A non-academic perspective on the future of lithium-based batteries.

The role of third-party validation and technology assessment.

James T. Frith
Principal
Volta Energy Technologies

Matthew J. Lacey
Senior Engineer
Scania

Ulderico Ulissi
Advisor
Sphere Energy SAS

Lukas Lutz
Co-founder
Sphere Energy SAS

Welcome!

Let's start with a quick temperature check of the (impressive crowd!)

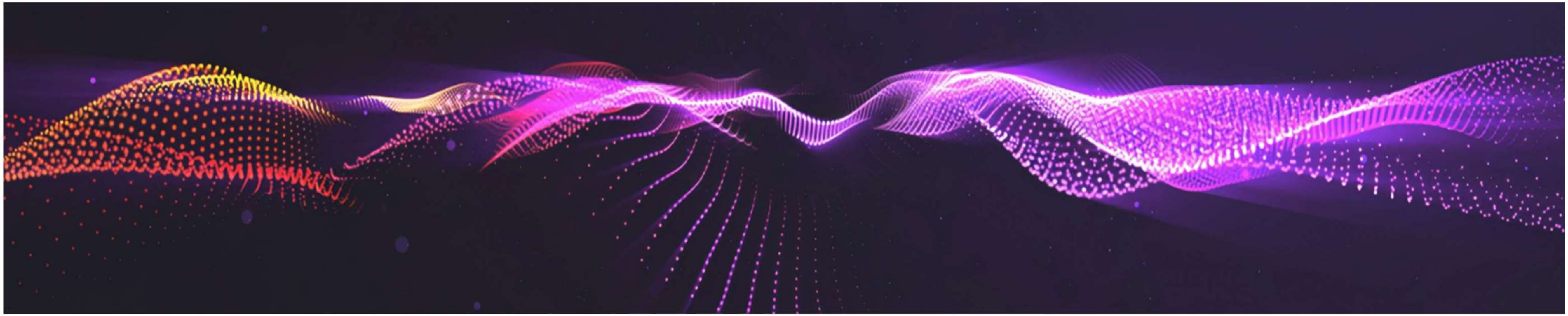
- ***Industrials:*** *What is your biggest challenge with battery technology?*
- ***Academics**: What is your biggest challenge when developing new battery technology?*

The agenda for today

1. **Theory vs. reality**
   Dr. Matthew Lacey
2. **Innovation – Lab to market**
   Dr. Uldercio Ulissi
3. **Why you need to understand markets**
   Dr. James Frith
4. **A proposed solution**
   Dr. Lukas Lutz

The agenda for today

1. **Theory vs. reality**
   Dr. Matthew Lacey
2. **Innovation – Lab to market**
   Dr. Uldercio Ulissi
3. **Why you need to understand markets**
   Dr. James Frith
4. **A proposed solution**
   Dr. Lukas Lutz

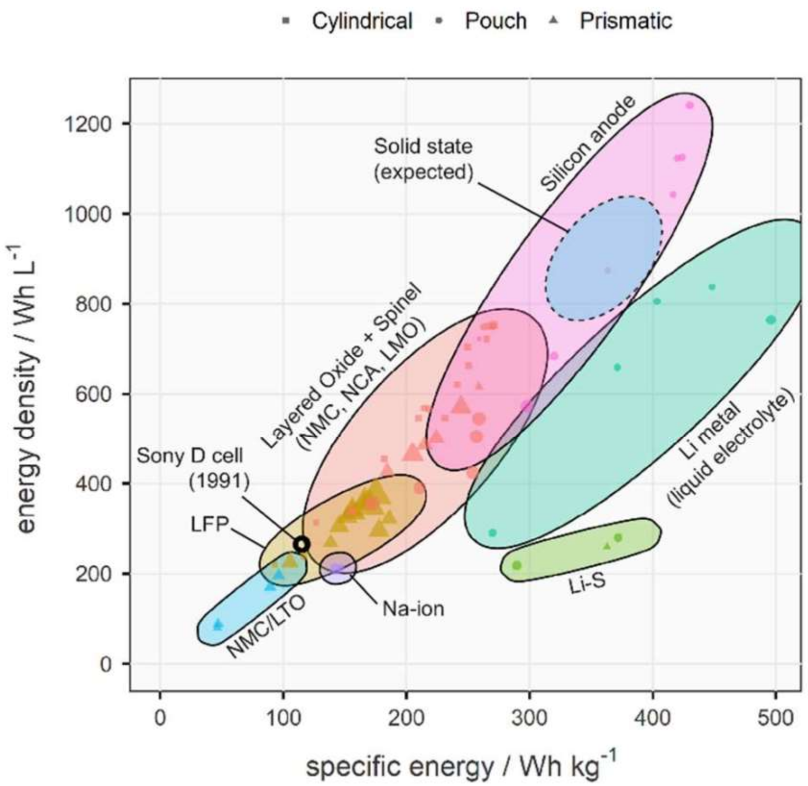


Theory vs. Reality

Dr. Matthew Lacey

Lithium batteries – State of the art

Current state-of-the-art (cell level)
based on publicly available specifications



Key Performance Indicators (KPIs), e.g., for an EV

- Range *(gravimetric and volumetric energy)*
- Power capability *(charge/discharge, pulse, IR)*
- Efficiency *(energy, coulombic)*
- Lifetime *(and available State-of-Charge)*
- Cost per energy *($/kWh)*
- Operating temperature and pressure
- Safety at the system level
- Overall system cost, including EOL
- CO_{2e} emission to produce a pack *(CO_{2e}/kWh)*
  - with carbon taxes, CO_{2e} = $

