WHEN TRUST MATTERS

Development, Trends, Opportunities and Challenges for Battery Vessels

For HKUST workshop

About Myself

Thomas Lo

Senior Principal

Market Area Manager HK & Macau

Thomas has over 35 yrs of international experience in the Energy Sector. He graduated as a Chemical Engineer and worked in Refinery Operation. After joining DNV, he started doing Risk Management of Offshore Oil and Gas assets but soon became a Class surveyor for some 20 years. He is a senior member of the Chinese SNAME and represented DNV China to the committee of CSNAME. In recent years he has moved into the decarbonization sector involving LNG, Hydrogen Production, Offshore Wind, Battery Storage and Hydrogen Fuel Cell…etc.

He is DNV Energy Systems' Market Area Manager for HK & Macau. His notable involvement in Hong Kong include:

- The HK Offshore LNG Terminal
- The HK Offshore Windfarm
- Battery Energy Storage Systems
- Hydrogen fuel cell vehicles

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Agenda

- Why Batteries
- What is Happening to Batteries
  - Early development
  - Present Days
  - Future Trends
- How to go about moving into Batteries
  - Opportunities
  - Challenges

Why Batteries?

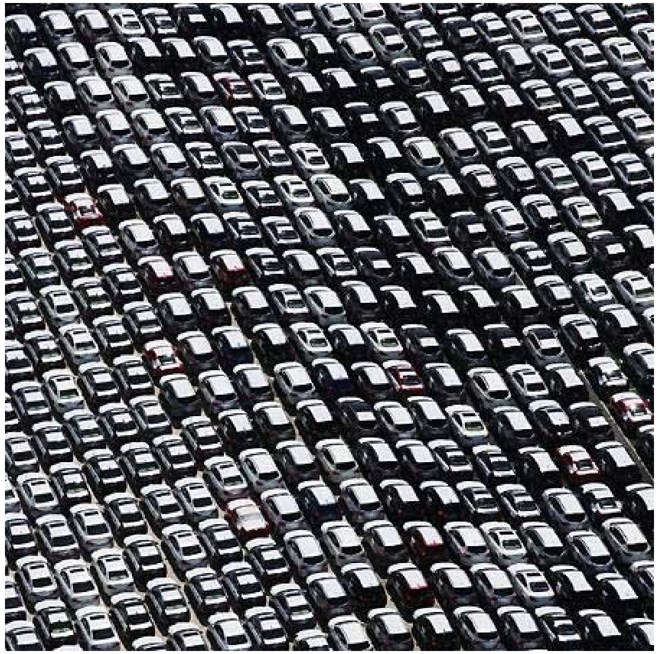
Ships provide large emissions and have large fuel costs

CO_2 ≈ 75,000
NO_x ≈ 2,000,000
PM ≈ 2,500,000

CO_2 ≈ 6,000
NO_x ≈ 70,000
PM ≈ 100,000

CO_2 ≈ 400
NO_x ≈ 7,000
PM ≈ 12,000

CO_2 emission from one big containership ≈ 75,000 cars



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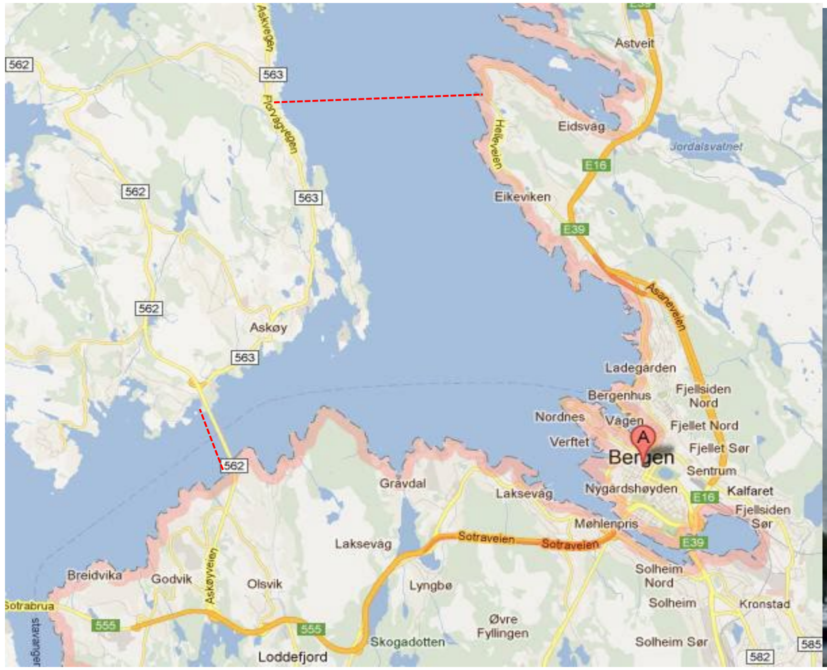
Reduce local emissions

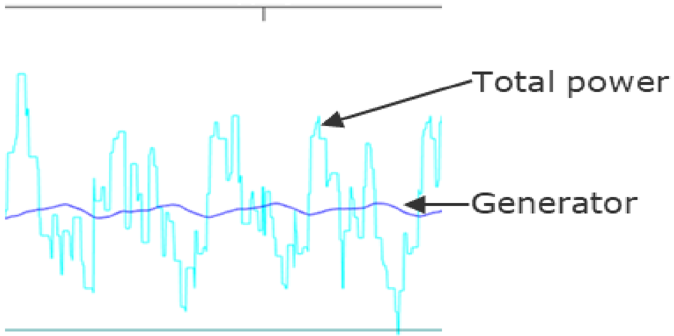


Batteries can eliminate or significantly reduce emissions in emission sensitive areas

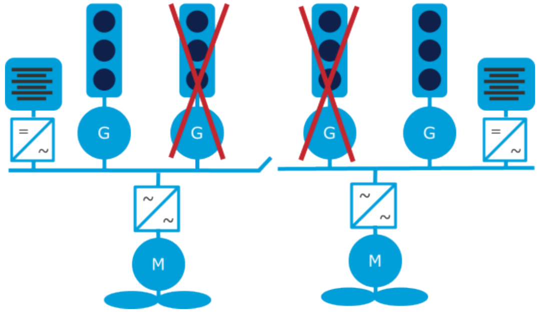
When are batteries useful?

IF → Enables → Fuel savings

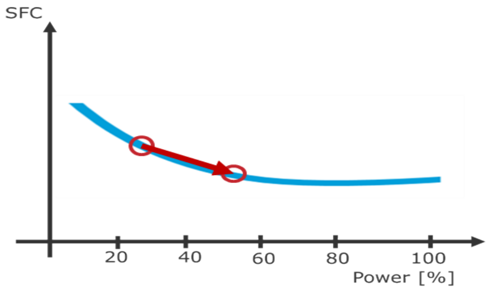
Peak shaving/load levelling



Reducing running engines



Improve machinery efficiency



- Peak shaving alone do not have significant effect.

