Synergy between Electrified Vehicle and Community Energy Storage Batteries and Markets

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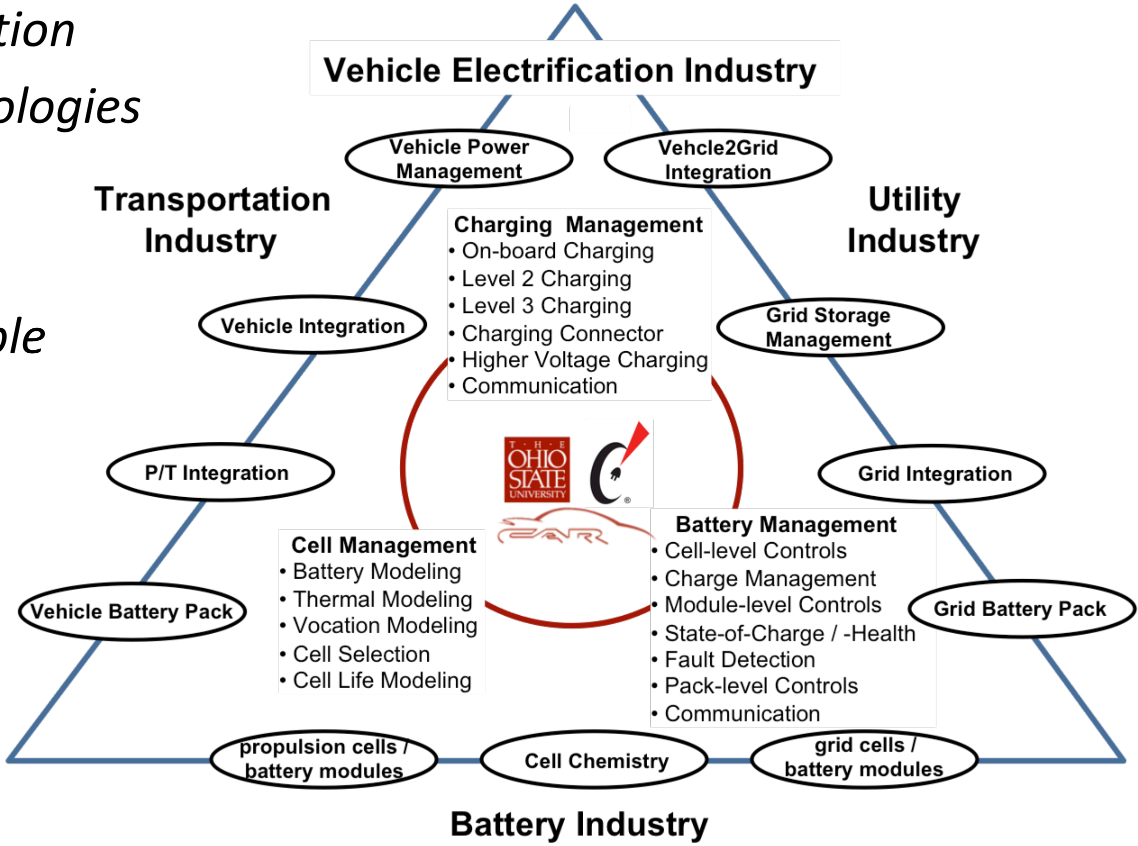
CAR Technologies is:

"(a) vehicle for the commercialization of intellectual property and technologies developed at OSU-CAR"

- *provides greater and more flexible engineering services support for a wider range of industry partners*

- *separates the roles of this commercial operation from the activities of the university research center*

