long multilateral horizontal wellbores connecting two 2.4 km deep vertical wellbores to create a U-tube shaped closed-loop geothermal system. The horizontal wellbores are intersected using magnetic ranging technology, and sealed with a chemical completion technique, resulting in a large subsurface heat exchanger. This paper includes updates on:

- Operation of the closed loop system
- Predicted and actual thermodynamic performance.
- Ongoing leak off monitoring and modelling.
- A dispatchability trial and automated load following algorithm implemented in 2023.

A transient thermodynamic model is trained using early production history and forecast is compared against actual performance demonstrating the predictability of conduction-based geothermal systems.

Projects in various stages of development which were enabled by Eavor-Lite™ will be briefly described along with some of the lessons learned during the operation of the pilot.

1. Introduction and Project Background

Eavor-Lite™ was constructed in Alberta, Canada in 2019. Eavor-Lite™ serves as a demonstration/pilot project to show various aspects of Eavor's Closed Loop technology (Eavor-Loop™) and serves as a platform for ongoing research and development.

Eavor-Lite™ is a full-scale prototype of the Eavor-Loop™, consisting of large U-tube shaped well with 2 multilaterals. The laterals are approximately 1700m long and are placed in the Rock Creek formation at depth of 2400m. See Figure 1.

Full extent of the project’s scope and goals is covered in great detail by Toews et al., 2020 and 2021.

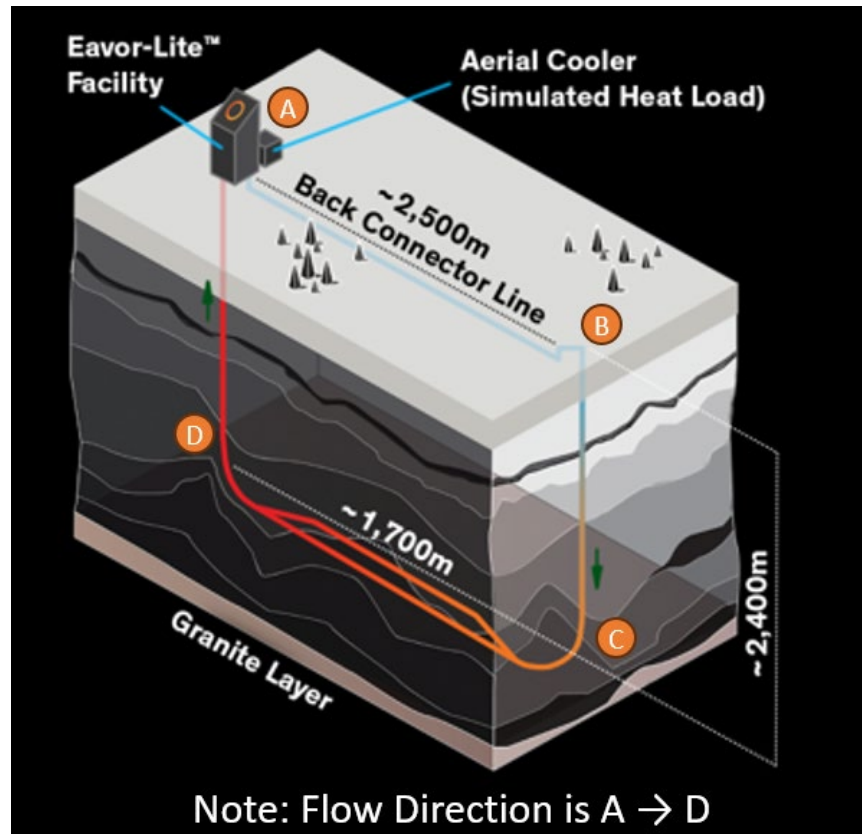


Figure 1: Schematic of Eavor-Lite™ Pilot

2. Summary of prior publications

Eavor has presented at multiple conferences and published many papers demonstrating various aspects of the Eavor-Lite™ Project.

