



# Batterier och Bränsleceller

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# Hur vi brukar omvandla energi...

Kemisk  $\rightarrow$  termisk  $\rightarrow$  mekanisk

Bränsle



Luft

+



=

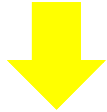
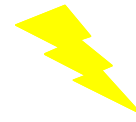
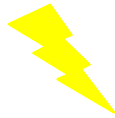
Arbete + Värme +  $\text{CO}_2$  +  $\text{H}_2\text{O}$



Men också avgaser:  
 $\text{SO}_2$ ,  $\text{NO}_x$ , partiklar etc.)

*Förbränning är enkelt men ineffektivt och ger växthusgaser och luftföroreningar.*

# Elektrokemiska celler kan göra skillnad...



Vätgas

+



Luft

=



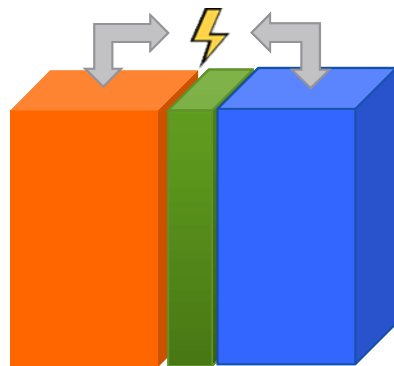
Arbete + Värme + Vatten

*Batterier och bränsleceller är effektiva och rena*

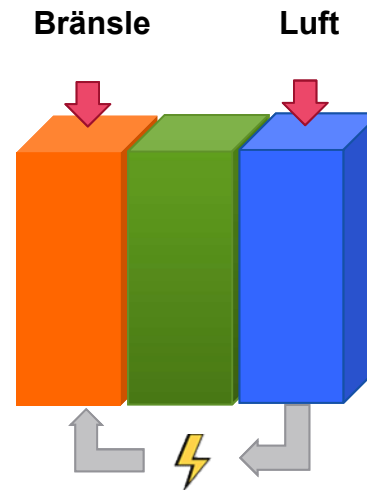


# Elektrokemisk energiomvandling

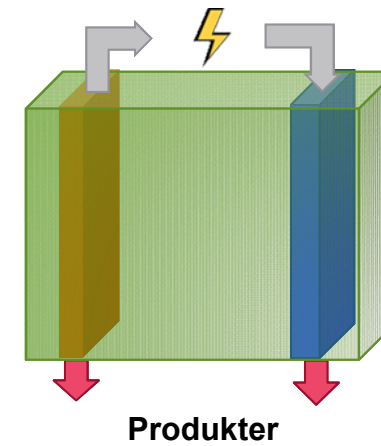
Batteri



Bränslecell

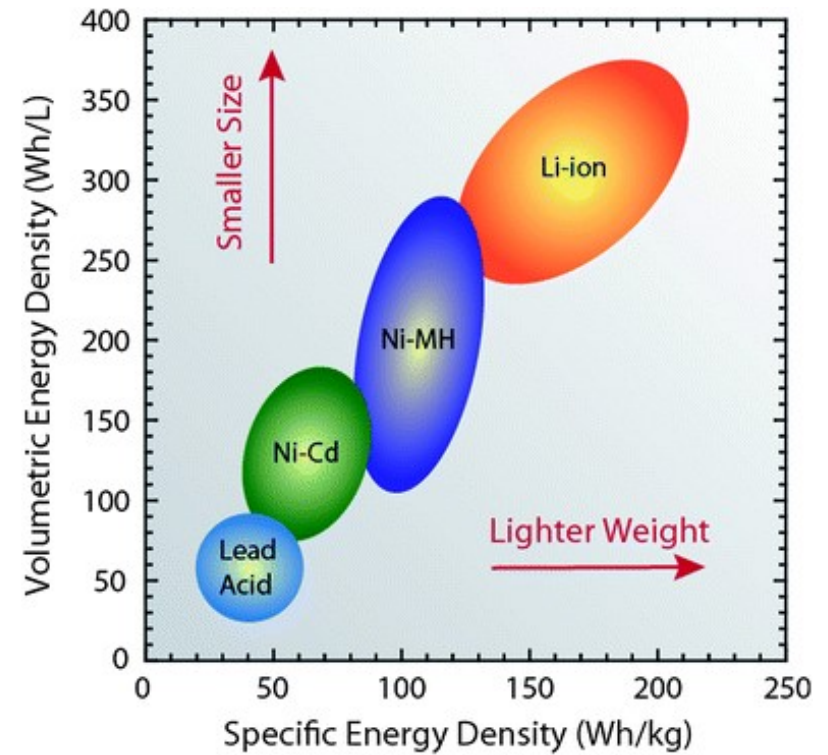
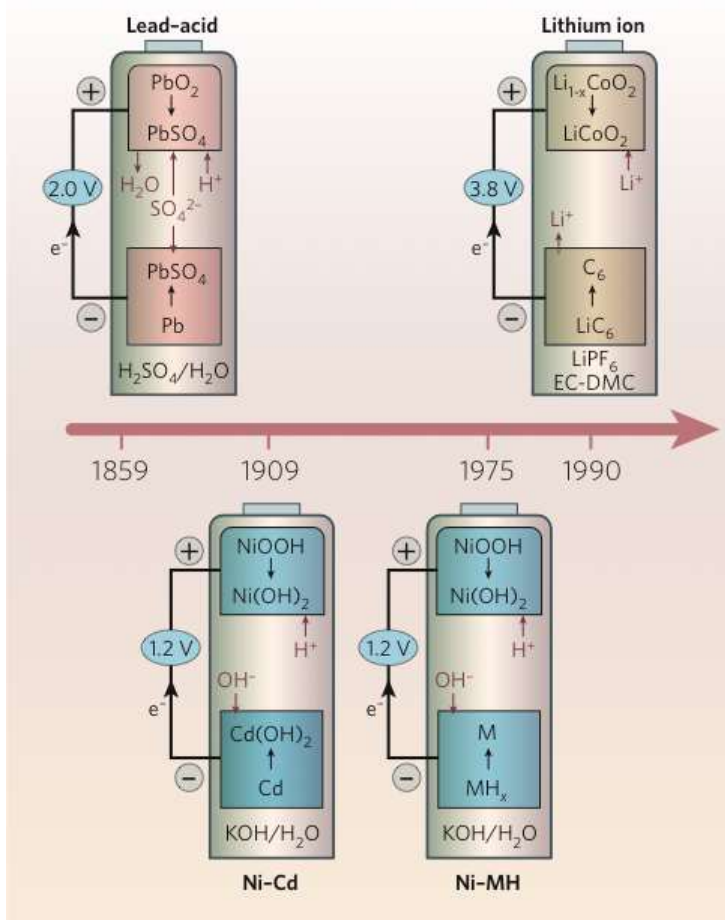


Elektrolysör

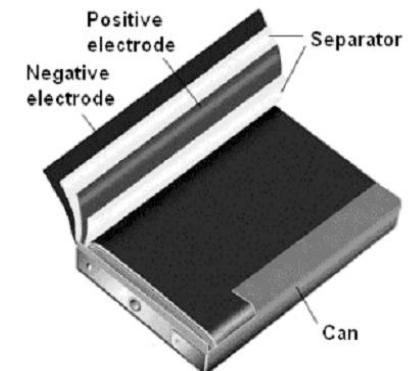
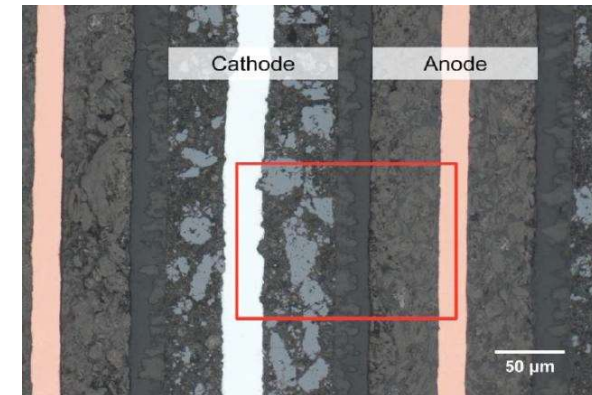
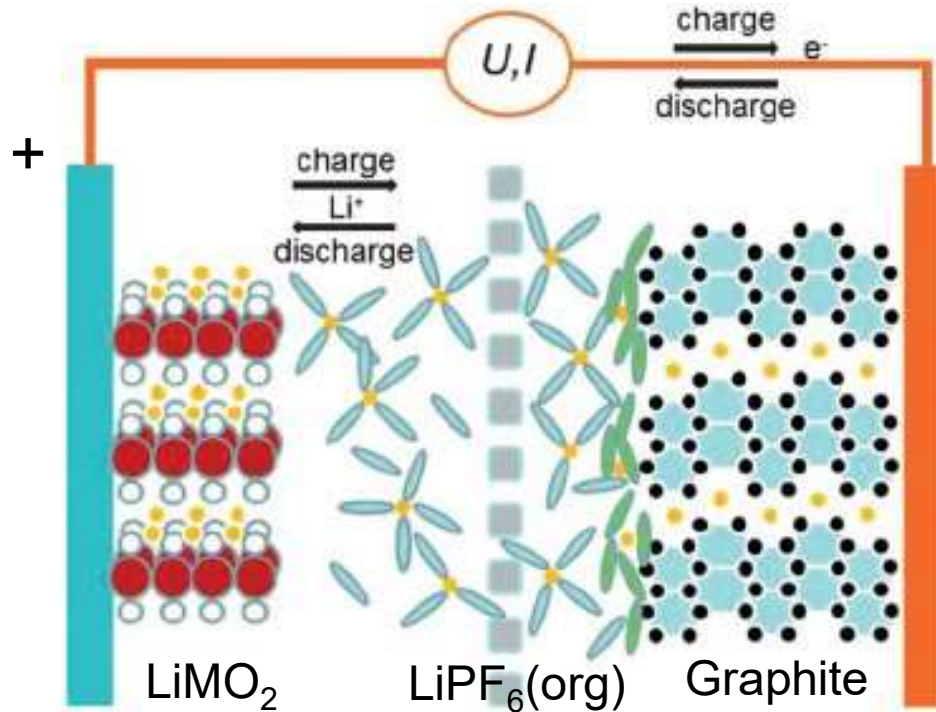




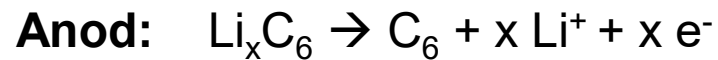
# Batteriutvecklingen



# Ett modernt Li-jonbatteri



*Urladdning:*



-3 V

1 V

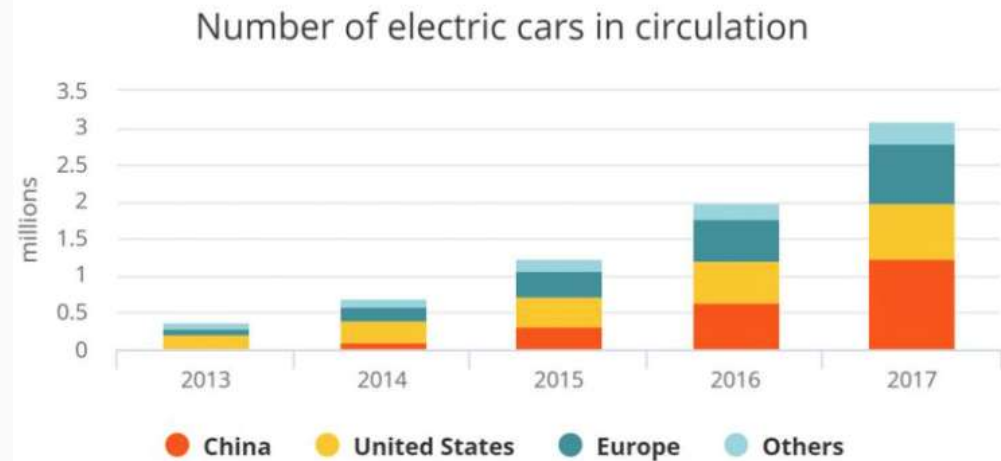
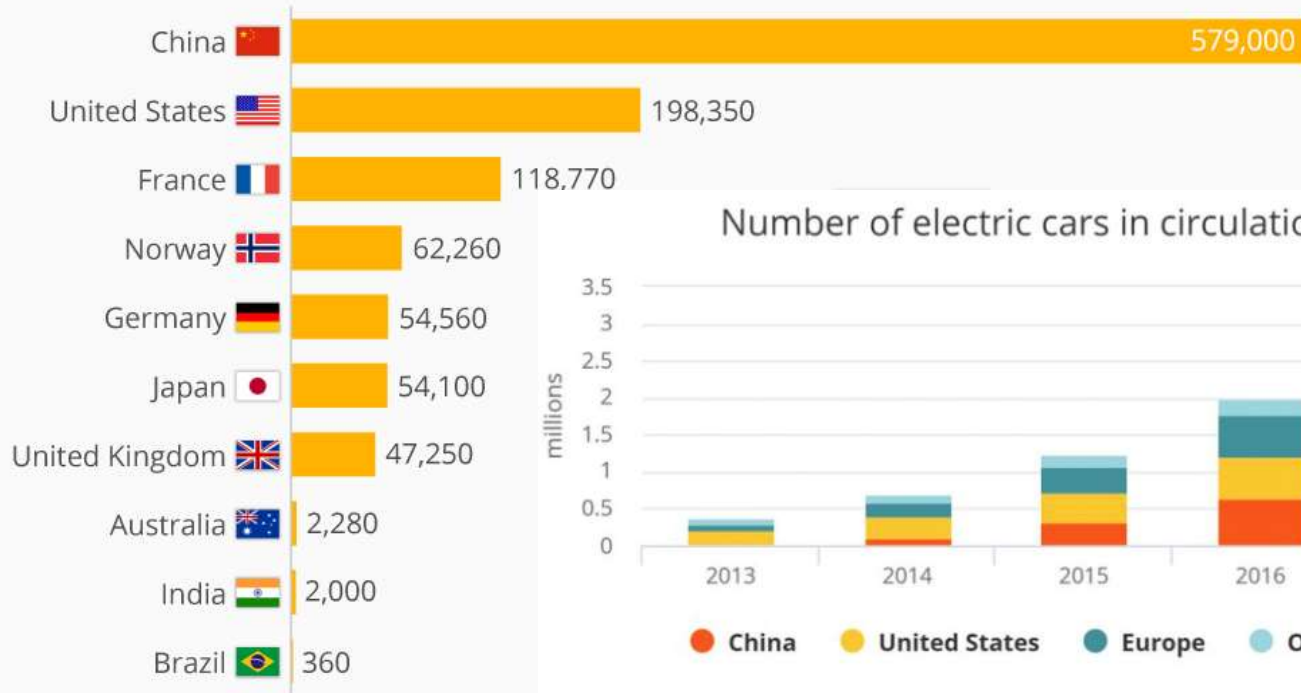
4 V

M= Co, Mn, Ni, (Fe)

# Batterifordon allt vanligare

## Electric Car Sales Are Surging In China

Electric vehicle sales (BEV and PHEV) by county in 2017\*



© OECD/IEA



\* Selected countries. BEV - Battery electric. PHEV - plug-in hybrid.

