Leveraging Machine Learning to Accurately Predict Si-Anode Performance

Technical developments, Predictive analysis and ML capabilities.

Benjamin Park, PhD | Founder & CTO

Enevate is a battery technology company supplying breakthrough technologies to the battery industry. Its pure silicon-dominant Li-ion cells designed with its own electrolyte and cell designs allow for unique properties including extreme fast charge while increasing high energy density, wide temperature operation, safety, and potential for reduced cost.

Enevate Fast Facts

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Pioneering advancements in silicon-dominant anodes leveraging accelerated battery testing & machine learning

Pioneers Founded 2005 in Southern California, USA

- Projected to be one of **first companies achieving next-gen silicon Li-ion commercialization** going to production in 2022

Vision A cleaner and sustainable environment through a variety of battery powered applications and products that are accessible and affordable to everyone

Business Model Battery technology licensing & transfer

- Non-capital intensive, leverages experienced high volume & quality battery makers to supply the EV industry

Technology Developed over 15+ years with ~500 patents issued and in-process

- Tested by 20+ battery and automotive manufacturers in Asia, US, and Europe
- Licensing new 4th Generation XFC-Energy® technology with eXtreme Fast Charge for high volume commercialization

Leading industry investors, partners, and customers

RENAULT, NISSAN, MITSUBISHI, LG Chem, Fidelity INVESTMENTS, SAMSUNG, ENERTECH

Advantages of Enevate's patented XFC-Energy® technology for high volume commercialization

- **10X faster charging, 5-minute extreme fast charge** with:
  - **30% longer range** with energy densities of 800-1000 Wh/L
  - **100% better low-temperature performance**
  - **Safer battery** with no lithium plating
  - **Higher efficiencies** in regenerative braking & charger utilization
- **Lower cost** than today's conventional graphite Li-ion battery technology
- **Designed for existing battery manufacturing equipment and processes**
- **Delivers up to a 26% CO_2 greenhouse gas reduction** during manufacturing compared to conventional li-ion batteries

Addressing Consumer & Key Industry Pain Points

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Pain Points for EV Adoption	Enevate Delivers
Carbon Footprint	Up to 26% smaller carbon footprint
Long Inconvenient Charging Time	Up to 10x Faster 5-minute Extreme Fast Charge
Price Premium over ICE	20% lower cost anode affordable EVs
Driving Distance	30% more EV range higher energy density
Low-temp performance	>100% better low temperature performance
Safety	Safer Battery, no lithium plating
Efficiency	Higher efficiencies in regenerative braking and charger utilization

Competitive advantage for EVs when they can charge as fast as refueling a gas vehicle

