The Electrification of the Automobile
Electric Drive Systems and Components

Larry Nitz
Executive Director
General Motors
2020

>1 billion vehicles
~3% annual growth worldwide
96% Dependence on Petroleum

35% of World’s Energy Comes from Petroleum
GM Strategy: Displace Petroleum Through Energy Diversity
Energy Diversity – Blending Strategy
“Liquid Fuels/Electricity/Hydrogen” as the In-Vehicle Energy Carriers

**Energy Resource**
- Oil (Conventional)
- Oil (Non-Conventional)
- Biomass
- Natural Gas
- Coal
- Renewables (Solar, Wind, Hydro)
- Nuclear

**Conversion**
- Petroleum Fuels
- 1st & 2nd Gen. Biofuels
- Syngas CO, H₂

**Energy Carrier**
- Liquid Fuels
- Regional Niche ICE
- Regional Niche Gaseous Fuels (e.g. CNG)
- Electricity
- Range-Extended EV: IC Engine/Fuel-Cell

**Propulsion System**
- Conventional ICE: Gasoline/Diesel
- ICE Hybrid
- Plug-In Hybrid ICE
- Battery Electric
- Fuel-Cell Electric

**Electrification**
GM Advanced Propulsion Technology Strategy

- Improved FE reduced Emissions
- Displace Petroleum
- IC Engine and Transmission Improvements
- Hybrid Electric Vehicles (PHEV)
- Battery Electric Vehicles (EREV)
- Hydrogen Fuel Cell
- Improved FE reduced Emissions

Energy Diversity

Petroleum (Conventional & Alternative Sources)

Alternative Fuels (Ethanol, Bio-diesel, CNG, LPG)

Electricity (Conventional & Alternative Sources)

Hydrogen
Electrification Begins: 1912 Cadillac

Geared Starter / Generator
Electrification Emerges Again: 1997 EV1

- Great Car
- Great Drivetrain
- Enthusiastic Customers
- Limited by “Range Anxiety”

Electric Drive
Induction Motor
103 kW peak; 35 kW cont.
10.9 single gear reduction

Power Electronics
54 liters
Today’s Electrification Opportunities
Portfolio of Solutions for a Full Range of Vehicles

- Mild Hybrid – BAS
- Full Hybrid – 2-Mode
- PHEV – 2-Mode
- EREV – Voltec
- FCEV – EV Drive

Electricity – ZEV Fuel
Today’s Electrification Opportunities
Portfolio of Solutions for a Full Range of Vehicles

All Use:
- 1 or 2 Large Electric Motors
- 1 or 2 Large Power Inverters
- High power or high energy battery
- “By-wire” controls of propulsion and braking
System Engineering the Chevy Volt

- Electrical
- Powertrain
- Thermal
- Chassis
- Interior
System Engineering the Chevy Volt

**Interior**
- HMI
- Electric Waterpump
- Electric A/C

**Electrical**
- High-Voltage Distribution
- HV Battery (Li Ion)
- HV Cables-DC
- HV Cables-AC
- Electric Power Steering
- Regenerative Brake System
- Electric Drive Unit

**Thermal**
- Electric Waterpump
- Electric A/C

**Powertrain**
- Power Electronics
- Engine

**Chassis**
Electric Drive Systems and Components

Key enablers for Automotive Electrification

Traction Battery
Software Controls
Power Electronics

Electric Drive with Integrated Motor
Electric Drive Software and Controls

- Safety Critical System: Torque and Direction Security
  - Accelerator “interpretation”, Shifter Direction
  - Processor checks, High voltage checks, Torque response error checks
  - Fail-soft actions to maximize system fault tolerance
  - 600 specific system and component diagnostics
Electric Drive Software and Controls

- **Safety Critical System: Torque and Direction Security**
  - Accelerator “interpretation”, Shifter Direction
  - Processor checks, High voltage checks, Torque response error checks
  - Fail-soft actions to maximize system fault tolerance
  - 600 specific system and component diagnostics

- **Integrated Computer Network:**
  - >10 processors networked
  - 3 high speed communication links
Electric Drive Software and Controls