Need to identify operational modes with:

1. **Low average engine loads**
2. **High load variations**

- Other operational factors like closed bus, prioritized load reduction/shedding strategy will improve battery benefit

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What is Happening – Early Development

In 2013 DNV led a Roundtable conference, declaration of collaboration and start up

The Green Coastal Shipping Program will be realized by the industry and government working together in a long-term partnership program

Maritime battery systems – What is happening?

- Eidesvik: Viking Lady, hybrid supply vessel, retrofit in Norway 2013
- Østensjø: Edda Ferd, hybrid supply vessel, construction Astilleros in Spain 2013
- Østensjø: large hybrid offshore construction vessel, construction Kleven in Norway 2016
- Fafnir Offshore: hybrid supply vessel, construction Havyard Ship Technology's yard in Leirvik, Norway.
- Island Offshore LNG KS: Island Crusader, construction STX OSV Brevik
- Eidesvik: Viking Queen , hybrid supply vessel, retrofit in Norway 2015
- SVITZER: 4 battery hybrid tugboats, construction of ASL Marine in Singapore
- KOTUG: RT Adriaan, hybrid tugboat in Rotterdam, retrofit 2012
- Foss: Carolyn Dorothy hybrid tug of LA, buildings Foss' Rainier Shipyard in USA, 2009
- Foss: Campbell Foss hybrid tug of LA, retrofit Foss' Rainier Shipyard in USA, 2012
- NORLED: Finnøy, hybrid ferry, retrofit 2013 in Norway
- NORLED: Folgefonn, hybrid/pure battery ferry 2014 in Norway
- Fjord1: Fannefjord LNG, hybrid hybrid ferry, retrofit
- Scottish Government: Hybrid ferry in Scotland, construction of Ferguson in Glasgow
- Scandlines: 4 battery hybrid ferries, retrofit 2013
- University of Victoria: Tsekola II, hybrid research vessel, retrofit in Canada
- NORLED: 100 % battery ferry, new building Fjellstrand in Norway 2015



Maritime batteries – What is happening?

- Electrification with Li-ion batteries - a global trend across sectors
- Hybridization with Li-ion batteries
  - can produce significant reductions in fuel consumption, maintenance and pollution
  - improve ship responsiveness, operational time and safety
  - may be a storage platform for black out prevention, energy recovery and renewable energy
  - enhances LNG based solutions
  - maritime power system providers are positioning themselves
  - Maritime Battery Forum is established
  - Green coastal shipping program is established

- Will provide a significant market penetration and environmental savings
  - In the future, most ships and vessels will be hybrid or plug-in hybrid

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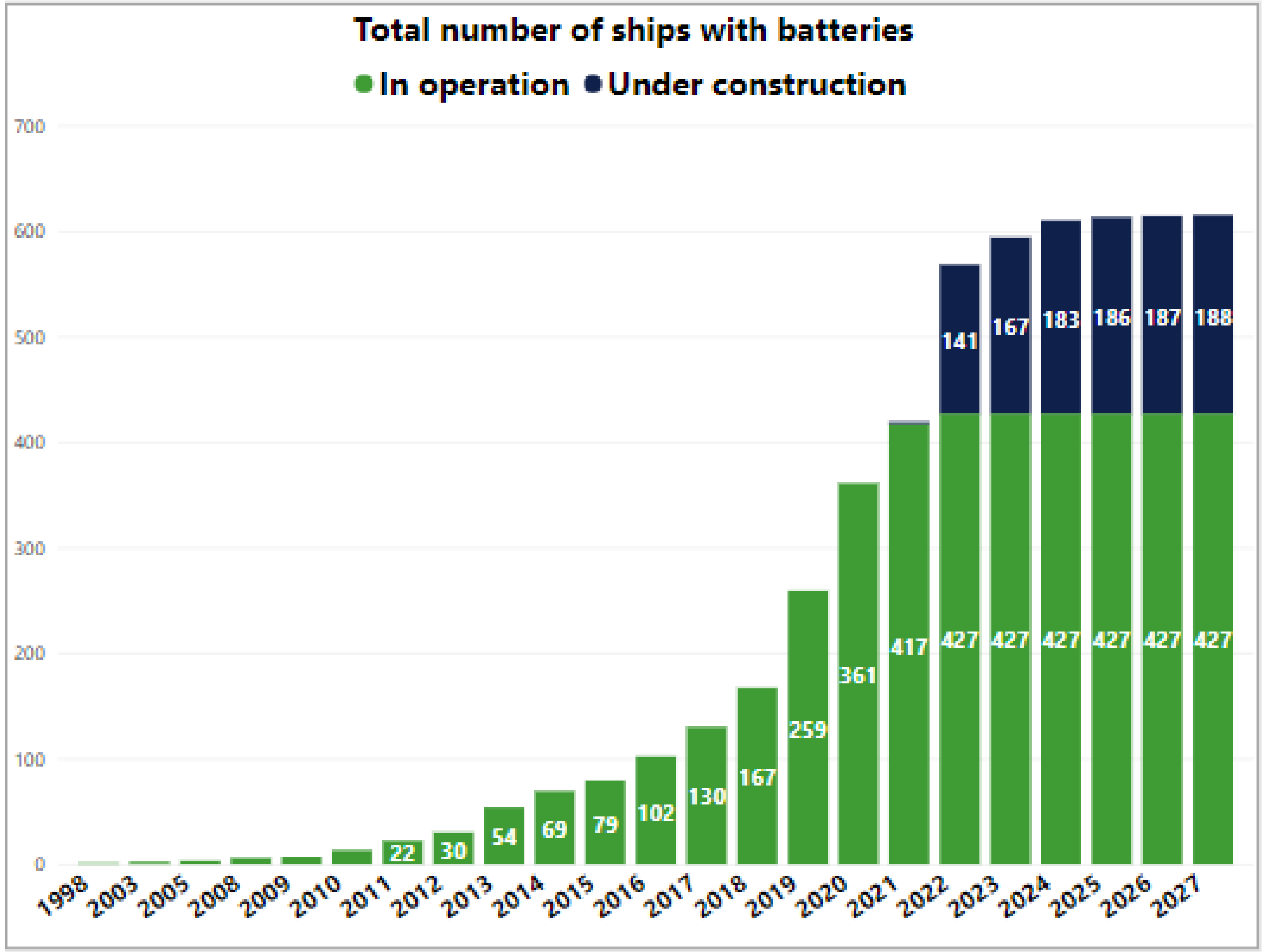
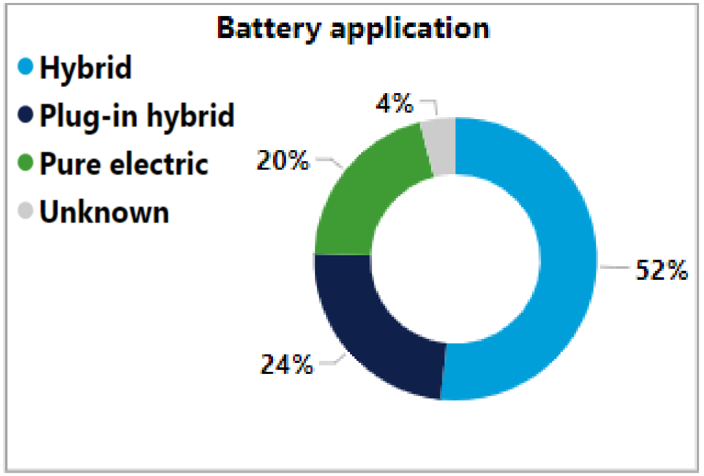
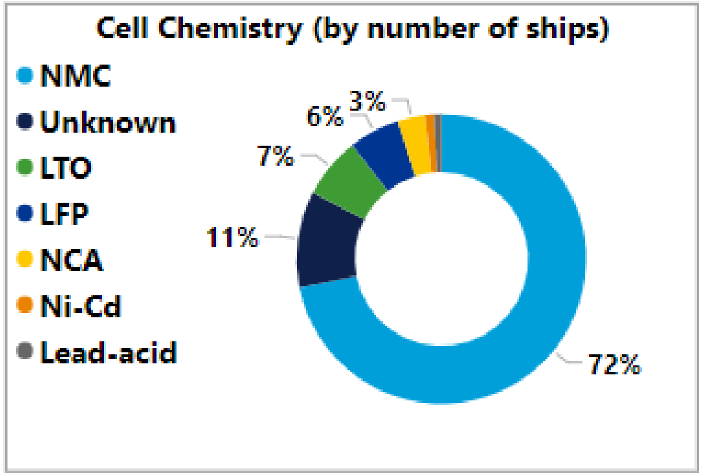
What is happening – Present days

