Challenges on the Road to Electrification of Vehicles

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Agenda

- **Electric Vehicle landscape**
  - Factors driving surge of interest and investment
  - Challenges for EV adoption
- Surprising Projections for EV/PHEV/HEV sales from the Analysis Model
- Outlook

Government Investment Has The EV Value Chain Salivating – Is it enough?

- The U.S. Department of Energy (DOE) has invested more than $5 billion to promote the electrification of transportation
  - $7500 tax credit for the purchase of an Electric Vehicle (EV)
  - $2.6 billion in loans to Nissan, Fisker, and Tesla to establish EV manufacturing facilities
  - DOE to up its automotive R&D investment portion in its $3 billion budget

- The Chinese government plans to invest $15 billion to speed adoption of electric vehicles

- South Korea's Battery 2020 Project aims to invest $12 billion in battery technologies

Global Auto Market
~ $500 billion

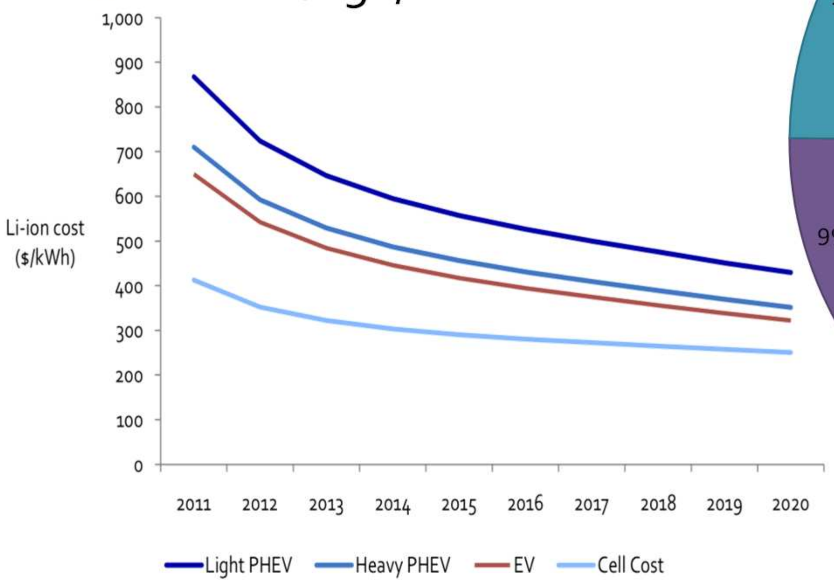
Adoption Challenges for EV

- Internal Factors
  - Battery Cost
  - Innovations to meet Emission standards for Internal Combustion Engine (ICE) and EVs

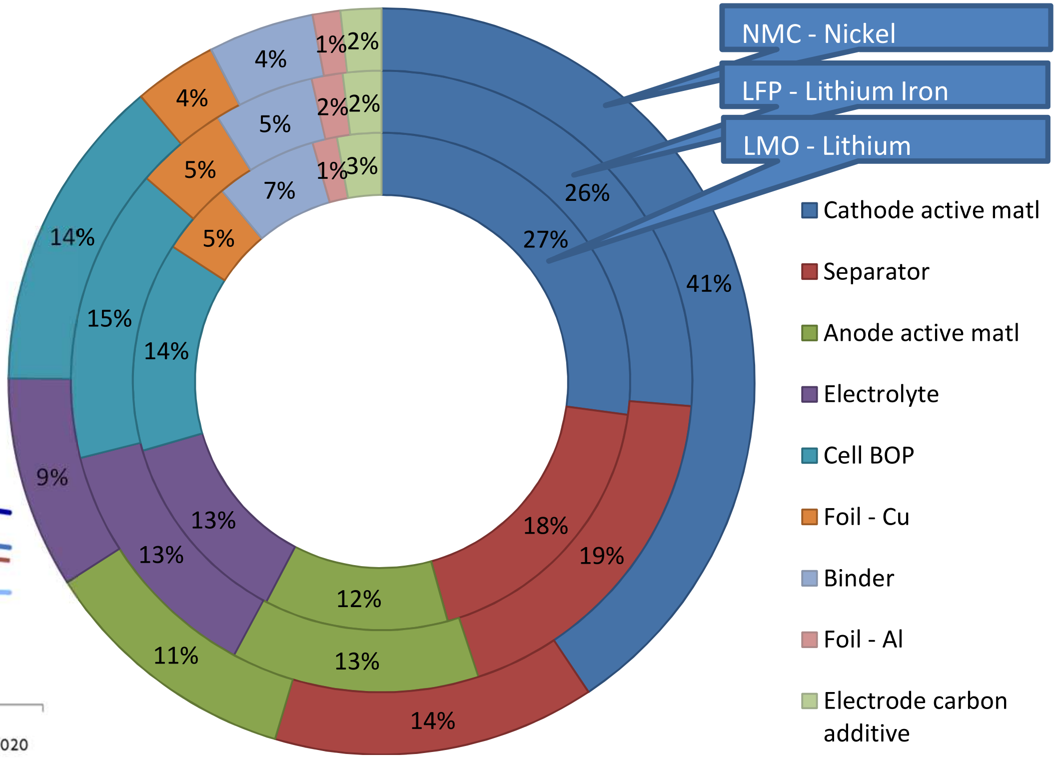
- External Factors
  - Cost of gasoline
  - Utility Infrastructure
  - EV Infrastructure – Charging Stations/Range anxiety

