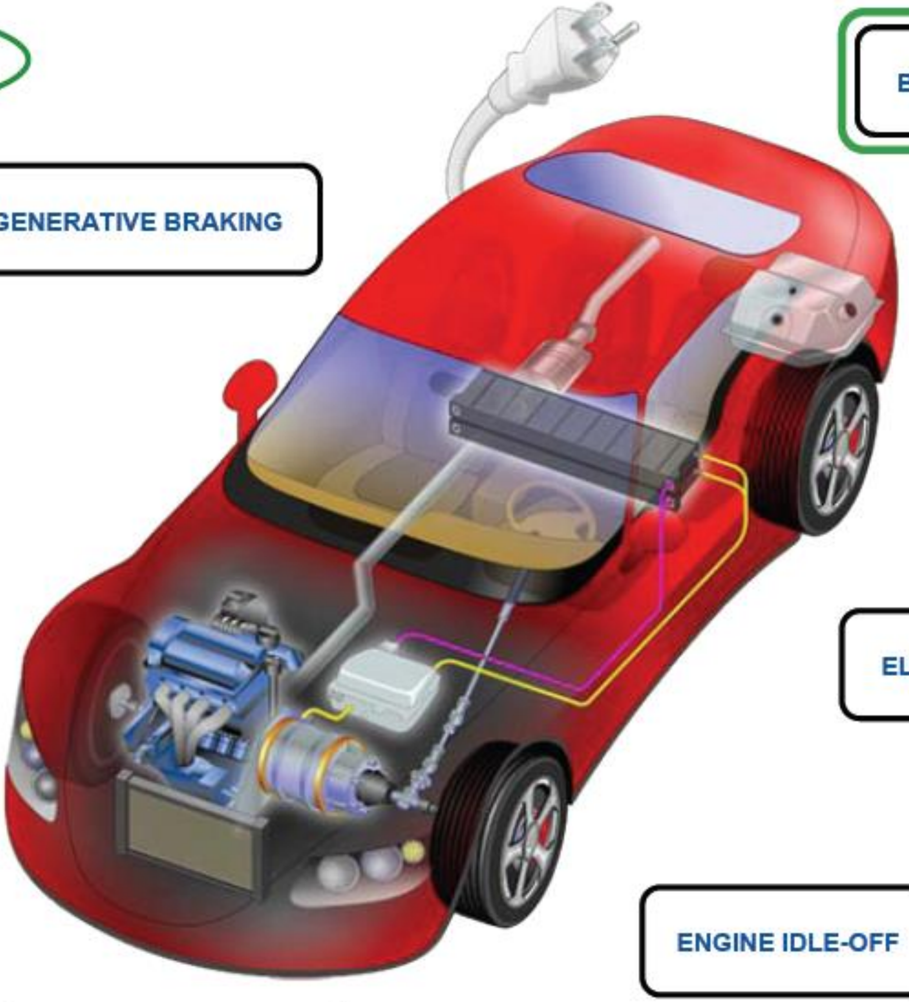
תאי דלק ובטריות לרכבים היברידים וחשמליים

פרופ' עמנואל פלד
בה"ס לכימיה
אוניברסיטת תל אביב
מוסד נאמן 18-10-2017

Outline

- The four types of electric vehicles (EV):
  Hybrid (HEV),
  Plug-in hybrid (PHEV),
  All Electric (BEV)
  Fuel cell hybrid EV (FCEV)
- Design and types of batteries and fuel cells.
- Cost and market introduction.
- Potential fuel saving and pollution reduction.

A Plug-In Hybrid-Electric Vehicle (PHEV)



Fuel Flexibility

PETROLEUM

AND/OR

ELECTRICITY

BATTERY RECHARGE

REGENERATIVE BRAKING

10KWh battery gives ~ 50 km range and costs today about $10,000

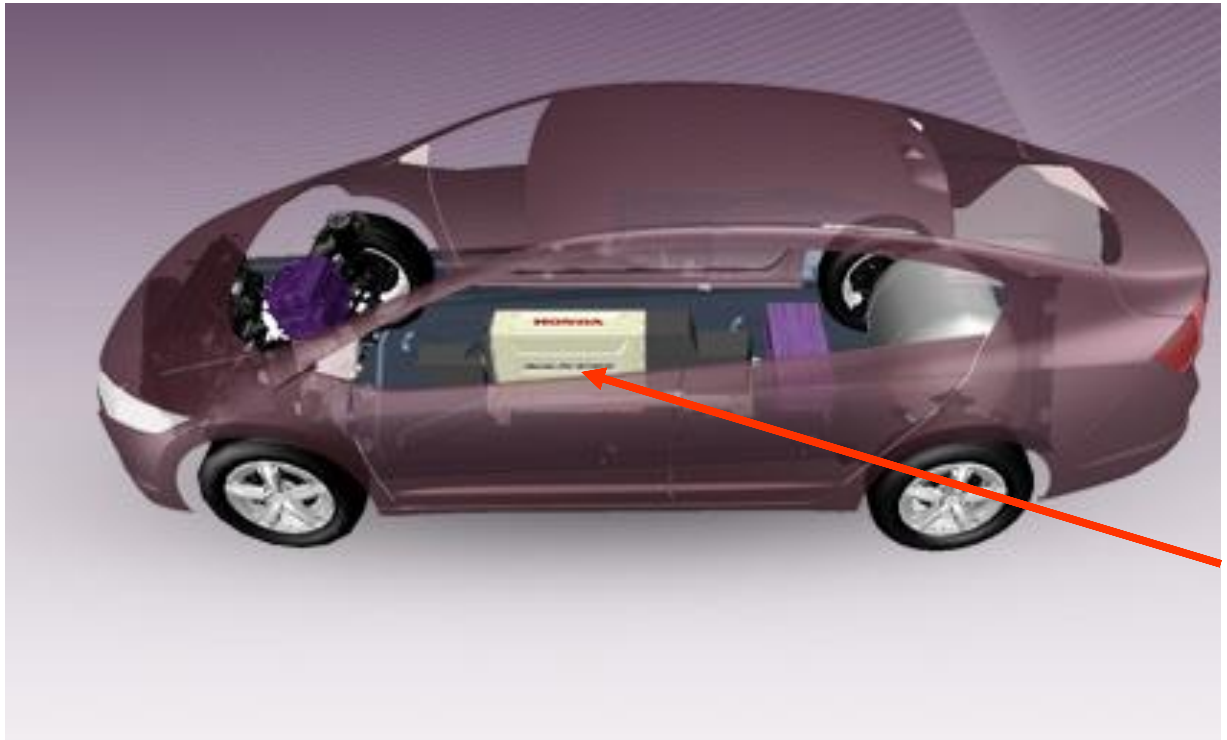
ELECTRIC ACCESSORIES

ADVANCED ENGINE

ENGINE IDLE-OFF

ENGINE DOWNSIZING

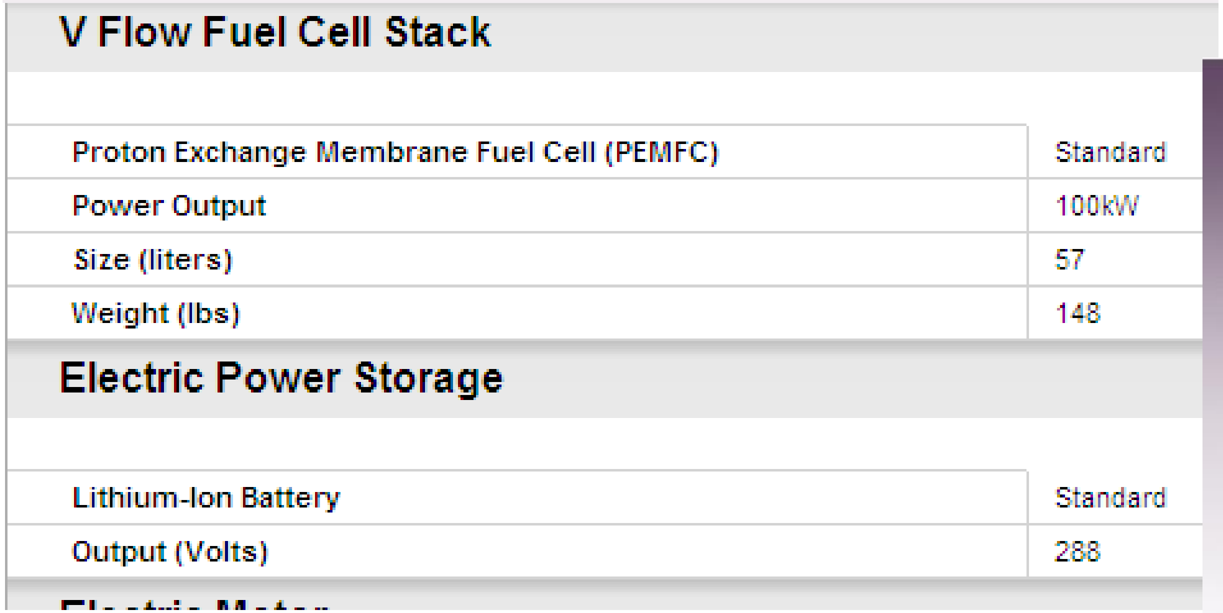
HFCEV
Honda FCX Clarity (2012)



FC Stack

1.75 kW/l

1.5 kW/kg



V Flow Fuel Cell Stack

Proton Exchange Membrane Fuel Cell (PEMFC)	Standard
Power Output	100kW
Size (liters)	57
Weight (lbs)	148