Project scope, goals, timelines and execution are addressed in the Case Study of Multilateral Closed-Loop Geothermal System paper by M. Toews, et al., 2020, while a paper by Jeanine Vany, 2020, goes to great depths to cover geological setting of the project, including thermal conductivity modelling and geomechanics.

A one year update on the project, including thermodynamic modelling is described in the “Eavor-Lite Performance Update and Extrapolation to Commercial Projects” by M. Toews, et al., 2021. While the work by M. Holmes, presented in “Analysis: Multilateral Closed-Loop Geothermal Systems as a Zero Emission Load-Following Resource” (2021) served as a basis for the dispatchability and load following algorithm which is covered in the later section.

3. Eavor-Lite operations

Since start-up, Eavor-Lite™ has produced close to 20 GWhth. The original temperature of the formation at TVD of 2400m was 78°C. After 4 years of operation, the outlet temperature is stable at ~ 50°C (at a production rate of 20m³/hr).

The project also serves as a testbed for Eavor's Research and Development. Since the start of operations, many trials have been run at site to progress Eavor's R&D and system understanding. Most notable trials include:

- Rock Pipe sealant augmentation – to show that Eavor's chemical sealant (Rock Pipe), which enables open hole completion of the multilateral section, can be reapplied after start-up and develop procedure for seal reapplication.
- Flow rate and operating pressure trials – test system behavior and predictability with models.
- Shut-in trial – to illustrate system recharge and black start capability.
- Fluid composition trials – test the effect of pH and viscosity on leak off.
- Downhole camera inspection – inspecting wellbore condition, multilaterals and intersection point using a camera run on coil tubing.

3.1 Thermosiphon

One of the unique features of the Eavor-Loop™ is that the system can operate without a pump, up to a certain flow rate – called the thermosiphon limit. Flow rates above thermosiphon limit require the input of a pump.

At Eavor-Lite™, the pump was only utilized for start-up and for various tests which require flow rate above thermosiphon limit. The total run time on the pump since start up is only 738 hours (compared to >30,000 hours of total system operation). For commercial projects, where trials and tests are limited, pumps will only be utilized for the initial start-up. Restarting Eavor-Loops™ after shut-ins do not require a pump, as the heel of the well (ex. Point C on the Figure 1.) has experienced larger degree of thermal draw vs. the toe of the well (ex. Point D on the Figure 1.), making the system black start capable. (Even after prolonged shut down, due to the thermal drawdown, there will be a temperature contrast between the inlet and outlet parts of the well).

3.2 Leak-off

Multilaterals in the Eavor-Loop™ are uncased. The last stage of completions operations before the wells are turned on is to apply the Rock-Pipe, which reduces the near wellbore permeability of the formation by several orders of magnitude.

Since Eavor-Loops™ are operated above formation pressure, application of Rock-Pipe is a necessary step to reduce the leak off into the formation. The original in-situ permeability of the Rock Creek formation, where Eavor-Lite's laterals were placed, is estimated 0.5-50mD (500 – 50,000 µD). Post Rock-Pipe application, the average permeability was reduced to 0.15-0.25µD, a reduction of 3-5 orders of magnitude.

Current leak-off rate is ~0.4m³/d compared to a throughput of ~480 m³/d, indicating the system is 99.9% sealed. This leak-off rate is reducing slowly with time. Leak off can be predicted by a steady

state – radial flow model, see Figure 2. (Note: the forecasted leak-off in Figure 2, uses constant operating conditions - constant dP, and working fluid viscosity).

