The Electrification of the Automobile

Electric Drive Systems and Components

Larry Nitz
Executive Director
General Motors

2020

>1 billion vehicles

~3% annual growth worldwide

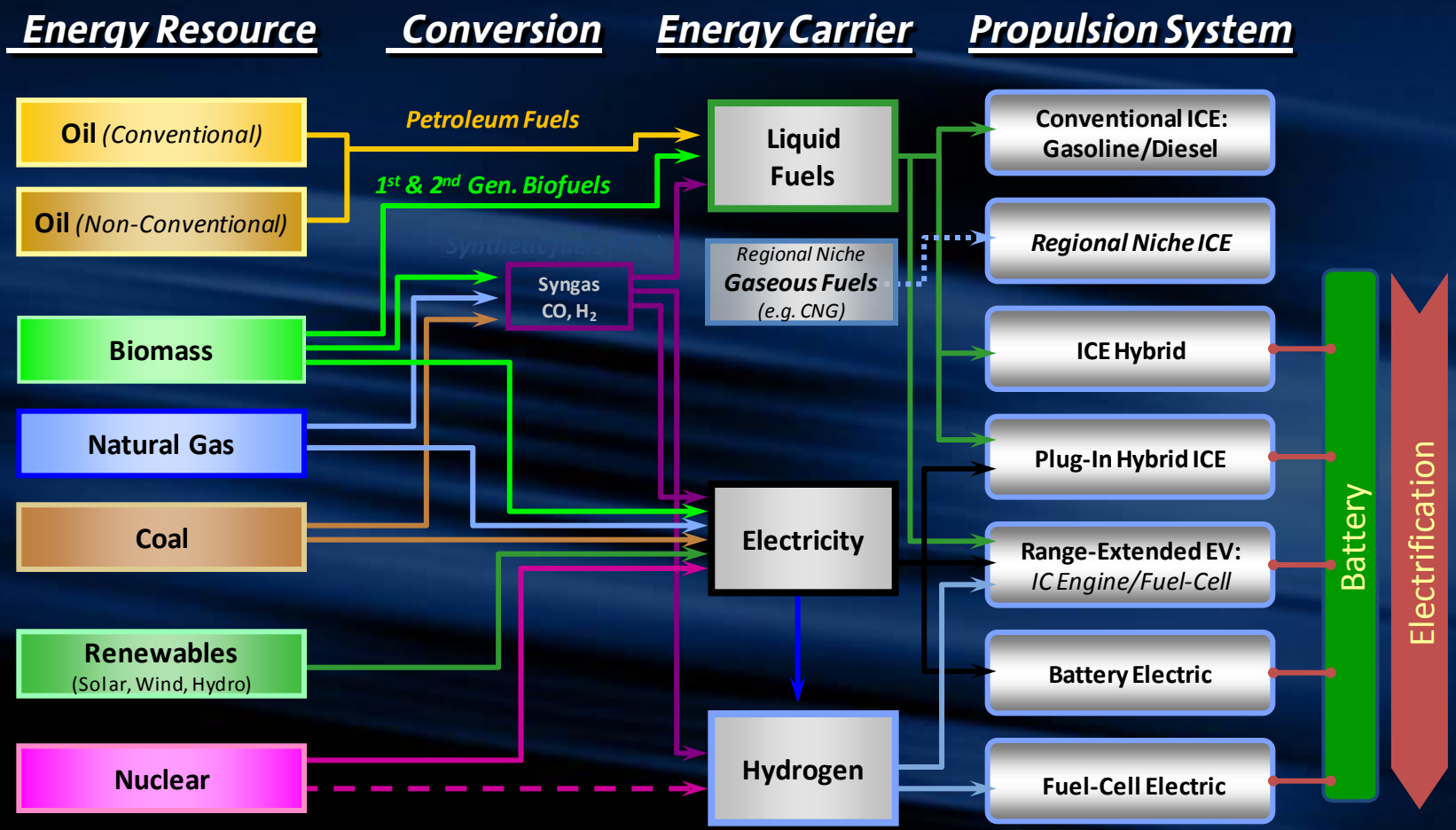
96% Dependence on Petroleum

35% of World's Energy Comes from Petroleum

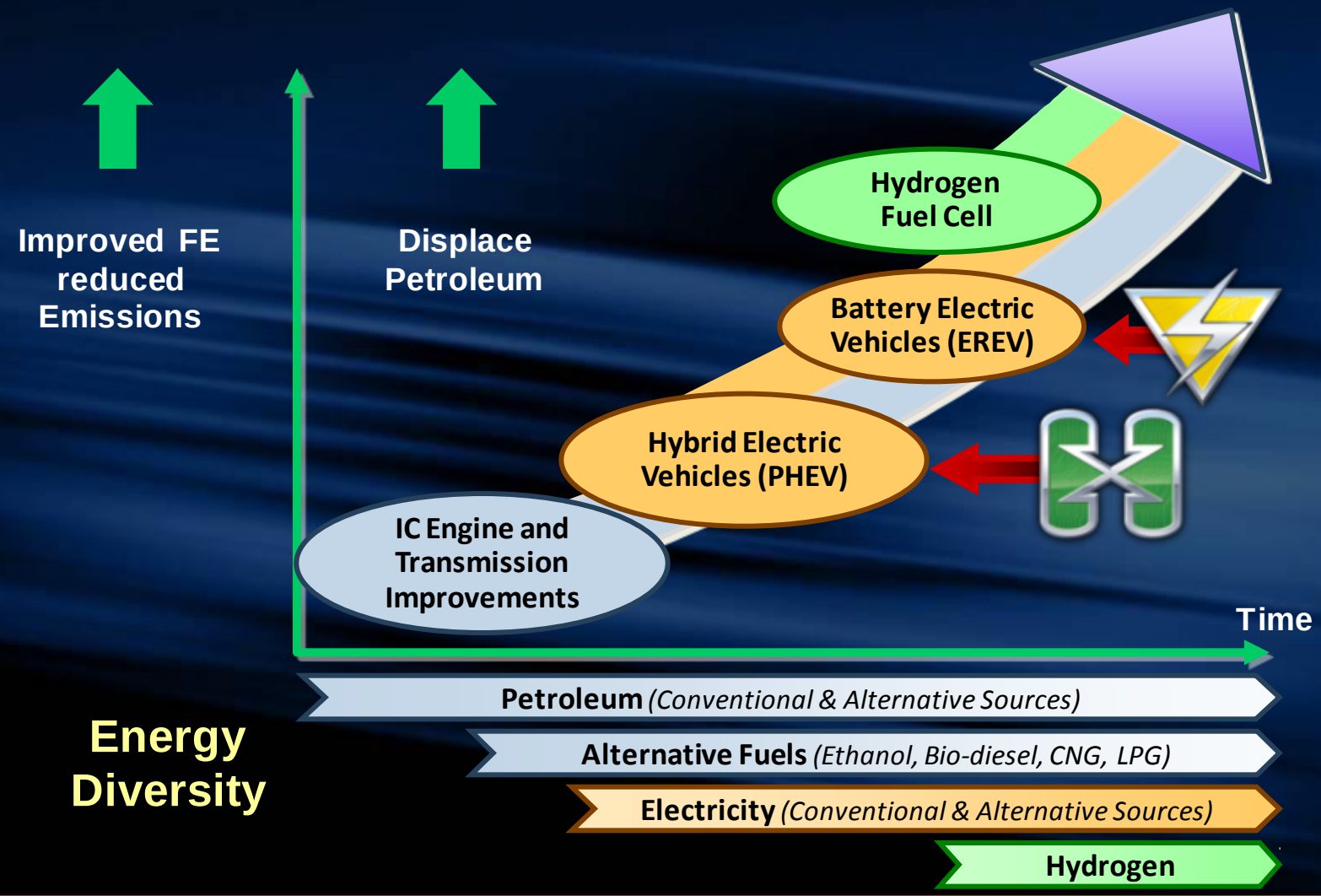
GM Strategy: Displace Petroleum Through Energy Diversity