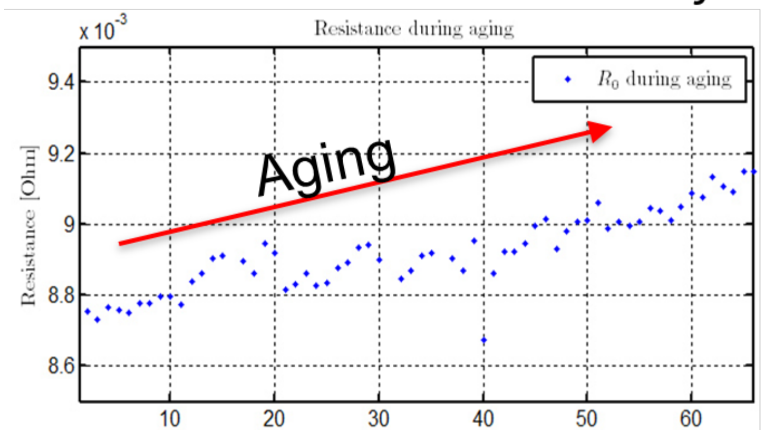


Today's Distributed Storage Focus

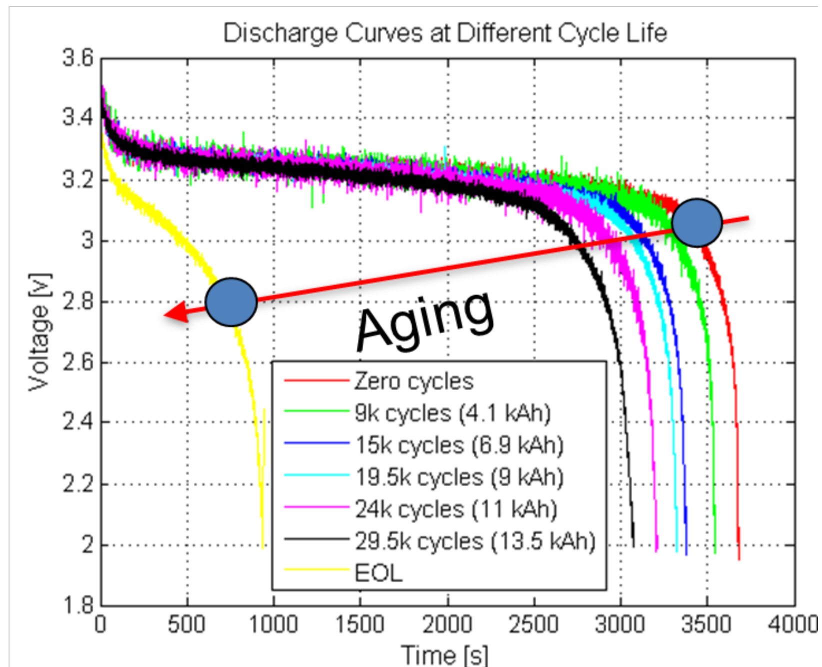
- Compressed Air Energy Storage
- Hydrogen
- Pumped Storage
- Sodium Sulfur Batteries
- Flow Batteries
  - Vanadium Redox Flow Batteries
  - Zinc Bromine Flow Batteries
- **Lithium Ion Batteries**
  - *Motive "and/or" Stationary*
- Other Advanced Batteries
  - Sodium Metal Halide
  - Metal Air Batteries

Automotive and Utility Problem:
Lithium Battery "Ages" with Use

Resistance Growth – Power fade



Capacity Fade



What are the *system-level metrics* and how do these relate to processes at the micro/nano-scale?

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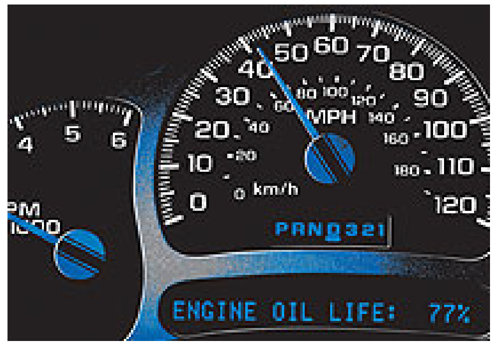
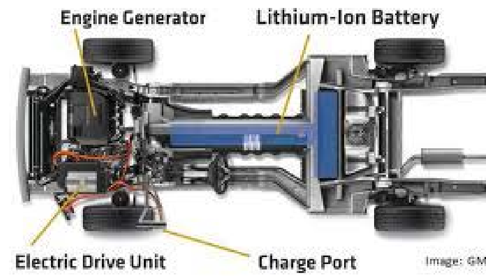
Oil Life Indicator "Parable"

