Maritime battery technology

Market developments and trends

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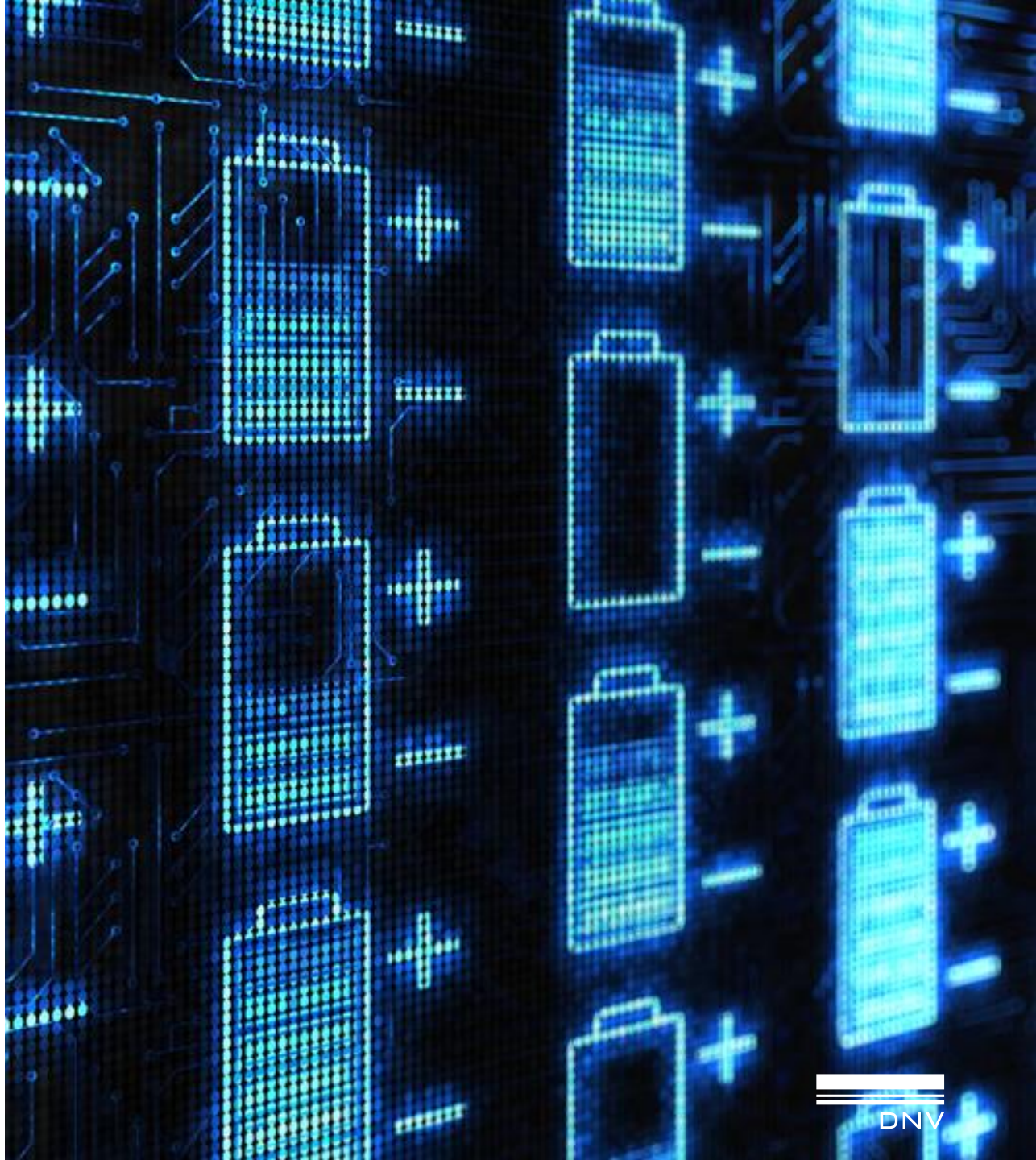
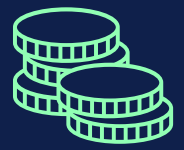
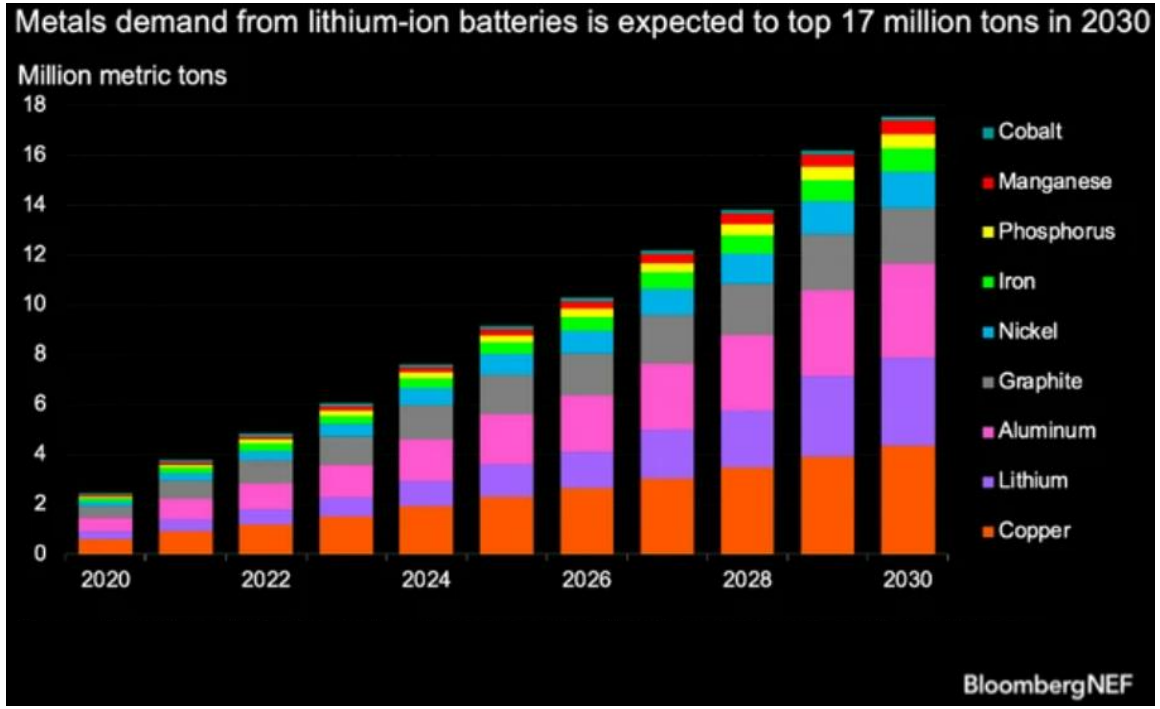
- ✓ **Maritime market uptake**
  - Vessel types
  - Regional
- ✓ **Technology update**
  - Research drivers
  - Current trends
  - Technology developments



Price developments 

- ✓ Raw material demand
- ✓ EV battery pack price forecast

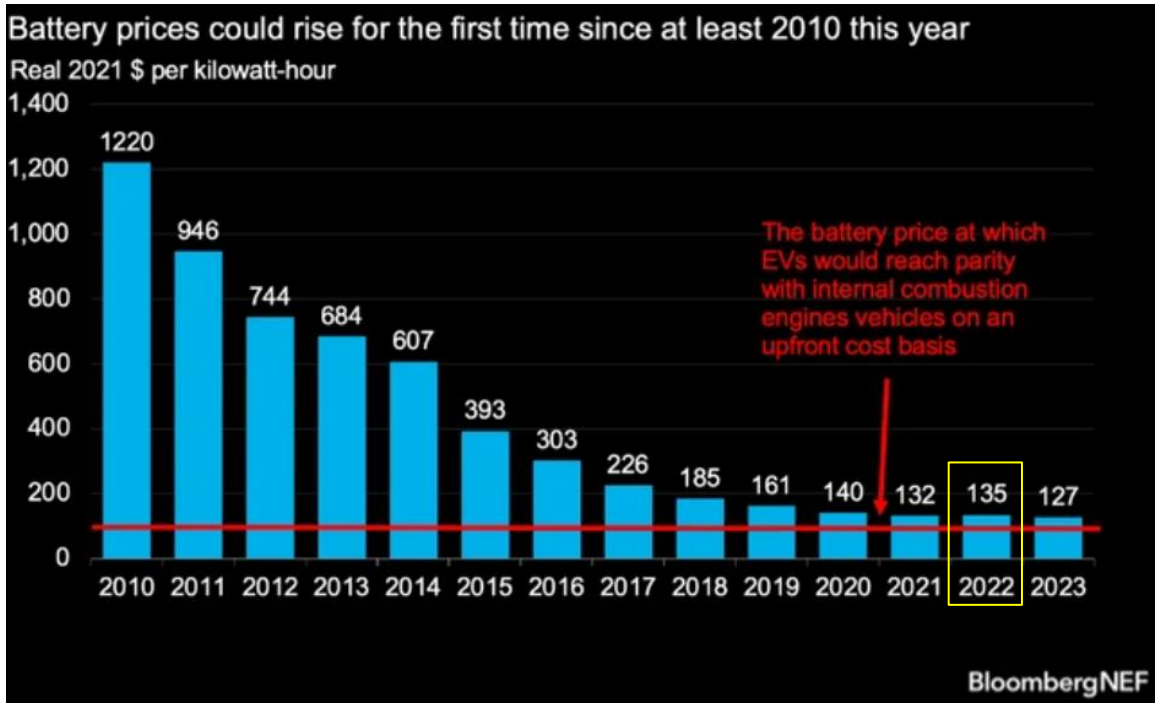
Accelerating global demand from multiple sectors



Source: Bloomberg NEF (2022)

- Short-term supply challenges foreseen to affect the market negatively to 2023.
- Lithium metal demand believed to more than sevenfold between 2021 and 2030.
- Reducing dependency on rare Earth minerals will be key to combat increasing Li-ion battery demand.
- LFP cell chemistries likely to increase in popularity at the expense of NMC cells.