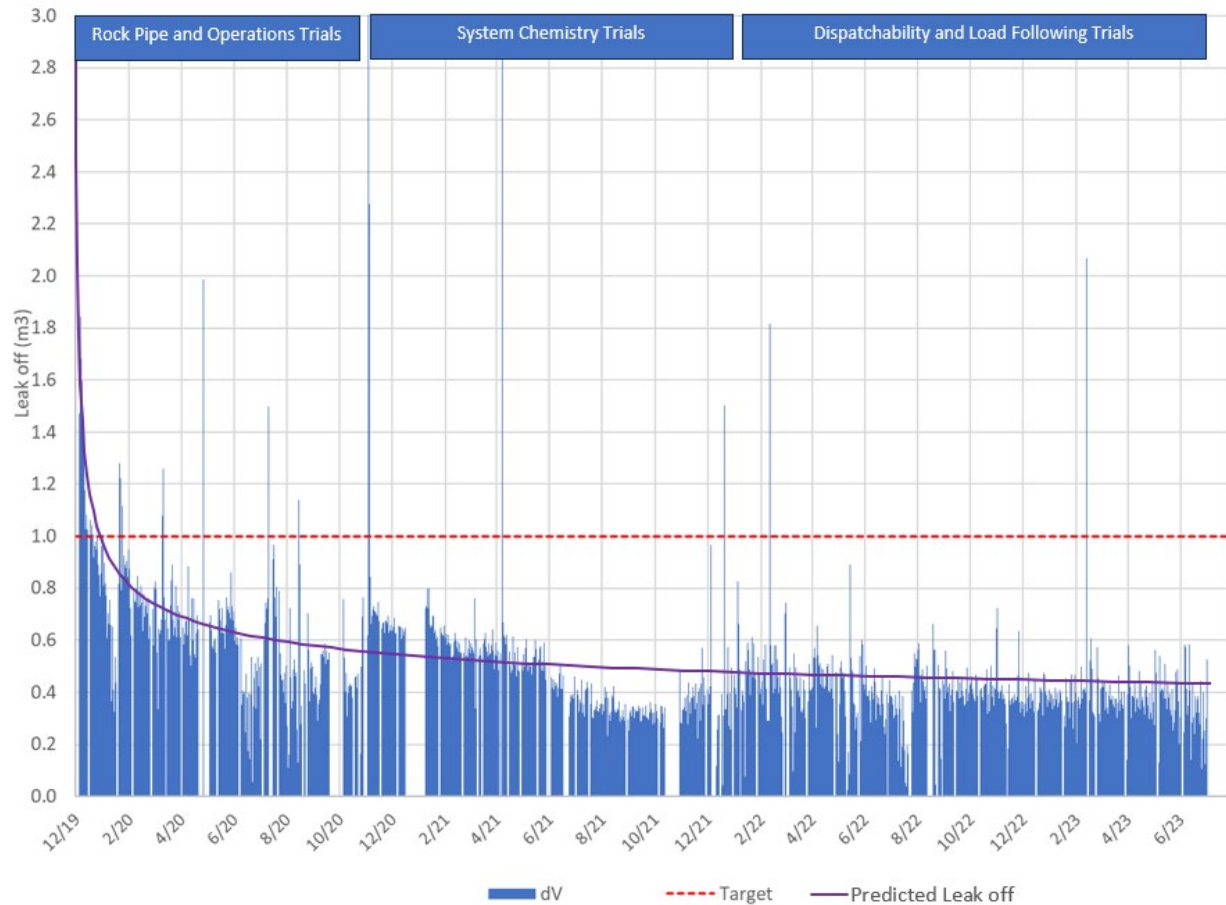


Figure 2: Historical leak-off vs. forecasted leak-off

3.3 History matching and production forecasting

The initial history match was trained on the first 60 days of data, optimizing for a series of variables which had some uncertainty (ex. formation thermal conductivity). After the initial training, data from a hold-out set was used to ensure the match was accurate.

Following the initial training of the model, there were periods where the working fluid was changed substantially (SG, viscosity, pH) for research purposes, which caused a minor discrepancy either on the pressure or temperature matches. However, after the working fluid was stabilized (ex. day 700), the match of forecasted data vs. actual showed very little error on both temperature and pressure plots (Figures 3 and 4).