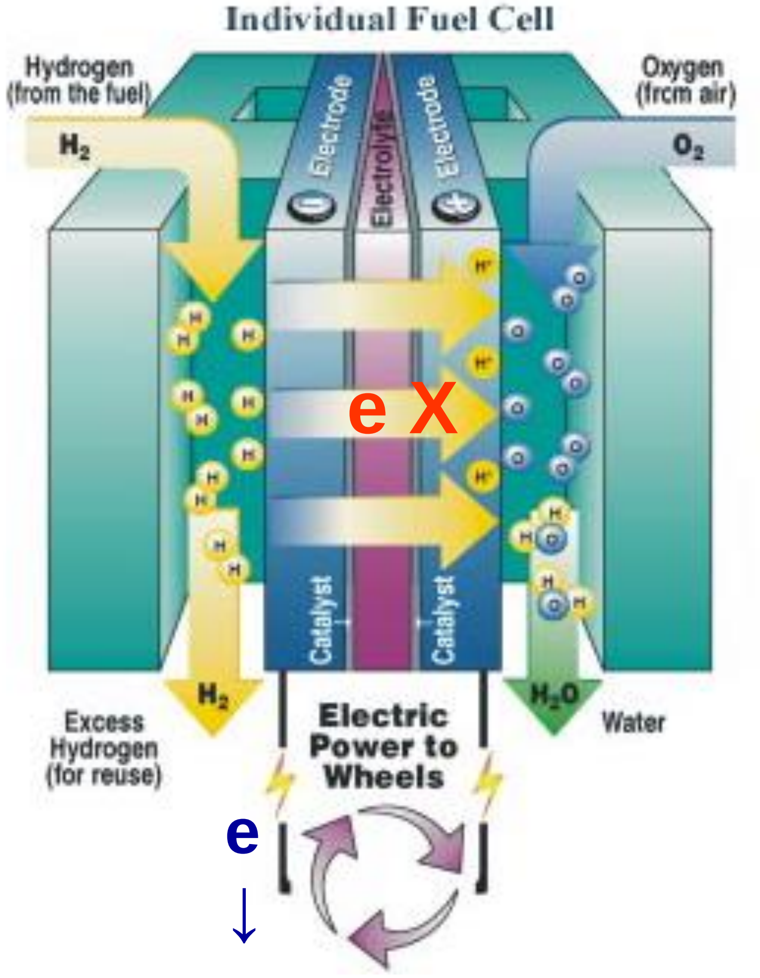
Electric Power Storage

Lithium-Ion Battery	Standard
Output (Volts)	288

Electric Motor

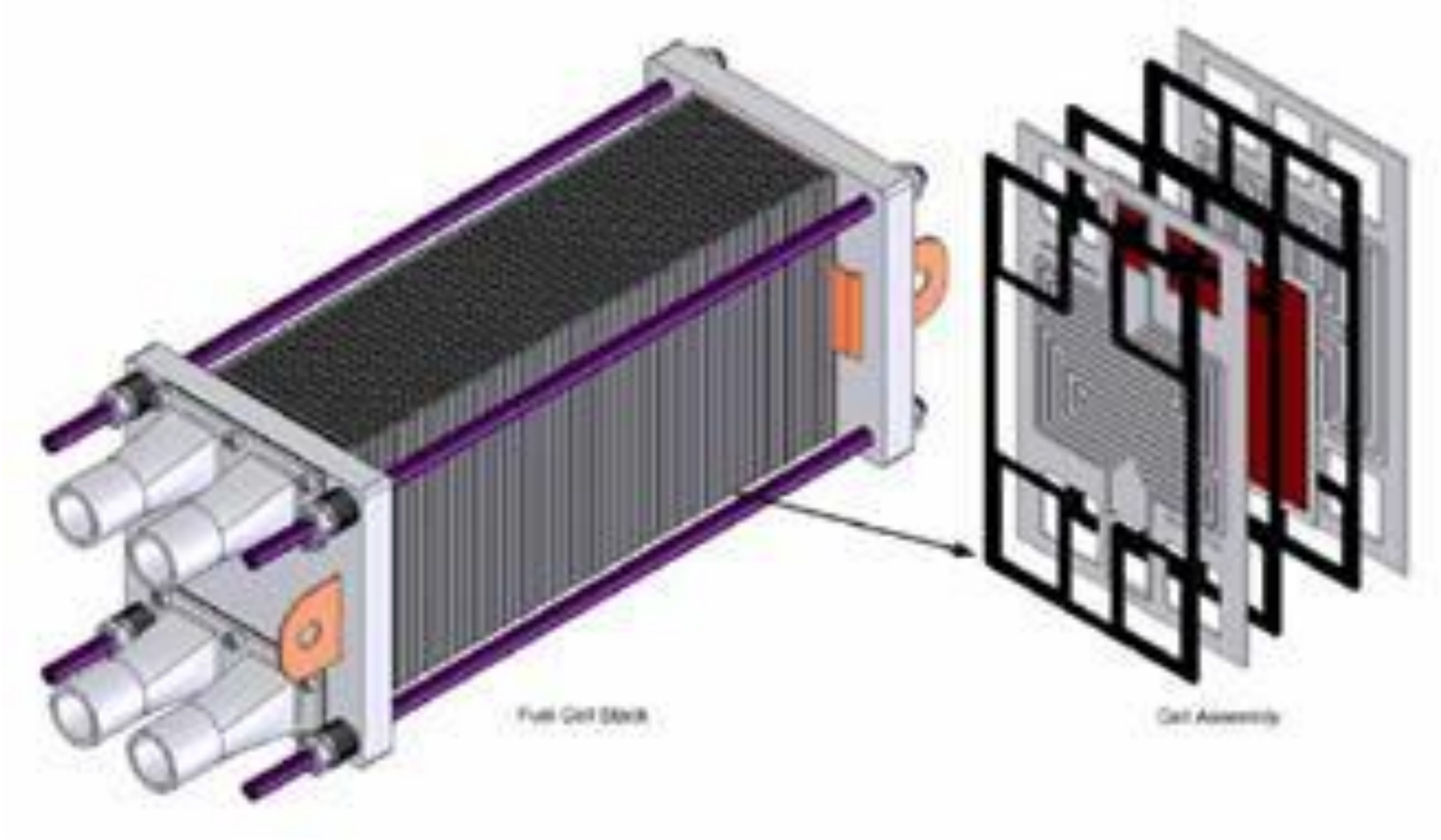
Basic Operation of a PCM Fuel Cell –

(FC is not a heat engine and does not obey Carnot low)



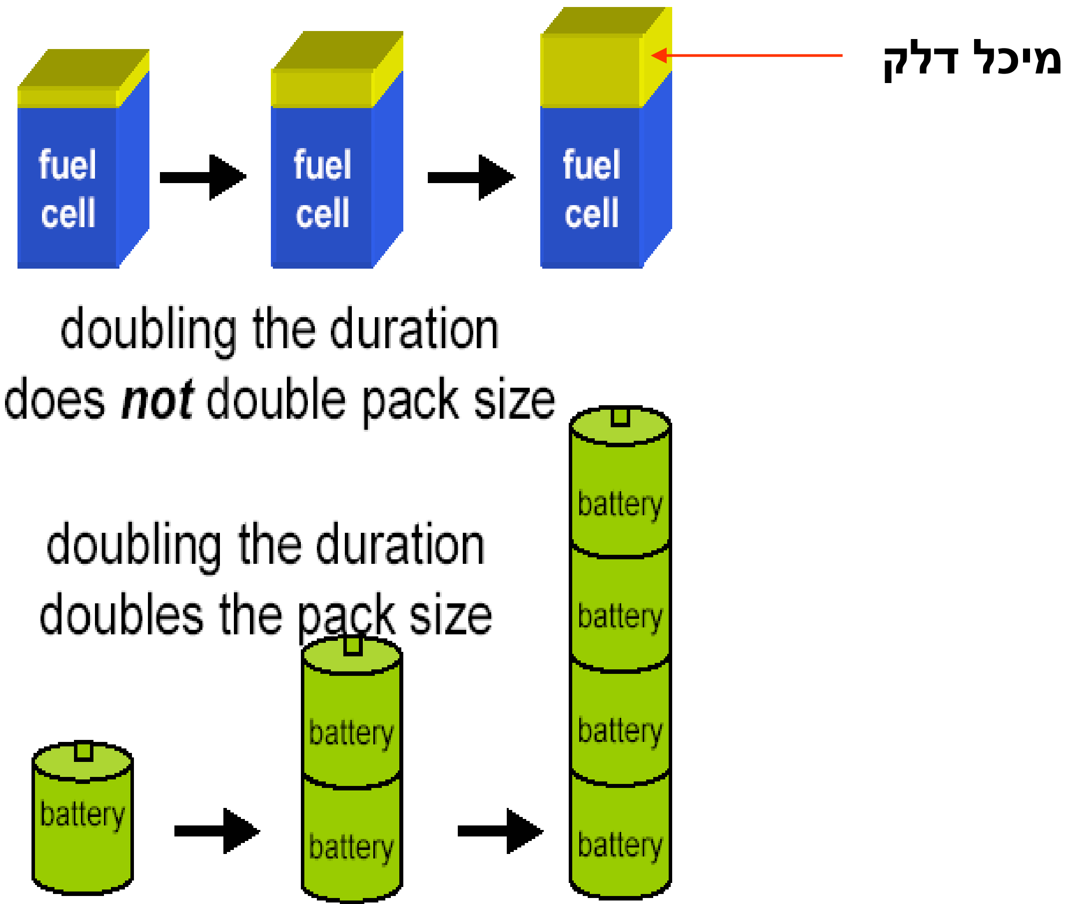
- Chemical Reaction Produces Electricity (at up to 100% efficiency)
- What is the difference between free gas combustion and FC operation
- $H_2 – 2e \rightarrow 2H^+$
- $O_2 + 2e + 2H^+ \rightarrow H_2O$
- In some cases it is possible to get electric work (energy) larger than the heat of the combustion!
- Fuel - H_2; oxidant - O_2
- By-Product - H_2O
- Platinum nano-particles catalysts