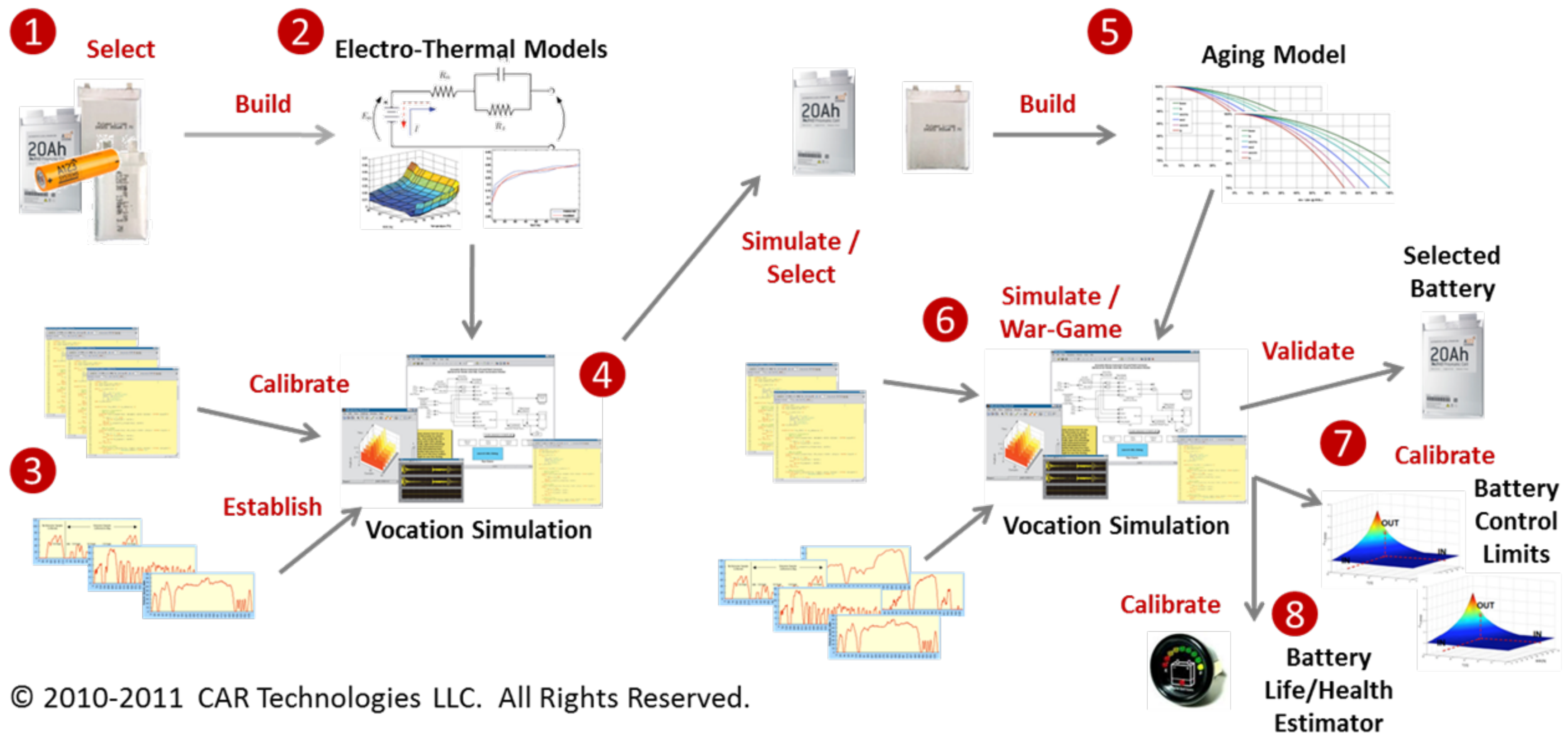




What is the application/vocation and how will the battery behave when in use?

(Primary Use, Secondary Use or Both)

