Li-ion Batteries and Electric Vehicles

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Introduction

- Why Electric Vehicles (EVs)?
- EV Types and Applications
- EV Considerations
- EV Design Architectures
- EV Battery Cell Packages
- EV Battery Cell Chemistries
- EV Economics
- Conclusions

Why Electric Vehicles (EVs)?

- Reduce consumption of crude oil (finite resource)
- Reduce dependence on crude oil (national security)
- Reduce environmental impact (green)
- Reduce transportation costs
  - First cost
  - Operating cost
  - Maintenance cost

EV Types and Applications

Passenger Cars

- Limited-Route/Return-To-Base
- Unlimited-Route

Delivery Trucks

- Limited-Route/Return-To-Base
- Unlimited-Route

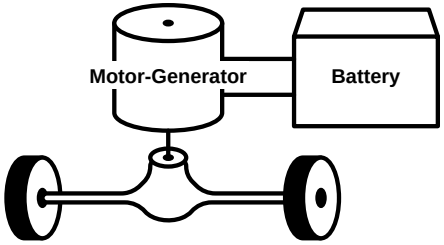
Buses

- Limited-Route/Return-To-Base
- Unlimited-Route

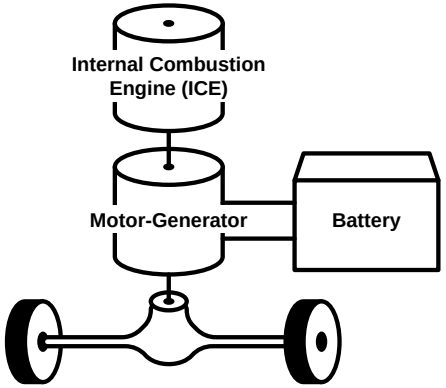
EV Considerations

- Driving Range
- Charging Stations
- Recharging Time
- Economics
- Safety

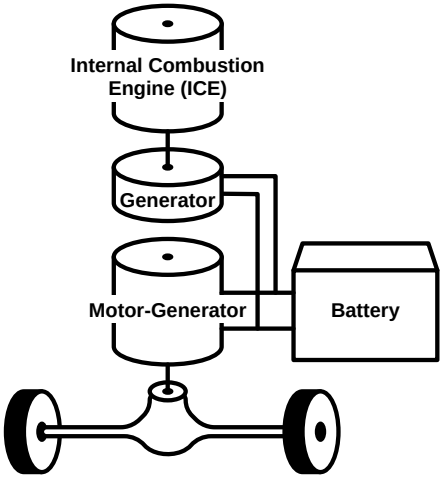