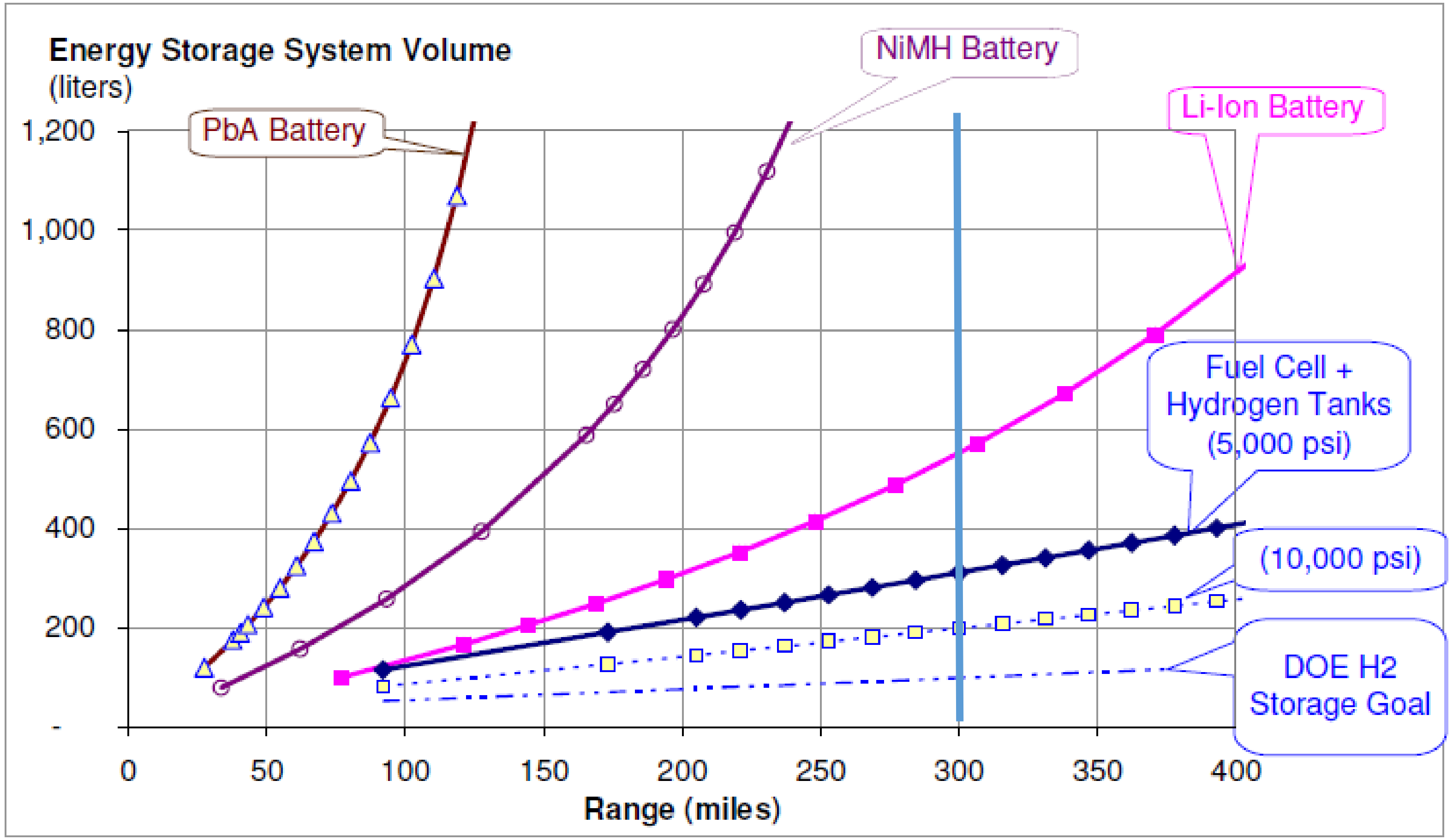
PEM FC stack



מה ההבדל בין תא דלק לסוללה?

- ההבדל הבסיסי בין תא דלק לסוללה הוא שבתא דלק יחידת ההספק מופרדת מיחידת האנרגיה וניתן לשלוט על כל אחת בנפרד.
- **יתרון תא הדלק גדל עם זמן השימוש!**





DOE Storage Goal: 2.3 kWh/Liter

BPEV.XLS; 'Compound' AF114 3/25/2009

Figure 6. Calculated volume of hydrogen storage plus the fuel cell system compared to the space required for batteries as a function of vehicle range

C. E. Thomas – Fuel Cell vs. Battery EV

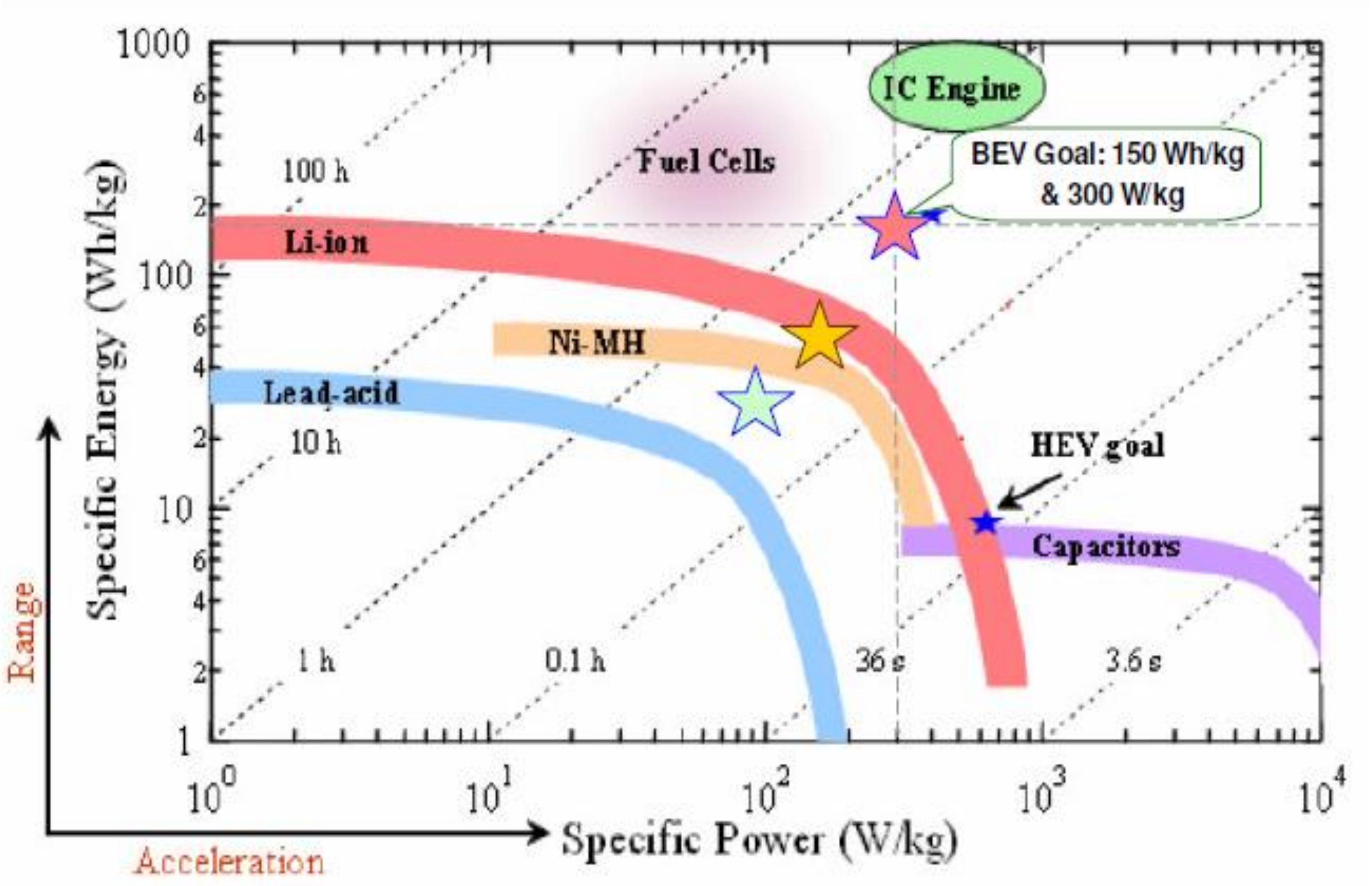


Figure 7. Specific Energy vs. Specific Power for battery technologies from Kromer and Heywood (MIT), May 2007; star symbols indicate the battery parameters used in this study that are all more optimistic than current battery performance

