Future Lithium Demand in Electrified Vehicles

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Outline

Vehicle Electrification at Ford

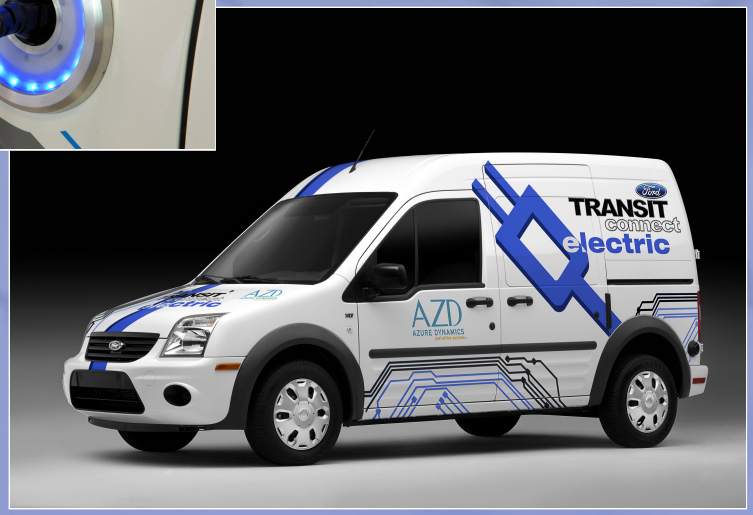
Advanced Battery Technology

Lithium Batteries

Electrified Vehicle Market Forecasts

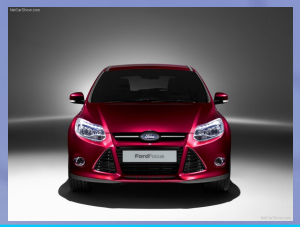
Key Challenges

Ford Electrified Vehicles

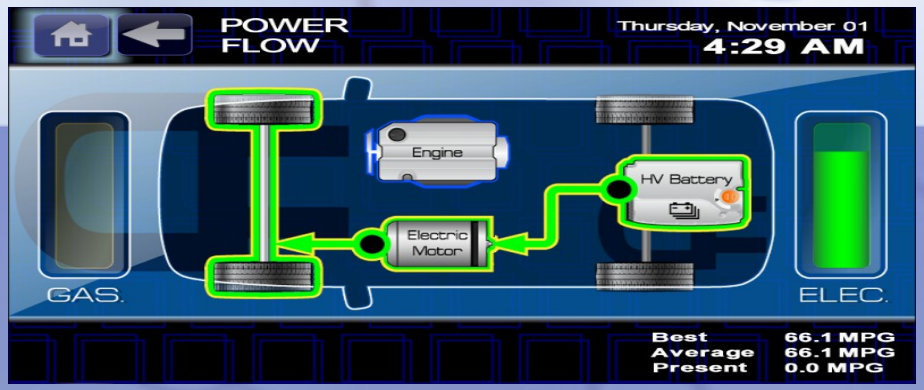


Announced Ford Electrification Plans:

Key is Leverage of High Volume Global Platforms

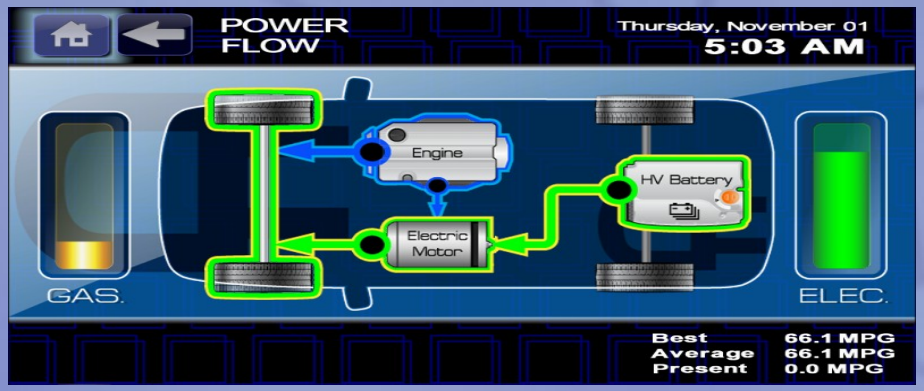
	2004 CY	2010 CY	2012 CY	2018+ CY
BEV Battery Electric Vehicles		Transit Connect (Global C-Platform)		
		Focus Electric (Global C-Platform)		
PHEV Plug-in Hybrid Electric Vehicles		Global C-Platform		
HEV Hybrid Electric Vehicles		Escape	Global C-Platform Next Generation HEV	
		Fusion/Milan	Global CD-Platform Next Generation HEV	

A “Power Split” Blended PHEV



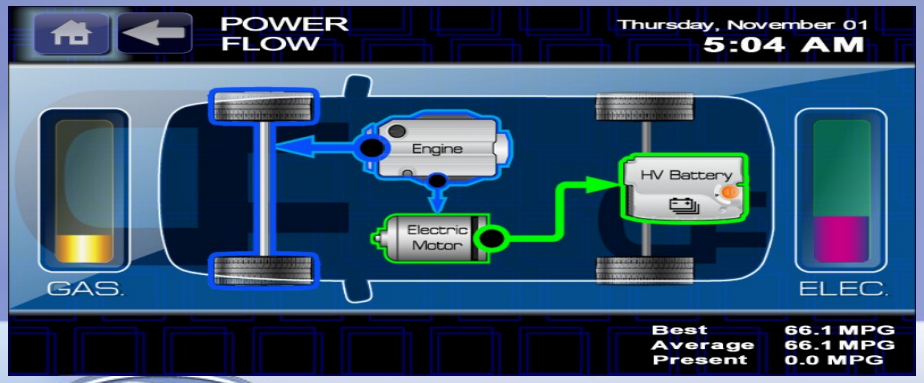
ELECTRIC DRIVE

At urban speeds, the high-capacity plug-in hybrid battery allows for extended battery-only driving distance