Battery ships, application and cell chemistry







Alternative Fuels Insight

Maritime Battery Forum

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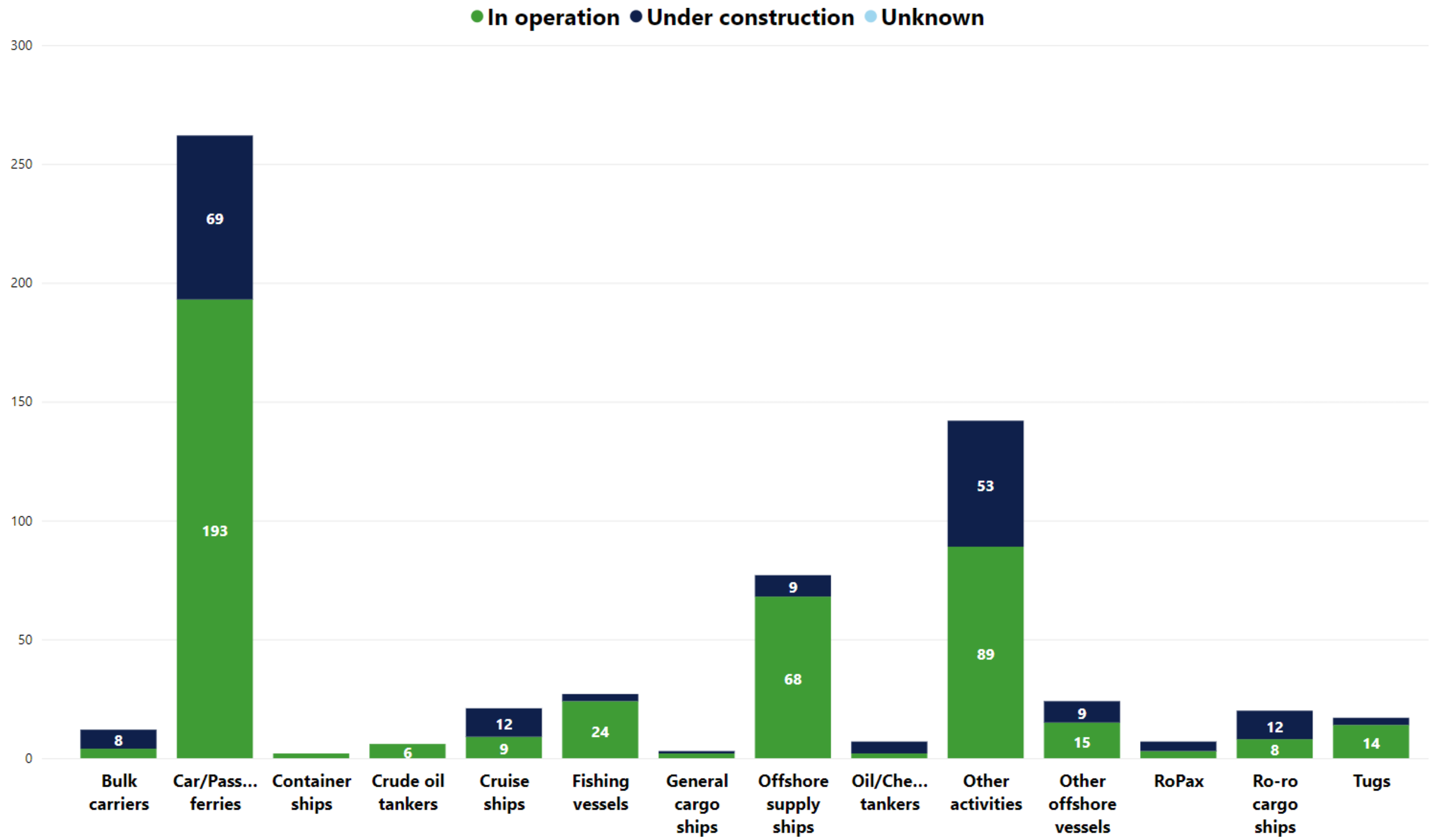
Battery ships at ship types



Alternative Fuels Insight

Maritime Battery Forum

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Ships for pure battery operation

Ships with frequent stays in port and relatively low energy needs

- Ferries, passenger vessels, short sea shipping
- Available port power and sufficient charging time, 5 to 10 minutes
- Max 60 minutes crossing and max 20 knots. However we have Re-Volt
- **Savings in fuel costs: 50% to 80% in Norway (crude oil price $ 110)**
- **Pay back depending on electricity prices and investments on land**