C. E. Thomas – Fuel Cell vs. Battery EV

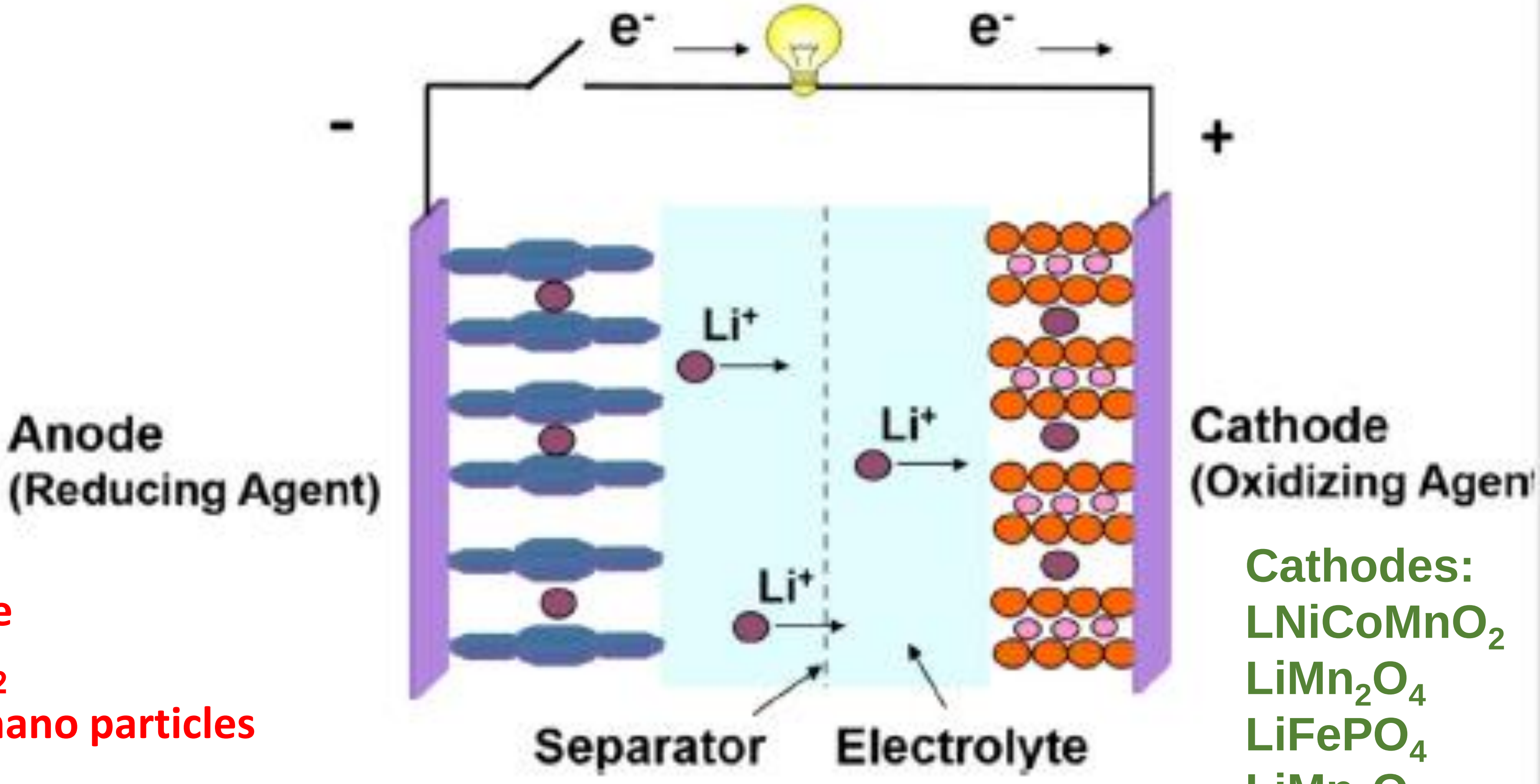
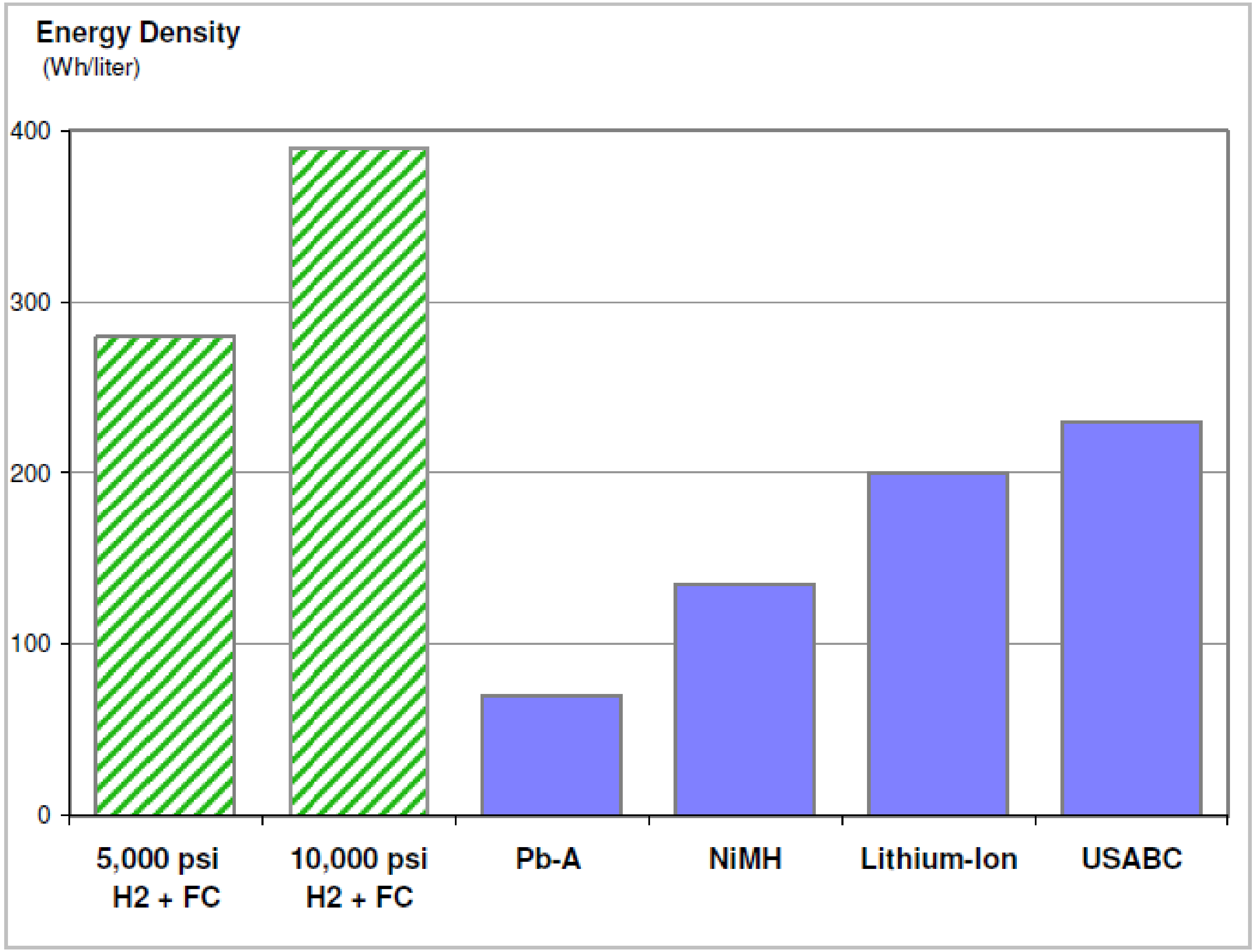


Fig. 8. The schematic view of Li-ion battery consisting of intercalation compoun
during discharge.

Anodes:
Graphite
$Li_4Ti_5O_{12}$
Silicon nano particles

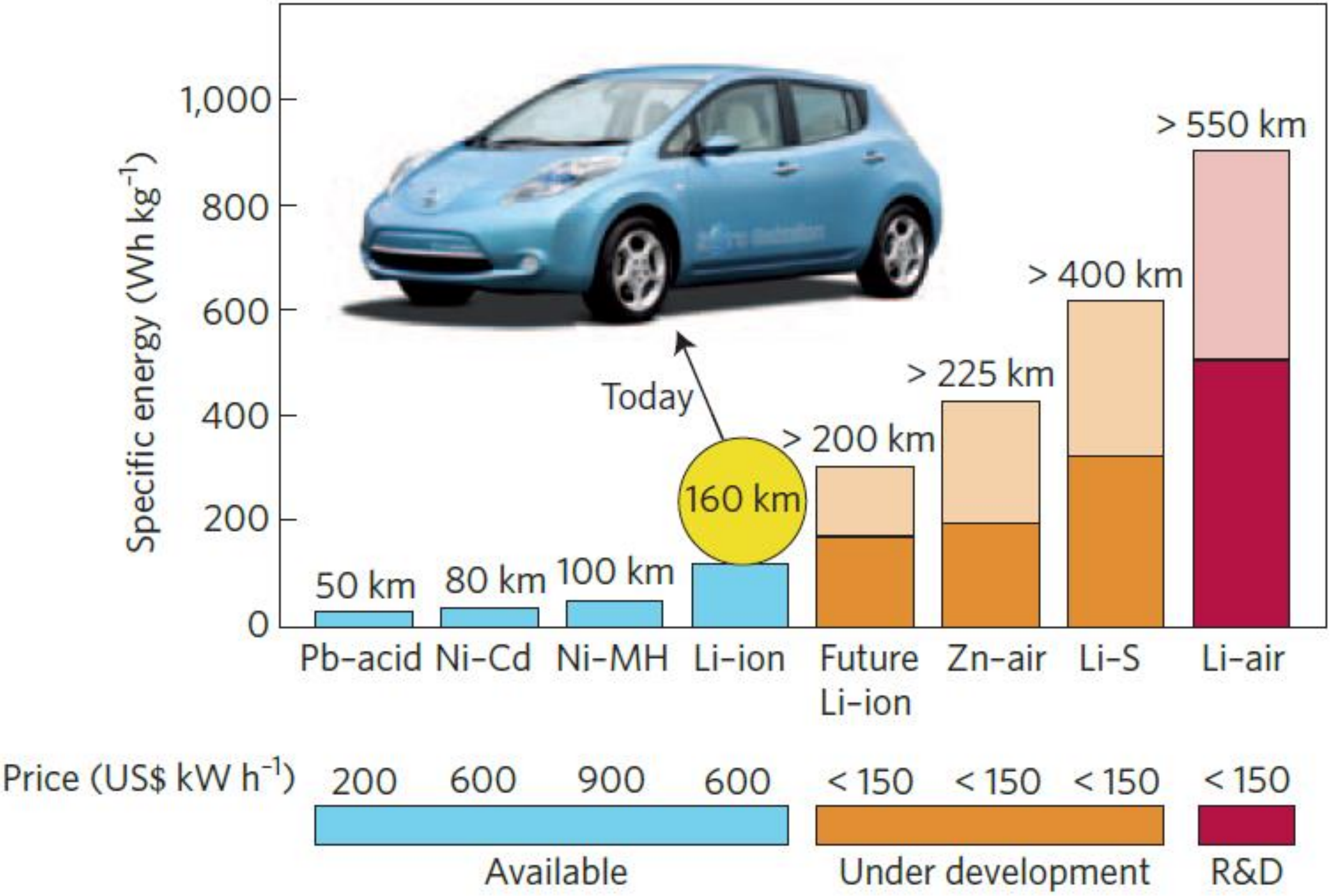
Cathodes:
$LNiCoMnO_2$
$LiMn_2O_4$
$LiFePO_4$
$LiMn_2O_4$



