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Is There a Moore's Law for Batteries?

NCCAVS Thin Film User's Group Meeting

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James Kaschmitter

PolyStor Energy Corporation

Livermore, CA

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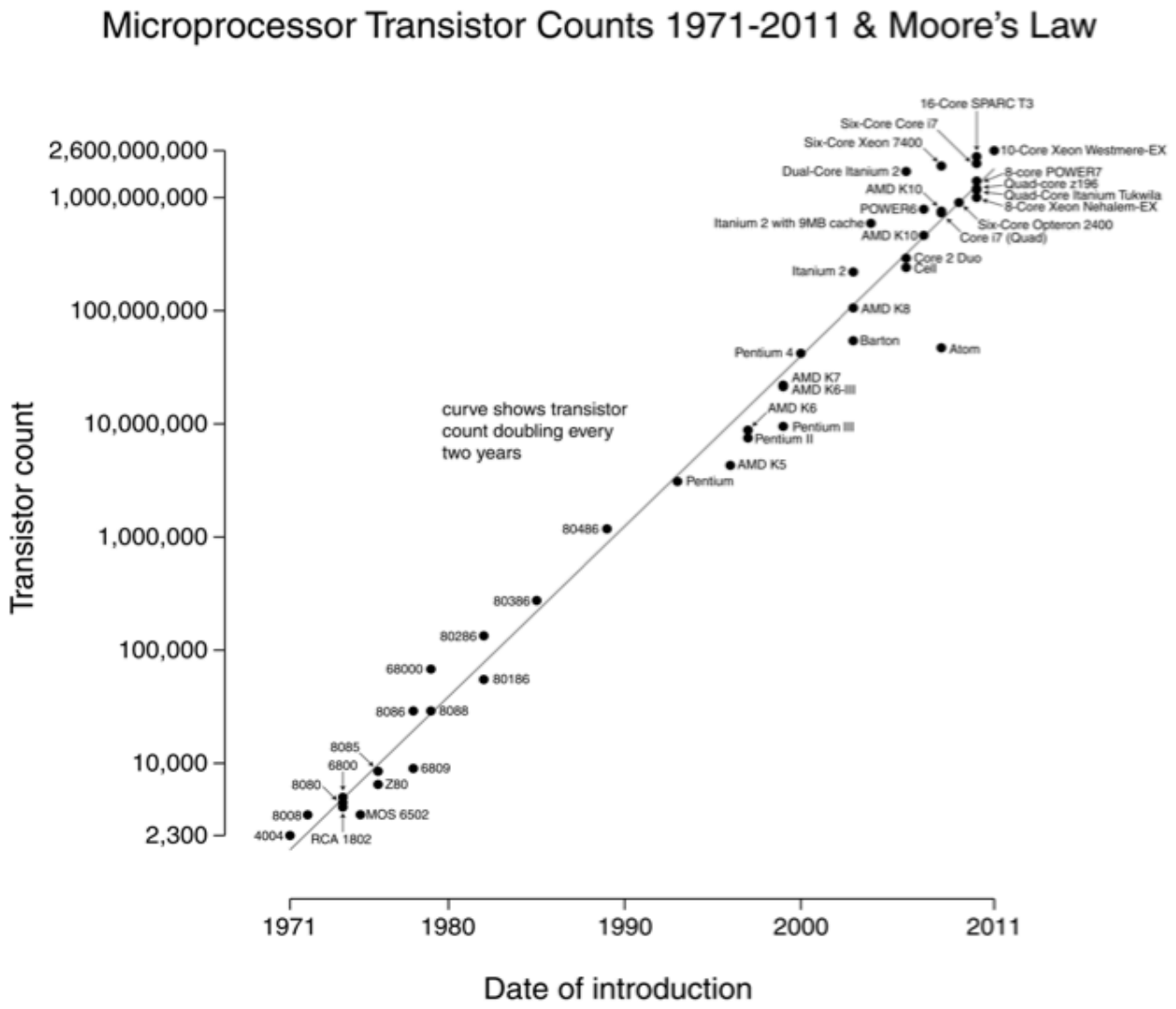
What is Moore's Law?

The law is named after Intel co-founder Gordon E. Moore, who described the trend in his 1965 paper.

The paper noted that the number of components in integrated circuits had doubled every year from the invention of the integrated circuit in 1958 until 1965 and predicted that the trend would continue "for at least ten years".

