POWERTRAIN STRATEGIES FOR THE 21ST CENTURY: NEXT GENERATION ELECTRIC VEHICLE STRATEGIES
CONFERENCE SUMMARY

Bruce Belzowski: Managing Director, Automotive Futures, UM Transportation Research Institute
- Federal government established new CAFÉ regulations for all manufacturers selling in the US in 2012
- Footprint-based GHG standards curves for MY2022-2025 are projected to achieve an industry-wide fleet average CO2 target of 175 g/mi in MY2025
- Augural CAFE standards are projected to result in average CAFE requirements increasing from 38.3 mpg in MY2021 to 46.3 mpg in MY2025
- Powertrain Strategies Survey
  - Fuel prices: the 2012 survey, they expected high increase, the 2014/2015 survey expects a smaller increase
  - Consumer Fuel Price Sensitivity: when consumers will make fuel economy a primary concern in new vehicle purchase: $4.55 per gallon
    - Consumers will consider purchasing a vehicle with an alternative powertrain: $5.01 per gallon
  - Expected growth in the use of ethanol, diesel, and electricity by 2025 for passenger cars
    - Light trucks by 2025: ethanol, diesel, compressed natural gas
  - Expected significant growth in hybrid passenger vehicles
    - Expected increase in hybrids and diesels for light trucks
  - Consumers are not willing to pay enough for manufacturers to produce alternative powertrains in 2025
- Engine Report:
  - Adjusted fuel economy:
    - Asian brands lead with the exception of Mazda leading at 32.8 mpg for cars
    - Total: Asian brands ahead with exception of Mazda
  - CO2 emissions:
    - American manufacturers have the highest CO2 emissions
  - Vehicle Footprint:
    - American manufacturers have the highest values

Sergio Muniz: UMTRI AF Visiting Researcher (from Federal Technological University of Parana, Brazil)
- Discussed his research into manufacturer EV strategies including their platform, marketing, and charging infrastructure strategies
- Consumers needs in electric vehicles market:
  - Cost:
    - Price of EV compared to ICEV (Internal Combustion Engine Vehicles)
- Price of gasoline compared to electricity
  - Mobility:
  - Vehicle’s electric range
  - Charging infrastructure
  - Charging time
- Platform concept in automotive industry is strictly related to a vehicle’s chassis even in flexible platforms
- Adapte1d Electric Platform (AEP)
  - Advantages: can reduce costs by commonality, economies of scale and scope
  - Disadvantages: Range limitation, can compromise dynamics of the vehicle, limitations on interior space and comfort
- New Electric Platform (NEP):
  - Advantages: conceive a BEV on a new basis
  - Disadvantages: higher costs associated to a new dedicated platform
- Electric Vehicle’s Design:
  - New Electric Vehicle Concept Design (NEVD)
  - Adapted Electric Vehicle Design (AEVD)
- Ford’s Electric Vehicle Platform Strategy:
  - Develop their EVs on the same ICEVs platforms and offer a considerable range of electric vehicles
- Volkswagen’s Platforms:
  - MQB platform:
    - Flexible platform in terms of powertrains and vehicle’s chassis
    - Launched in 2012 for all VW group brands
  - MEB platform:
    - All-new platform for the manufacturing of new all-electric (BEV)
    - Launched after the Diesel Emissions Scandal
- General Motor’s Platform:
  - Reduce platforms world-wide
  - New generation of Volt (PHEV) pure electric range improved to 53 miles
- Nissan’s Platform:
  - Common Modular Family (CMF):
    - Announced in 2012
    - Modular architecture strategy
    - Core modules allows a variety of combinations to produce a variety of models at the same platform
    - Goal is to increase common modules to a wide range of models and car segments
- BMW’s Platform:
  - Developing a new electric car platform called FSAR (Flat Battery Storage Assembly) and will be closely associated with BMW’s new CLAR (Cluster Architecture), the new RWD architecture
- Mercedes-Benz’s Platform:
  - Company announced their 5th new platform for their electric vehicles: EVA (Electric Vehicle Architecture) with the first model built on it will be launched by 2018 or 2019
  - Plans to base at least 4 electric vehicles models on this platform: two sedans and two SUVs
    - Powered by an electric motor at either axle, enabling all-wheel drive
    - Multi-model vehicle architecture enables various body styles
Mercedes plans to produce its own batteries

