IEEE Vehicle Power and Propulsion Conference:

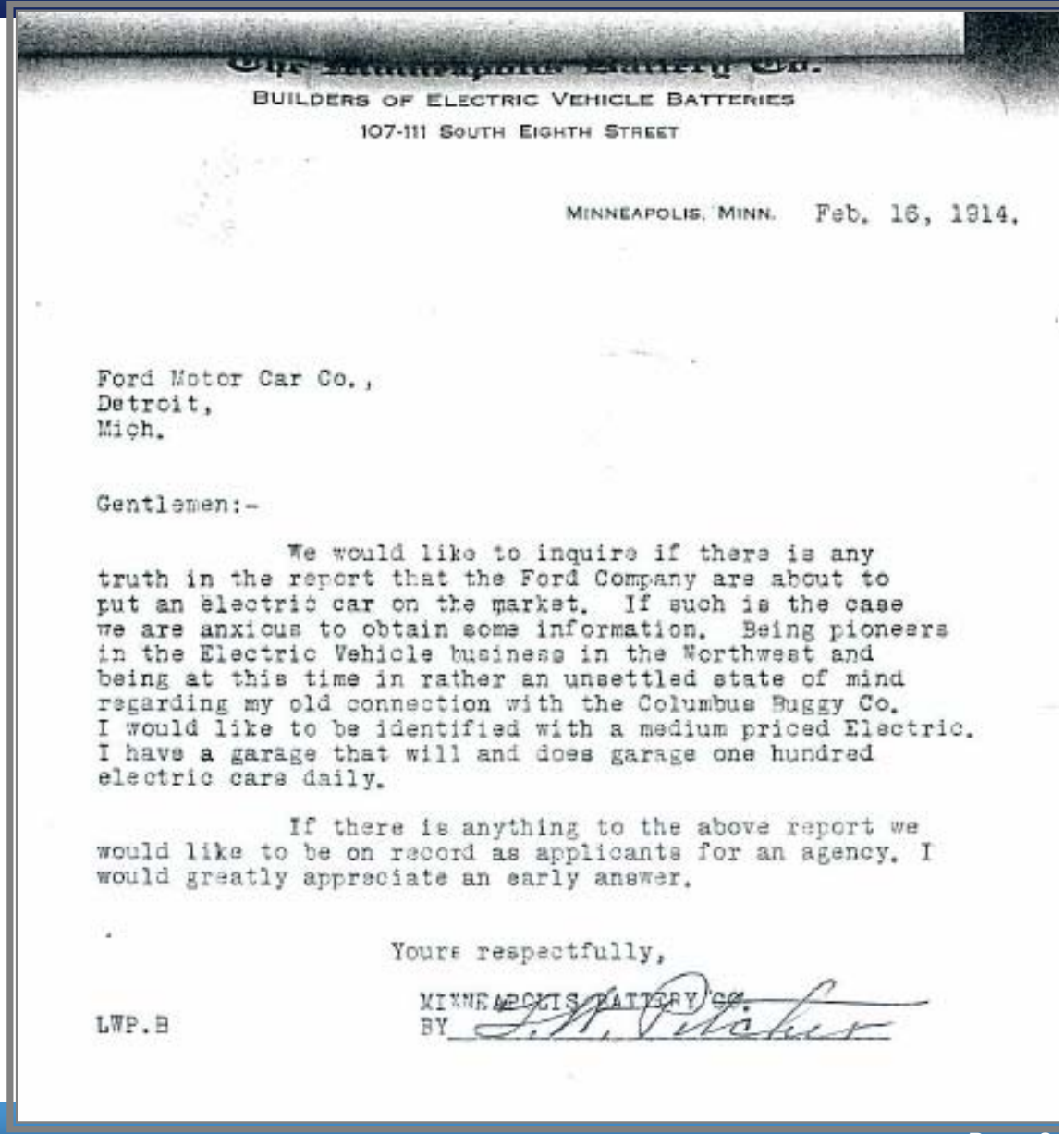
Key Issues and Solutions for Mass Electrification of Transportation

Nancy Gioia

Director, Sustainable Mobility Technologies and Hybrid Vehicle Programs,
Ford Motor Company

Electrification of vehicles: 100 year old vision…

- In the early 1900's more than 27 companies were building electric cars
- In 1914, Henry Ford and Thomas Edison experimented with an electric car using Edison Batteries
- In 1915 the Ward Motor Vehicle Company offered an electric wagon for $875 on an 1 yr installment plan for the vehicle and a $10.50/month rental fee for the Edison Storage battery



The Minneapolis Battery Co.
BUILDERS OF ELECTRIC VEHICLE BATTERIES
107-111 SOUTH EIGHTH STREET

MINNEAPOLIS, MINN. Feb. 16, 1914.

Ford Motor Car Co.,
Detroit,
Mich.

Gentlemen:-

We would like to inquire if there is any truth in the report that the Ford Company are about to put an electric car on the market. If such is the case we are anxious to obtain some information. Being pioneers in the Electric Vehicle business in the Northwest and being at this time in rather an unsettled state of mind regarding my old connection with the Columbus Buggy Co. I would like to be identified with a medium priced Electric. I have a garage that will and does garage one hundred electric cars daily.

If there is anything to the above report we would like to be on record as applicants for an agency. I would greatly appreciate an early answer.