@StatistaCharts

Source: International Energy Agency

statista

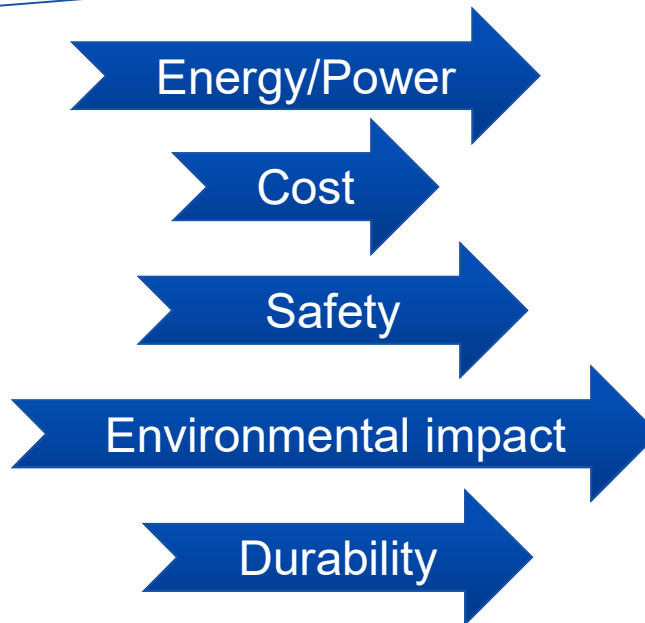
1,1 miljoner av totalt 80 miljoner personbilar/ år

# Batterier i fordon ställer höga krav

Small cells  
5.3 Wh



Large cells  
and packs  
33 kWh

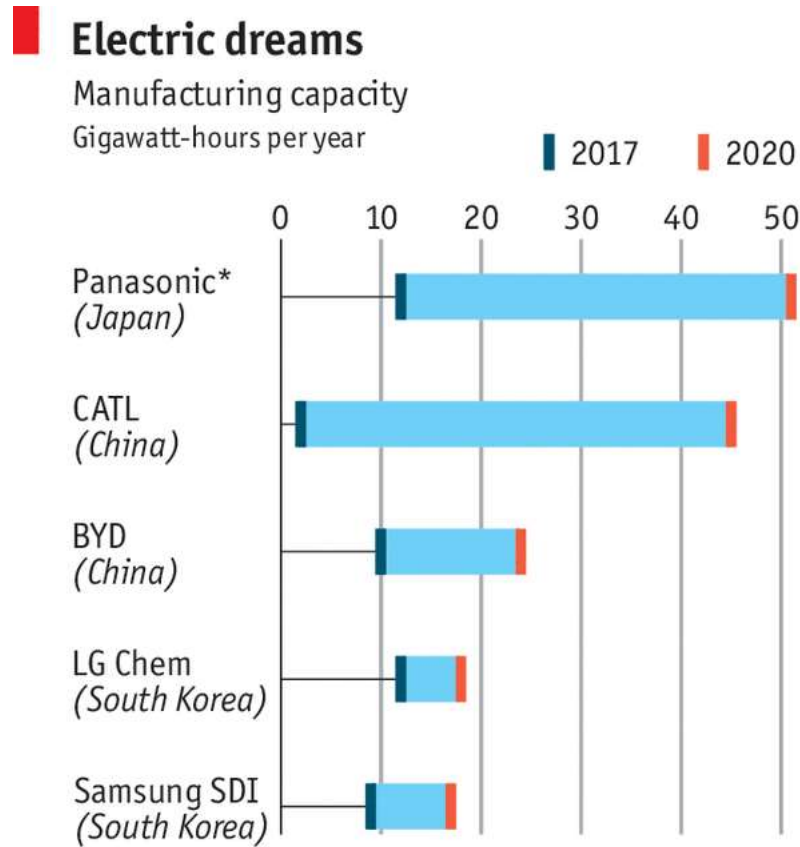






# Går det att elektrifiera alla transporter?

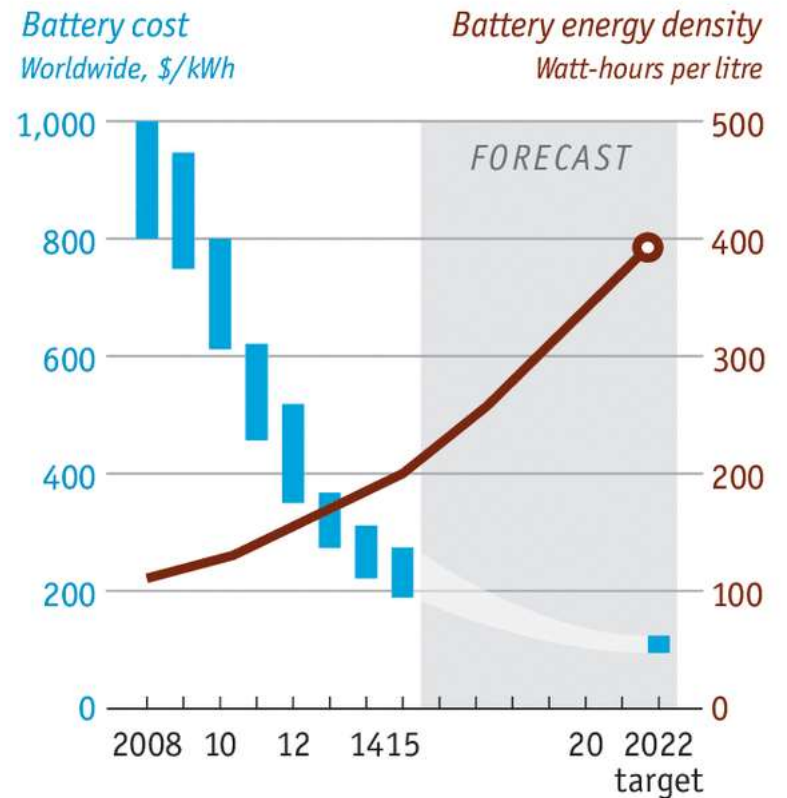
## ökad produktionsstakt



Sources: Cairn ERA; US Department of Energy

Economist.com

## lägre pris och högre prestanda



\*Includes Tesla gigafactory

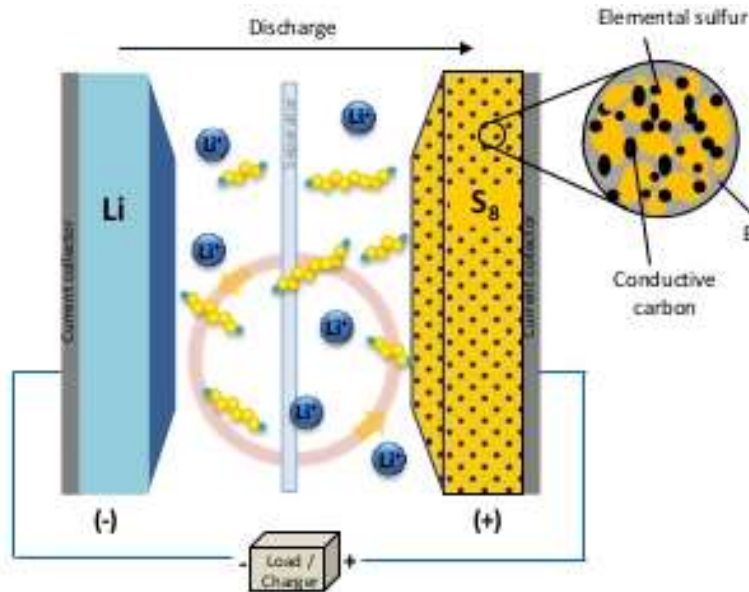
# Batteriutvecklingen Li-jon batterier

Figure: Material Development of High Energy Density Battery

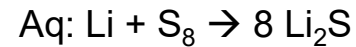


Inblandning av mer Ni i katodmaterialet och mer Si i anodmaterialet ökar energitätheten men minskar sannolikt livslängden

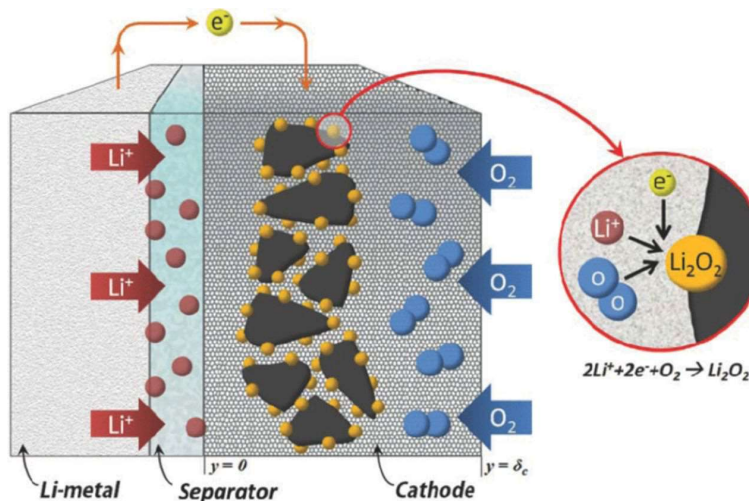
# Nya batterikoncept: litium-svavel eller luft



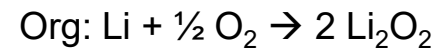
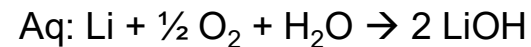
## Lithium – Sulfur



- Average voltage: **2.1 V**
- Specific capacity: **1675 mAh/g**
- Theoretical specific energy: **2500 Wh/kg**

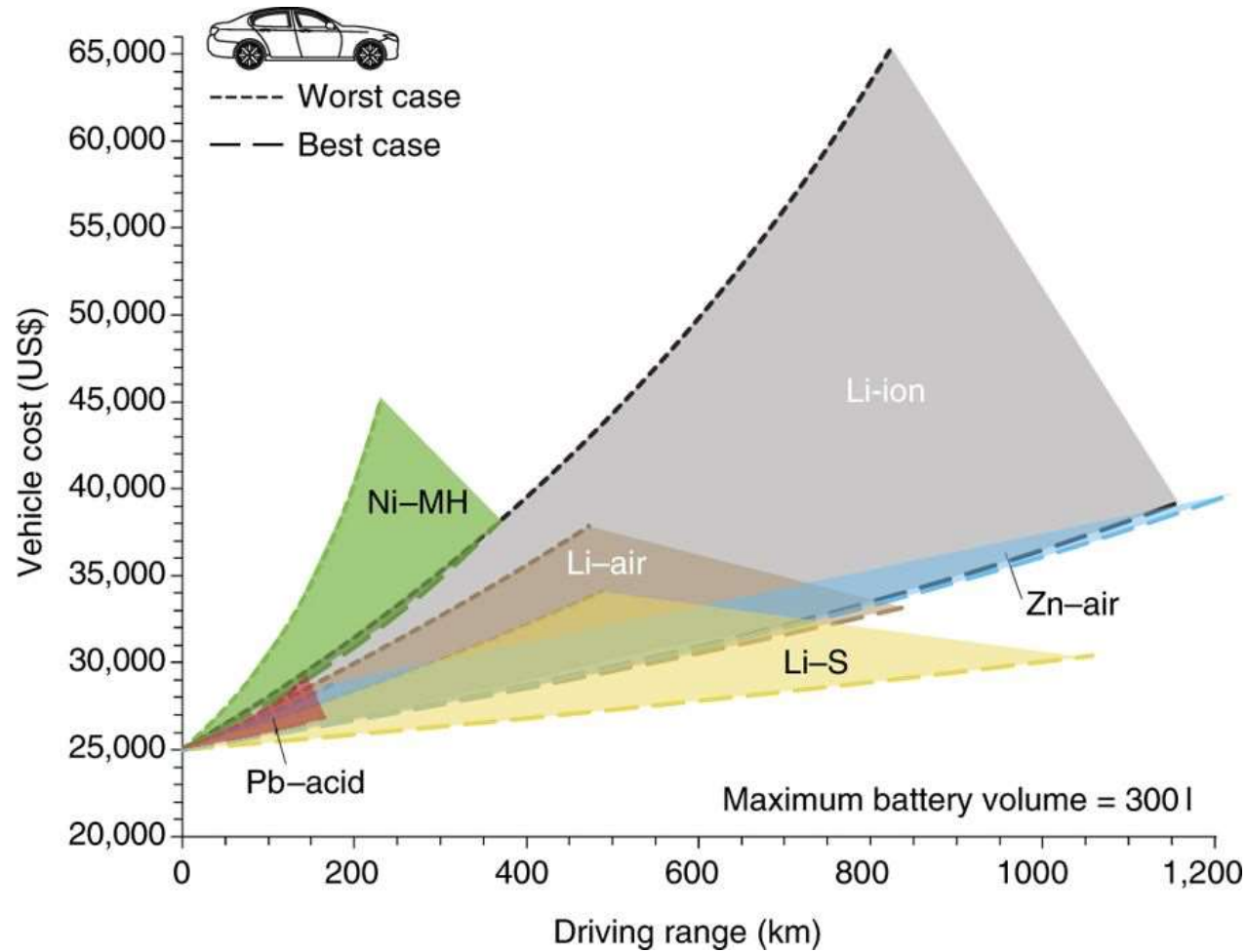


## Lithium - Air (O<sub>2</sub>)



- Average voltage: **2.91 V**
- Specific capacity: **3840 mAh/g**
- Theoretical specific energy: **5800 Wh/kg (aq)**  
**11420 Wh/kg (org)**