His prediction has proven to be uncannily accurate, in part because the law is now used in the semiconductor industry to guide long-term planning and to set targets for research and development

It has become a self-fulfilling prophecy



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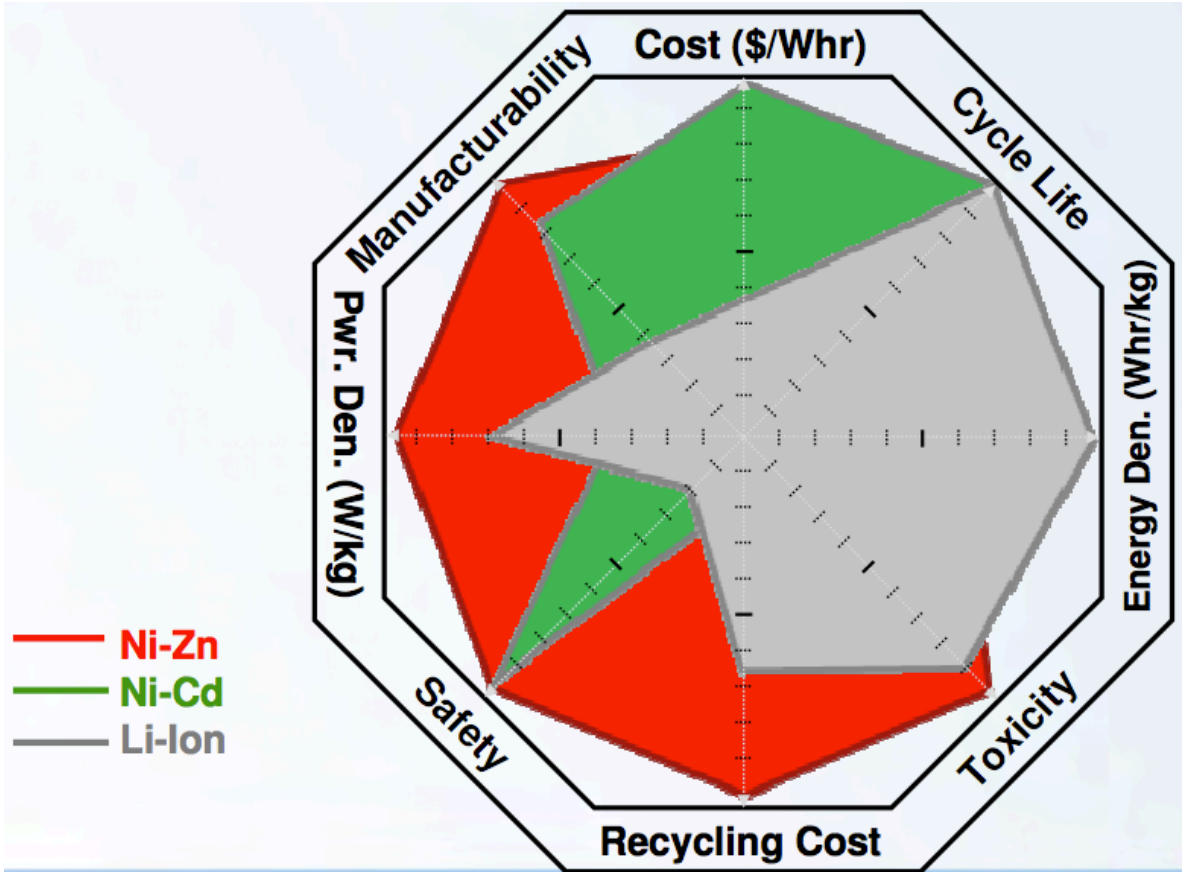
Battery Specs are Highly Multi-Dimensional
Which Spec Should We Use?



Whr/l performance dominates most high volume applications: cell phones, etc.