EV Design Architectures



Battery Electric Vehicle



Parallel Hybrid Electric Vehicle



Series Hybrid Electric Vehicle

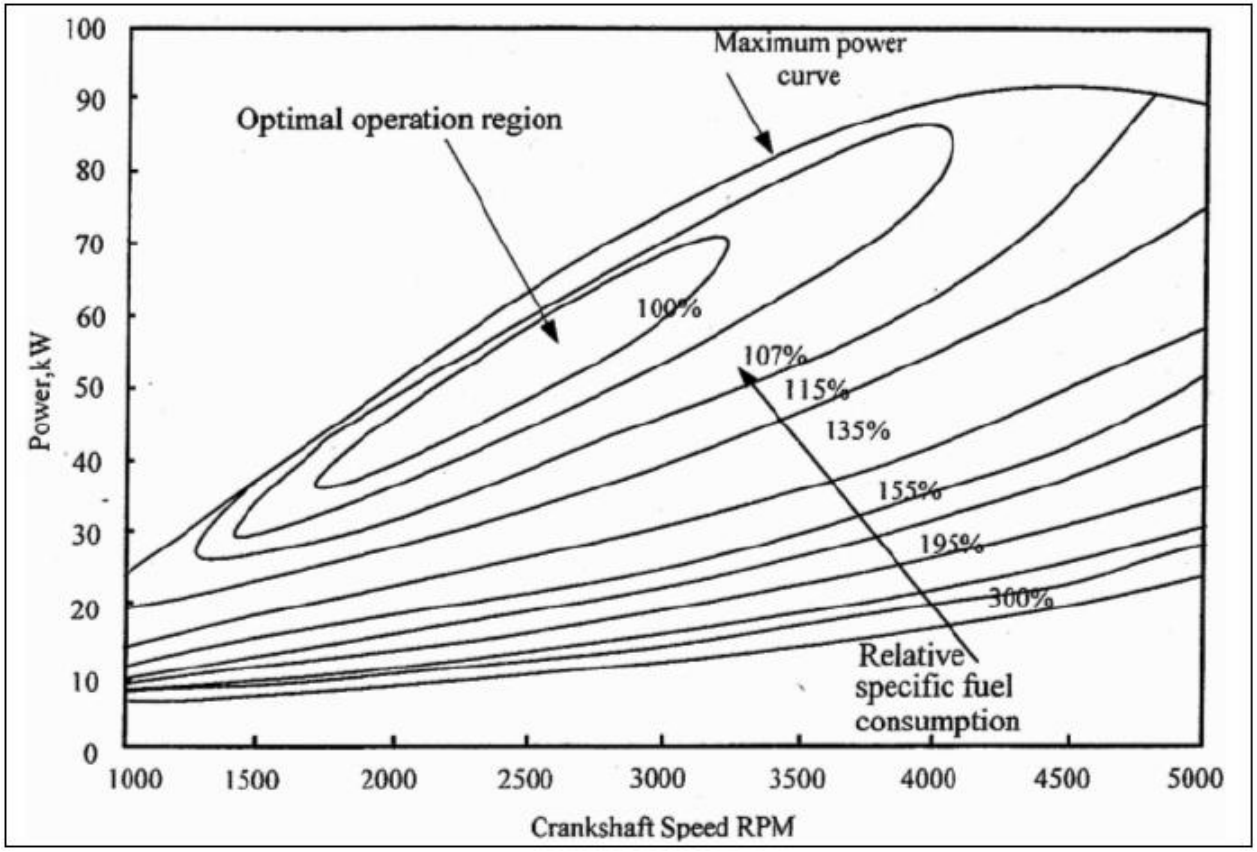
Why Hybrid?

- Extend Driving Range
- Reduce Weight, Size and Cost of Battery
  - For example, car with 400 mile range:
    - Gas @ 33 mpg = 12 gal *[equivalent: 432 kWh (gross), 200 kWh (net)]*
      - 72.9 lbs, 1.62 cu ft
    - Electric @ 0.5 kWh/mile = 200 kWh:
      - 5,000 lbs, 80 cu ft, $150,000 ***Much more than weight/cost of car!***
    - Hybrid @ 40 mpg = 10 gal + 3.0 kWh *[increase fuel efficiency by 20-50%]*
      - 60.8 lbs, 1.35 cu ft
      - 75 lbs, 1.2 cu ft, $2,250
      - Total: 136 lbs, 2.55 cu ft, $2,250

Gas – the ultimate in energy density !!!

NOTE: Calculations based on LFP batteries.

Essence of Hybrid Operation



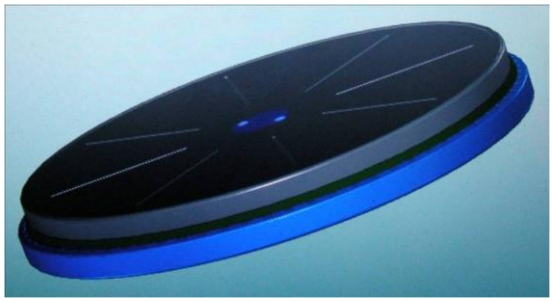
- Use motor to augment power outside of optimal operating region.
- Use generator and regenerative braking to recover energy.