Lithium-ion cells are complex devices, and each component will generally influence each KPI

Other considerations (incl. socio-economic)

- Manufacturing, scalability
- Supply chain, geopolitical issues
- Capital investments required, “ESG” risks
- Thermodynamic versus technological limit

What's wrong with these sentences...?

one of the most desirable aspects of future energy technologies. Beyond Li-ion batteries, Li–S is of great relevance to follow as it adapts to the specificity of each application. It is among the most suitable elements for high-performance energy storage systems, given its high theoretical capacity (1674 mA h g^{-1}) and energy density (2600 W h kg^{-1}) relative to Li-ion batteries (300 W h kg^{-1}).

$LiMnO_2$) [2]. Beyond the limitations of Li-ion batteries (typically around 150–200 Wh kg^{-1}), lithium-sulfur (Li-S) system is promising owing to its low cost and high theoretical energy density (~2567 Wh kg^{-1}), safety, a wide temperature range of

to clean and sustainable energies nowadays.[1] As candidates for storing electric energy,[2] Li-ion batteries have been limited by their theoretical energy densities (~350 Wh kg^{-1}) that made it far from meeting the real demands.[3]

In comparison Li-O_2 battery has an ultrahigh theoretical specific energy density (about 3500 Wh kg^{-1}) and been expected to be used for next-generation rechargeable batteries. If Li

From battery theory to battery pack

theory	‘reversible’	cell	pack
2390 Wh/L	**1865** Wh/L	**675** Wh/L	**270** Wh/L

materials chemistry (theory → ‘reversible’)

engineering (cell → pack)

Representative example, based on graphite-SiO_x || NCA cylindrical cells

From battery theory to battery pack

Image: Tesla Motors club user wk057

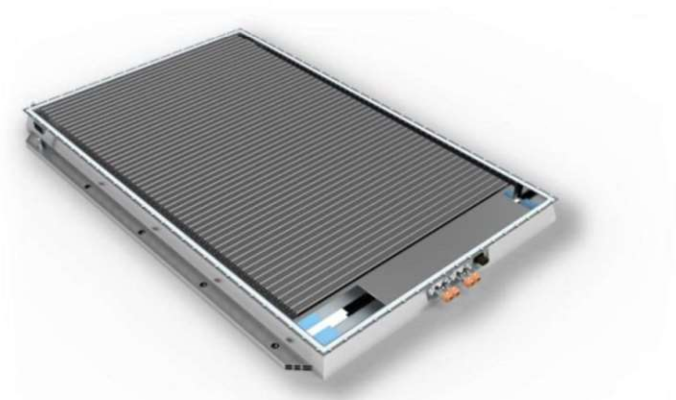
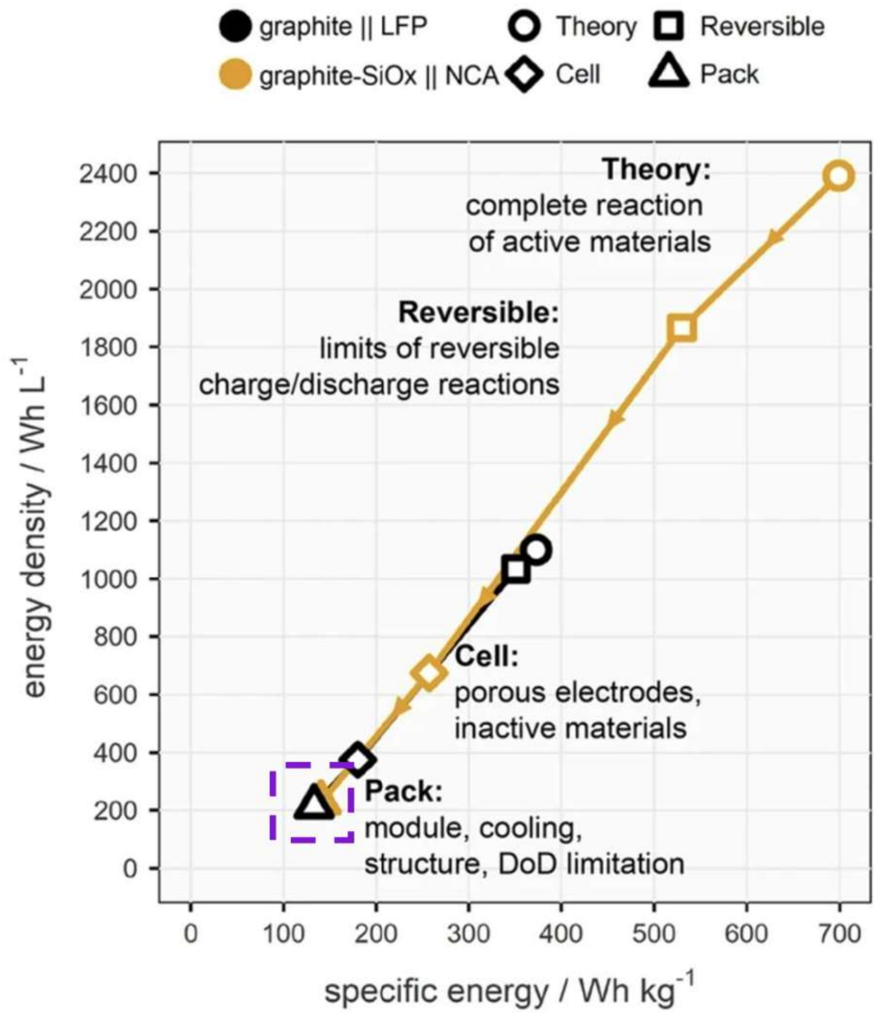


