CHANGING WHAT'S POSSIBLE

Technology-to-Market

Activities beyond the purely technical

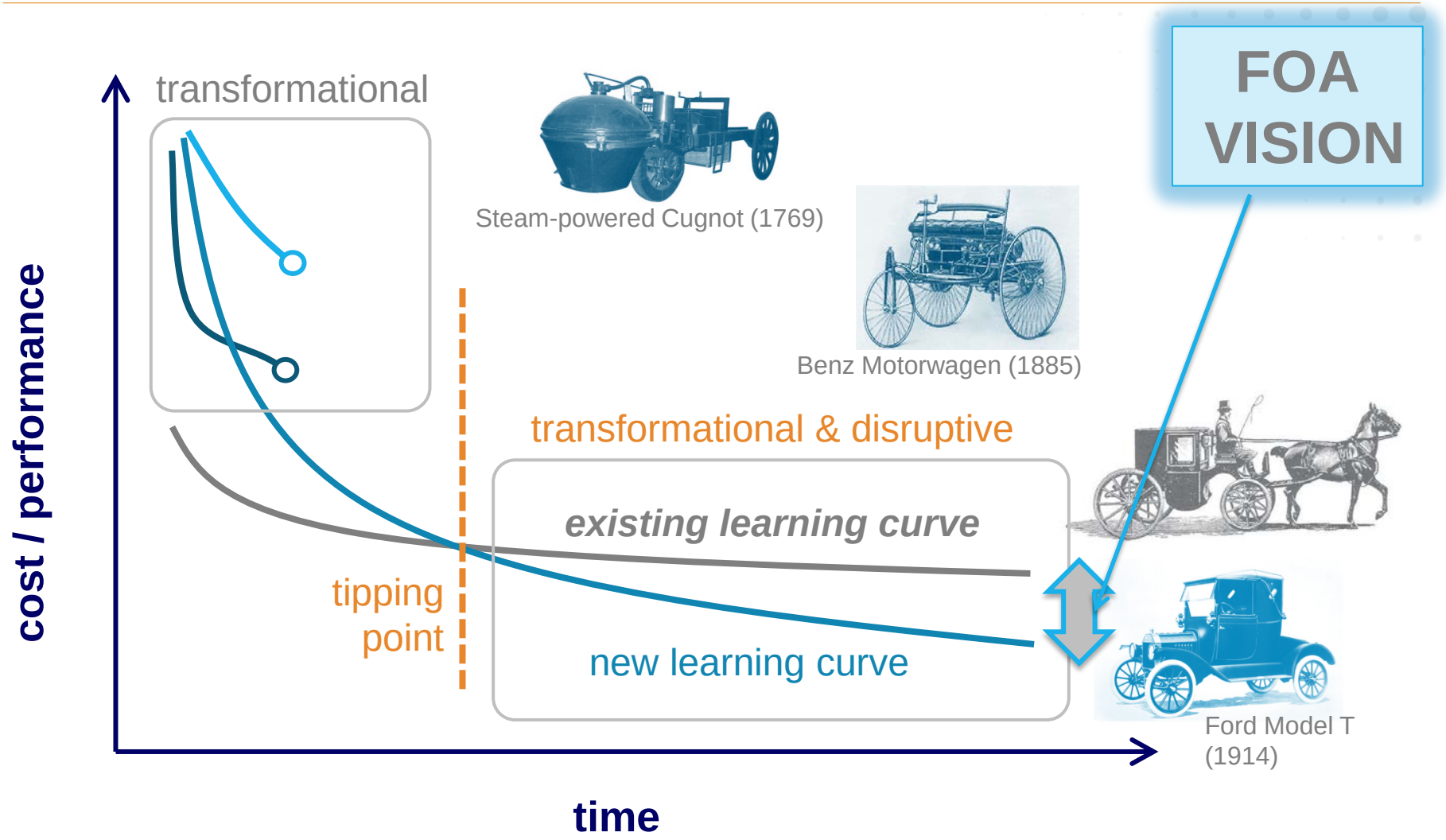
SUE BABINEC
January 29, 2014

SPECIAL THANKS TO T2M MEMBERS/PD Ilan Gur & Mark Johnson

Topics

- Summary of “T2M” goals & approach
- A Few Historical Perspectives
  - Follow-on Funding
  - Project / Scale-up Scoping
- Tools & Resources – a list

Transformative & Disruptive Technologies



Heilmeier's Catechism* as our guide

Bringing Transformative & Disruptive Technologies into the Market is More Complex than with Existing Technologies & Known Learning Curves

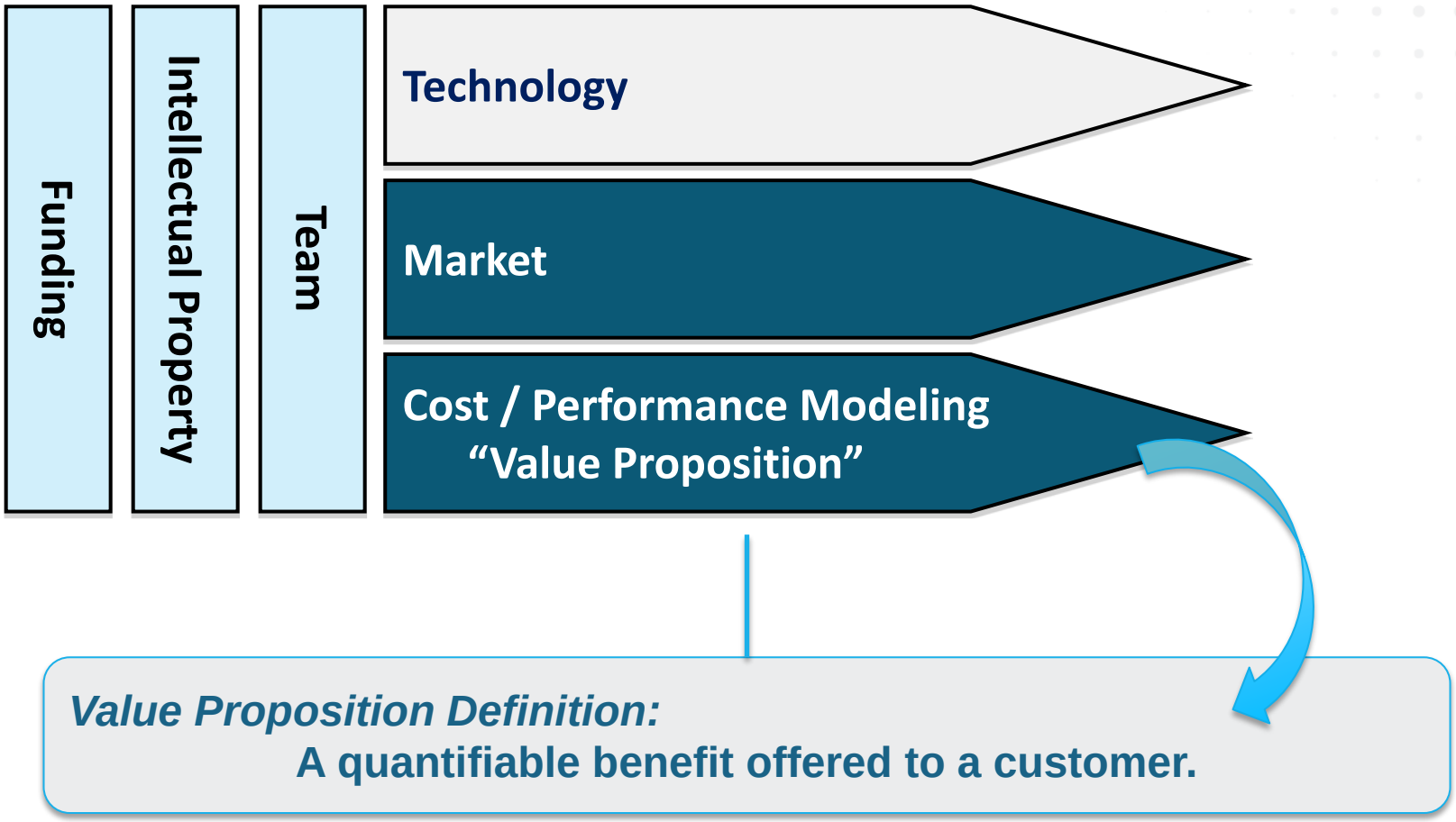
Especially for Energy!