Energy Diversity – Blending Strategy

"Liquid Fuels/Electricity/Hydrogen" as the In-Vehicle Energy Carriers

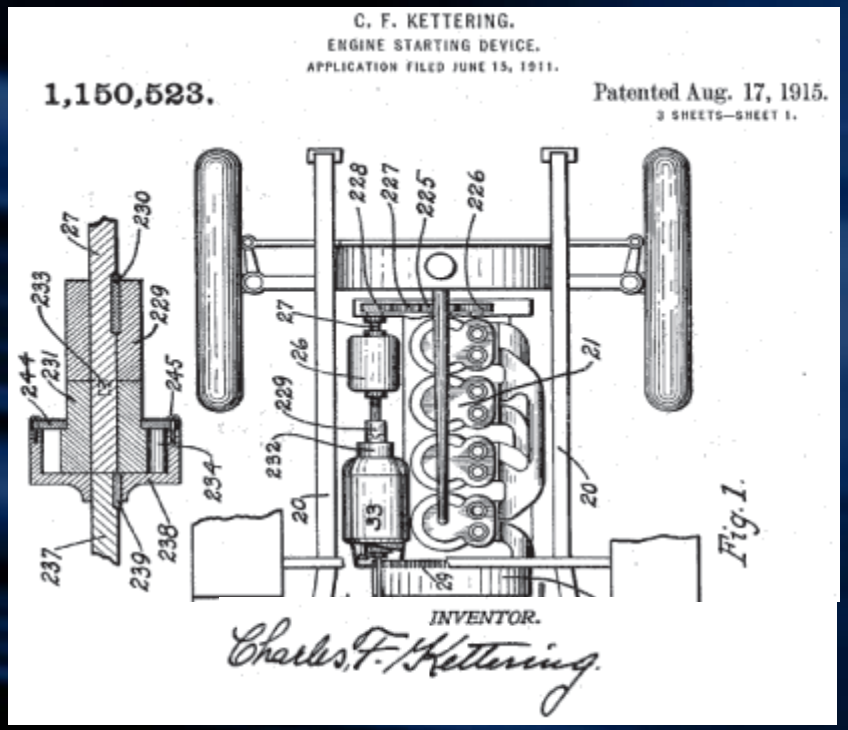


GM Advanced Propulsion Technology Strategy

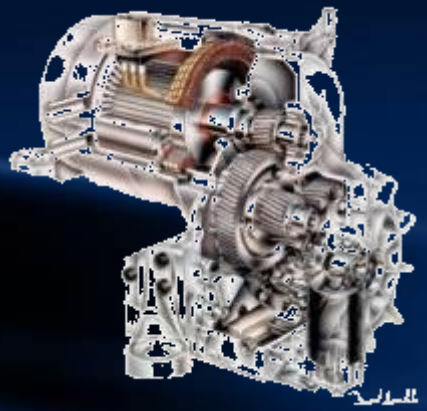


Electrification Begins: 1912 Cadillac

Geared Starter / Generator



Electrification Emerges Again: 1997 EV1



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

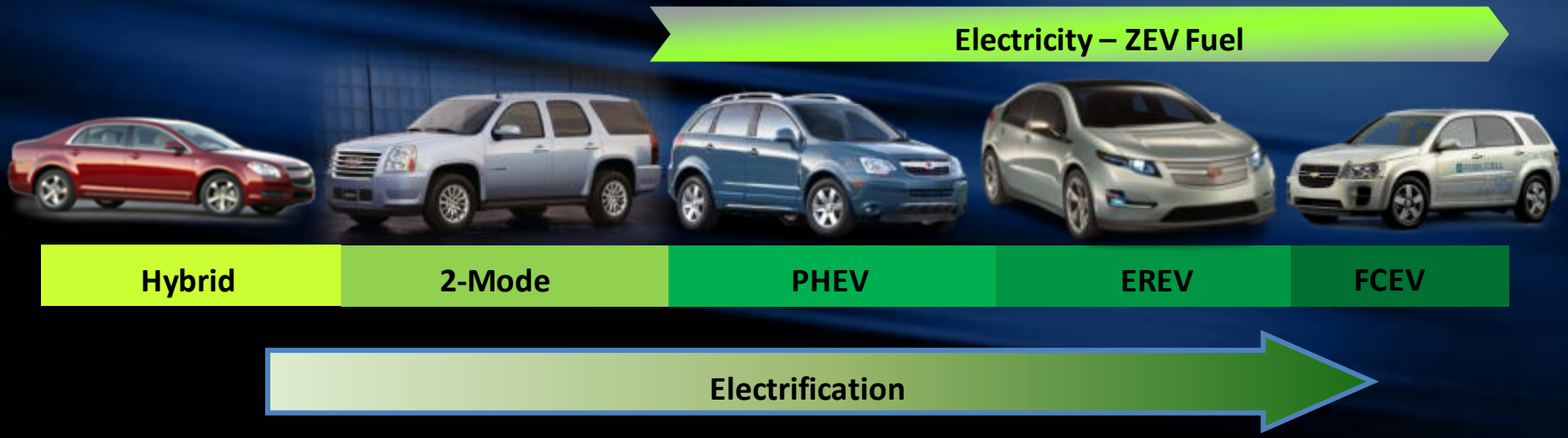
Power Electronics
54 liters