# Kostnad mot körsträcka, vad att vänta?

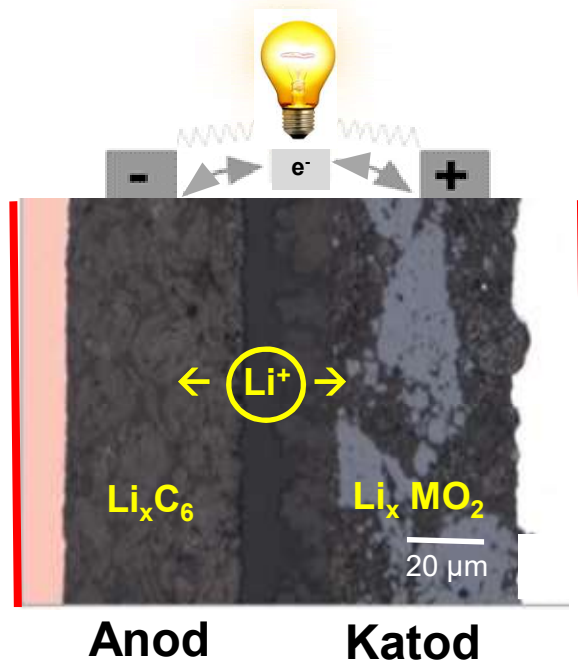


Z. P. Cano, D. Banham, S. Ye, A. Hintennach, J. Lu, Mi. Fowler & Z. Chen "Batteries and fuel cells for emerging electric vehicle markets" Nature Energy 3, 279–289 (2018)



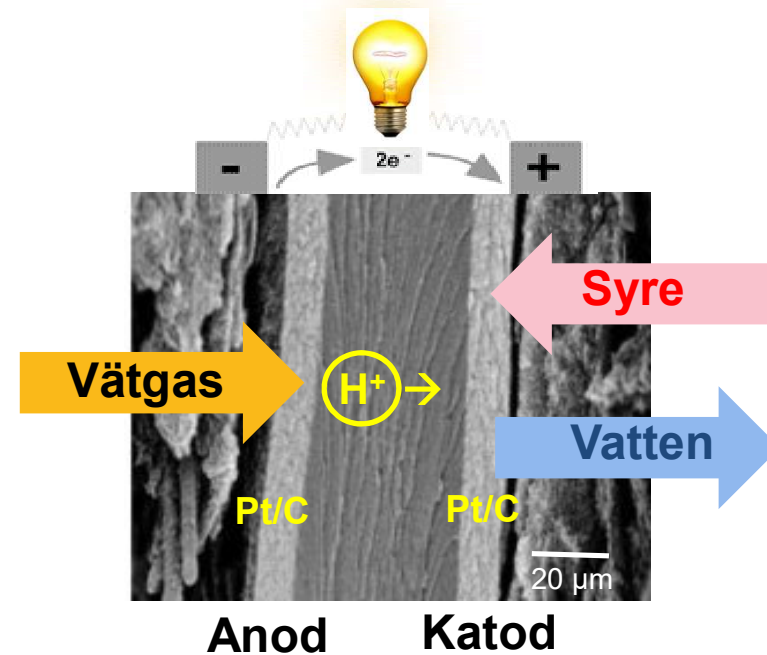
# Kan bränslecellen vara ett alternativ?

## Li-jonbatteri



*Lagrar energi i det fasta materialet*

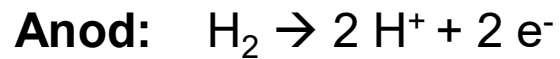
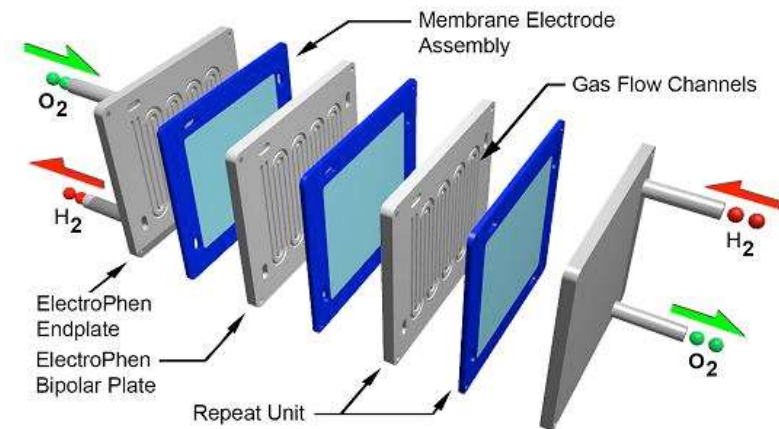
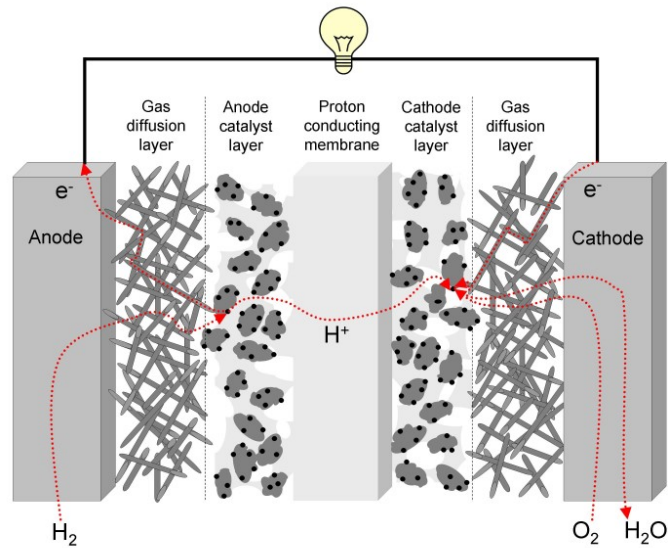
## Polymerbränslecell



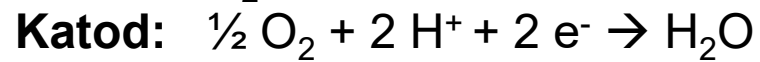
*Omvandlar effektivt ett bränsle till el*

# Bränslecellens reaktioner

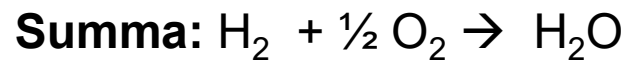
## Polymerbränslecell



$E^\circ = 0 \text{ V}$

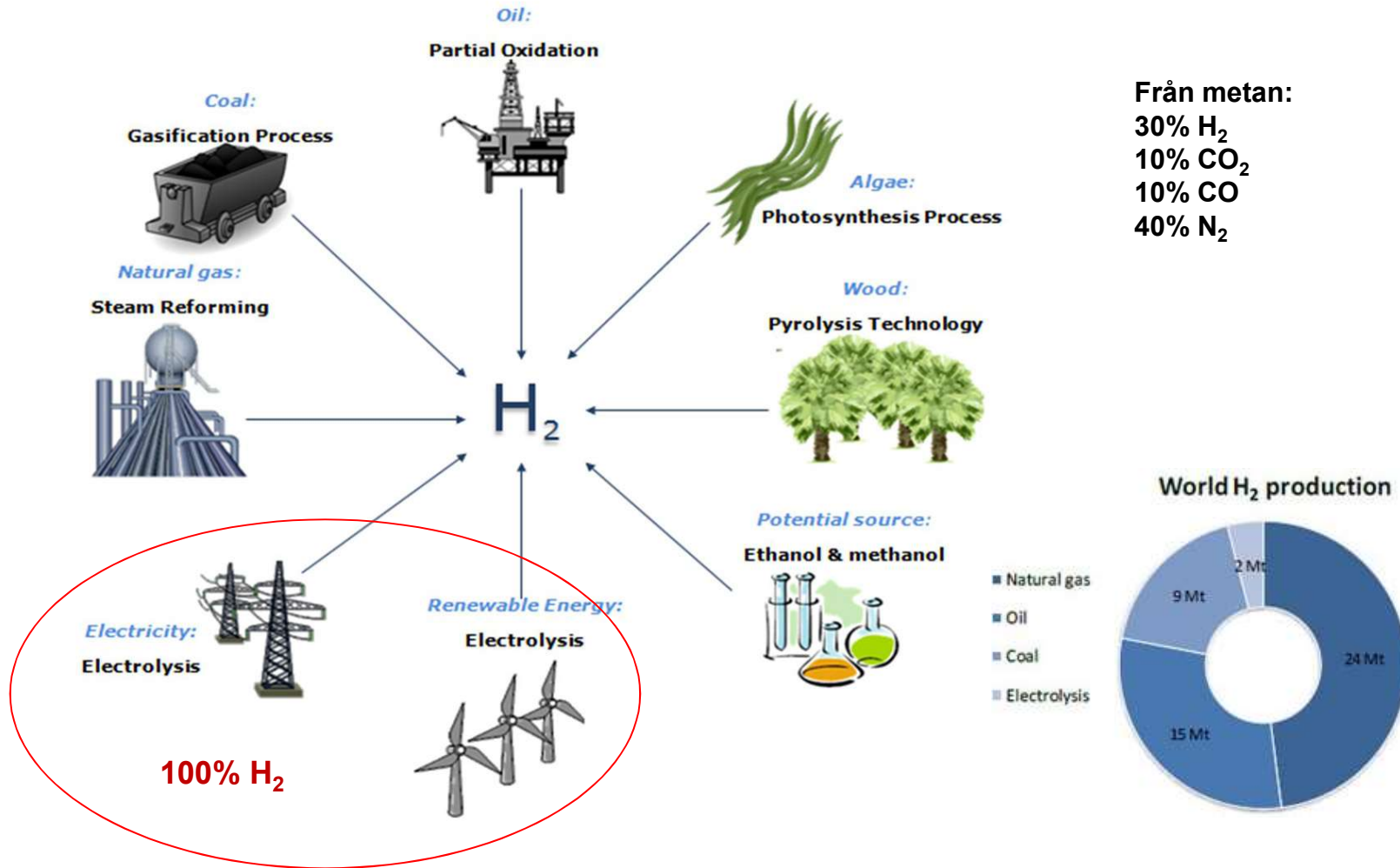


$E^\circ = 1,2 \text{ V}$

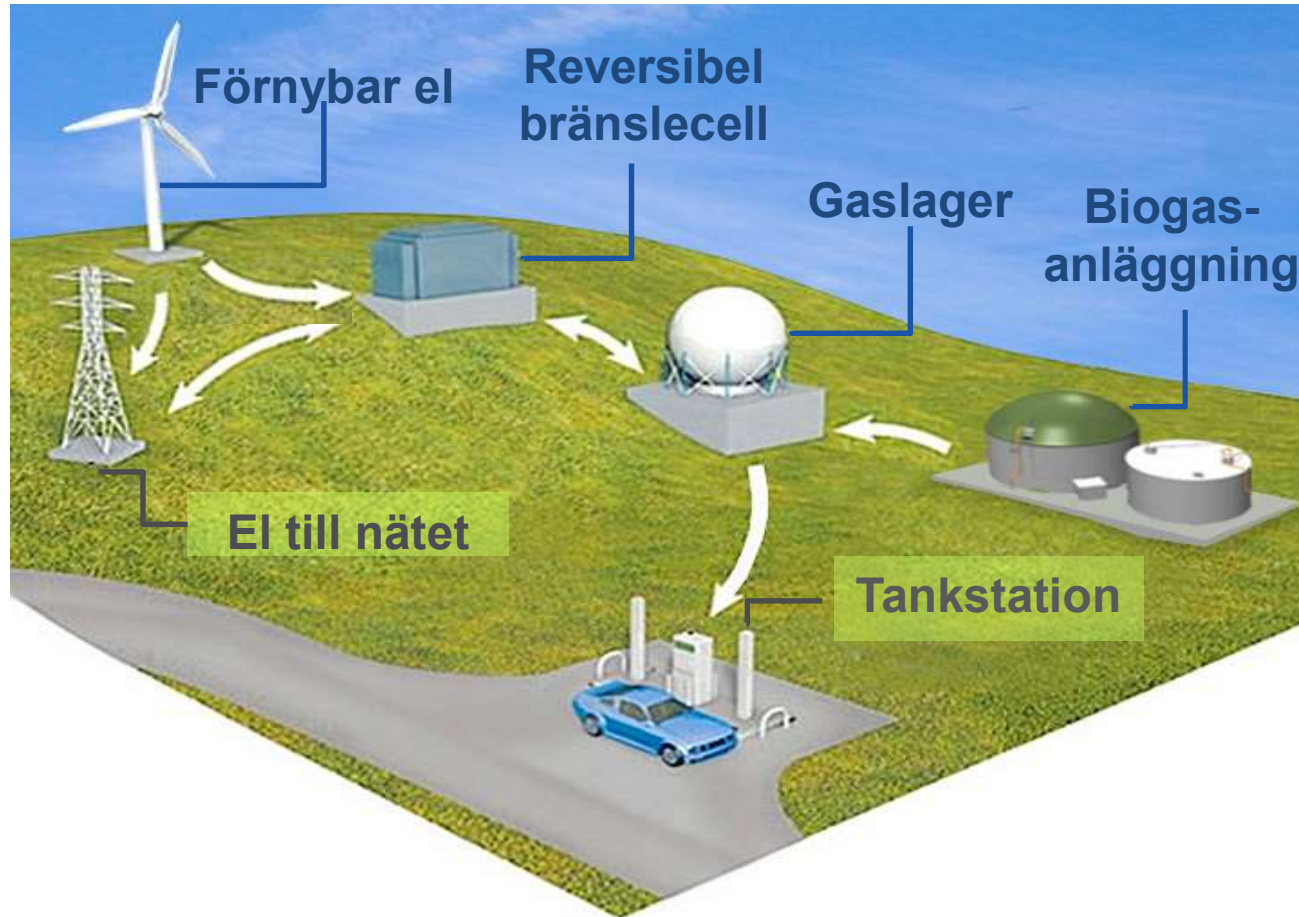


$E = 1,2 \text{ V}$

# Vätgas kan tillverkas på många sätt



# Bränsleceller för energisystemet







# Bränslecellsfordon (FCEV)

## ex) 2015 Toyota Mirai Fuel Cell Sedan

### Räckvidd:

Omkring 500 km

### Bränslecellen (370):

Vikt: 56 kg

Effekt: 114 kW (153 hp)