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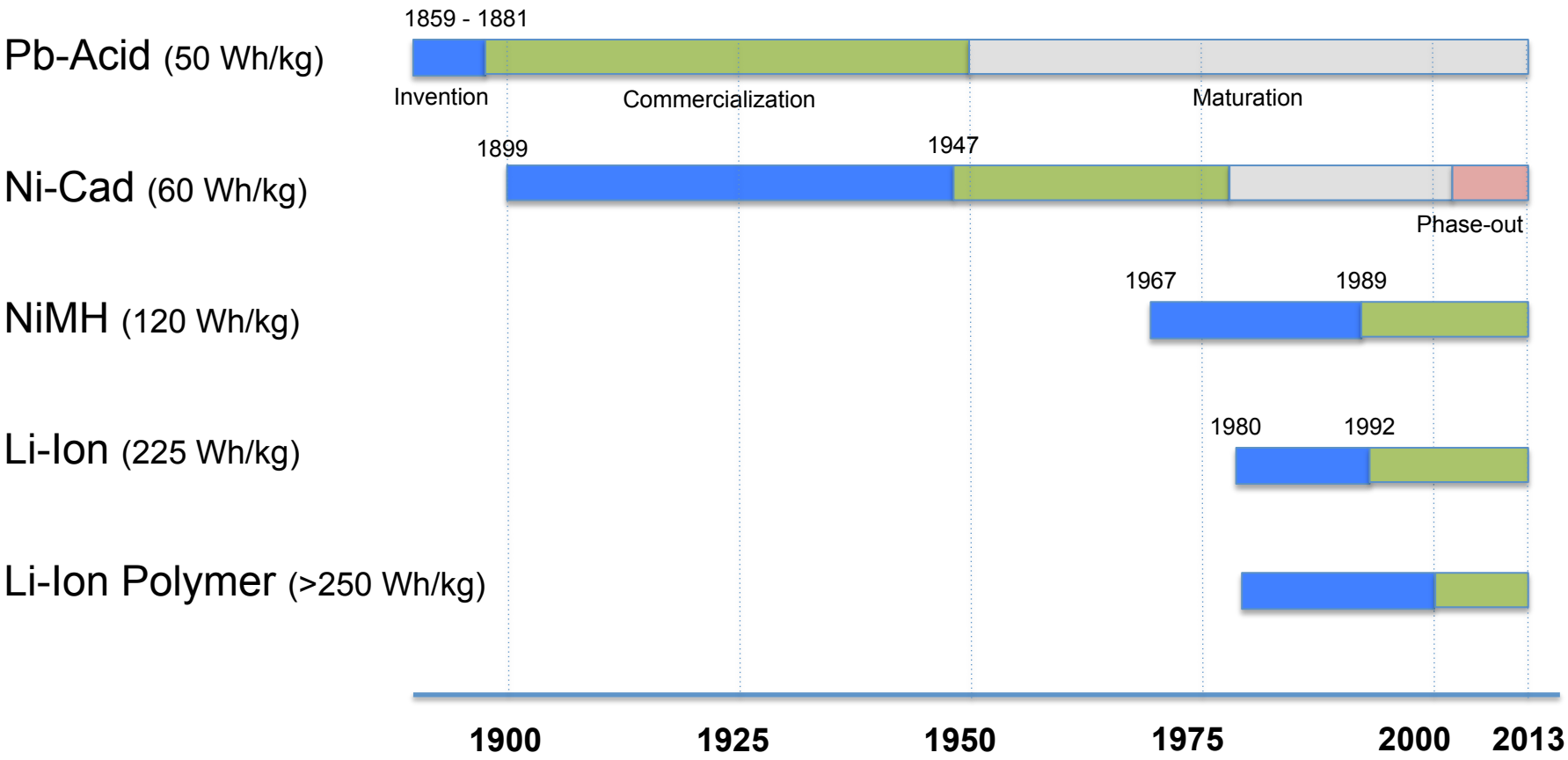
Timelines for Major Primary Battery Systems