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

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

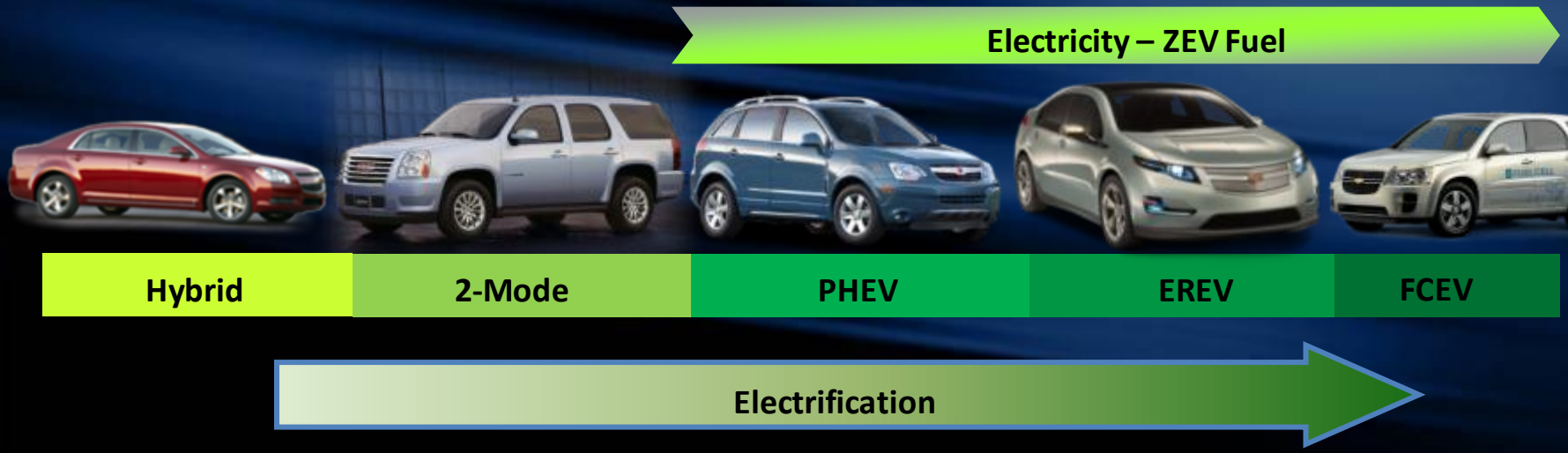


Today's Electrification Opportunities

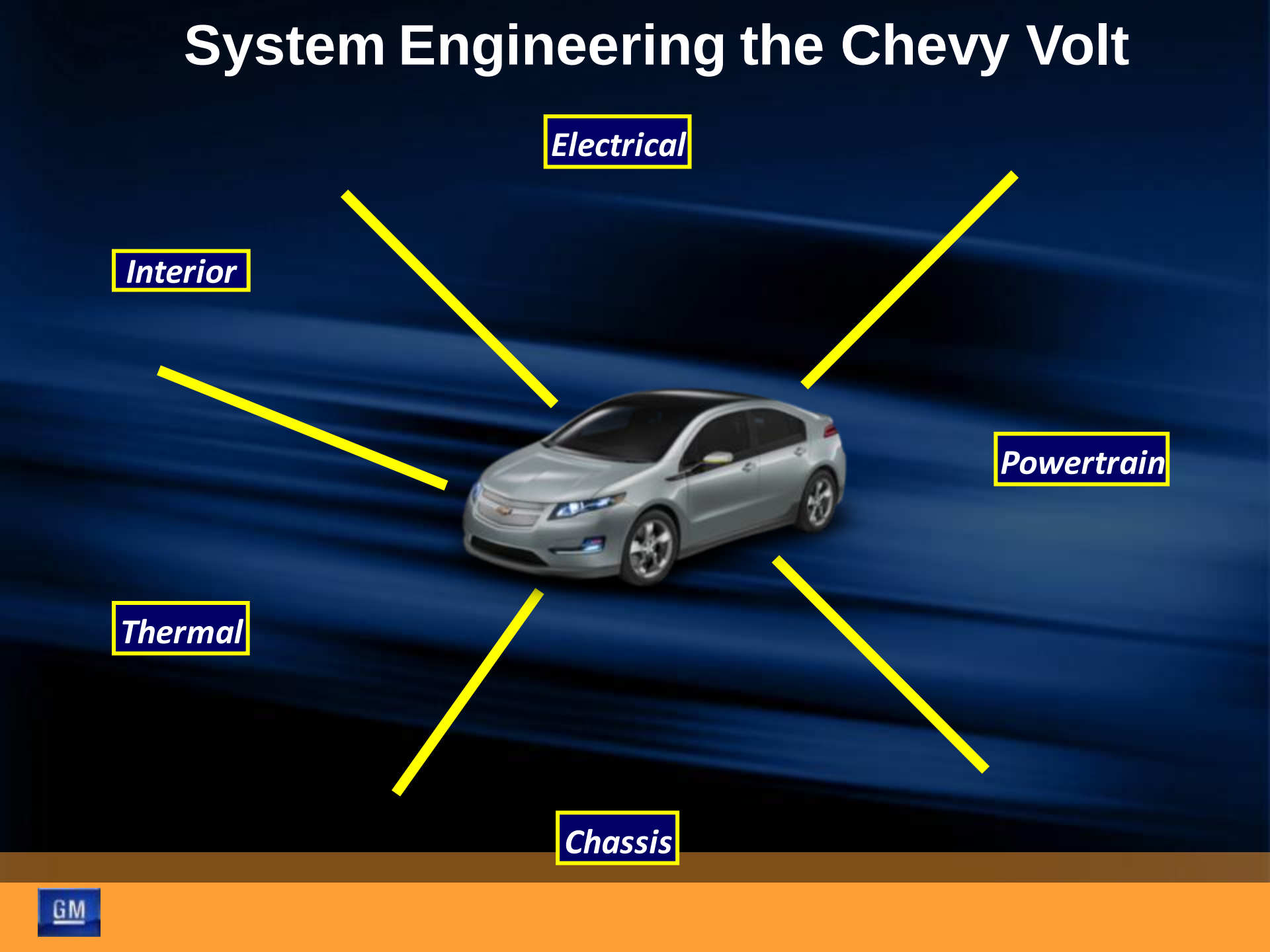
Portfolio of Solutions for a Full Range of Vehicles

All Use:

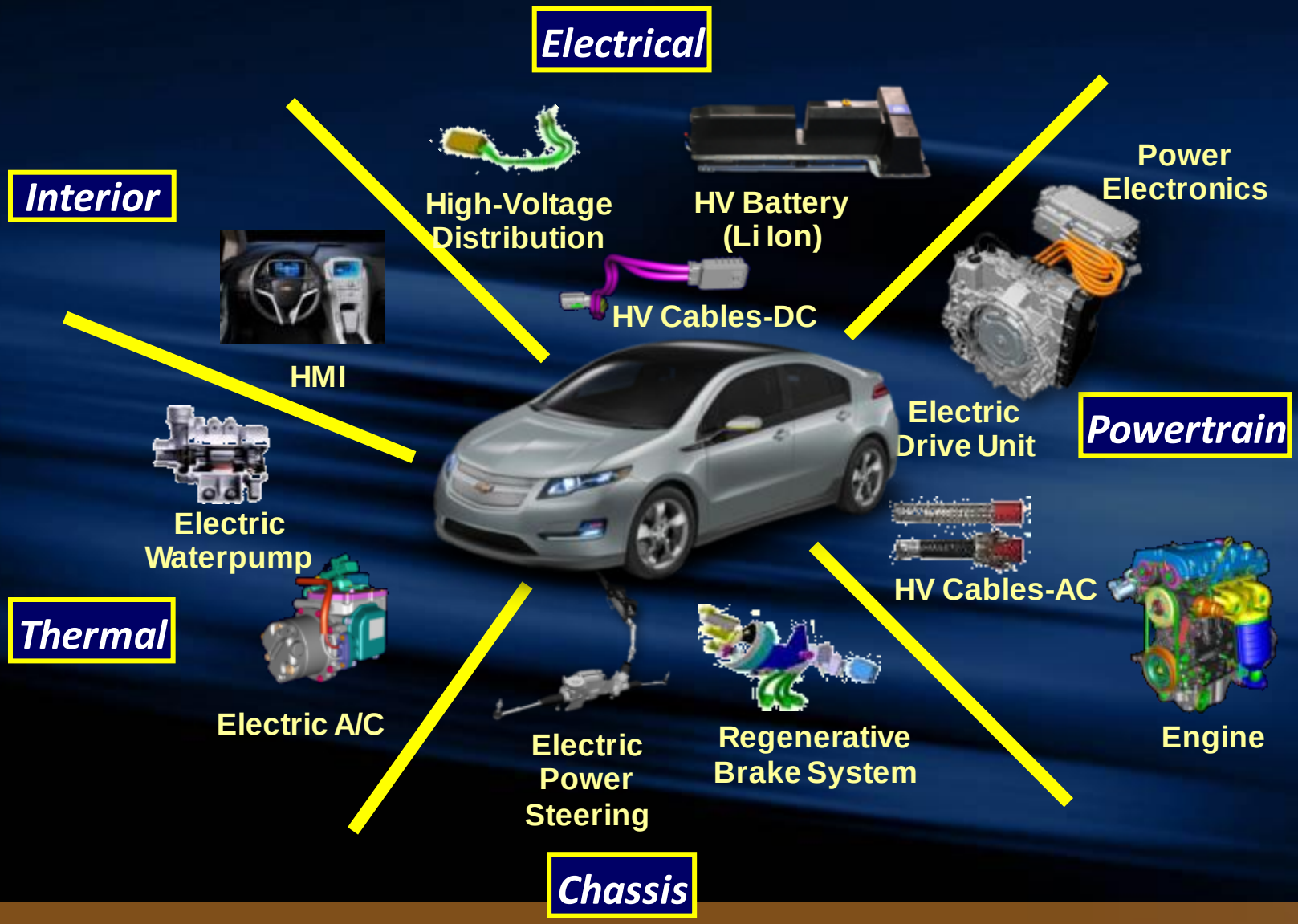
- 1 or 2 Large Electric Motors
- 1 or 2 Large Power Inverters
- High power or high energy battery
- "By-wire" controls of propulsion and braking