H2Gen: Wt_Vol_Cost.XLS; Tab 'Battery'; S34 - 3 / 25 / 2009

Figure 5. Energy density of hydrogen tanks and fuel cell systems compared to the energy density of batteries

Batteries Specific Energy



Li Ion Batteries

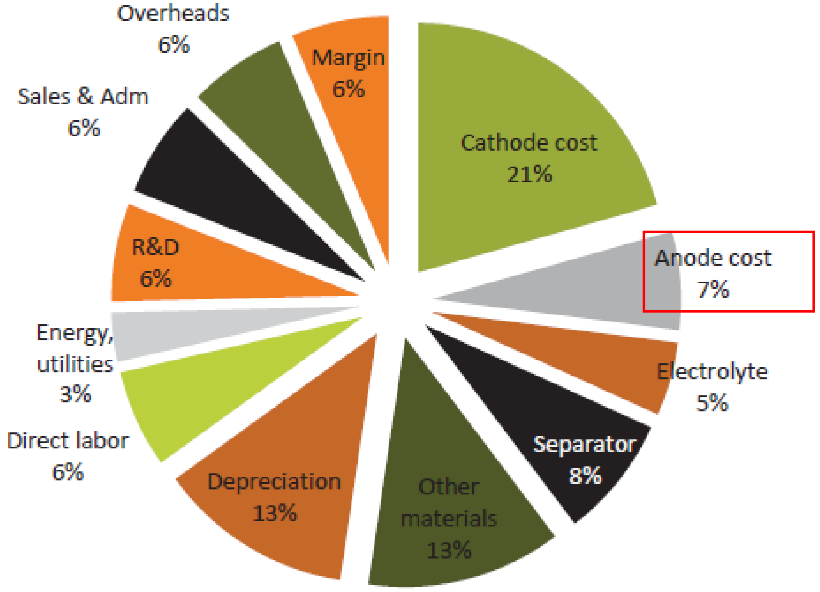
BATTERY	Advantage	Disadvantage
$LNiCoO_2$/Graphite	Energy density	Safety, cost
$LiMn_2O_4$/Graphite	Cost, safety, power density	HT longevity
$LiFePO_4$/Graphite	Cycle life, power, safety	Low energy density (about 60% of LNCO)
$LiMn_2O_4/Li_4Ti_5O_{12}$	Cycle life, power, safety	Lowest energy density (about 40% of LNCO)

תודה על ההקשבה

פרויקטי מו"פ אגירת אנרגיה ובטריות לרכב חשמלי (בקבוצת המחקר של פרופ' עמנואל פלד באוניברסיטת תל אביב)

- בטרית ליתיום גופרית , פרויקט אירופאי (HELIS, HORIZON 2020 and INREP)
- סופר קבלים מימיים ואל מימיים (מגנט TEPS עם אלביט)
- אנודת ננו חלקיקי סיליקון , מגנט TEPS עם תדיראן) ופרויקט אירופאי (MARS)
- זרזים לתאי דלק (מפא"ת ואינרפ)
- אנודת חוטי סיליקון ננומטרים (Momentum Fund)
- בטרית ליתיום מדפסת בתלת ממד (מפא"ת)
- בטריות ליתיום ונתרן – אויר (אינרפ, לטווח הארוך)

Average cost structure of Li ion cell in 2014



source: The rechargeable Battery market and main trends 2014-2025 C.Pillot Avicenne Energy

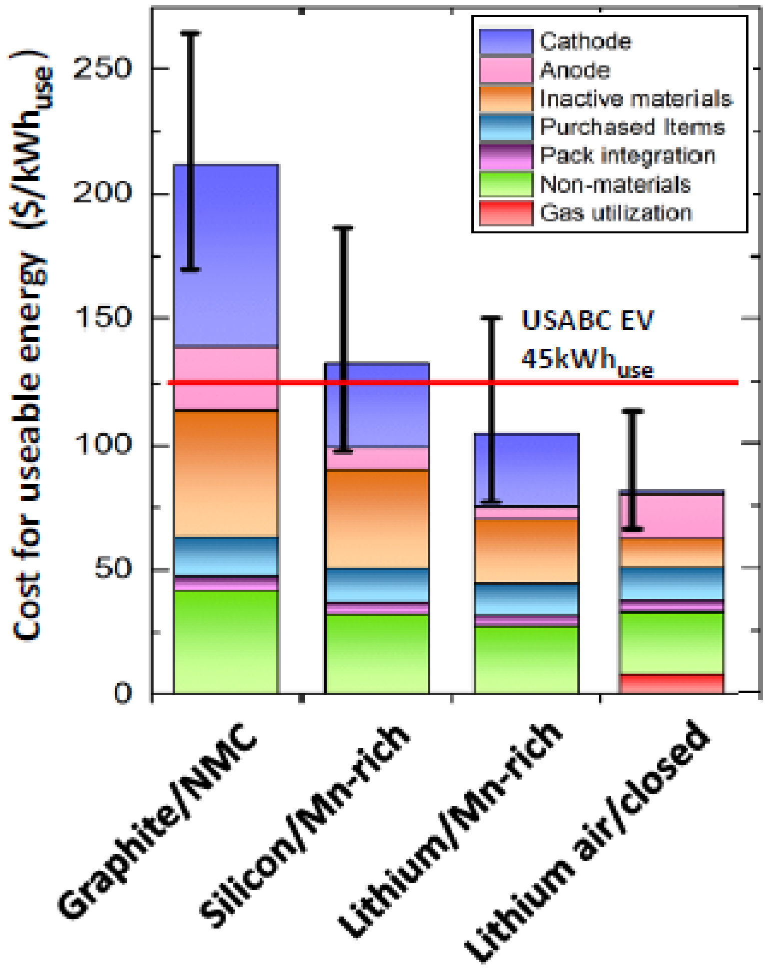
COGS = 90% x 15 B$ =12.2 B$

Anode = 7% x COGS = 0.8 B$

Projected Cost

- Extensive cost modeling has been conducted on advanced battery chemistries using the ANL BatPaC model.
  - **Lithium-ion:** silicon anode coupled with a high capacity cathode presents moderate risk pathway to less than 125/kWh$_{\text{use}}$
  - **Lithium metal:** a higher risk pathway to below \$100/kWh$_{\text{use}}$
- **These are the best case projections:** all chemistry problems solved, performance is not limiting, favorable system engineering assumptions, high volume manufacturing.

Projected Cost for a \$100/kWh Battery Pack

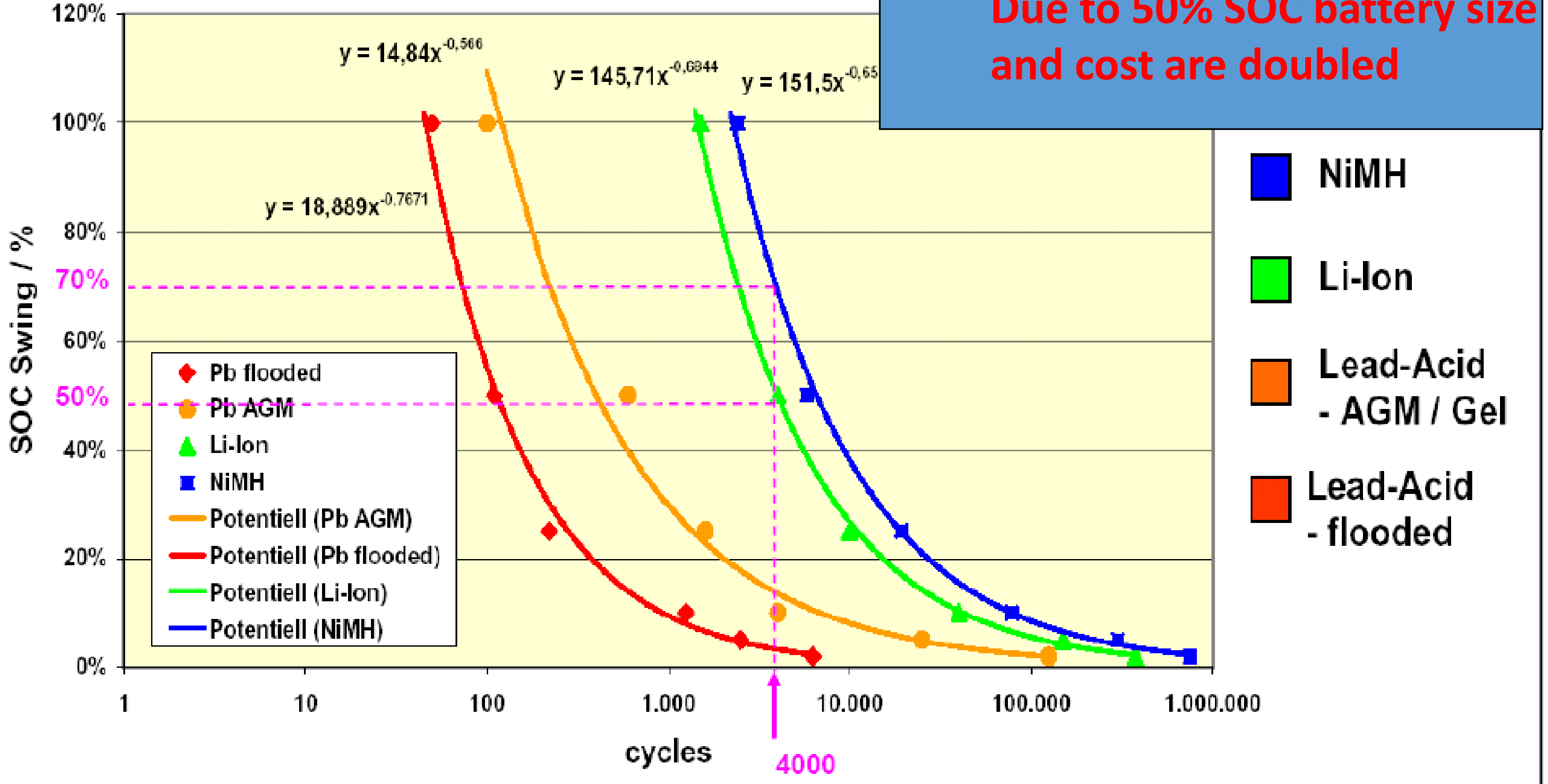


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

* DOE VTO advanced battery R&D program (2016)