Price parity delayed to 2026



Source: Bloomberg NEF (2022)

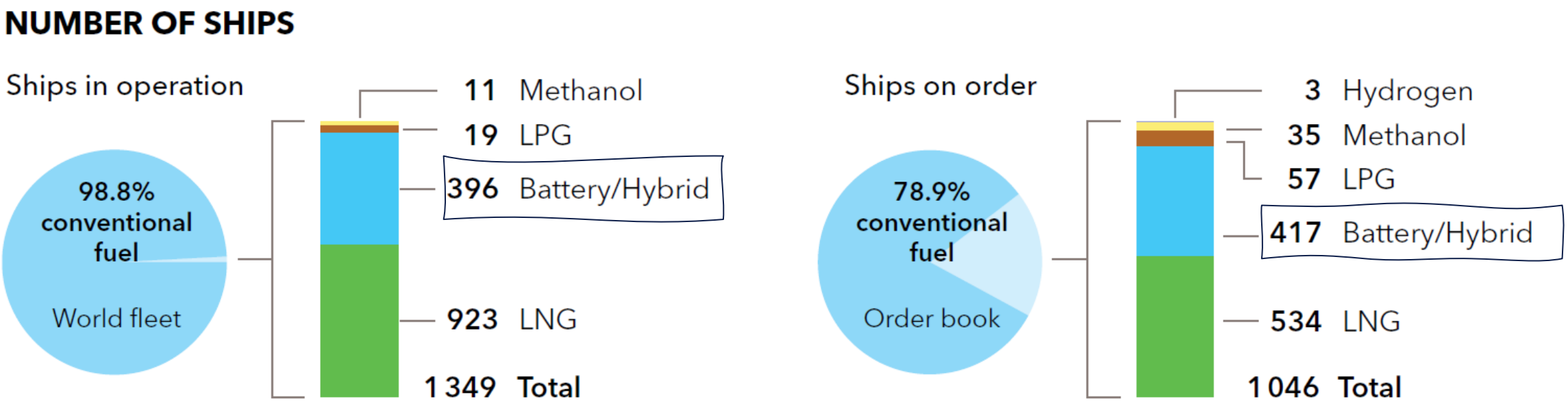
- Golden threshold: **100** USD per kWh.
- EV price parity is now expected in 2026, vs. previous estimate 2024.
- Marine battery packs could come down to **400** USD per installed kWh from 2026 if inflationary pressures persist
  (4-6 X the price of EV packs)

Maritime market uptake

- ✓ Vessels and vessel types with installed Li-ion batteries
- ✓ Regional uptake of Li-ion batteries

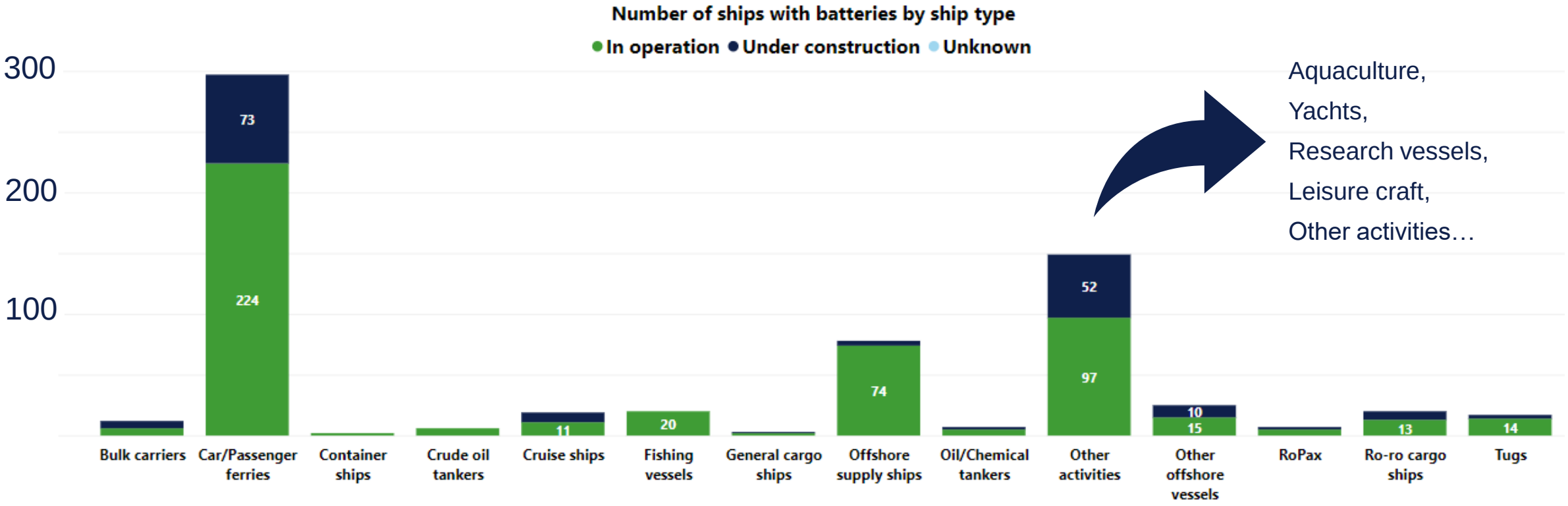
Alternative fuels towards zero-emissions

Alternative fuel uptake in the world fleet by number of ships and gross tonnage



Source: DNV Maritime Forecast (2022)

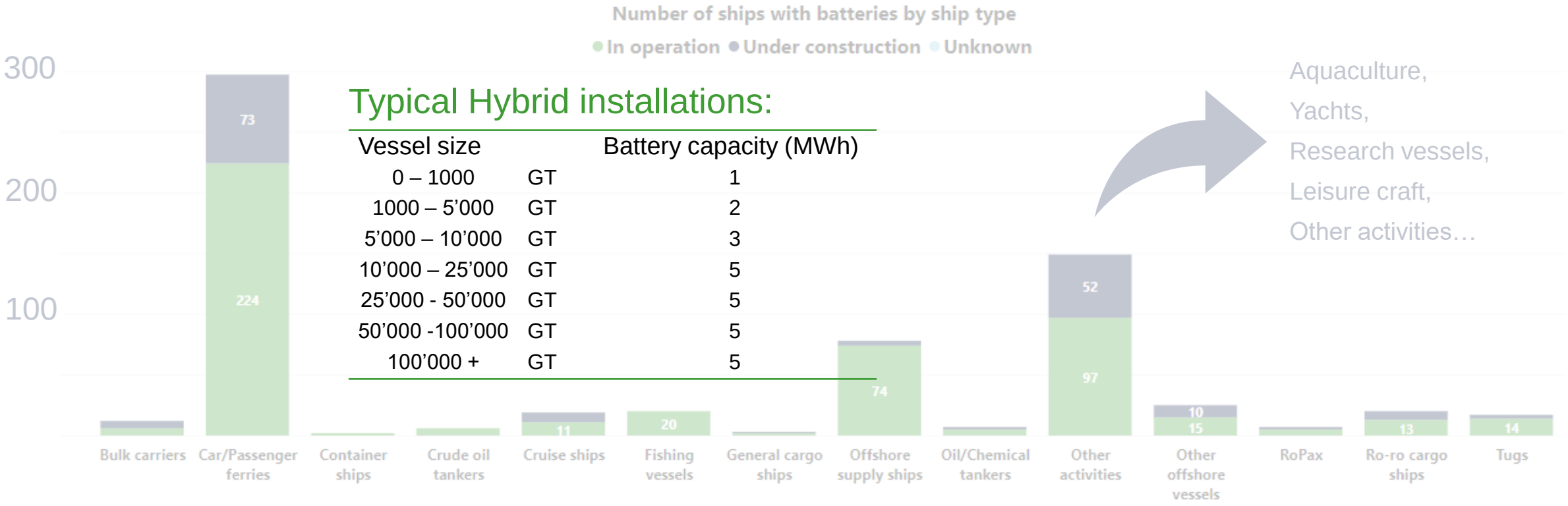
What vessels are installing batteries?



Source: DNV Alternative fuels insight (2022)

What vessels are installing batteries?

… and at what capacities?



Typical Hybrid installations:

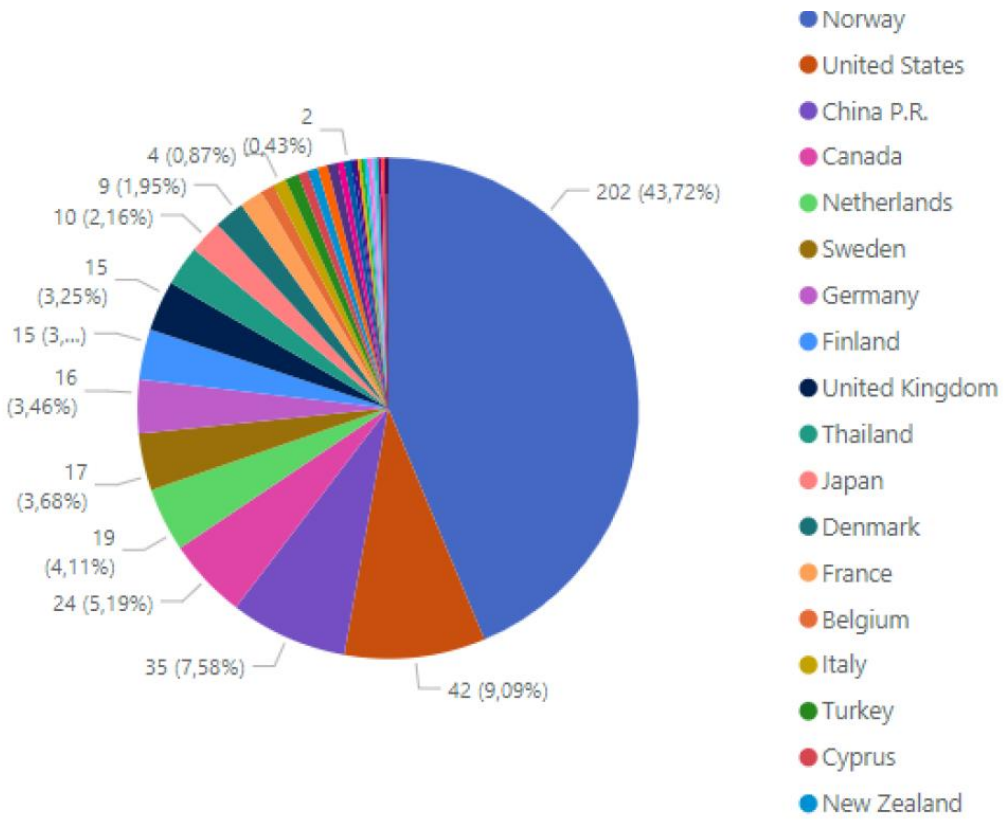
Vessel size		Battery capacity (MWh)
0 – 1000	GT	1
1000 – 5’000	GT	2
5’000 – 10’000	GT	3
10’000 – 25’000	GT	5
25’000 - 50’000	GT	5
50’000 -100’000	GT	5
100’000 +	GT	5