Image: BYD



Food for thought

i. **Inappropriate comparisons** of apples to oranges are very common (e.g. theory to cell-level metrics)

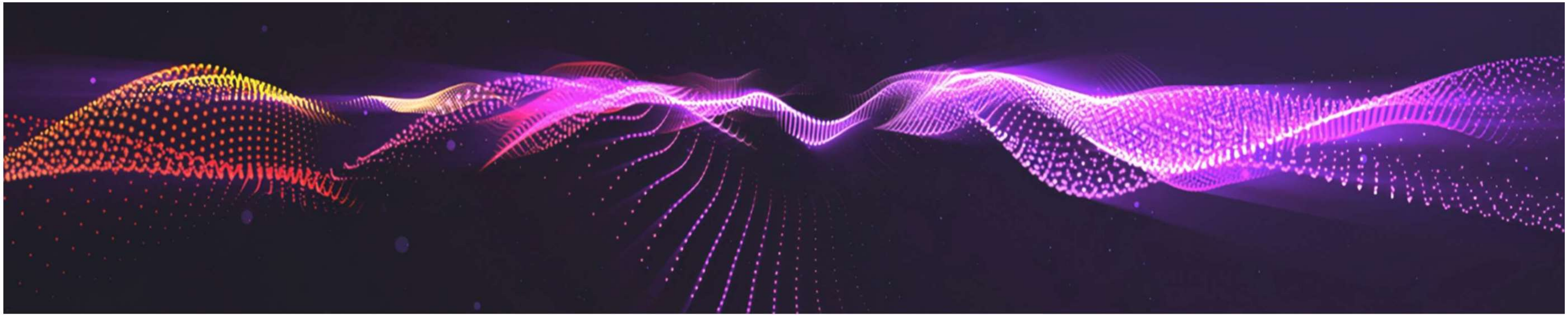
ii. Extrapolating from one scale (or chemistry) to another is tempting, but **will be misleading** if the bottlenecks change

iii. Manufacturers have exploited the better thermal stability of **LFP** to produce highly **volume-efficient packs**, significantly improving energy density **without much innovation in underlying chemistry**

iv. Up to now, automotive industry has largely sought **energy density improvement** via **next-gen chemistries** (Si anode, solid state etc), with **market introduction not expected until later this decade**