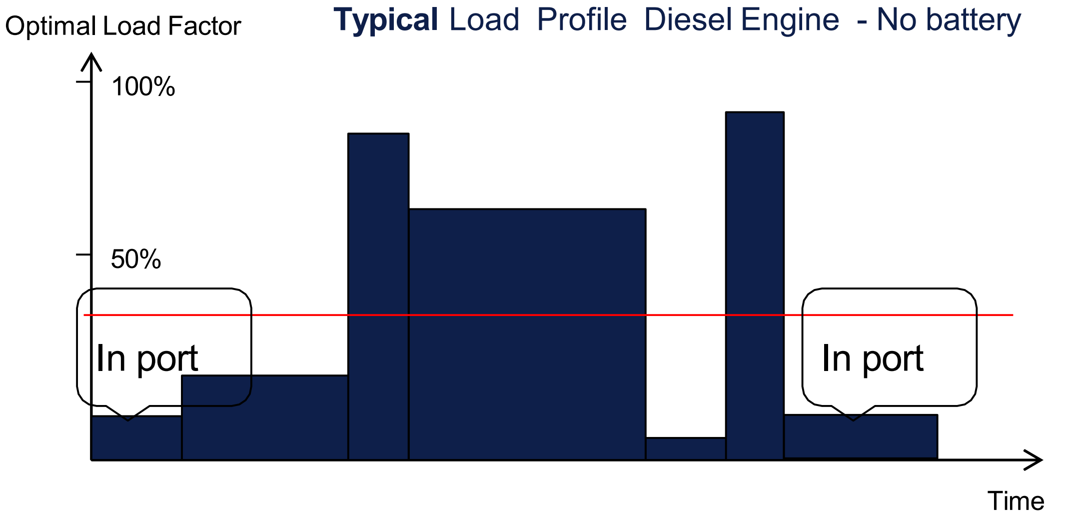
Ships for battery hybrid operation

- **Ferries**
- **Offshore Vessels**
- **Tugs**
- Dry cargo with cranes
- HSLC
- Wind Vessels
- Passenger ships
- FPSO
- Shuttle tankers
- Passenger
- Military
- Research ships
- Special ships
- Auxiliary engines in deep sea shipping

- **Hybridization**
  - **ships with low engine utilization in periods, or**
  - **ships with large power variations**

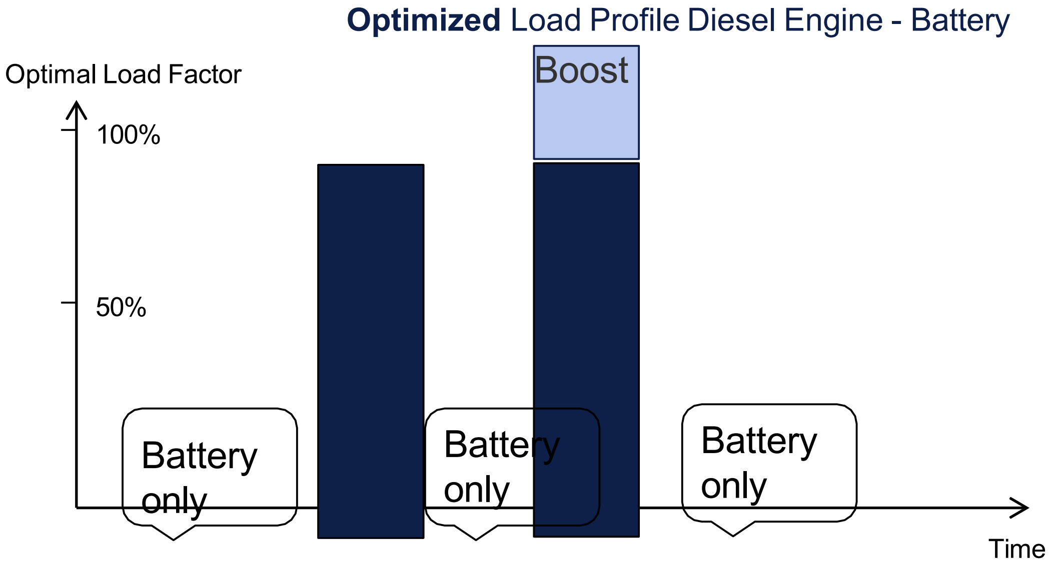
Battery hybridization – low engine utilization

- Batteries can reduce fuel consumption, maintenance and emissions
- Diesel engines run at optimal load, when they first run



Battery-only mode

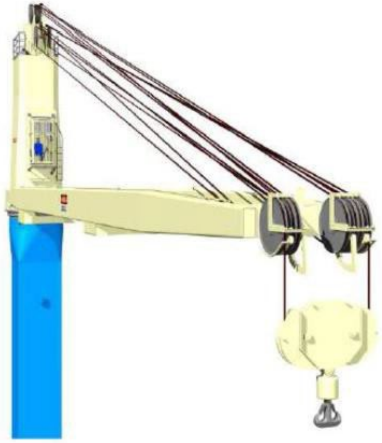
- In waiting situations
- In environmental sensitive areas
- In port

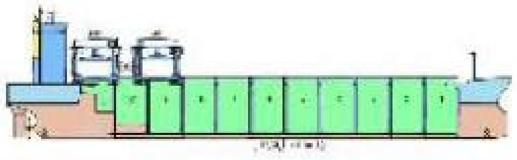


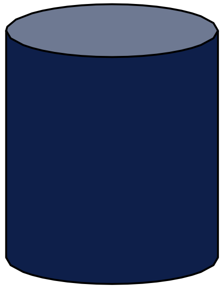
Plug-in hybrids can provide further benefits

Reduced Cost (Example)

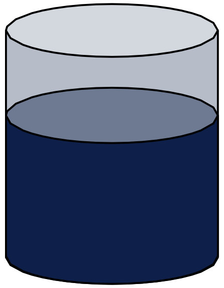
The hybrid system has annual savings of 110,000 $ (oil price $ 100)