Sample OEM Lithium Battery Characterization & Aging Campaign



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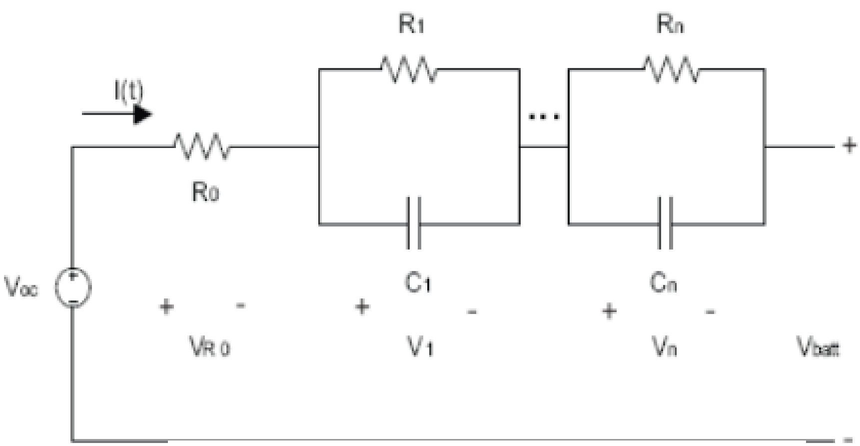
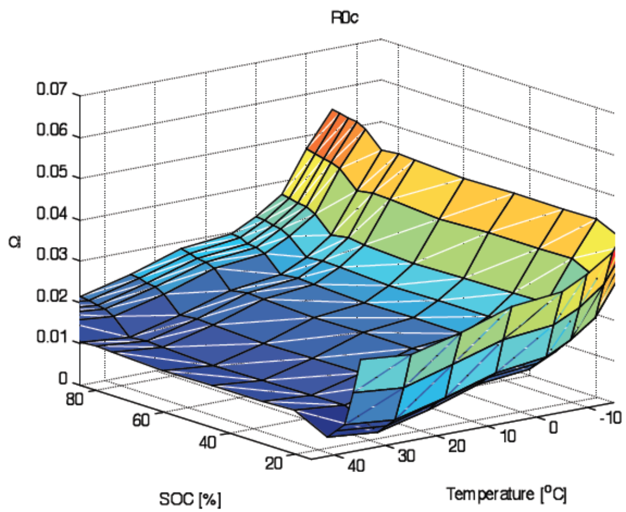
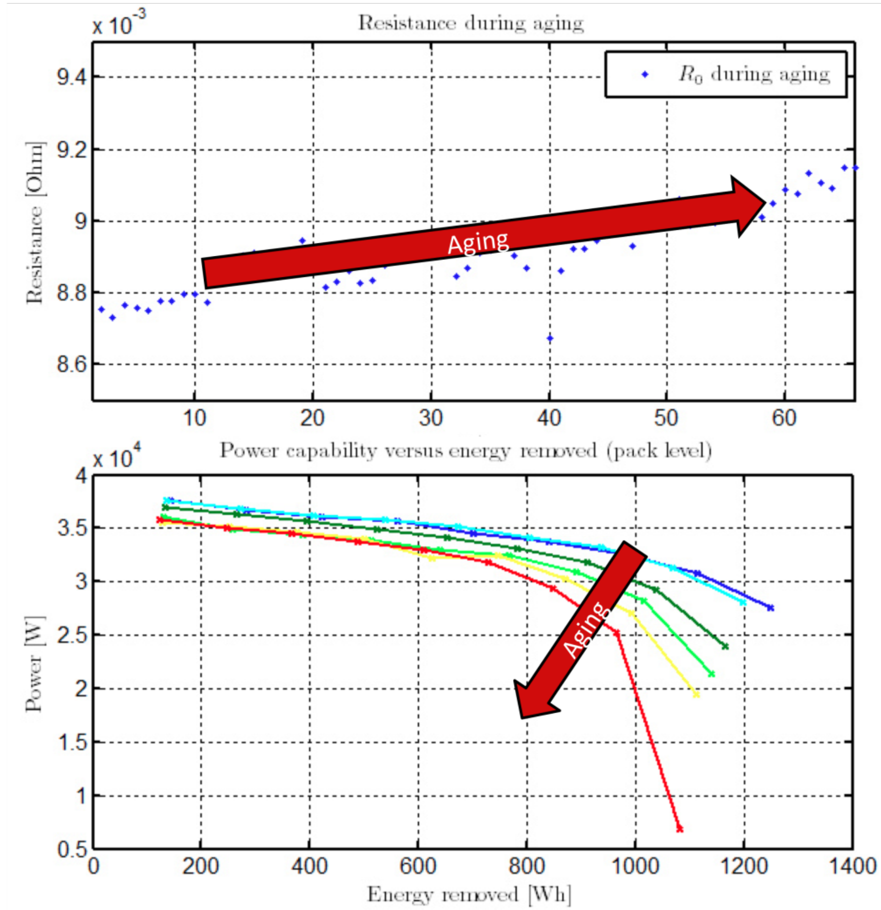
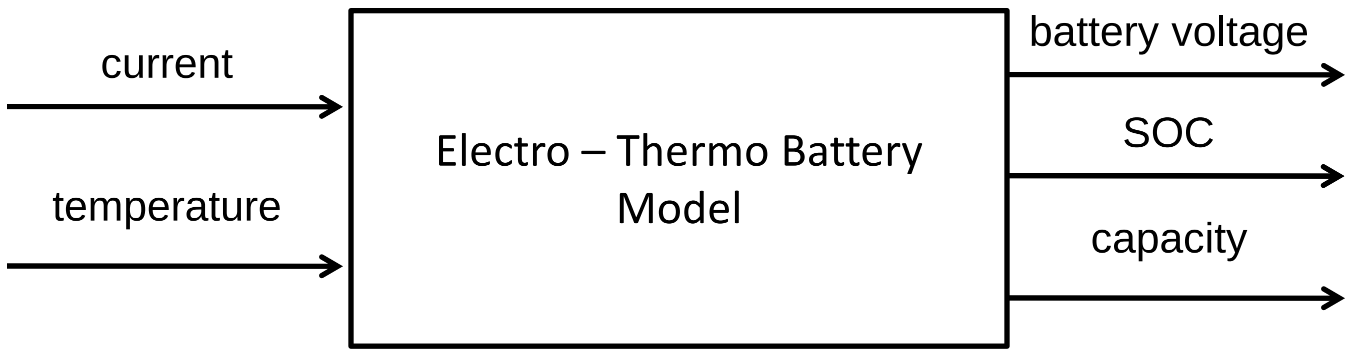
Sample OEM Battery Modeling Approach