The agenda for today

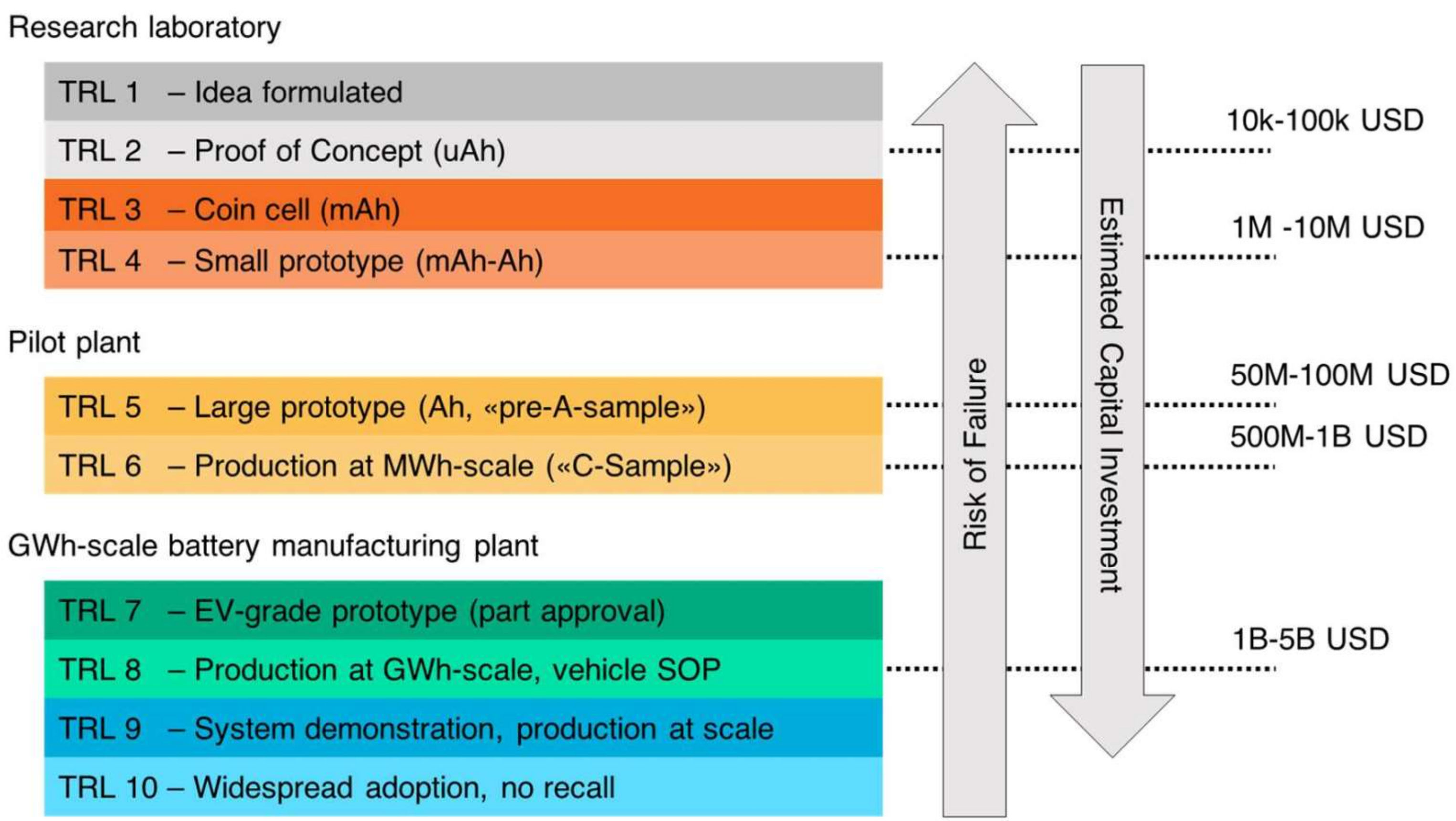
1. **Theory vs. reality**
   Dr. Matthew Lacey
2. **Innovation – Lab to market**
   Dr. Uldercio Ulissi
3. **Why you need to understand markets**
   Dr. James Frith
4. **A proposed solution**
   Dr. Lukas Lutz



Innovation – Lab to market

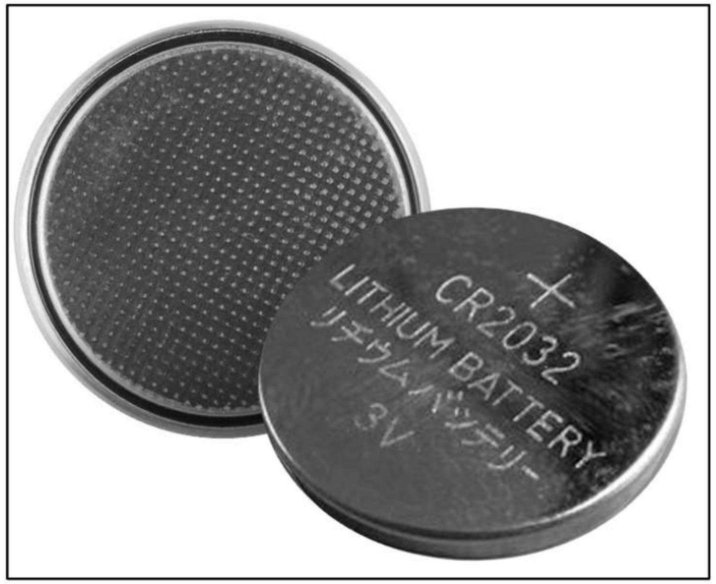
Dr. Ulderico Ulissi

From the lab to the "GWh"-factory



- **Technology Readiness Levels** can be used to assess the maturity of a technology
- For **EV** market adoption, a battery and its sub-components **need** to be mass-manufactured

What is the order of magnitude?