Yours respectfully,

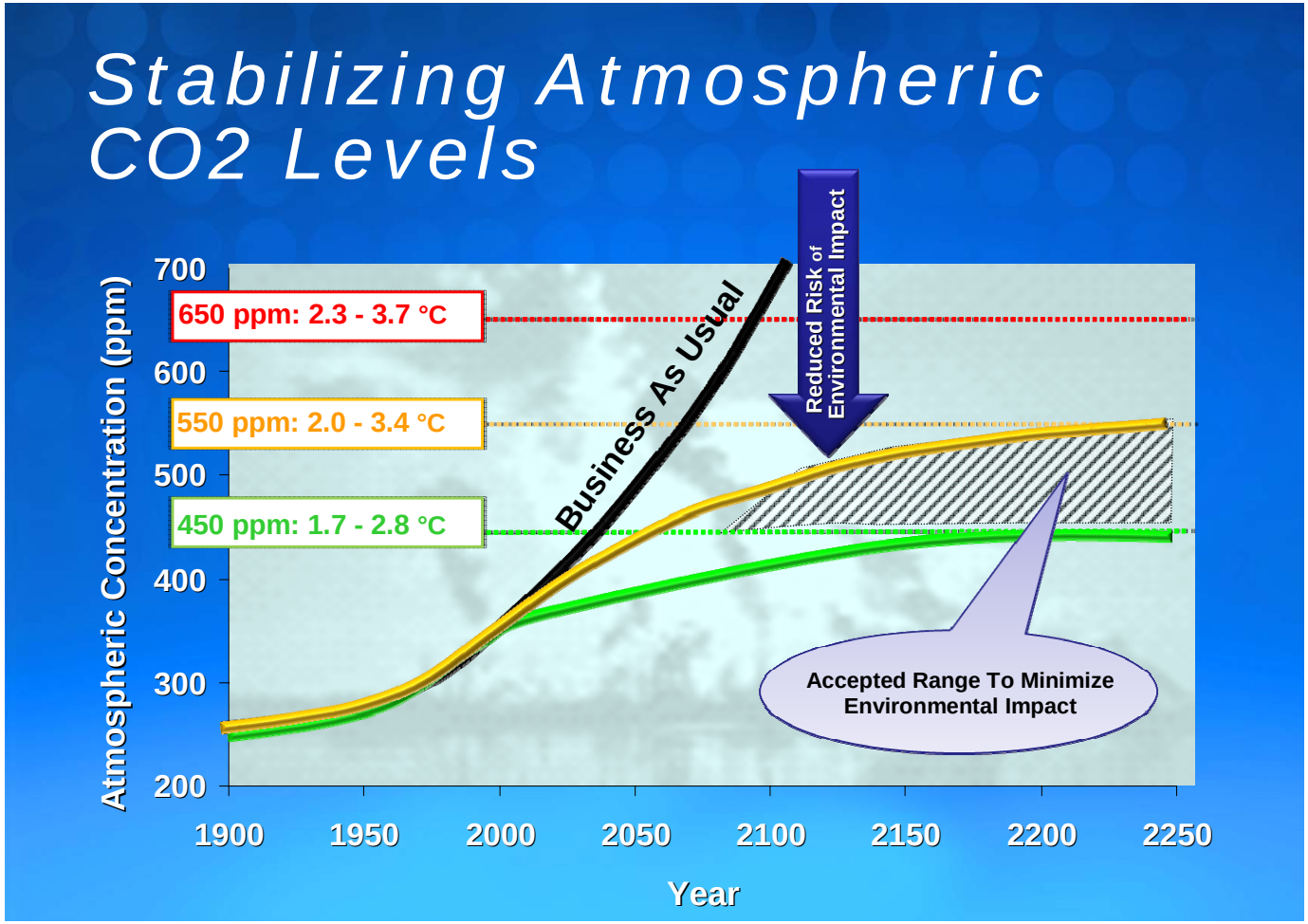
MINNEAPOLIS BATTERY CO.
BY

LWP.B

Agenda

- Ford's Sustainability Strategy and Announced Electrification Plans
- Advances in Hybrid Technology
  - Its all about systems engineering and cost reductions
- Realizing the Power of Plugging In
  - A new interconnected world
  - Its all about collaboration
- What Will it Take to Accelerate Electrification?
  - Obstacles and Challenges

What's Driving Us?



- Simply "not getting worse" is not good enough
- CO2 reduction is required on a global basis going forward
- This is a long term commitment for a sustainable future

Sustainability Strategy – Technology Migration

Near Term

- Significant number of vehicles with EcoBoost engines
- Electric power steering 70 – 80%
- Dual clutch and 6 speed transmissions replacing 4 and 5 speeds
- Increase Hybrid applications
- Increased unibody applications
- Introduction of additional small vehicles
- Battery management systems 75%
- Aero improvement up to 5%

Mid Term

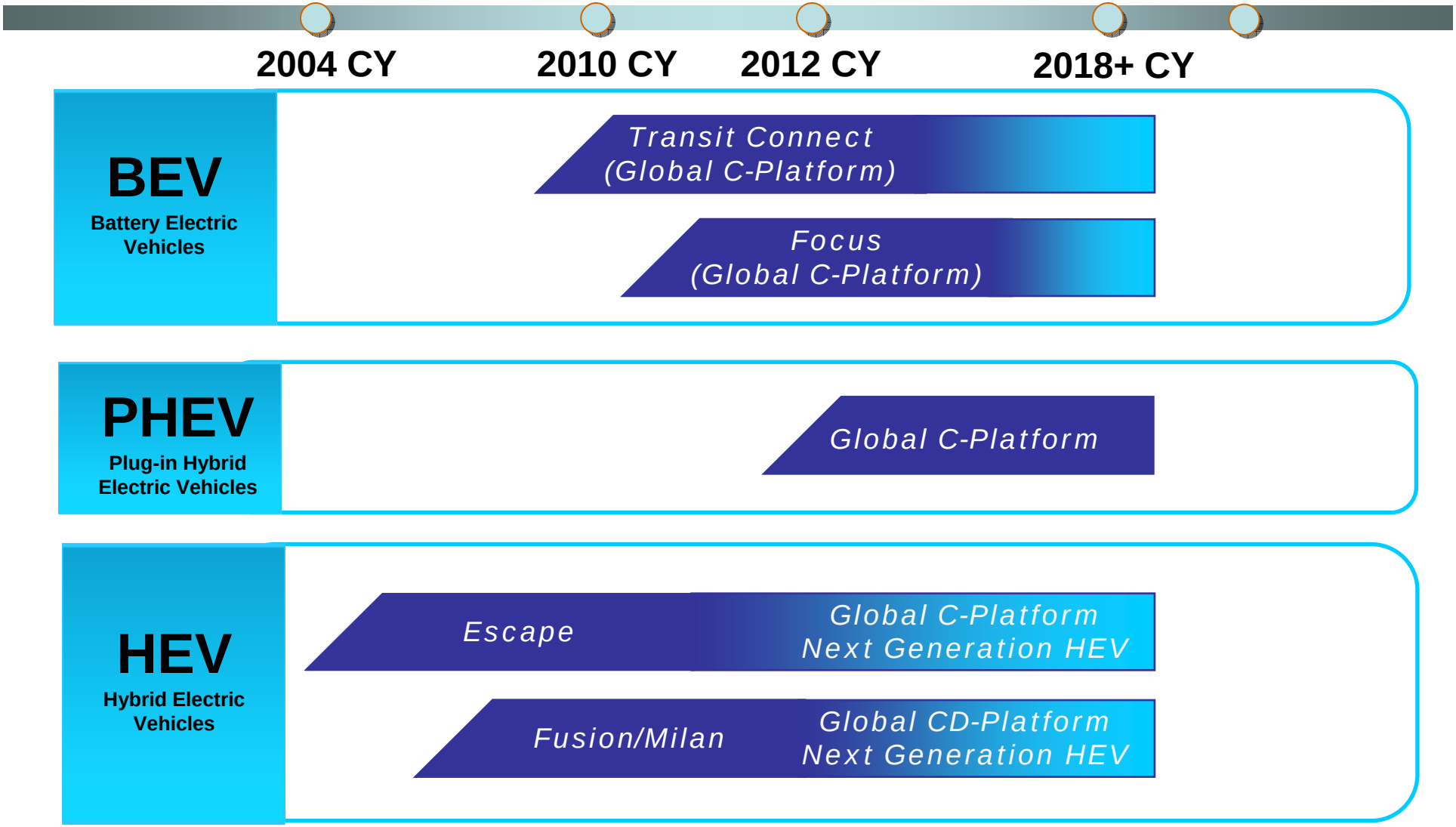
- EcoBoost engines available in nearly all vehicles
- Electric power steering 100%
- Six speed transmissions 100%
- Weight reduction of 250 – 750 lbs
- Engine displacement reduction aligned with weight save
- Additional Aero improvements up to 5%
- Increased use of Hybrids
- Introduction of PHEV and BEV
- Diesel use as market demands