Battery Cost

- Currently at \$650-\$1000/kWh at high volume
- >20 kWh for 100 mi range
- >\$15,000 per vehicle
- Goal: \$150/kWh ?



% component price in Li-ion chemistries



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Source: Lux Research Mar 2011 Report – Small Batteries Big Sales – The Unlikely winners of EV Market

Source: Lux Research May 2010 Report – Looking Inside Li-ion Batteries for Cost Reduction

Innovations to Meet Emission Standards

- Sets up a moving target for EV/ Plug-in Hybrid Electric Vehicle (PHEV) and other Hybrid Electric Vehicles (HEV)

- Benefits both ICE and EV
  - Low-rolling resistance tires
  - Regenerative braking
  - Light weighting
  - In-Wheel technology

- Benefits ICE
  - Direct fuel injection – Ford F150
  - Cylinder shut off – Volkswagen

Cost of Gas

- US Energy Information Administration (EIA)

- Oil Prices At
  - $80 - $90 this year
  - $95/Barrel by 2015
  - $108 by 2020
  - $134 by 2035

- Worst case
  - $146 in 2015
  - $169 by 2020

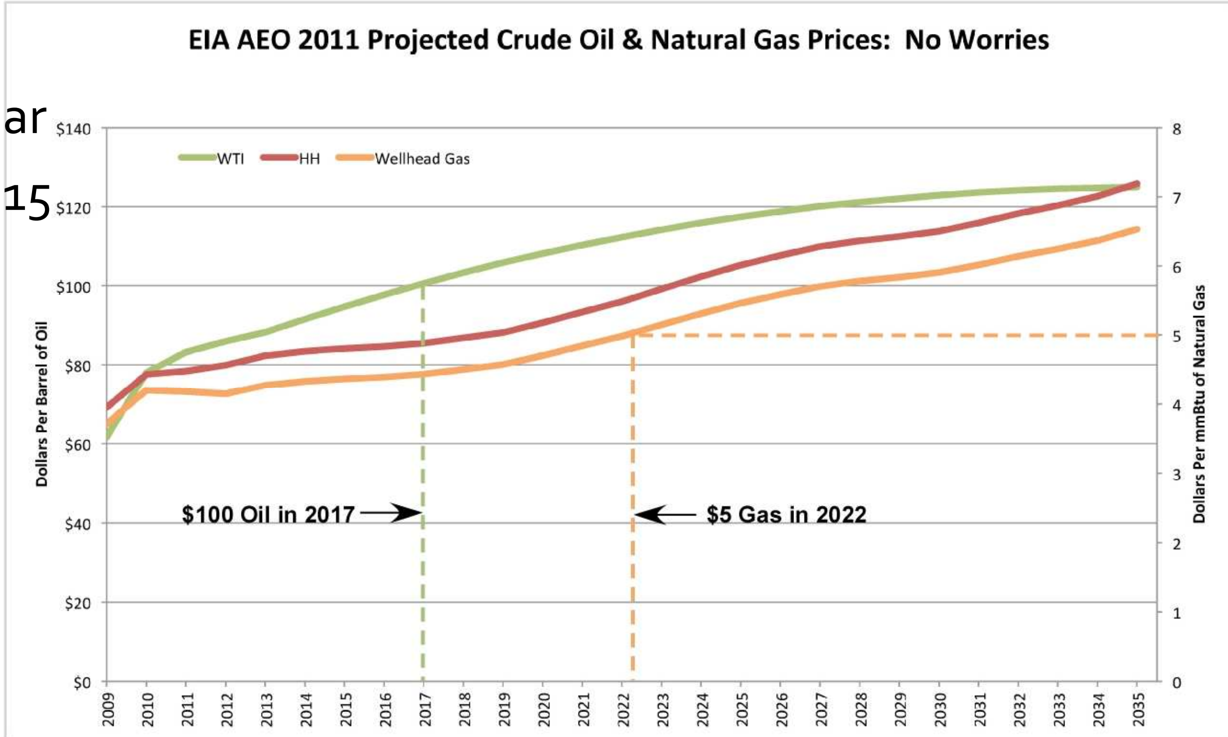

Figure 1. Projected crude oil and natural gas prices. Source: EIA AEO 2011.

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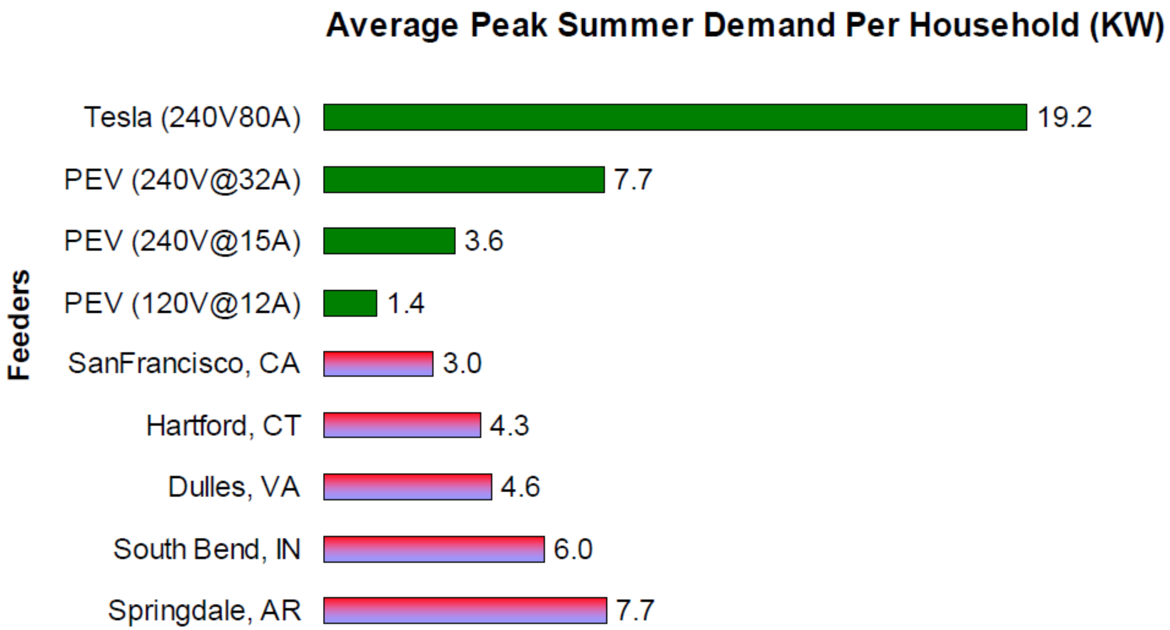
Utility Infrastructure

- 3 – 4 houses per utility pole top transformer



PEV Peak Demand Depends on Charging Capacity (Voltage/Amperage)

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EV Charging Infrastructure

- > 30 companies making Level 1 and 2 chargers
  - Few hours to charge
- > 10 companies making Direct Current (DC) Fast chargers, Level 3 chargers
  - 30 min charging time
- Many more options for in home chargers, typically Level 1 or 2
  - Overnight charging
- > 5 companies looking at wireless inductive charging
- Better Place and other companies looking at other ideas