Effekttäthet: 3.1 kW/L

### Batteri:

1.6 kWh Nickel-metallhydrid

### Vätgastank (70 MPa):

Energitäthet: 5.7 wt%

### Marknad:

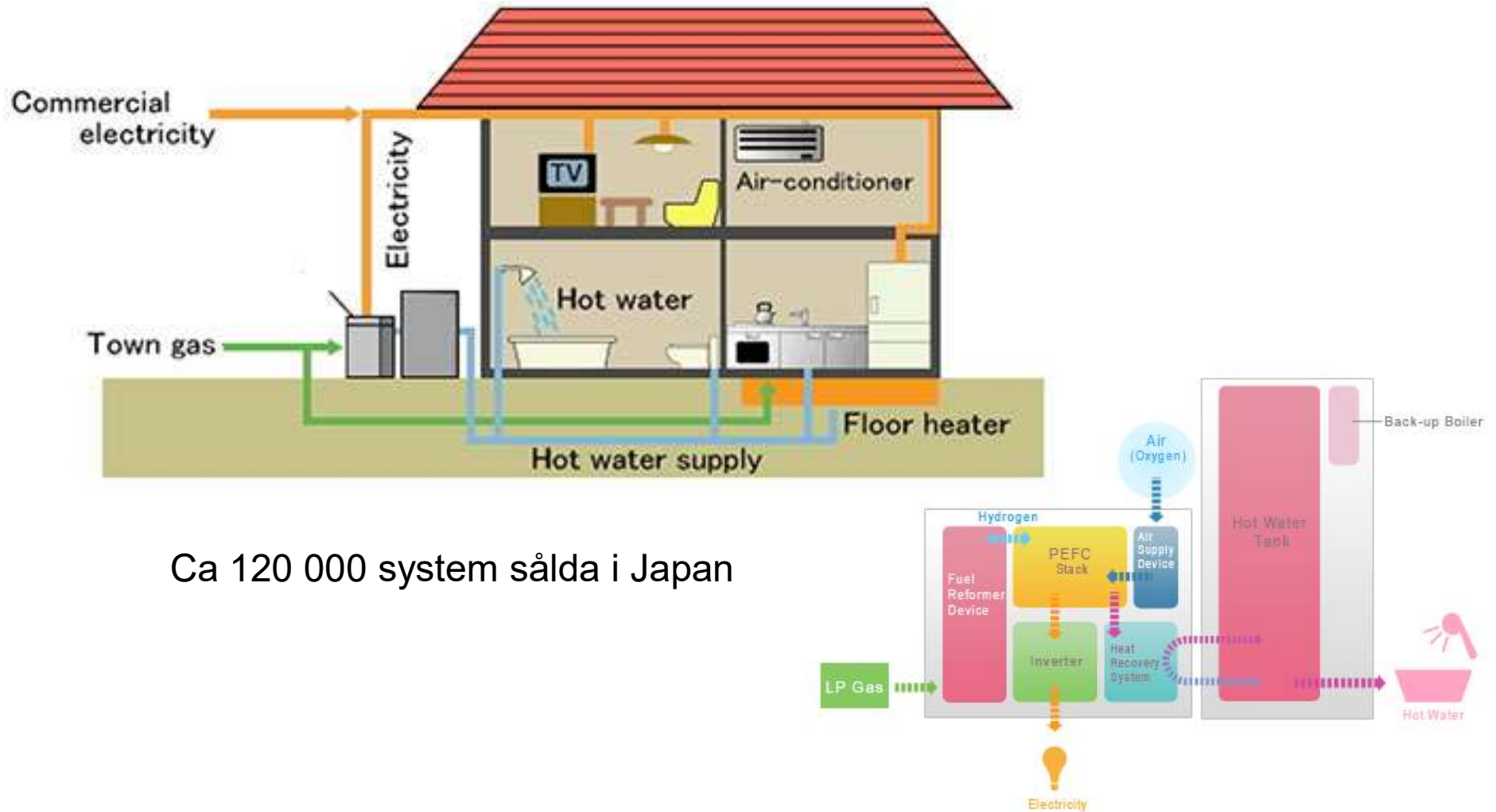
Mer än 5000 bilar i USA och Japan.





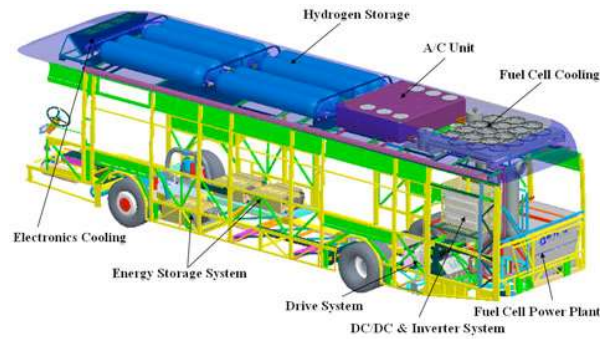
# El och värme i byggnader

## Ex) Ene-farm Japan

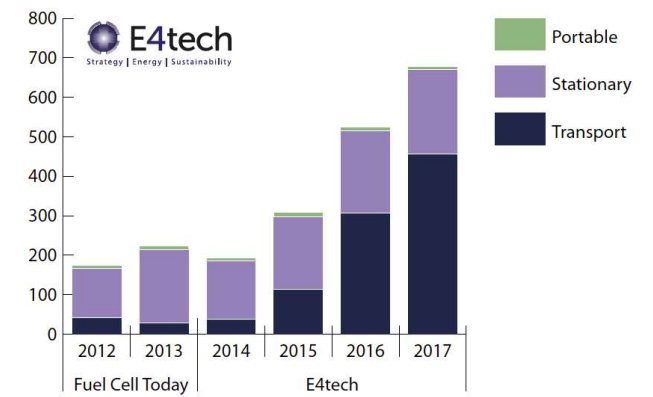




# ...och andra tillämpningar...



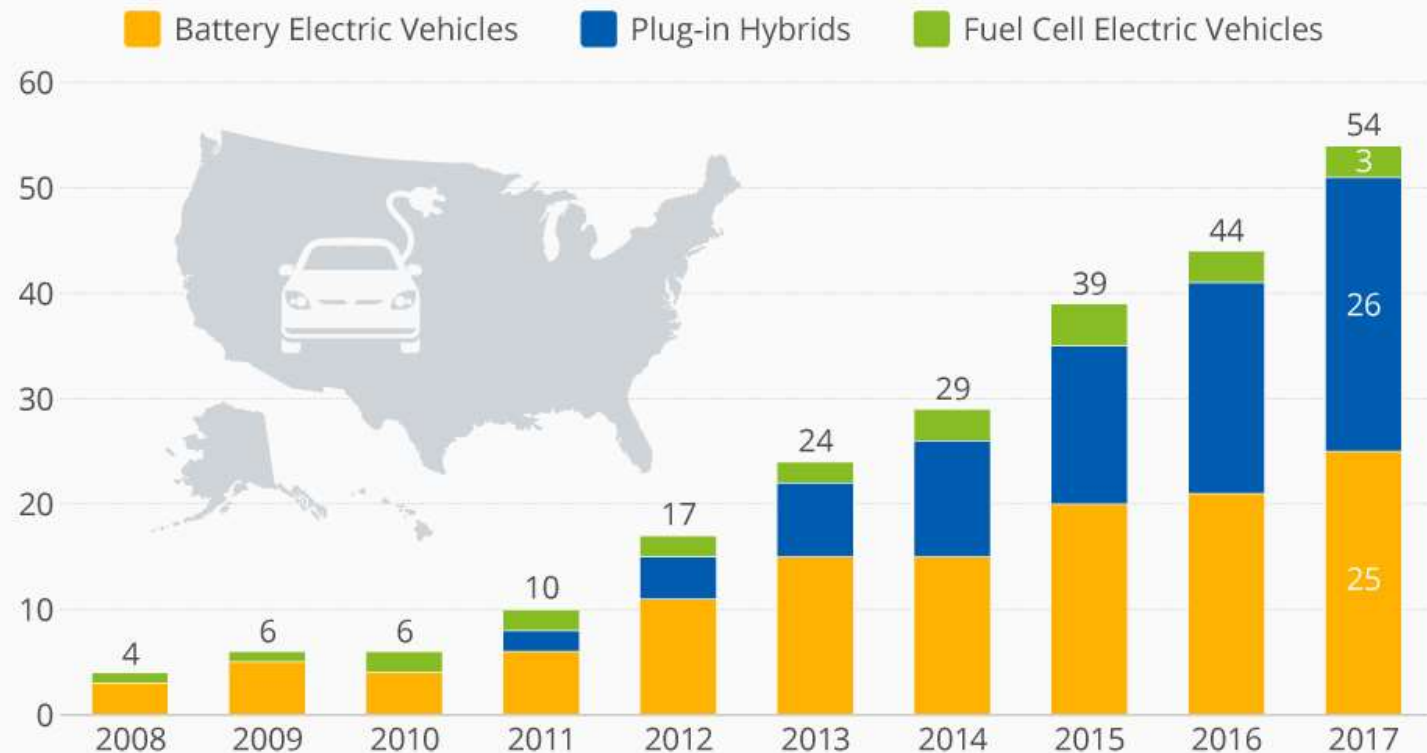
Megawatts by application 2012 - 2017



# Tillgängliga fordonsmodeller i USA

## Electric Vehicle Buyers Have the Agony of Choice

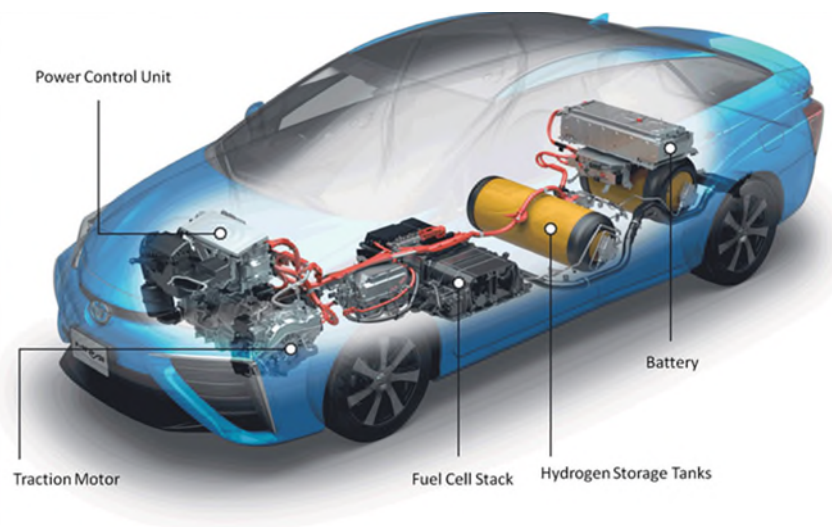
Number of electric vehicle models available to consumers in North America\*





# Skillnad på drivlinans vikt och volym

Bränslecellsbil (FCEV)



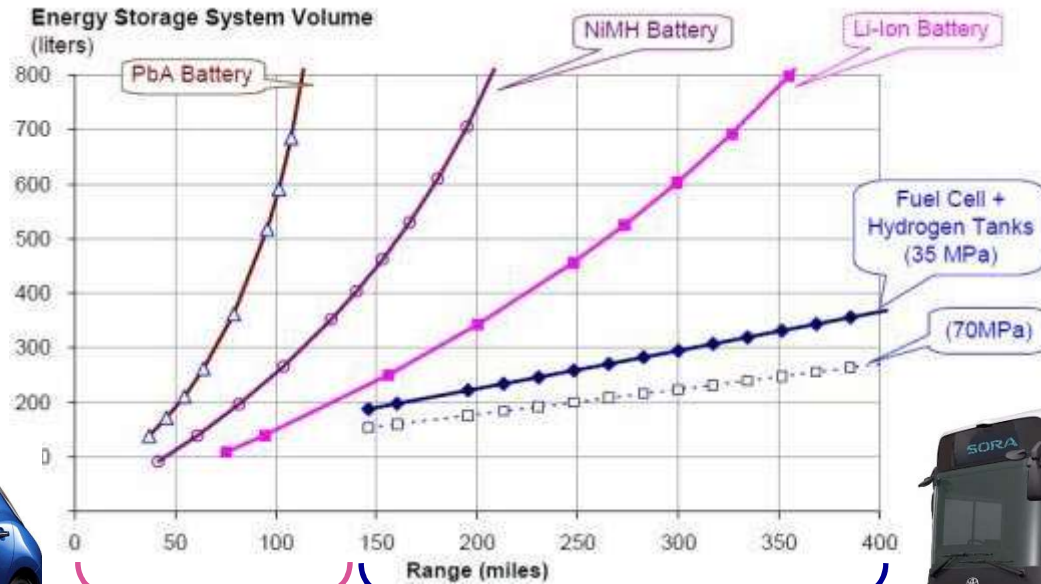
Mer energi → större vätgastankar  
eller högre tryck