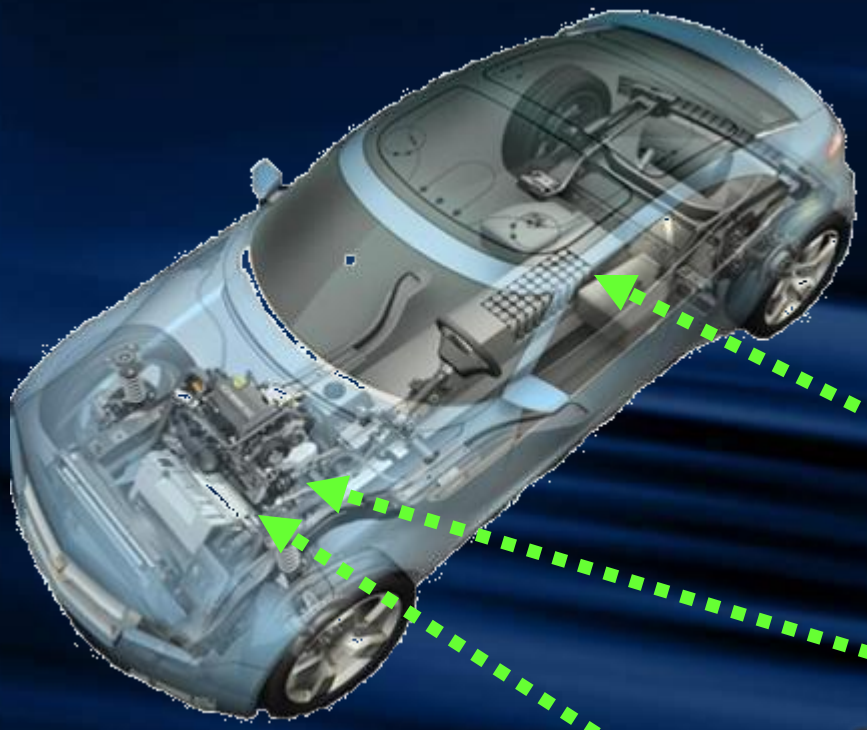
System Engineering the Chevy Volt



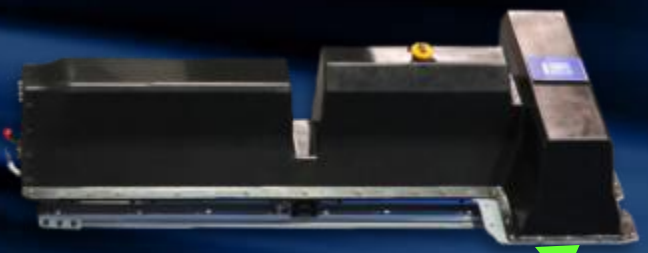
System Engineering the Chevy Volt



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

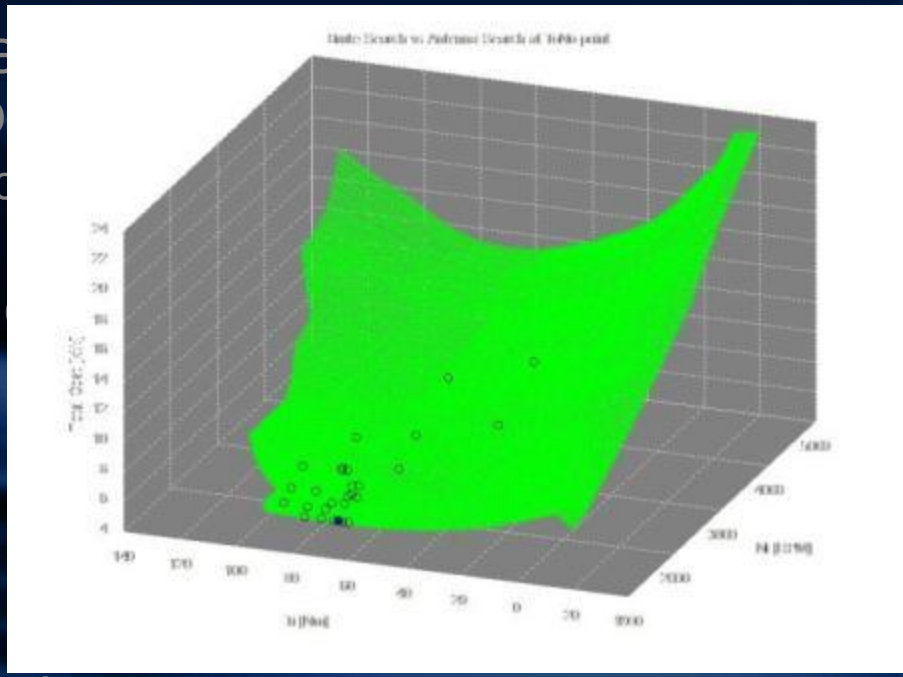
- Safety Critical System: Torque and Direction Security
  - Accelerator “interpretation”, Shifter Direction
  - Processor checks, High voltage checks, Torque response error checks
  - Fail-soft actions to maximize system fault tolerance
  - 600 specific system and component diagnostics