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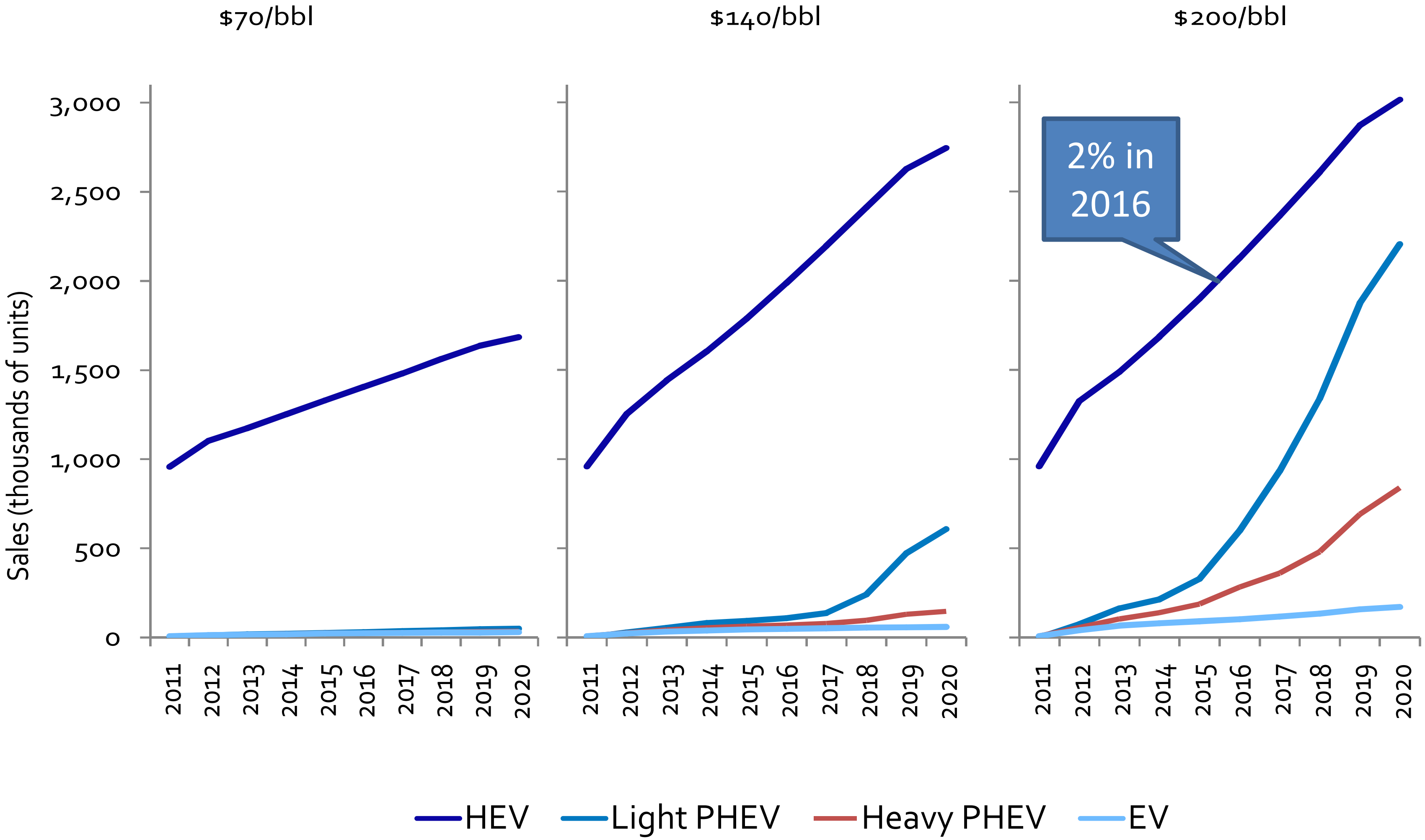
Lux's Demand-Driven Market Model

- Analysis accounts for:
  - Technology improvements (including ICE technologies)
  - Component cost reductions
  - Gas/electricity prices
  - Driving habits
  - Governmental subsidies
- Model is based on relative **payback periods** of electric vehicles vs. ICE vehicles and has two phases:
  - A "tree hugger phase" (logarithmic growth)
  - A "growth phase" (logistic growth)
- Types of vehicles modeled:
  - HEV: contains a NiMH battery pack (such as the Toyota Prius)
  - Light PHEV: a PHEV-12 with a Li-ion battery pack (such as Toyota's planned PHEV)
  - Heavy PHEV: a PHEV-40 with a Li-ion battery pack (such as the Chevy Volt)
  - EV: contains a Li-ion battery pack (such as the Nissan Leaf)

Global Unit Sales for HEVs, PHEVs, and EVs: Three Scenarios



Source: Lux Research Mar 2011 Report
– Small Batteries Big Sales – The Unlikely winners of EV Market

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Outlook

- ICE will be a technology of choice for the near future

- High cost of batteries as a major issue in EV adoption will lead to
  - Micro-hybridization
  - Lot of interest in improving battery technology
  - Possible oversupply in batteries!