313 tons used

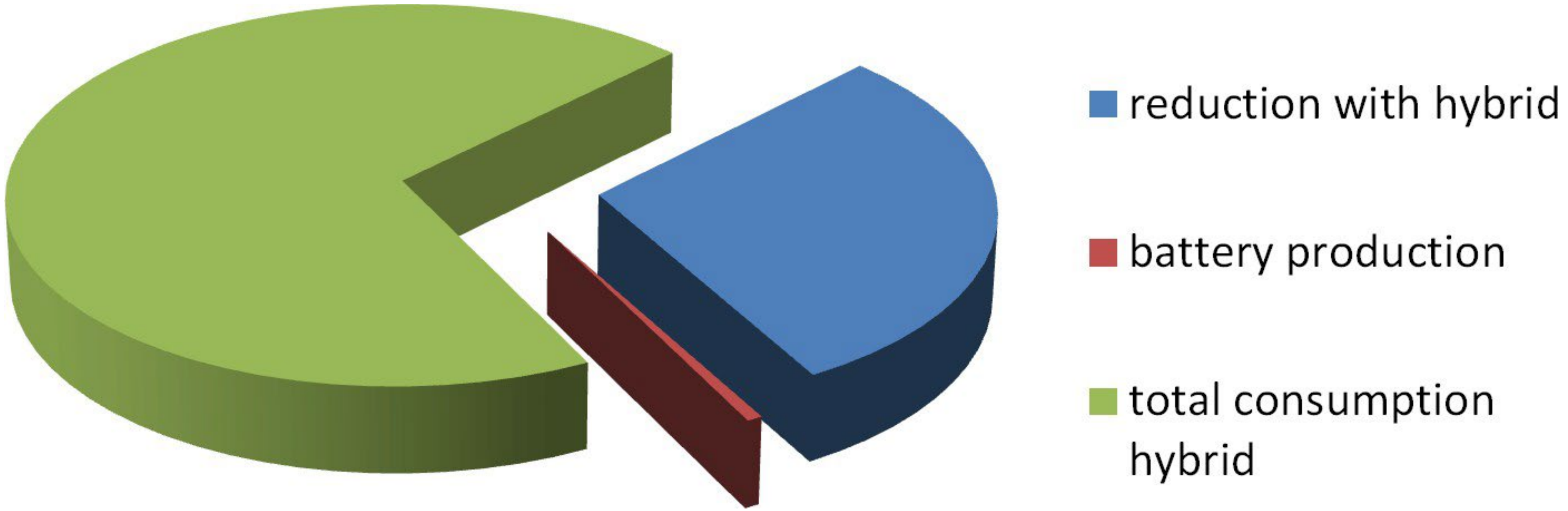


217 tons used

Savings due to:
1. Optimum load
2. Reduced transients
3. Regenerative breaking

Emission Reduction (Example)

For hybrid ship's CO_2 emissions from battery production is negligible compared to reduced emissions during operation



A Li-ion battery will save the environment ten times as much CO_2 if the battery is placed on a ship instead of a private car

What is happening – Future Trends

Trends in battery development

The last few years

- Li-ion batteries have dominated the markets
- Reduced battery prices
- Increased energy density and improved safety, quality and reliability
- Very few issues with cells from the leading producers are reported
  - Nissan Leaf: 1 billion km driven in 4 years – very few battery issues
  - Toshiba: Several million LTO cells the last 4 years, not a single cell failure

Next 5 years:

- Variants of Li-ion batteries will be dominating the market
  - Energy applications: NMC and iron phosphate
  - Power applications: NMC and LTO
- The systems will have active cooling in order to control heat build-up

Longer perspective:

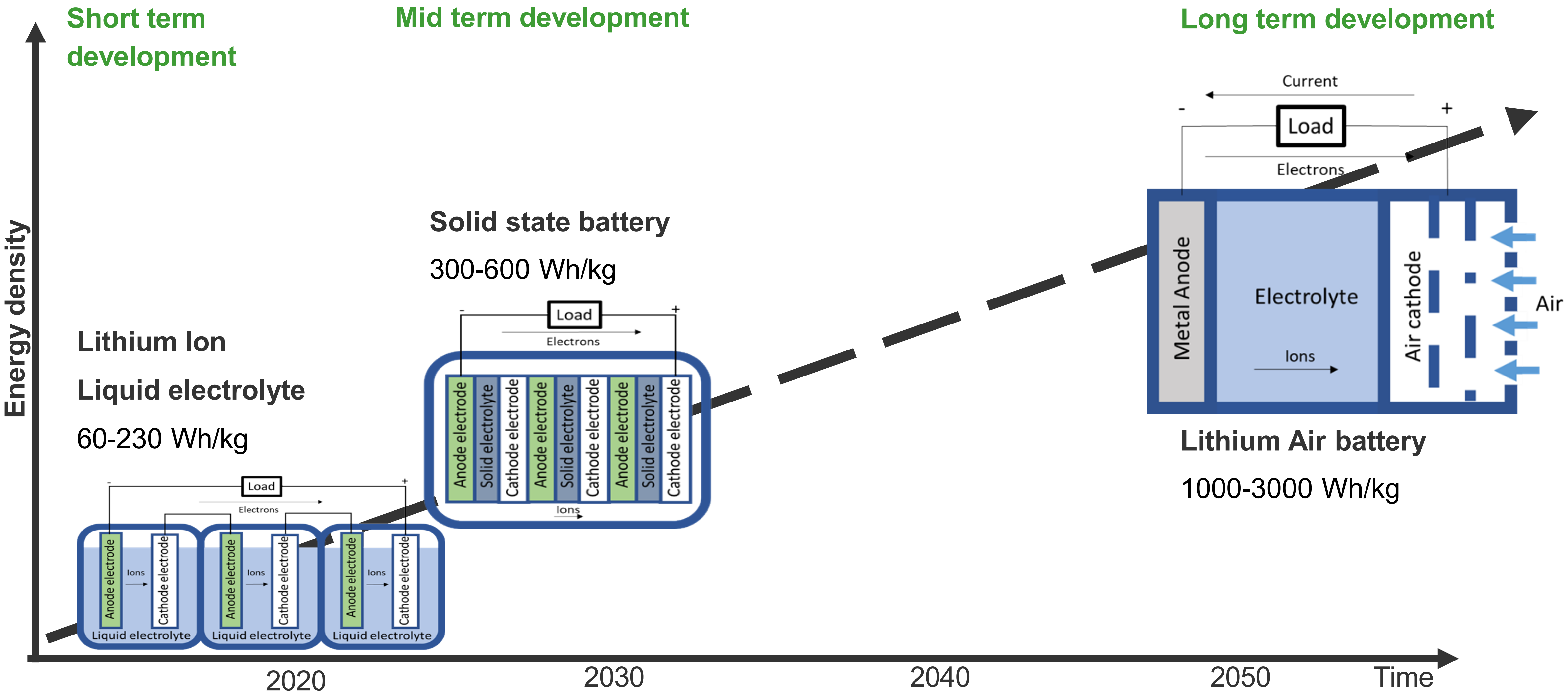
- New chemistries may play a role

Battery research drivers

- **Stationary systems**: Focused on finding **cheaper** and **more available** lithium substitutes
  - Compromises the specific energy and energy density.