BLENDED ELECTRIC/ENGINE DRIVE

At higher power demands and vehicle speeds, the vehicle automatically switches to blended electric/engine mode, providing propulsion using both the engine and the high-capacity battery



HYBRID DRIVE

In hybrid drive mode, the vehicle continues to operate as a standard hybrid electric vehicle

Ford

Key Automotive Targets

HEV (40kW battery full hybrid system example)

High specific power: >2,000W/kg (<20kg battery)

-30C cranking capability: 5kW

Extremely high shallow cycle life: 500k cycles

Long operating life: 15 years

High power/energy ratio: >20:1

Cost: goal of $20/kW ($800) @ 100k/year

PHEV (Ford Escape Plug-in Hybrid battery system example)

Higher energy power battery: 10kWh / 25mi / 140kg / 95 liters

Requires full power over a wide temperature range

Both high deep (5,000) and shallow (500k) cycle life required

Must be fully abuse tolerant when packaged in the crash zone

Power/energy ratio: 5:1 to 15:1

Cost: $700-1,000/kWh ($5-15k); goal = $200-300/kWh @100k/year

EV (30kWh electric vehicle battery system example)

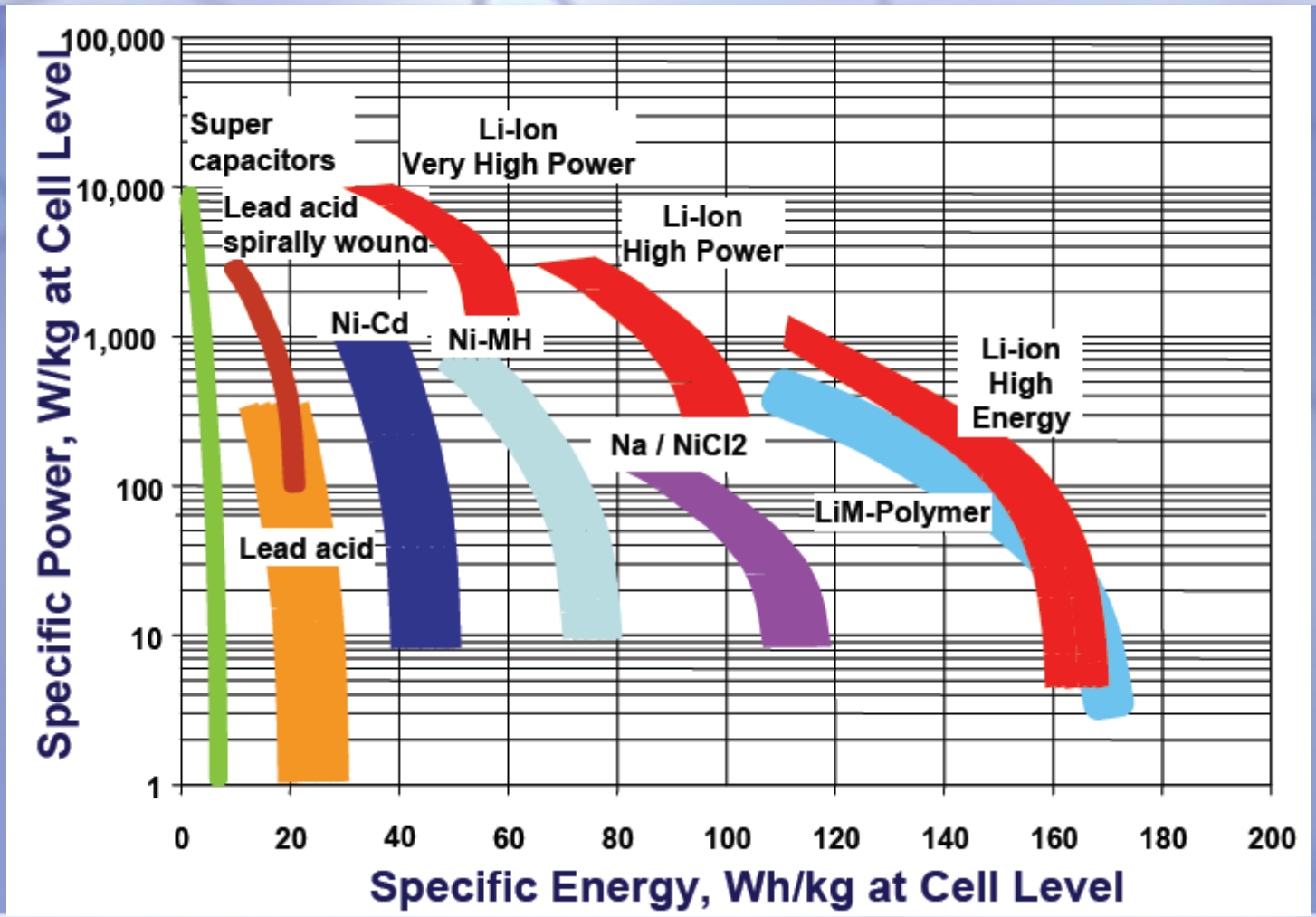
High energy density: >120Wh/kg (30kWh / 100mi / 250kg battery)