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

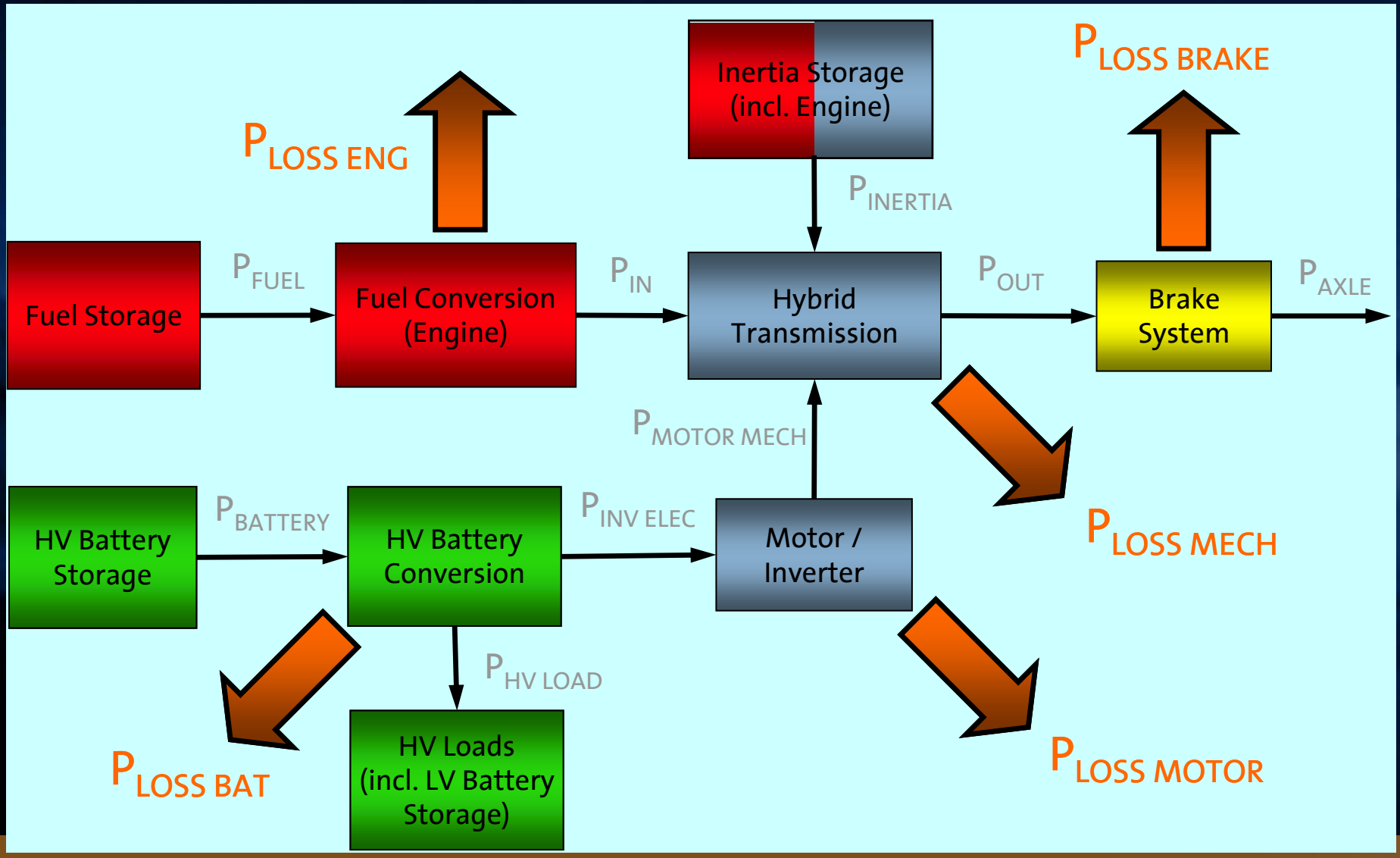
Electric Drive Software and Controls

- Safety Critical System: Torque
  - Accelerator “interpretation”, Shifter D
  - Processor checks, High voltage chec
  - Fail-soft actions to maximize system
  - 600 specific system and component
- Integrated Computer Network:
  - >10 processors networked
  - 3 high speed communication links



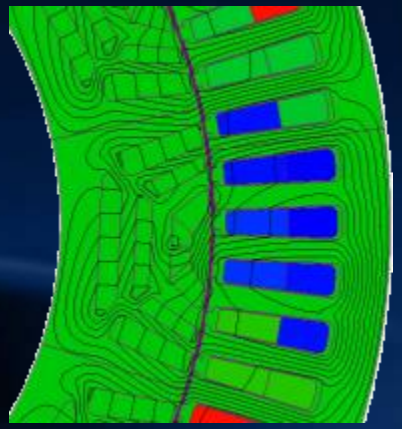
- Hybrid System Functional Domain
  - Real time optimizer – engine, motors, battery, drive unit
  - Engine Start/Stop control
  - By-Wire blending of regenerative and friction braking
  - Actively dampen driveline
  - Switch current to motors for best torque/efficiency

Hybrid Control System Loss Optimization



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

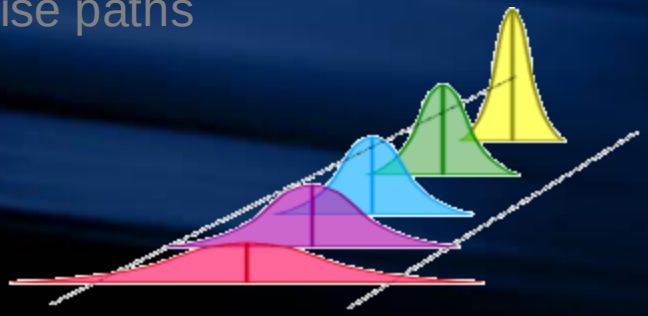
- High Torque / Power / Efficiency
  - Motors designed with modern magnetic FEA tools
  - Motors designed as integrated part of a electric drive with interconnections, thermal and Rotor-Stator GDT
- Automotive Cost
  - Low cost components and production methods
    - PM motors use rare earth types magnets
    - Low cost position sensor or sensor-less

- 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 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

- 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

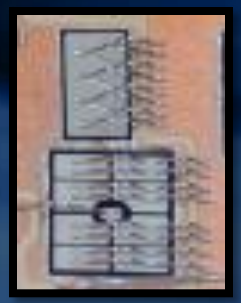
~20L today – > ~7L future

Power Inverters

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

~20L today – > ~7L future

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

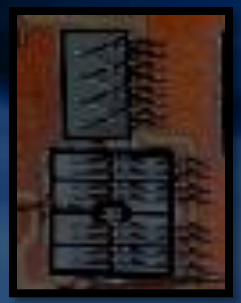


Power Inverters

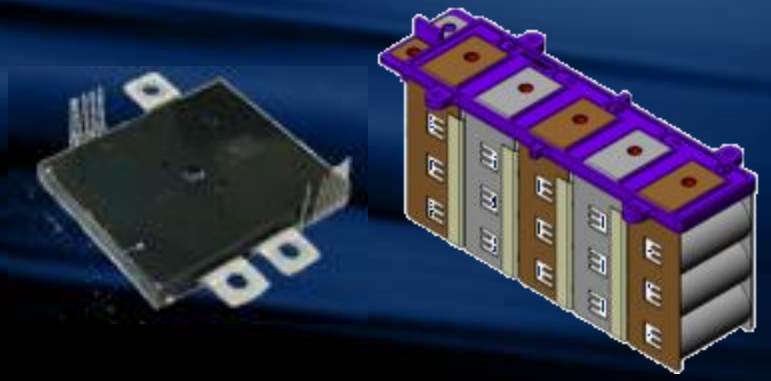
- Automotive Packaging Size
  - Miniaturization
  - Ruggedization
  - Temperature and Vibration tolerance