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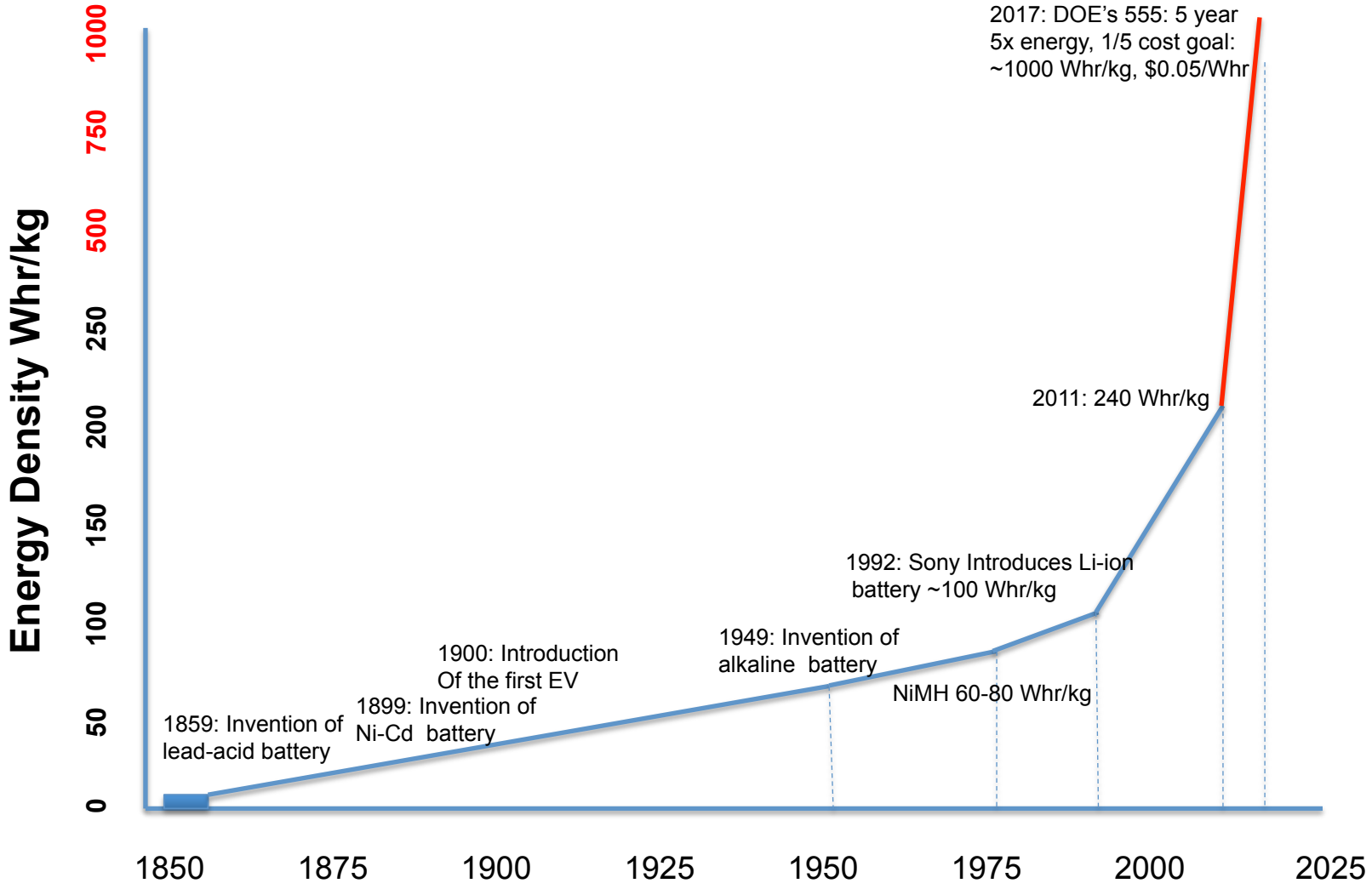
A History of Rechargeable Battery Energy



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18650 Capacity Increase ~ 100 mAh/yr

'91 '93 '95 '97 '99 '01 '03 '05 '07 '09 '11

Capacity of 18650 cylindrical cell (volumetric energy density)
gravimetric energy density

1st Gen.
a-C/$LiCoO_2$
1100 (240) 85
900 mAh (200 $Whdm^{-3}$) 70 $Whkg^{-1}$

2nd Gen.
Graphite/$LiCoO_2$
1250 (270) 100
1600 (350) 125
1800 (400) 145
2000 (450) 160
2200 (490) 175
2400 (540) 190
2600 (580) 210
2800 (630) 225
High Capacity
Improvement of Graphite and Electrolyte additives
High Voltage (4.1→4.2V)
Thinner Separator
Denser Electrode
High Voltage (4.35V)
11 Wh
225

