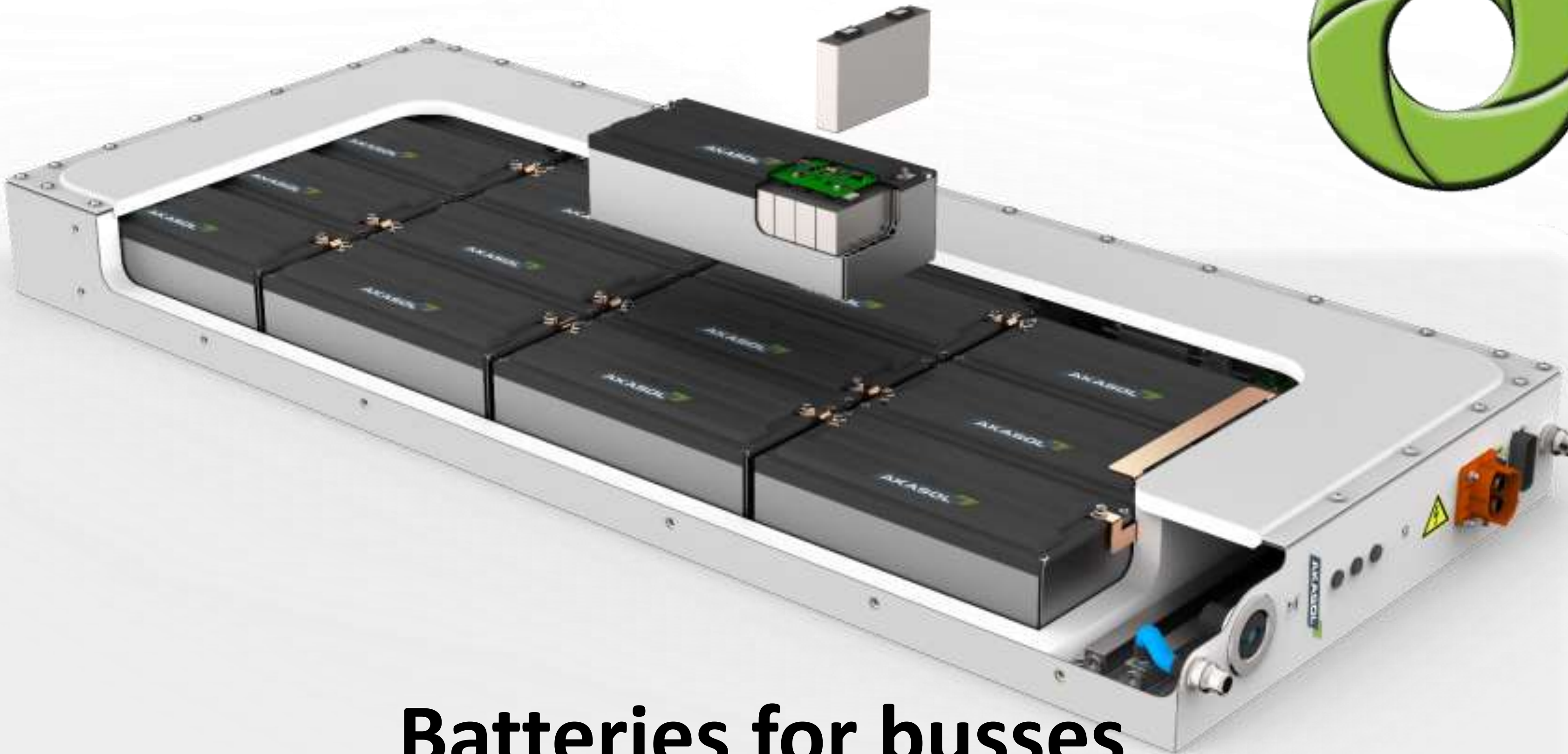


Batteries for busses

Technology, market and emissions

Egil Mollestad, dr. ing.