- Tesla’s Platform:
  - Model S and Model X share the same platform, but Tesla Model 3 created a new vehicle platform that will include a sedan and will also be the basis for the Tesla’s next generation Crossover

- Toyota’s Platform:
  - 2016 Prius is based on Toyota New Global Architecture (TNGA) concept, a worldwide modular architecture
    - Many platforms will be created as long as new models will be developed

- Fiat-Chrysler’s Platform:
  - goal is to reduce platforms and increase commonality of parts and components among models and FCA brands
  - Improve architectural convergence and synergies: common systems/components and unique modules

- Peugeot-Citroen-DFM’s Platform:
  - announced 2 new electric vehicle platforms on which the company will base 4 new BEVs and 7 new PHEVs on by 2019-2021
  - PHEVs will be based on PSA’s Efficient Modular Platform-2 and will allow for up to 38 miles
  - Common Modular Platform (CMP) was developed with Dongfeng and has a variant compatible to BEVs compact city cars, sedans and compact SUVs

- Infrastructures in the USA include 13,957 electric stations and 34,522 charging outlets
  - Compared to about 170,000 gas stations

**Jonathon Ratliff**: Manager of Zero Emission Vehicles at Nissan Technical Center

- Discussed the improvements in the new generation Nissan Leaf
- EV customer expectations:
  - Range: mileage per charge
  - Drivability: driving performance
  - Charging: easy to charge
  - Cost of the vehicle

- Technology Trend:
  - Driving range: Double driving range in the near future
  - Drivability: increased motor power, plus AWD
  - Charging: QC power increase with battery capacity

- Technical Breakthrough of EV:
  - Focus on higher capacity battery, higher power e-powertrain, and convenient charging
  - Battery technology: affects autonomy range expansion, further acceleration performance, and flexibility for various vehicles
    - Focus on high energy density and high power density
    - Cell material and module innovation: improve chemical structure, increase the number of cell-stacking (high-density stacking)
    - Packaging innovation: more than 2 times the battery capacity within the same size constraints as the current one
  - E Power-Train: affects autonomy range expansion, further acceleration performance, and flexibility for various vehicles
    - Magnet innovation:
- Reduced Dy contents in the magnets by 40%, applying the grain boundary diffusion magnet technology
- Towards 2020, further Dy reduction and/or zero to be expected
  - Electromagnetic steel innovation:
    - Used Silicon steel (Electromagnet steel sheet) of less than 0.35 mm in thickness
    - Thin iron plate expected small iron loss and high efficiency
  - Power Semiconductor innovation:
    - Wide band gap technologies expected for system-level improvement
  - Electric drive enables high power models: game change of high power models by common EV assets and dedicated PF
- Charging:
  - High-power quick charge:
    - Widening standard and developing technology needed for infrastructure, vehicles, and batteries
    - Goal is to move over 100 kW
  - Wireless Charging System

Janghwan Shin: UMTRI AF Visiting Researcher (from LG, Korea)
- Discussed the results of his year-long research about the future technology trends in electric vehicle battery and its impact on advanced powertrain performance
- Energy density for longer range is a requirement for EV battery
- EV battery components:
  - Cell:
    - Excellent stability based on separator technology
    - Lightweight pouch that generates little heat
    - Secured competitiveness in the material through raw material development
  - Module:
    - Easy to change the designs according to customer’s requirements
    - Variety of cooling systems can be applied
  - Pack:
    - Efficient cooling system and highest stability
  - BMS:
    - Accurate battery management system through proprietary algorithm
    - Smooth communication between the automotive and battery software
- Next generation battery:
  - Advanced LiB:
    - Advanced cathode (high voltage)
    - New anode (metal series)
    - Advanced electrolyte
  - Post LiB:
    - New material (sulfur, air, etc.)
    - New anode (Lithium metal)
    - Solid electrolyte
- Evaluation criteria for new technology:
Practicability of new technology:
- Perform as a product
- Possibility of Mass production