Long Term

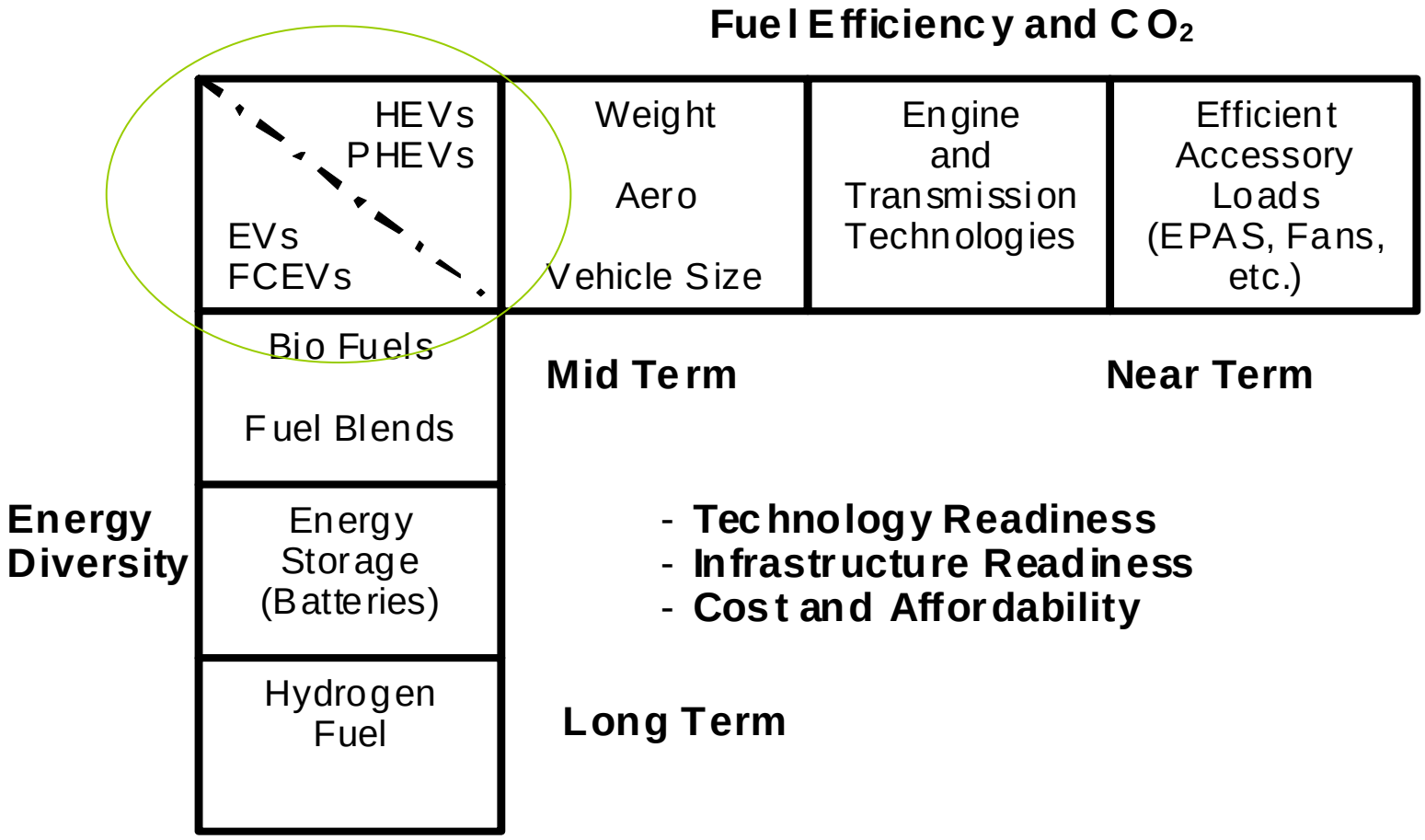
- Percentage of internal combustion dependent on renewable fuels
- Volume expansion of Hybrid technologies
- Continued leverage of PHEV, BEV
- Clean electric / hydrogen fuels

Comprehensive Strategy to Address Climate Change and Energy Security

Announced Ford Electrification Projects:
Key is Leverage of High Volume Global Platforms



Technology Suite



Electrification Technologies – Background

Function / System	Engine stop/start	Engine Assist (Downsize)	Regenerative Brake	Electric launch	All Electric Drive	Fuel Economy Improvement
Micro-hybrid (14V)	YES (> 0.3 sec)	Minimal (< 3 kW)	Minimal (< 3 kW)	NO	NO	3-6%
Mild Hybrid (42V)	YES	Modest (< 9 kW)	Modest (< 9 kW)	NO	NO	8%/12%
Medium Hybrid (100+V)	YES	YES	YES (full benefit)	NO	NO	40%
Full Hybrid (300V)	YES	YES	YES	YES	NO	55%+
Plug In Hybrid (based on Blended Full)	YES	YES	YES	YES	No (Blended) Yes (Series)	80%+
Battery Electric Vehicle	YES	No Engine	YES	YES	YES	Infinite

HEV → PHEV → BEV Components

	HEV	PHEV	BEV
Battery	Yes (Power)	Yes (Energy)	Yes (Energy)
Electric AC	Yes	Yes	Yes
DC/DC Converter	Yes	Yes	Yes
Regen Brakes	Yes	Yes	Yes
Motor(s)	Yes	Yes	Yes
Inverter(s)	Yes	Yes	Yes
Transmission	Yes	Yes	No
EV Gearbox	No	No	Yes
Charger	No	Yes	Yes

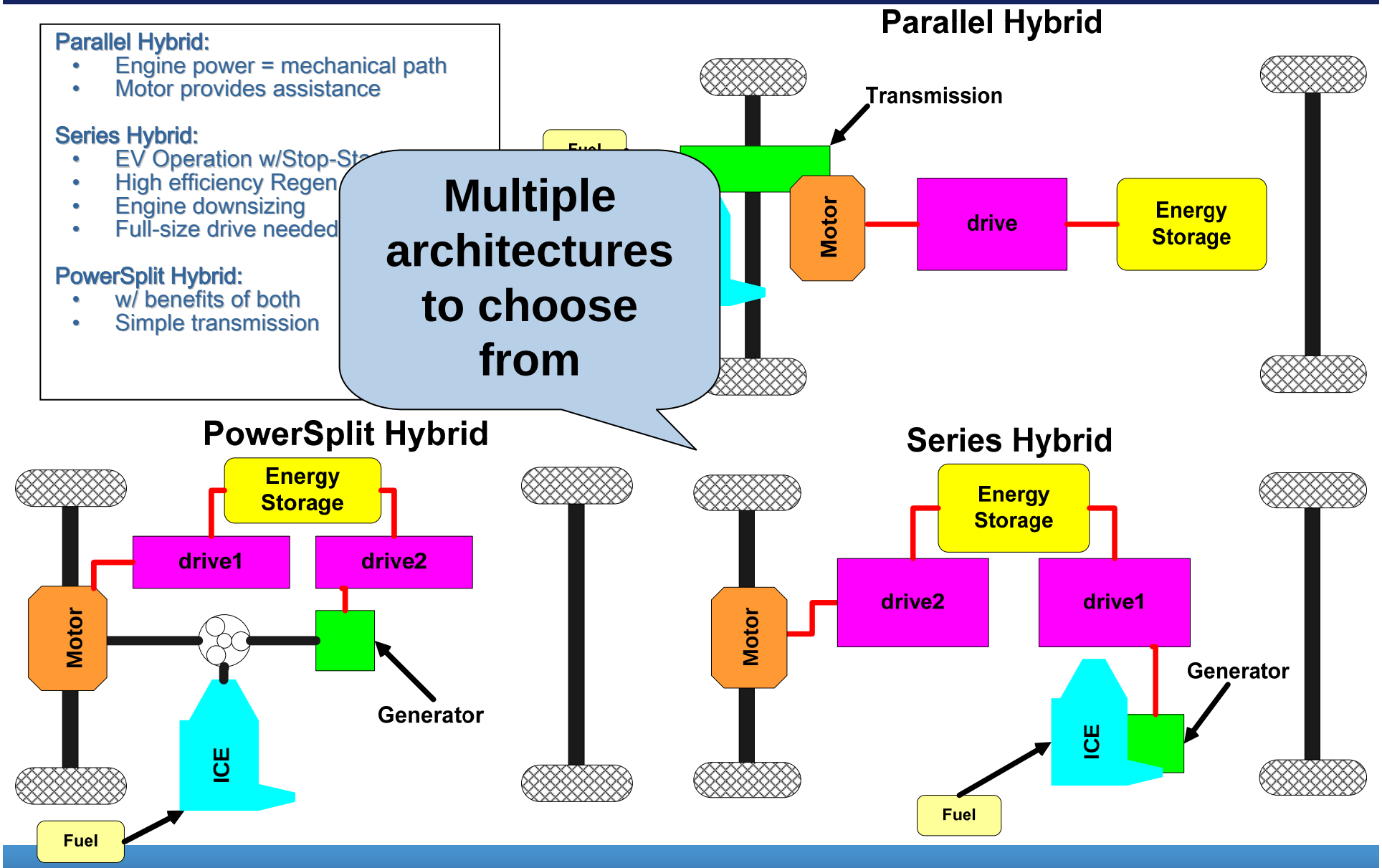
Hybrid Vehicle Types

Parallel Hybrid:
- Engine power = mechanical path
- Motor provides assistance

Series Hybrid:
- EV Operation w/Stop-St
- High efficiency Regen
- Engine downsizing
- Full-size drive needed