One "2032" coin-cell (mWh)

- 1.6cm Ø positive electrode
- Positive electrode active material loading: $4 mg/cm^2$
- **8mg of "cathode active material" (CAM)**

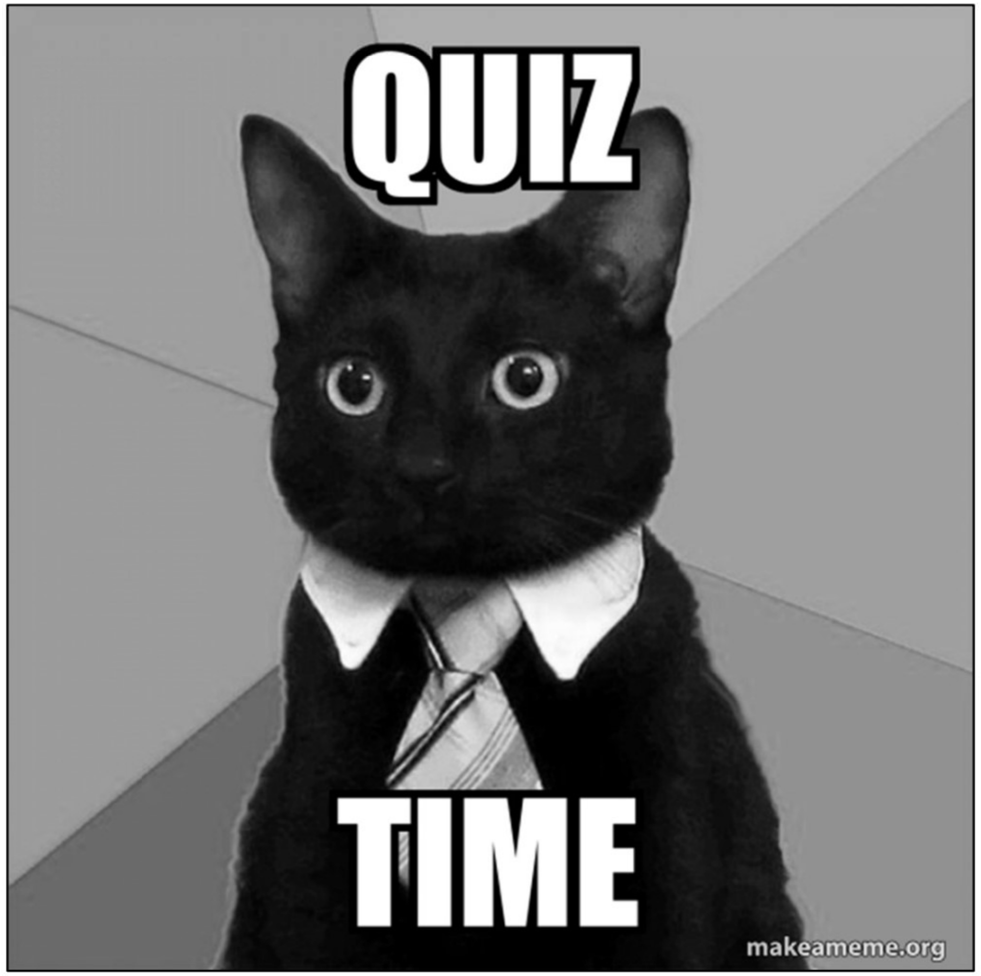
One 75 kWh Tesla 3 pack

How much more "cathode active material" is required to manufacture one pack?

Images: https://www.secondlife-evbatteries.com/products/tesla-model-3-75kwh-pack, https://amimarine.com/product/cr2032-coin-cell-battery/

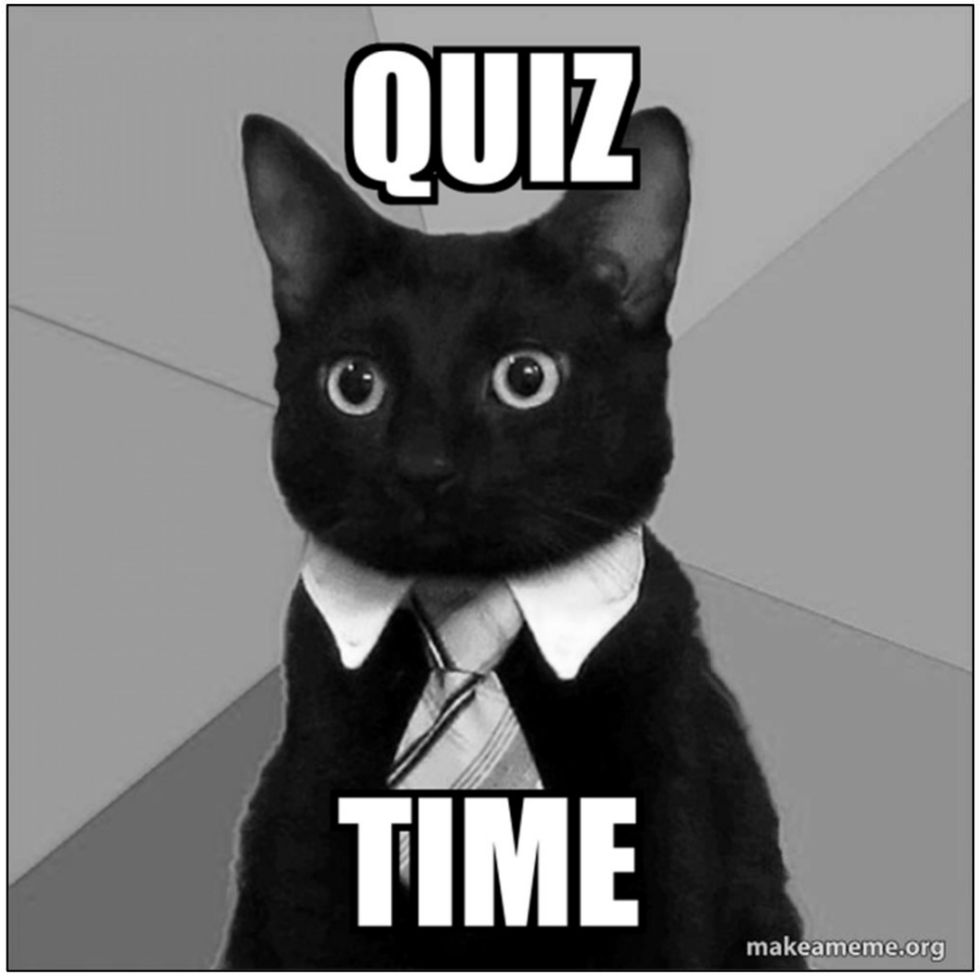
One 2032 coin-cell can require 8mg of “CAM"