Aquaculture,
Yachts,
Research vessels,
Leisure craft,
Other activities…

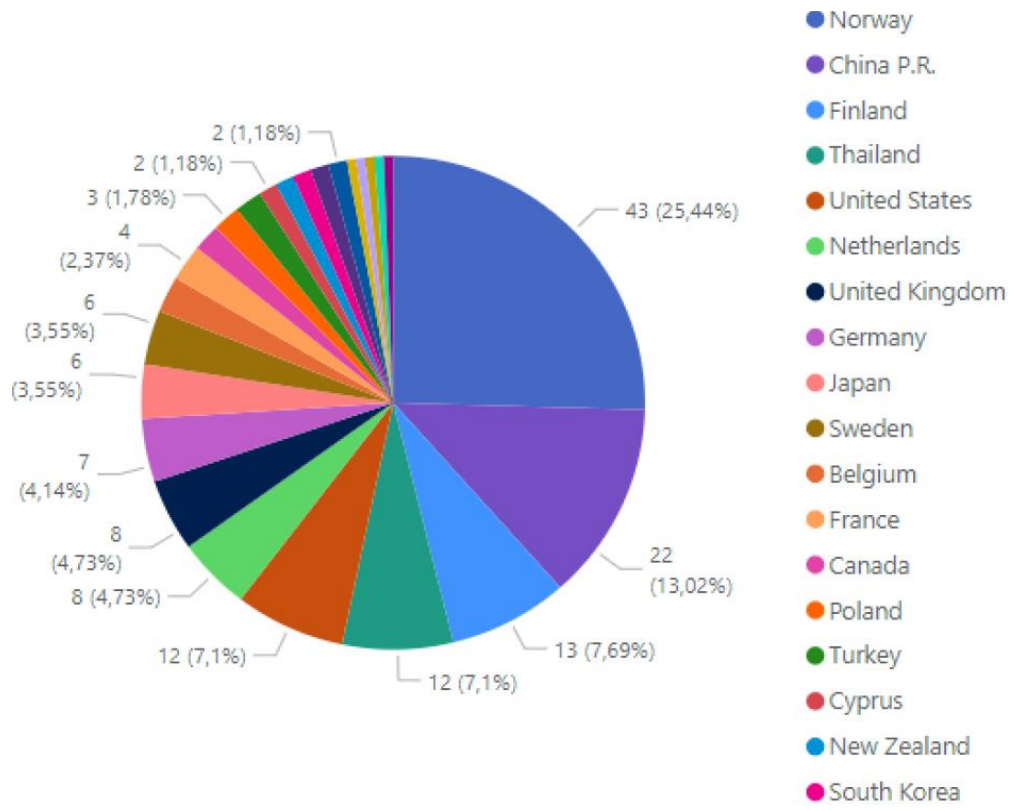
Source: DNV Alternative fuels insight (2022)

Vessels with installed batteries vs. orderbook

All electric and hybrid vessels by country



Electric and hybrid vessels on order by country



Source: Clarkson WFR (2022)

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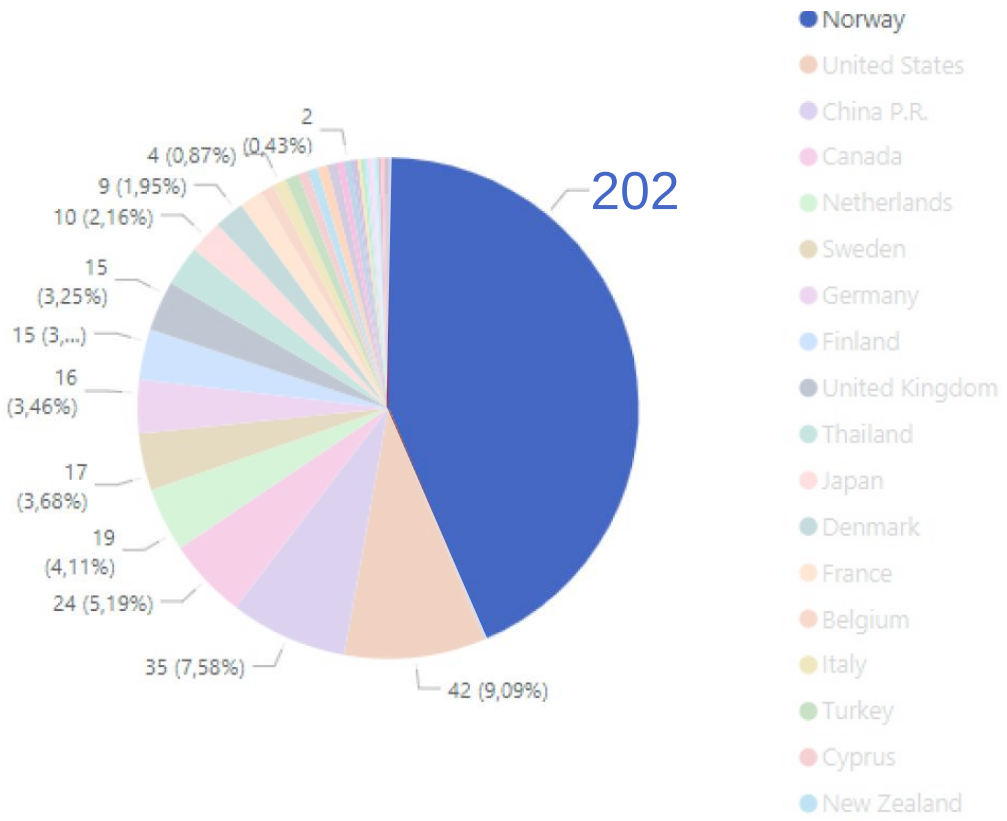

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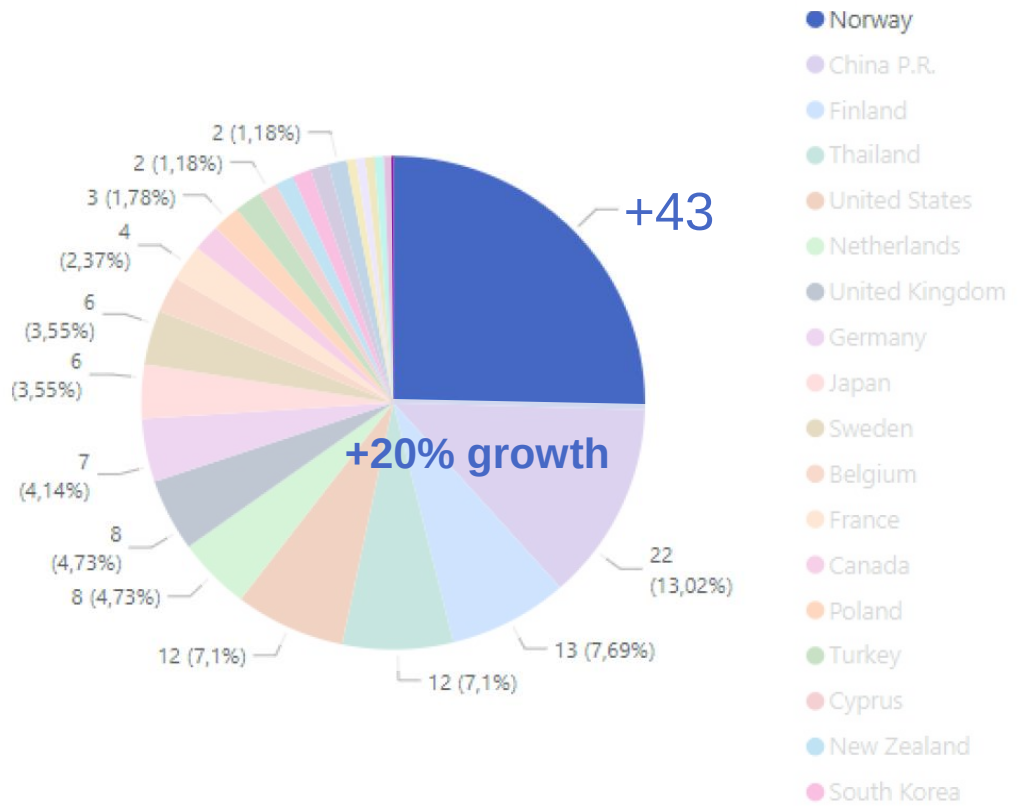

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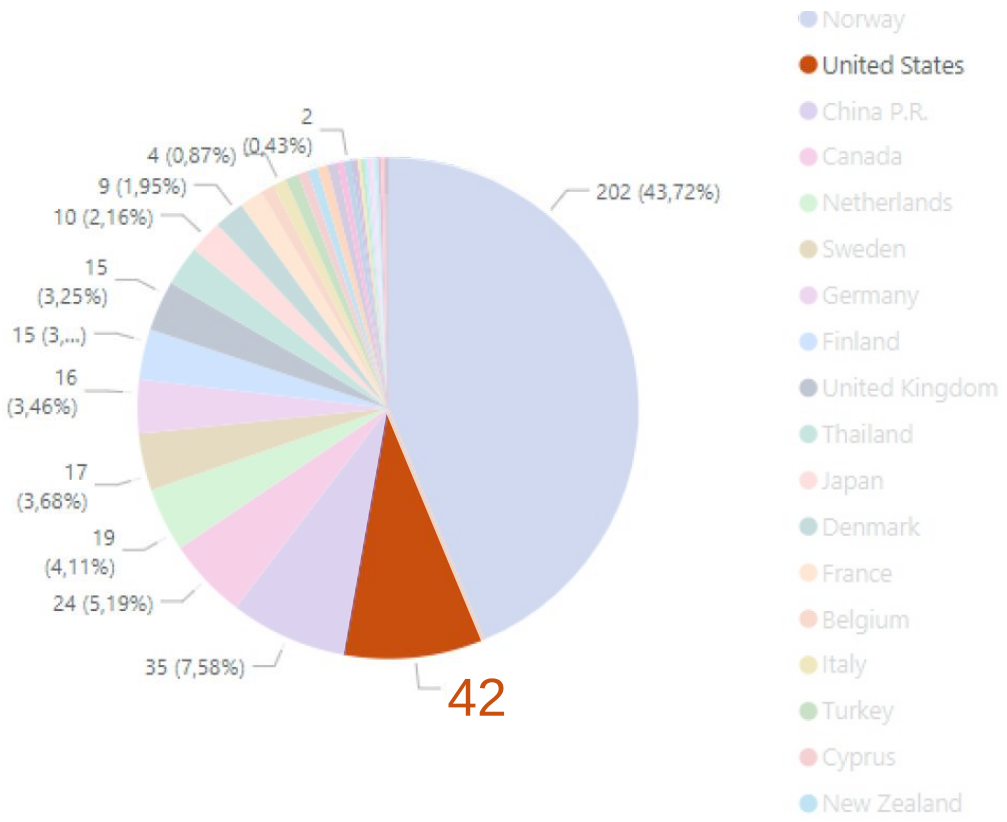

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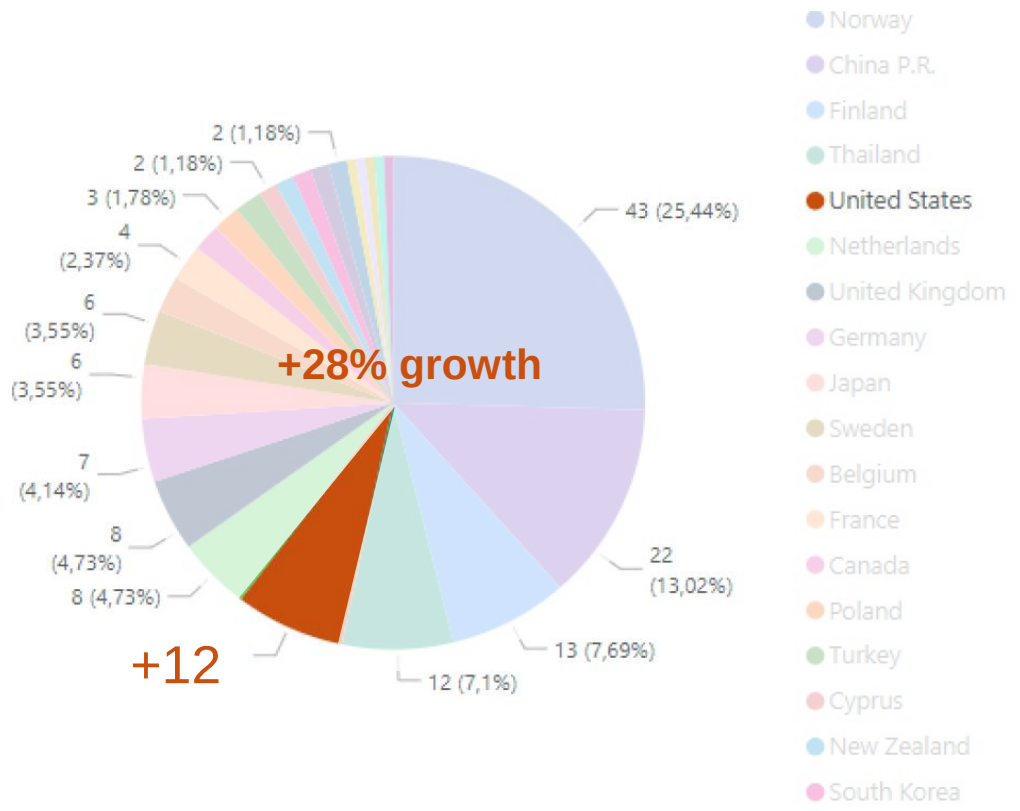