Next 30 minutes: *clarify, restate, emphasize our "T2M" approach*

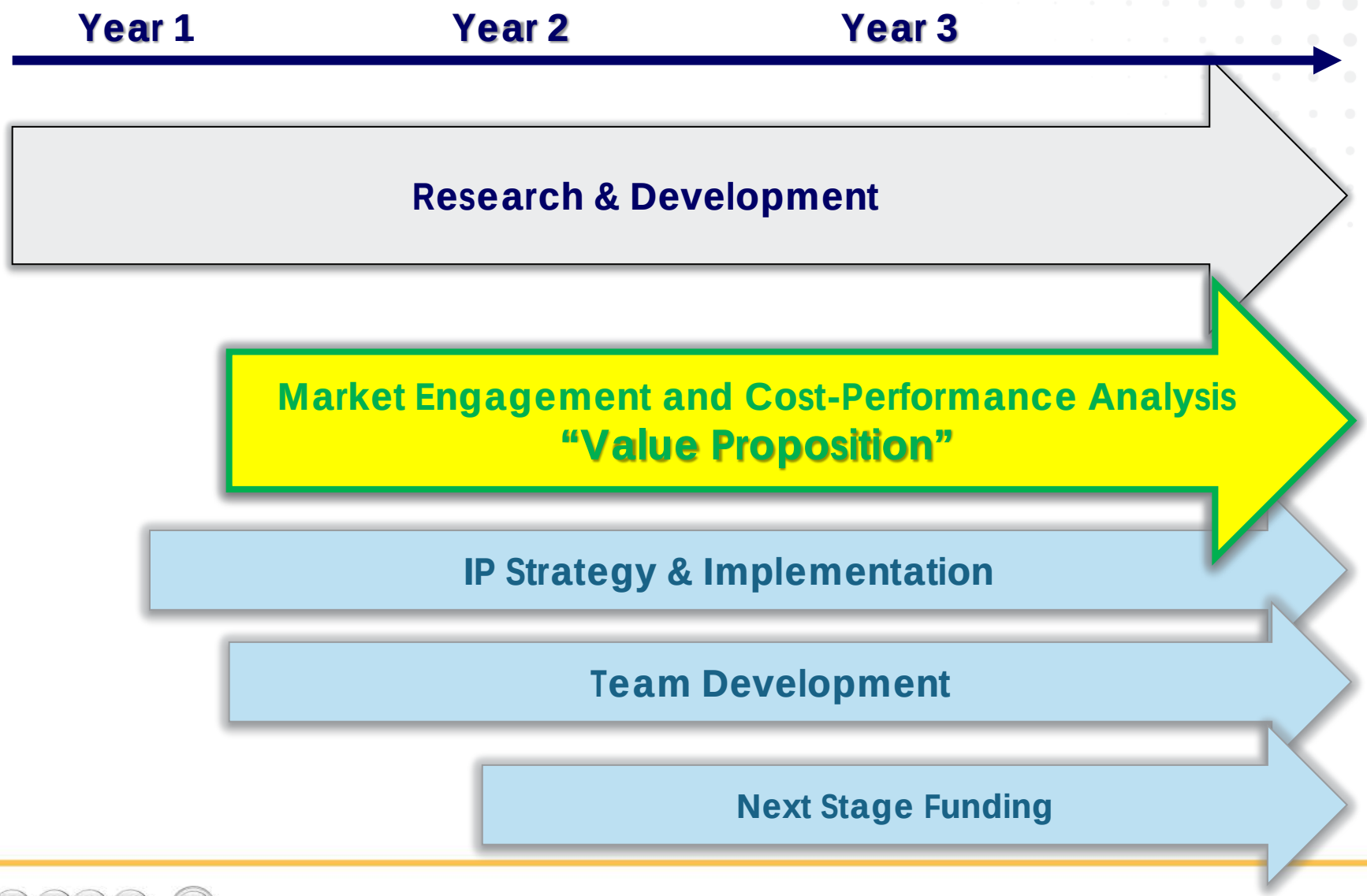
inspire you using logic

- We do not follow-on fund, but we help/guide you towards it. Begin planning in far in advance.
  - EARLY
  - EARLY
  - EARLY
- ARPA-E transformative technologies are defined as at/below existing cost. You need to think
  - COST
  - COST
  - COST
  - **Techno-Economic Modeling is your friend**
- Cost effective manufacturing & product design – great opportunity for innovation!
  - UNDERSTAND
  - ENVISION
  - EXECUTE

Technology-to-Market



Key Activities for RANGE Teams



Patent Protection

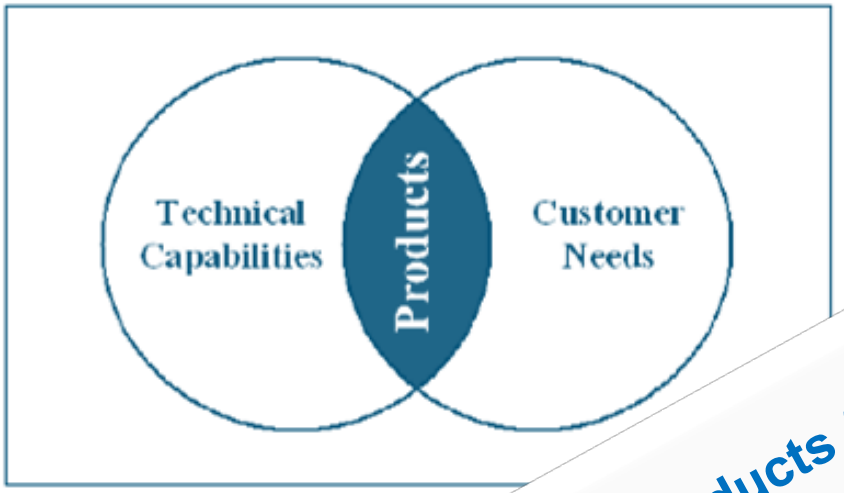
- Patents now go to “first to file”
  - Timely filing is critical
- ARPA-E supports $30k for patenting
  - Typically out of T2M budget
- Patents are an important part of business development & risk control
- Please see us when issues arise

Techno-Economic Modeling Requires a Product Concept

HOW DO YOU GET AN INITIAL CONCEPT EARLY IN A PROJECT??

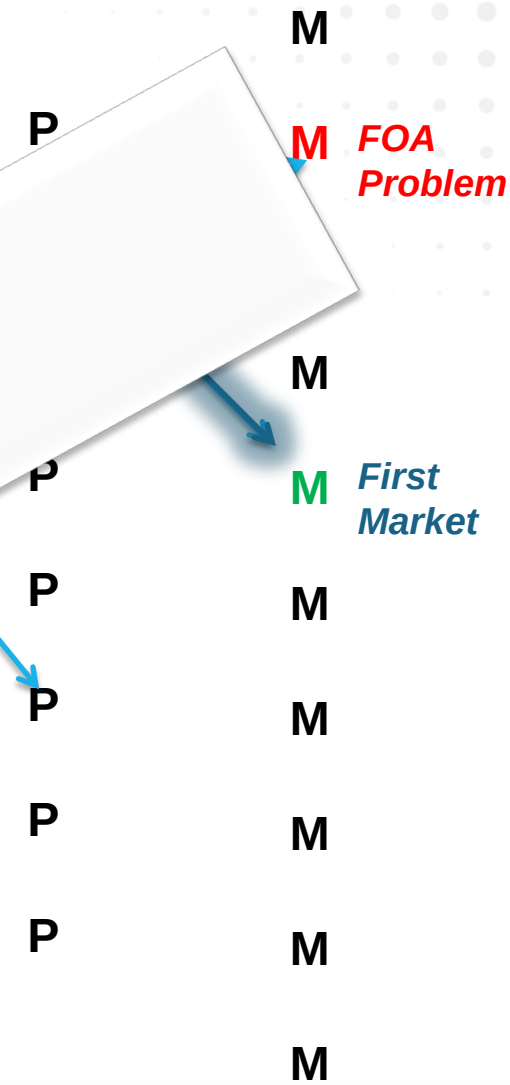
FIRST – NEED PROOF OF CONCEPT

MARKET: *Technology → Products → Markets*



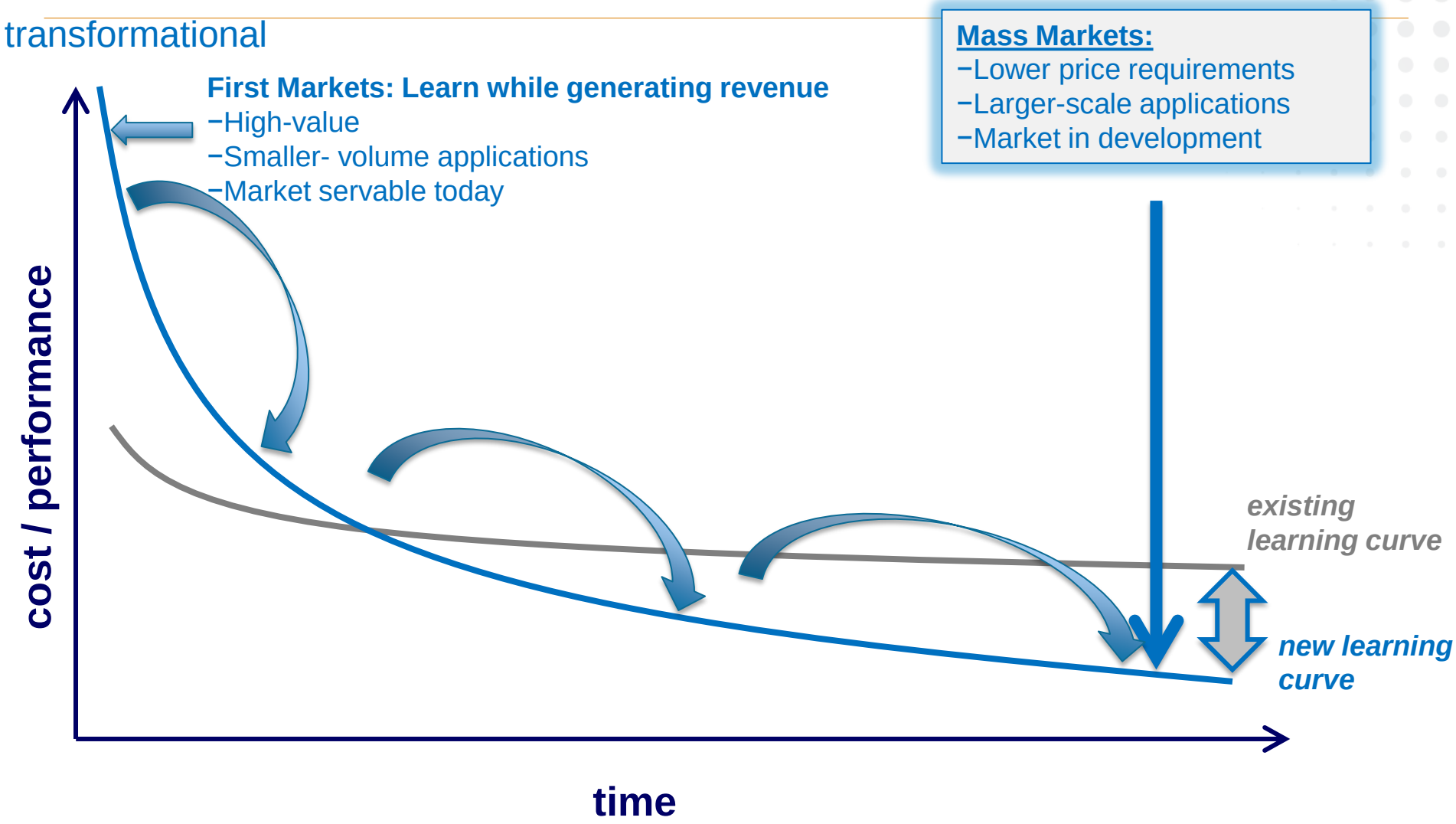
There is no product
and te

You need to consider products & markets sooner than you likely anticipated



From: NCSU Technology, Entrepreneurship, Commercialization Program (2009)

First Markets for Transformative Technologies:



"UNDERSTANDING THE MARKET - MARKET ENGAGEMENT":

Getting past the Standard Interaction

Hey check out my super-expensive, unreliable gadget that we cooked up in lab and have no idea what to do with!

What they hear:

Hey check out my new BATTERY that can solve all your Problems!

Lab Researcher

I'm trying to be polite. Actually, you haven't told me enough to have any clue of how interesting this is for me.

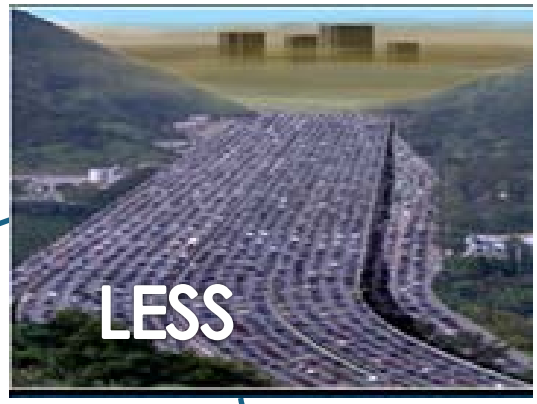
What they really mean:

Interesting!

OEM R&D Engineer

Getting past the Standard Interaction

Working toward shared goals



MORE

How do we go from cool technology to scalable products?