How much more is contained in a Tesla 3 Pack (75 kWh)?



One 2032 coin-cell can require 8mg of “CAM"

How much more is contained in a Tesla 3 Pack (75 kWh)?



Answer:

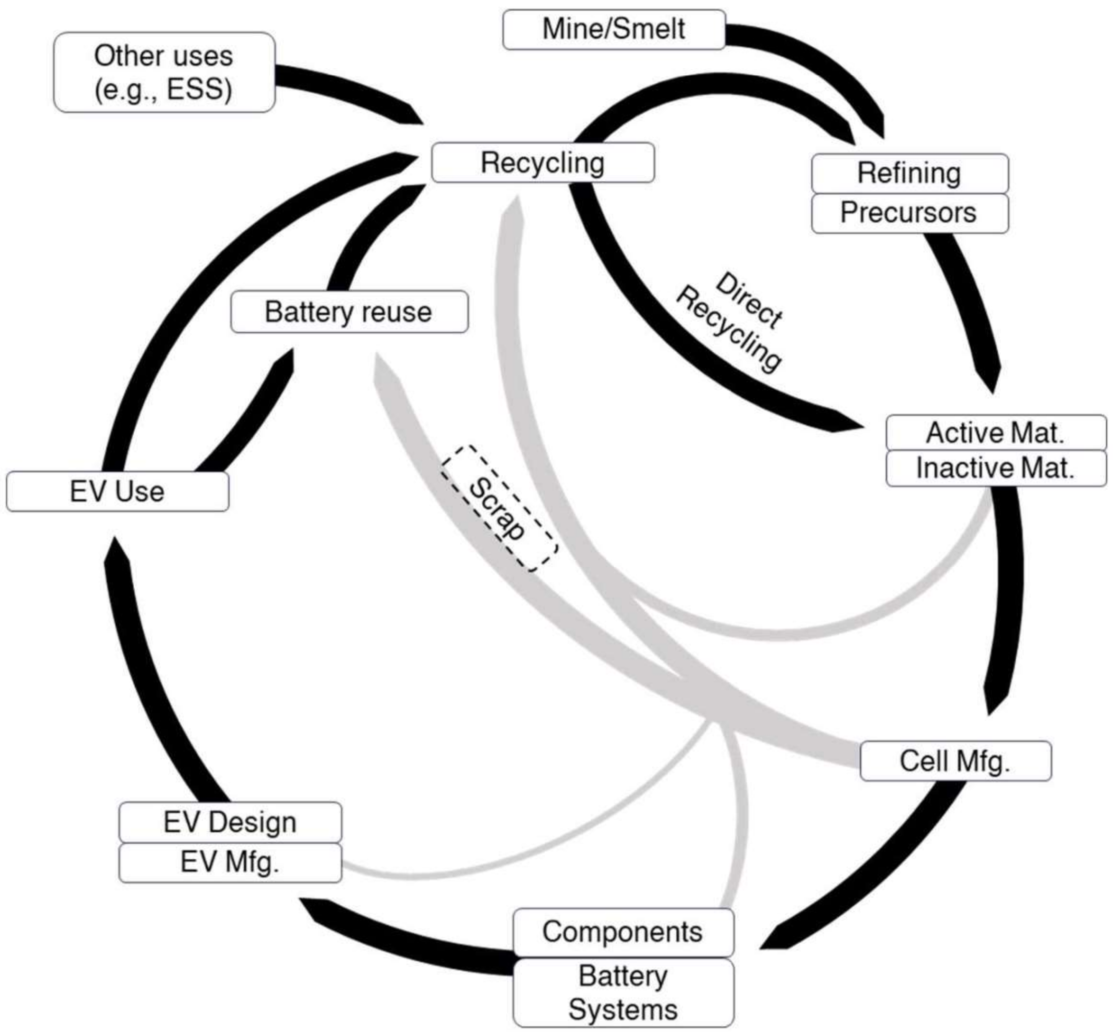
14,000,000x (ca. 110kg)

One “10 GWh/y” battery pack manufacturing plant could produce enough batteries for ca. 130,000 Tesla 3 per year. It would require **at least** 14,300 tonnes of “cathode”.