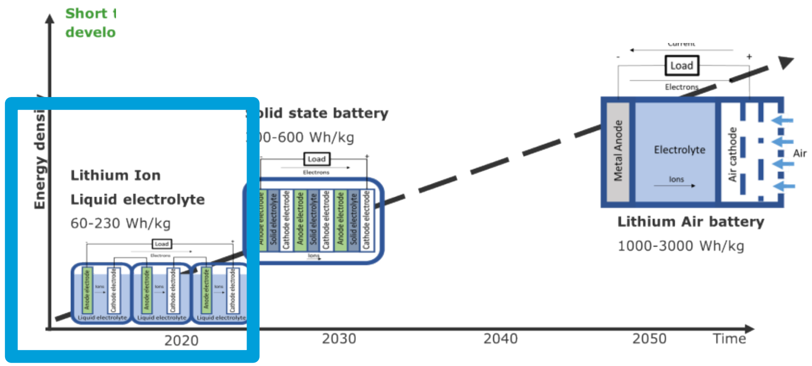
- **Automotive and Consumer Electronics:** Higher **specific energy**, **energy density** and **specific power**
- Structural changes of the electrodes, which affect both lifetime and safety.
- Applicable for maritime

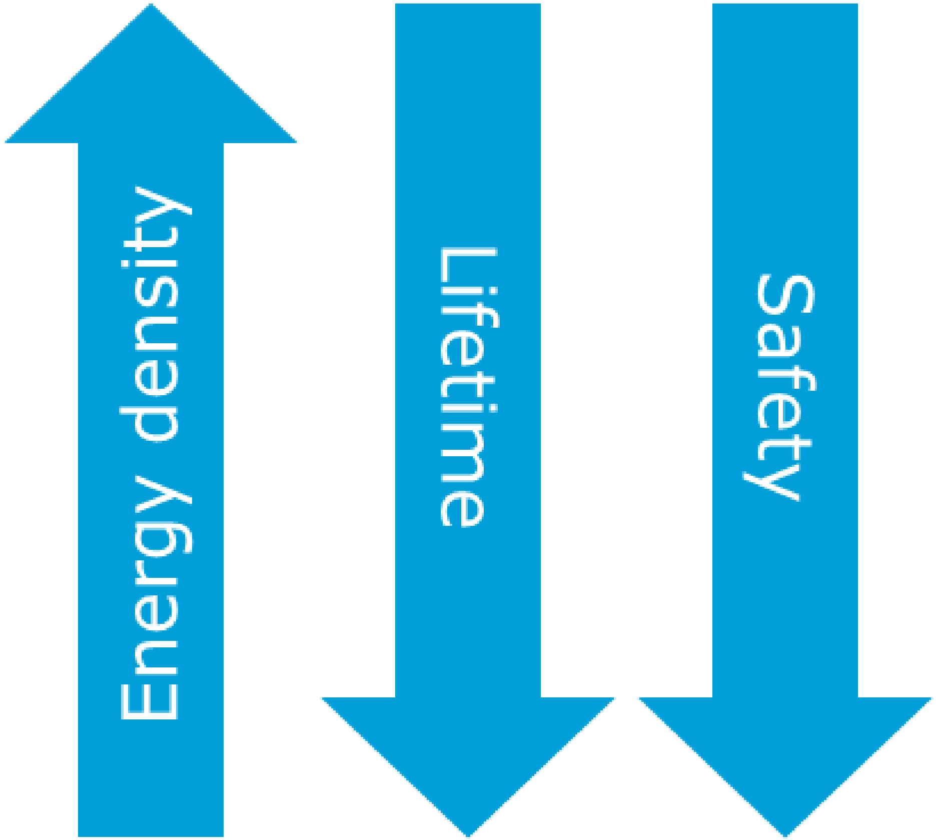
Roadmap for energy dense batteries



Short term development

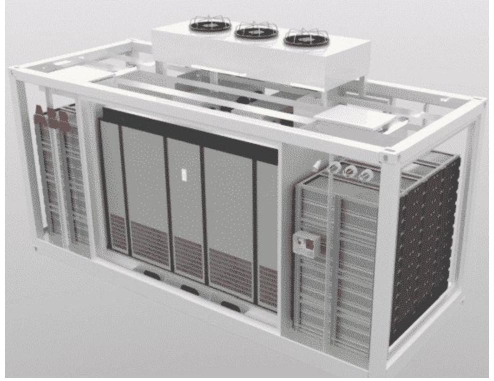
- Pushing towards **maximum energy density** and **minimum cost**.
  - Silicon in the anode
    - Increases energy density, Decreases lifetime
  - Lower cobalt, higher nickel
    - Reduces cost, Increases energy density, decreases lifetime, decreases thermal stability
  - Lithium-Sulphur; Nikola Motor, concept studied in maritime. Produces SO2.
- Zinc-Ion; low energy density, but cheap and safe



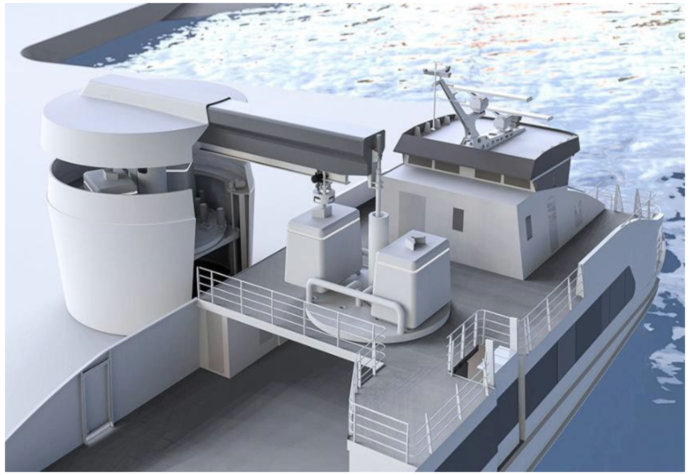


Short term development in maritime

- Containerized battery modules.
  - DNV has a battery container type approval programme.
  - Typical size: 10ft: 700-800 kWh, 20ft: 1.5 – 2.0 MWh.



- Swapping of battery modules/containers instead of fast charging.
  - Is under development by several companies.
  - Regular 20ft containers and special made containers are under development



Battery powered ships in a nut shell

- Good investment
- Improved ship responsiveness, regularity and safety
- Improved environmental profile and reputation
- Acquired competence in a future oriented technology
- Increased robustness
  - Increases in fuel prices
  - Changes to stricter environmental regulations
- Decision support tools are available

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How to go about moving into "Battery"

Opportunities

- Battery prices are going down
- Fuel prices are going up
- Decarbonization is a must
- Solutions are available for pure battery or hybrid
- All of the above make a good business case

Battery prices

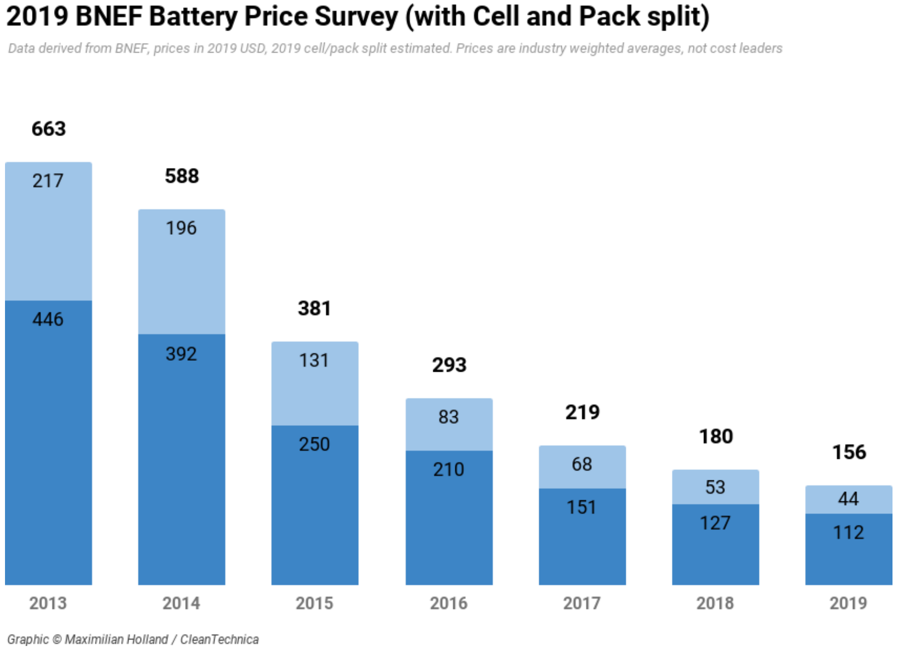
- The battery packs price is about 156 $/kWh in 2019.