~20L today – > ~7L future

- 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



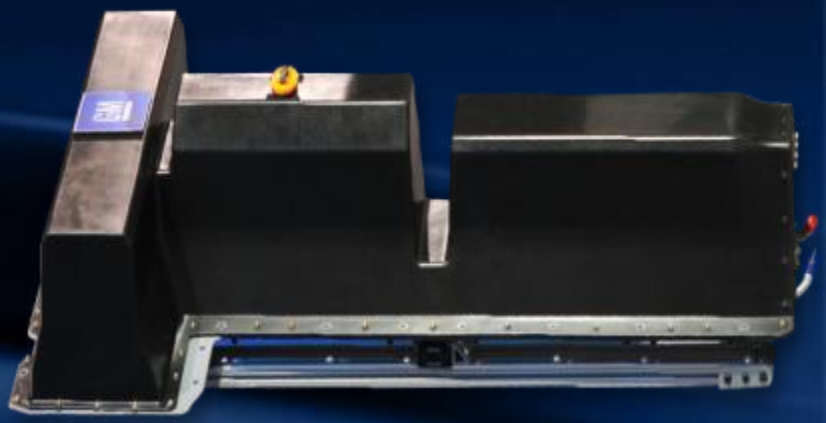
Chevrolet Volt - Advanced Battery Technology

Creating the “Practical EV”

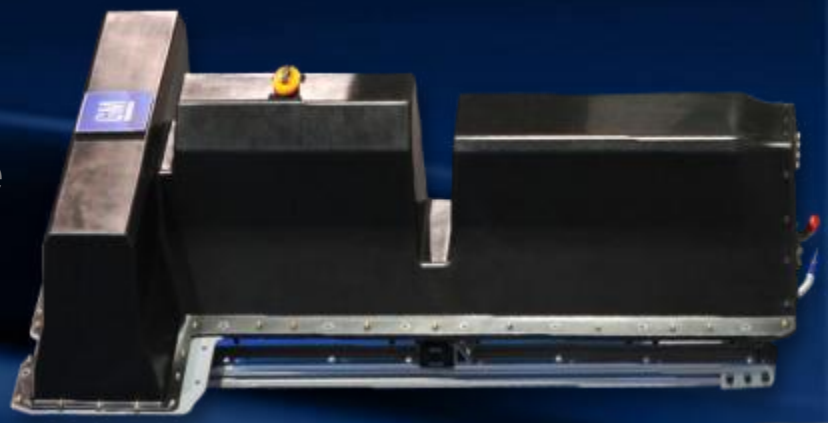
- 16 kWh (~8 kWh usable)
- 40 miles of EV driving
- High energy, high power for EV
- Charging:
  ~ 3 hours @ 220 Volts
  ~ 8 hours @ 110 Volts
- Life: >10 years/150,000 mi

Battery Pack/Cell

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

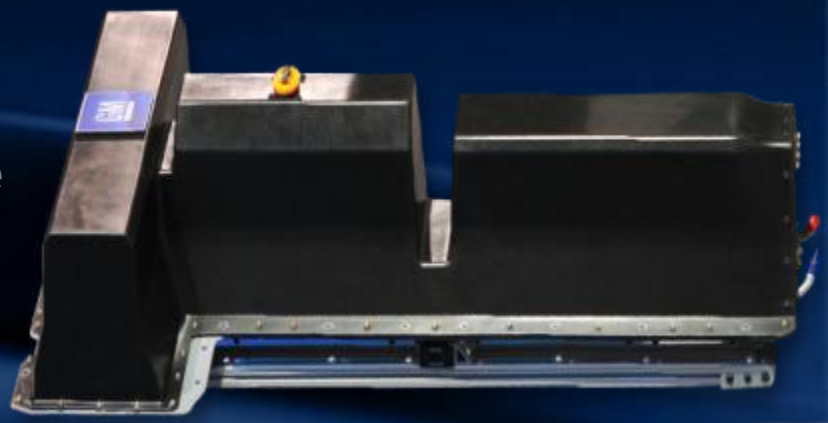


Battery Pack/Cell



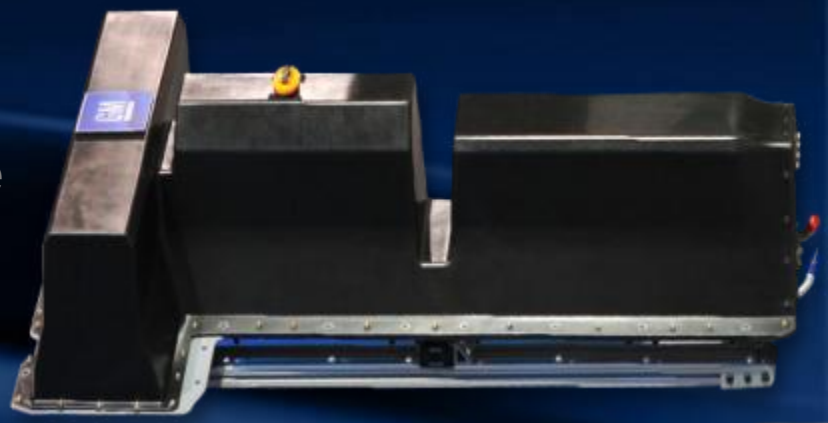
- Automotive Life
  - Battery systems with >10yr / 150k mile life
  - High capability pack thermal systems
  - HV interconnections, monitoring, control
- Automotive Costs
  - Large format cells – new chemistry and materials
  - Automotive volume manufacturing systems
  - Smart integration of thermal 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

