Electrification Technology (ELT)

Electric Drive Technology Analysis

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FLEX POWER CONTROL

JUNE 19, 2018

PROJECT ID: ELT088

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Project Objective and Relevance

- Understand and define drivers to enable large market penetration of electrification technologies focusing on power electronics and motors
  - Understand the market trends and needs
  - Understand how technology insertion occurs
  - Breadth and depth of technology considered
  - Viability of technology
  - Commercialization

State of Transportation

- Achievements beyond what were thought to be possible have been accomplished
  - High reliability and performance are yielding everyday driver capable vehicles, when not that long ago EVs were thought of as a second or third car only
- Vehicle Technology Electric Drive has made a difference and continues to do so
- Challenge is having technologies that enable a wide range of vehicle types and purposes

Challenges of Electrifying ICE Vehicles

- Vehicles are optimized for Internal Combustion (IC)
- Remaining open space may not be available (e.g. crash)
- Consumers don't want to make compromises in vehicle features (i.e. usable vehicle space)
- Creating benefits that offset additional cost
  - Operating cost
  - Performance benefit (i.e. AWD)

P1: Belt Driven Starter (up to 18,000 RPM)

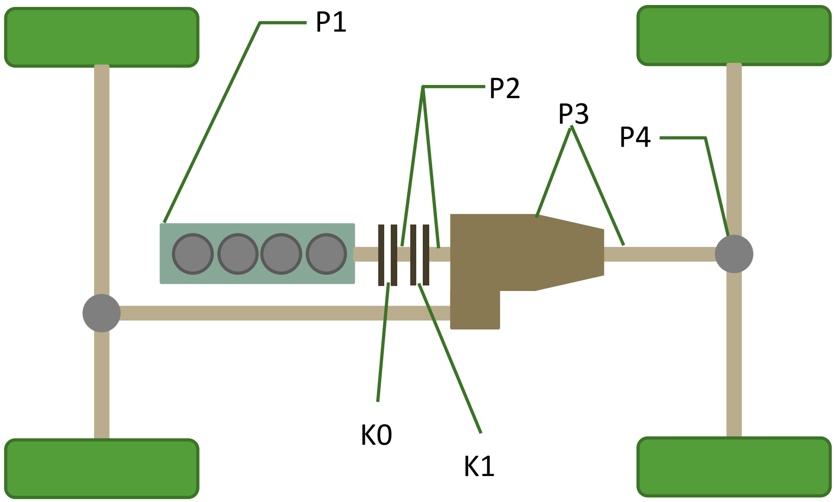
P2: Electric Machine on gear input

P3: Electric Machine on gear output

P4: Axle Drive (12,000 RPM)

K0: Clutch (Separation)

K1: Clutch (Startup)



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Hybrid Examples

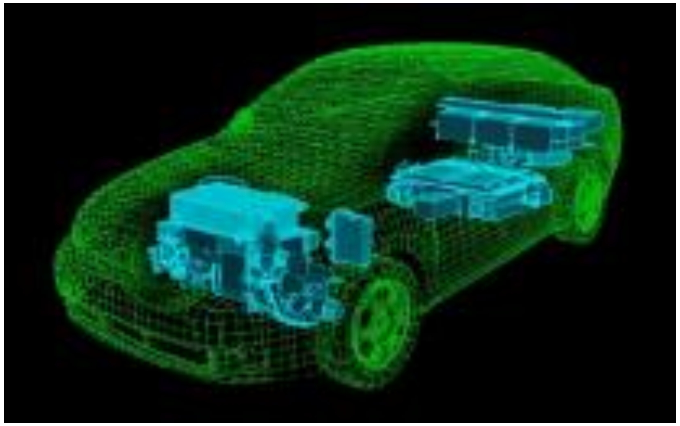
Example Conventional vs. Hybrid

- Chevrolet Malibu Hybrid
  - 4.2 Cu Ft less trunk space
  - 12V battery is moved from under hood to trunk to make room for electronics
- Ford Fusion
  - Hybrid version has 4.0 Cu Ft less trunk space
  - 12V battery is moved from under hood to trunk to make room for electronics
- Toyota Camry
  - Hybrid version has 2.3 Cu Ft less trunk space
  - 12V battery is moved from under hood to trunk to make room for electronics