Li-ion Cell Technology Development Experience

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HIGHLY EXPERIENCED IN LI-ION TECNOLOGY DEVELOPMENT

15+ years

Li-ion Cell Development

4 generations

Silicon-dominant Li-ion Cell Technology

1 million meters

Electrodes Produced

150k Li-ion cells

Assembled and Finished

190k electrical tests
Performed

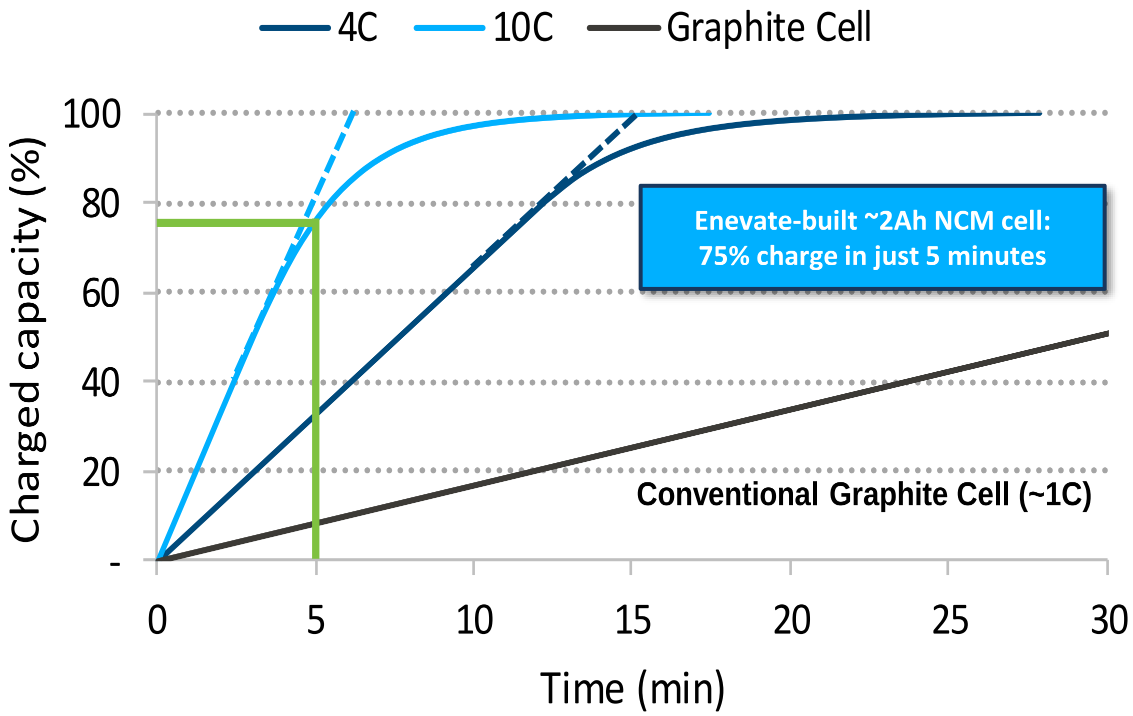
3,000 channels
Available for Battery Tests

136 million hrs, **15,000** yrs
Cumulative Cell Testing

4 billion datapoints, **890 GB** data
Collected & Analyzed

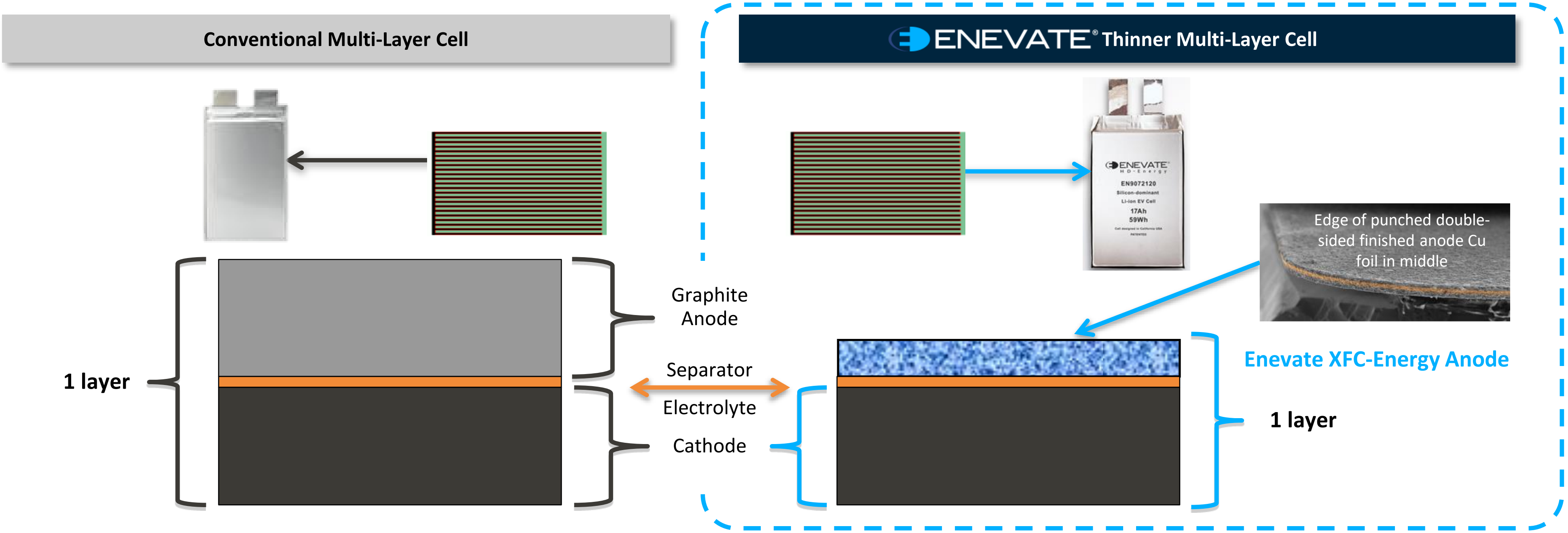
How does Enevate Achieve...
Extreme Fast Charge + High Energy Density?