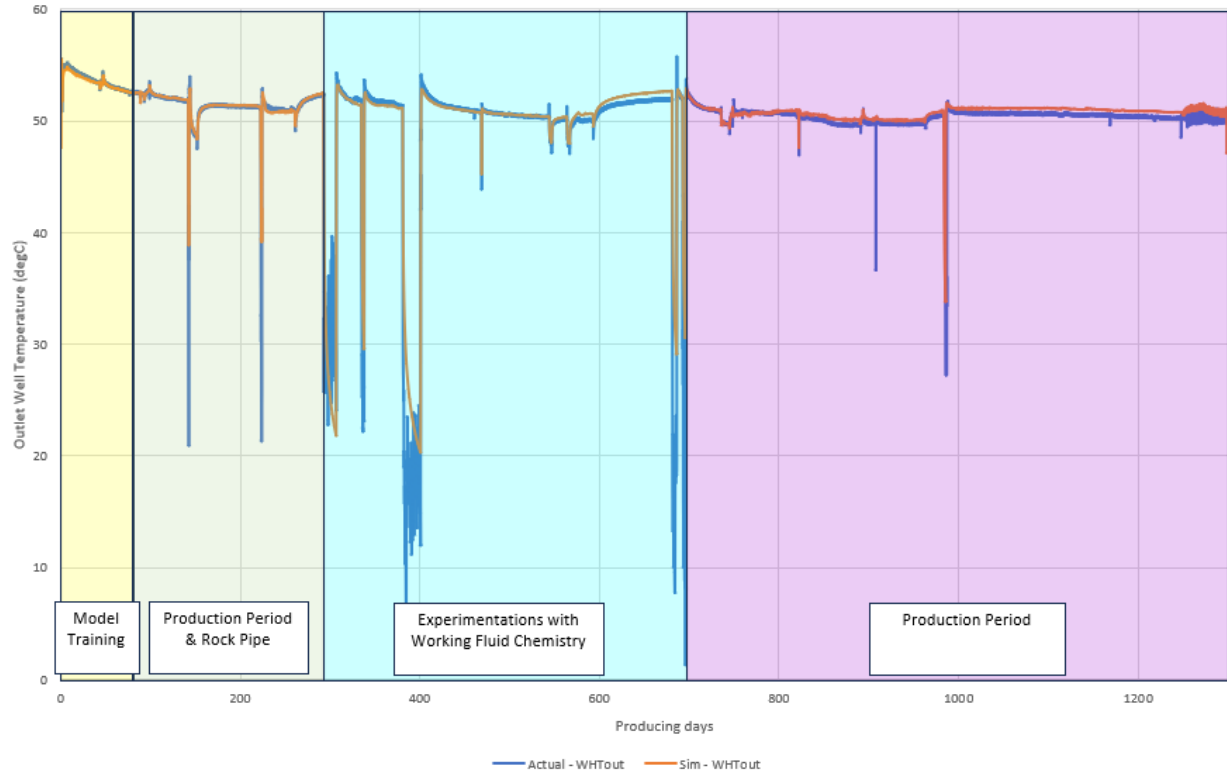


Figure 3: Forecasted vs. actual Outlet Well Temperature (°C)