EV Architectures

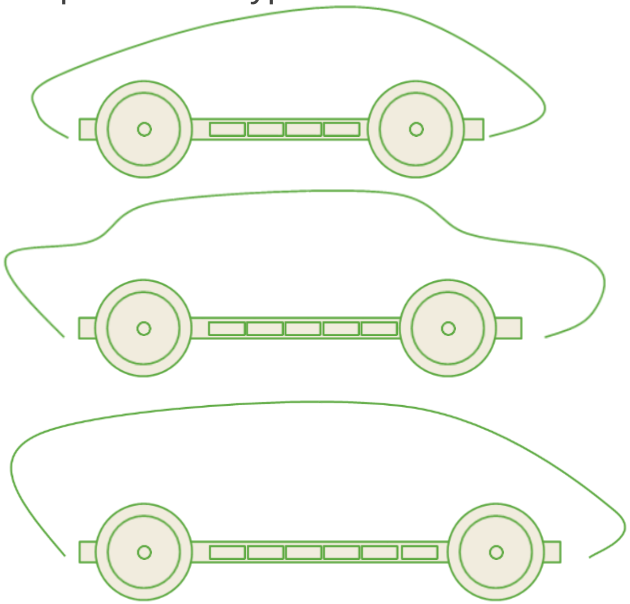
EARLY INDUSTRY EV'S

- Small vehicles
- Typically dedicated individual components for each vehicle



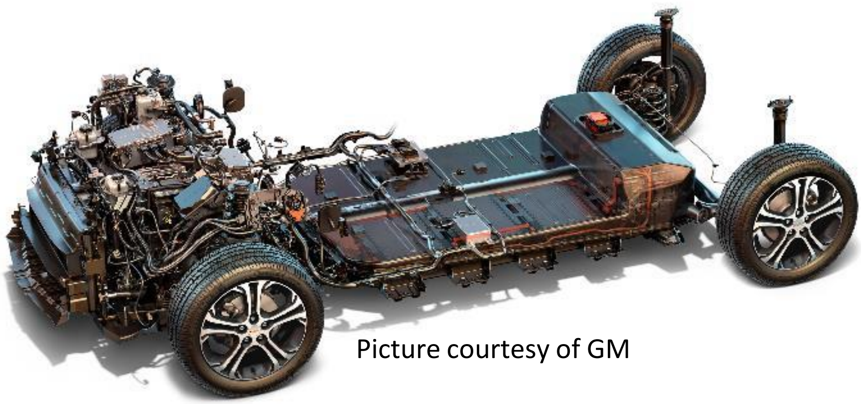
PURPOSE BUILT EV'S

- Scalable architecture
  - Small and large vehicles
  - Running chassis (skateboard)
  - Maximize useable space
  - Multiple vehicle types