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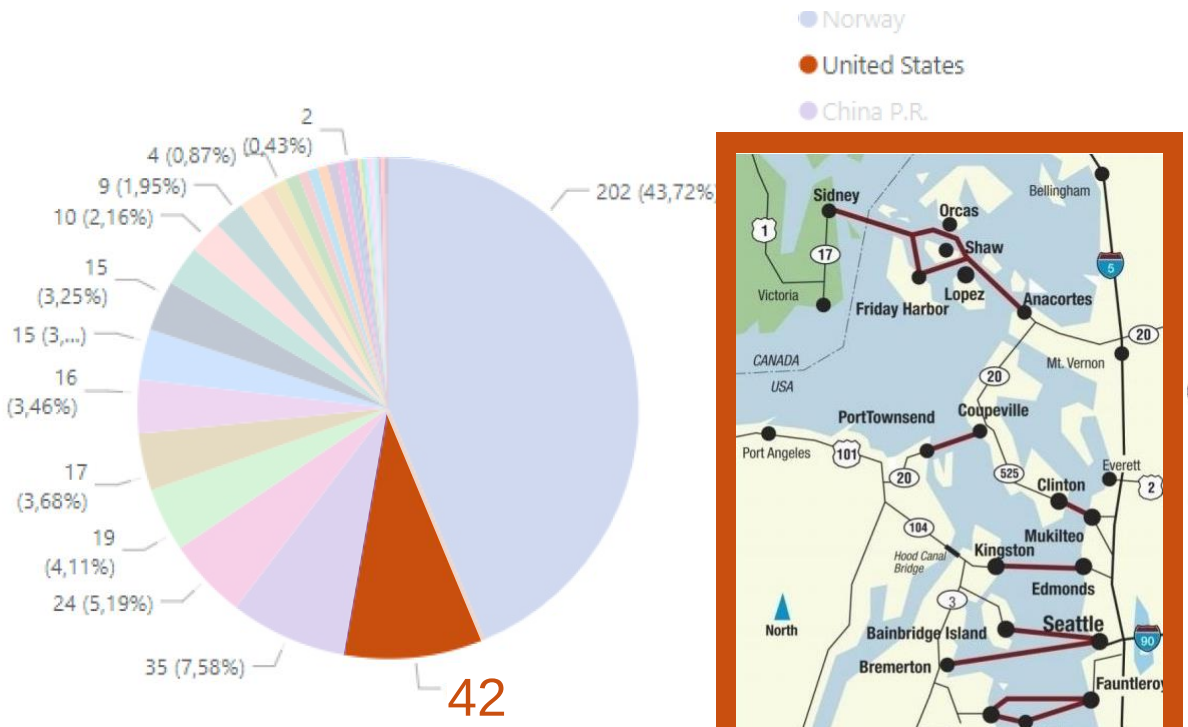

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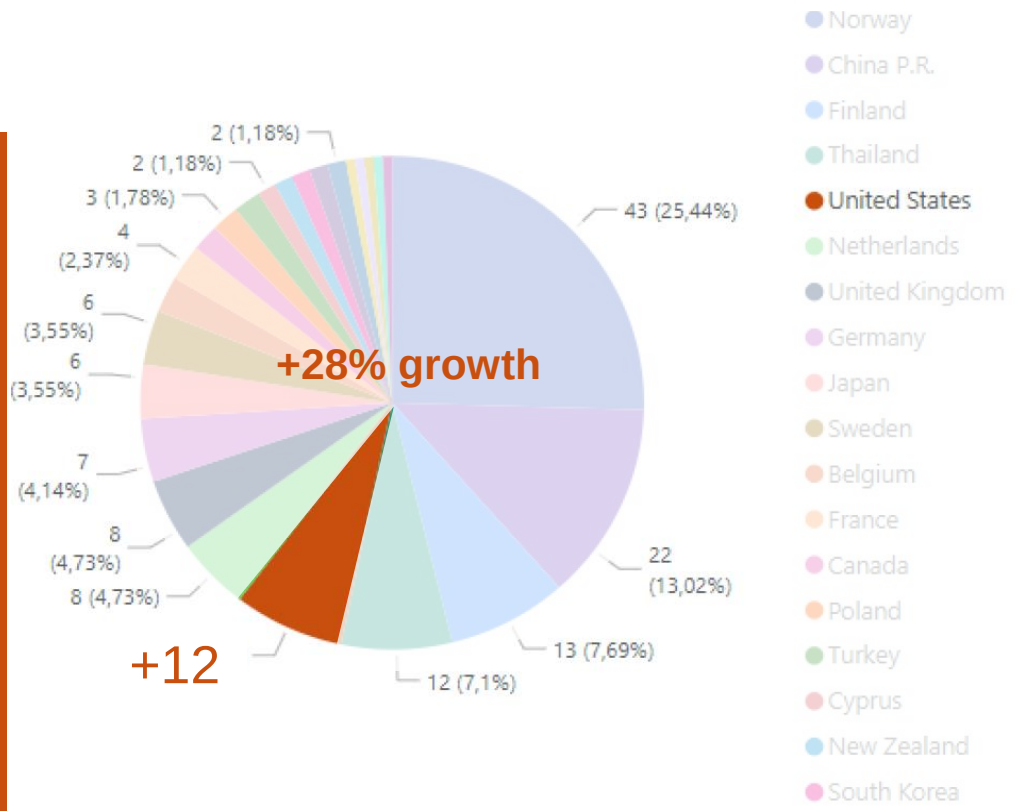

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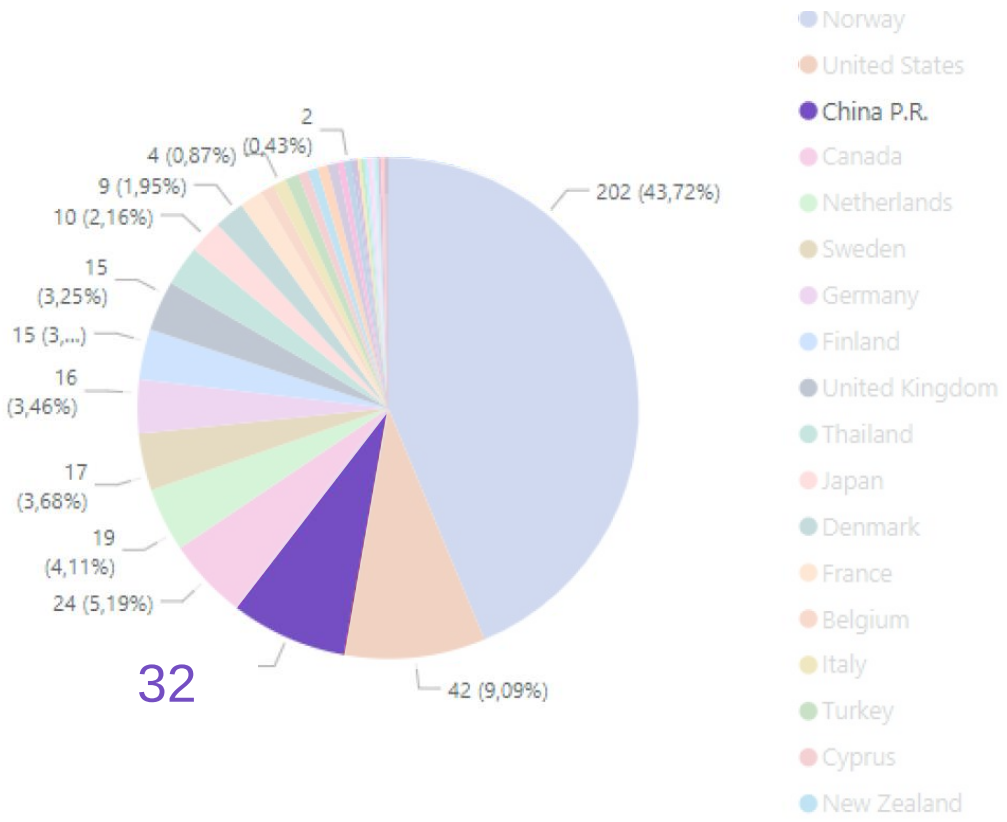

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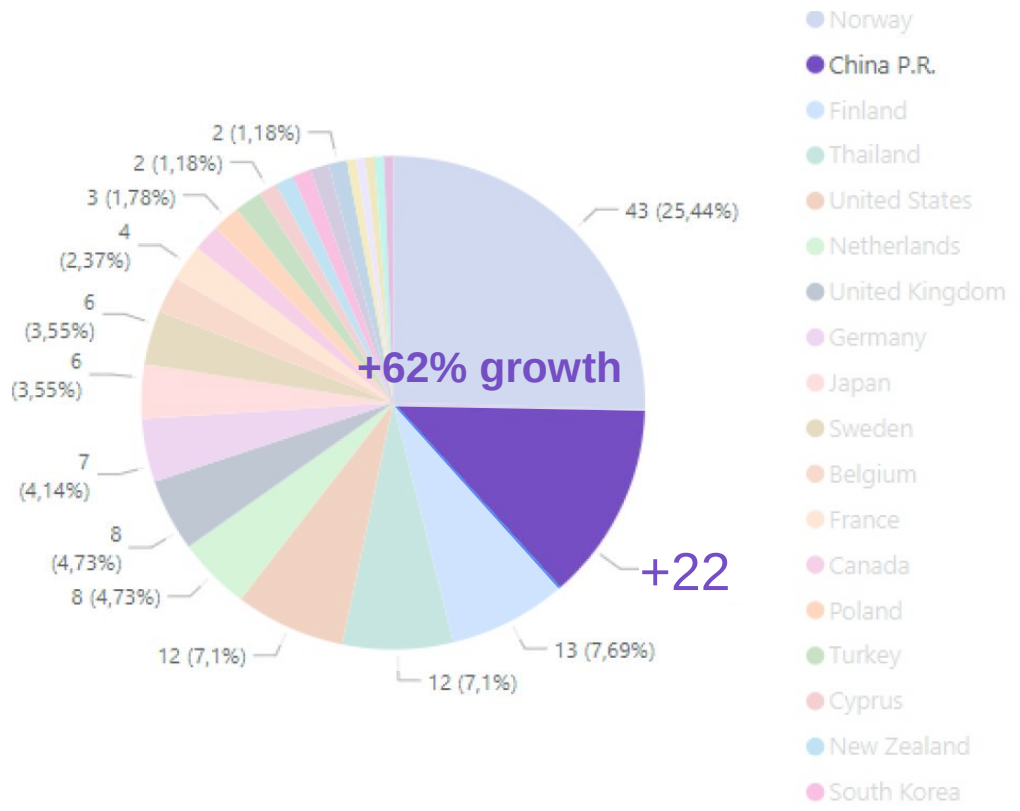