Elbil (BEV)



Mer energi → fler och större batterier

# Vilket system ska man välja?

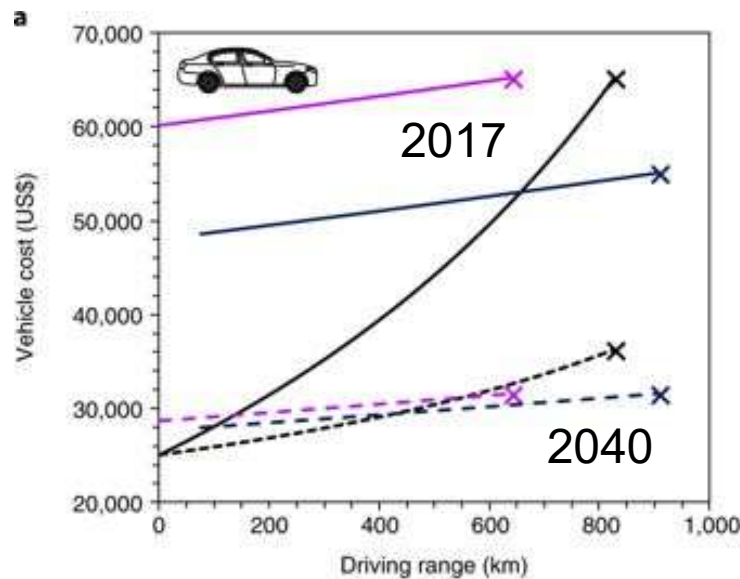


Korta sträckor  
Lätta fordon

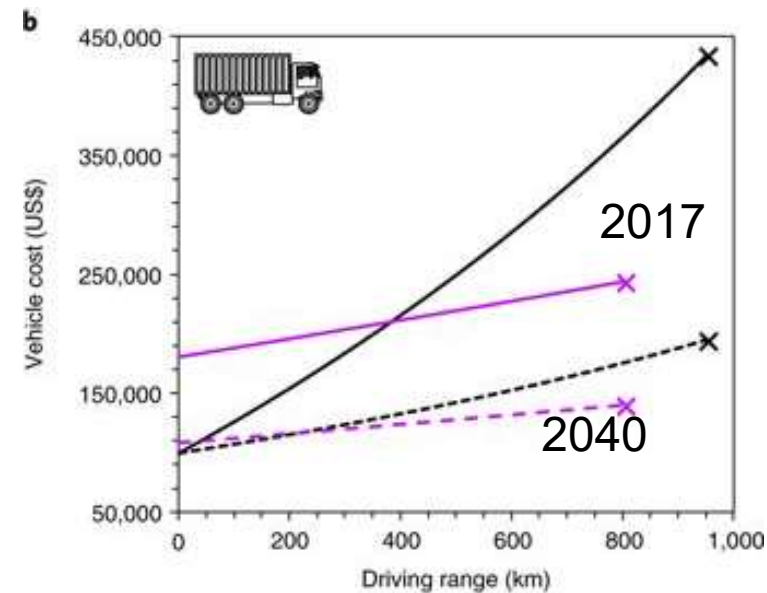
Långa sträckor  
Tunga fordon



# Kostnadsjämförelse: Li-jon (BEV) och bränslecellsbil (FCEV)



- Li-ion BEV (2017)
- - - Li-ion BEV (2040, projected costs)
- Conventional FCEV (2017)
- - - Conventional FCEV (2040, projected costs)
- Plug-in hybrid FCEV (2017)
- - - Plug-in hybrid FCEV (2040, projected costs)



- Li-ion BEV (2017)
- - - Li-ion BEV (2040, projected costs)
- Conventional FCEV (2017)
- - - Conventional FCEV (2040, projected costs)

# Utmaningar för forskningen



Resurser/Kostnad



Livslängd



Hållbarhet

**Nya material** → förstå funktionen under drift  
→ bättre, billigare, mer hållbara/miljövänliga

**Cellens design** → förstå begränsningar och förluster  
→ öka effektivitet och användning

**Cellens drift** → förstå åldring/försämringar → öka livslängden



# Tack för uppmärksamheten!





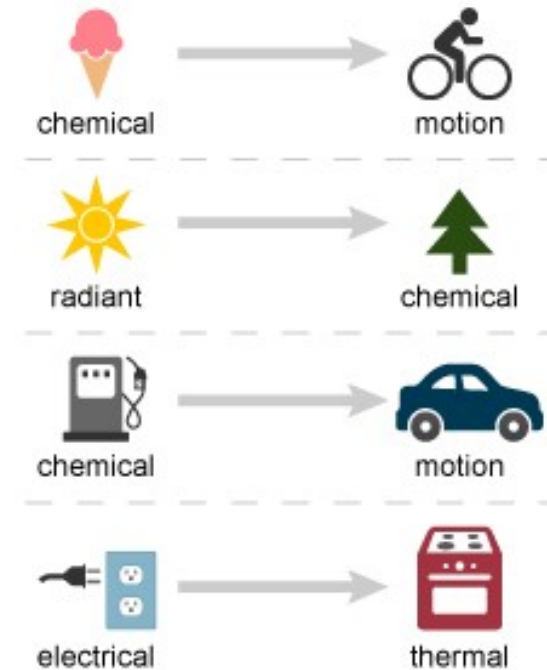


# Energien är inte obegränsad

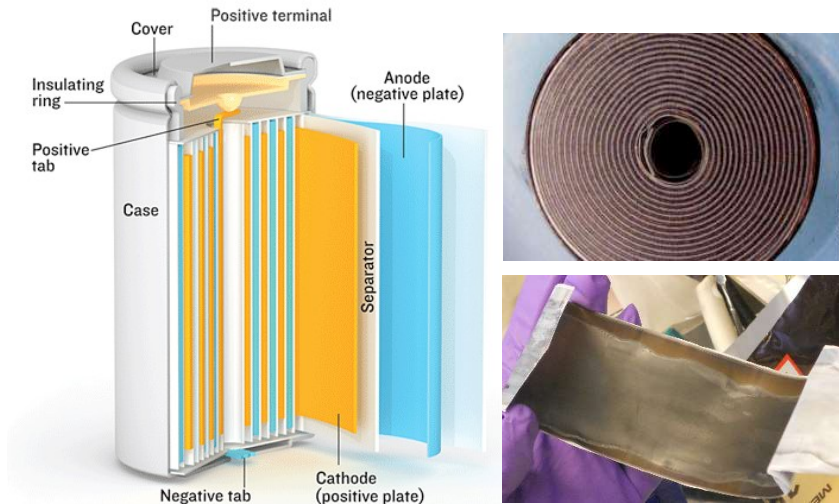
*Termodynamikens första huvudsats:*

**Energi kan varken skapas eller förstöras, den kan endast byta form.**

Ju högre energivärde i ett batteri,  
ju mer energi åtgår att tillverka det.



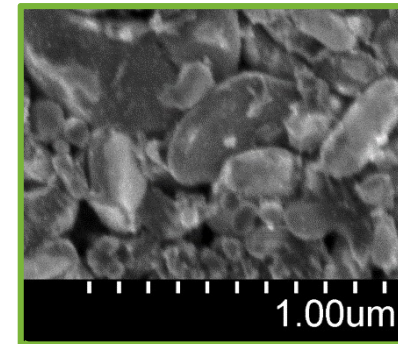
# Li-jonbatteriet inuti



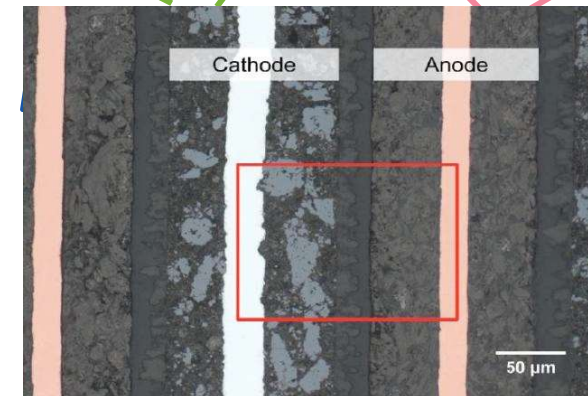
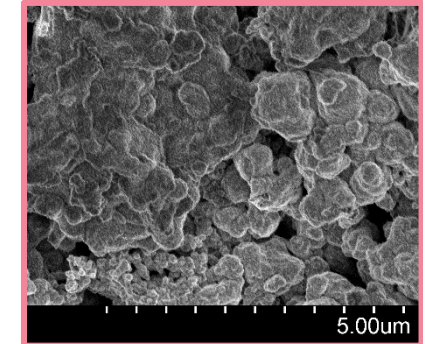
Effekten (W) och Energin (Wh) ges av:

- Typen aktivt material
- Mängden aktivt material
- Temperaturen
- Li-jonens tröghet genom elektrolyt och de fasta materialen