- In absence of a major breakthrough in Li-ion, other technologies including Ultracapacitors and even Fuel cells will continue to gain interest

Questions?

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Backup Slides

Electric Vehicles Span A Wide Range Of Technologies

Technology	Application	Pros	Cons	Representative Manufacturers
Lithium ion	E-bikes; HEVs; PHEVs; EVs; Heavy Vehicles	High energy and power densities	High cost; safety concerns	**LG Chem Power (LGCPI); JCI-Saft; A123 Systems; NEC; GS Yuasa**
Lead-acid	E-bikes; micro-hybrids	low cost	Low cycle life; limited high-rate performance	**Johnson Controls; Exide Technologies**
NiMH	E-bikes; HEVs	Better performance than lead-acid, lower cost than Li-ion	Lower performance than Li-ion; higher cost than lead-acid	**Panasonic**
Supercapacitors	Micro-hybrids; heavy vehicles	Highest power densities	Lowest energy densities; high cost	**Maxwell Technologies; Nesscap**
Fuel Cells	FCVs	Higher energy density than batteries	Lack of infrastructure; high cost of FCV drivetrain	**Honda, Toyota, GM, Daimler**

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Different Li-ion Chemistries

- **LMO/LMS have low cost potential but cycle life improvement is still needed.** Lithium manganese oxide/lithium manganese spinel (LMO/LMS) is a very attractive chemistry due to its comparatively low cost and good safety profile, but there are concerns about cycle-life, since the manganese content can dissolve upon repeated cycling. LG Chem, GS Yuasa, NEC, and Mitsubishi Chemical are currently developing LMO/LMS chemistries.

- **LFP has excellent cycle life but limited energy density, with low cost potential.** Lithium iron phosphate (LFP) is another chemistry that is more stable than LCO, and thus offers improved safety, but the trade-off is in lower operating voltages and energy densities. Manufacturers commonly use nanostructured cathode surfaces and/or doped materials (LFP with a small amount of another element or elements mixed in) to improve performance. Manufacturers like A123Systems, Valence Technology, and BYD use LFP.

- **NMC and NCA offer higher energy density, but at a cost.** Nickel manganese cobalt and nickel cobalt aluminum (NMC and NCA) offer a compromise between the high-energy density of LCO and the low cost and relative safety of LMO/LMS and LFP. Developers include Panasonic, Saft, and Nichia.

EV Sales projections

Vehicle/Yr	2011	2012	2013	2014	2015	2016
e-bikes	30,616,956	31,595,163	32,605,702	33,649,691	34,728,291	35,531,703
micro-hybrids	7,104,001	16,253,867	24,287,089	29,359,174	33,971,788	37,368,967
HEV 70	959,010	1,103,179	1,173,748	1,252,879	1,330,634	1,406,597
LPHEV 70	-	10,975	18,224	21,614	25,542	29,805
HPHEV 70	8,269	13,296	17,598	20,775	23,625	26,041
EV 70	7,890	12,641	16,567	19,487	21,896	23,964
HEV 140	959,010	1,253,583	1,440,283	1,604,749	1,788,542	1,988,509
LPHEV 140	-	28,778	53,471	81,869	93,282	108,086
HPHEV 140	8,269	27,170	43,229	55,063	62,710	69,316
EV 140	7,890	22,960	33,670	40,261	45,161	49,369
HEV 200	959,010	1,326,234	1,488,965	1,685,673	1,899,678	2,128,056
LPHEV 200	-	75,592	164,780	214,690	330,316	600,840
HPHEV 200	8,269	55,487	104,045	139,201	188,409	283,020
EV 200	7,890	42,114	66,695	79,907	91,197	102,145
HEV 70 = Hybrid Electric Vehicle @ $70/barrel oil price						