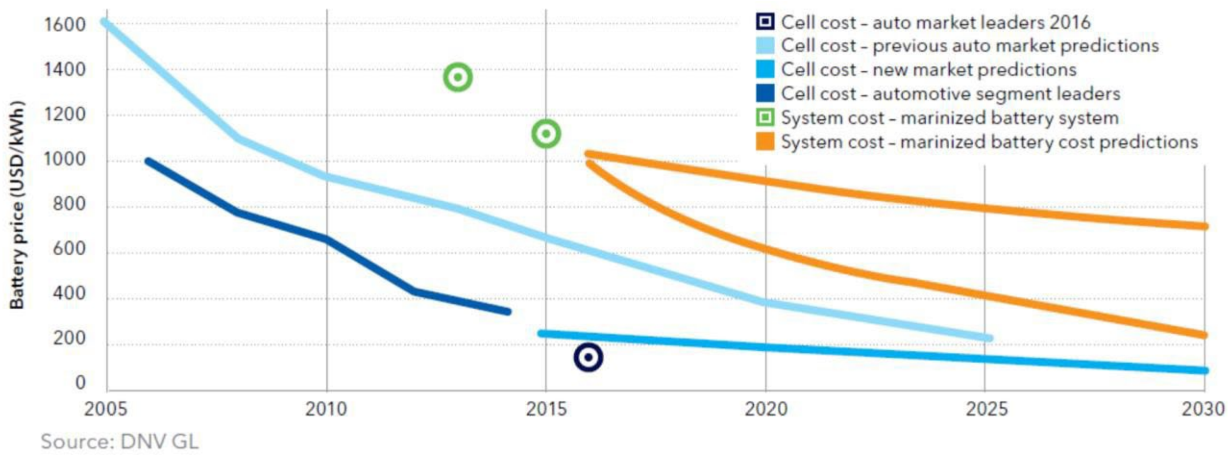
- Price is expected to be close to 100 $/kWh by 2023.
  - 100 $/kWh is seen when EV will reach price parity with ICE vehicles.
  - High energy dense cathodes, falling manufacture cost and pack design will drive the price further down.

- Marine battery systems is offered now at 600-1000 $/kWh, and is expected to drop to 200-800 $/kWh by 2030

- Solid state battery cells are predicted to be 400-800 $/kWh within the next three years

https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/





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Economy for hybrid ships - general examples (crude oil price $ 110)

Hybrid system cost ≈ $2,000,000
Annual fuel costs ≈ $2,500,000
Savings potential ≈ 15%
Annual savings ≈ $375,000

Pay back ≈ 5 years

Hybrid system cost ≈ $1,000,000
Annual fuel costs ≈ $800,000
Savings potential ≈ 30%
Annual savings ≈ $240,000

Pay back ≈ 4 years

Hybrid system cost ≈ $300,000
Annual fuel costs ≈ $250,000
Savings potential ≈ 30%
Annual savings ≈ $75,000

Pay back ≈ 4 years

Challenges - important steps in going into “Battery”

Are batteries feasible for my ship?

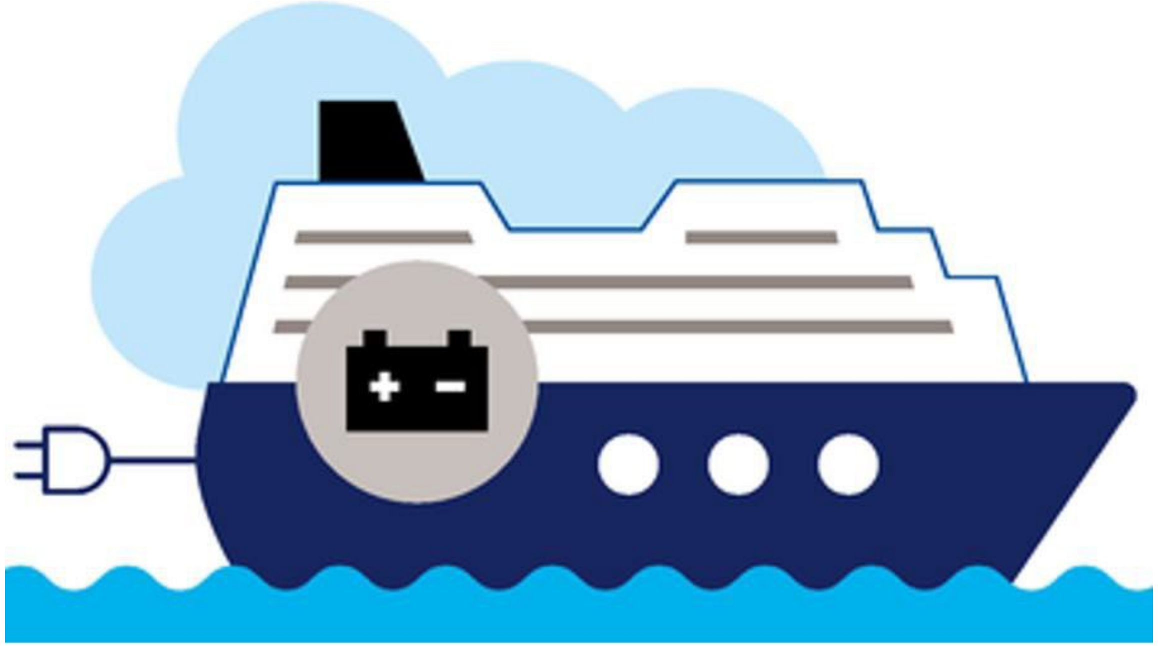
- Technical feasibility studies
- Concept design review
- Cost, payback time and sensitivity analysis

How to select and operate the battery?

- Technical tender evaluation
- Battery system business risk assessment
- Battery life time assessment and battery sizing optimization analyses

How to make the battery installation safe?

- Battery system safety risk analysis
- Technology Qualification, batteries novel to maritime industry



Challenges - are batteries feasible for my vessel?