- **Safety Critical System:** Torque and Direction Security
  - Accelerator “interpretation”, Shifter Direction
  - Processor checks, High voltage checks
  - Fail-soft actions to maximize system fault tolerance
  - 600 specific system and component diagnostics

- **Integrated Computer Network:**
  - >10 processors networked
  - 3 high speed communication links

- **Hybrid System Functional Domain**
  - Real time optimizer – engine, motors, battery, drive unit
  - Engine Start/Stop control
  - By-Wire blending of regenerative and friction braking
  - Actively dampen driveline
  - Switch current to motors for best torque/efficiency
Electric Traction Motors

- High Torque / Power / Efficiency
  - Motors designed with modern magnetic FEA tools
  - Motors designed as integrated part of an electric drive with interconnections, thermal and Rotor-Stator GDT
Electric Traction Motors

- **High Torque / Power / Efficiency**
  - Motors designed with modern magnetic FEA tools
  - Motors designed as integrated part of a electric drive with interconnections, thermal and Rotor-Stator GDT

- **Automotive Cost**
  - Low cost components and production methods
    - PM motors use rare earth types magnets
    - Low cost position sensor or sensor-less
Electric Traction Motors

- **High Torque / Power / Efficiency**
  - Motors designed with modern magnetic FEA tools
  - Motors designed as integrated part of an electric drive with interconnections, thermal and Rotor-Stator GDT

- **Automotive Cost**
  - Low cost components and production methods
    - PM motors use rare earth types magnets
    - Low cost position sensor or sensor-less

- **Extremely Low Noise**
  - Very low torque ripple and stator strain design methods
  - Drive Unit motor interface designed to mitigate noise paths
Electric Traction Motors

- **High Torque / Power / Efficiency**
  - Motors designed with modern magnetic FEA tools
  - Motors designed as integrated part of an electric drive with interconnections, thermal and Rotor-Stator GDT

- **Automotive Cost**
  - Low cost components and production methods
    - PM motors use rare earth types magnets
    - Low cost position sensor or sensor-less

- **Extremely Low Noise**
  - Very low torque ripple and stator strain design methods
  - Drive Unit motor interface designed to mitigate noise paths

- **Automotive Quality**
  - Six Sigma design and process capability
Power Inverters

- Automotive Packaging Size
  - Miniaturization
  - Ruggedization
  - Temperature and Vibration tolerance

\[ \sim 20L \text{ today} \rightarrow \sim 7L \text{ future} \]
Power Inverters

- **Automotive Packaging Size**
  - Miniaturization
  - Ruggedization
  - Temperature and Vibration tolerance

- **Low Loss Motor Currents Switching**
  - Advanced Commutation Control
  - Improved Power Semiconductors
    - Silicon IGBT, SiC, GaN FETs

~20L today → ~7L future
Power Inverters

- **Automotive Packaging Size**
  - Miniaturization
  - Ruggedization
  - Temperature and Vibration tolerance

- **Low Loss Motor Currents Switching**
  - Advanced Commutation Control
  - Improved Power Semiconductors
    - Silicon IGBT, SiC, GaN FETs

- **Automotive Cost**
  - Connector and cables
  - Power module construction
  - Film capacitor size and package
Chevrolet Volt - Advanced Battery Technology

Creating the “Practical EV”

- 16 kWh (~8 kWh usable)
- 40 miles of EV driving
- High energy, high power for EV
- Charging: ~ 3 hours @ 220 Volts
- ~ 8 hours @ 110 Volts
- Life: >10 years/150,000 mi
Battery Pack/Cell

- **Automotive Life**
  - Battery systems with >10yr / 150k mile life
  - High capability pack thermal systems
  - HV interconnections, monitoring, control
Battery Pack/Cell

➢ **Automotive Life**
  – Battery systems with >10yr / 150k mile life
  – High capability pack thermal systems
  – HV interconnections, monitoring, control

➢ **Automotive Costs**
  – Large format cells – new chemistry and materials
  – Automotive volume manufacturing systems
  – Smart integration of thermal and control functions
Battery Pack/Cell

- **Automotive Life**
  - Battery systems with >10yr / 150k mile life
  - High capability pack thermal systems
  - HV interconnections, monitoring, control