1. **Si-dominant Anode** to meet market demand & next-gen specifications
2. **Electrolyte & Additives** prevent side reactions & growth on Si surface
3. **Cell Design & Cell Formation** to optimize performance



Silicon Dominant vs Graphite Dominant Performance

ENEVATE VS CONVENTIONAL LI-ION CELLS



Enevate is able to deliver more energy in a smaller cell through our innovative XFC-Energy technology, employing a silicon dominant micro-matrix

Challenges Enevate is addressing with ML

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Current Challenges

- The industry consensus is that silicon is the next chemistry for EVs. Batteries containing silicon, however, have certain properties that BMS need to address.
- Voltage hysteresis complicates the interpretation of voltage-based measurements - especially when determining true state-of-charge.
- Degradation mechanisms are different from conventional graphite cells; simultaneously maximizing cell life and user experience can both lower warranty claims and improve customer satisfaction.
- Machine learning can produce accurate and robust state-of-charge and state-of-health models for BMS applications but developing these models for new cell chemistries requires data not readily available in the industry.

Enevate's capabilities to address the challenges

- 15+ years of experience and an extensive dataset of 4B+ datapoints has the best dataset for ML.
- Prototyping, testing, and data pipeline allowing agile generation of ML data using any test conditions, cell design, process conditions, and raw materials desired.
- 500+ License IP portfolio in cell chemistry focusing on Si-dominant anode.
- A team of ML experts with specific expertise in the Si anode space

Enevate modeling efforts

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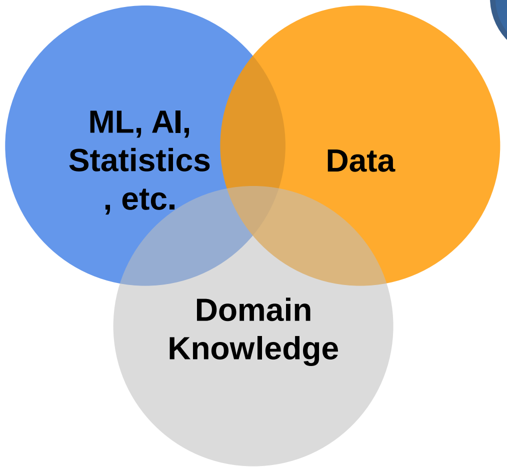
- **Physics-based modeling**
  - Porous electrode models
    - Electrochemical model of Enevate cell
    - Si anode-specific capacity fade model
  - 3D thermal models coupled to e-chem models
  - DFT models to support materials informatics work
- **Machine Learning**
  - Materials informatics – Si anode electrolyte discovery
  - BMS models & algorithms
    - SOH models
    - SOC models
    - Parameter optimization and algorithm design
  - Performance forecasting
    - Cycle life prediction using early cycling data
    - Cycle life prediction using formation and QC data



BMS data and model development roadmap

- Randomized cycling data
- Discrete feature engineering
- Linear models
- Ensemble models

- Drive cycle data
- Timeseries feature engineering
- Models that work with raw data
- Deep learning models