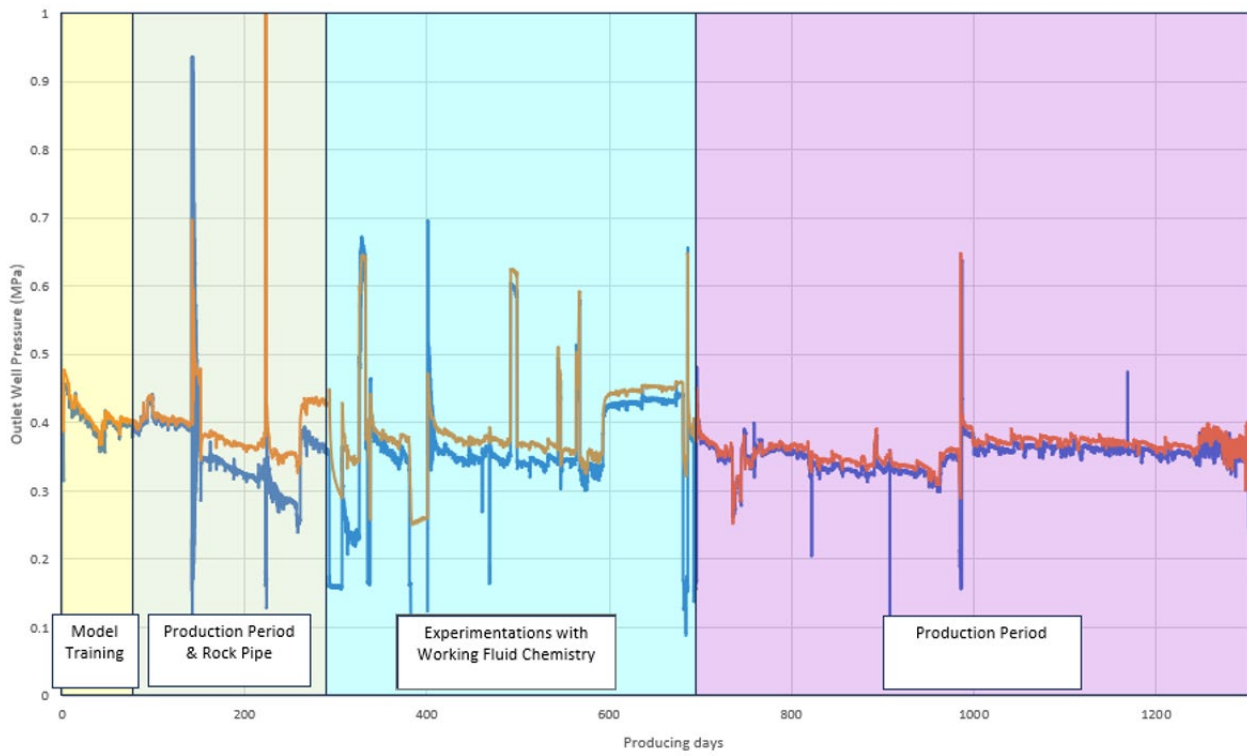


Figure 4: Forecasted vs. actual Outlet Well Pressure (MPa)

The current error between the forecast and actual data is $\sim 0.25^{\circ}\text{C}$ and can be attributed to the changes in working fluid properties due to the addition of corrosion inhibitor and biocides as well as small fluid losses due to leak off.

3.4 Eavor-Lite™ Uptime

Since start-up the system has shown exceptional uptime of 96.2%, including any downtime associated with system trials (such as dispatchability and thermal recovery trials, both of which required a system shutdown). Outside of those trials, system reliability is 99.6% with the only downtime attributed to a 3rd party power outage. As Eavor Lite does not produce any electricity (heat demonstration), power loss to site triggers a plant ESD for preservation purposes. Since commercial projects will produce electricity, PLC logic will be programmed that in the event of power/grid loss, Eavor Loop™ flow rate will be reduced to match plant's electrical load.