PowerSplit Hybrid:
- w/ benefits of both
- Simple transmission

Multiple architectures to choose from



Multiple Cost Drivers

Application/Usage (Drive Cycles)
- Peak to Average Power Ratio
- Thermal Cycling
- Power Cycling
- Desired Range

Technology
- Silicon Technology (IGBT, Diodes) – Industry Standards vs. Custom?
- Power Module Packaging and Cooling Technology
- Capacitor Technology
- Sensing Technology
- Battery Cell Technology

Commonality and Reuse
- Power Density – Package Size
- Fixed vs. Tunable
- Connection Systems

Total cost is very high – investment and component cost

Customers - Drive Patterns

- Low speed, stop and go city driving
- High speed highway driving
- Hilly terrain driving
- Driving with towing
- Off road driving
- Very high speed driving

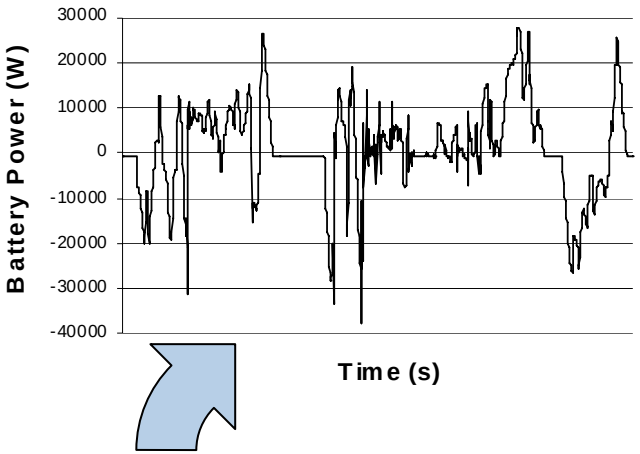
Many factors to consider…with regional differences

Fuel economy / Energy economy & effectiveness of vehicle hybridization will vary significantly based on driving conditions.

In order to determine the right Hybrid architecture, important to understand the customer usage/segment.

Hybrid Systems Design Approach

Inverter duty cycles simulated in Matlab/Simulink



Generated 90th Percentile Drive Profile Equivalent to 10 Years/150k Miles

Based on analyses of RWUPs, Estimate Inverter Usage

Cumulative Stress Function

Based on duty cycle and component degradation with cycling and time. Used to reconcile life vs. Fuel Economy & Performance

System Design Optimization … Specification Development… Needed for Low Cost, Robust Design

RWUPs based on PRVD

90% Customer (Driving Style, Loc

90% Environment (Temperature, T

Inverter Key Life Tests

Accelerated tests to Validate inverter cycle life

Application/Usage Optimization

Vehicle Targets

Customer Usage

Power Electronics System Specs

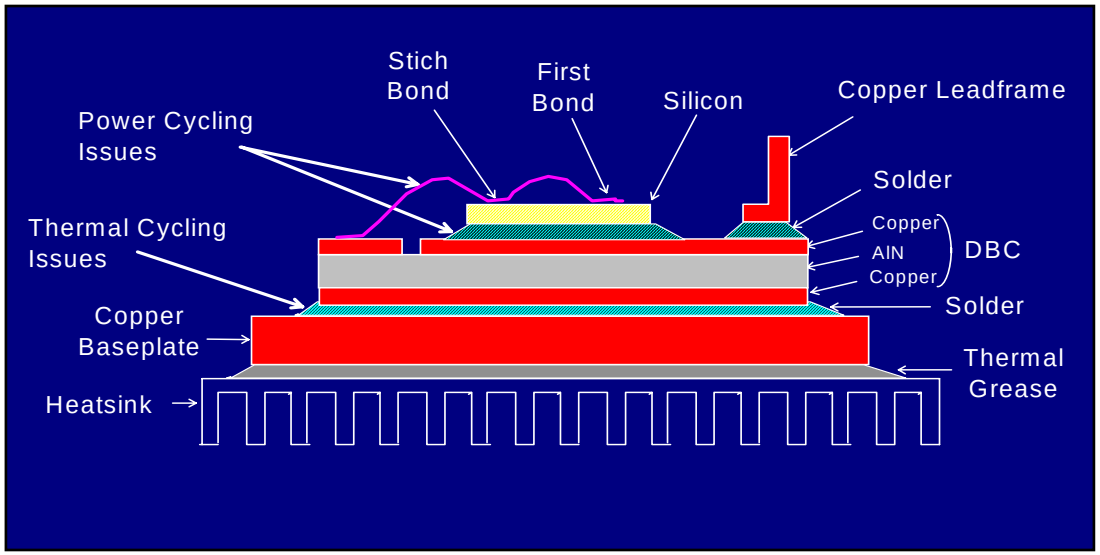
Power Module Silicon and Cooling Technologies & Design

Junction Te

Silicon

Cost &

Multiple Design/ Learning Cycles Needed for Affordability



TODAY

ct Baseplate vs. Double Sided Cooling
ient to Steady State Thermal Resistance
w Cost Materials based Thermal Stack

Lower Cost & Smaller Size

TOMMOROW

Technology Evolution – Silicon

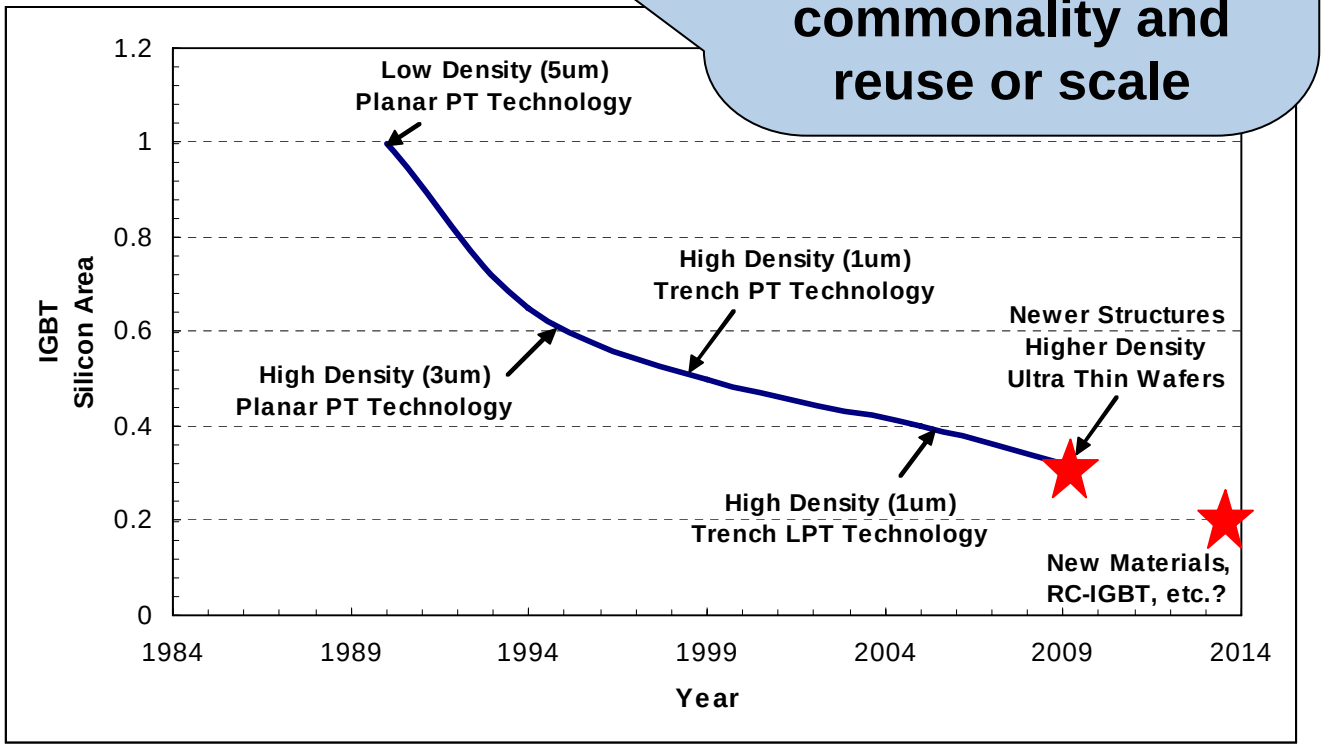
- Current Density (Silicon Area)
- Better Switching vs. Conduction loss trade-off
- Operating Junction Temperature (150 to 175C)
- Lower Cost Starting Wafer Material
- Wafer Size (6 inch to 8 inch)
- Wafer Yield Improvements