Lab researcher

OEM R&D Engineer

Developing Scalable BATTERY Technologies

YOUR RANGE TEAM CAN HELP

****

Ping Liu – Career in Echem & Batteries / PhD on graphite anodes

John Lemmon: Science & Technology Development & Scale-Up at GE
Echemical Generation & Storage: GE & PNNL

Aron Newman: Argonne National Lab, Physical Sciences & Eveready Battery

Sue Babinec: Science & Technology & Scale-Up at Dow Chemical
Technology Director at A123

Discuss Strategy Often – during Quarterly Reviews . . . .

Cost-Performance Analysis

- **Expectations**
  - **Customers do *not* expect a perfect cost model**
  - **Customers do need reason to believe value outweigh costs**

- **Work in Phases as Technology Develops**

Technology Development

Cost-Performance Analysis

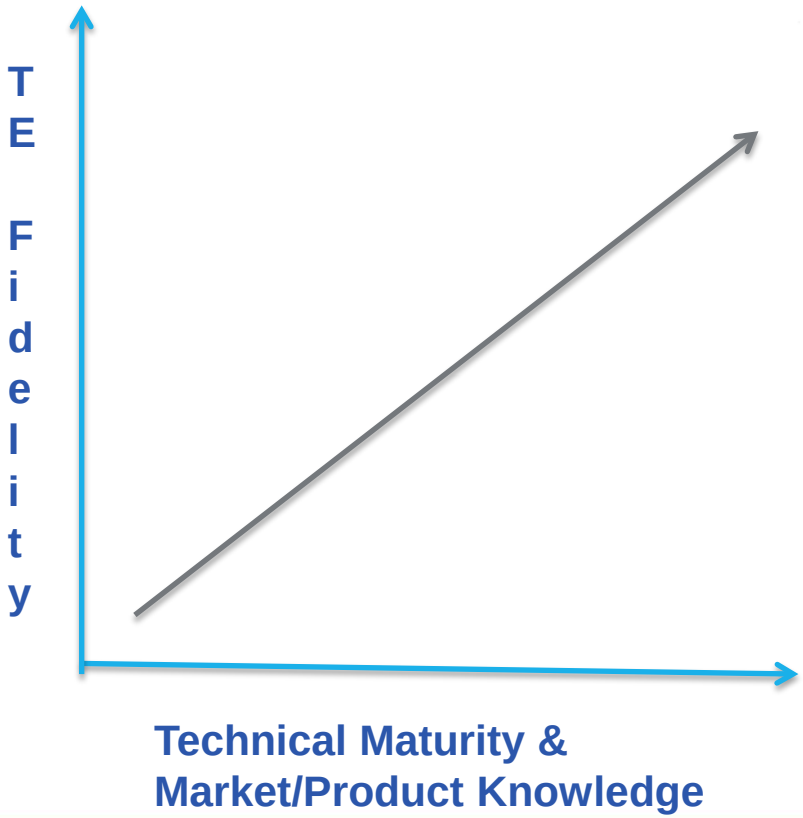
Techno-Economic Modeling:

Limiting Impact of Technical Uncertainties by Financial "sorting"

6 months in the lab/market can save you 2 days of TE Modeling

Inherently Challenging and Interdisciplinary

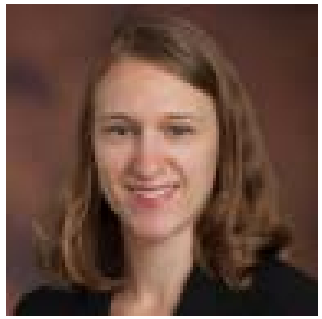
- ***Based on a Cost/Manufacturing Model but More than a "Cost Model"***
- ***Connector of Research Outcomes ↔ Relevant Economic Factors***
- ***Not to be Outsourced – Key Decision Making tool for the team***



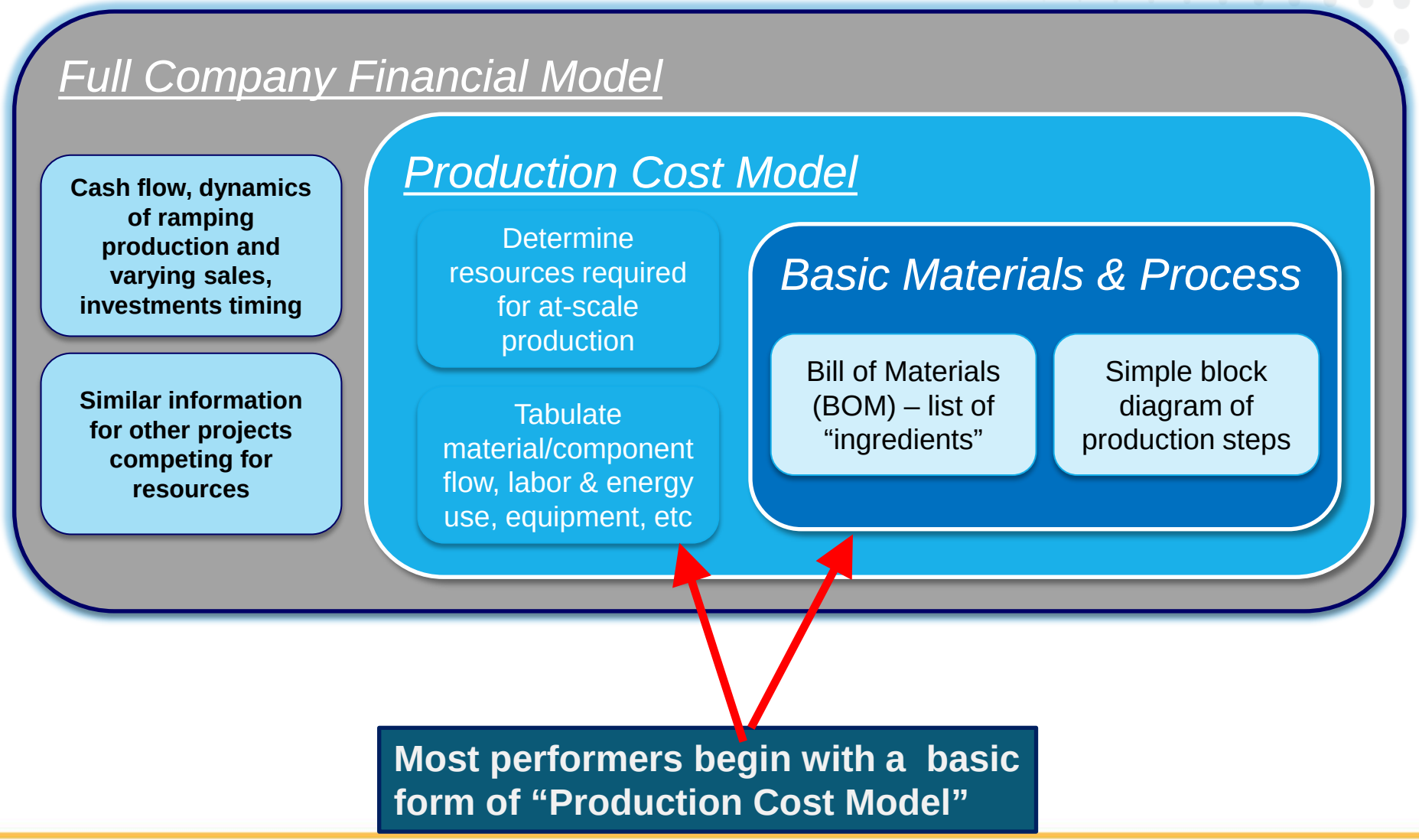
Manufacturing, Economics & Customer Needs

- Manufacturing
  - Adam Stooke
  - T2M team

- Cost / Performance
  - Dr. Elizabeth Santori



Economic Modeling for Technology



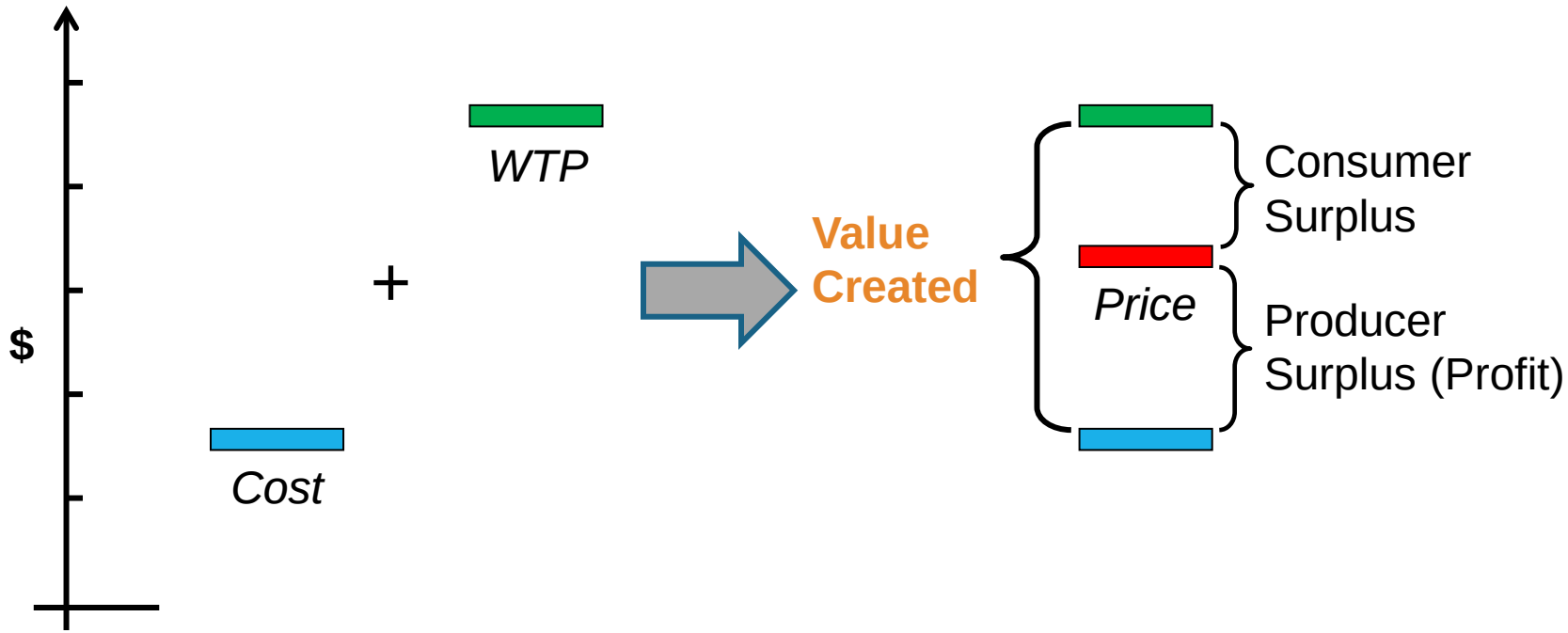
Most performers begin with a basic form of "Production Cost Model"