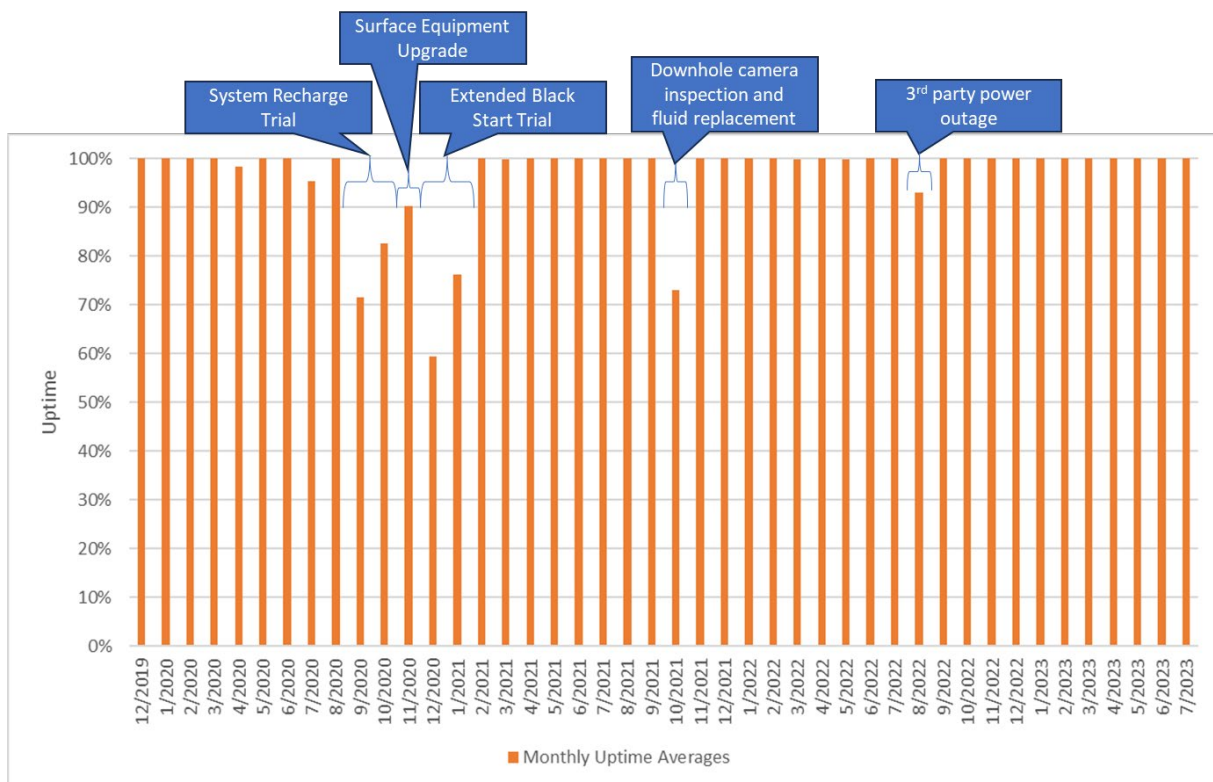


Figure 5: Eavor-Lite™ System Reliability

3.5 Load-following Algorithm

In a prior publication by Holmes (2021), the abilities of the Eavor-Loop™ technology as a zero emission load-following resource (ZELFR) was explored. As a load-following resource, the Eavor-Loop™ is capable of providing both baseload and dispatchable energy production to meet the fluctuating demands of a population over a 24 hour period. Holmes and co-authors show the value that a ZELFR can bring as the globe trends towards net-zero electricity grids by providing grid resilience and reducing overall system costs.

To take advantage of the Eavor-Loop's™ ability to provide dispatchable energy, and meet a grid's energy requirements, the operator must be able to

1. Anticipate future energy demands from the grid,
2. Account for the physical heat transfer and energy storage mechanisms unique to the closed-loop Eavor-Loop™ system, and
3. Convert this information into actions to be enacted by the surface facility to achieve the future energy demand.

To perform these tasks manually would be onerous and difficult, especially as one's interpretation of future energy demands changes with information that is constantly being updated.

To address these difficulties, Eavor has implemented a load-following algorithm at Eavor-Lite™ to automate the three key steps outlined above to automatically produce a dispatchable energy curve.