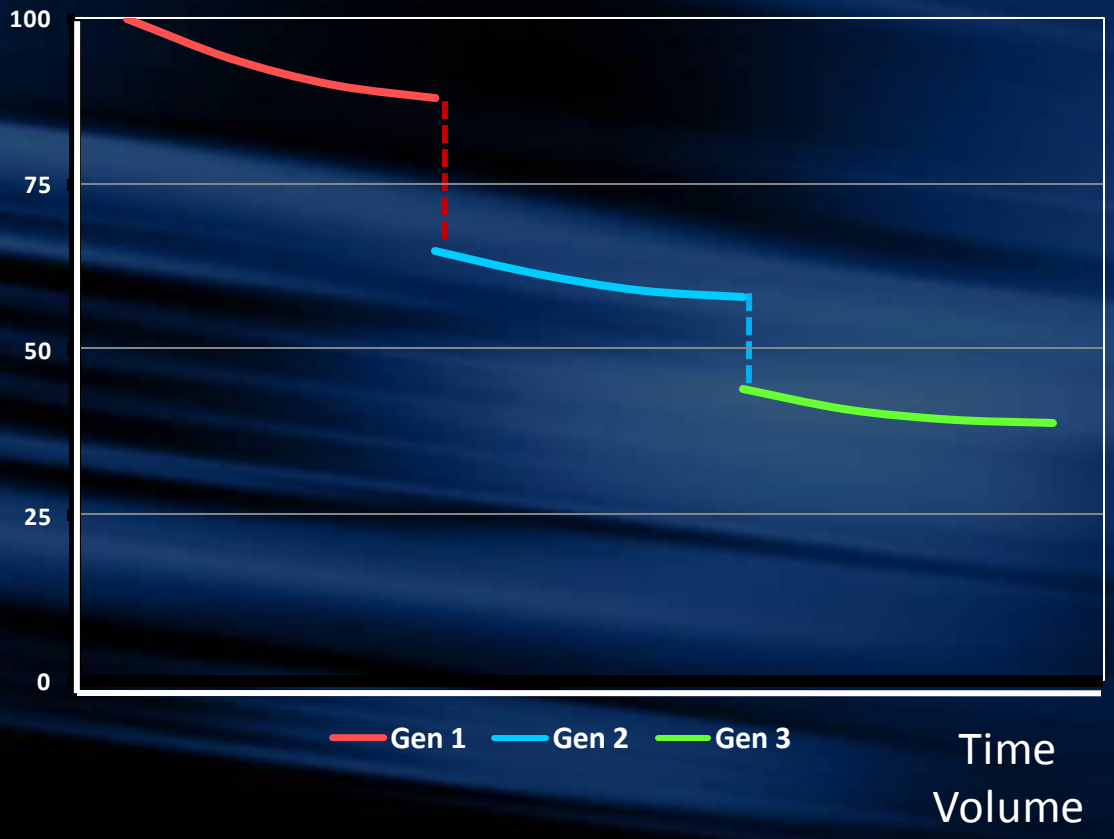


- Automotive Life
  - Battery systems with >10yr / 150k mile life
  - High capability pack thermal systems
  - HV interconnections, monitoring, control
- Automotive Costs
  - Large format cells – new chemistry and materials
  - Automotive volume manufacturing systems
  - Smart integration of thermal 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

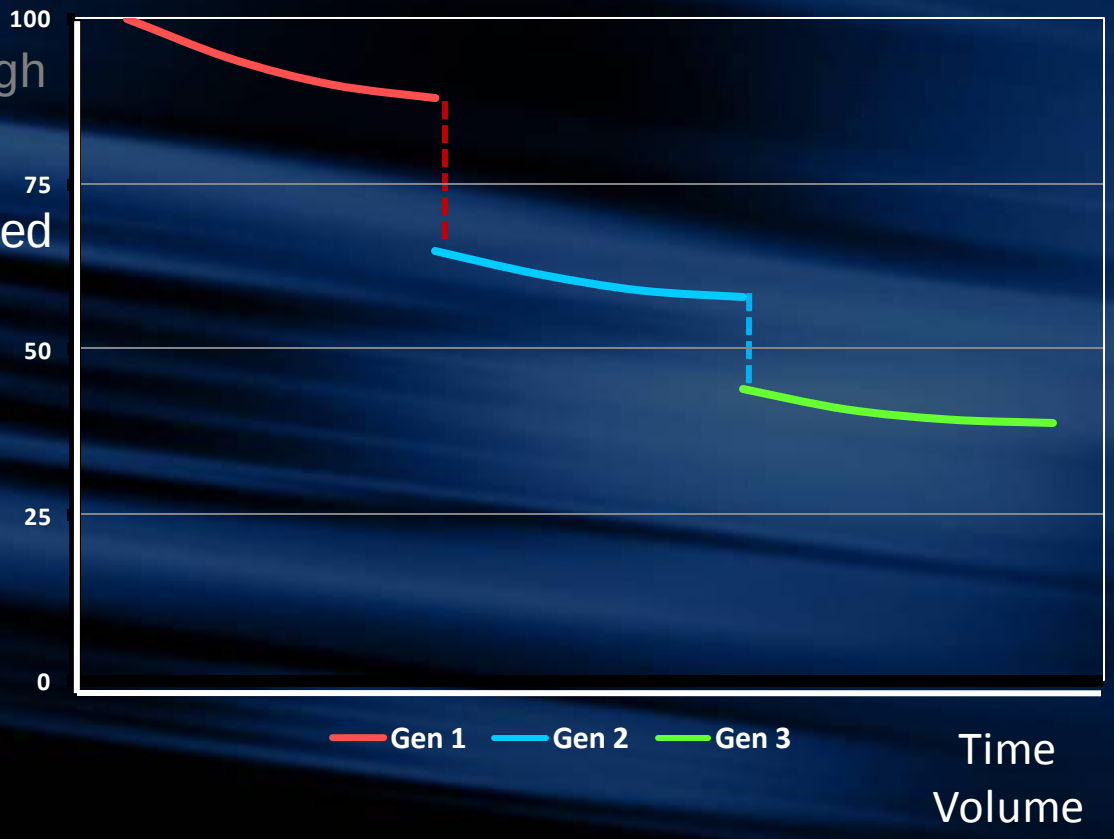
Enabled through Generational Learning

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

Advanced Propulsion Technology Cost Reduction

Enabled through Generational Learning

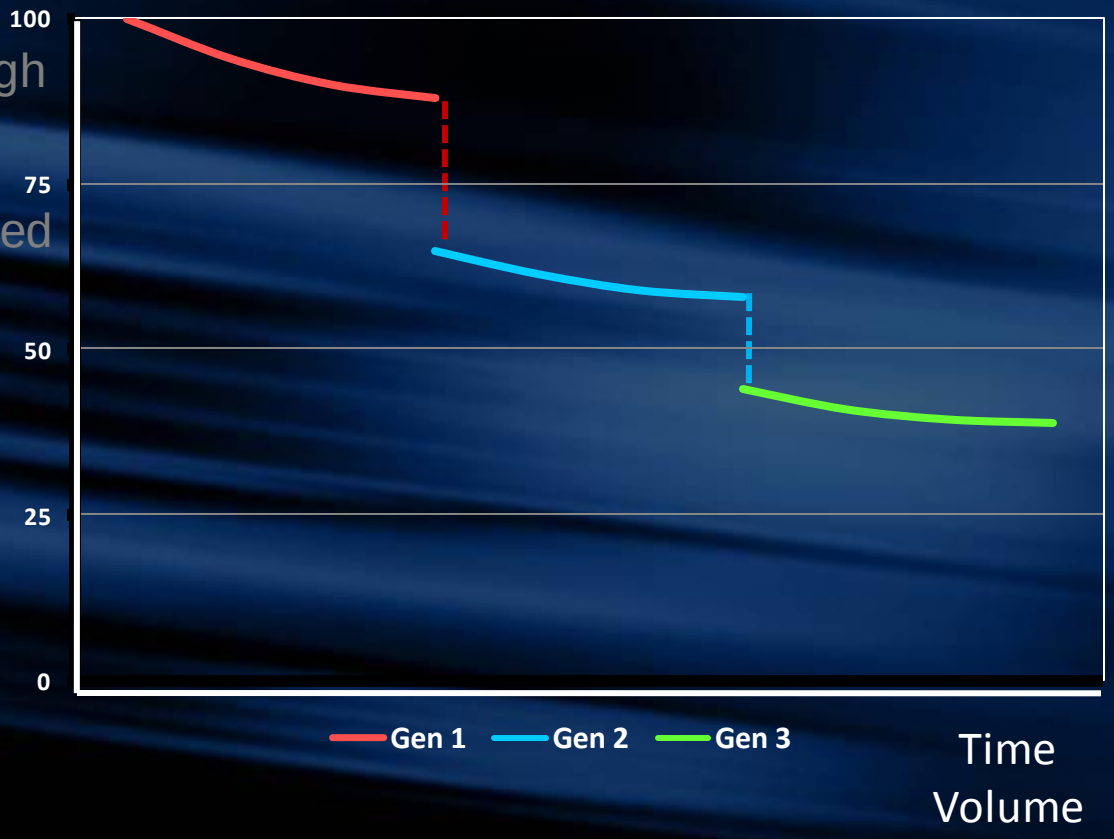
- **Limited** cost reduction opportunities within a given design generation
- Some efficiencies gained through **increased volume**
- Significant cost reduction enabled through generational changes based on **in-use experience**