Katod:  
Mineralpartiklar

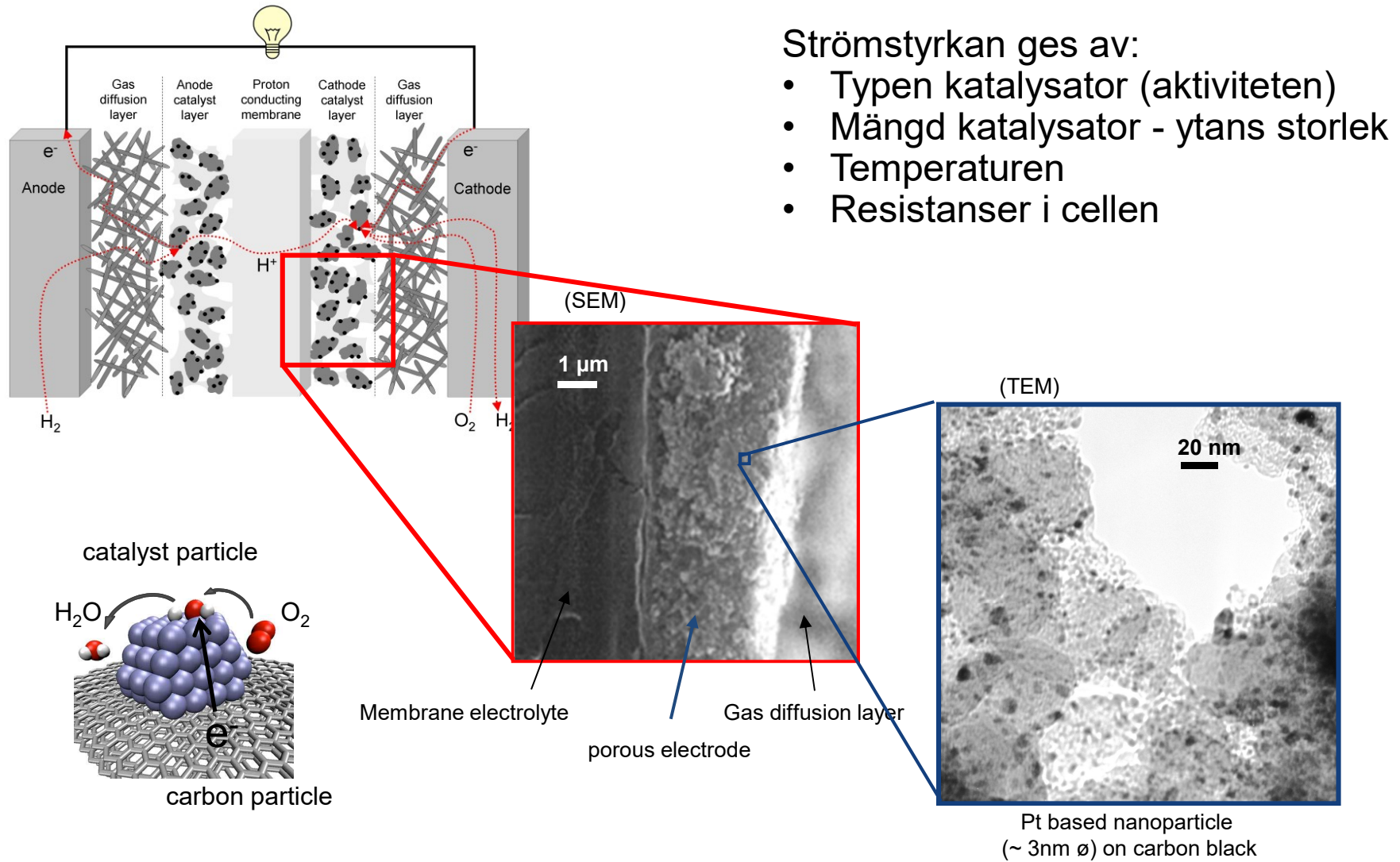


Anod:  
Kolpartiklar



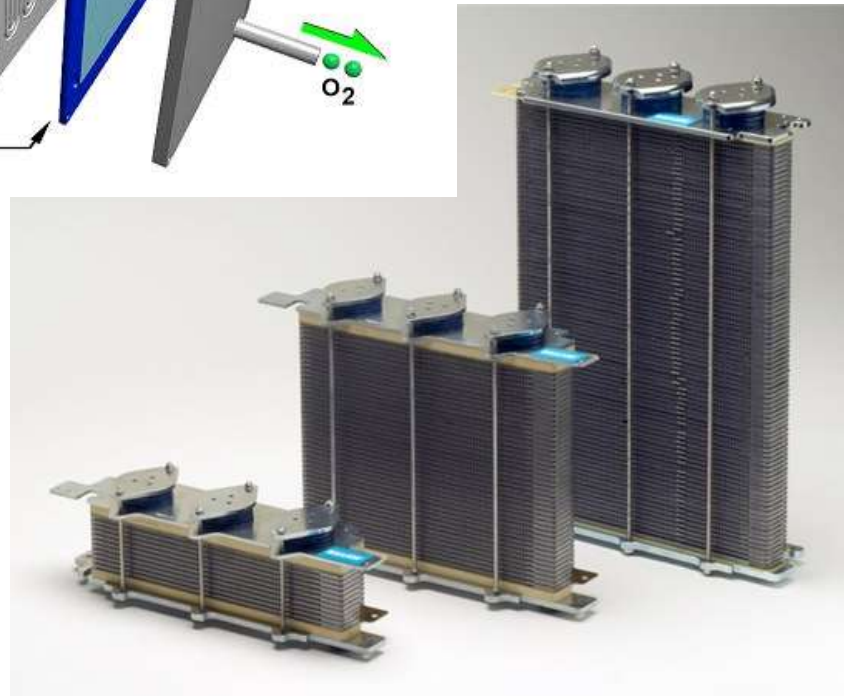
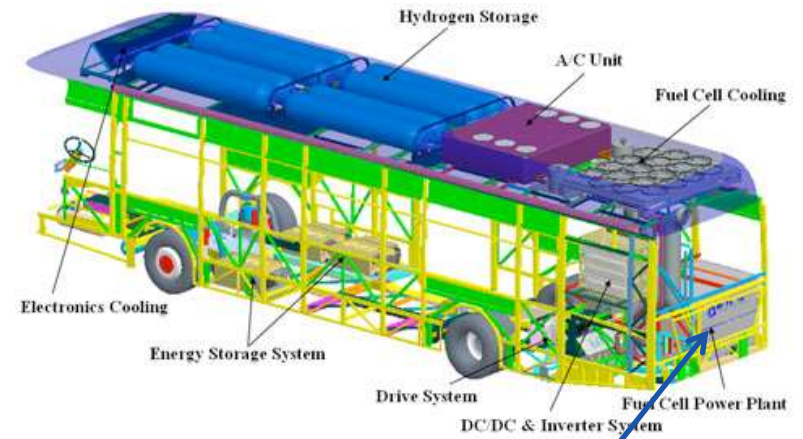
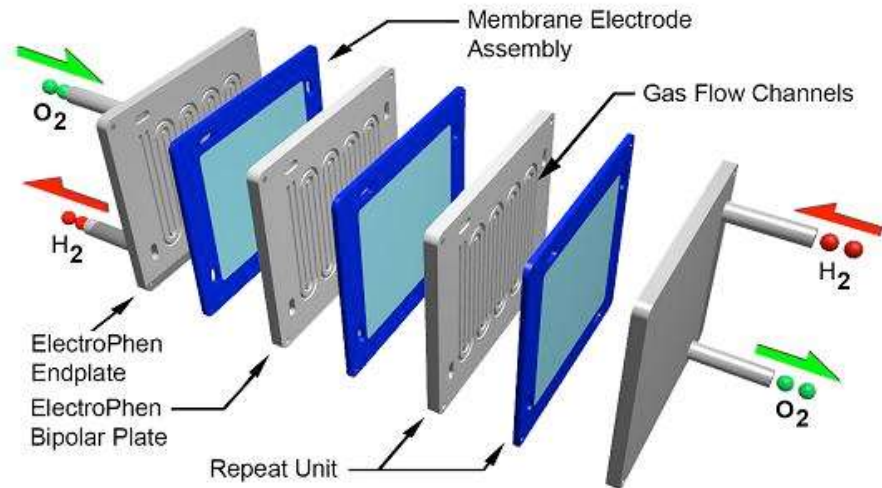
Aluminium      Poröst filter med elektrolyt      Koppar

# Bränslecellen inuti





# Flera celler kan staplas



150 kW för buss





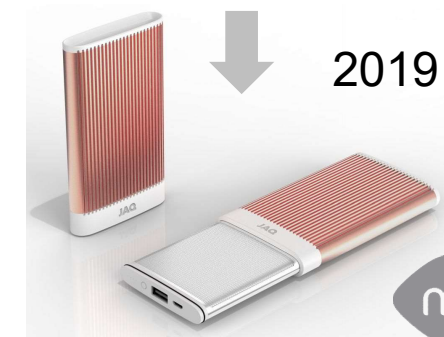
# Utvecklingen har gått från små bärbara bränsleceller...



2012



2016



2019

myFC®  
Instant Green Energy





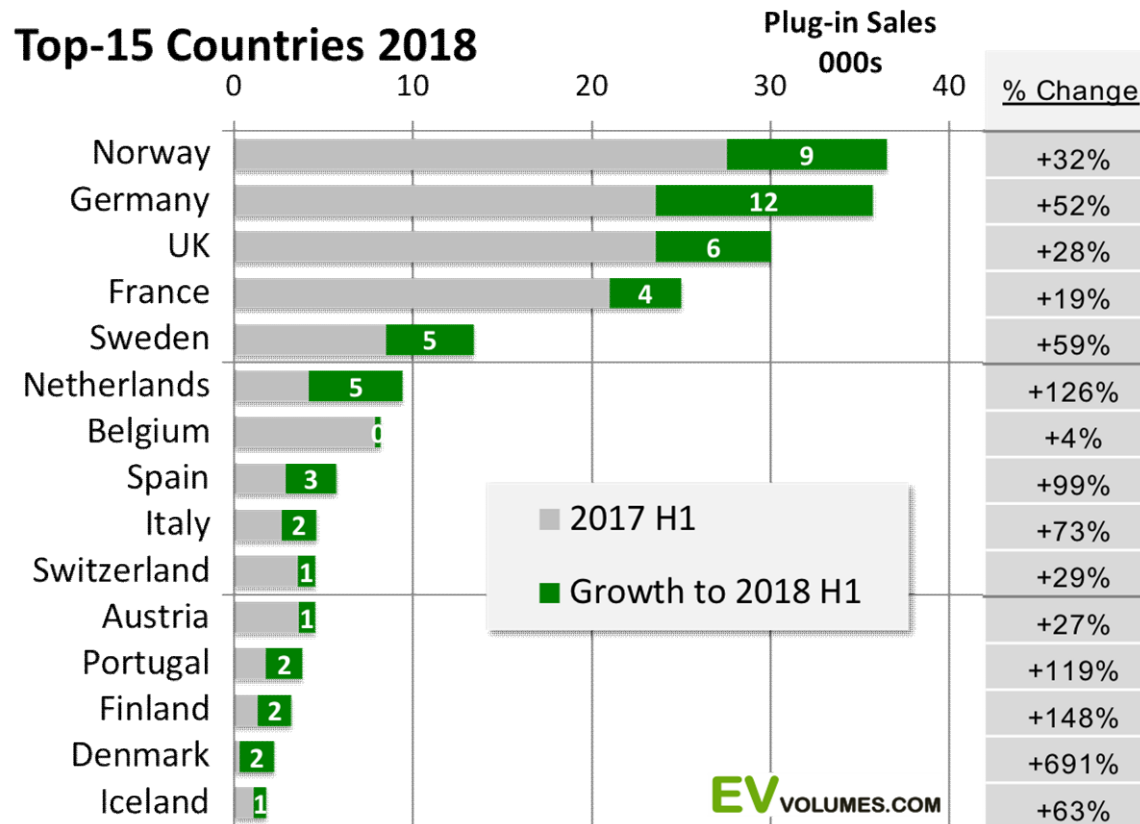
# Välkommen till KTH och kemiteknik!