High deep discharge cycle life: 3,000 cycles to 80-90% DOD

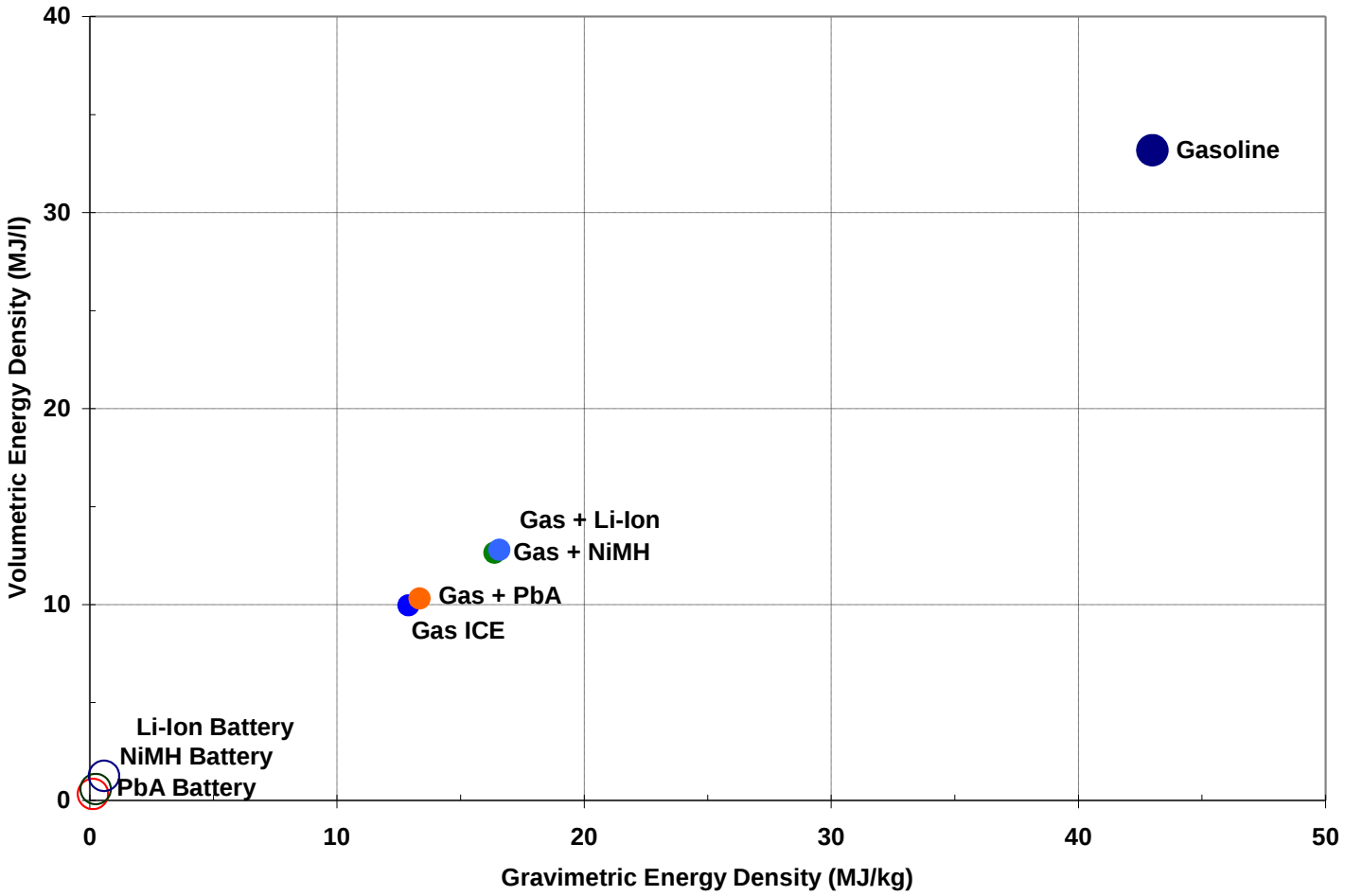
Power/energy ratio: 2:1 to 4:1

Cost: $500-600/kWh (>$10k); goal of $100/kWh; prospect of $300/kWh

Energy Storage Options



Fuel Energy Density



Why Li-Ion for Future HEVs?

Advantages

40-50% battery weight reduction

20-30% battery volume reduction

5% efficiency improvement

Simplified battery controls due to straightforward “voltage indicative” SOC algorithm

Disadvantages

Requires time-consuming and expensive qualification

Sloping voltage vs. SOC may also apply to power

Requires comprehensive system approach to ensure fail-safe operation

The PHEV Enabler

Li-Ion batteries are the obvious energy storage option for PHEV

50% less weight (~ 100-200 lbs)

30% less volume, but still tight packaging

High degree of application compatibility

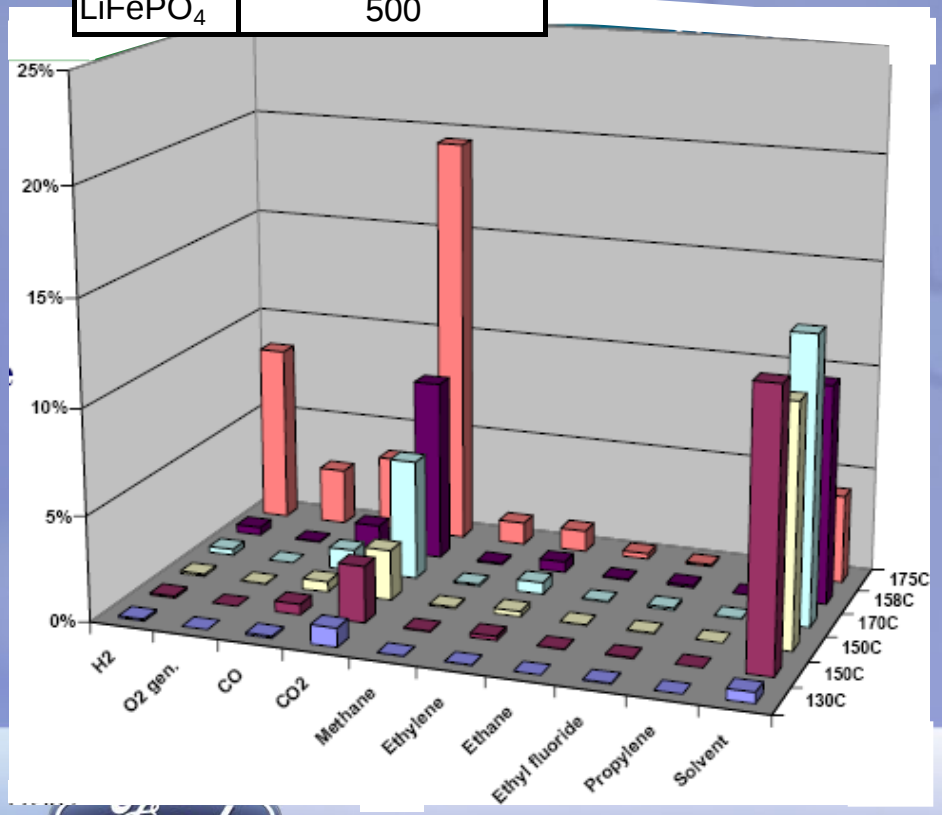
- Well resolved SOC
- Historic research focus on high energy
- Reasonable power-to-energy ratio design flexibility