CEO, ZEM as

Background from the EV industry
Supply battery systems and electrical drivelines to maritime sector

Draft / Confidential

3500 electrical EVs

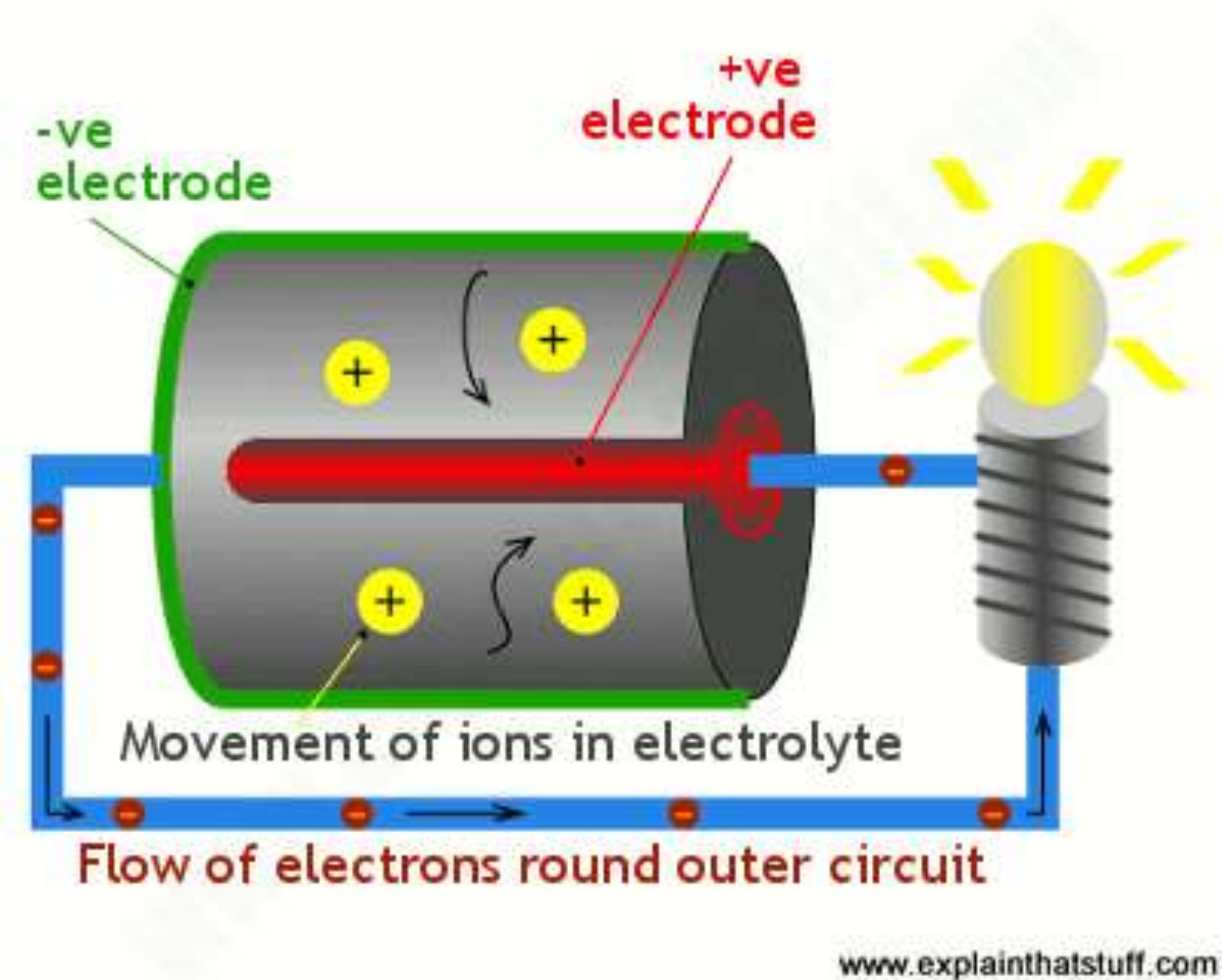
Supply skips

Work boats

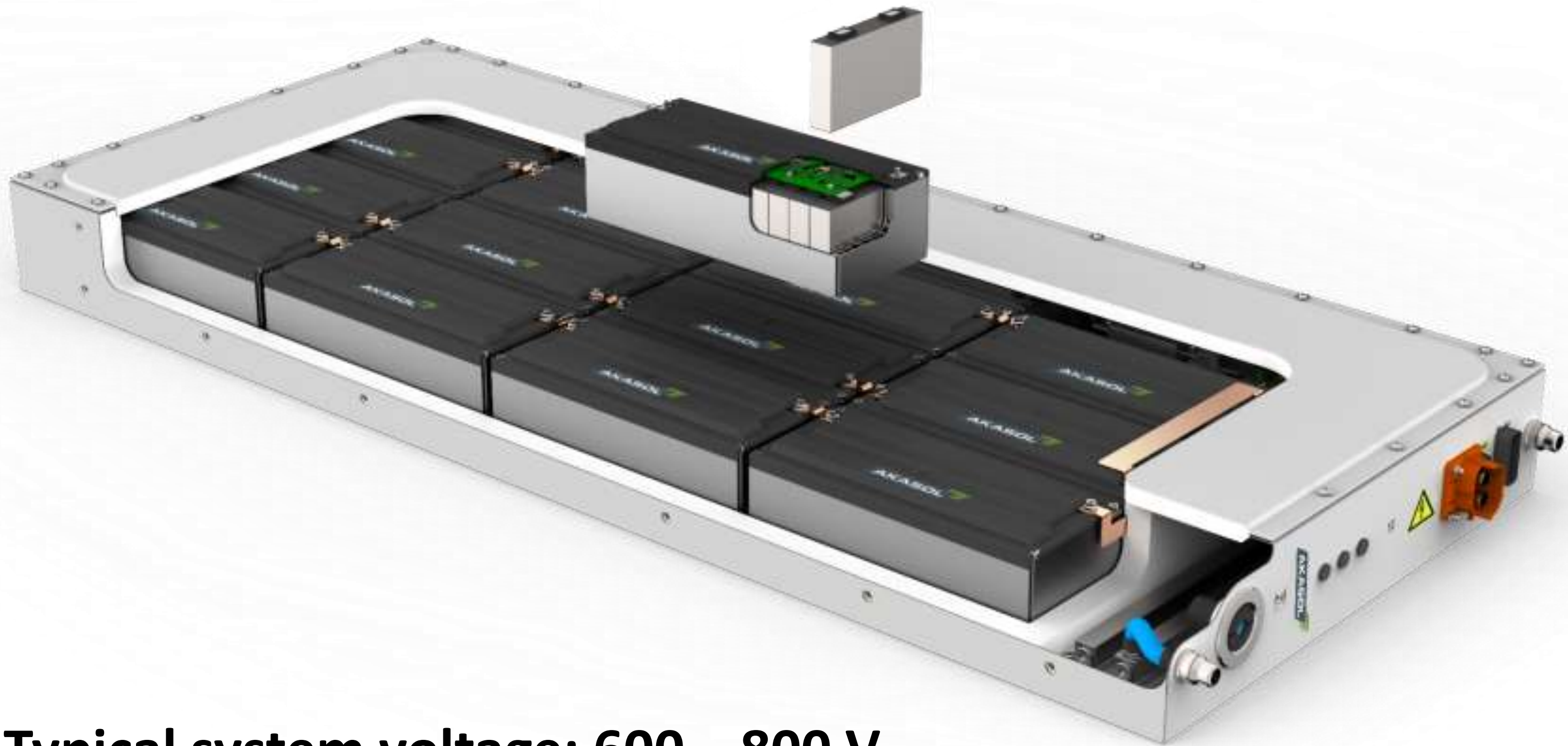
Ferries/ tourist boats

Free fall Life boats

Principle of a battery cell

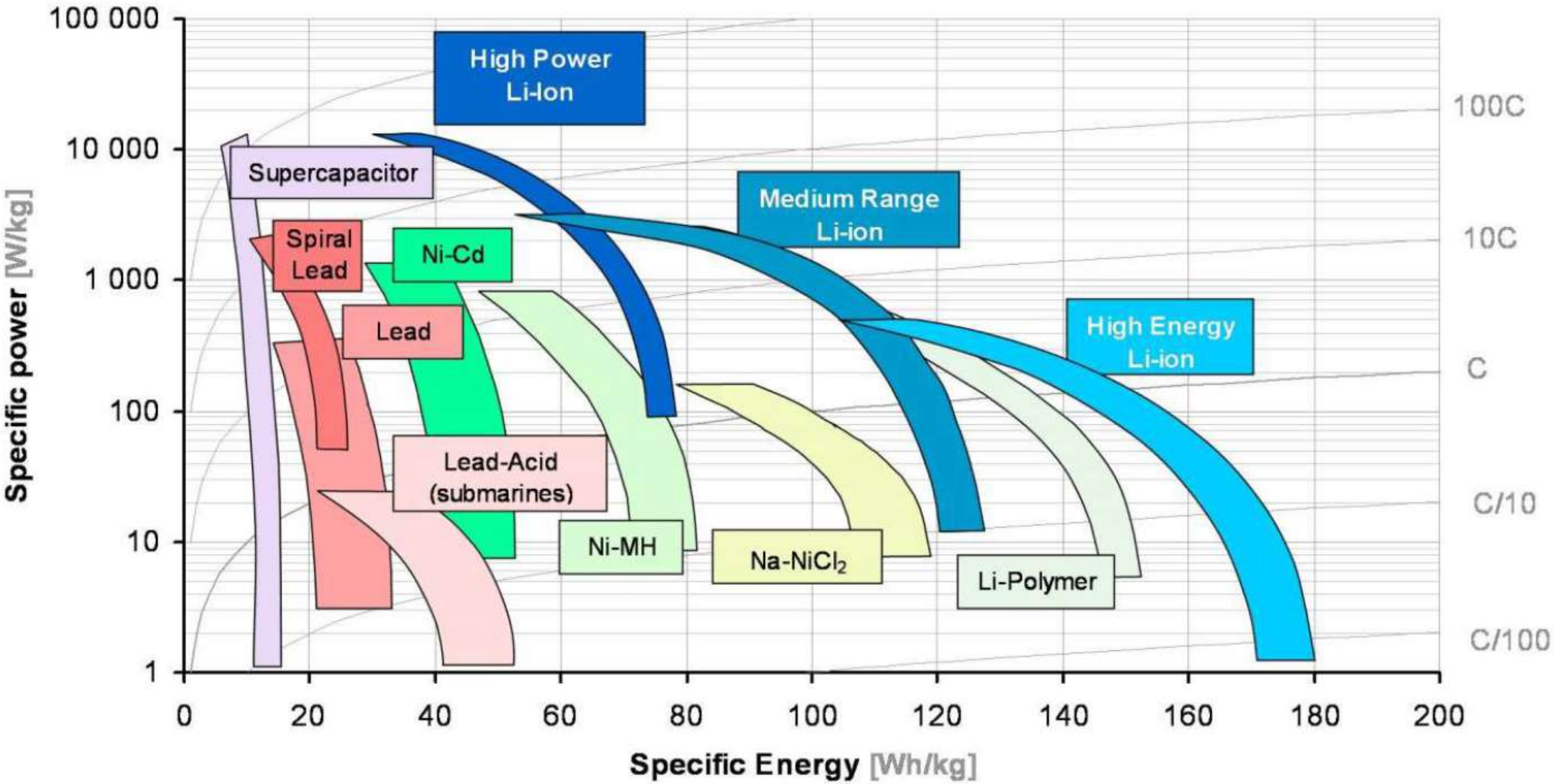


How is a bus battery built?



Typical system voltage: 600 – 800 V

New battery technology has made battery powered busses a real alternative



Main battery chemistries for electric and hybrid busses

Lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$) - NMC

Energy cell (battery powered busses)

Power cell (hybrid busses)

Main advantages:

- High energy density
- Good power density
- Good cycle life
- Reasonable cost

Volvo electric bus with NMC battery

Main suppliers:

- LG Chem
- Samsung
- And many others

Most used chemistry for EVs and busses

Lithium Iron Phosphate ($LiFePO_4$) - LFP

Main benefits

- Good safety
- Good power density
- Good cycle life
- Relatively cheap
- Do not contain cobalt

BYD bus with LFP batteries

LFP is the battery chemistry used by the Chinese bus manufacturers (several hundred thousand electrical busses in China)