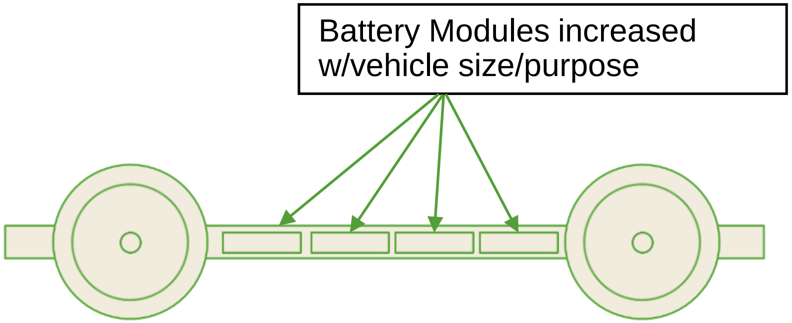


Looking Towards 2025

- Moving towards pure EVs from Hybrids
  - > 200 mile range
    - Increased consumer acceptance
  - ≥ 60 kWh energy storage
    - Required for extended range
  - Propulsion power ≥ 150 kW
    - Provide reasonable acceleration
  - Mass of vehicles > 3,500 lbs.
    - Increases in spite of light-weighting
- Integrating Powertrain into Chassis
  - Production of multiple vehicle types
  - Integration into flat package



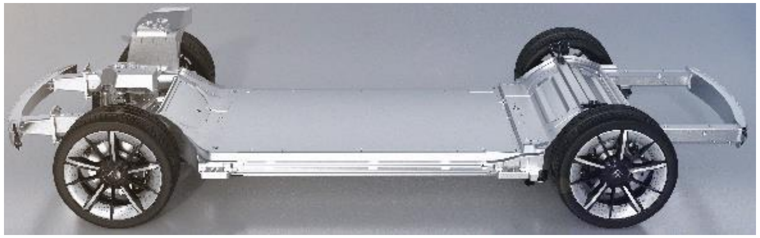
Picture courtesy of GM



Industry Adoption of Skateboard Chassis

- Skateboard increases usable space for vehicle footprint & production scalability
- Electric drive enables skateboard design
- Industry examples of skateboard chassis
  - GM Autonomy Concept
  - Tesla Model S and Model 3
  - Daimler Autonomous Concept
  - Jaguar
  - Faraday Future

Jaguar I Pace



Faraday Future

Trends in Transportation

- "Mobility as a Service"
- Fleet Perspective
- 15 year/300K miles
- Charging
  - Grid Infrastructure (GITT)
  - Battery (EESTT)
  - Power Transfer (EETT)
    - Dynamic Wireless Charging
    - Extreme Fast Charging
    - Autonomous (wireless with auto docking)

Picture courtesy of GM

R&D to Commercialization

Technology Process

R&D
(18 to 24 mo.)

Advanced Development
(18 to 24 mo.)

Product Development
(36 mo.)

Engineering Decisions

Application

- Requirements
- Form, Fit, and Function

Approach

- Dependent on Application
- Dependent on available technologies, processes, and materials

Proven Technology

- Components
- Processes
- Materials

Technology Deployment Findings

- Lack of system and component understanding of Tier 2, 3, and 4 suppliers
  - Detailed understanding of impact of supplied part/material not available
  - Trade-offs not understood
  - Unable to make timely R&D or product engineering decisions
- OEM’s and Tier 1’s desire to have engineered fundamental understanding of new technology/techniques/materials

Need: Method of continuous collaborative and coordinated technology engagement!

Strategy Based on Learning

- Accelerate innovation, understanding and adoption of technology
- Engage industry from OEMs, Tier 1, 2, and 3 suppliers, equipment manufacturers, and National Labs
- Engage National Labs and Universities for fundamental technology shifts necessary in materials and approaches

Broadening Technology

- Co-Develop with suppliers power electronics and motors
  - Design, develop, and build hardware with suppliers
  - Engage suppliers in trade-studies and testing to further mutual understanding of components
  - Educate lab personnel in limitations and trade-offs of producing part/material
  - Create fundamental understanding for suppliers so they may contribute to innovation.

Supply Base critical to meeting program targets!

Increasing Commercialization Potential

- Science out new technology/techniques/materials in a comparative study
  - National Lab job is to enable technology not create product
  - Comparative design approaches can create tremendous value by creating detailed data
  - Enables advanced development engineering decisions to incorporate technology
  - Lab work results would directly feed advanced development at OEM’s and Tier 1’s

Well defined evaluation criteria critical for commercialization!