Wider range of electrode material choices

Long term cost potential

Li-Ion Cell Venting Considerations

Cathode Type	Vent Gas Relative Volume
LCO	950
NCA	750
NMC	950
$LiMn_2O_4$	700
$LiFePO_4$	500



- Li-Ion vent gas volume and composition are relatively independent of cathode type
- Potential vent gas volume is significant for all cathode chemistries under related abuse test conditions
- Vented gases and electrolyte solvents are flammable, some are toxic, and some are immediately reactive
- Therefore, vent gases must be managed to avoid:
  - Entry into passenger airspace
  - Direct contact with potential ignition sources

Plug-In Challenges Outside of the Technical Realm

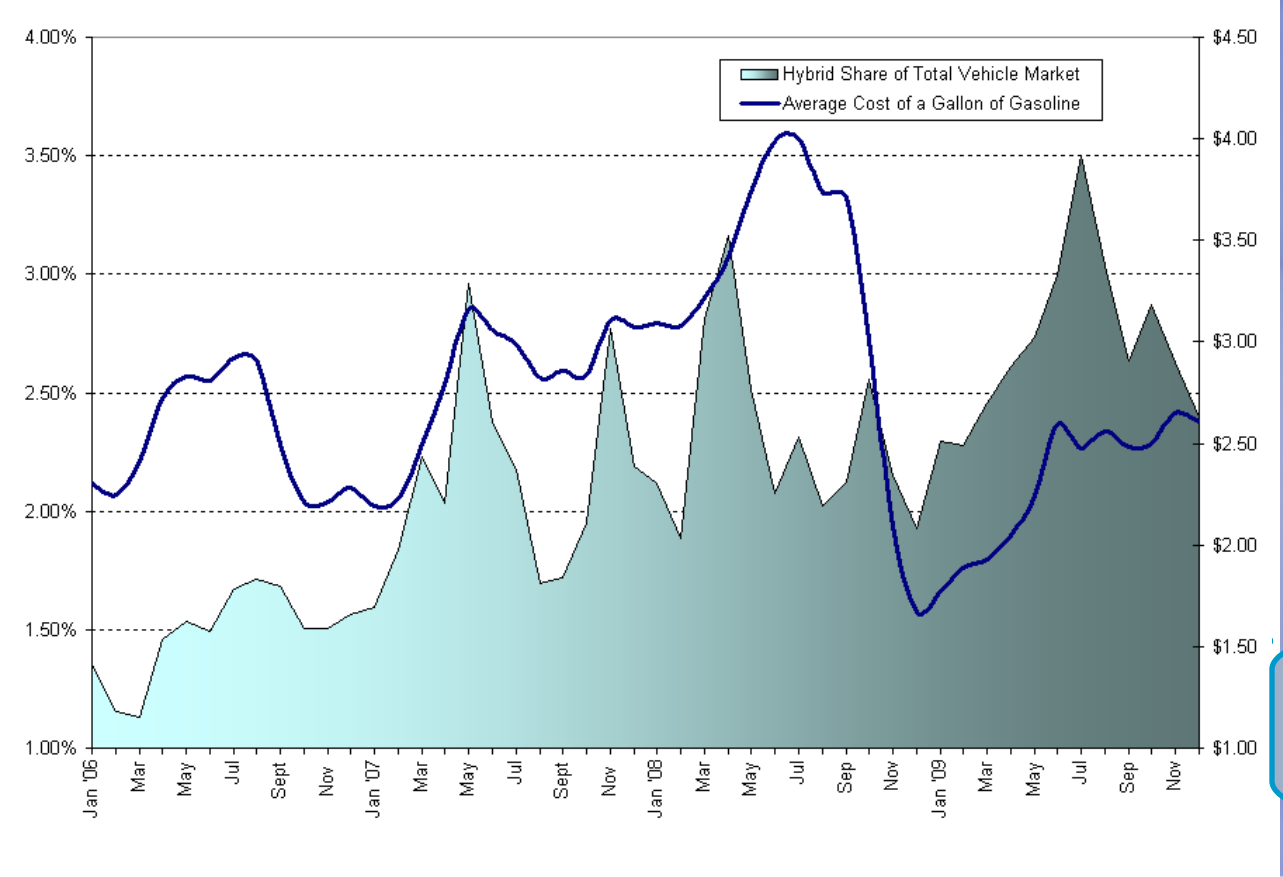
In order to deliver plug-in vehicles to the mass market, challenges that lie outside of the automotive realm must be addressed such as:

- **Battery – durability and cost**
- **Charging infrastructure**
- **Customer 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?

Electric Market Prospect

Fuel Prices Impact HEV Sales –
Volatility is incredible in the US...