Multiple Technology Cycles Needed for Affordability

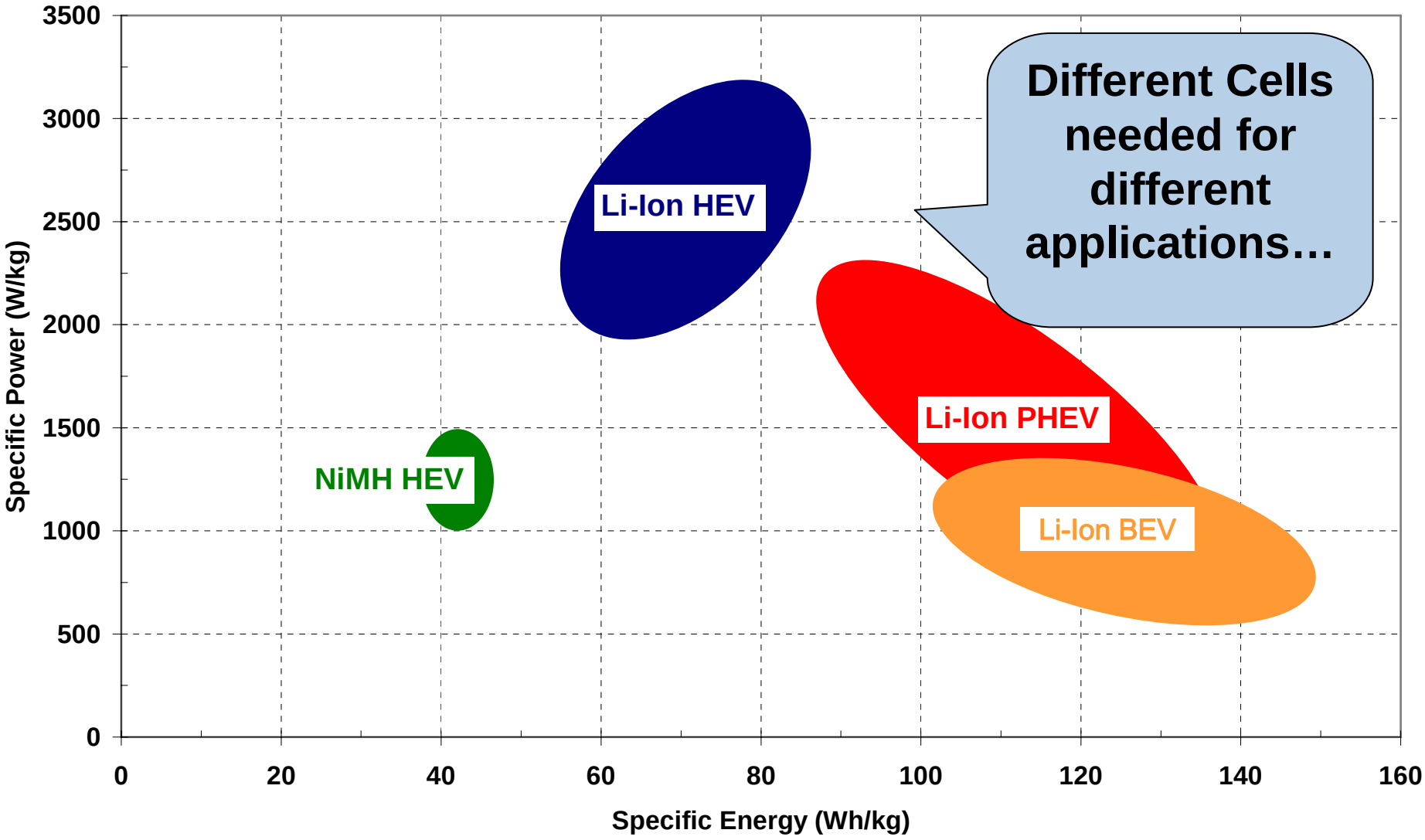
… competes with commonality and reuse or scale

Cost Drivers:

- Chip Shrink
- Higher Yields
- Larger Wafers



Hybrid Battery Technology Comparison



Battery Affordability…Need to reduce the cost

- Major cost is the battery
- Battery cost estimated to reduce ~3%/yr with technology
- Battery cost could drop 20 - 40% immediately with volume (need enough vol. to fill a battery line…)