EV Battery Cell Packages

18650 Cylindrical

Pouch Prismatic

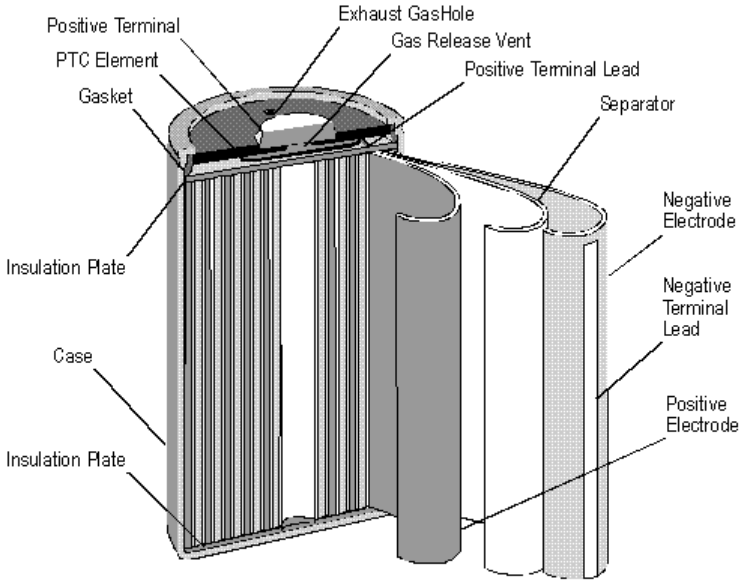
Can Prismatic



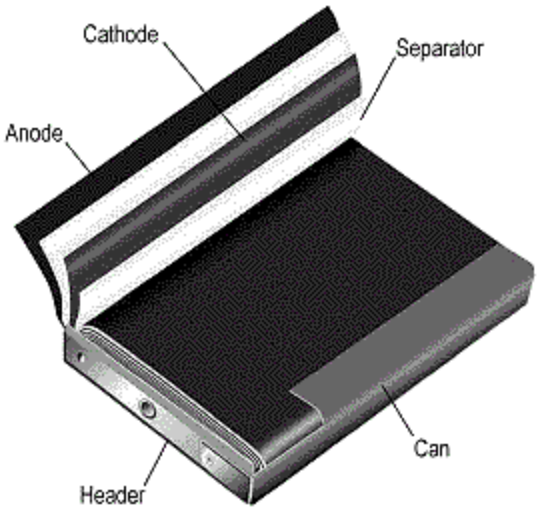
InvenTek Rolled-Ribbon™

Yintong Energy Annular

EV Battery Cell Construction