Umicore EU cathode active material plant in Nysa, Poland, is expected to reach a capacity of 40 GWh/y in 2024.

In 2022, global EV sales reached 10M (with an average pack size of 40-60 kWh)

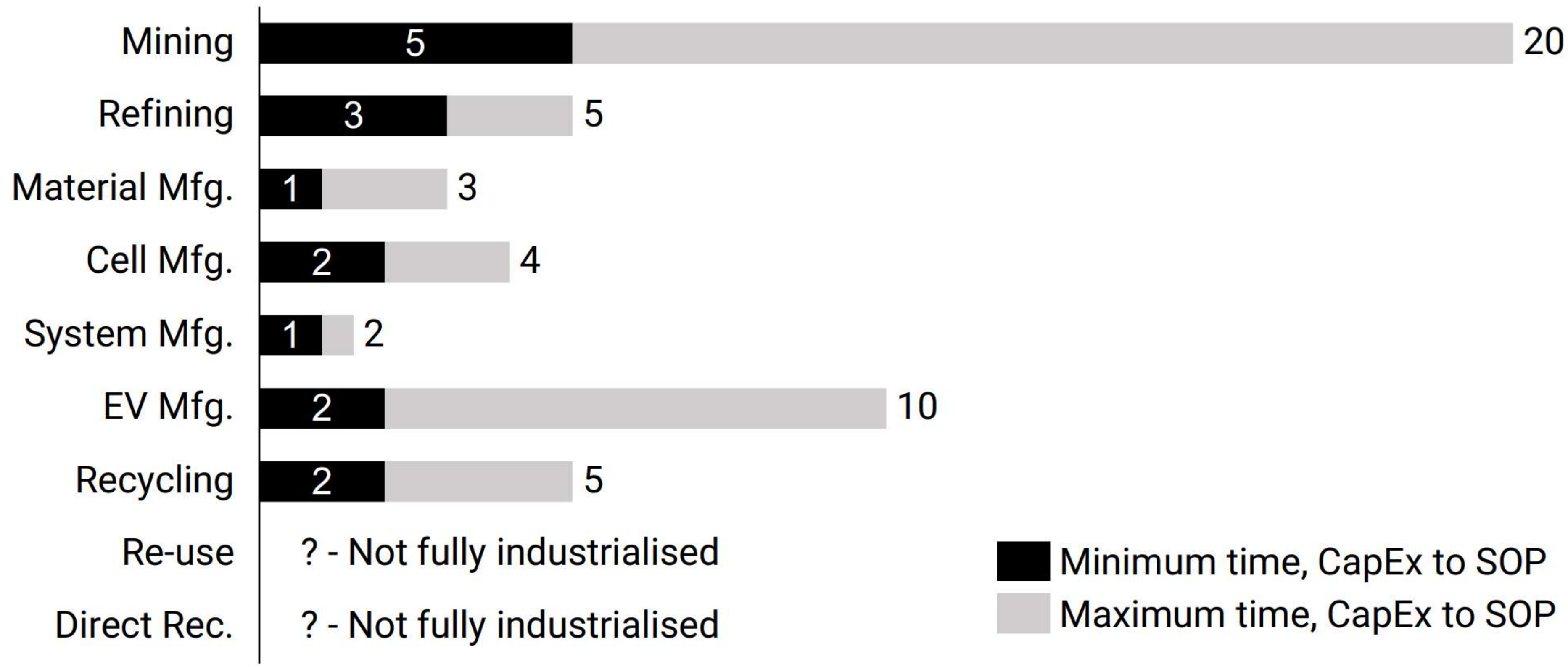
Understanding complex supply chains is crucial



Each step can require a diverse set of expertise

- Operating a “cathode” (chemical) plant is **radically different** from operating a “cell” manufacturing plant (high-precision, high automation)