The algorithm is split into two separate models (orange nodes), and their functions are summarized in the figure below:

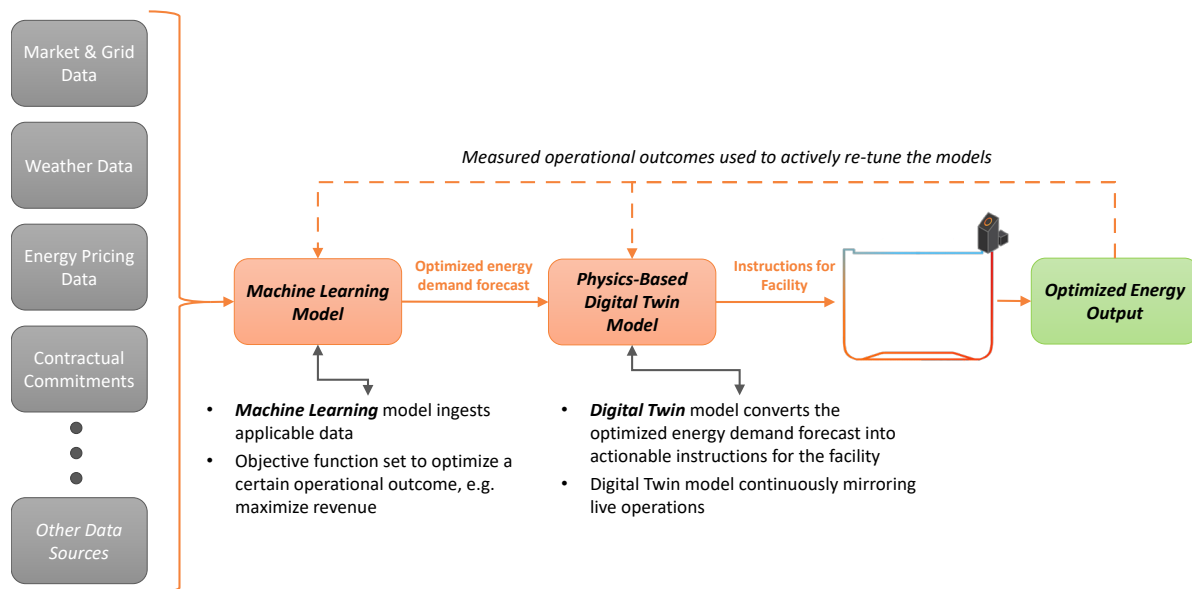


Figure 6: Load-following algorithm high-level architecture.

The Eavor-Lite™ demonstration facility is not currently connected to the local power grid, and as such the “Machine Learning” model has been replaced by a model that produces an energy production curve to offset a typical electricity generation “duck curve” typical of grids with high amounts of wind and solar generation.

The figure below shows the thermal production from Eavor-Lite™ and the demand target set by the algorithm over a 48-hour period.