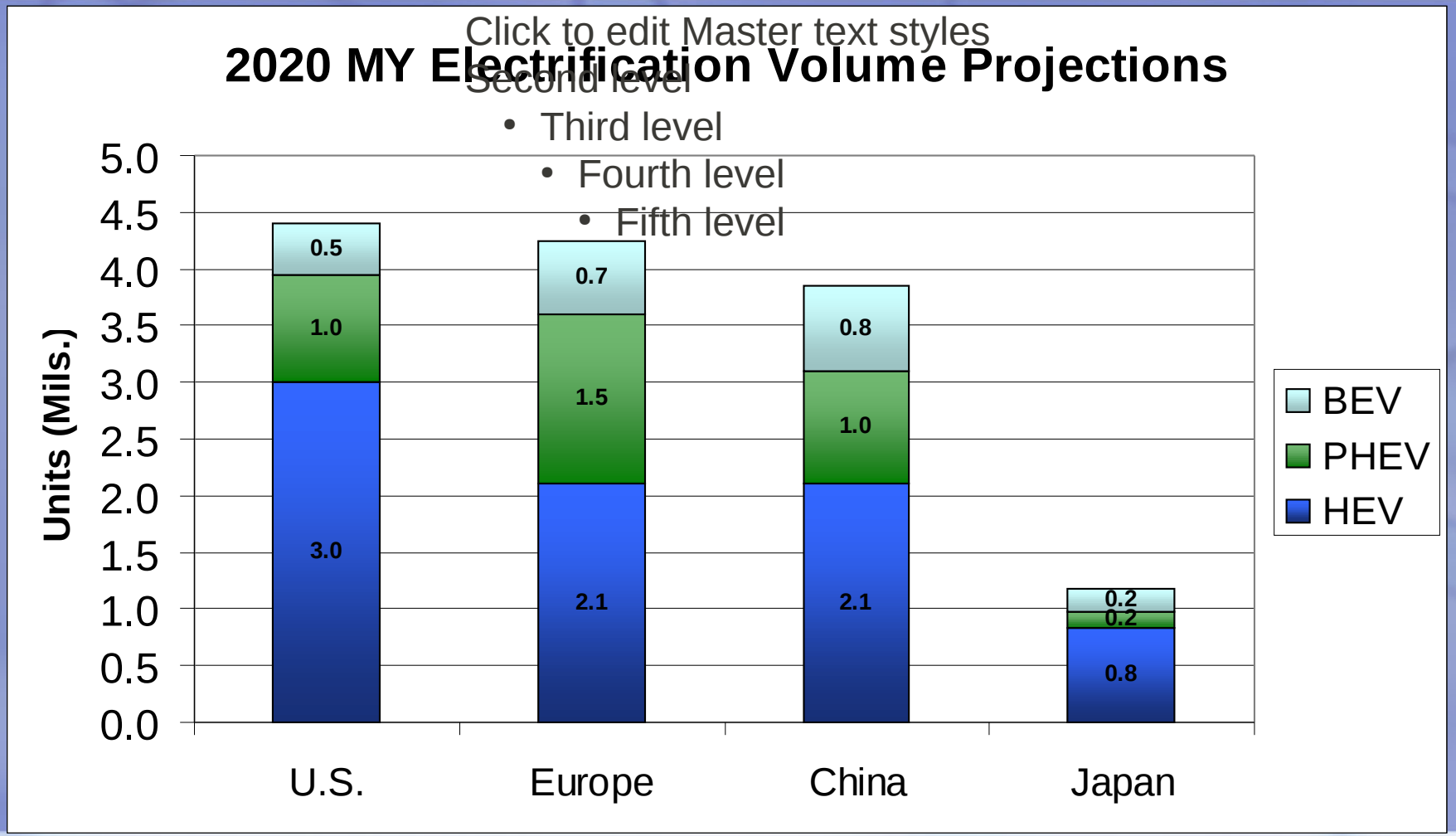


Peak of ~3.5% of Fleet

Today ~2.4% of a Smaller Fleet

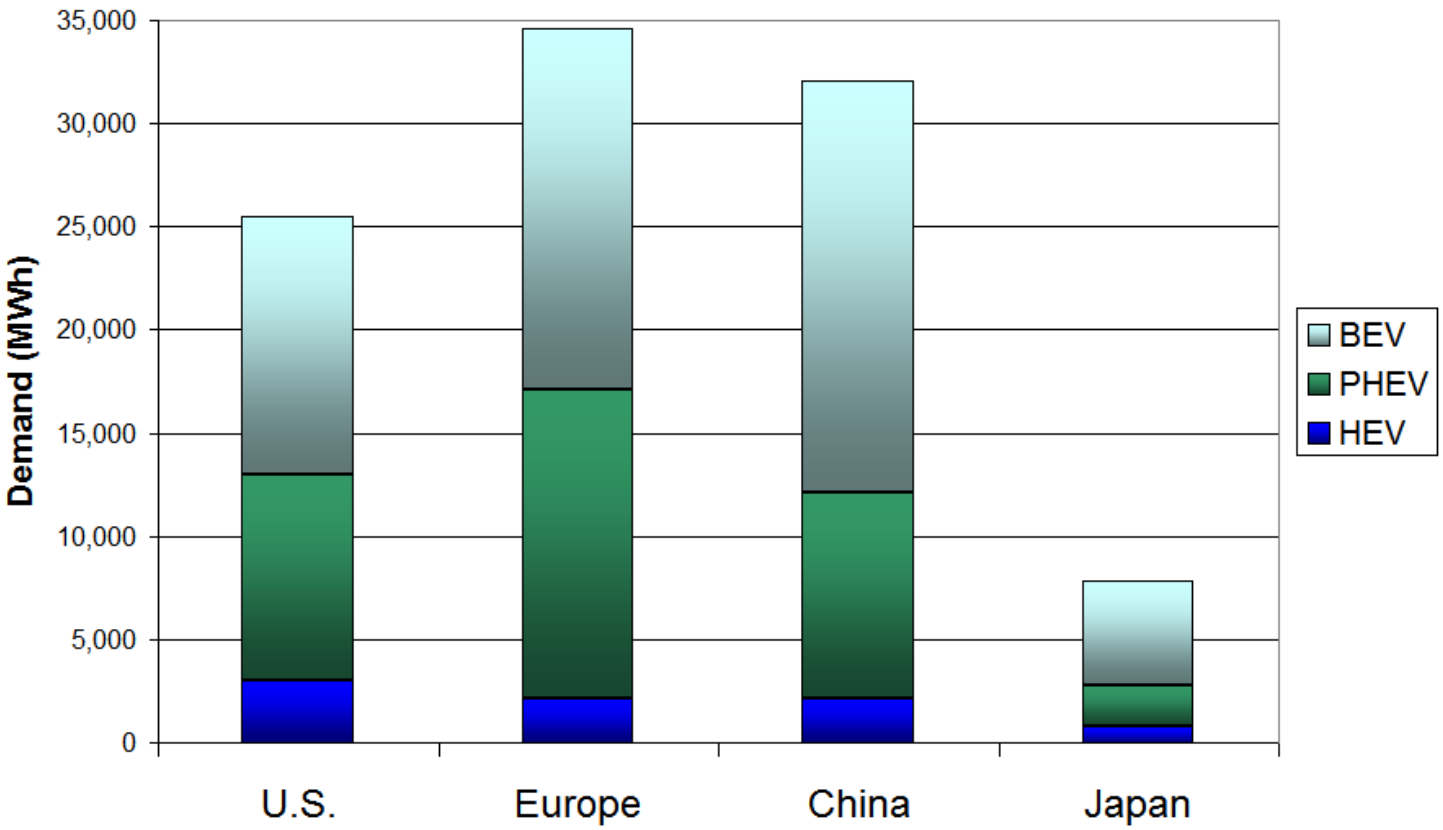
2020MY Global Electrification Volume

Click to edit Master text styles
- Second level
  - Third level
    - Fourth level
      - Fifth level