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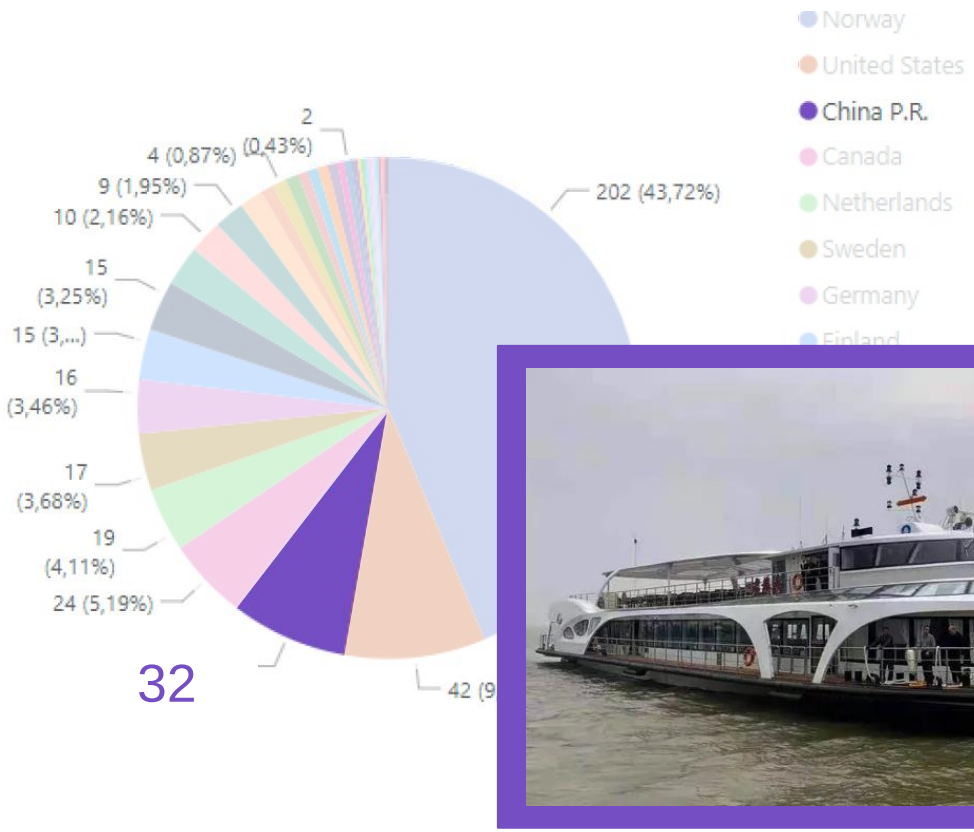

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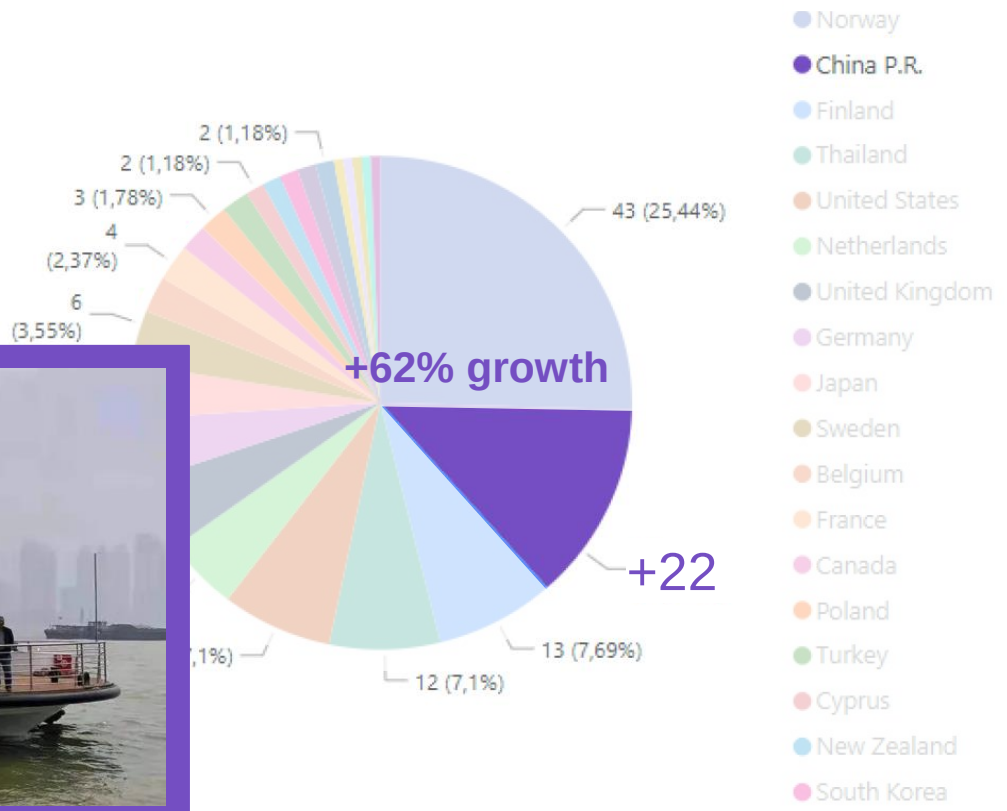

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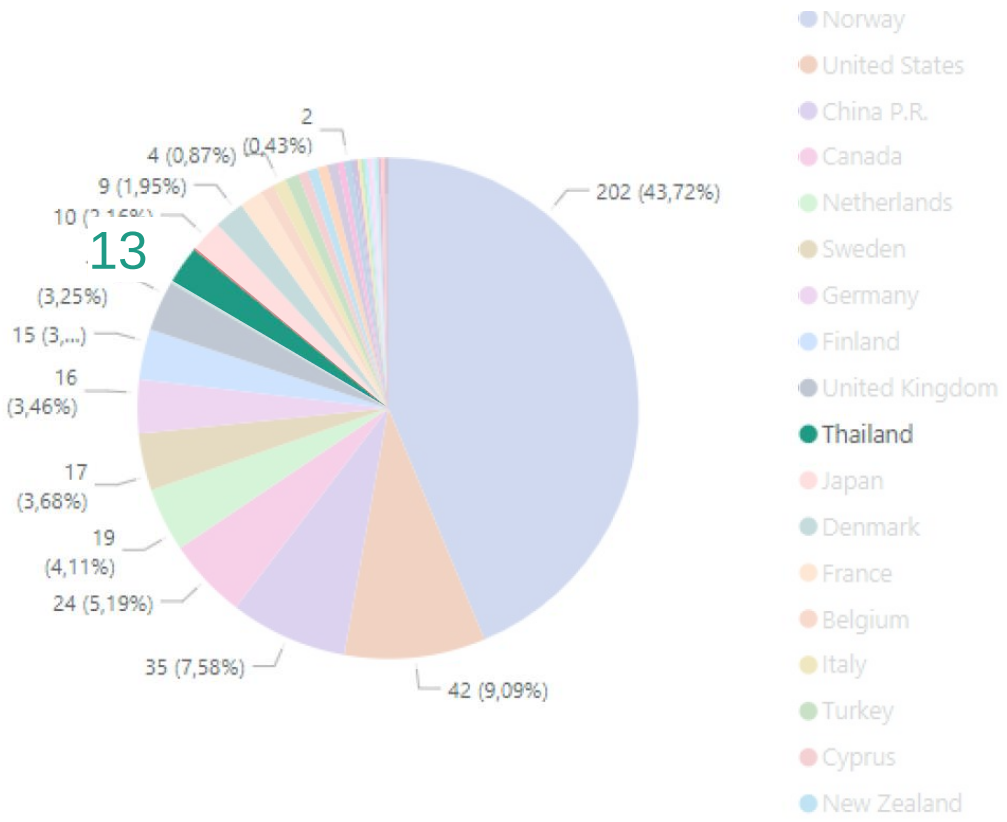

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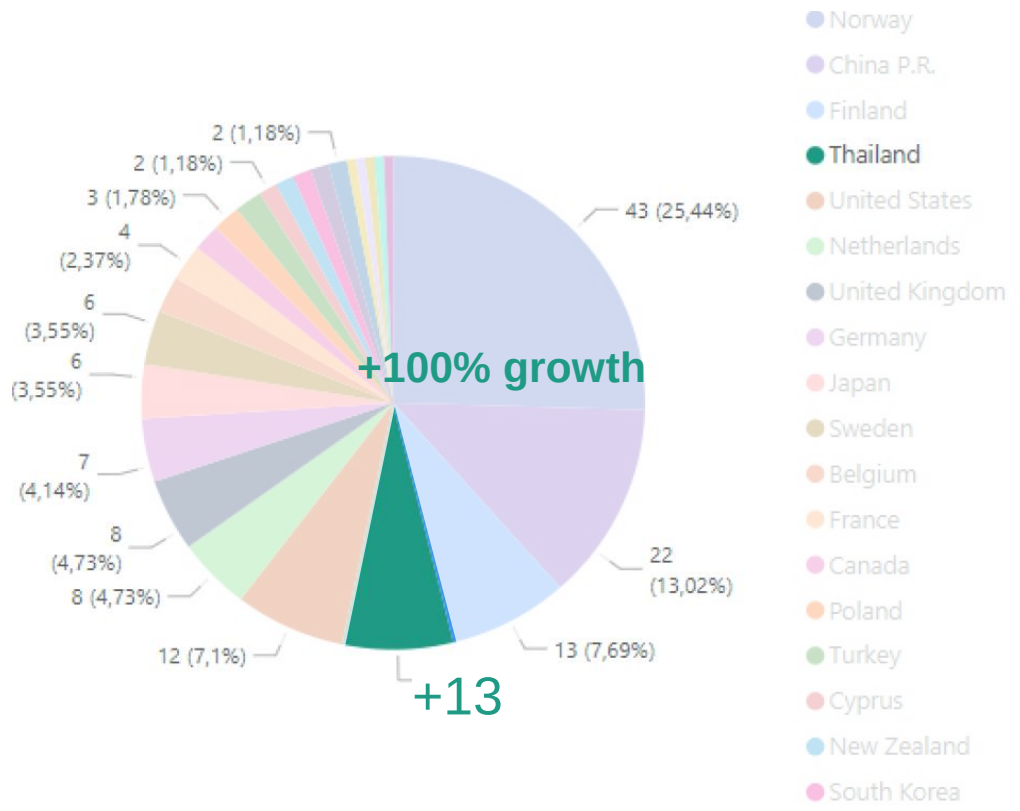