Compatibility as vehicle component:
- Compatibility as electrical vehicle component:
  - Cost, weight, safety, comparability
  - Charging convenience
  - Driving performance

Promising Technologies:
- Lithium-Sulfur Battery: 600-2600 Wh/kg
  - Pros:
    - Higher energy capacity
    - Sulfur is cheap and abundant
    - Similar operation and manufacturing process with LiB
  - Cons:
    - Limited life cycle
    - Corrosive material
    - Lower voltage and conductivity
    - Lithium metal availability and dendrite forming

- Solid-state Battery: 400-800 Wh/kg
  - Pros:
    - Nonflammable and superior safety
    - Enables lithium metal anodes
    - Enables high voltage cathodes
    - Reduced mass and cost
    - Performs at high temperatures
  - Cons:
    - Lower ionic conductivity
    - Limited low temperature performance
    - Interface and system integration
    - Needs to design new manufacturing process

- Lithium Air Battery: 700-11,000 Wh/kg
  - Pros:
    - Highest energy density
    - Needs anode material only (no cathode material)
    - Lighter weight
  - Cons:
    - Short life cycle
    - Requires a device for pure oxygen
    - Low conductivity and poor power output
    - Lithium metal reliability

Advanced EV powertrain should have 5-6 times more driving range by advanced EV powertrain
Advanced Lithium battery will take us to the future
- Post Lithium battery may not be needed
Ou-Jung Kwon: Cell Chemistry Technical Expert, Electrified Powertrain Engineering at Ford Motor Company

- Discussed Ford’s work with the UM battery lab and how the relationship with UM provides Ford with important battery R&D support
- R & D $2.1 million investment in a battery lab at UM to boost research and development
- Electrified vehicle demand moves in the similar way as fuel price
- Ford leads in the number of Lithium Battery vehicles sold in the US
- R&D needs:
  - Need a stepping stone scale where the complexities of the modern manufacturing technology are included, but at a scale that is manageable in a research context
  - Gap between an EV cell and a coin cell is too large to allow for meaningful extrapolations on performance, durability, safety, and manufacturing feasibility and cost
- Ford collaborated with U of M
- The Partnership:
  - Better utilization of equipment, higher level of expertise possible in a well-staffed and well-used facility
  - Close collaborations with U of M staff, students, and other partners
  - UMEI provides facilities and dedicated technical staff
- Vision for the Ford/UM/MEDC Battery Fabrication Lab
  - Multiple scales for cell fabrication
  - Highest quality fabrication equipment
  - Support multiple start-up companies
  - Support ARPA-E and USABC
- Fabrication and testing of smaller cells have several benefits:
  - Faster, less expensive testing
  - Validation of electrochemical models
  - Exploration of cell designs and robustness of manufacturing processes
- Steps:
  - Pilot Scale Mixing: very important in battery development
    - Planetary Mixer:
      - 2-3 hours mixing time
      - 3-5 L Working volume
      - Max 75 rpm (planetary) and 7500 rpm (homogenizing disperser)
  - Pilot Scale Coating:
    - Multi-Head Coater
      - Slot-die, comma reverse, micro-gravure
      - Continuous and intermittent pattern coating
      - 2 drying zones with 4 meter oven, IR heater in 1st zone
      - Edge positions and auto tension control
      - Max 5 meter/min coating speed
  - Pilot Scale Calendering Press and Slitting
    - Calendering Press:
      - 60kN press
- Heated roll, up to 150 degrees Celsius
- Edge position and auto tension control
- Max 10 m/min
- **Slitter:**
  - Multiple material capability
  - Spacer changeable knife cartridge
  - Max 10 m/min
- Cell Assembly in Dryroom
- 18650 cells: what Tesla is making (follows a linear model on the chart for energy density)
- Ford is making the Automotive Cell (has more of an exponential graph for energy density)
- Future Ford’s Automotive LIB R&D:
  - **Material:**
    - Next generation materials
    - Strategic materials
  - **Manufacturing:**
    - Cell design and process
    - Performance and safety testing
    - Cost analysis
  - **Management:**
    - Electrochemical and thermal model
    - Prediction of battery performance and degradation under vehicle dynamic condition
    - Integration with vehicle simulation and control algorithm development