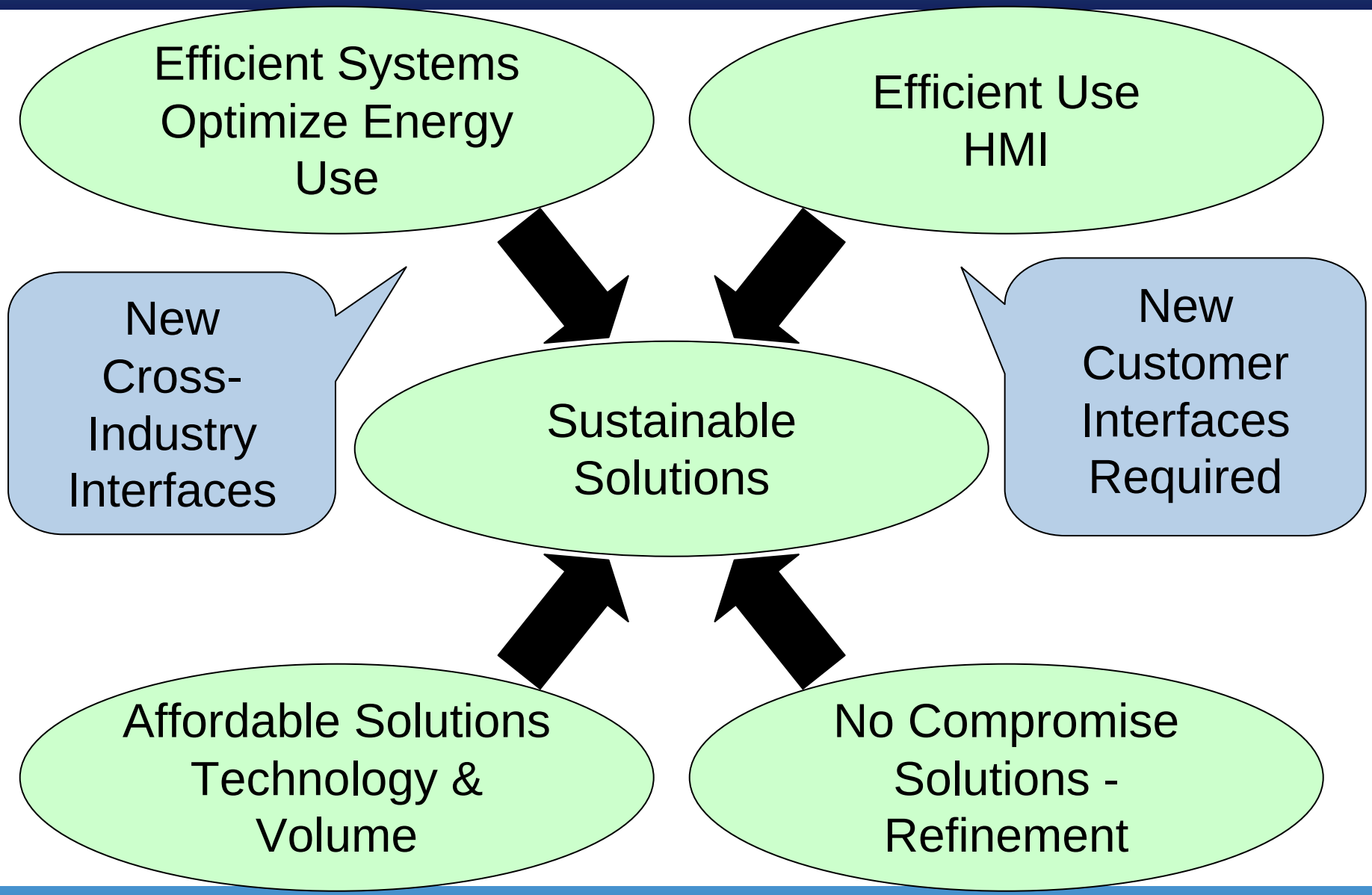
Largest near term opportunity to reduce cost: stable, committed volume…

Are there other potential users… stationary applications?

What is economic volume for Batteries ?

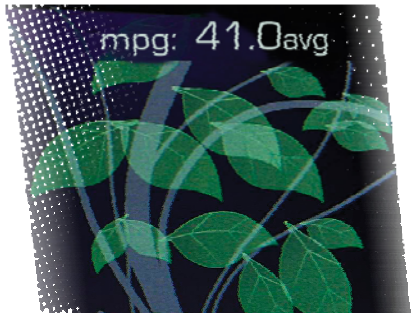
	AH	Low Vol. Cost	Cells/yr	Cells/Veh	Veh/Yr
HEV	5-6	X	10-12M	~80	125-150K
PHEV	~40	3-4X	8-10M	~80	75 - 100K
BEV	~60	5-6X	7 - 9M	~100	50-80K

Total Look Towards Sustainability



SMARTGAUGE™ *WITH ECOGUIDE*

New Knowledge and Skills Needed: Customer and Engineer



GRAPHICALLY TRACKS DRIVER'S EFFICIENCY

Advances in Technology Conclusions

- Key issue facing advances in Hybrid Technology and migration
  - Hybrid costs, investment and business equation for the customer and industry
  - Availability of skilled engineers (OEMs and supply base)
- Need to understand the customer usage
- Pick the right Hybrid architecture
- Optimize designs for usage
- Select technologies to address cost
  - Rapid technological change required on many components over next 10 years

Good News - Costs are coming down
Key Challenge – Costs are not coming down fast enough

Realizing The Power of Plugging-In

Two industries tied together through a common fuel to change the transportation and energy paradigm

What goes into a PHEV?
Total system approach required…

High Voltage EDS

1) Increase wire diameter to handle 60 kW peak power
2) Modify safety shutdown

110V AC Plug-In

Rear Cargo Area

1) Replace production high voltage battery with high energy Li-Ion battery
2) Add battery charger
3) Add gateway module for plug-in control
4) Revise rear structure for added weight and safety performance
5) Redesigned suspension for added weight

Transaxle/Engine Compartment

1) Modify transaxle oil lubrication/cooling circuit for extended engine-off durability
2) Add oil to air heat exchanger to increase continuous operating capability of electric machines

Brakes / Chassis

1) Update regen and brakes/chassis for revised weight distribution/function

Other Areas

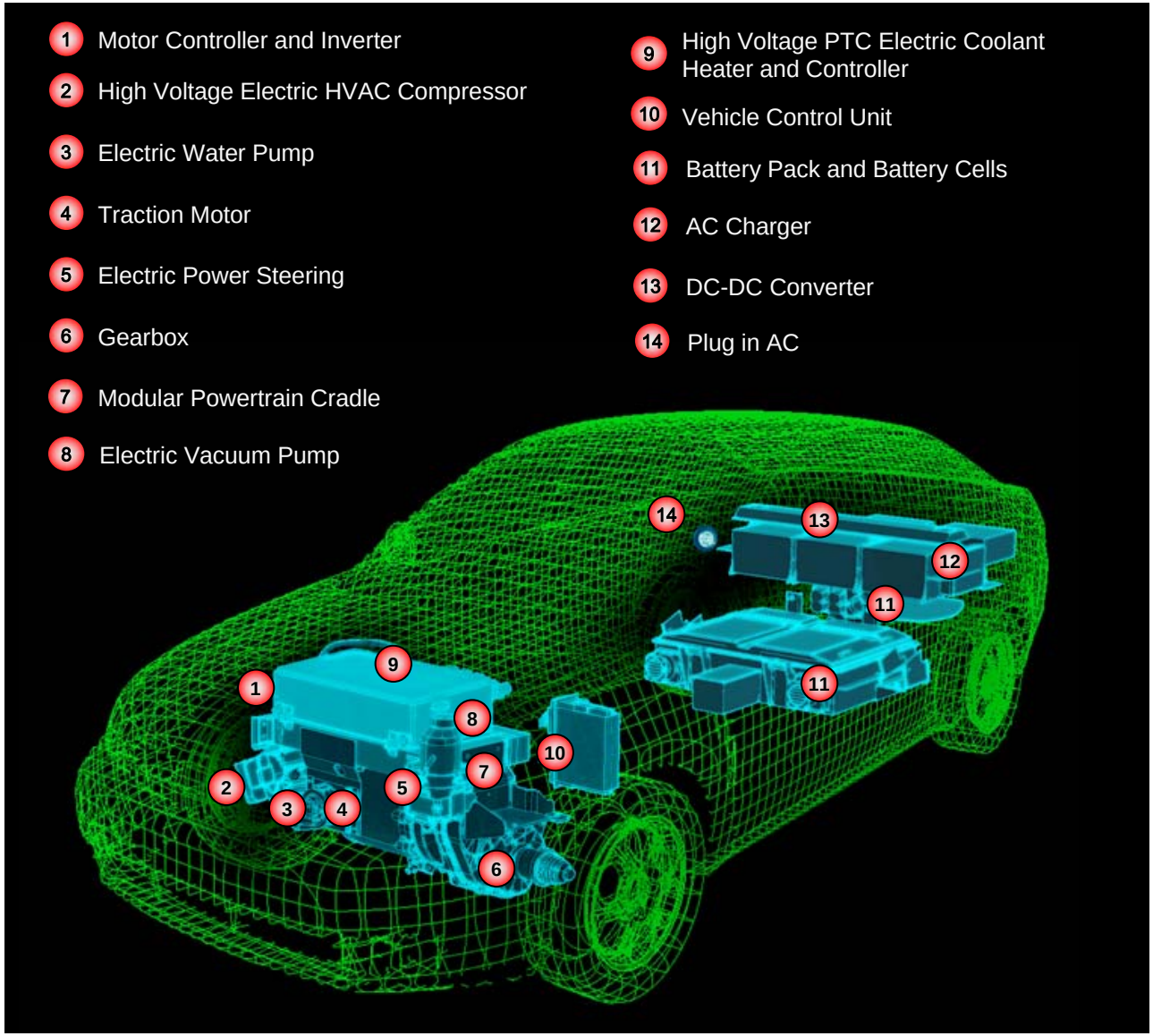
1) Emissions - need revise strategy to meet PZEV w/extended engine off time
2) Climate control - tailoring new approaches for heating vehicle and defrosting during extended engine off time