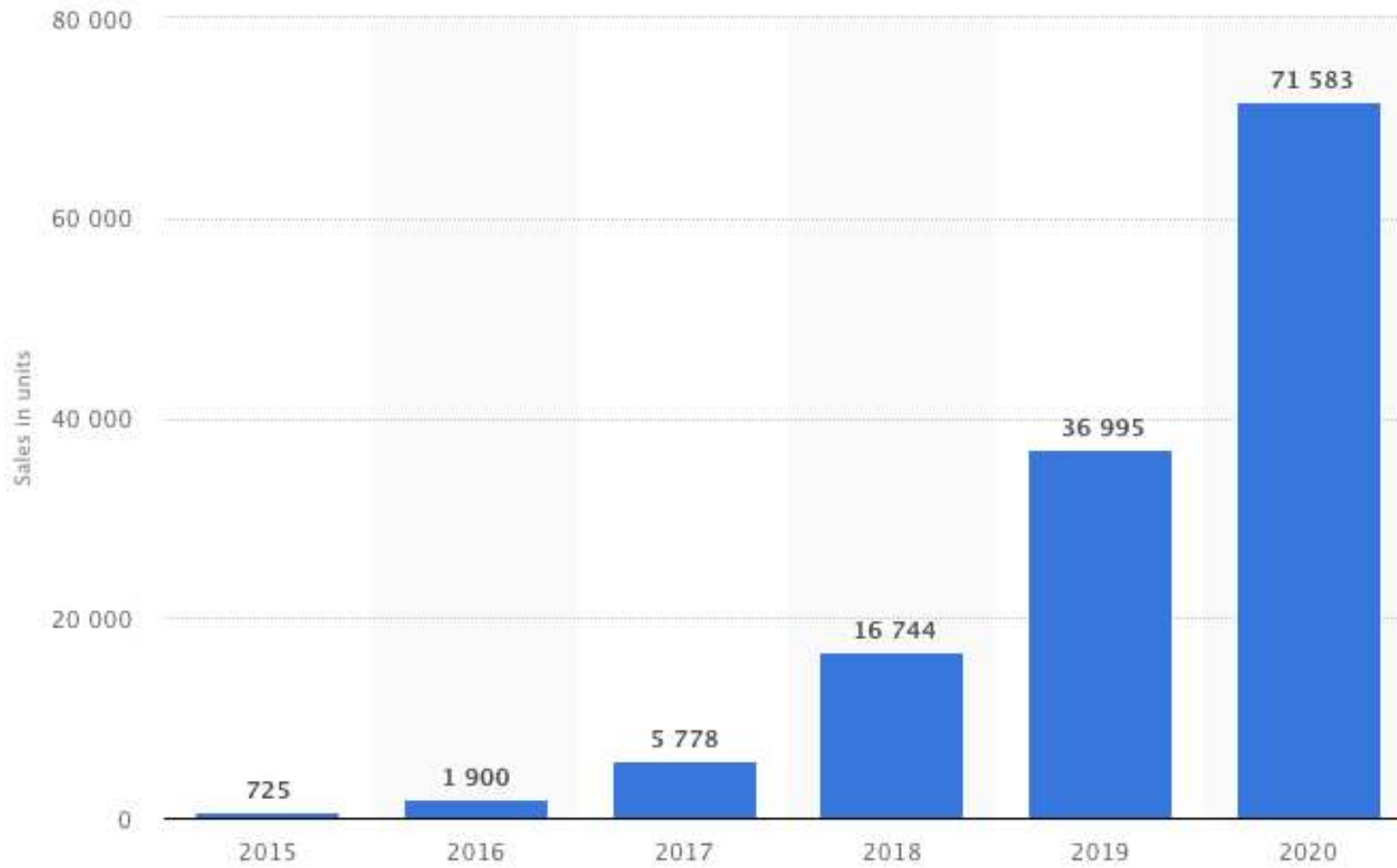
## Team Sleipner – KTH Transport Labs





# Elbilsförsäljningen i Europa

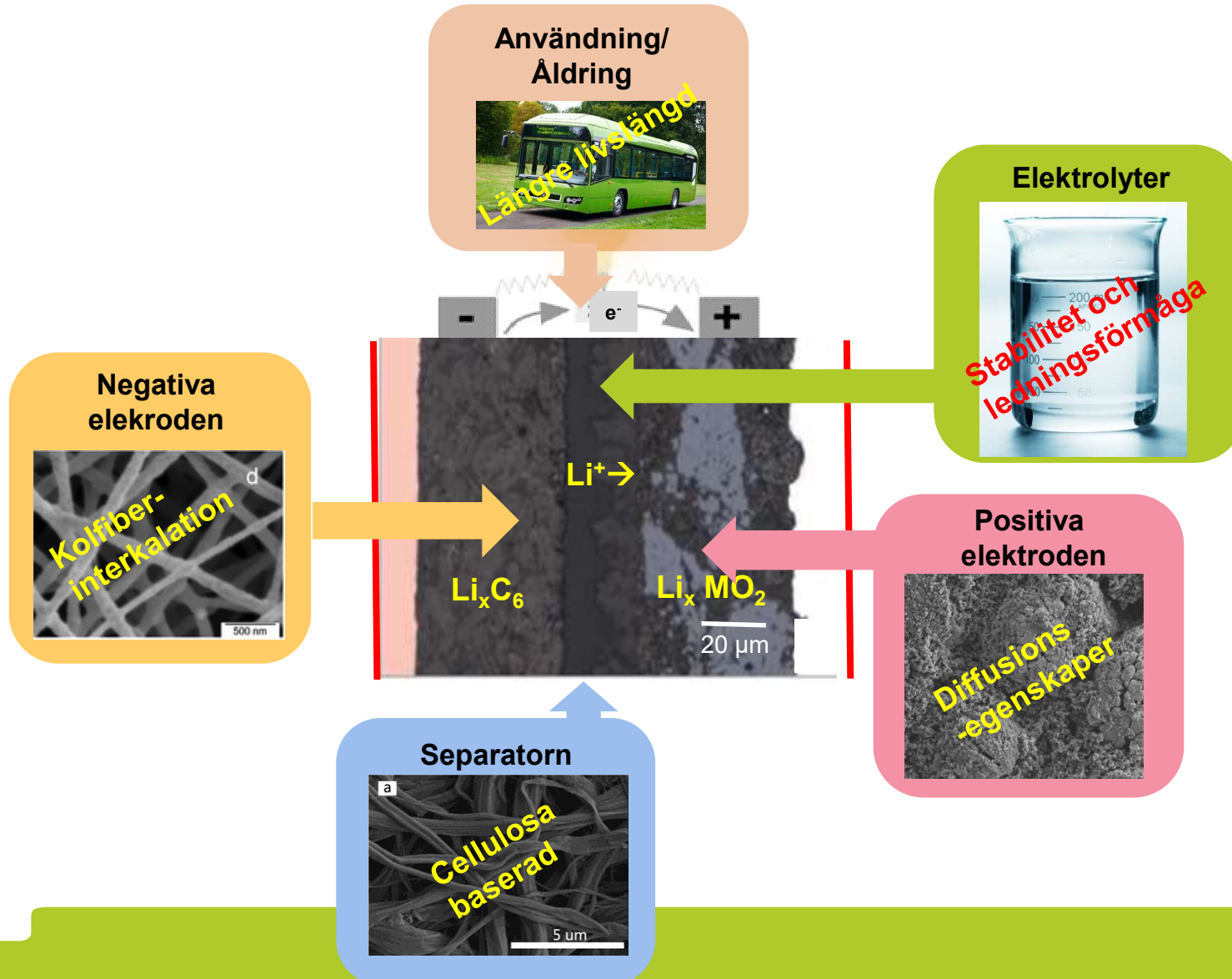






# Forskning batteri Kemiteknik KTH

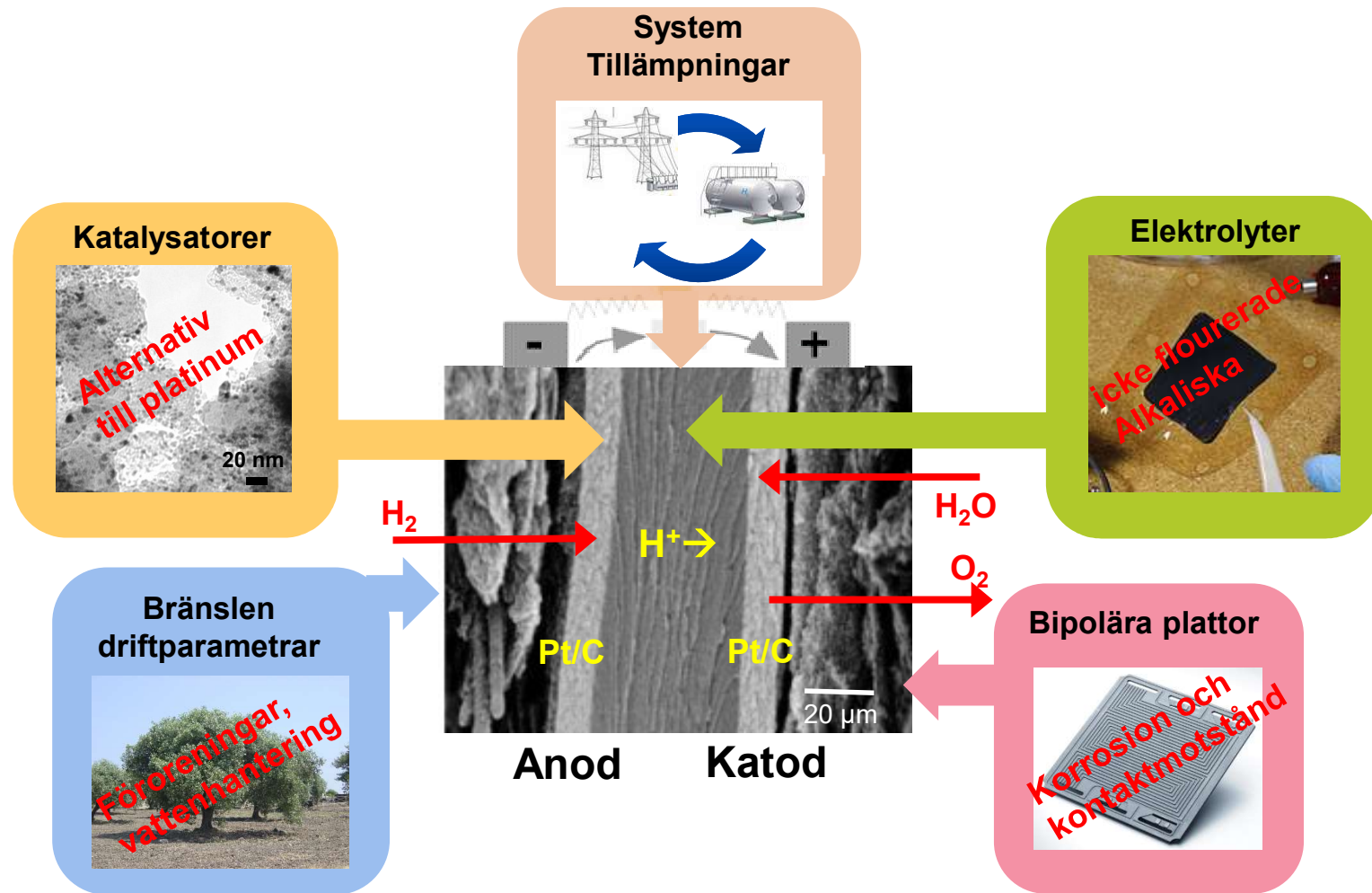
## Elektrokemisk karakterisering och modellering





# Forskning bränsleceller Kemiteknik KTH

## Elektrokemisk karakterisering och modellering

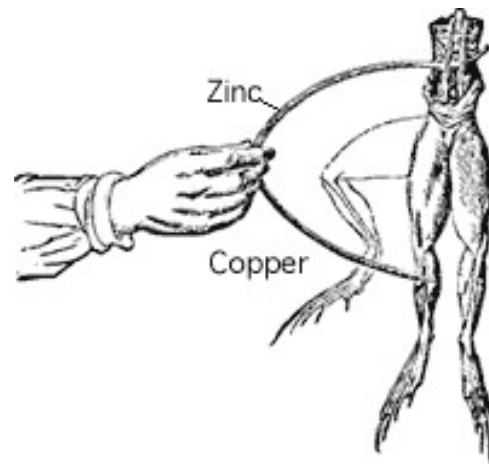




# Galvani upptäckte elektrokemin



Luigi Galvani  
(1737-1798)



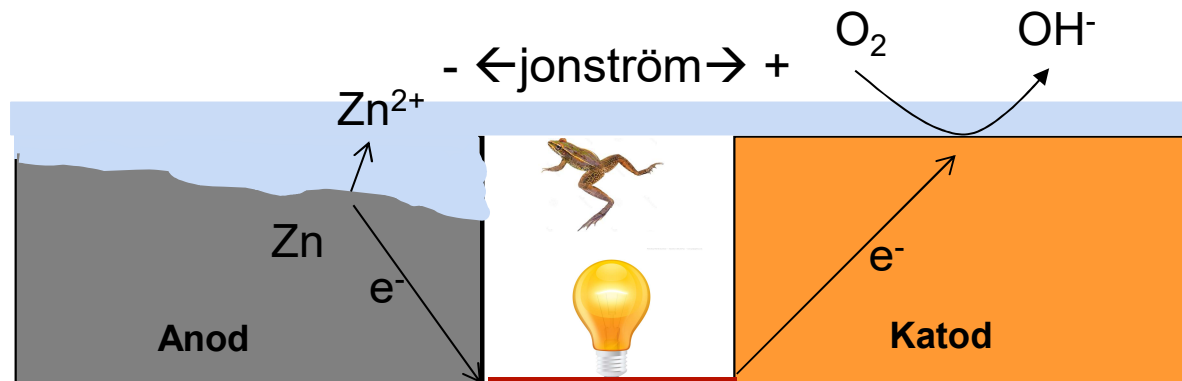
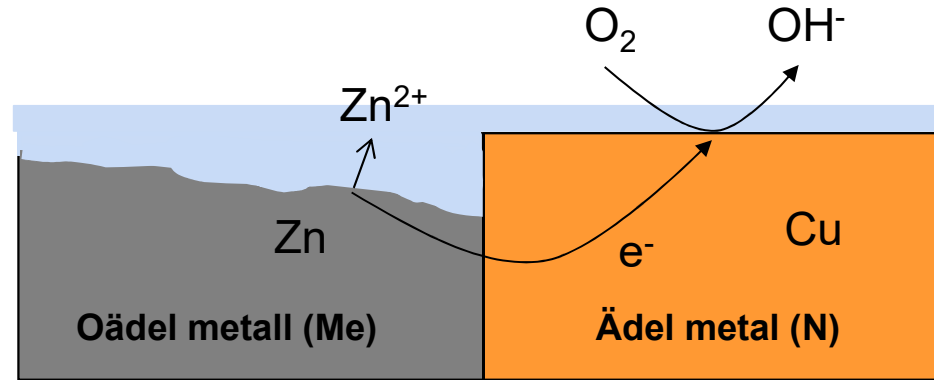
Galvanis sprattlande groda 1762

Energiomvandling:

Kemisk → Elektrisk → Mekanisk



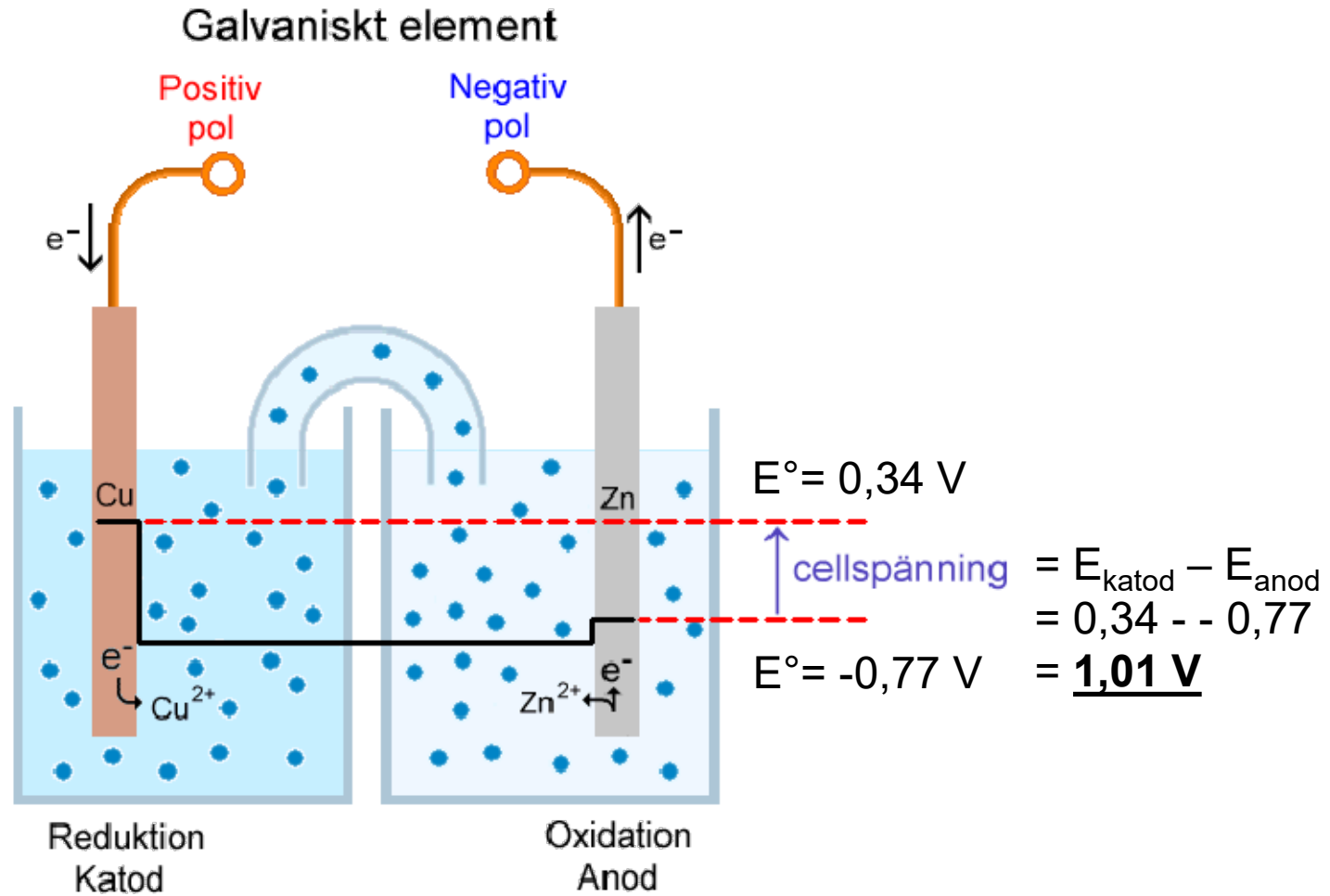
# En spontan reaktion - Galvaniska cell



elektroner  $\rightarrow$   
 $\leftarrow$  elektrisk ström



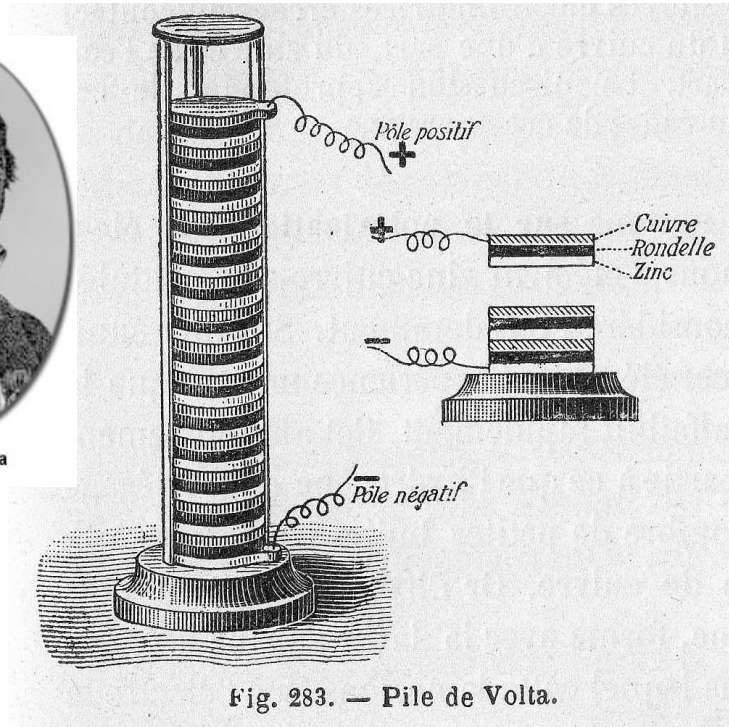
# Zn/Cu- batteriet



# Utvecklandet av första batteriet



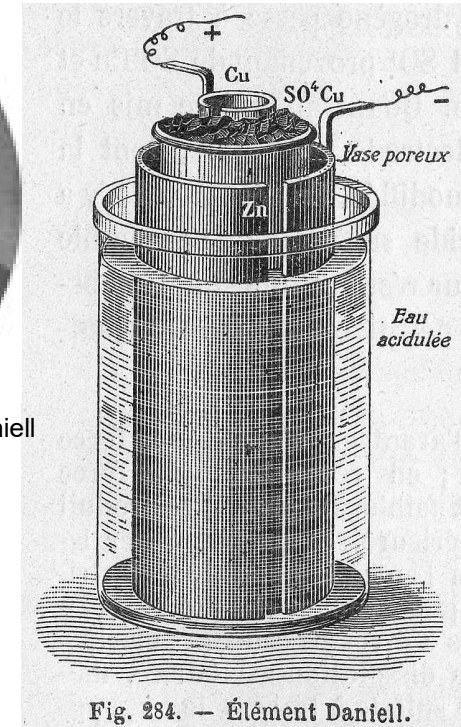
Alessandro Volta  
(1745-1827)