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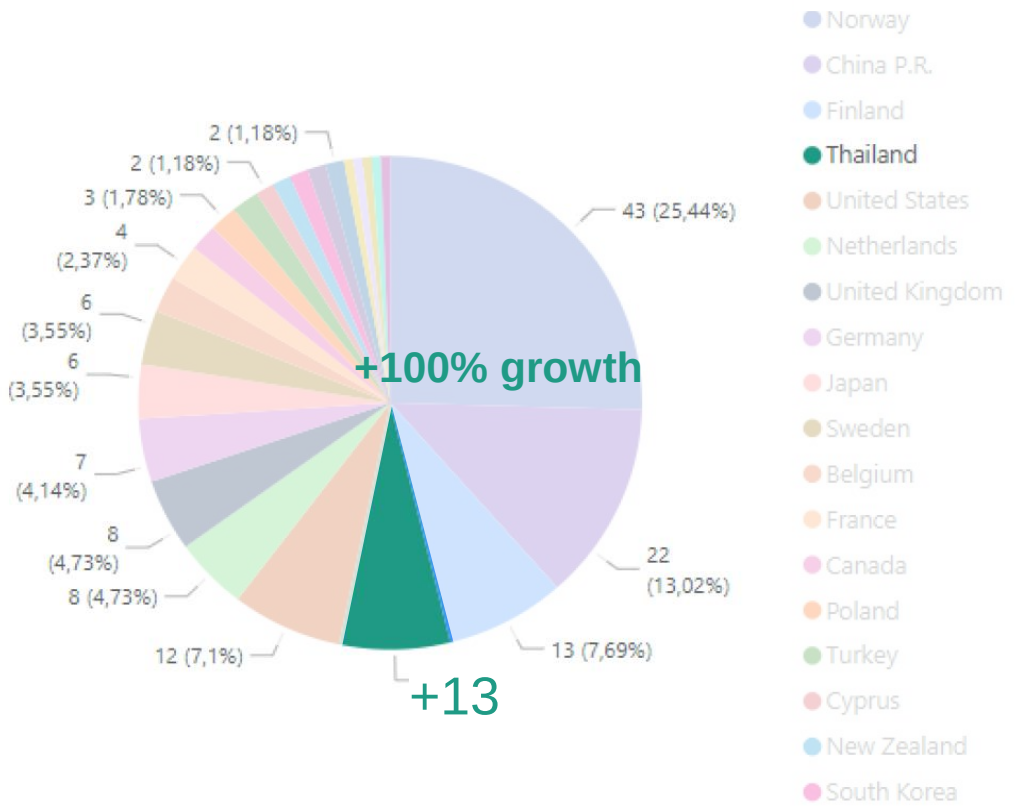

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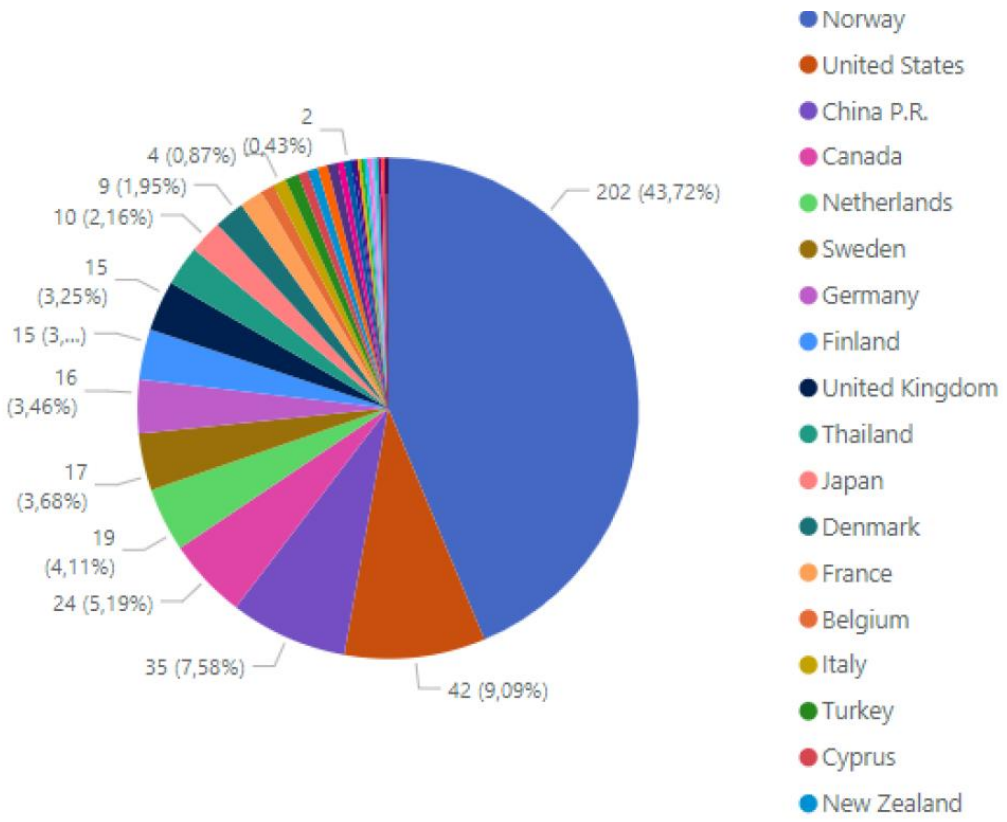

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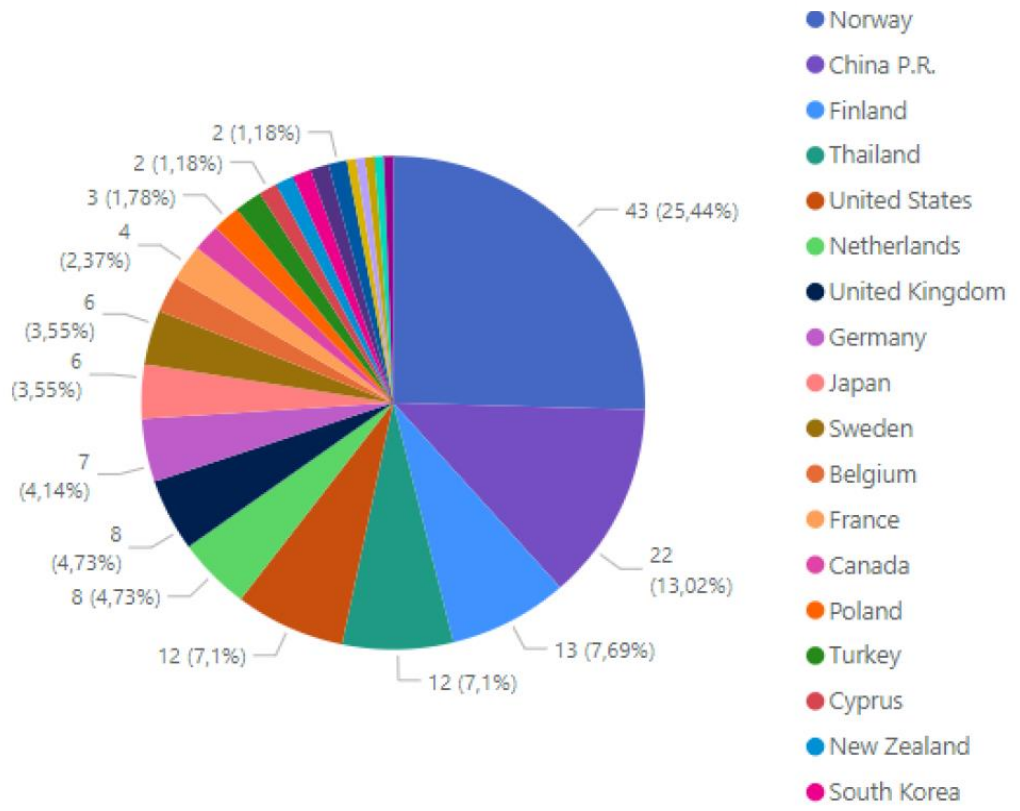


Source: Clarkson WFR (2022)

Technology Update

- ✓ Current technology trends
- ✓ Technology developments, short- to long term

Battery research drivers

Stationary systems:

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

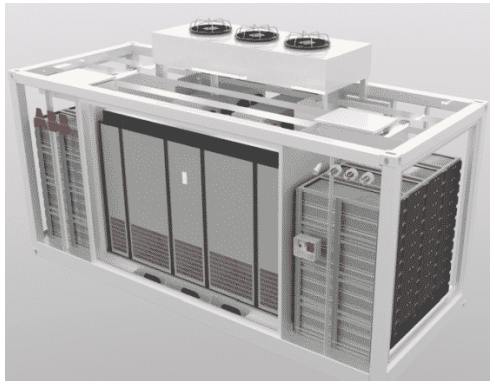
Automotive and Consumer Electronics:

- Higher **specific energy**, **energy density** and **specific power**
- Structural changes of the electrodes, which affect both lifetime and safety.

Current technology trends (marine systems)

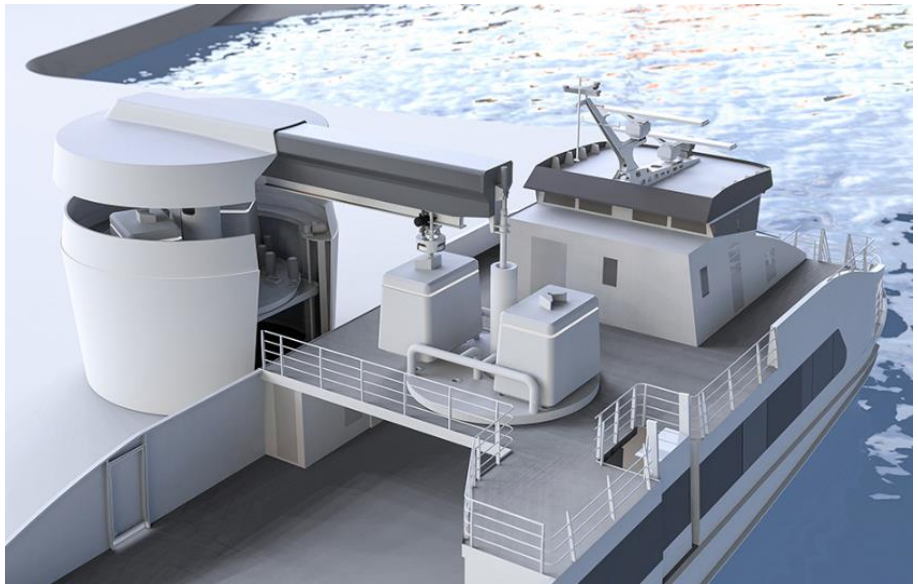
Rising demand for containerized battery installations.

- DNV has a battery container type approval programme.
- Size: 10 ft. 7– 800 kWh, 20 ft. 1.5 – 2.0 MWh.