Cost & Value

- *Production cost* (necessary but not sufficient by itself)

  + *Willingness to pay* (customer value)

  → ***Value creation*** potential of product



Cost Modeling Enables Research & Development

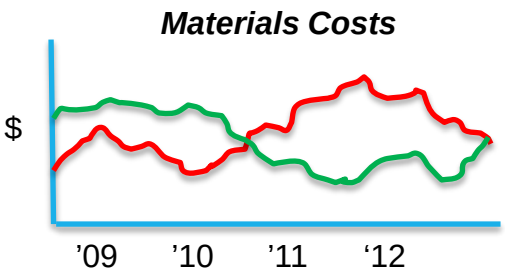
- Model integrates many variables/calculations together for holistic consideration

1+1 = 3

- Identify cost drivers → steer research

$$ → R&D → $$

- Easily test scenarios / update with new cost information



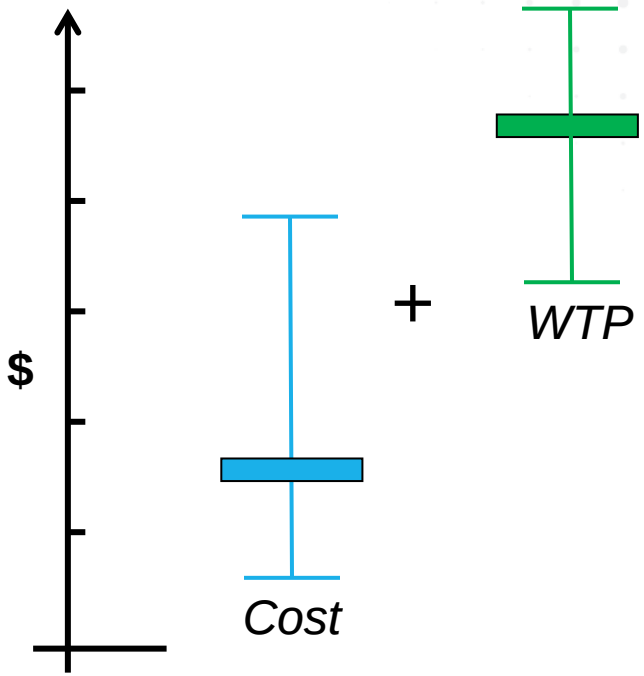
- Communicate results with stakeholders
  - Internal: R&D, Management, Marketing
  - External: Investors, Customers

Modeling Benefits, Despite Uncertainty

- **Common concerns:**

"too early!! . . . .There is too much uncertainty to calculate exactly how profitable this company/product would be."

- **Modeling still beneficial:**
  - **Make uncertainties explicit**
  - **Identify most valuable improvements**
  - Develop targets, metrics
  - Bound with theoretical limits
  - Create thought framework for reducing uncertainties



Template Worksheets

#	Sheet Name	Description
1	Process Diagram	“Hand-drawn” block diagram
2	Results Summary	Displays key model inputs, outputs, essential analysis
3	Production Model & OpEx	Step-by-step calculations: materials, labor, and production requirements (core of whole spreadsheet)
4	CapEx	Building, equipment, tools, etc.
5	Product Performance	Performance metrics, tied to production model if possible, supporting product value to customer
6	Financial	“Fully loaded” product cost, price, margin, payback period
7	Cost Analysis	Sensitivity analysis, step-by-step breakdown, scaling
8	Mass & Energy	Supporting calculations regarding materials and processes

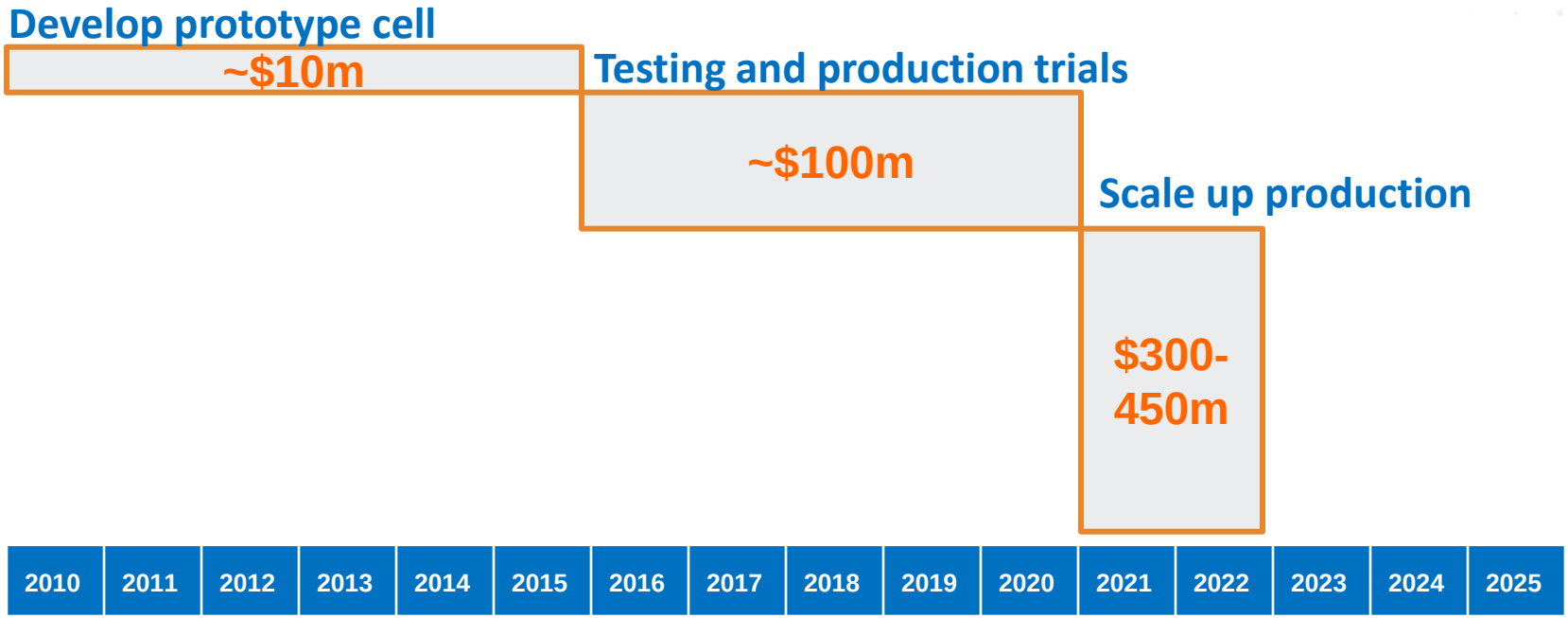
ESSTIMATING SCOPE**: BUILDING A BATTERY FACTORY:

Taking a concept to prototype might cost ~$10 million.

Taking the prototype to production can cost ~$100.

Building a 1.5 GWh per annum facility can cost ~$300-450 million.

Technology Development Gantt – Aggressive Timeline



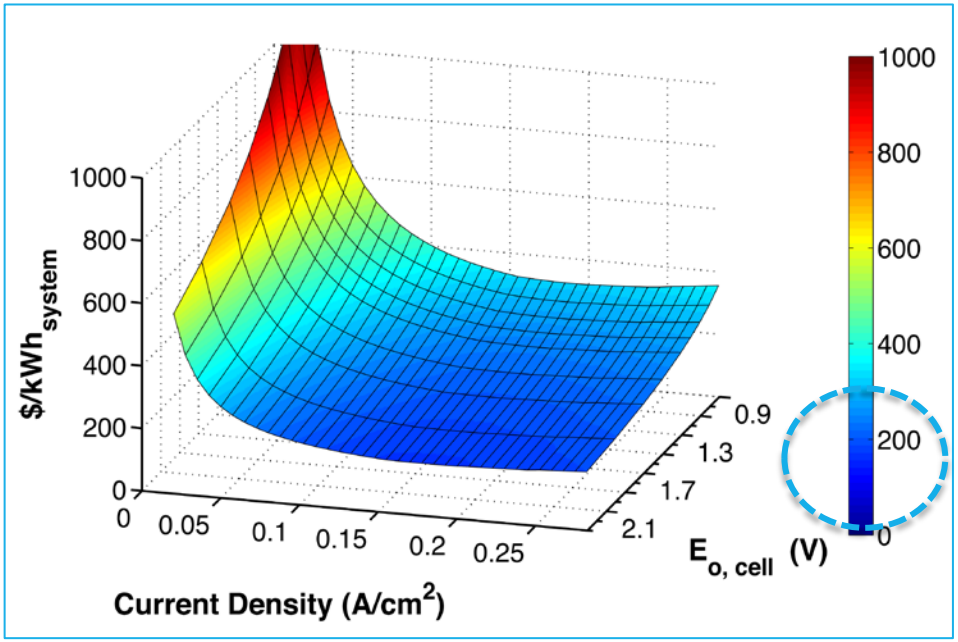
Proprietary and confidential information

** Greg Callman ARPA-E 2012

ARPA-E TE Model: *Cost/Performance Model for Flow Cells Example*

- **Developed at ARPA-E - Dr. Elizabeth Santori**
  - Incorporates available cost information – from PNNL cost-performance model
  - Uses simplified electrochemical model
  - Available to interested performers (with some caveats)
- **Starting Point in analysis**
  - Not validated – does not claim to calculate the true cost – focused on enlightening and educating the experimentalist
  - Does include dominant Capex costs, but not Opex
  - Does include Nernstian and Butler-Volmer behavior, with approximations
  - Adaptable for many chemistries
- **Sensitivity Analysis Uses**
  - RESEARCHER: what is most important, what to attack first?
  - ARPA-E: Uniform approach – scenario analysis
    - Apples-2-apples comparison between chemistries
    - Understanding common sensitivities, e.g. current density, membranes, etc.