Continuing Work

- Implementation of approach for broadening technology base and increasing commercialization
  - Establishment of process and procedures
    - Working Documents
      - Defines tasks to be performed
      - Goals and objectives of technology evaluation
      - Roles and responsibilities
    - Exit Criteria
  - Building supplier involvement
    - Engaging supply base on the 2025 inverter and motor
    - Developing ongoing working relationship between suppliers and National Labs

Any proposed future work is subject to change based on funding levels

Summary

- **Relevance:** Understand and define drivers to enable large market penetration of electrification technologies

- **Approach:** Work with OEM's, supply base, and researchers on identifying, understanding, and documenting barriers of introducing technology

- **Collaborations:** Working with the supply base, OEMs, National Labs, and DOE

- **Technical Accomplishments:**
  - Decision drivers identified
  - Process GAPS
  - Broadening Technology
  - Commercialization

- **Future Work:** Implementation of process and continued engagement

Any proposed future work is subject to change based on funding levels

Backup Slides

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Initial Collaboration

Critical Technology Elements

- The Ames Laboratory — Creating Materials & Energy Solutions — U.S. Department of Energy
- Argonne National Laboratory
- NREL — National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- USCAR — United States Council for Automotive Research LLC

OEM	Ford; FCA Fiat Chrysler Automobiles; GM; John Deere
Tier 1	AC Propulsion; BorgWarner; Delphi; UQM Technologies
Tier 2	ABB; AK Steel; AVX A Kyocera Group Company; Infineon; SBE; Semikron innovation+service; Kyocera; Wolfspeed
Tier 3	ATT Advanced Thermal Technologies; GE Global Research; Henkel; Heraeus; Indium Corporation; Interplex Industries, Inc.; IIC Indiana Integrated Circuits; LORD; Momentive inventing possibilities; Storm Power Components; Rogers Corporation; Wolverine Tube, Inc.

Critical Assumptions and Issues

- Critical assumptions
  - Information provided by all constituents was given accurately
  - All parties have a vested interest in successful deployment of electrification technology
  - Technology process is flexible and can be adjusted as appropriate by constituents
- Mitigation strategy
  - Continued engagement and consensus of broad based coalition of stakeholders

Approach/Strategy

- Work with OEM's, supply base, and researchers on identifying, understanding, and documenting barriers of introducing technology
- Broaden technology base
  - Adapt technology to new uses
  - Incorporate/enable supply base technology into electrification 2025 goals
- Align and facilitate introduction of next generation of power electronics and electric machine devices and materials (i.e. WBG, covetic materials)
  - Reduce cost of the traction drive system by 50%
  - Reduce size of the traction drive system by 90%
  - Reduce cycle time from R&D to commercialization by 30%
- Uniqueness - Evaluates technology insertion as an ecosystem/process

Major Challenges and Barriers

- Cost still remains the leading factor
- Size and mass constrain the number of vehicle applications
- The need for higher power devices driven by market demand
- Taking advantage of Wide Band Gap requires significant technology changes over current Silicon based systems
  - Electrical performance and temperature capability of packaging
- Decrease motor cost that is predominately driven by total material and overall size of the motor
  - Developing New Magnets without Heavy Rare-Earth and Non-Rare Earth Magnets
  - Developing Electrical Steels
  - Developing Motor designs without Heavy Rare-Earth that meet targets
- Motor Efficiency
  - Dependent on system need and specific motor application

Industry View

- Research focuses on addressing those gaps that are not or can't be worked by industry
  - Special technical knowledge needed to address
  - Analytical capability/resources to understand fundamental elements
- Identified technology gaps
  - OEMs driven
    - 100kW and greater WBG inverters
    - Micro packaging of power electronics
    - Non-rare earth machines
    - Improved materials and processes (i.e. copper, steel, etc.)
  - Supplier base driven
    - System trade-offs
    - Standard tests and requirements understanding
      - What does it mean as you move toward margins of performance
- Production scale needed to be competitive 500K units per year