xEV BATTERY EVOLUTION – What's in Store For the Future?

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xEV Battery Evolution – What's In Store For the Future?
Topics

What does recent history of xEVs & their battery capabilities tell us about xEV batteries of the future?

What segments will xEVs encompass in the future, and what will be required of their traction batteries?

What battery advancements are in store for the next two generations (8 to 10 years) of xEVs?

Ford **BEV Battery** Evolution: From Nickel-Iron to Lead-Acid to Nickel-Metal Hydride to Lithium-Ion

Parameter	1913 Nickel-Iron	1992 Sodium-Sulfur	1997 Lead-Acid	1999 Nickel-Metal Hydride	2000 Lead-Acid	2011 Lithium-Ion	2012 Lithium-Ion	2017 Lithium-Ion
Vehicle	Experi-mental	Ecostar	EV Ranger	EV Ranger	TH!NK Neighbor	Transit Connect	Focus Electric MY2012	Focus Electric MY2017
Vehicle Range	?	100 miles	58 miles	82 miles	31 miles	56 miles	76 miles	115 miles
Nominal Voltage	?	300 V	312 V	300 V	72 V	350 V	310 V	310 V
Capacity	?	125 Ah	74 Ah	95 Ah	73 Ah	80 Ah	75 Ah	108 Ah
Installed Energy	?	37 kWh	23 kWh	28 kWh	5 kWh	28 kWh	23 kWh	33.5 kWh
Weight	?	354 kg	870 kg	485 kg	195 kg	275 kg	300 kg	308 kg
Specific Energy	~40 Wh/kg	105 Wh/kg	26 Wh/kg	58 Wh/kg	27 Wh/kg	102 Wh/kg	77 Wh/kg	109 Wh/kg

Not all touted battery cell technologies make it into widespread production with staying power

Ford **FHEV Battery** Evolution: NiMH to Li-Ion Cell Technology

PARAMETER	GEN I (2004) 	GEN II (2009) 	GEN III (2012) 
Cell Type	Ni-MH Cylindrical	Ni-MH Cylindrical	Li-Ion Prismatic
Vehicles	Ford Escape Hybrid Mercury Mariner Hybrid Mazda Tribute Hybrid	Ford Fusion Hybrid Mercury Milan Hybrid Lincoln MKZ Hybrid	Ford Fusion Hybrid Ford C-MAX Hybrid Lincoln MKZ Hybrid
System Peak Power	Dischg/Chg: 39/31 kW	Dischg/Chg: 27/25 kW	Dischg/Chg: 35/35 kW
Mass (Normalized)	**100%**	**70%**	**47%**
Volume (Normalized)	**100%**	**84%**	**68%**
Cell Power Density (Normalized W/liter)	**100%**	**120%**	**140%**

Significant advancements in production battery cell technology can be realized Gen-over-Gen

Implementation Timeline – New Production xEV Battery Cells at Ford

GEN I (MY05 – MY12)

GEN II (MY10 – MY12)

GEN III (MY13 – MY18)

FORD/LINCOLN xEV	TYPE	MY05	MY06	MY07	MY08	MY09	MY10	MY11	MY12	MY13	MY14	MY15	MY16	MY17	MY18
Ford Escape Hybrid	FHEV	✓		✓			✓								
Ford Fusion Hybrid	FHEV						✓			✓		✓			
Lincoln MKZ Hybrid	FHEV							✓		✓		✓			
Ford Focus Electric	BEV								✓					✓	
Ford C-MAX Hybrid	FHEV									✓		✓			
Ford C-MAX Energi	PHEV									✓					
Ford Fusion Energi	PHEV									✓					✓