Sensitivity Analysis: *Cell Voltage and Current Density*
Membrane Cost and Current Density

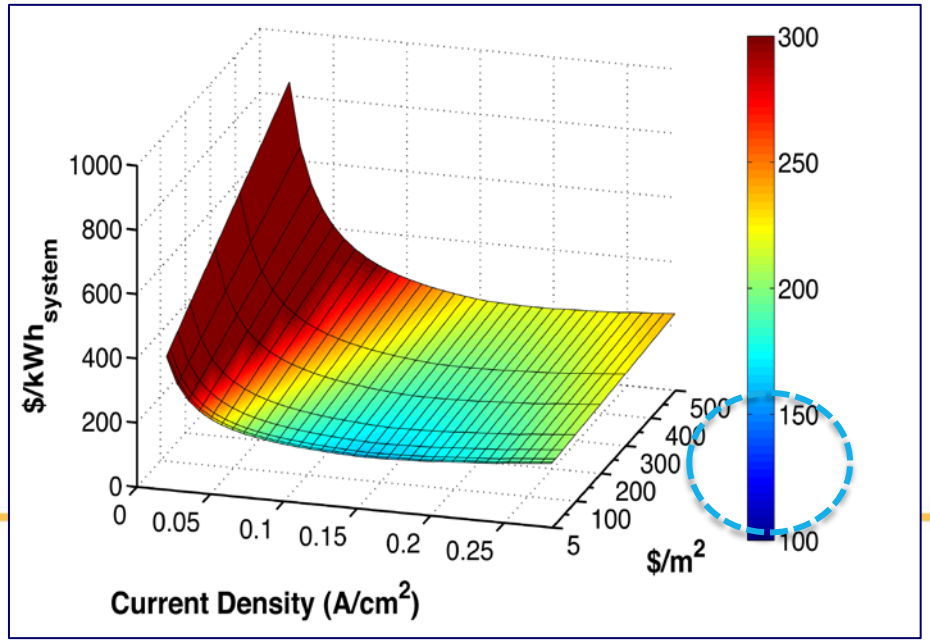


Cost of membrane: $5−500 m^{-2}

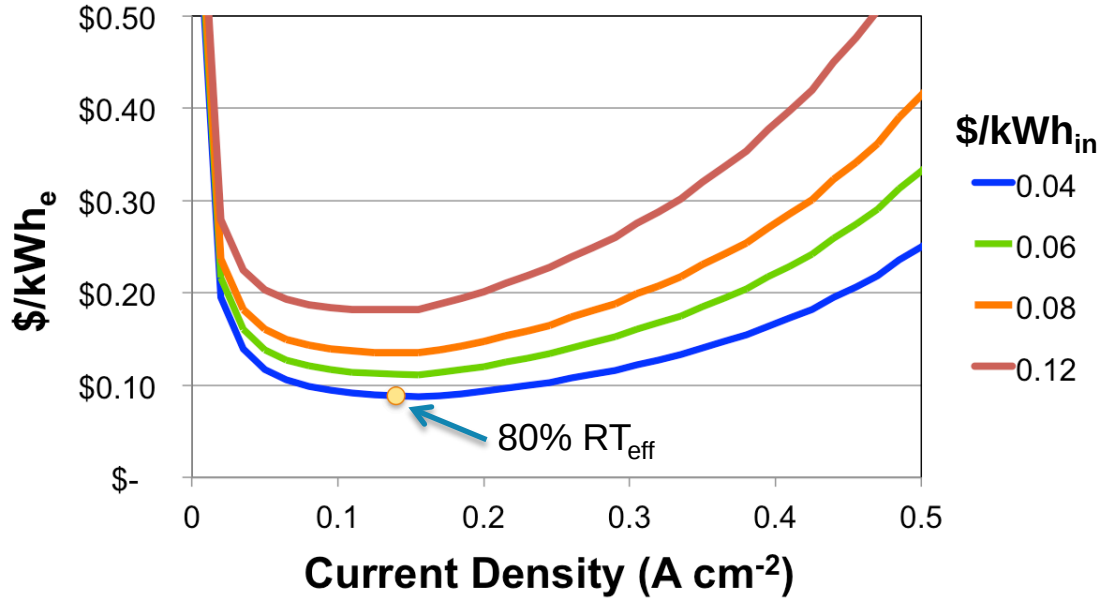
E^o cell: 1.5 V

E^o cell: 0.9−2.3 V

(membrane = $500/m2)



Frame costs in terms of GRIDS goals: $ $kWh_{e\ out}$



$$\$/kWh_e = \frac{\$/kWh_{in}}{RT_{eff}} + \frac{\$/kWh_{system,out}}{Cycles}$$

Cost of final electricity | **Cost of fuel** | **Cost of system**

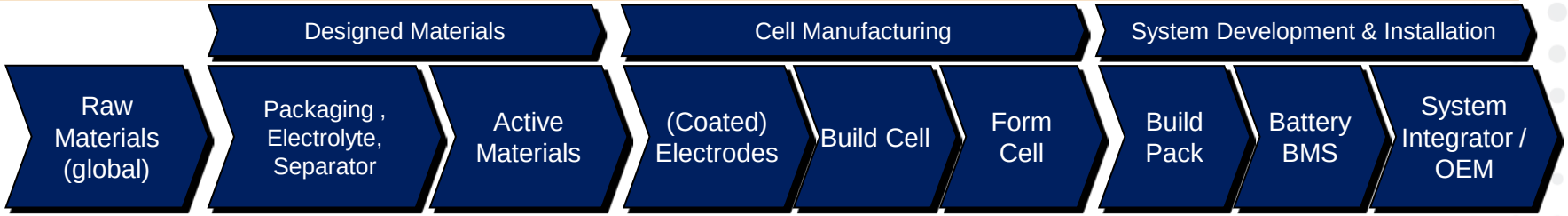
$/kWh$_{system}$ includes RT efficiency, DOD

Looking Forward

LOOKING BACKWARD

- Value Chain Lessons
- Funding of Previous Performers

Value Chain – Energy Storage for Transportation: *Despite the number of players, the market appears to prefer upstream specialization and downstream integration*

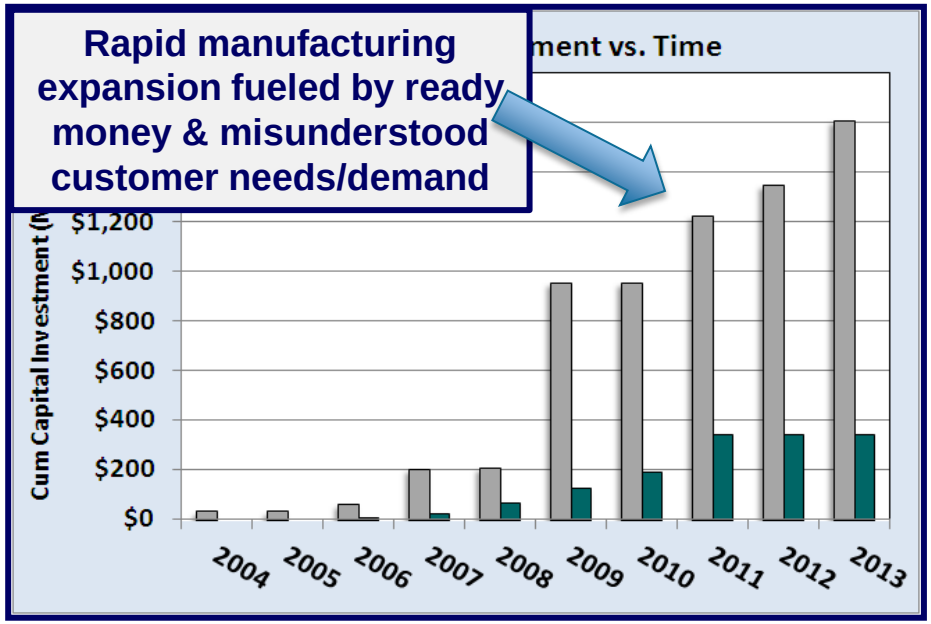


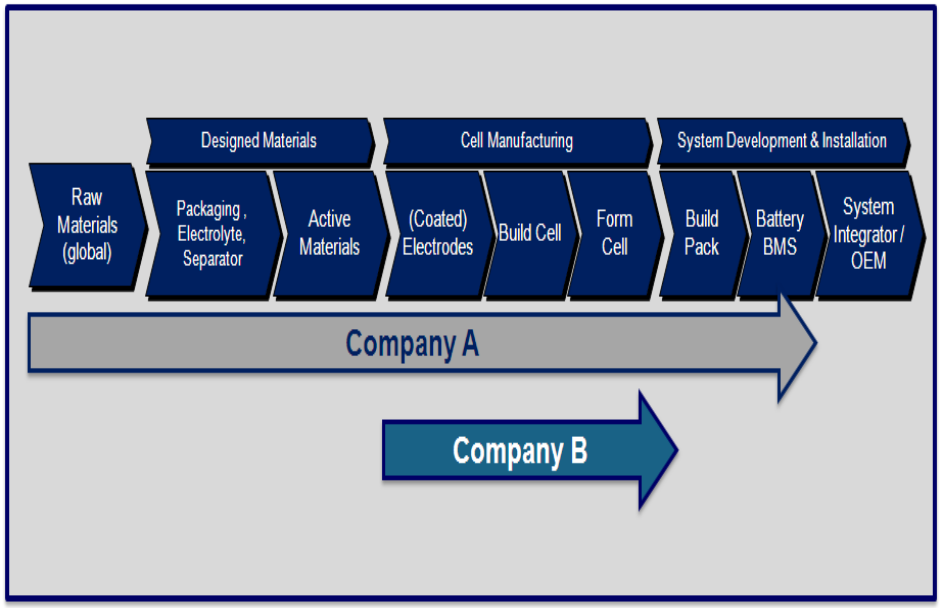
We put together a relatively in-depth overview of value chain and recent market dynamics - US and Global.

– it is ready now but we think that it will be appropriate/effective for this audience towards the end of Q3 of this year

Value Chain Scope, Investors, Timing ⟶ *Risk*

Fast growth & broad scope can give rise to complications such as time spent in financing activities, manufacturing problems/cascading errors & increases in fixed costs,





Company A filed for Bankruptcy, Company B remained viable

Follow-on Funding

- What do you want to make/provide next
  - Who wants it and why – what is the problem solved
  - How much will it cost to manufacture
    - Capex
    - Opex
  - How much will you gain – who are the customers

- What are the risks?

Strategic Investor*?

ATTRIBUTE	FINANCIAL VC	CORPORATE VC
STRUCTURE	Partnership - shared decisions	Bureaucracy - committee or autocratic decisions! - can be very slow
PRIME DIRECTIVE	Return on capital to Partners, Limited	Keep the enterprise going! - do no harm! - new internal business
RISK	Rationally manage risk! - shared risk, shared reward! - syndication	Take no risk! - no shared rewards
CAPITAL	Defined pool from Limited Partners! - General partners participate! - defined limits on each investment	Investment on case-by case basis! - consent/capital from operating businesses
EXPECTED OUTCOME	Return on capital! - financial business ! - divest at highest value!	New or additive business development! - acquire at lowest value! - little interest in financial returns
BOARD ROLE	Specified in term sheet! - preferences, control	Specified in term sheet! - controlled, limited
FOLLOW-ON INVESTMENT	Yes if sensible	Capricious! - changes with authority in corporation
VALUE ADDED	Business, company development! - financial network! - executive talent! - capital raises	- technology possibly (should be understood before investment)! - market access

Tools & Resources

1. **Cost & manufacturing analysis – ARPA-E**
    1. Manufacturing
    2. Flow Cell Cost/Performance
2. **Automotive-specific cost considerations**
    1. Fleet standardization of components
    2. Regulatory
    3. Warranty
3. **National Labs and DOE VTP**
    1. Argonne National Lab (ANL)
    2. DOE Vehicle Technologies Program (VTP)
    3. National Renewable Energy Lab (NREL)
    4. Oak Ridge National Lab (ORNL)
4. **Scale-Up Test /Validation Options**
    1. National Labs - Argonne & ORNL
    2. University – University of Michigan Energy Institute
    3. State- NYBEST
    4. Carederock
    5. Private – Xalt Energy, more to come (?)