Battery Cycle Life Depends on State of Charge Swing

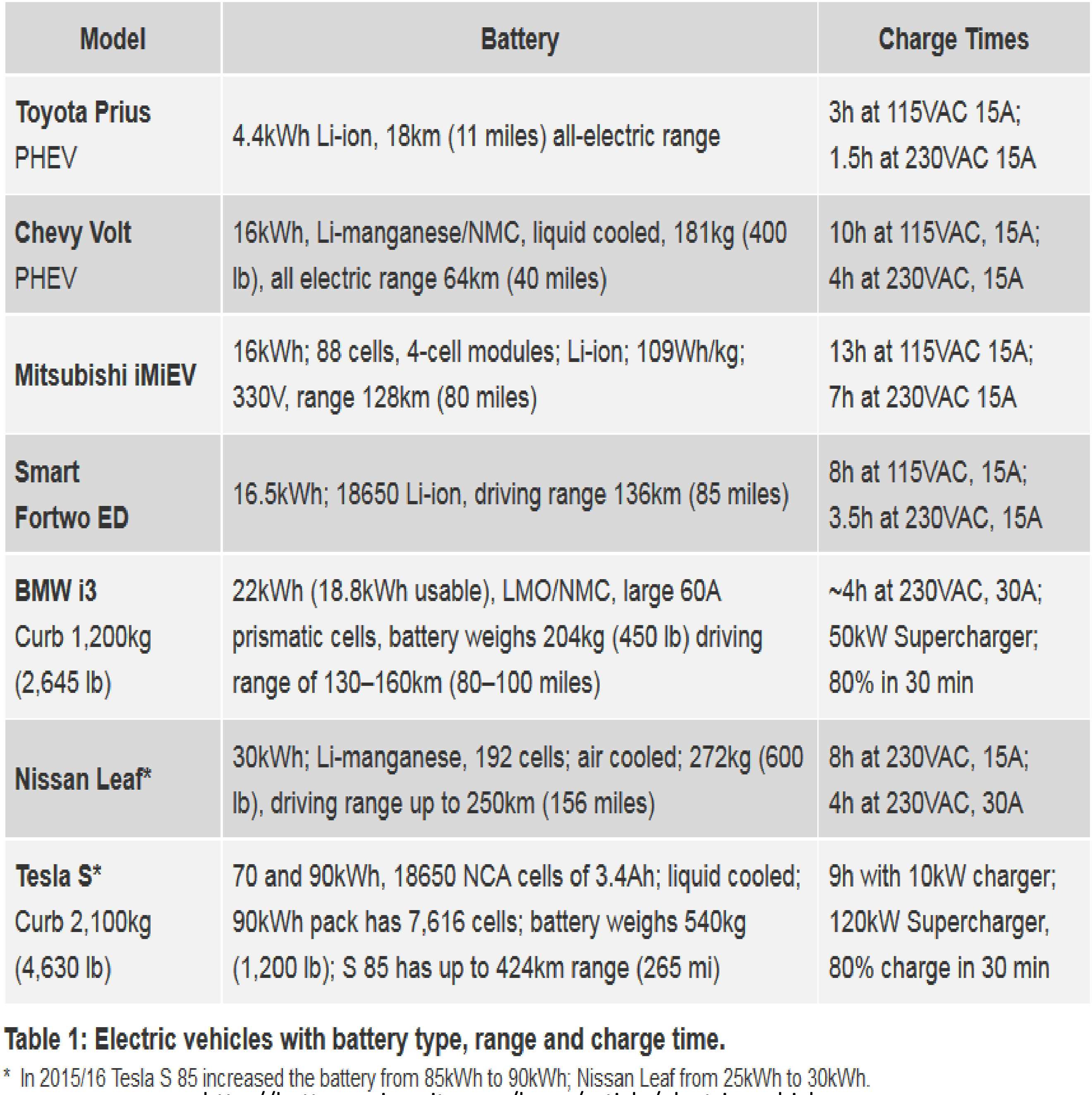
- PHEV battery likely to deep-cycle each day driven: 15 yrs equates to 4000-5000 deep cycles
- Also need to consider combination of high and low frequency cycling



Due to 50% SOC battery size and cost are doubled

Source: Christian Rosenkranz (Johnson Controls) at EVS 20, Long Beach, CA, November 15-19, 2003

EVs on the road



Model	Battery	Charge Times
Toyota Prius PHEV	4.4kWh Li-ion, 18km (11 miles) all-electric range	3h at 115VAC 15A; 1.5h at 230VAC 15A
Chevy Volt PHEV	16kWh, Li-manganese/NMC, liquid cooled, 181kg (400 lb), all electric range 64km (40 miles)	10h at 115VAC, 15A; 4h at 230VAC, 15A
Mitsubishi iMiEV	16kWh; 88 cells, 4-cell modules; Li-ion; 109Wh/kg; 330V, range 128km (80 miles)	13h at 115VAC 15A; 7h at 230VAC 15A
Smart Fortwo ED	16.5kWh; 18650 Li-ion, driving range 136km (85 miles)	8h at 115VAC, 15A; 3.5h at 230VAC, 15A
BMW i3 Curb 1,200kg (2,645 lb)	22kWh (18.8kWh usable), LMO/NMC, large 60A prismatic cells, battery weighs 204kg (450 lb) driving range of 130–160km (80–100 miles)	~4h at 230VAC, 30A; 50kW Supercharger; 80% in 30 min
Nissan Leaf*	30kWh; Li-manganese, 192 cells; air cooled; 272kg (600 lb), driving range up to 250km (156 miles)	8h at 230VAC, 15A; 4h at 230VAC, 30A
Tesla S* Curb 2,100kg (4,630 lb)	70 and 90kWh, 18650 NCA cells of 3.4Ah; liquid cooled; 90kWh pack has 7,616 cells; battery weighs 540kg (1,200 lb); S 85 has up to 424km range (265 mi)	9h with 10kW charger; 120kW Supercharger, 80% charge in 30 min

Table 1: Electric vehicles with battery type, range and charge time.

* In 2015/16 Tesla S 85 increased the battery from 85kWh to 90kWh; Nissan Leaf from 25kWh to 30kWh.