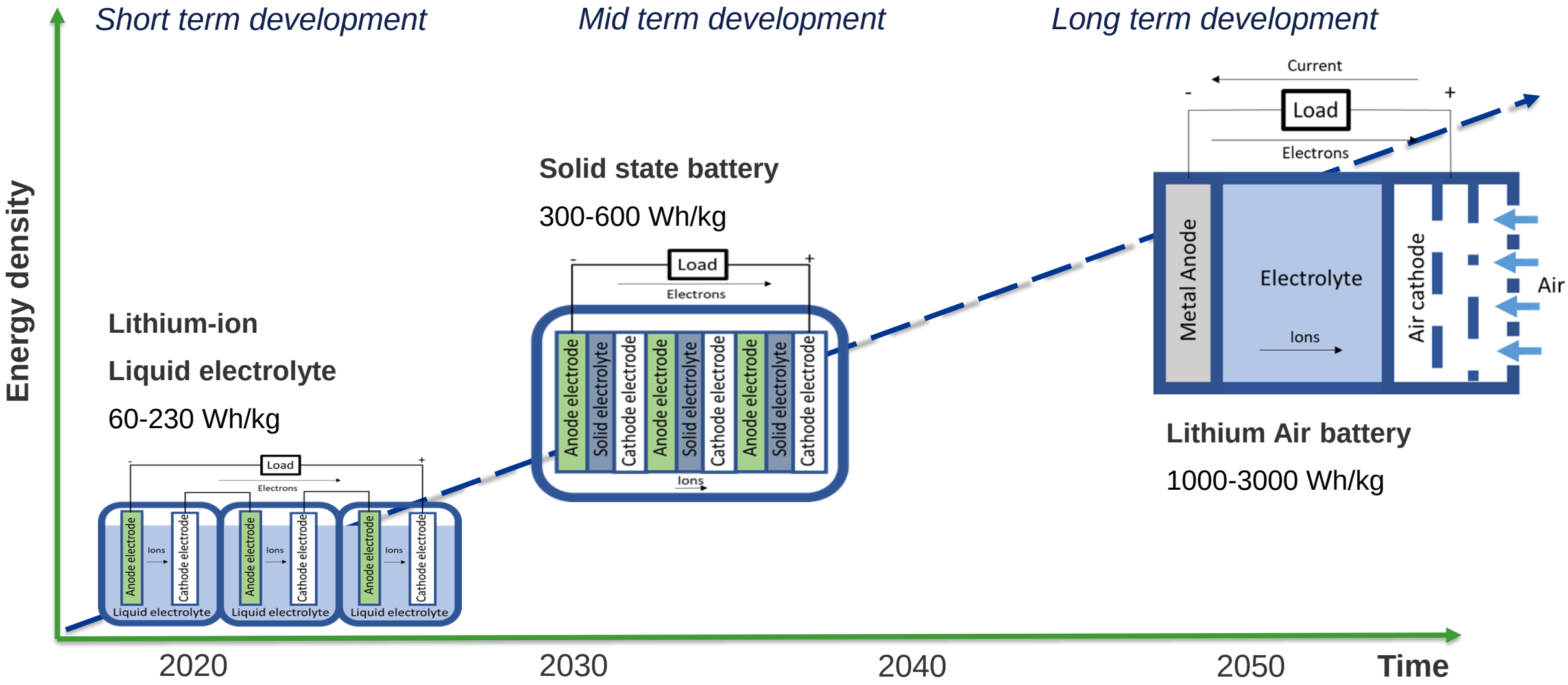


Swapping of battery modules/containers as an alternative to fast charging capabilities.

- Under development by several companies.
- Both regular 20 ft. containers and special made marine grade packs are under development

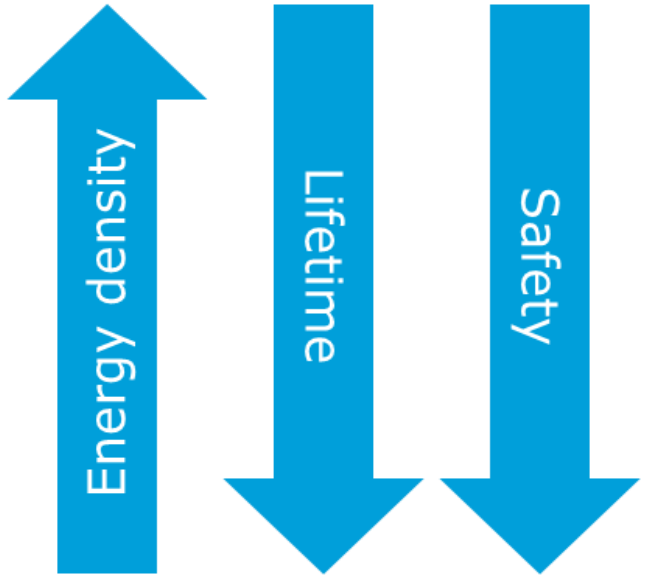


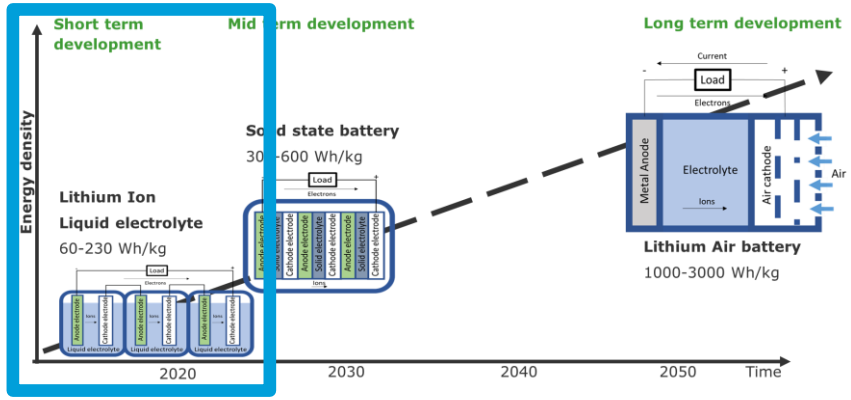
Technology developments



Short term development

- Pushing towards **maximum energy density** and **minimum cost**.
  - Silicone in the anode:
    - increases energy density,
    - decreases lifetime (expands when cycling)
  - Lower cobalt, higher nickel content:
    - reduces cost,
    - increases energy density,
    - decreases lifetime,
    - decreases thermal stability
- Hard to produce commercial batteries over 300 Wh/kg.
  - Close to the theoretical limit of conventional liquid electrolyte lithium-ion batteries.





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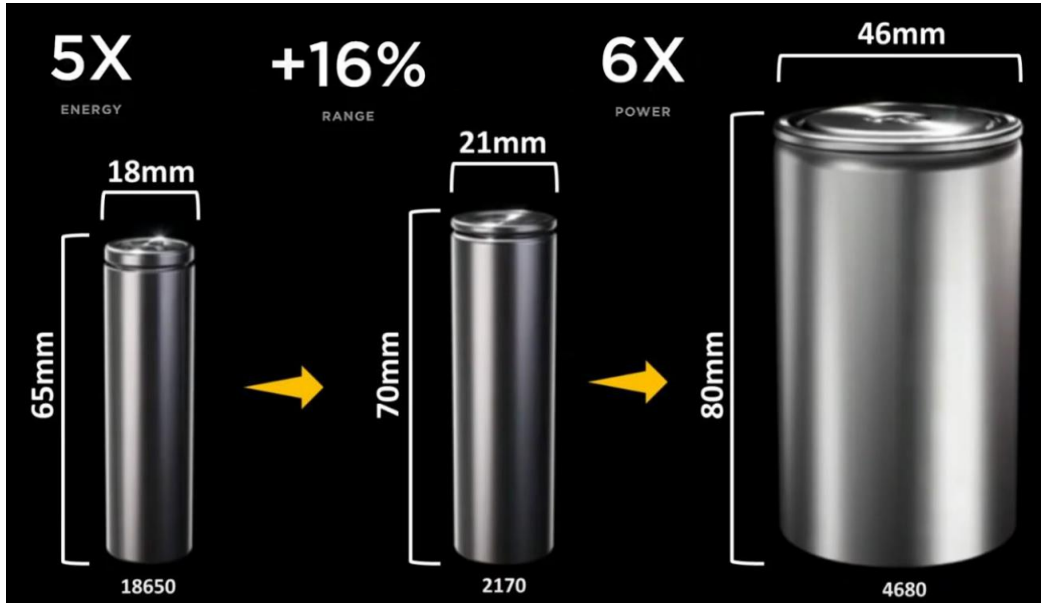
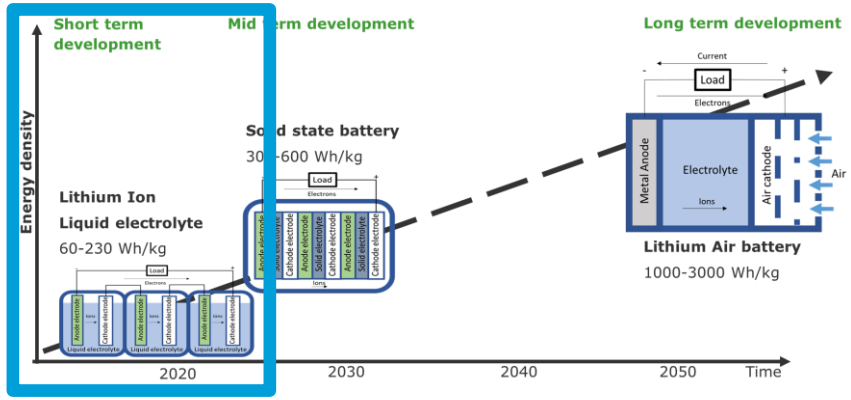
- Hard to produce commercial batteries over 300 Wh/kg.
  - Close to the theoretical limit of conventional liquid electrolyte lithium-ion batteries.
- Cell form factor and pack optimization remain important topics for increasing Li-ion power and/or energy density.