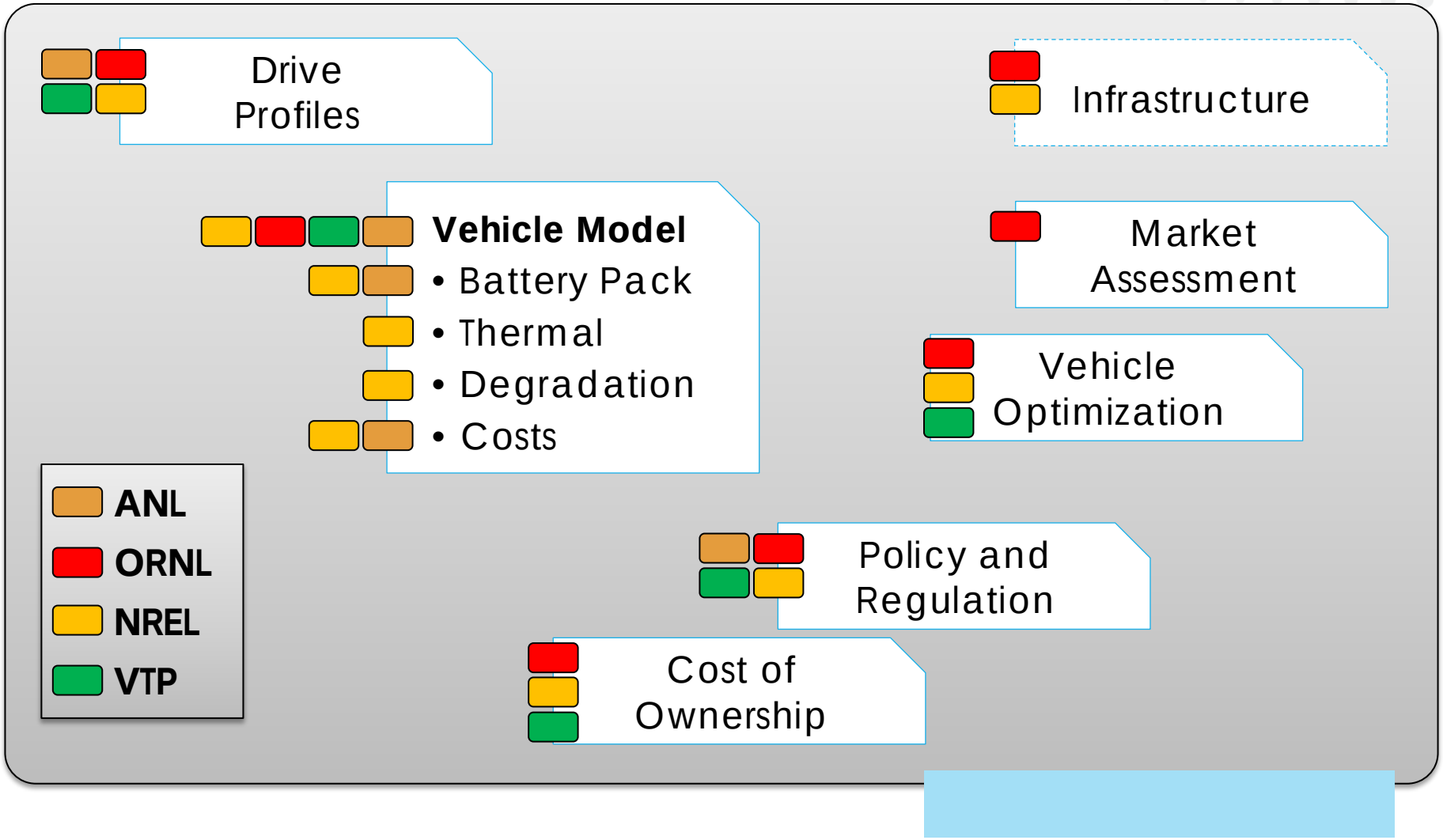
Innovation

People creating value through the implementation of new ideas

- Herman D'hooge, Intel
- Innovation Network

Back up slides

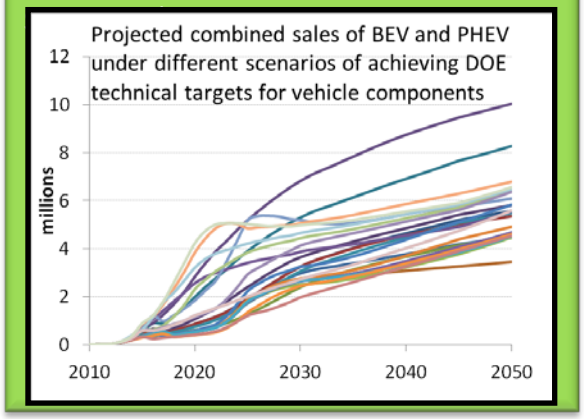
Landscape of xEV Resources from the DOE



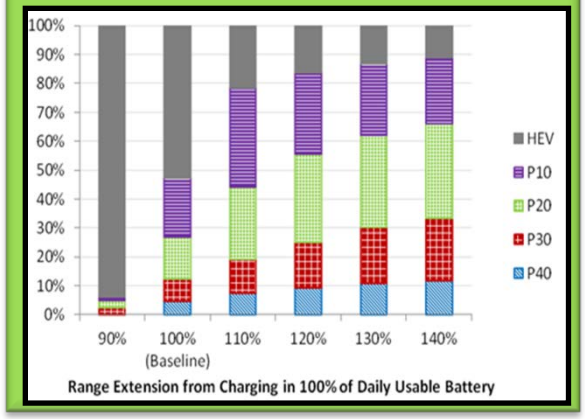
ORNL xEV Modeling Tools

ORNL has expertise in modeling the interactions between technology, infrastructure, behavior, policy and market.

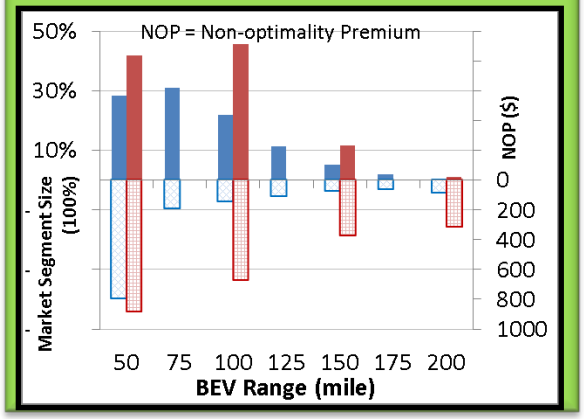
MA3T-- estimate demand for PEV by 1458 consumer



MOR-PHEV- Optimize PHEV e-range for U.S. drivers



MOR-BEV- Optimize BEV range for U.S. drivers

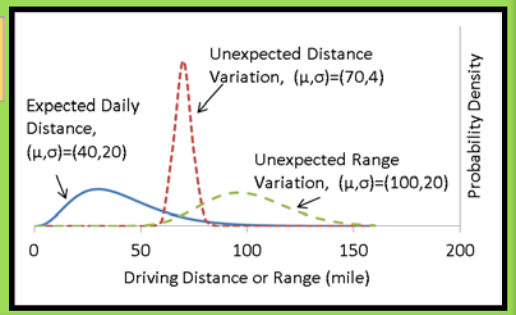


SED-- Quantify value of electric range and its sensitivity to charging infrastructure, range certainty, distance certainty, battery cost, value of

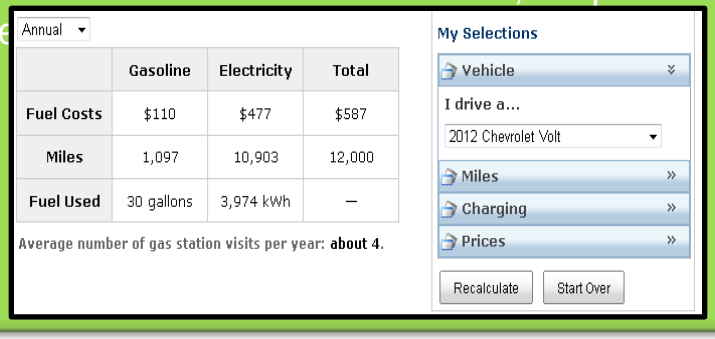
$$S = 365 S_0 \int_{R_e}^{+\infty} f(x_e)\,dx_e$$

$$E = 365 E_0 P_{ed} P_e$$

$$D = 365 D_0 P_{ed} (1 - P_e)$$



PHEV Calculator-- Estimate PHEV energy costs for individually-customized travel patterns; based on GPS-validated methods; simple que



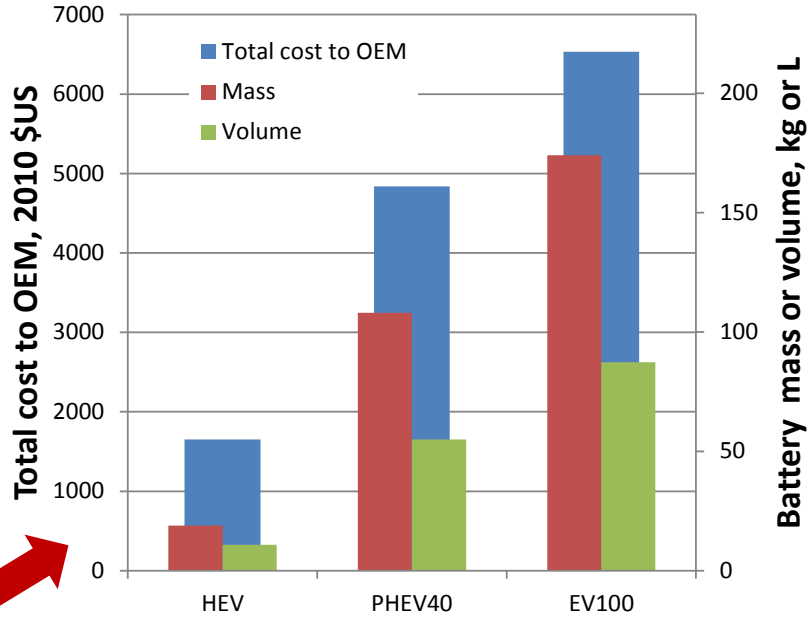
Summary of ORNL Areas of Expertise

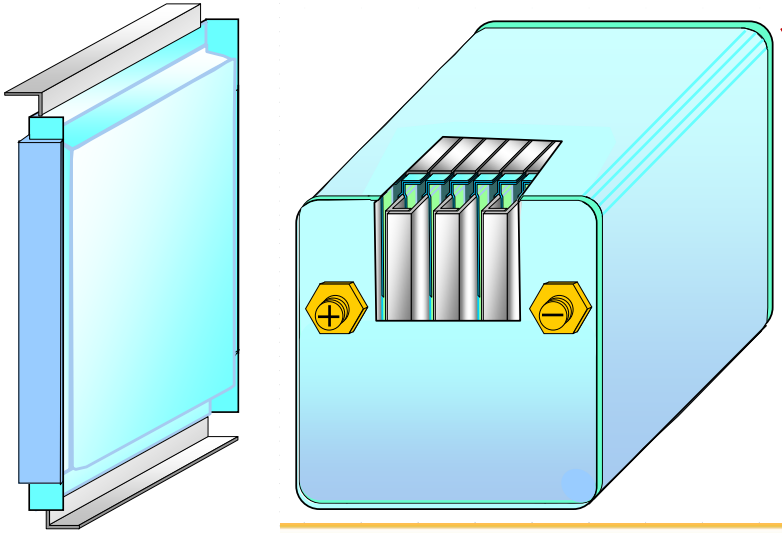
Applications of ORNL analytical tools generate insights about drivers and barriers of the PEV market, at both system and component levels.