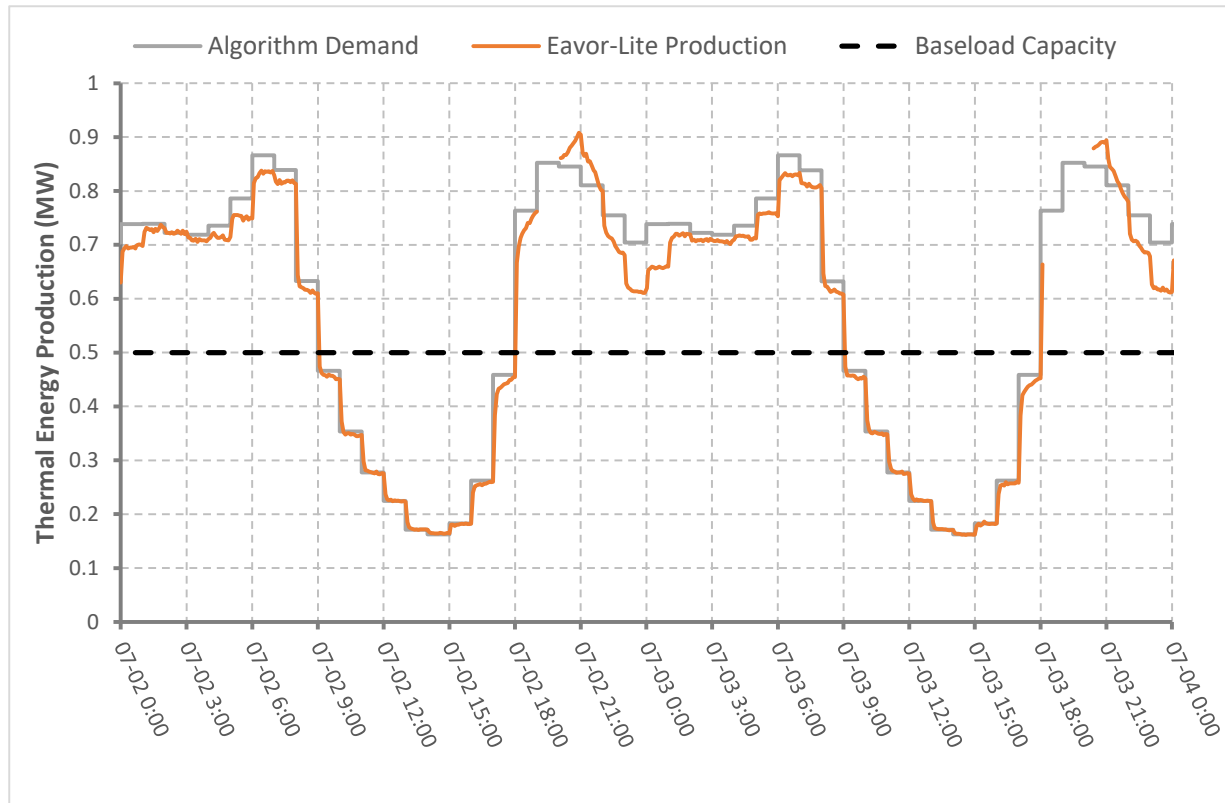


Figure 7: Eavor-Lite™ load-following algorithm results over a 48-hour period.

To meet the input demand curve, Eavor-Lite™ reduces production and stores the energy in the subsurface for production later in the day when it is needed.

The preliminary results show the algorithm does a satisfactory job of being able to convert an energy demand curve into actionable instructions for the facility that ultimately yields a production curve that closely matches the algorithm's requested demand. Although the Eavor-Lite™ pilot of the algorithm showcases a use-case in the presence of a wind/solar dominated grid, the algorithm is highly customizable to different Eavor-Loop™ projects that may be operating in a variety of energy generation contexts.

4. Eavor's Projects Following Eavor-Lite™

To prove Eavor's latest technologies such as Insulated Drill Pipe (IDP) and ability to drill in hot dry rock (HDR), Eavor has recently completed a multi-lateral Eavor-Deep™ project in New Mexico. Eavor-Deep™ reached depths of 18,130ft and drilled over 20,000ft of basement rock. Rock Pipe, which has been developed at Eavor-Lite™ has also been used to seal Eavor Deep and reduce the leak off by a similar amount to Eavor-Lite™.

The upcoming commercial Eavor-Loop™ project at Geretsried, which began drilling in July 2023 and was the recipient of a €91.6MM EU Innovation Fund grant, will consist of 4 Eavor-Loops™, with 12 multilaterals each, and will draw on the experience and lessons learned of both Eavor-Lite™ and Eavor-Deep™.

5. Conclusions

Eavor-Lite™ has been instrumental in showcasing and derisking closed loop geothermal technology. The pilot project serves as a platform for development and validation of closed loop thermodynamic models which accurately predict temperatures and pressures (<0.5% error in temperature prediction) after four years of operations and despite intermittent changes to the working fluid for various trials. Monitoring of leak off helps provide better understanding of the leak off mechanism, while the R&D and trials executed at Eavor-Lite™ helped improve the Rock Pipe completions, leading to lower Eavor-Loop™ completions costs.

The transient thermodynamic model which was developed and validated was fundamental to the development and testing of load following algorithm which amplifies the value of Eavor-Loop™ and allows the Loop to serve as zero emission load-following resource.

Lessons learned while operating the Eavor-Lite™ have been captured, documented and addressed for future projects, which should result in lower operating costs (both fixed and variable).

6. References

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