Advanced Propulsion Technology Cost Reduction

Enabled through Generational Learning

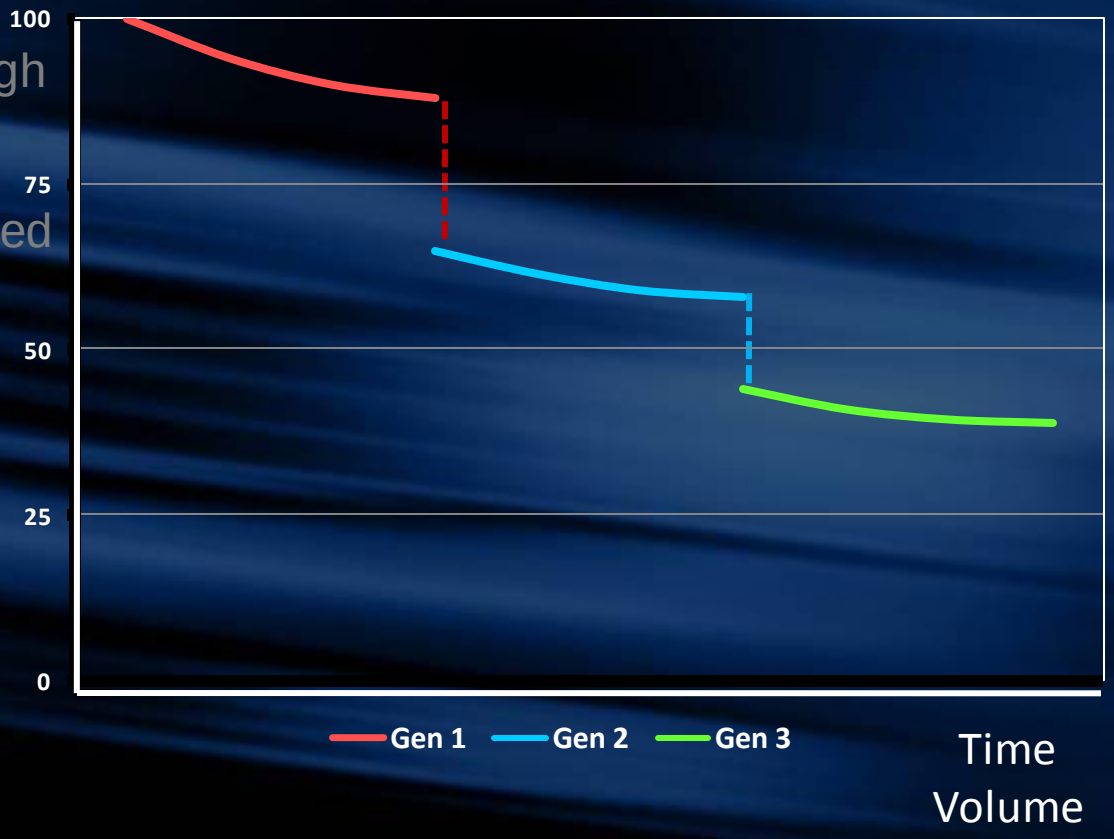
- **Limited** cost reduction opportunities within a given design generation
- Some efficiencies gained through **increased volume**
- Significant cost reduction enabled through generational changes based on **in-use experience**
- Generational **Speed Matters**



Advanced Propulsion Technology Cost Reduction

Enabled through Generational Learning

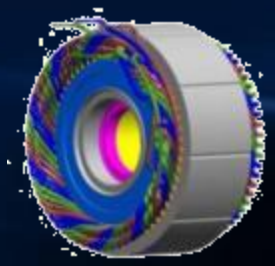
- **Limited** cost reduction opportunities within a given design generation
- Some efficiencies gained through **increased volume**
- Significant cost reduction enabled through generational changes based on **in-use experience**
- Generational **Speed Matters**
- **Flex manufacturing** must be used to preserve capital across generations



Industry Needs Teams with New Specialized Skills

Significant Engineering Talent Shortfall

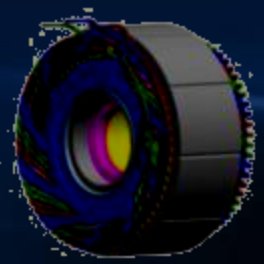
- Electric Machines
  - Electro-magnetics, mechanical, thermal, HV electrical, systems



Industry Needs Teams with New Specialized Skills

Significant Engineering Talent Shortfall

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

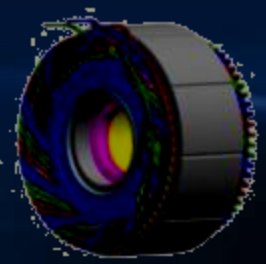


- Power Electronics
  - HV and LV electrical, mechanical, thermal, systems, controls

Industry Needs Teams with New Specialized Skills

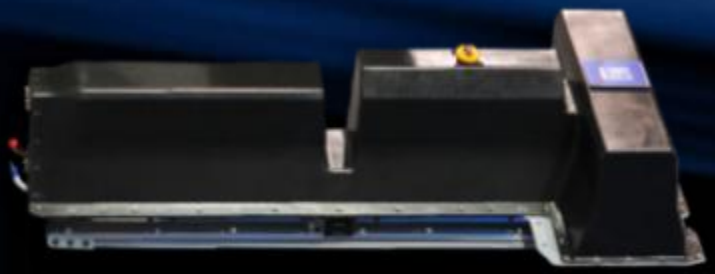
Significant Engineering Talent Shortfall

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



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

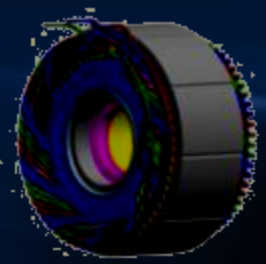
- Hybrid Battery
  - Electrochemistry, mechanical, thermal, HV and LV electrical, systems, controls



Industry Needs Teams with New Specialized Skills

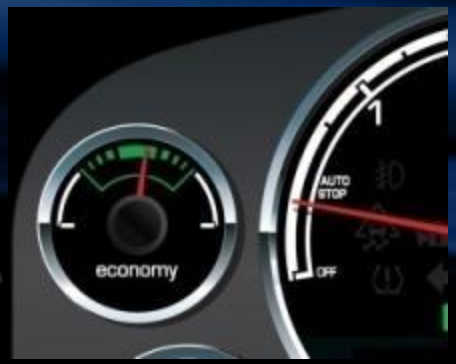
Significant Engineering Talent Shortfall

- 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

EcoCAR
The NeXt Challenge

U.S. DEPARTMENT OF ENERGY

GM

Argonne

Government of Canada

Gouvernement du Canada

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

Sponsors

U.S. DEPARTMENT OF ENERGY
GM
Government of Canada
Gouvernement du Canada
The MathWorks
dSPACE
AVL
freescale semiconductor
California Environmental Protection Agency
AIR RESOURCES BOARD
NATIONAL INSTRUMENTS
A123 SYSTEMS
WOODWARD
BOSCH
igus
vector
SEMTECH
SENSORS' EMISSIONS MEASUREMENT TECHNOLOGY
MAGNA
SIEMENS
RFA
Snap-on
EcoMotors INTERNATIONAL™
DELPHI
EPRI

GM

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

GM

Thank you for your attention