- PEV value and travel pattern characterization
  - Lin, Z., Dong, J., Liu, C., & Greene, D. (2012). Estimation of Energy Use by Plug-In Hybrid Electric Vehicles: Validating Gamma Distribution for Representing Random Daily Driving Distance. *Transportation Research Record, 2287*(1), 37-43.
  - Lin, Z., & Greene, D. (2011). Predicting Individual Fuel Economy. *SAE International Journal of Fuels and Lubricants, 4*(1), 84-95.
  - Lin, Z., & Greene, D. L. (2011). Assessing Energy Impact of Plug-In Hybrid Electric Vehicles: Significance of Daily Distance Variation over Time and Among Drivers. *Transportation Research Record, 2252*(1), 99-106.
- Optimal vehicle design and consumer preferences
  - Lin, Z. (2012). Optimizing and Diversifying the Electric Range of Plug-in Hybrid Electric Vehicles for U.S. Drivers. *Internationa Journal of Alternative Powertrains, 1*(1), 108-194.
  - Lin, Z. (2012). *Battery Electric Vehicles: Range Optimization and Diversification for U.S. Drivers.* Paper presented at the 91st Transportatin Research Board Annual Meeting, Washington, DC.
- Charging infrastructure—needs and impacts
  - Dong, J., & Lin, Z. (2012). Within-day recharge of plug-in hybrid electric vehicles: Energy impact of public charging infrastructure. *Transportation Research Part D: Transport and Environment, 17*(5), 405-412.
  - Lin, Z., & Greene, D. L. (2011). Promoting the Market for Plug-In Hybrid and Battery Electric Vehicles: Role of Recharge Availability. *Transportation Research Record, 2252*(1), 49-56.
- Integrated analysis of PEV market and societal value
  - Lin, Z., & Greene, D. (2010). *A Plug-in Hybrid Consumer Choice Model with Detailed Market Segmentation.* Paper presented at the The 89th Annual Meeting of Transportation Research Board, Washington, DC, January 10-14, 2010.
  - (Working) Impacts of DOE technical targets on EV's demand and environmental impacts
  - (Working) Sensitivities of EV demand to consumer preferences, energy prices, and range value

Modeling Li-ion Battery Performance and Cost: BatPaC

- Modeling real-world battery packs from bench-scale data
  - Prediction year 2020
  - Total cost of battery pack
  - Mass and volumes
- Battery is designed based on pack requirements and cell chemistry performance





- BatPaC model used by U.S. EPA and DOT for 2017-2025 light duty vehicle rule making
- Support from DOE EERE VTP: Dave Howell, Peter Faguy, and Tien Duong
- Available free-of-charge from www.cse.anl.gov

Modeling Li-ion Battery Performance and Cost: BatPaC

- BatPaC is based in Microsoft Excel® and may be modified to meet individual users' needs
- Existing BatPaC capabilities includes six Li-ion chemistries, liquid and air thermal management options, uncertainty calculation, etc

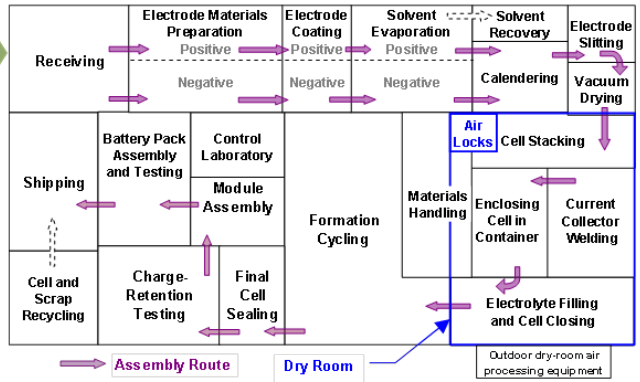
Iterate Over Governing Eqs. & Key Design Constraints

- Cell, module, & pack format
- Maximum electrode thickness
- Fraction of OCV at rated power

Battery Pack Components

- Volume
- Mass
- Materials
- Heat generation

$$Process\ cost = Baseline\ cost \cdot \left(\frac{Processing\ rate}{Baseline\ processing\ rate}\right)^{p}$$



- **Pack specifications**
  - Power and energy (range)
  - Number of cells
- **Cell Chemistry**
  - Area-specific impedance (ASI)
  - Reversible capacity C/3
  - OCV as function of SOC
  - Physical properties

Governing Equations

$$E = N \cdot C \cdot \left(U_E - \frac{C}{3}\frac{ASI_E}{A}\right)$$

$$L = \frac{C}{Q \cdot \rho \cdot \varepsilon \cdot A}$$

$$I = \frac{P}{A \cdot N \cdot U_P\left[\frac{V}{U}\right]}$$

$$A = \frac{ASI_P \cdot P}{N \cdot (U_P)^2\left[\frac{V}{U}\right]\left(1-\left[\frac{V}{U}\right]\right)}$$

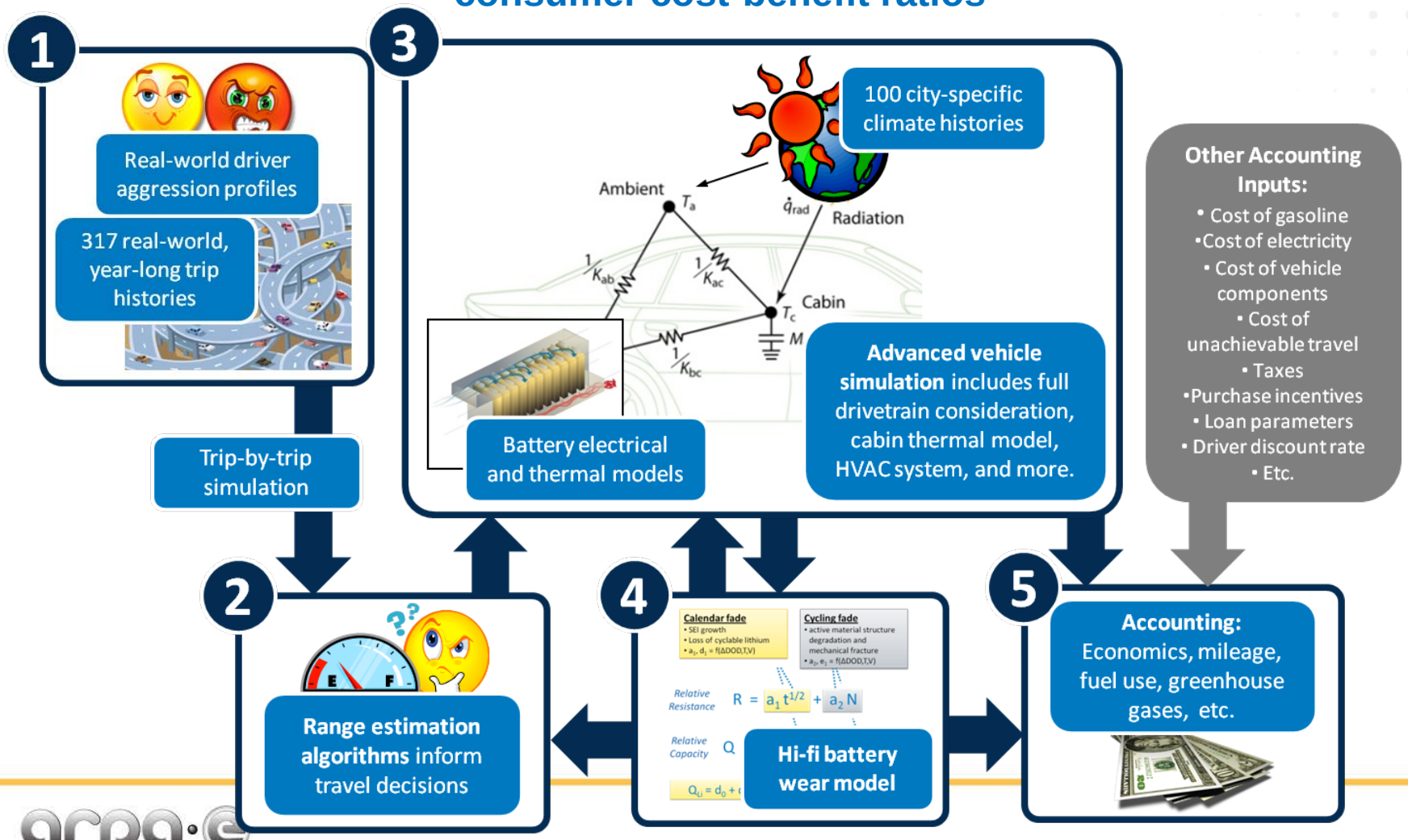
$$ASI = \frac{\alpha + f(I)}{L} + \beta$$

Total Cost to OEM

- Materials & purchased items
- Individual process steps
- Overhead, depreciation, etc.
- Warranty

NREL's Battery Ownership Model (BOM)

- **Objective: Perform accurate techno-economic assessments of HEV, PHEV, and BEV technologies and operational strategies to optimize consumer cost-benefit ratios**