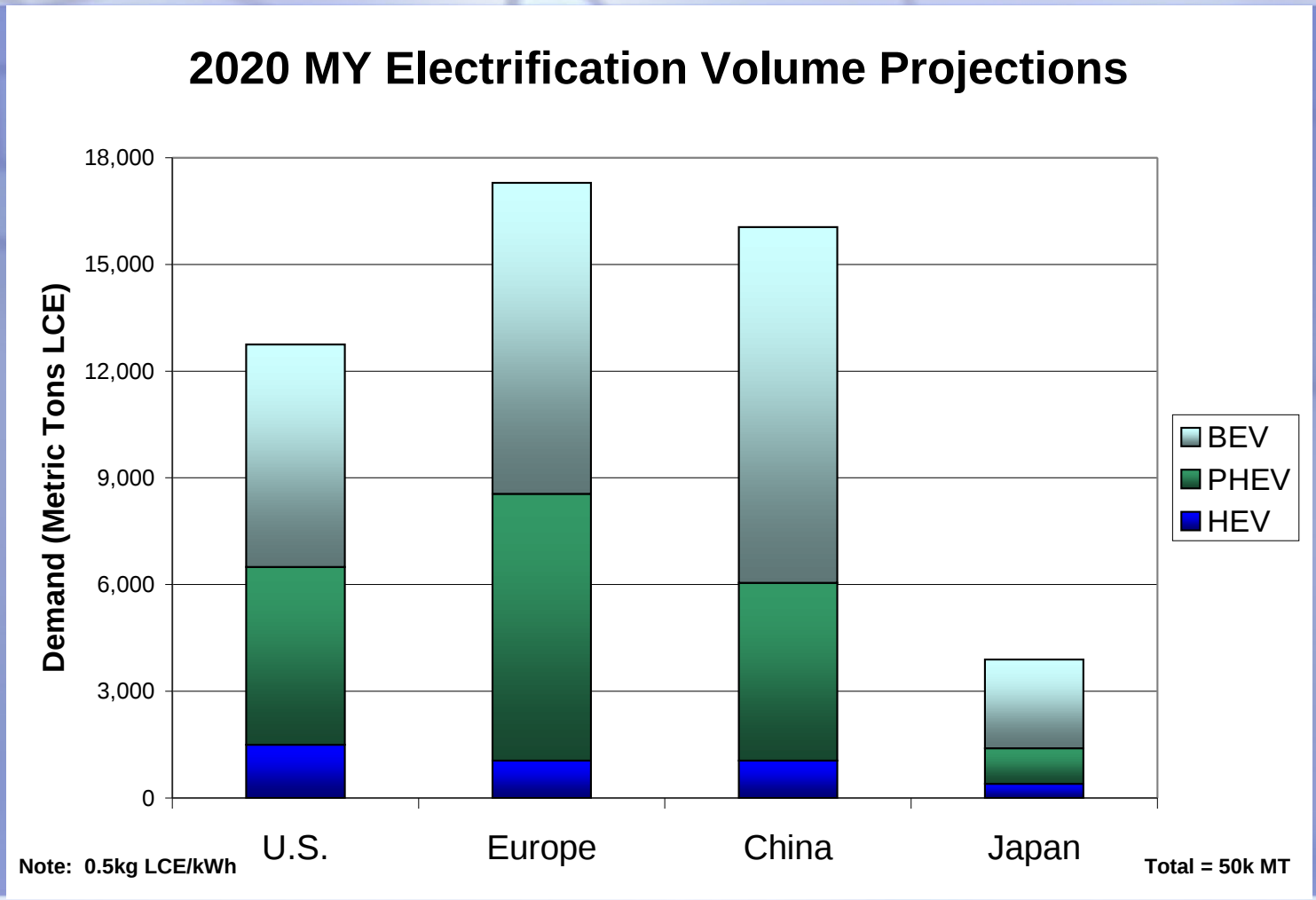


Note: Data is aggregated from consultancy papers

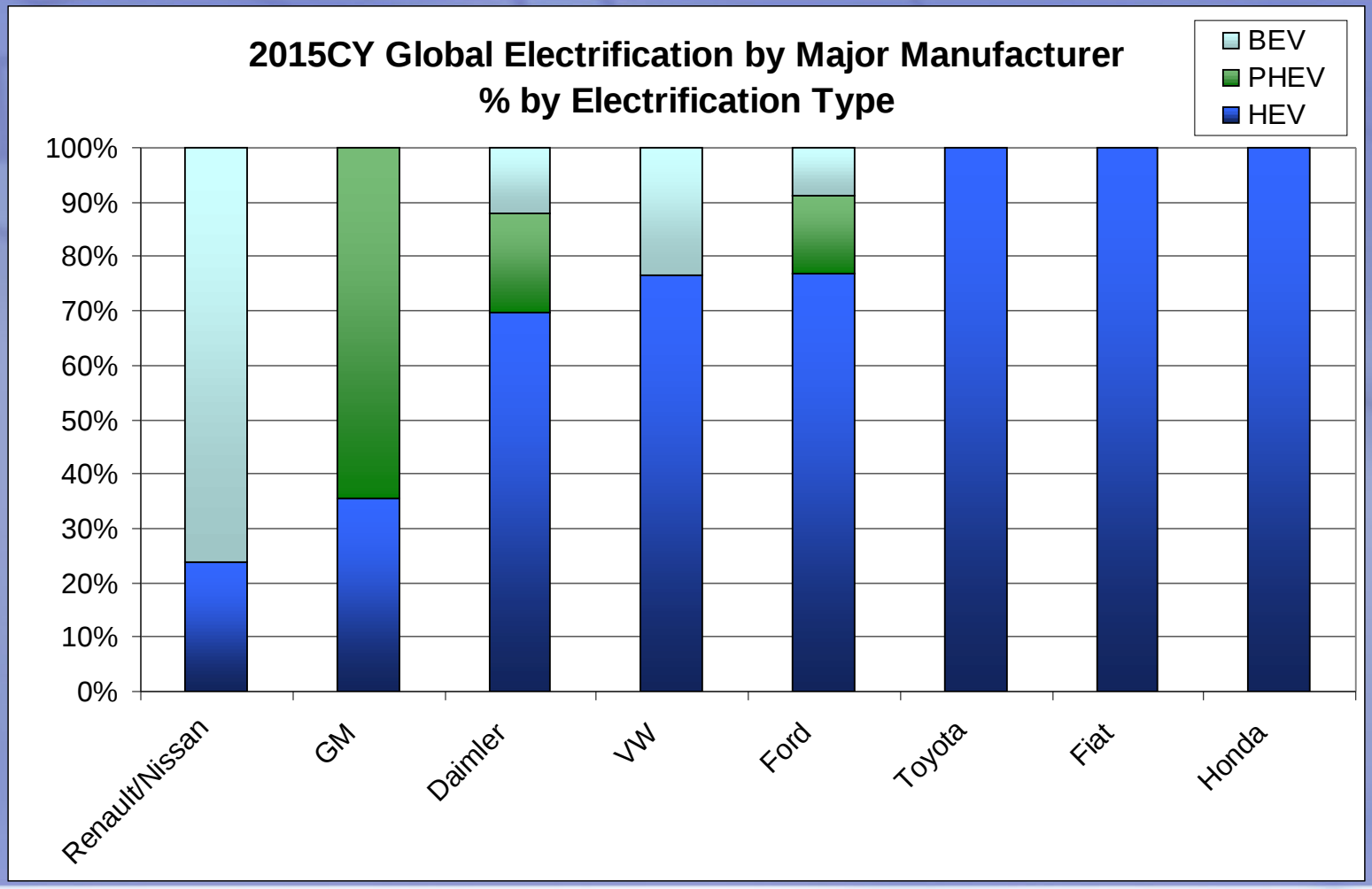
Battery Market Prospect



Lithium Market Prospect



Electric Market Prospect



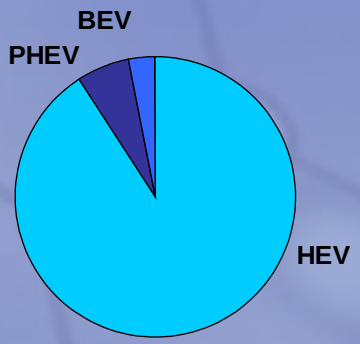
Note:
- All data is from CSM Worldwide global comprehensive vehicle production and sales forecasts.
- Major manufacturers are those with >100,000 electrified vehicle sales projected in 2015