OSU - CAR Tech 4P Model



1st order ("4 P") equivalent circuit:

a) capacity function of temperature, **age**

b) V_{OCV}, R_0, R_1, and C_1 functions of: SOC, temperature

- R_0 also function of battery current, **age**

b) SOC function of capacity, temperature, battery current

c) inputs: battery current, battery temperature

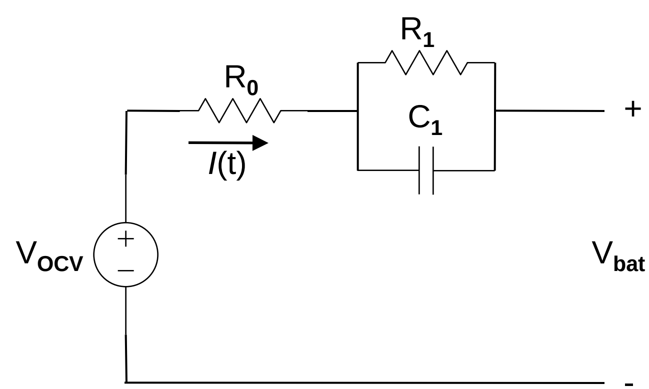
d) outputs: battery voltage, SOC, capacity

e) age = function of operating age and calendar age

f) operating age function of weighted Ah (Wh)