http://batteryuniversity.com/learn/article/electric_vehicle_ev

DOE goals for EV battery

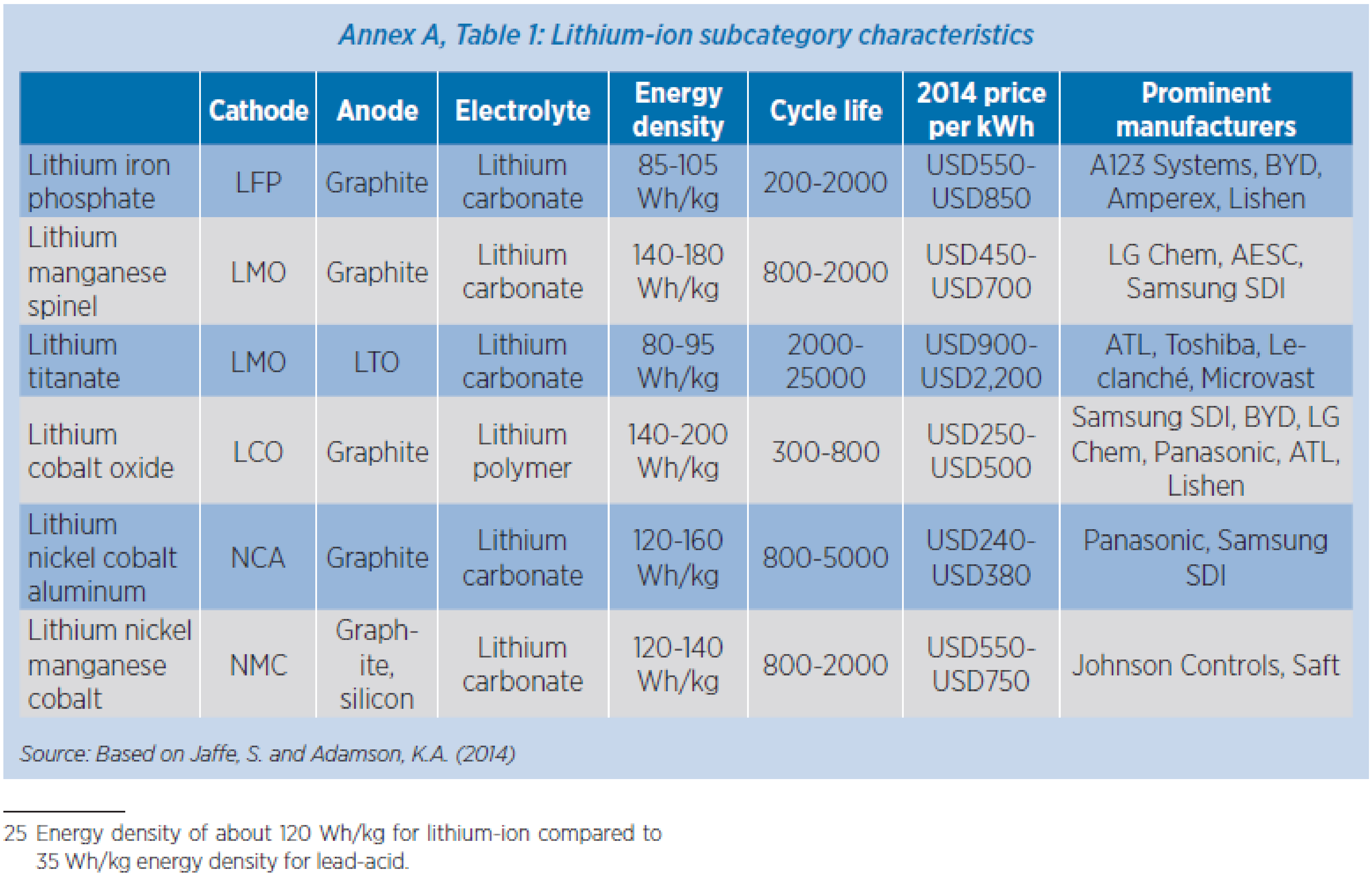
250Wh/kg

400 Wh/l

2kW/kg

Estimated ED and range of Silicon anode based advanced Lithium battery

270Wh/kg (**400** kM)



Annex A, Table 1: Lithium-ion subcategory characteristics

	Cathode	Anode	Electrolyte	Energy density	Cycle life	2014 price per kWh	Prominent manufacturers
Lithium iron phosphate	LFP	Graphite	Lithium carbonate	85-105 Wh/kg	200-2000	USD550-USD850	A123 Systems, BYD, Amperex, Lishen
Lithium manganese spinel	LMO	Graphite	Lithium carbonate	140-180 Wh/kg	800-2000	USD450-USD700	LG Chem, AESC, Samsung SDI
Lithium titanate	LMO	LTO	Lithium carbonate	80-95 Wh/kg	2000-25000	USD900-USD2,200	ATL, Toshiba, Leclanché, Microvast
Lithium cobalt oxide	LCO	Graphite	Lithium polymer	140-200 Wh/kg	300-800	USD250-USD500	Samsung SDI, BYD, LG Chem, Panasonic, ATL, Lishen
Lithium nickel cobalt aluminum	NCA	Graphite	Lithium carbonate	120-160 Wh/kg	800-5000	USD240-USD380	Panasonic, Samsung SDI
Lithium nickel manganese cobalt	NMC	Graphite, silicon	Lithium carbonate	120-140 Wh/kg	800-2000	USD550-USD750	Johnson Controls, Saft

Source: Based on Jaffe, S. and Adamson, K.A. (2014)

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[25] Energy density of about 120 Wh/kg for lithium-ion compared to 35 Wh/kg energy density for lead-acid.

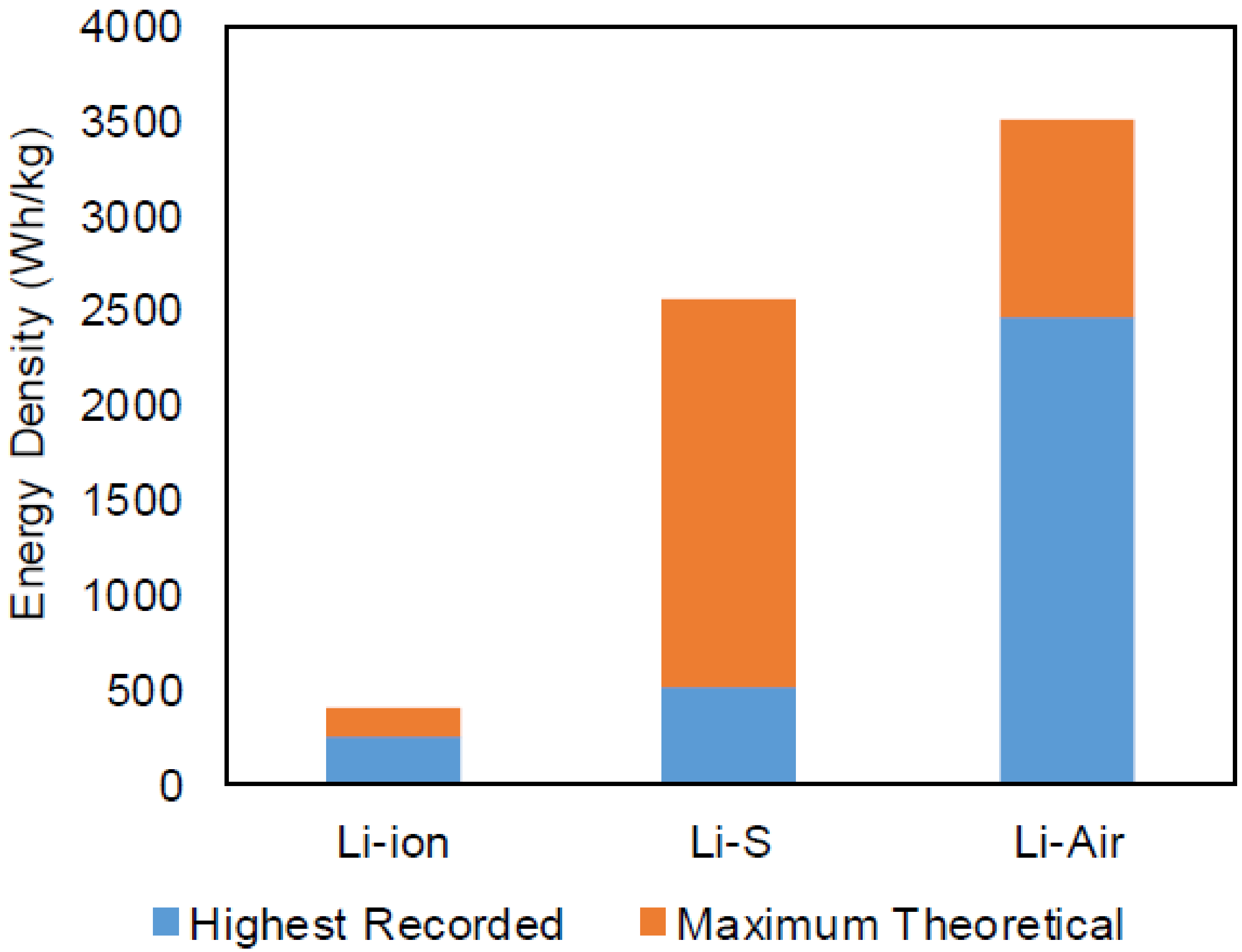
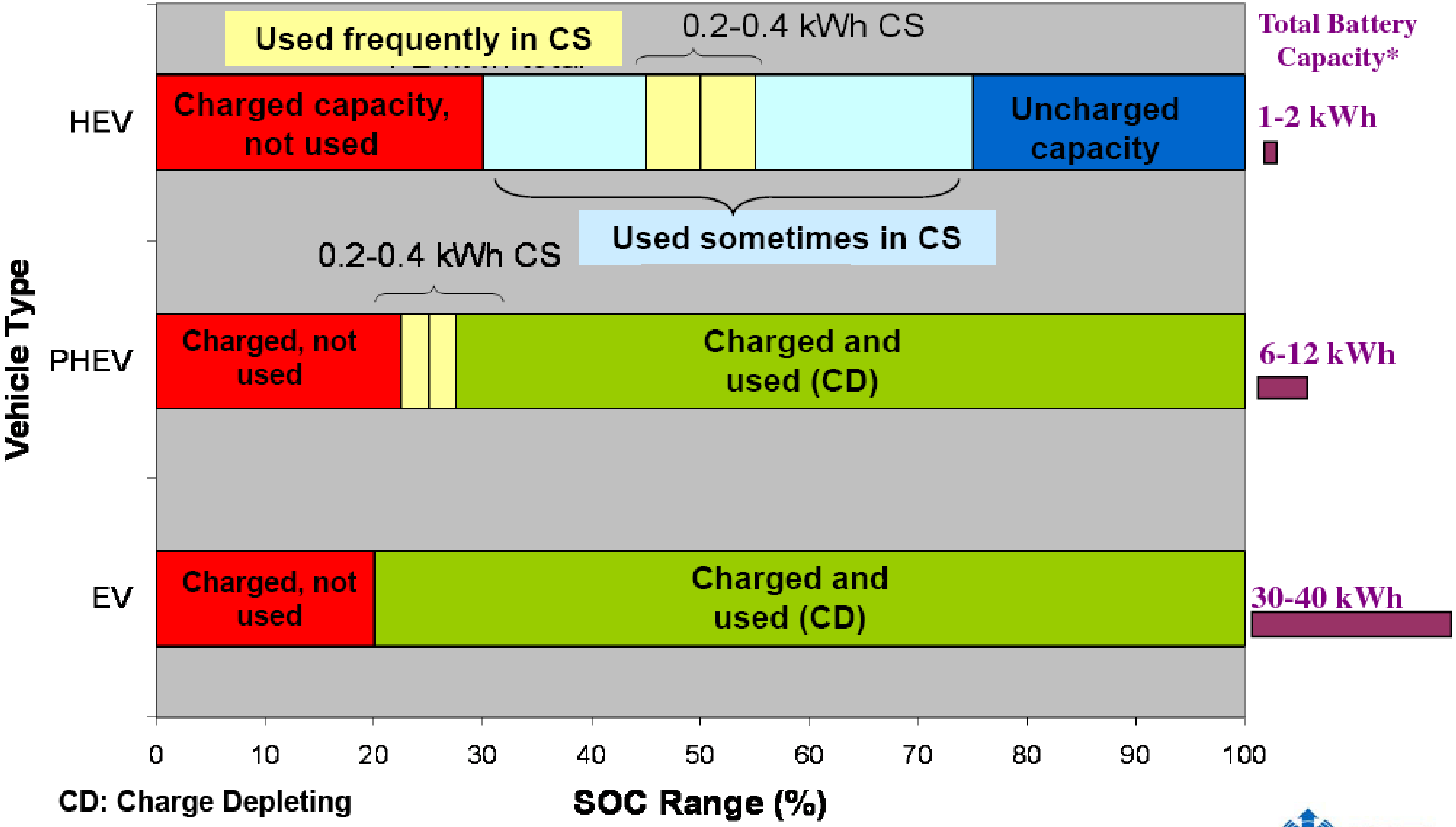


Figure 2: The highest recorded values may not be scalable due to practical challenges of manufacturing on a large scale. Values obtained from [19, 22-24].