Ford Focus BEV – A Zero Emissions Solution

No ICE, all BEV

- Powered by an electric motor and high-voltage lithium-ion battery cells
- Targeted range of 100 miles
- Other vehicle systems (e.g., HVAC) also require electric solutions
- 14 new components
- Have to rethink every system

Move from an engine driven hydraulic world to motor/battery driven electric world…

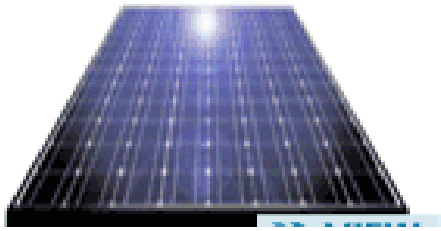


Current State:
Independent Solutions

Appliances
Tools

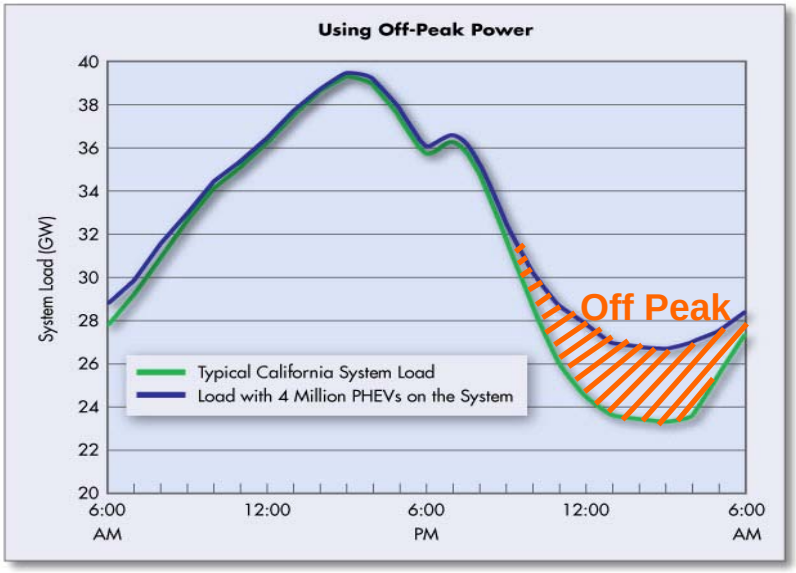
Home Generators

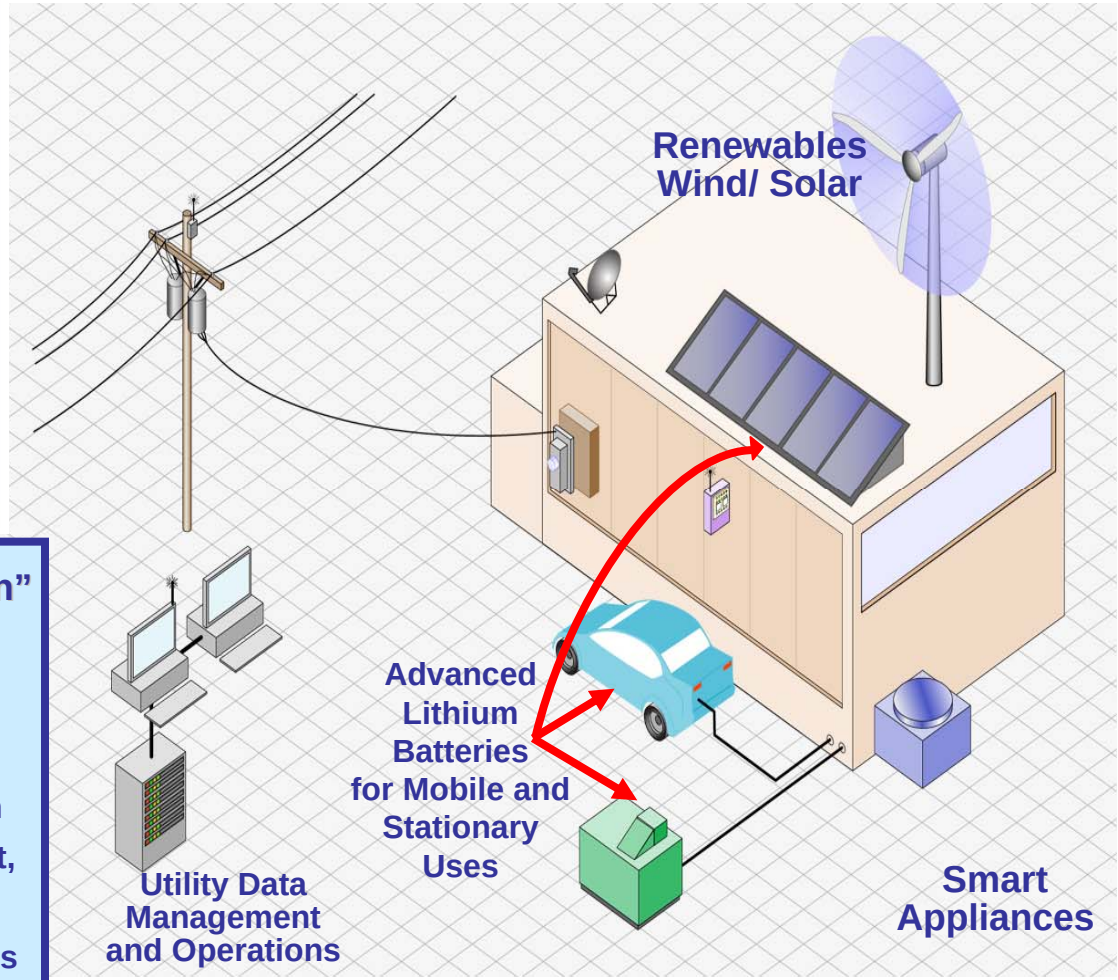
Solar Panels



Windmills

Future State:
Integrated Energy World Utilities & Autos Working Together





Exploring Customer Value From "Plugging In"

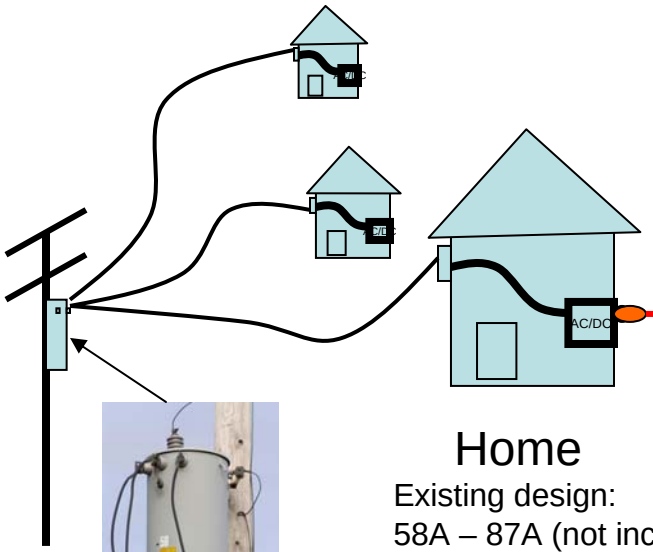
- Use low cost off-peak energy to charge vehicle
- Storing energy in advanced batteries - "drive" the wheels and occasionally "power" the house
- Storing energy on-site from wind/solar generation
- Finding new uses for generation capacity, at night, may help lower future electricity rates
- Night time energy use may help enable renewables
- Finding new uses for "new" batteries may help lower costs of future hybrid batteries

Lower PHEV/BEV acquisition & Ownership Costs? Utility Value?