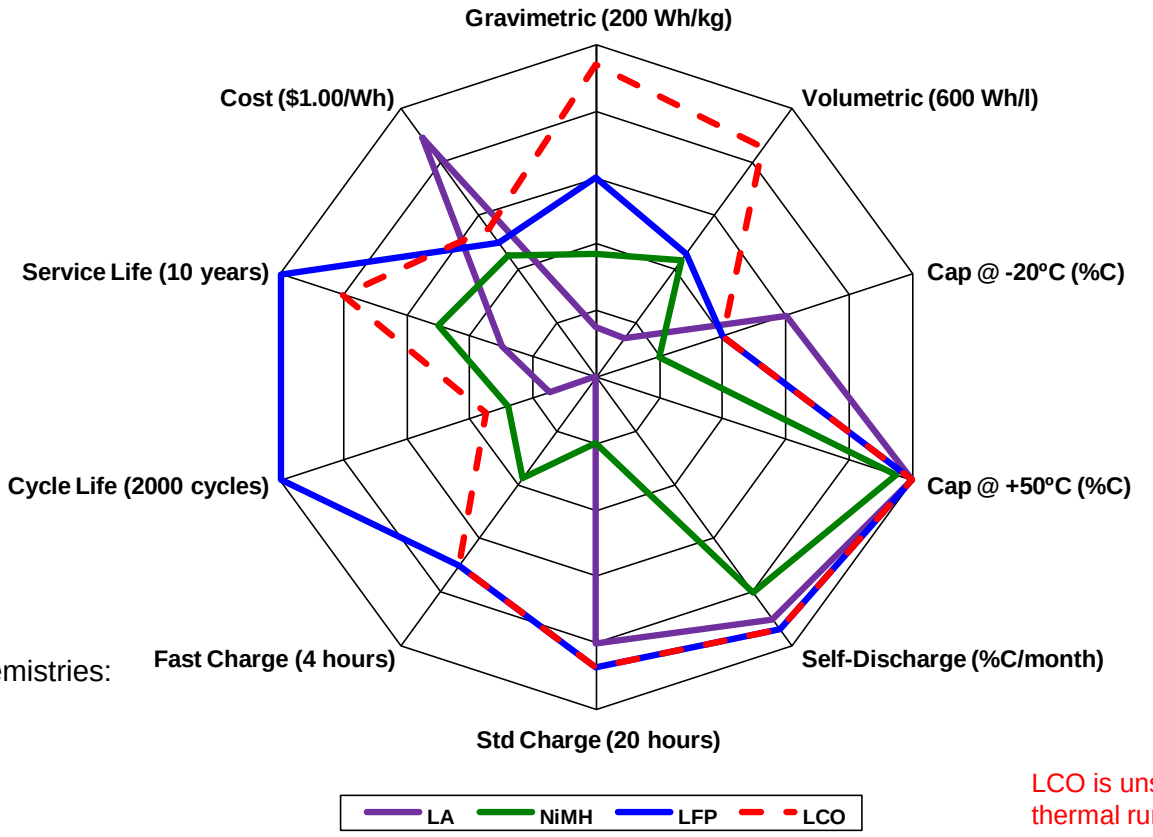


Design courtesy of Panasonic



Design courtesy of Polystor

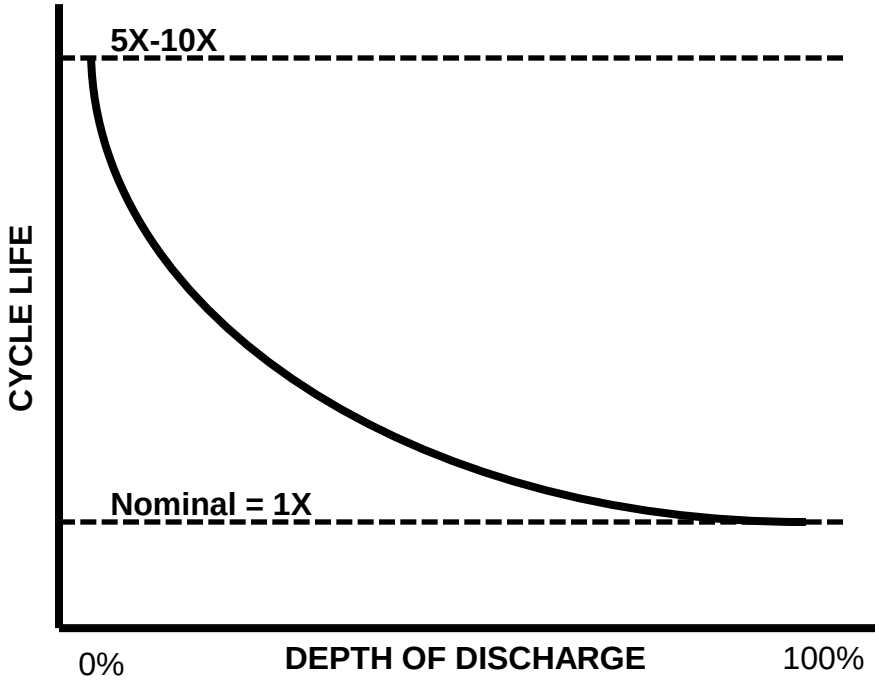
EV Battery Cell Chemistries



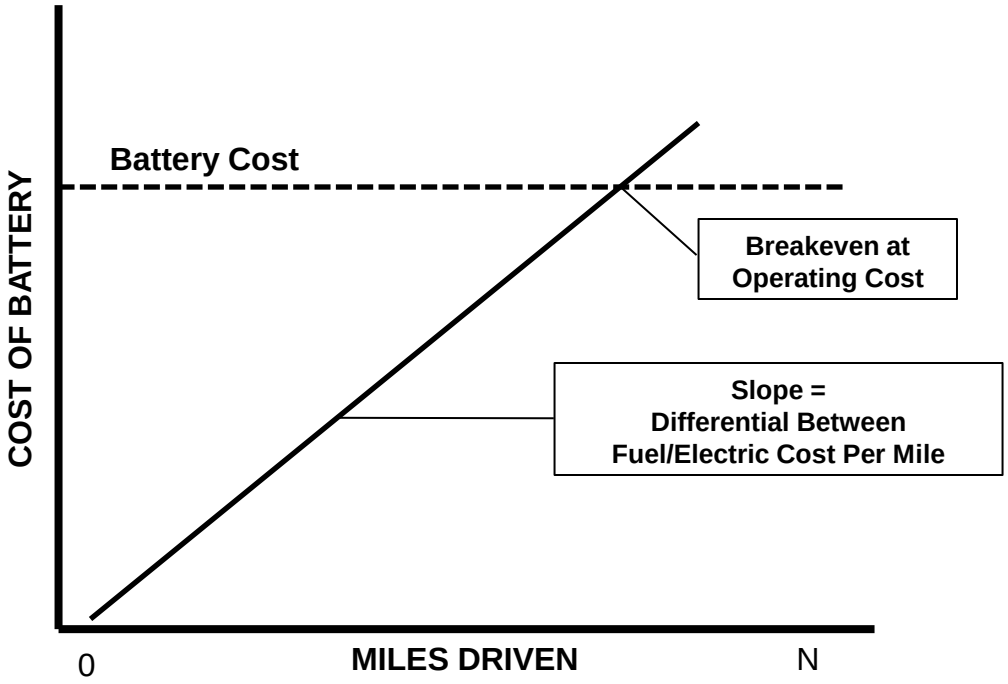
Other Li-ion Chemistries:
LMO
NMC
NCA
LTO