Electrification Product Plan

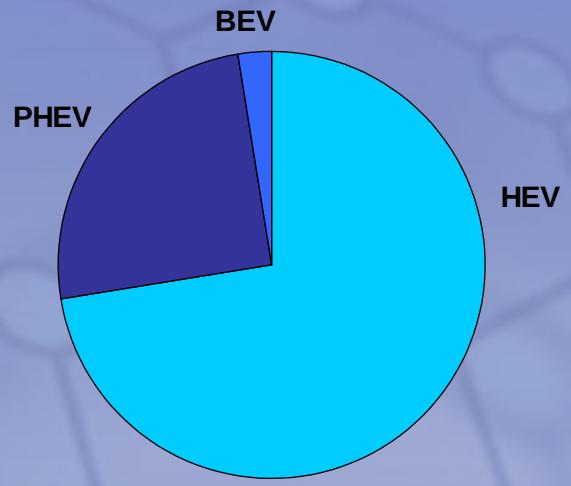
Ford Global Electrified Volume

2010 CY

2015 CY



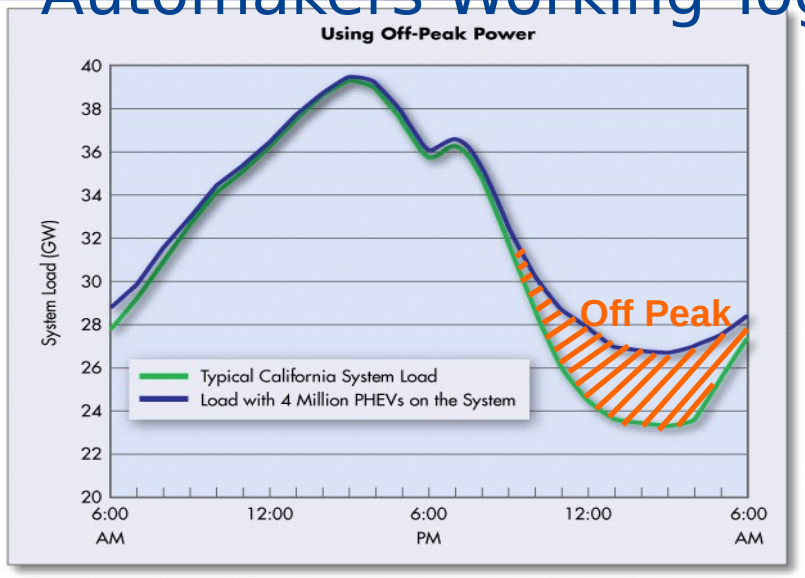
2020

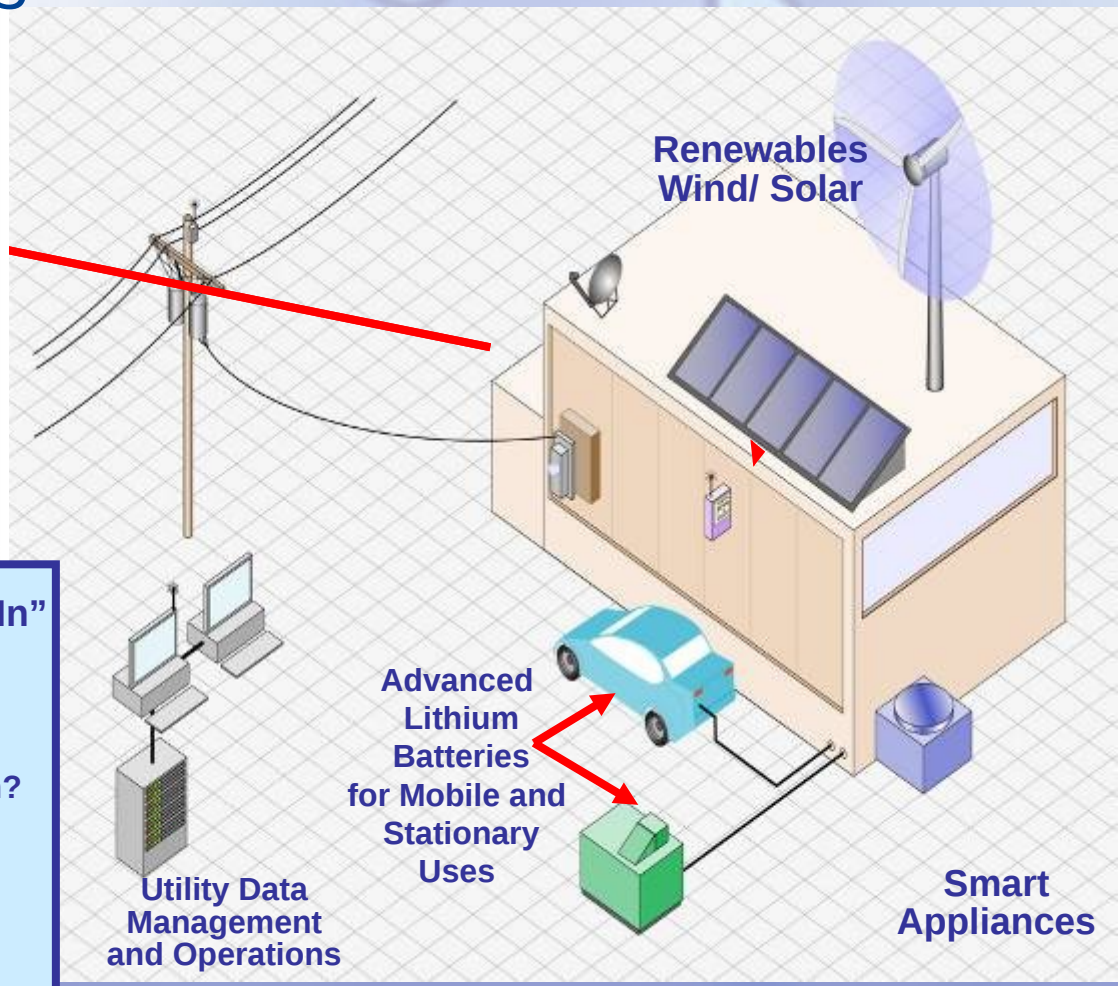


Balanced Portfolio
Global Flexibility
Volume will be predominantly HEV
Plug-ins gaining acceptance

Balanced growth also provides flexibility to react to volatile external factors

Future State: Integrated Energy World with Utilities & Automakers Working Together





Exploring Customer Value From "Plugging In"

- **All New System View:**
  - What components are in the new system?
  - How will the grid and energy flow be controlled in the future?
  - Who are the parties involved?
  - What new integration is needed?
  - What are the key technologies and standards needed?

Many Open Questions…

Integrating a new energy eco-system

What will it take to accelerate electrification?

- **Aligned Goal**
  - Accelerate the production of HEV, PHEVs, BEVs, and V2H technologies that delight customers and provide a reasonable rate of return to all
- **New Business Approaches / Partnerships (OEM/Utility Collaboration)**
  - Plugged-In Future: Transportation and Utilities become interdependent
- **Customer Affordability and Sustainable Business Proposition**
  - Customers desire price and performance parity with conventional vehicles (no compromises)
  - Cost of Ownership key to customers (mass market)
  - Near-term: Jump-start industry – combined incentives
  - Mid-term: Grow volume/infrastructure with customer focused profitable product
  - Long-term: Greater customer value (short pay back) with profitability parity (sustainable business for all)

Integrated Approach with Shared Responsibilities

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

- **Manufacturers**
- **Utilities**
- **Battery suppliers**
- **Governments**
- **Consumers**

TOWARD A SUSTAINABLE FUTURE