**Jacob Bemrich**: Systems Engineering Manager, Robert Bosch Battery Systems LLC
- Discussed the lithium ion trends for electrified mobility including high voltage and 48-volt systems
- **Influence variables on eMobility:**
  - Infrastructure
  - User experience UX
  - Business models
  - Technology
  - Megatrends
  - Legislation
- PHEV and EV with strong growth in market volume
- HEV growth decreasing
- Customer expectations towards an EV:
  - Driving range greater than or equal to 350 km
  - Good performance
  - Fast charging
  - No battery exchange during vehicle life
  - Reasonable safety
  - Affordable
- Energy Density: Need to increase 3x by 2025 to supply what consumers want
- Cost: Needs to decrease 4x by 2025 to supply what consumers want
- Battery Cell Technologies
• Market until 2020 dominated by Li-ion technology
• Energy density in 2020 already close to the technical limit of LIT
• Post Li-ion Technologies (PLIT) with potential for higher gravimetric and volumetric energy densities in combination with improved safety
• EVs w/ SOP >2020
• PLIT with solid state electrolyte is very promising

• PLIT cell technologies:
  o At least one electrode not intercalating lithium
  o Cells with metallic Lithium anode are counted among PLIT

• Solid state cells:
  o Bosch acquired Californian battery technology company Seeo
  o Engineering prototype cells available

• Solid state cells: Safety
  o Safety test results show that there were no smoke or flame during crush, penetration test, short circuit test, thermal shock, over-discharge, overcharge
  o Stable up to 180 degrees Celsius

• Li-ion technology will dominate the market until 2020
• Technical limit of automotive Li-ion expected at ~350-400 Wh/kg
• Post Li-ion with potential to further increase energy density and to reduce cost
• Solid state cells for EV expected to be ready for series past 2020
• Bosch 48 V Mild HEV:
  o BRS 48V shows considerable market growth
  o 48V seen as a bridge to a higher voltage future
  o Power-net requirements may drive manufacturers towards 48V solutions
  o New concepts may change the landscape

Ram Vijayogopal: Argonne National Laboratory
• Discussed his recent research that compares the powertrain energy densities of electric and gasoline vehicles over a 30-year timeframe and across three different vehicle types by examining projected changes in vehicle weight reduction, battery technologies, powertrain components, power and energy requirements, and powertrain energy and power densities
• Specific energy of gasoline is about 100x that of the present day batteries
• Consider useful energy output; energy out is more important than energy in
• Assumptions regarding technology improvements:
  o Weight reduction:
    ▪ Reducing glider mass helps both conventional & BEVs
    ▪ BEVs can reduce energy storage for every kg saved by light weighting
    ▪ By 2045, a BEV 300 could weigh the same as a conventional vehicle
• Future BEVs will have much lighter battery packs
  o Approximately 75% lighter than present packs
    ▪ 2017 goal for JCSER: 400 Wh/kg
    ▪ Long term goals: over 500 Wh/kg
• Vehicle energy consumption shows BEVs are more efficient
• BEVs have lower net energy consumption at wheel due to regenerative braking
• For all vehicles, energy consumption decreases as technology progresses
  o Vehicle energy consumption decreases over time due to advanced technologies
    ▪ Light weighting
    ▪ Decreased component losses
    ▪ Improved transmissions
• Conventional and BEV powertrain specific energy variation shows opposite trends
  o Both powertrain see a decrease in energy consumed or required
  o BEVs have a much larger decrease in weight compared to conventional, resulting in an opposite trend
• Energy density advantage of gasoline to battery could be halved by 2030
• When mass of powertrain is considered, advantage of gasoline over battery is reduced by a factor of 10
• When powertrain mass and efficiency are considered, advantage of gasoline over battery is further reduced