3rd Gen.
Graphite/LiNMC, LiNCA
2900 (630)
3000 (680)
3100 (680) 240

Mass recall

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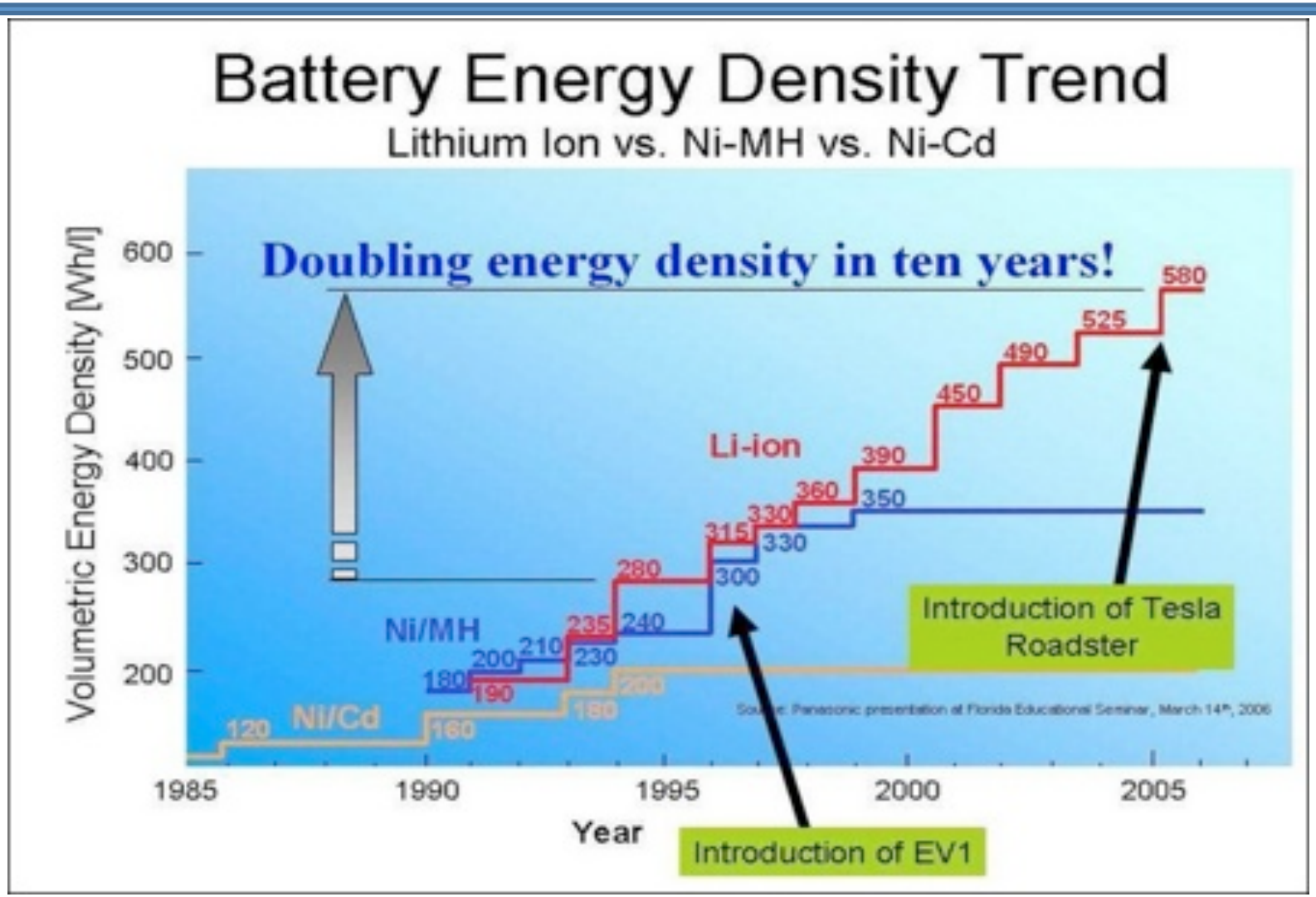
Energy Density Increases for Major Systems