LCO is unstable and subject to thermal runaway. Unsafe.

Battery Cycle Life



EV Economics – Battery Electric (operating cost only)



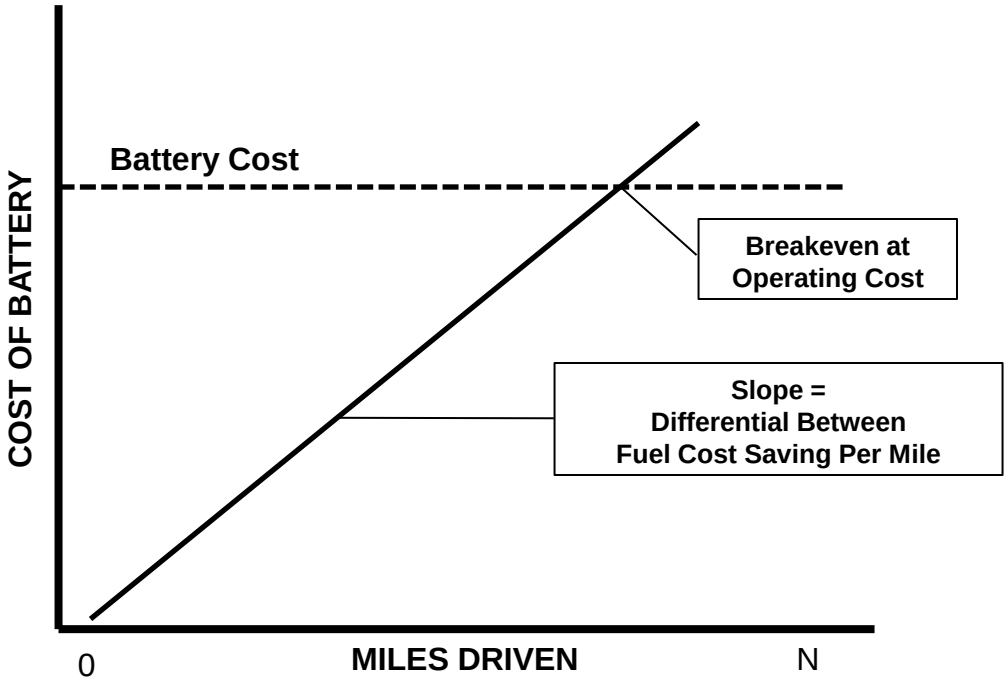
EV Economics – Battery Electric (operating cost only)

- 40 Mile Limited Range Car, 0.5 kWh/mile, 33 mpg
  - Battery = 20 kWh = $15,000
  - @ $0.12/kWh and $2.65/gal, Breakeven = 740,740 miles
  - @ $0.12/kWh and $3.50/gal, Breakeven = 325,657 miles

- 40 Mile Limited Range City Bus, 3.0 kWh/mile, 5.0 mpg
  - Battery = 120 kWh = $90,000
  - @ $0.12/kWh and $3.00/gal, Breakeven = 375,000 miles
  - @ $0.12/kWh and $4.00/gal, Breakeven = 204,545 miles

But battery cycle life is limited to 100,000 miles !!!