Lithium Titanate (Li_2Ti0_3) - LTO

Main benefits

- Very good power density
- Very long cycle life
- Safe

Main disadvantage

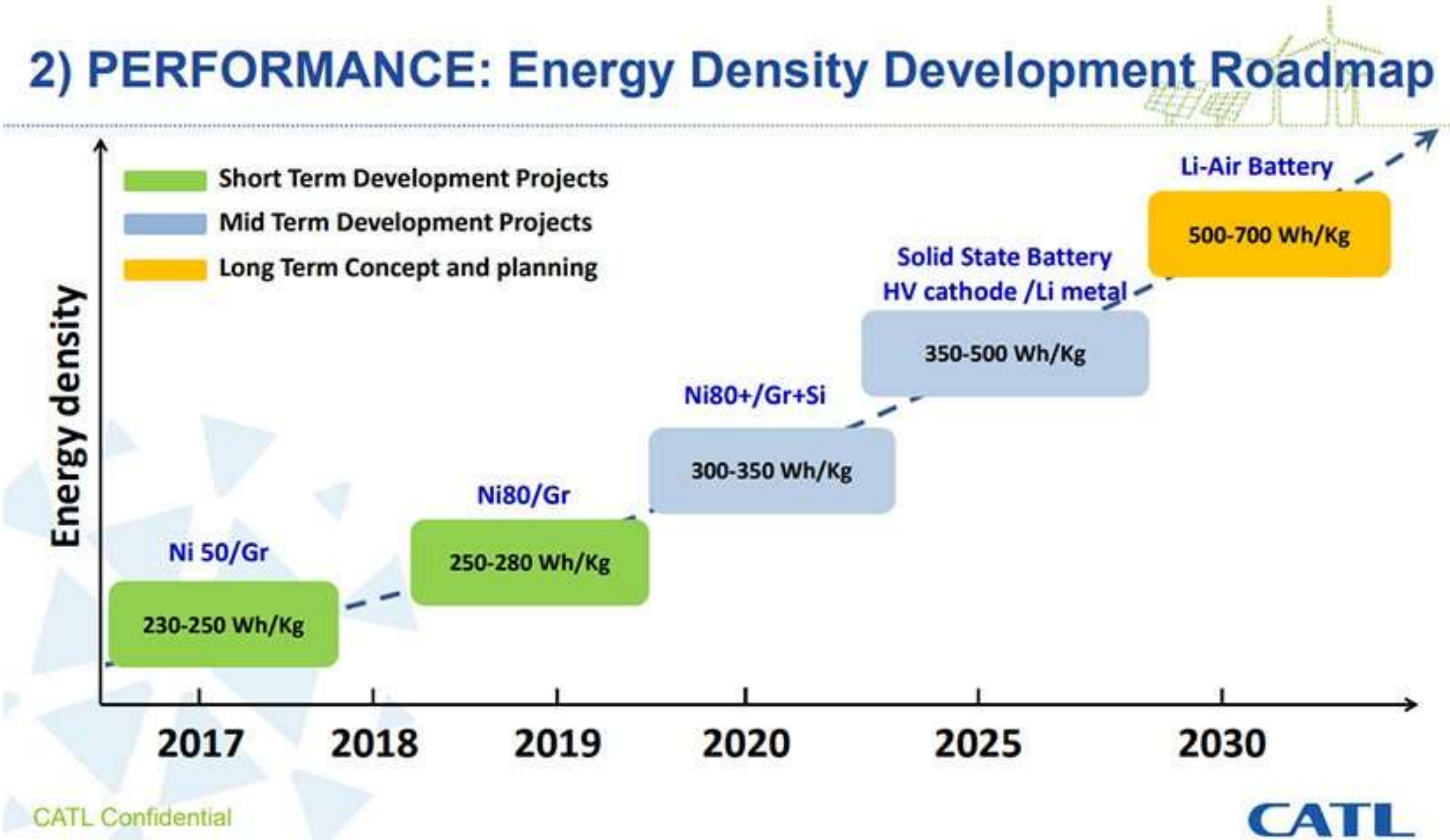
– Low energy density
– Expensive

Van Hool hybrid bus with LTO battery

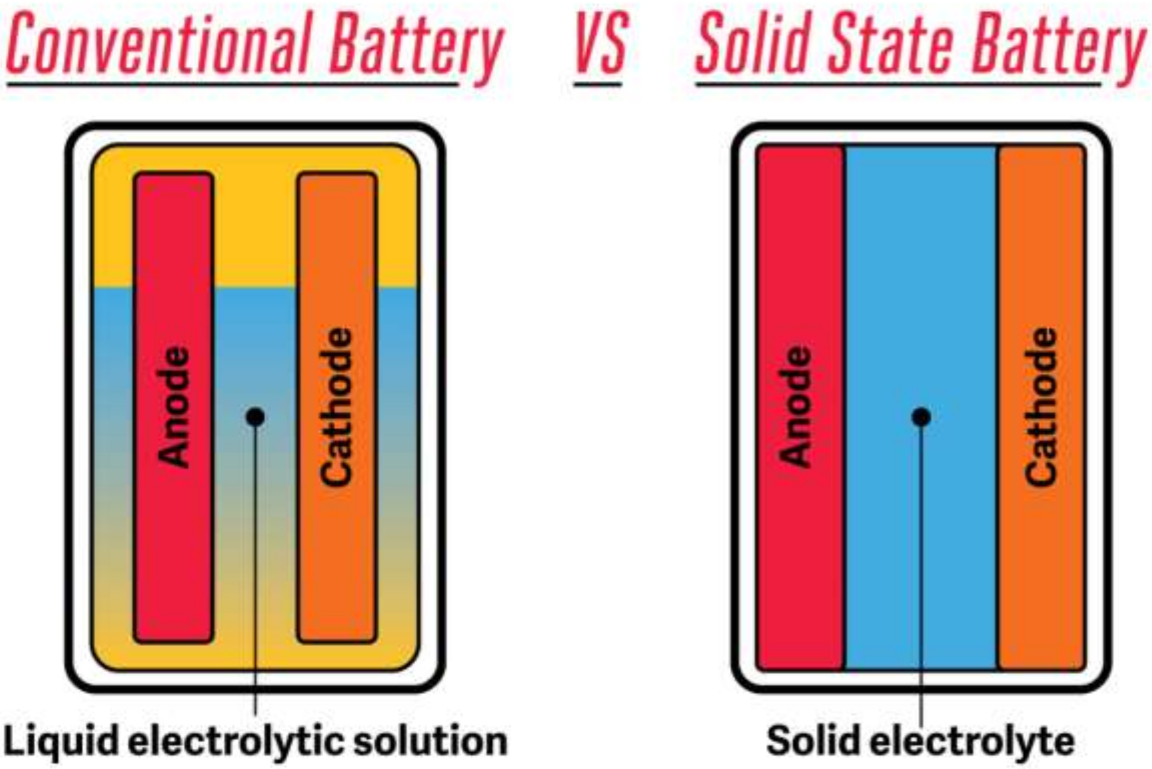
Good system for hybrid applications, if very fast charging is required, and very long cycle life

Cell price is 2 – 3 times of NMC

What can we expect for the future?



What differs solid state batteries from conventional batteries?



Is raw materials and supply of batteries an issue?

- Cobalt is expensive and limited
- Most of the cobalt comes from Congo
- Some of the mines have questionable ethical standards
- Lithium could be an issue, lithium can be replaced by other materials
- However – good cobalt free alternatives (iron phosphate)

Efficient recycling schemes will be very important!

Demand is growing faster than the supply!

Battery cell market is dominated by Asian suppliers, but strong initiatives in Europe

Illustration of the Nothvolt giga-factory in Sweden (under construction)

Freyr is planning a giga-factory in Mo i Rana

How good are electrical busses for the environment?

Assumed driving profile and diesel consumption:
3 l per 10 km, 360 km per day, 108 l diesel per day

CO_2 emissions: 3.1* kg x 108 l = 330 kg/day

Battery powered bus:
200 kWh** batteries produced in Asia: 130 kg CO_2/kWh x 200 kWh = 26.000 kg CO_2

When is the environmental «cost» of the battery is zero compared to a diesel bus***:

26.000 kg CO_2/330 kg/day = 79 days

An electric city bus in Norway is climate positive after about 2 ½ months!
And take away the local emissions (SOx and particles)

* Combustion of 1 l diesel makes 3.1 kg CO_2
** Typical CO_2 emission from producing 1 kWh with an Asian energy mix is 130 kg/kWh
***Assumes that electricity powering the bus is emission free (Norwegian hydro power)

CO_2 calculation - EV

Assumptions:

- 60 kWh battery
- 15.000 km driving range per year
- Average consumption diesel car: 0.6 l/mil

Emissions from diesel car:

- 1.500*0.6*3.1 = 2.790 kg

CO2 emissions from battery production

- 130 kg/kWh x 60 kWh = 7.800 kg

Time for CO2 neutral*:

- 15.000 km/year: 2.8 year
- 20.000 km/year: 2.1 year
- 30.000 km/year: 1.4 year

*Assumed 100% renewable electricity not calculated any CO2 emissions from diesel production

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egil.mollestad@zemenergy.com

www.zemenergy.com