Engineering Distinguished Lecture Series

California’s Clean Transportation Future
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Edison expected Battery-Powered Electric Cars to replace the Internal Combustion Cars

Ni-Fe Alkaline Battery

144 mile (230 km) range
Avg. Speed: 12.3 mph (20 km/h)

Weight: 1080 kg
Energy Density: 30-50 Wh/kg
Nominal Cell Voltage: 1.2V
A Hundred Years Later ..... 

**Toyota Prius**  
~50 MPG  
1 kWh battery  
Battery Cost: about $1,200

**Chevy Volt**  
~100 MPGe  
16 kWh battery  
Battery Cost: about $10,000

**Nissan Leaf All Electric**  
≥ 24 kWh battery  
Battery Cost: about $15,000

Battery affordability and performance are key to enable large market penetration of hybrid and electric vehicles.
Advanced Batteries Enable New Vehicle Platforms

Electric Vehicles (EV)
- Plug-in Hybrid (PHEV)
  - Nissan Leaf
  - Chevy Volt
  - Toyota Prius
  - Honda Civic
  - BMW1
- Full Hybrid
  - Micro 1
  - Micro 2
  - Daimler
  - Smart for Two
- Mild Hybrid
  - Start-Stop
  - Regenerative Braking
  - Power Assist (Acceleration Boost)
  - Electric Driving (but with ICE)
- Electric Driving (Charging independent From ICE – still with ICE)

Added Electric Function

Increased Efficiency
Why Li-ion cells for PHEVs and EVs?
Higher cell voltage & higher energy/power densities

Portable energy storage: wt. & vol. very important

6800 18650-cells in Tesla Roadster Battery pack

Gravimetric Energy Density (Wh/kg)
Volumetric Energy Density (Wh/l)

Lithium Batteries (LIB, LPB, PLI, ...)
Ni-MH
Ni-Zn
Ni-Cd
Lead-Acid

lighter
smaller
What happens in a Li-ion cell?

Charging
Requires Energy

Discharging
Supplies Energy

Process reversibility should be ~100% for good cycle life
Li-ion cell voltages and energy/power densities depend on cathode/anode combination

Flexible Chemistry

Voltage vs. Lithium

- 6 V: \( \text{Li} + 0.5\text{F}_2 \leftrightarrow \text{LiF} \)
- 5 V: \( \text{LiMO}_2 \leftrightarrow \text{Li}_{(1-x)}\text{MO}_2 + x\text{Li}^+ \)
- 4 V: \( \text{LiFePO}_4 \leftrightarrow \text{FePO}_4 + x\text{Li}^+ \)
- 3 V: \( \text{Li}_{4/3}\text{Ti}_{5/3}\text{O}_4 + 3\text{Li}^+ \leftrightarrow \text{Li}_{7/3}\text{Ti}_{5/3}\text{O}_4 \)
- 2 V: \( \text{Li}_x\text{Si}, \text{LiAl}, \text{Li}_x\text{Sn} \)
- 1 V: \( \text{Li} + 6\text{C} \leftrightarrow \text{LiC}_6 \)
- 0 V: \( \text{Lithium} \)

Water stable region: Pb-acid, NiCd, NiMH

Organic-based electrolytes
The Future .....?

- **Nissan Leaf (140 Wh/kg)**

- **Price ($/kWh)**: 200, 600, 900, 600, <150, <150, <150, <150

- **Specific Energy, Wh/kg**:
  - Pb-acid: 50 km
  - Ni-Cd: 80 km
  - Ni-MH: 100 km
  - Li-ion: >160 km
  - Future Li-ion: >200 km
  - Zn-air: >225 km
  - Li-S: >400 km
  - Li-O2: >500 km

- **Available**:
  - Under Development and R&D:

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