Deep Understanding V2G Connectivity

Distribution Substation

Existing design:
29A – 56A/ home*
per standard utility sizing methods

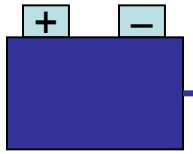


Multiple Home Pole Transformer

Existing design:
31A – 59A/ home*
per standard utility sizing methods

Home

Existing design:
58A – 87A (not including charger)
per NEC220



Battery

Existing battery: capable of charging at the vehicle worst case drive cycle discharge rate.

Charge Plug/Cord Level 1 & 2 available per SAE J1772 ©

Vehicle

Existing wiring: capable of worst case drive cycle

* Multiplication factor (Coincidence factor) varies from region to region and utility to utility.

Considering vehicles with 3.5 kW chargers, based on our understanding of NEC code, the calculated home current requirement will increase by 17% to 25% and each utility component will equally be impacted.

Today's Plug-in Project – Much to Learn Collectively!!!

- ✓ Unique partnership between automotive and utility sectors to accelerate the commercialization of PHEVs
- ✓ Project goals:
  - ✓Creation of New Business Models
  - ✓Development of open architectures, standards and specifications
  - ✓Create Customer Demand based on realistic expectations
- ✓ Diversifies transportation energy supply
- ✓ Future Vision: *From Independent to Integrated*

Two industries connected by a common fuel … driving our transportation and energy future…

What will it take to accelerate electrification? Challenges and Obstacles

- **Aligned Goal**
  - Accelerate the production of HEV, PHEVs, BEVs, and V2H technologies that delight customers and provide a reasonable rate of return to all
  - 1 million Plug-ins by 2015
  - Energy Security; Climate Change; Employment (green jobs)

- **New Business Approaches / Partnerships (OEM/Utility Collaboration)**
  - Today: World of independent solutions
  - Opportunity: Convergence of technologies and industries
  - Future: Transportation and Utilities become interdependent

- **Customer Affordability and Sustainable Business Proposition**
  - Customers desire price payment parity with ICE (Internal Combustion Engine)
  - Cost of Ownership key to customers
    - Need to recoup cost in 3 years or less
    - Fuel price a key driver to buying behavior
    - Monthly vehicle payment and monthly fuel payment critical to customer affordability
  - Near term customer incentives provide a kick – difficult habit to break
  - HEV price premiums do not cover added cost
  - Require solutions to reduce cost and achieve profitability parity (sustainable business proposition for all)

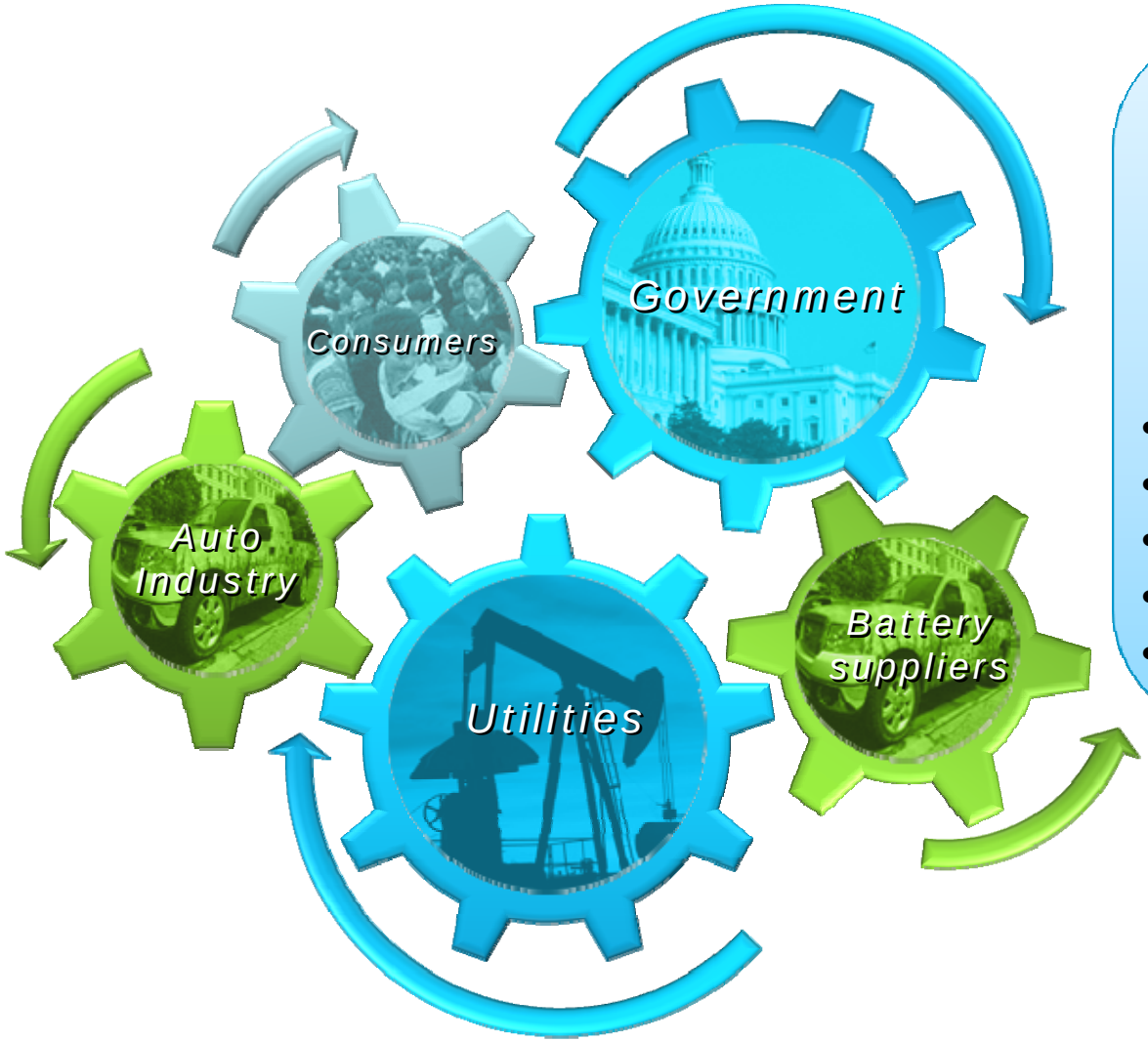
Plug-In Challenges Outside Of The Traditional Automotive Technical Realm

In order to deliver plug-in hybrids to the mass market, challenges that lie outside of the automotive realm must be addressed such as:

- ✓ **High Voltage Battery – durability and cost**
- ✓ **Charging infrastructure**
- ✓ **Customer behavior and access to charging**
- ✓ **Payment – remote charging, varying rates**

How to achieve these goals in a sustainable way – making a business case that provides value to all stakeholders?

Integrated Approach With Shared Responsibility



The development of a sustainable electrified market will be dependent on close cooperation between

- *Manufacturers*
- *Utilities*
- *Battery suppliers*
- *Governments, and*
- *consumers*


Ford