- How do you operate today?
- What are you dimensioned for, what are you using in real life?
- Do you have extra gensets running just in case?
- Do you have varying loads?
- Do you have low load scenarios?
- Do you have cargo handling?
- Do you have high requirements for redundancy and fast response?
- How does your system react to worst case single failure?
- How do you ensure smarter use of you vessel today?

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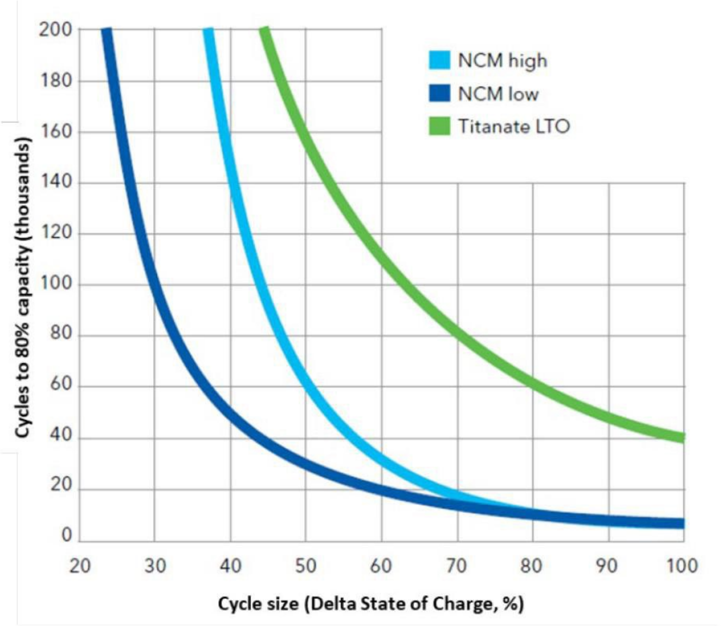
Challenges - how to select and operate the battery?

- The battery energy will degrade over time.
- Determined by State of Health (SOH).
- Will also affect the probability to catch fire. (Thermal Runaway)
- Do not want to change the battery system earlier than the payback time.

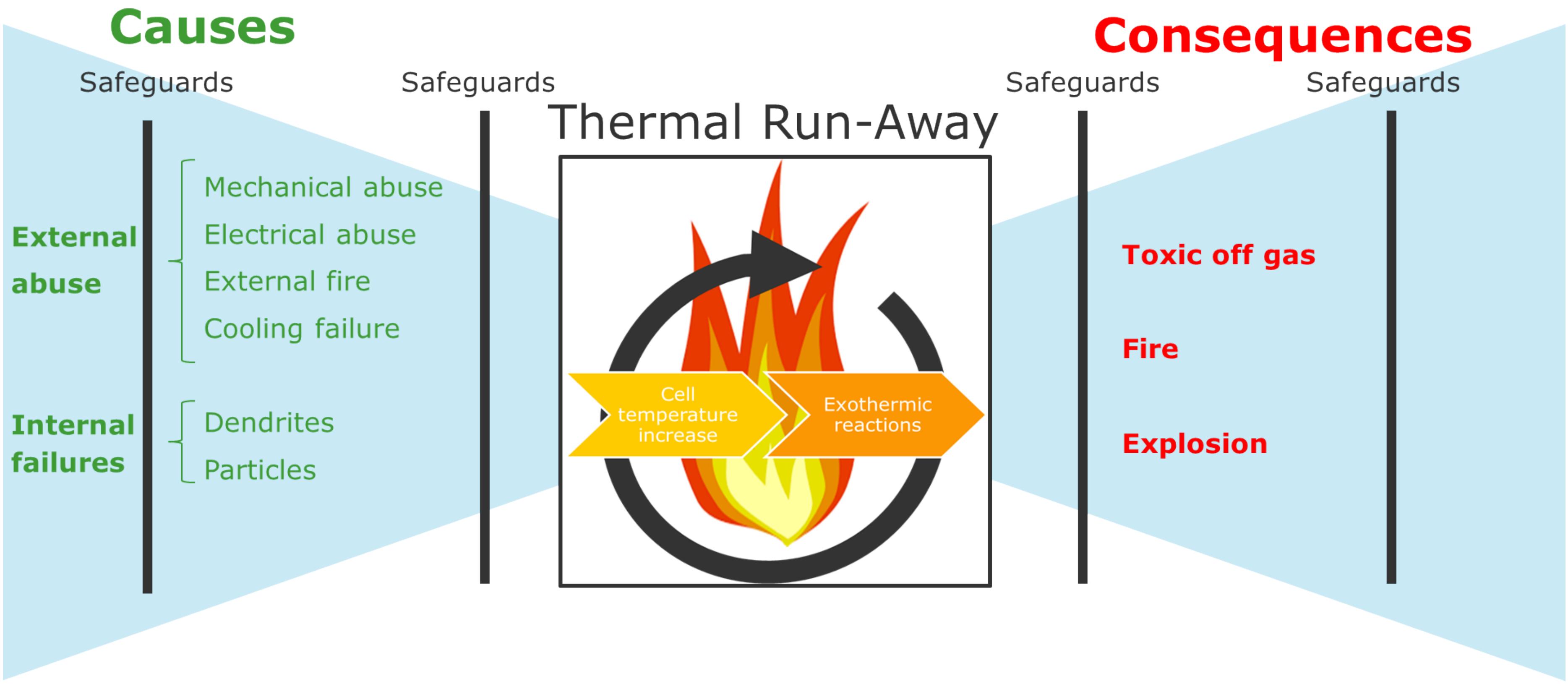


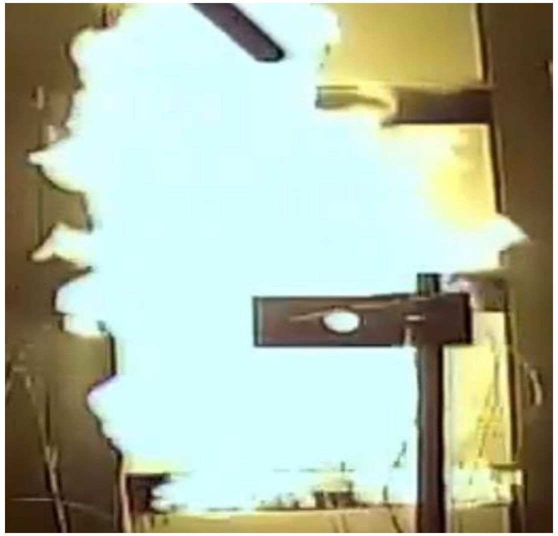
Cell before and after cycle testing to end of life

Challenges - How to select and operate the battery?

- **Battery AI;** combination of machine learning and semi-physical methods to model battery behavior under a range of real-world conditions.
- Can analyze complex duty cycles of real-world operating conditions and determine the constituent abuse factors.
- The effect of these abuse factors is then modelled to determine expected total degradation.

Challenges - Safety of Battery systems





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Thank you!

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