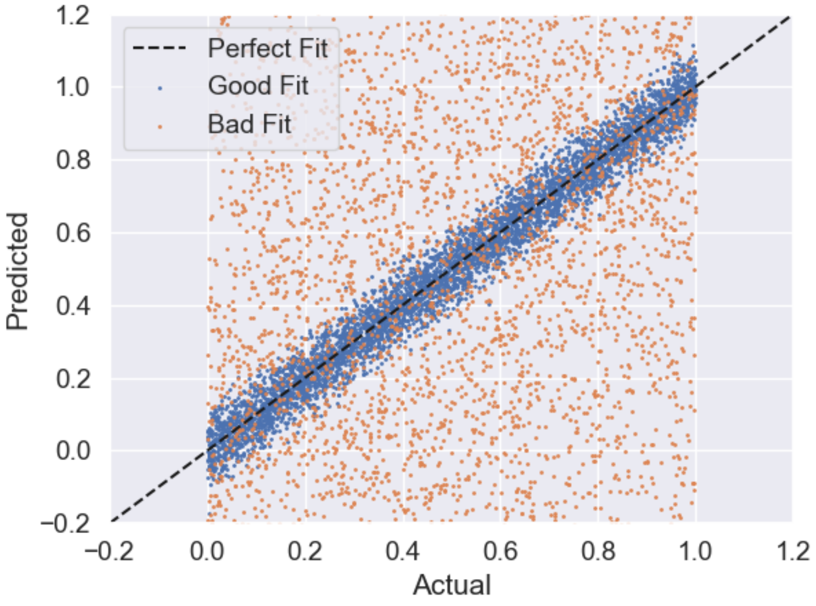
- Drive cycle data with varied temperature
- Data direct from BMS
- Fusion models
- BMS algorithms
- Integration into BMS

Measuring Model Performance

Depending on the type of application, there are several different metrics to assess model performance

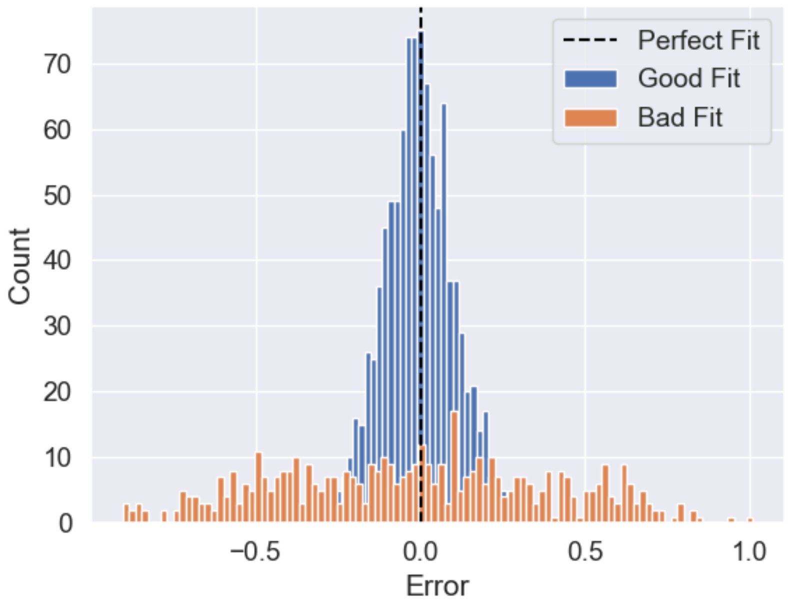
Example of Visualizing the Distribution of a Model's Error

"Actual vs Predicted" Plot



- "Perfect" Model performance → All points lie on the diagonal of the plot → Zero error
- Tighter the distribution of points around the diagonal → Closer to zero error → Good model performance
- Useful, but difficult to quantify exactly how far from "perfect" model is performing or how many points lie on or close to the diagonal

Histogram of Errors



- Useful in verifying how many predictions have or are close to zero error

Many other metrics exist such as:

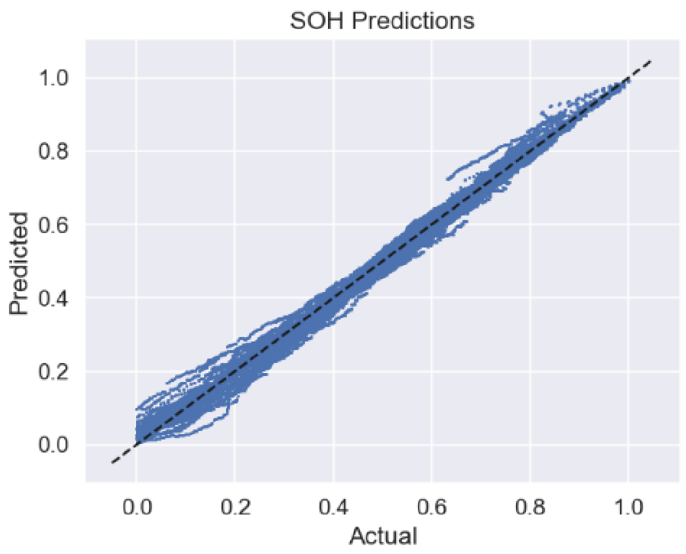
Mean Absolute Error, Root Mean Squared Error, R-Squared, etc. for Regression
and
Sensitivity, Specificity, Precision, etc. for Classification

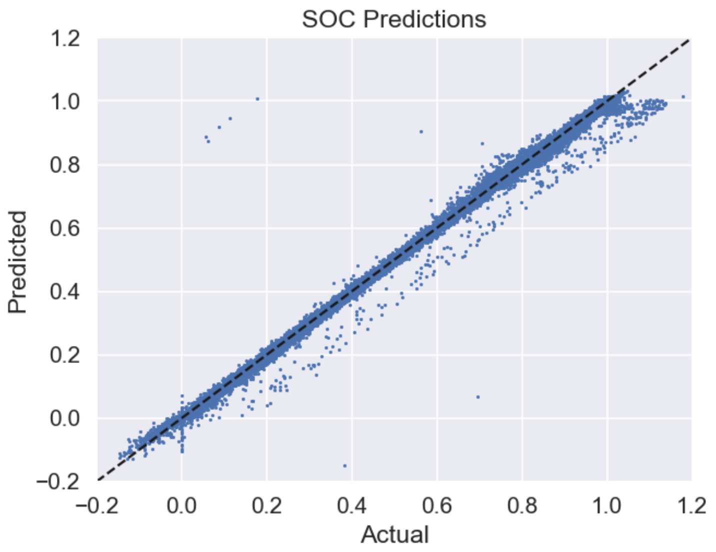
Metrics are typically chosen based on needs

Cell State Models (SOC and SOH)

- Unique training dataset of Si anode cells
- Handles hysteresis of Si
- Preliminary models achieve excellent performance
- Planning on implementation in BMS systems

	SOH	SOC
Mean Absolute Error	1.67%	0.84%
RMS Error	2.26%	2.01%
R-squared	0.991	0.997





In Silico Electrolyte Development

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Experimental Data

Handful of electrolytes with full set of measured properties and test in cells

DFT Model (Quantum Chemistry)

10^3 - 10^4 structures simulated

Machine Learning (ML) Model

Entire library calculated

Viable candidates selected and sourced

Candidates tested in cells

Materials Library

>10^5 possible structures with the same motif

>>99% of structures have unknown physical properties

Hybrid DFT/ML approach to calculate the properties of the entire materials library to discover the ideal electrolyte.

Enevate has accelerated:

- Cell testing
- Predictive capabilities
- Materials discovery
- Information systems (data management)

ML Benefits with Enevate

- **Makes easier the use of next-generation Li-ion battery chemistry in vehicles**
  - Increased energy density, faster charge, better safety.
  - ML solutions for Si-anode technology require a combination of data and ML expertise; Enevate is uniquely positioned to deliver both.
- **Reduced model development time by 6 to 9 months**
  - We can rapidly produce cells, data, and models based on customer needs.
  - Our existing data and models allow us to apply transfer learning to reduce quantity of new data required.
- **Improved model accuracy resulting in lower risk of field failures**
  - Our domain expertise give us understanding of the greatest operational risks to Si-anode batteries
  - This understanding allows us to engineer models and algorithms to avoid overcharge and accelerated capacity fade
- **Improved product characteristics (incl. product life, spec) with potential margin improvements**
  - Accurate SOC and SOH models can be implemented in BMS algorithms to perform adaptive cell balancing and charge rate optimization
  - These algorithms can increase the charge speed of the vehicle and extend pack lifetime.

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Thank you!

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