EV Economics – Hybrid Electric (operating cost only)



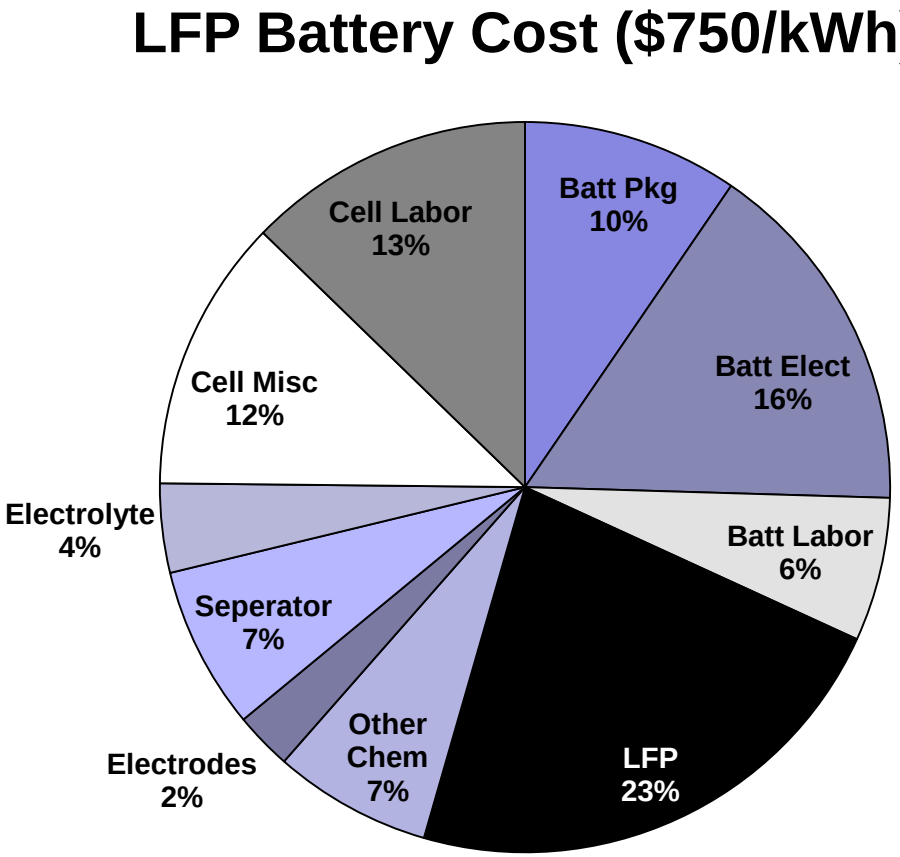
EV Economics – Hybrid Electric (operating cost only)

- Hybrid Car, 33 mpg → 42 mpg (+30%)
  - Battery = 3 kWh = $2,250
  - @ $0.12/kWh and $2.65/gal, Breakeven = 130,755 miles
  - @ $0.12/kWh and $3.50/gal, Breakeven = 99,000 miles

- Hybrid City Bus, 5.0 mpg → 6.5 mpg (+30%)
  - Battery = 20 kWh = $15,000
  - @ $0.12/kWh and $3.00/gal, Breakeven = 108,333 miles
  - @ $0.12/kWh and $4.00/gal, Breakeven = 81,250 miles

In hybrid mode, battery cycle life is >> 200,000 miles !!!

EV Battery Cost Breakdown



Estimate another 20-30% cost reduction available as volumes increase.

Conclusions

- Li-ion is the right choice for EVs today -- in particular LFP
- BEVs: On “operating cost” basis alone, economics challenged
  - It is believed that there will be substantial “maintenance cost” savings, particularly for fleet vehicles. Just too early to prove at this time.
  - Can be many other significant benefits that go beyond direct economics, such as environment issues and their associated indirect costs
- HEVs: Economics are “marginally” supportable now
  - Likely to become solid with cost reductions and improved hybrid efficiencies that can be reasonably and realistically expected
- Key to broad adoption of EVs in the future will be safe higher energy density cells
  - Given the state of electrochemical technology and the speed of introduction for new electrochemical technologies, don’t expect new game-changing technologies to be in the market for 5-10 years

Thank You !