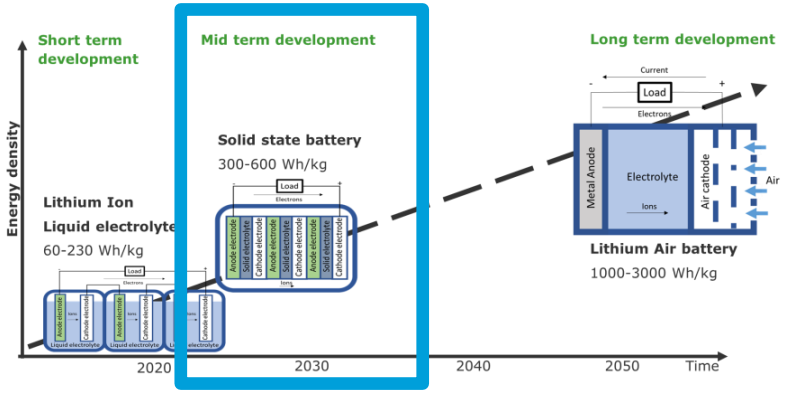
Source: Tesla (2021)



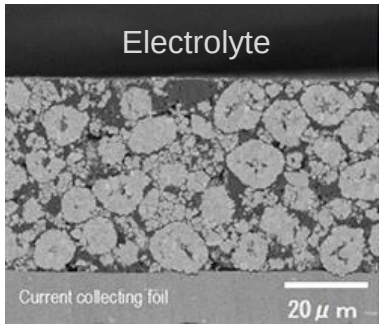


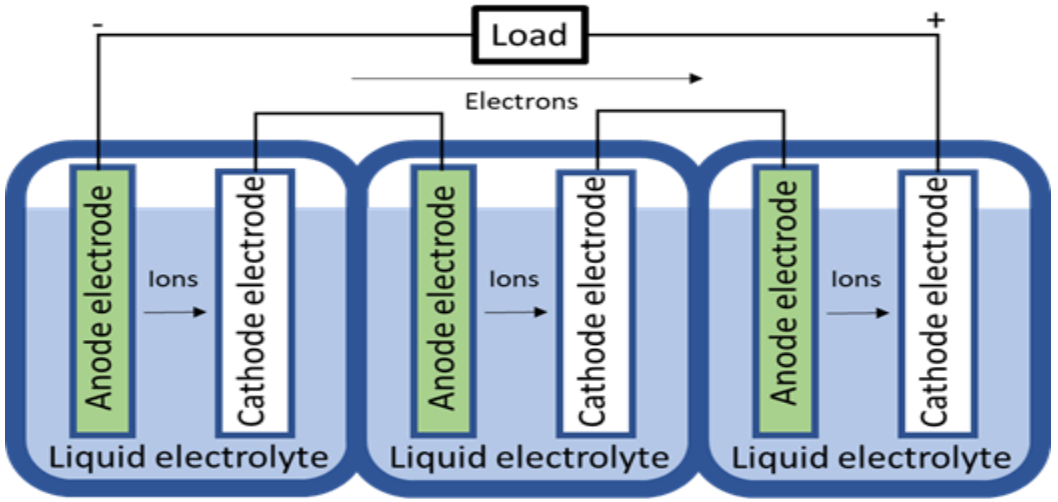
Mid term development

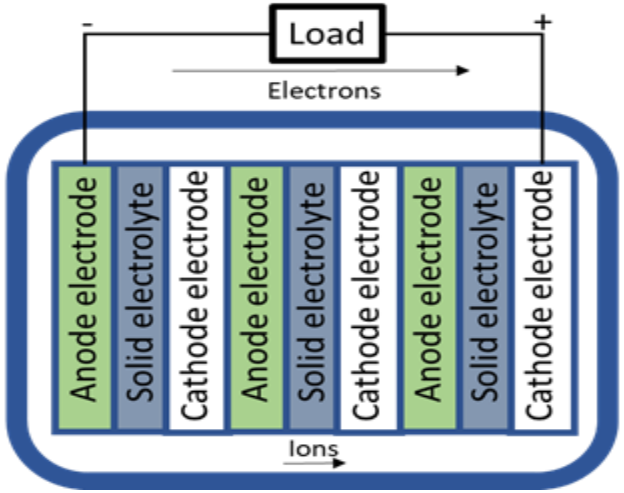
- **Solid State Batteries:** Use a solid electrolyte instead of liquid
- **Energy density increases:** May be 3 times higher than conventional batteries
- **Safety improvements:** Not as flammable and do not produce explosive gas
- **Challenges:** Low conductivity and interface resistance. Perform poor in cold weather. Electrodes and electrolyte might swell. Expensive.



Not a smooth surface!



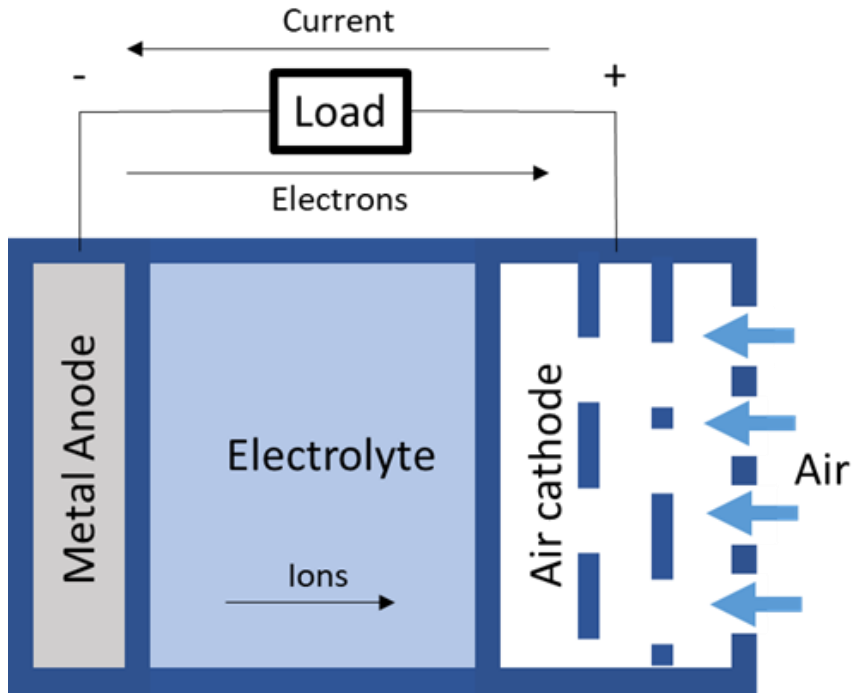


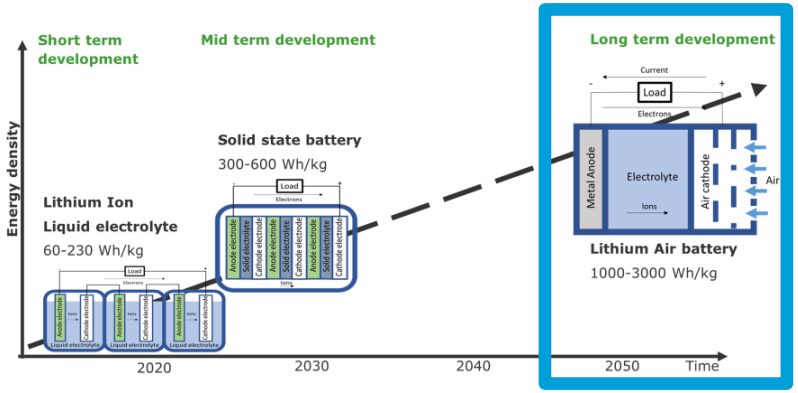


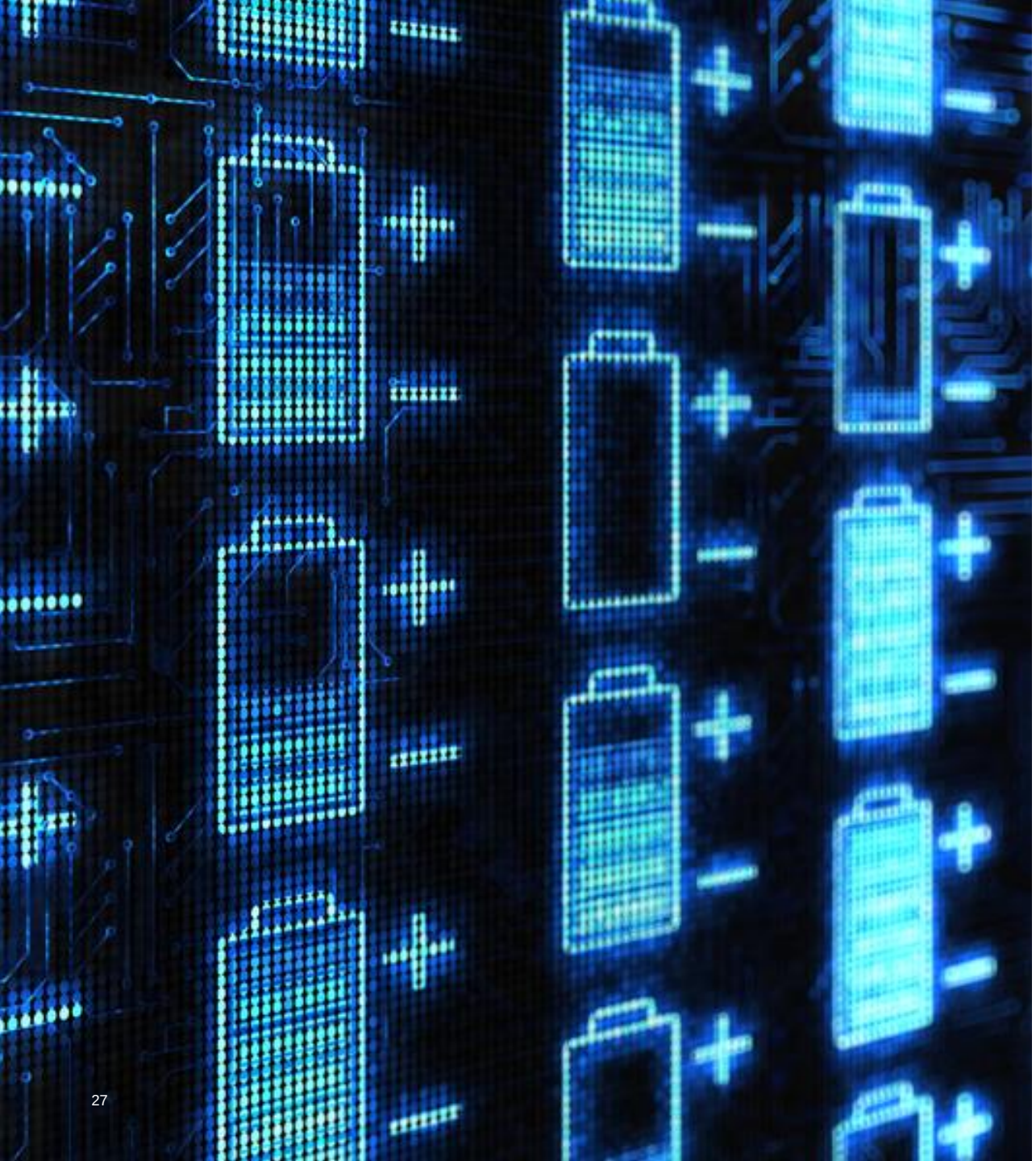
Practical energy density reduction

Long term development

- **Lithium Air:** Cathode reacts with oxygen in air
- **Energy density increases:** May be 5-13 times higher than conventional batteries.
- **Challenges:** Vulnerable to moisture and CO_2
- **Early research:** No stable electrolyte found yet. Solid state electrolytes might solve some key challenges, like dendrite growth and electrolyte volatility.







Summary

- Short term price increases expected
- Strong market developments expected to continue in America and Asia, in addition to healthy growth in North-Europe.
- Current liquid electrolyte Li-ion cells will struggle to reach 300 Wh/L, getting close to theoretical limit.
- The jury is unfortunately still out on Solid state batteries and suitability for the marine market
- Lithium-air could unlock deep sea applications for fully battery electric ships.

Thank you for listening

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