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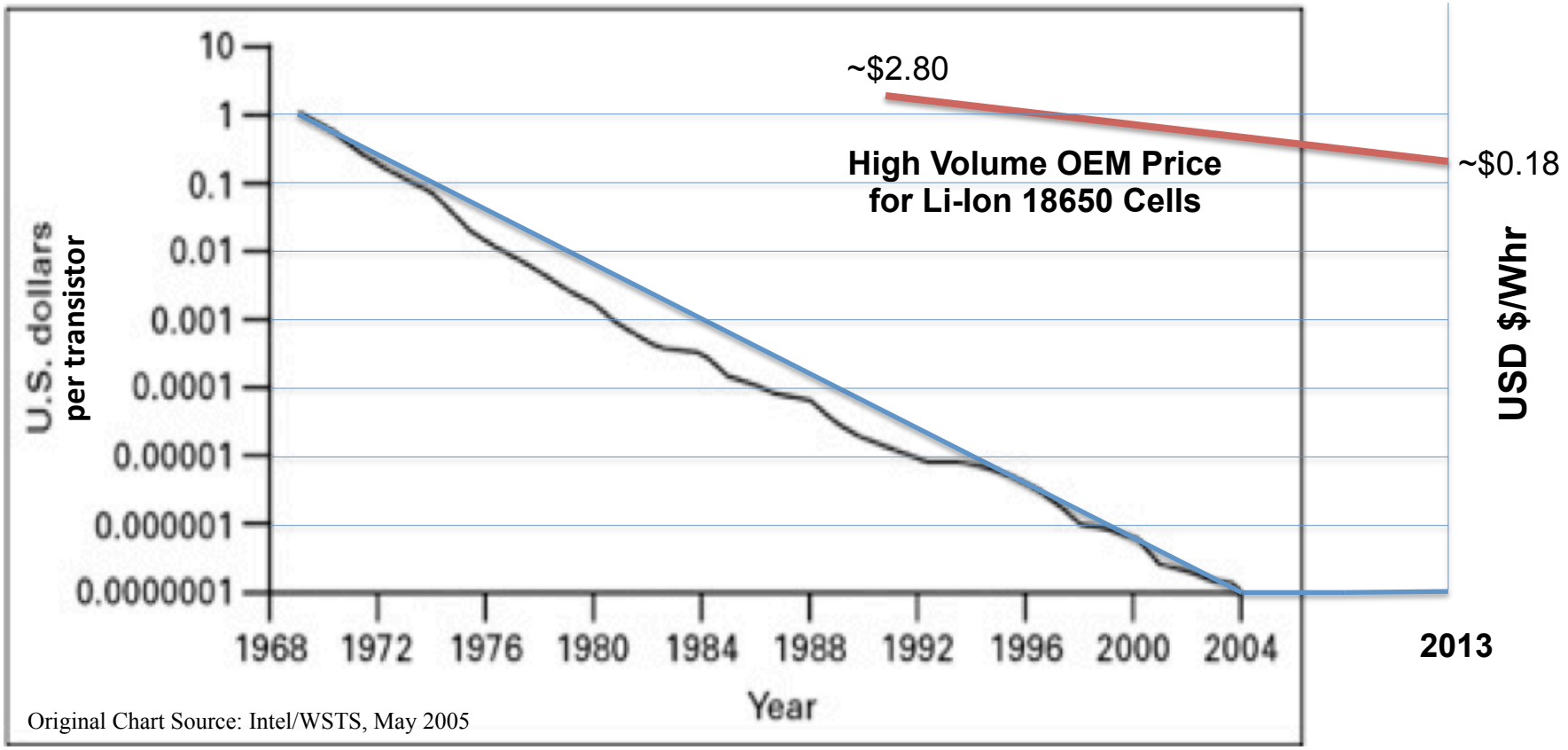
Transistor vs. Li-Ion Cell Pricing



- **The rapid drop in transistor costs helped accelerate widespread adoption of the technology**
- **Li-Ion is still too expensive for many applications, especially when considering short cycle life**

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Observations

- Moore's Law is not a fundamental law of nature and seems rather to be a serendipitous anomaly - there's no reason to believe that it is universal across all technologies
- Planar semiconductor technology is only about 55 years old. Batteries are much older and the sharp rise in energy density is comparatively recent. So, why hasn't the energy density increased more rapidly?
  - Lack of major economic need or markets to drive the technology? - No longer true
  - Lack of major investment ($Ts in transistors vs. $Bs in batteries)? – Less true over the past decade
  - Failure to achieve a level of manufacturability similar to semiconductors?
  - Or fundamental barriers in energy storage technologies?
- There is no good analogue for a Moore’s law in energy storage
  - Increases in energy storage densities appear to occur in unpredictable spurts as fundamentally new technologies are occasionally introduced and then mature
- Batteries need more development to meet the needs of transportation and grid
  - Cost
  - Life
  - Energy and power density
- **We can’t rely on steady, predictable improvements (ala Moore’s law) in battery technology as a solution to our energy problems**