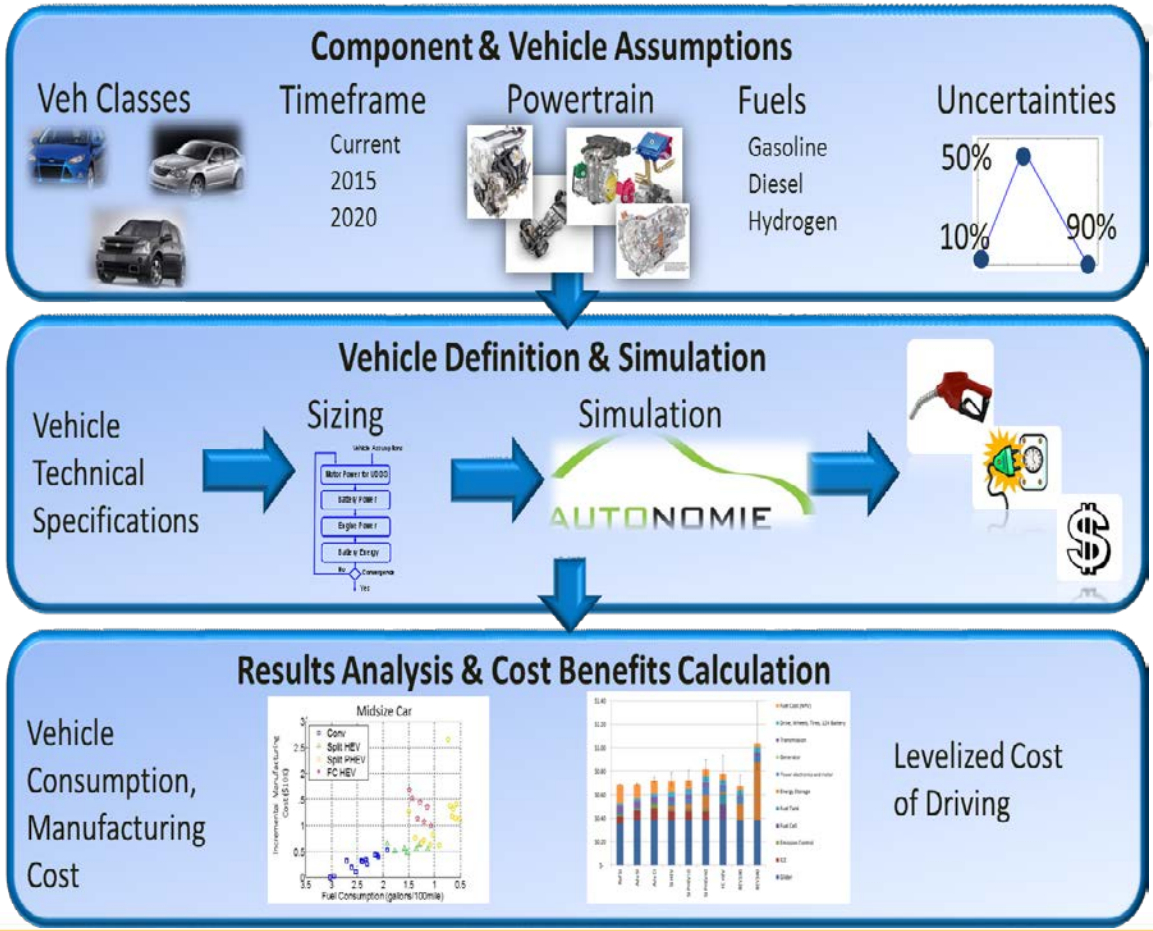
EV Everywhere Analysis Process Flow,

in three steps…

1. DOE experts **define the bounds of technical possibility** for technology key metrics
   - 90% “low progress” scenario
   - 50% “mid case” scenario
   - 10% “high progress” scenario

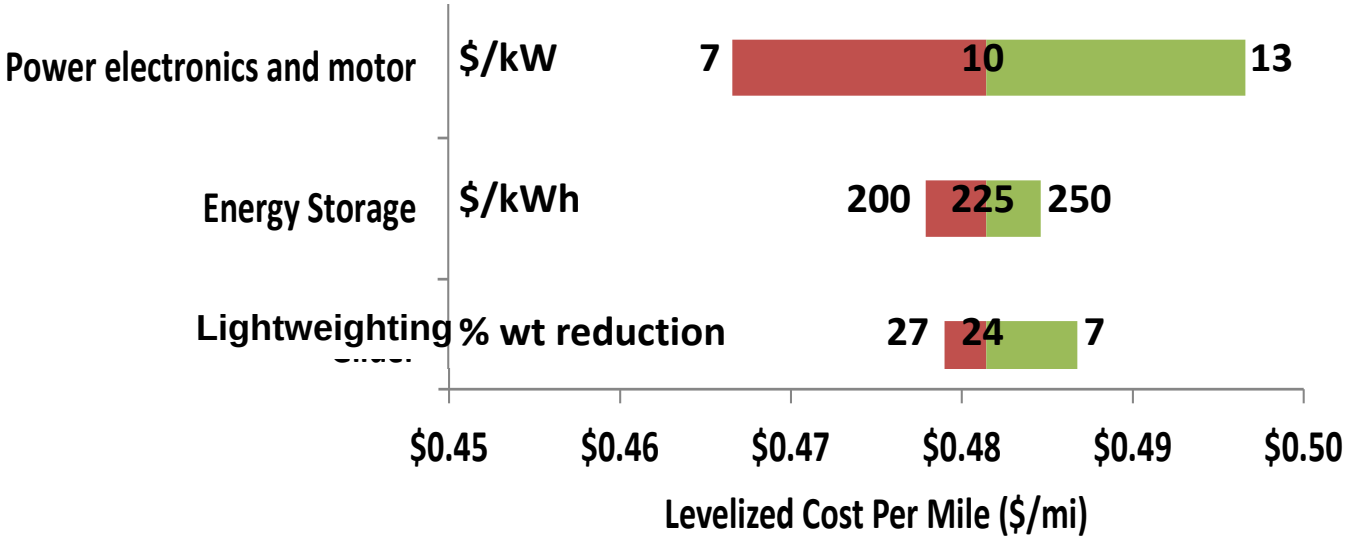
2. **Define virtual vehicles** in Argonne National Lab’s *Autonomie* modeling and simulation software

3. **Compare vehicles in a 5-year simple payback framework** within bounds defined by experts



arpa·e
CHANGING WHAT'S POSSIBLE

Analysis: 2022 Midsize SI PHEV40



$/kW	5
$/kWh	190
% wt	29

LCD-implied targets

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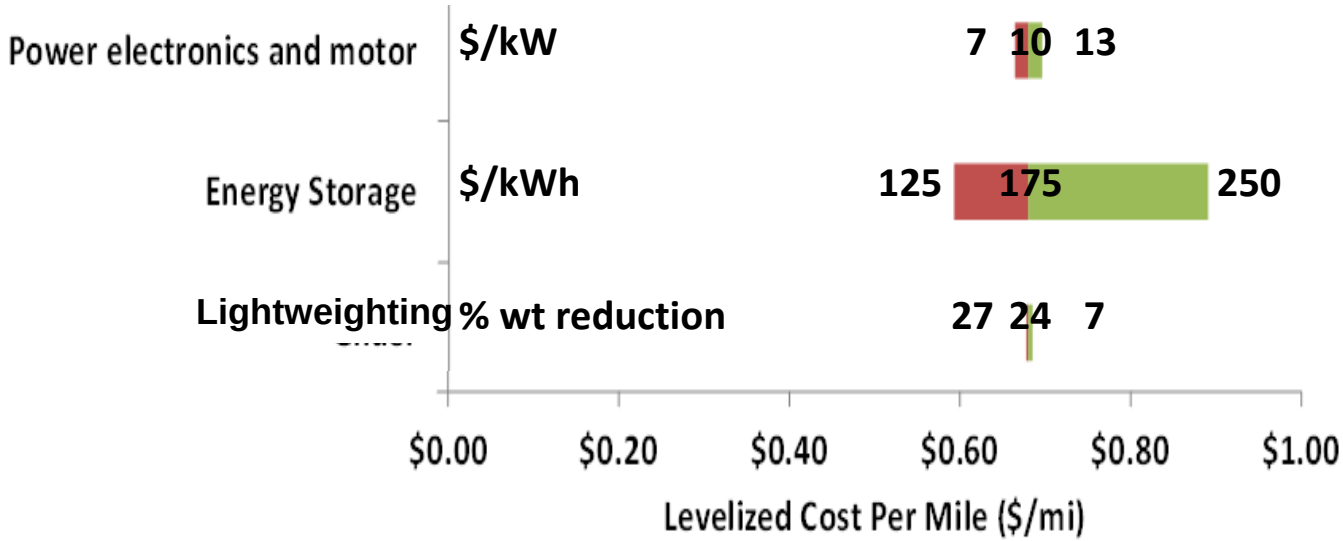
CHANGING WHAT'S POSSIBLE

Analysis: 2022 Midsize AEV300



$/kW	4
$/kWh	110
% wt	30

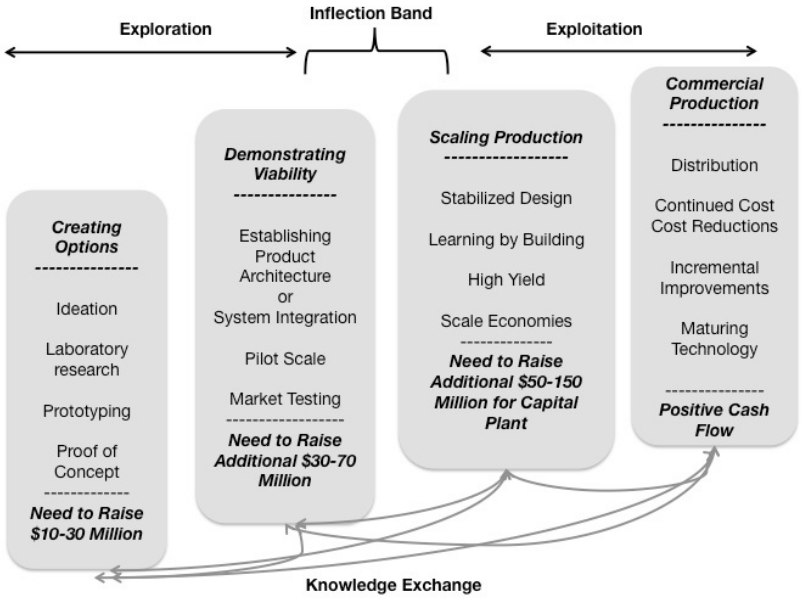
LCD-implied targets

arpa·e
CHANGING WHAT'S POSSIBLE

A Positive Program Outcome / Goal: Tap Potential of US Manufacturing

"The U.S. as One of the Developed World's Lowest-Cost Manufacturers: Behind the American Export Surge" Boston Consulting Group (2013)

- Great Productivity Adjusted Skilled Labor
- Low Energy Cost
- Low Export Shipping Cost



Lester and Hart (MIT, 2011)

Importance of Clusters, Knowledge Growth and Scaling in Manufacturing – MIT Production in the Innovation Economy Group (2013)

ARPA-e Energy Summit

- Monday/Tuesday/Wednesday February 24/25/26
  - DC area
  - Great Community building & networking
  - Many opportunities to connect to follow-on partners

- **This is a great opportunity to move project forward – prepare!**
  - What are your goals going in?
  - What message do you want to push at your poster
  - Who do you want to meet – arrange in advance