g) calendar age function of time, temperature

$$SOC(t) = SOC(t_0) - \int_{t_0}^{t} I(\tau)d\tau \,/\, capacity$$

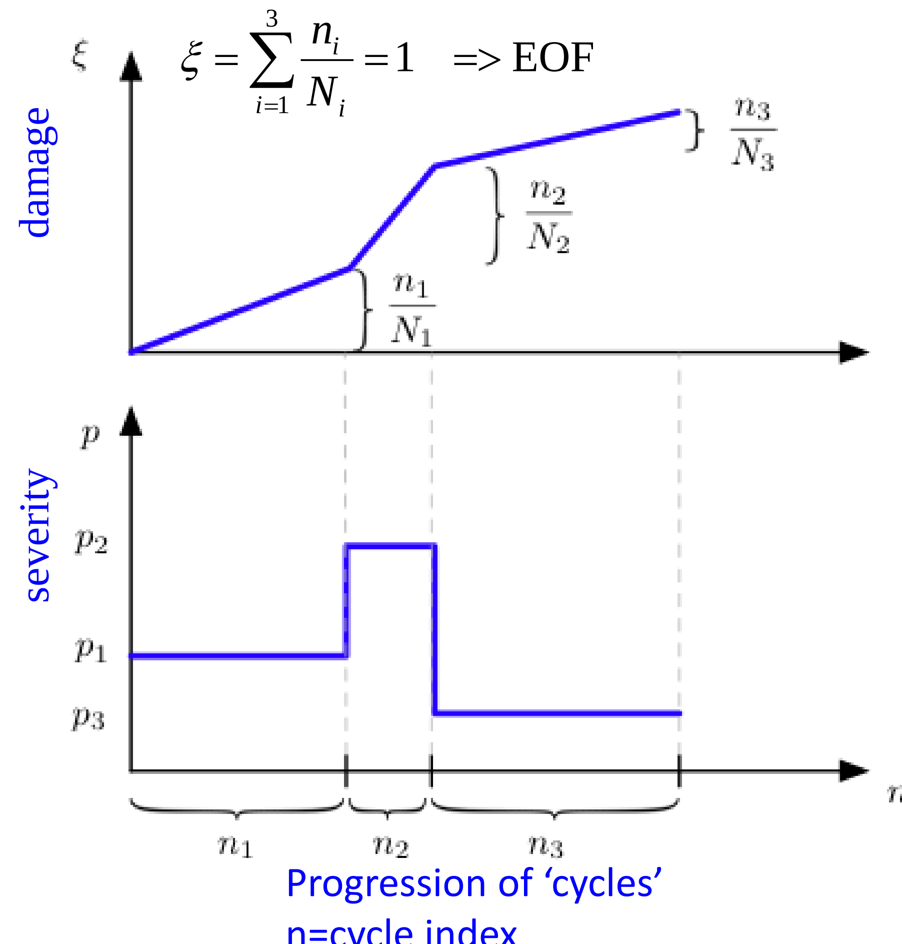


How do we approach the modeling of the aging effects that can’t be readily seen or directly measured?

Palmgren-Miner (Cumulative Damage) Rule

- Well known methodology for modeling fatigue of mechanical components
- Basic assumptions:
  - every cycle increases the damage measure by some amount (depending on its severity)
  - damage is cumulated irreversibly
  - life ends when cumulative damage exceeds threshold
- Implication:
  - Total life can be estimated knowing the sequence of loading cycles

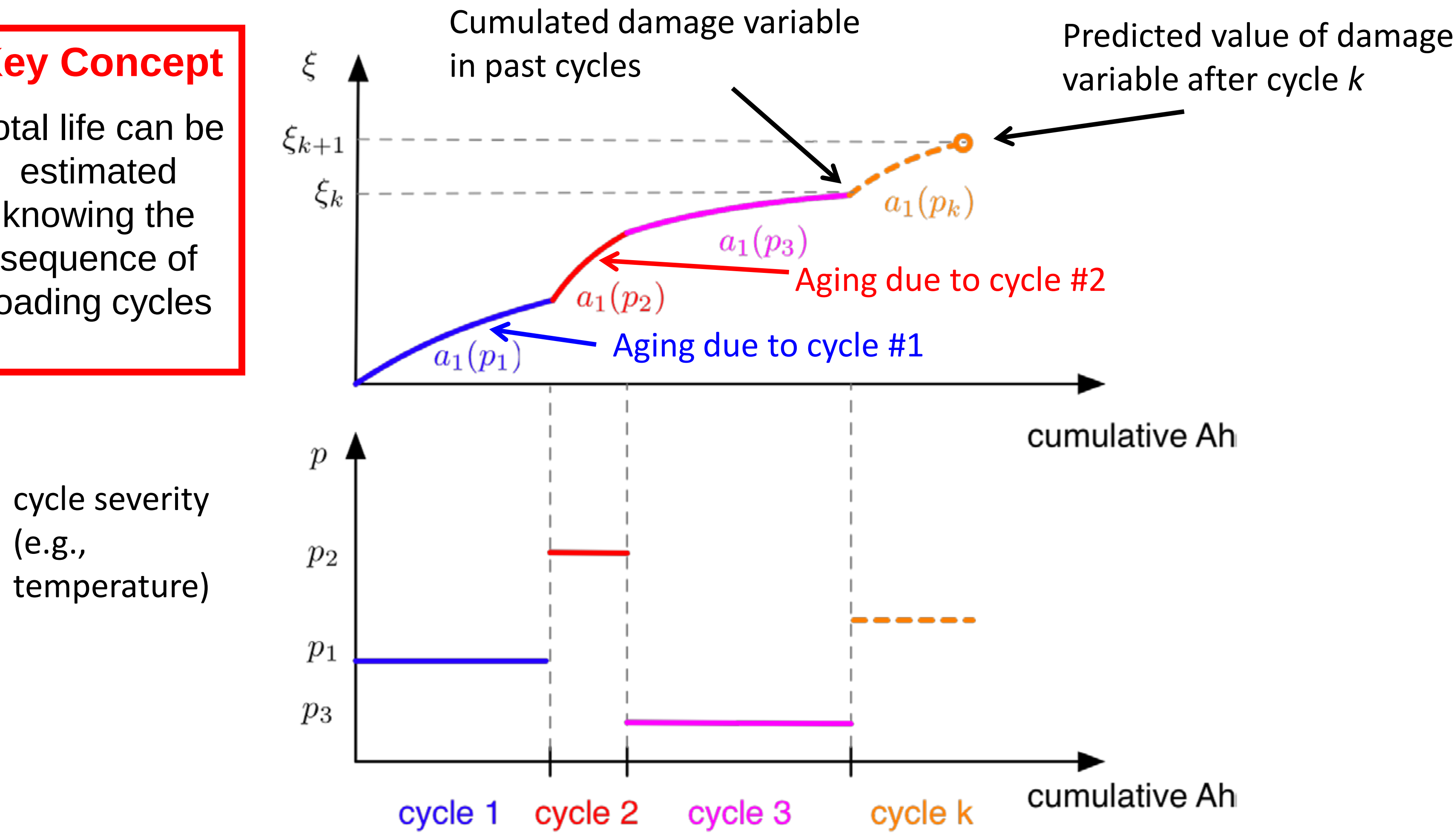
N_i is the total life of the component if it were aged under condition p_i