Volta med sin Cu/Zn stapel 1798



John Frederic Daniell  
(1790-1845)

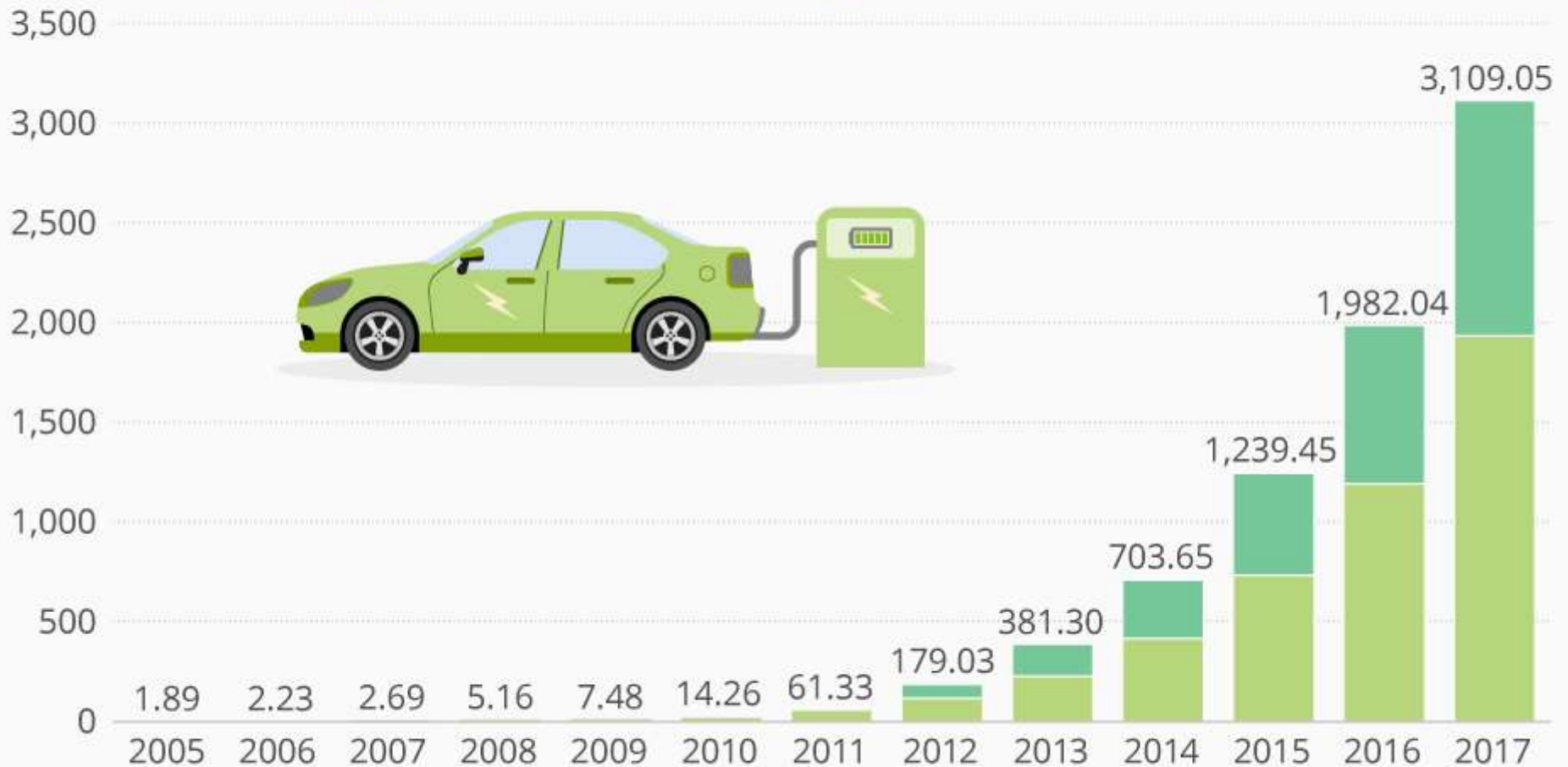


Daniell med sitt Cu/Zn batteri 1836

# Electric Car Stock Ramping Up at a Fast Pace

Global electric vehicle stock by year and engine type (in 1,000)

Battery electric vehicle Plug-in hybrid vehicle



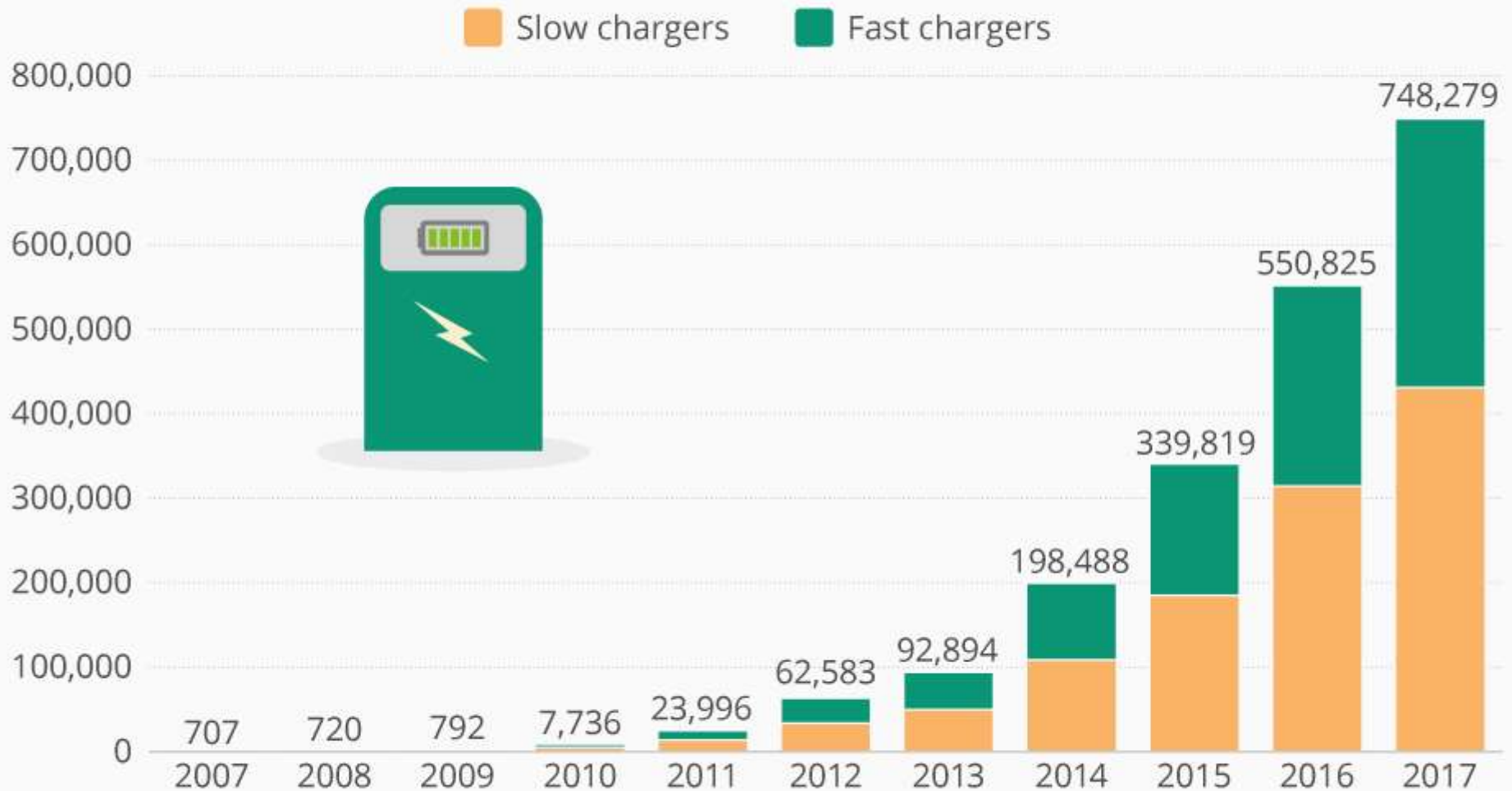
@StatistaCharts Source: IEA

statista



# E-Car Charging Infrastructure Becoming Mainstream

Global publicly accessible electric vehicle chargers by type



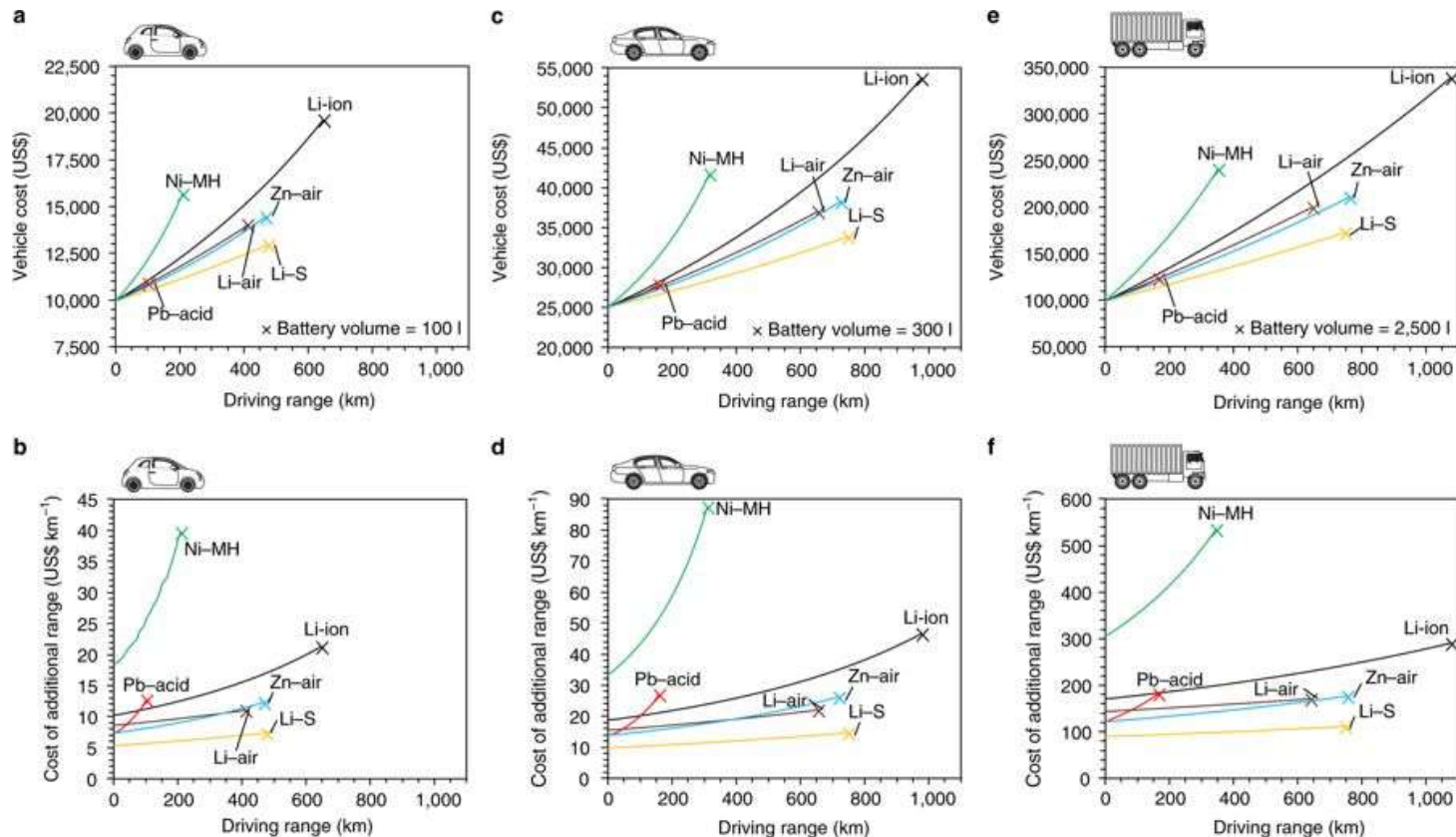
@StatistaCharts Source: IEA

# Jämförelse olika batterikoncept

10,000 \$, 650 kg,  
0.0985 Wh km<sup>-1</sup> kg<sup>-1</sup>

25,000 \$, 1,500 kg,  
0.0777 Wh km<sup>-1</sup> kg<sup>-1</sup>

100,000 \$, 24,000 kg,  
0.0445 Wh km<sup>-1</sup> kg<sup>-1</sup>



Z. P. Cano, D. Banham, S. Ye, A. Hintennach, J. Lu, Mi. Fowler & Z. Chen "Batteries and fuel cells for emerging electric vehicle markets" Nature Energy 3, 279–289 (2018)