- **Automotive Costs**
  - Large format cells – new chemistry and materials
  - Automotive volume manufacturing systems
  - Smart integration of thermal and control functions

- **Automotive Safety**
  - Safe cell, safe pack, safe monitoring, safe control
Battery Pack/Cell

- **Automotive Life**
  - Battery systems with >10yr / 150k mile life
  - High capability pack thermal systems
  - HV interconnections, monitoring, control

- **Automotive Costs**
  - Large format cells – new chemistry and materials
  - Automotive volume manufacturing systems
  - Smart integration of thermal and control functions

- **Automotive Safety**
  - Safe cell, safe pack, safe monitoring, safe control

- **Automotive Quality**
  - Six Sigma design and process capability
  - Supplier / OEM / R&D teamwork
Advanced Propulsion Technology Cost Reduction
Enabled through Generational Learning

- Limited cost reduction opportunities within a given design generation
Advanced Propulsion Technology Cost Reduction
Enabled through Generational Learning

- **Limited** cost reduction opportunities within a given design generation
- Some efficiencies gained through **increased volume**
Limited cost reduction opportunities within a given design generation

Some efficiencies gained through increased volume

Significant cost reduction enabled through generational changes based on in-use experience
Advanced Propulsion Technology Cost Reduction
Enabled through Generational Learning

- Limited cost reduction opportunities within a given design generation
- Some efficiencies gained through increased volume
- Significant cost reduction enabled through generational changes based on in-use experience
- Generational **Speed Matters**
Limited cost reduction opportunities within a given design generation

Some efficiencies gained through increased volume

Significant cost reduction enabled through generational changes based on in-use experience

Generational Speed Matters

Flex manufacturing must be used to preserve capital across generations
Industry Needs Teams with New Specialized Skills

Significant Engineering Talent Shortfall

- Electric Machines
  - Electro-magnetics, mechanical, thermal, HV electrical, systems
Industry Needs Teams with New Specialized Skills

Significant Engineering Talent Shortfall

- **Electric Machines**
  - Electro-magnetics, mechanical, thermal, HV electrical, systems

- **Power Electronics**
  - HV and LV electrical, mechanical, thermal, systems, controls
Industry Needs Teams with New Specialized Skills

Significant Engineering Talent Shortfall

- **Electric Machines**
  - Electro-magnetics, mechanical, thermal, HV electrical, systems

- **Power Electronics**
  - HV and LV electrical, mechanical, thermal, systems, controls

- **Hybrid Battery**
  - Electrochemistry, mechanical, thermal, HV and LV electrical, systems, controls
Industry Needs Teams with New Specialized Skills

Significant Engineering Talent Shortfall

- **Electric Machines**
  - Electro-magnetics, mechanical, thermal, HV electrical, systems

- **Power Electronics**
  - HV and LV electrical, mechanical, thermal, systems, controls

- **Hybrid Battery**
  - Electrochemistry, mechanical, thermal, HV and LV electrical, systems, controls

- **Controls**
  - Energy systems, safety, LV electrical, optimization, communications, electric machine complex vector/sensor-less
17 Participating Universities
Embry-Riddle Aeronautical University
Georgia Tech
Howard University
Michigan Technological University
Mississippi State University
Missouri Univ. of Science and Technology
North Carolina State University
The Ohio State University
Ontario Institute of Technology
Pennsylvania State University
Rose-Hulman Institute of Technology
Texas Tech University
University of Victoria
University of Waterloo
University of Wisconsin
Virginia Tech
West Virginia University
Electrification of the Automobile – Summary

- GM is committed to Advanced Propulsion Technologies
  - No one solution - today and tomorrow
    - Conventional Improvements
    - Electrification (Hybrid, PHEV, EREV, Fuel Cell EV)

- Electrification is an area of Intense Focus and Opportunity
  - Volume with planned Generations of technology will develop cost effective products, a mature supply base, and satisfied customers
    - Significant cost reduction - technology shifts
    - Volume alone will not markedly improve the cost basis
    - Must begin the significant investment now

- GM is dedicated to the Electrification of the Automobile
  - Engineering talent is being deployed
  - Industry, Government and Academia must help prepare the next generation engineers to support this new competitive reality
Thank you for your attention