Implications for Aging Model

Key Concept

Total life can be estimated knowing the sequence of loading cycles



Each cycle represents operation at constant operating conditions
Each cycle has a duration n_k expressed in cumulative Ah

Key Elements of the Aging Campaign

- Cell Characterization and Electro-Thermal Model
- Vocational Modeling

❑ Calendar Aging

❑ Baseline Severity

❑ Severity Factor Mapping

❑ Vocational Aging

❑ Charging Stress

✓ *Expensive*

✓ *Time-consuming*

✓ *Important for accuracy*

- Humidity (or other) Impact Analysis
- Vocation/Cell/Aging – Control Limits and Strategies
- Battery State Estimator

Battery Aging in Motive/Stationary Applications

- **Batteries deteriorate with use:**
  - Internal resistance increases → Power fade
  - Capacity decreases → Range decrease
- **CAR Technologies' approach "calibrates" a battery model suitable for:**
  - ***Vocational simulations***
  - ***Design optimization***
  - ***Control algorithm development***
  - ***Prognosis and diagnostics techniques***
- **Business applications of this model include:**
  - **Warranty → failure analysis and wear analysis**
  - **Warranty / Service / Second Life → battery "odometer" (residual life / health)**

Implications for Distributed Energy Storage

- **Application/Vocation Matters**
  - Most distributed energy storage platforms need to perform multiple application to achieve commercially acceptable ROIs
  - Which combination of grid applications will the distributed energy storage platform be required to perform? How frequently? Under which conditions?
- **Secondary Use (with a proper aging model)**
  - You can measure the effective capacity of the battery at any point and reliably project its remaining useful life
  - If you know how much time a <u>specific</u> battery spends at <u>specific</u> conditions, you can project the life and health of the battery for a second <u>specific</u> vocation

Recommendations for DES

- Standard Battery OEM testing and Auto Industry testing is no longer "state of the art" (in many cases)
- Battery testing needs to be performed where the "battery lives'" – vocation(s) matters
- Building an aging severity factor map is time consuming and expensive – opportunity for open standards and collaboration
- Battery Management Systems (BMS) need to be more open – support re-use and recycling (triage)
- BMS should be tracking cumulative time (Ah) spent at specific (standardized) conditions – support 3rd-party service, warranty, value-chain analysis
- Industry opportunity for a module-based certified battery "odometer" to enable 3rd-party transactions