Battery Usage in EVs, HEVs, and PHEVs



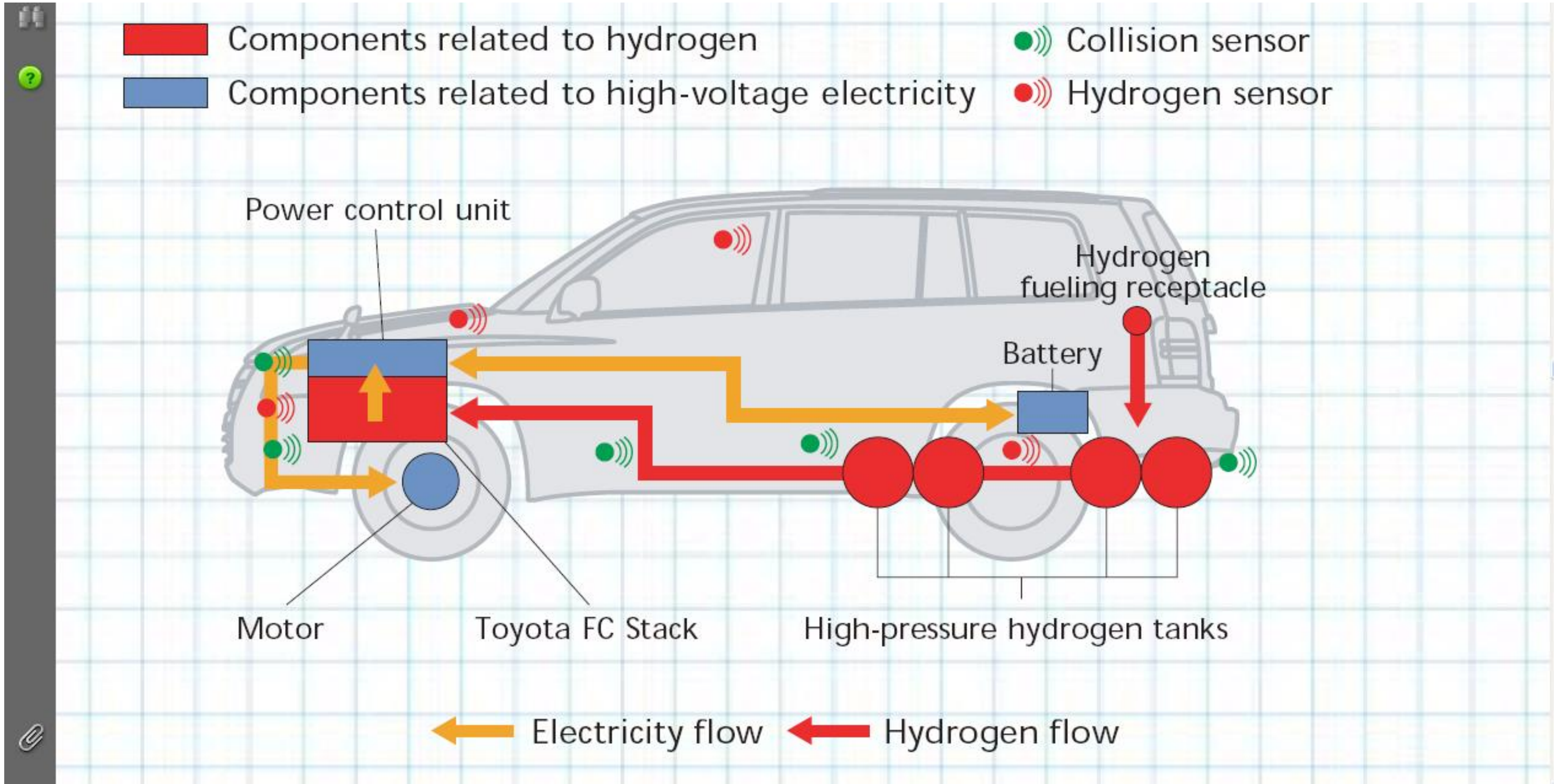
CD: Charge Depleting

CS: Charge Sustaining

*Battery capacity for a midsize car

Safety issues

- **If a collision occurs, sensors in the TOYOTA FCHV’s front, rear and sides detect impact and instantly shut the valves on the high-pressure hydrogen tanks.**
- **For additional safety, the valves are also closed if leakage is detected by any of the hydrogen sensors placed at multiple locations within the vehicle,**
- **The high pressure hydrogen tanks are designed for maximum safety to avoid rupture even if the vehicle suffers a rear-end collision**



Ignition of a hydrogen FC car and of a common gasoline car

הבעיה הכבדה – התפוצצות
אנרגטית של תערובת מימן
–אויר המכילה מעל 5% מימן
באויר (בדומה להתפוצצות
הדירה בירושליים מדליפת
גז בישול)
לכן מכוניות מונעות בגז או
במימן לא מורשות לחנות
בחניונים סגורים (תת
קרקעיים)

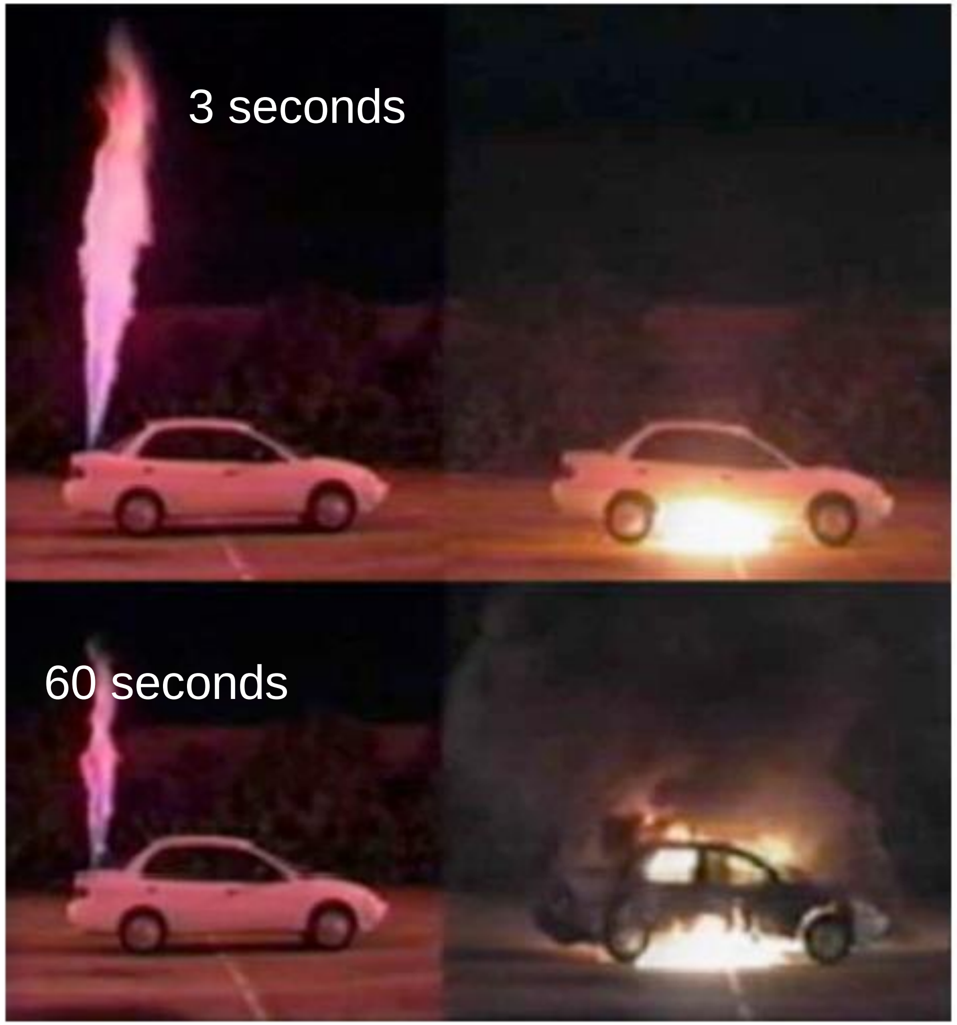


Fig. 6. *On the left is a vehicle with a hydrogen tank, and on the right a vehicle with a standard gasoline tank. Both tanks have been deliberately punctured and ignited. The top panel shows the two vehicles 3 seconds after ignition. We see that, due to the buoyancy of hydrogen, the flame shoots up vertically, whereas gasoline is heavy and spreads beneath the vehicle. The bottom panel shows the two vehicles 60 seconds after ignition. The hydrogen supply has burned*