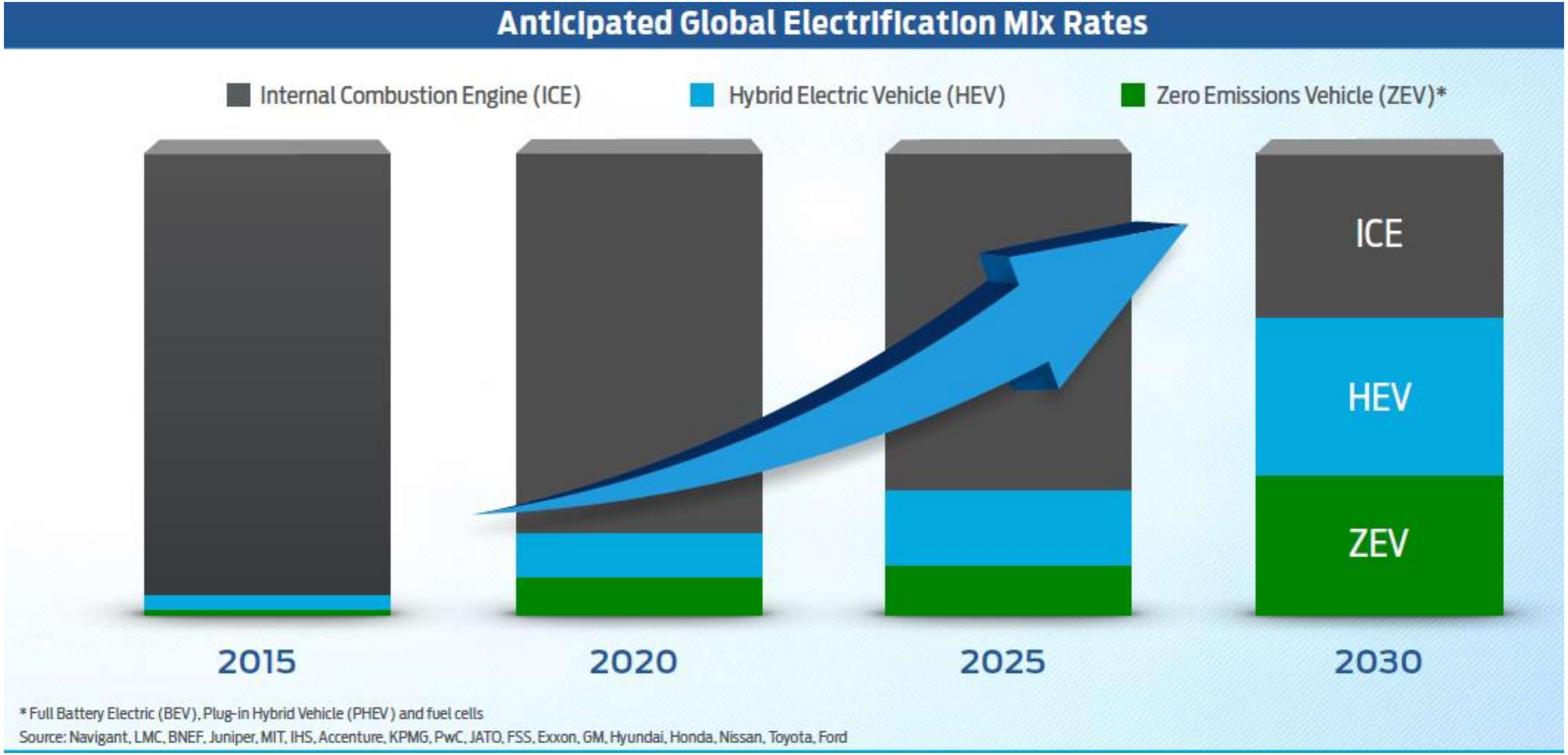
Nickel-Metal Hydride (MY05 – MY11)

Lithium-Ion (MY12 – MY18)

Battery cell technology advanced quickly in the past, making introduction of new battery cells into production at Ford at 2-to-3-year intervals not unusual.

This is expected to continue in the next two generations of xEVs at Ford...

Increasing Significance of Electrified Vehicles to Global Market in the Coming Years



Some studies project that electrified vehicle production will surpass ICE vehicles by 2025-2030

Future xEV Applications & Corresponding Battery Needs – More And More Electrified Vehicle Applications at Ford

- Additional BEV, PHEV, FHEV, 48-V mHEV, and 12-V LVPN nameplates
  - Cars, trucks, SUVs, cargo vans, taxis, etc.

- Performance vehicles
  - Police vehicles
  - Mustang
  - etc.

- Autonomous vehicles

Future xEV Applications & Corresponding Battery Needs – Battery Technical/Commercial Needs For Future Applications

BATTERIES FOR ALL xEVs

- Increased value (lower $/kWh) in smaller packaging space (higher Wh/l)

BATTERIES FOR FHEV, 48-V mHEV, 12-V LVPN applications

- Similar power/energy levels but at reduced cost ($/kW & $/kWh)

BATTERIES FOR BEV, PHEV applications

- Greater installed energy via increased battery cell energy density (Wh/liter), but also at reduced cost ($/kWh)
  - For BEVs, potentially frequent DC Fast Charging

- Can these future xEV battery needs be met with conventional lithium-ion technology, or will they require a different battery chemistry?

Future xEV Applications & Corresponding Battery Needs – Battery Technical/Commercial Needs For Future Applications

BATTERIES FOR PERFORMANCE VEHICLE APPLICATIONS

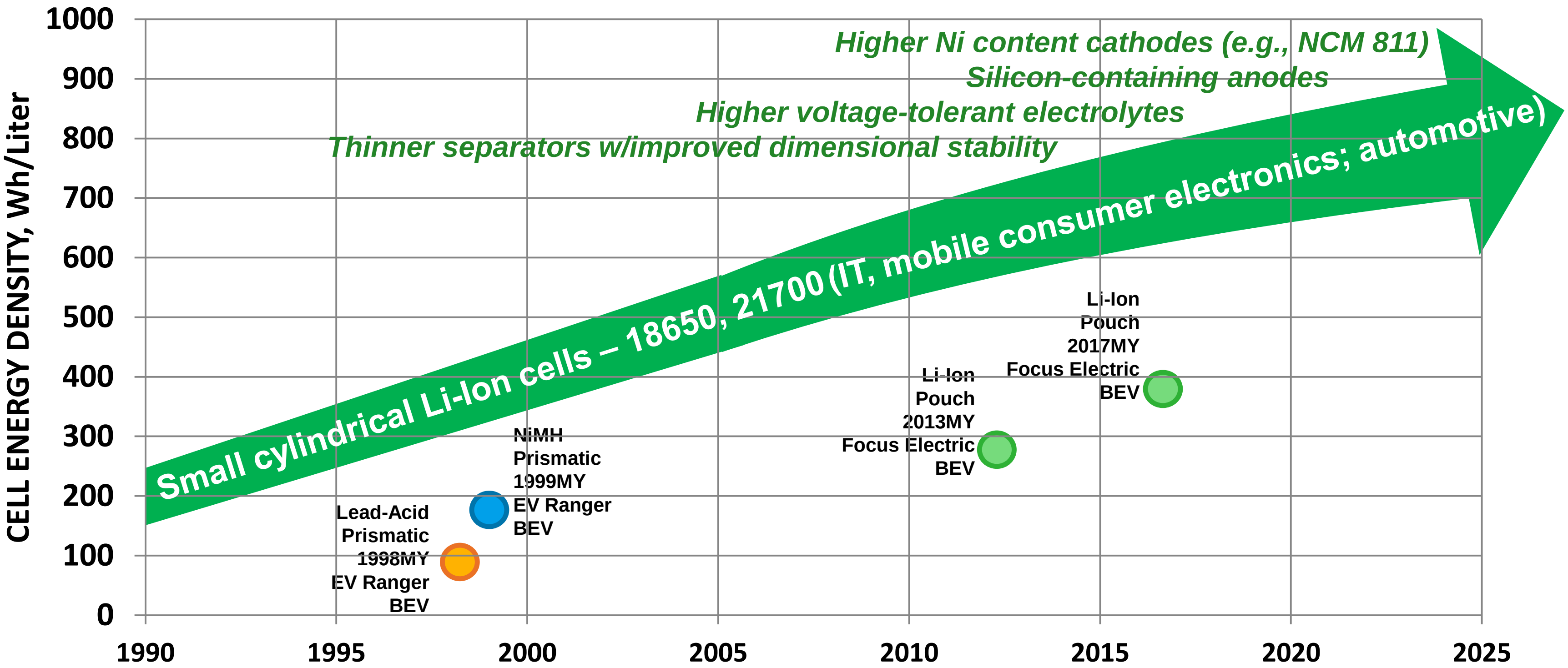
- Higher power/current limits; lower cell resistance
- Longer sustained high power/current pulses
- Increased battery thermal capability to support higher peak/sustained demand
- Increased value for installed energy (lower $/kWh) for all applications

BATTERIES FOR AUTONOMOUS VEHICLE APPLICATIONS

- Increased peak and average power demand – larger batteries than for non-AV
- Every-cycle fast charge tolerance for certain classes of BEVs and AVs
- Greater Wh/day throughput necessitates greater battery thermal design capability and battery cell durability – requires Wh/liter & $/kWh sacrifices

- Can these future xEV battery needs also be met with conventional lithium-ion technology, or will they require a different battery chemistry?

Battery Cell Energy Density Progression
Small Cylindrical Li-Ion Cells & Ford Electric Vehicle Battery Cells



Small format Li-Ion cells may achieve 800-900+ Wh/liter, large format 600-750 Wh/liter in the next 10 years. 700 Wh/liter may be sufficient even for autonomous vehicle needs...

Future Battery Technologies For the Next Two Generations of xEVs
Ongoing Evolution/Advancement of Lithium-Ion Cell Technology

- Continued trend of significant generational advancements every 2-3 years
  - Cathodes with increased nickel content (e.g., NCM 622 & 811)
  - Anodes with blends containing silicon
  - Higher voltage-tolerant electrolytes
  - Thinner separators with improved dimensional stability at high temperature
- Conventional large format lithium-ion cells with 600-750 Wh/liter for non-fast charge BEV applications may be realized in the next 8-10 years
- Ceiling for ‘conventional’ lithium-ion may be approximately 800-1000 Wh/liter
  - Could be approaching conventional technology ceiling in next 8-10 years
  - Even 700 Wh/liter (tolerant of DCFC) may be ‘good enough’ for AV BEVs

- BEV cell costs of $70-$80/kWh ultimately needed – Li-Ion will approach or meet

Future Battery Technologies For the Next Two Generations of xEVs

Battery Technologies Beyond Lithium-Ion

- BEYOND LITHIUM-ION
  - A number of contenders, each with significant challenges yet to overcome
    - Solid electrolyte Li-Ion (Solid State), polymer electrolyte Li-Ion or Li anode
    - Lithium-sulfur, lithium-iron disulfide, lithium-silicon alloy
    - Aluminum-air
    - Sodium-ion
  - Challenges generally with cycle life, either power (A/cm^2 of electrode area) or with abuse tolerance, power/energy vs. temperature, and/or demonstration of low-cost, high-volume cell manufacturing processes
    - Won't be ready in time for the next generation of xEVs, and probably not for the next two generations of xEVs. Beyond that, who knows?
- Technology changeover from Li-Ion generally requires 20-30% technical and/or cost benefit for sufficient Return On Investment – cost benefit will be key

Thank You!

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Lincoln MKZ Hybrid