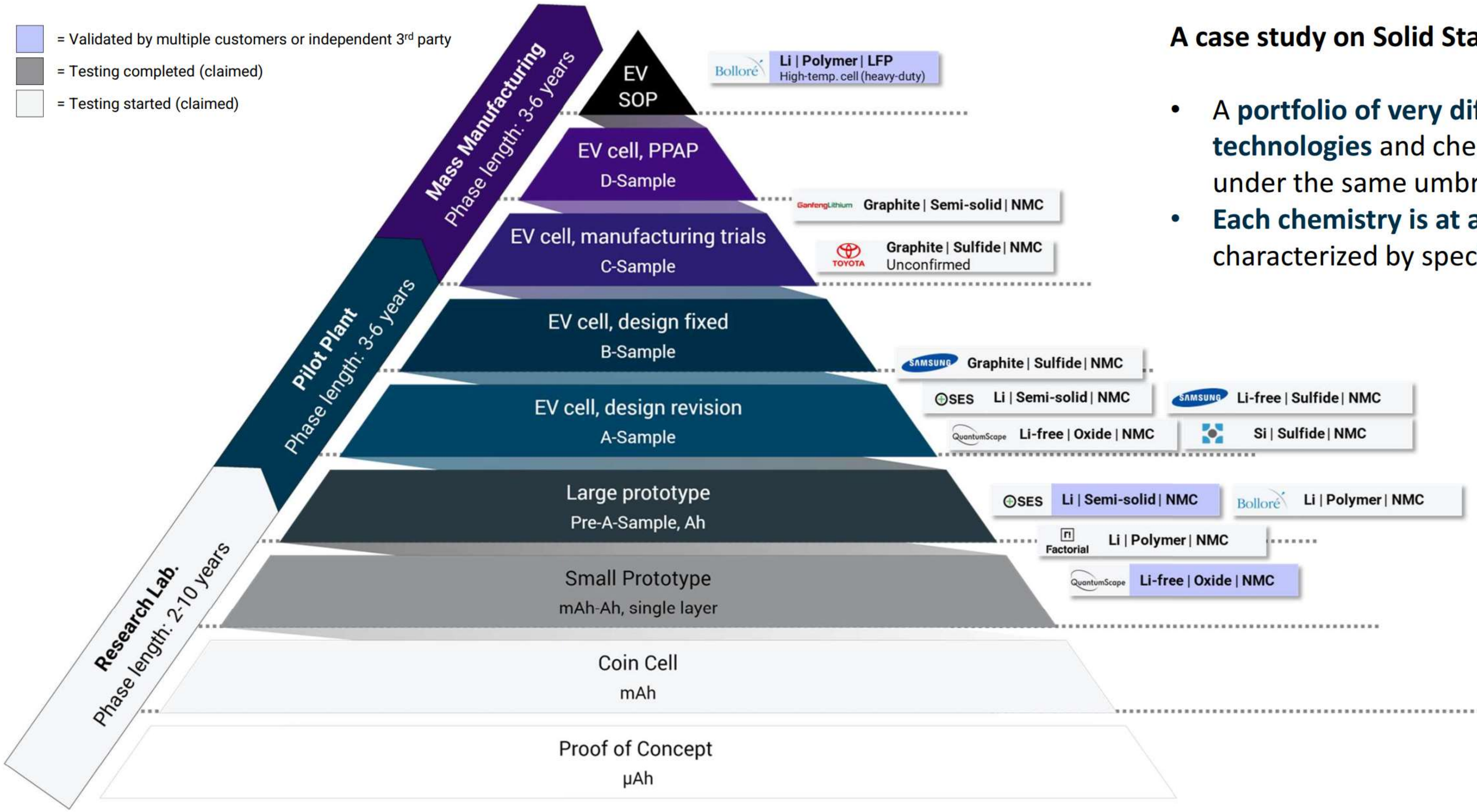
Time-to-market varies



Even if we consider that a **company is scaling up a mature technology** and has all the required **know-how, setting up a manufacturing plant can take several years**

- *CapEx: Capital expenditures (when a company spends money)*
- *SOP: Start-of-Production (when a company starts manufacturing)*

It is a long way to the “SOP”

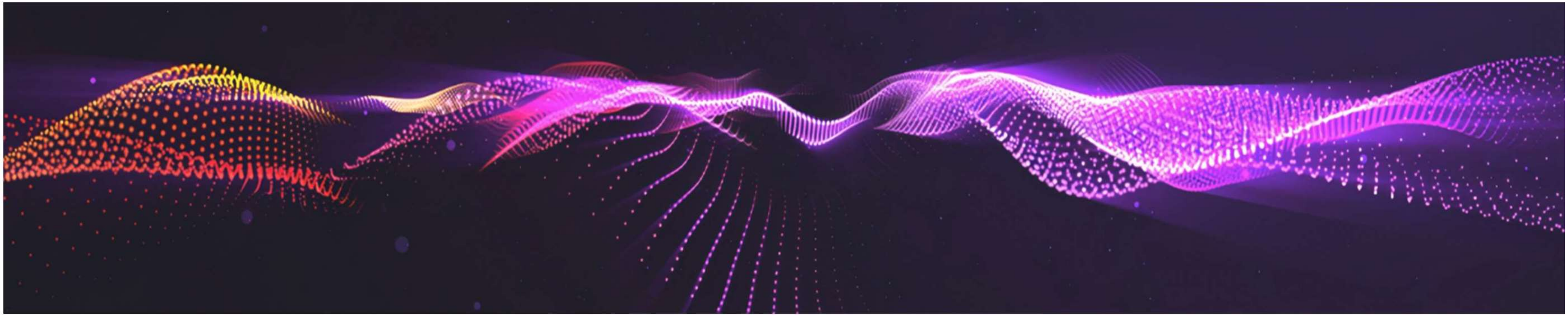


A case study on Solid State Batteries

- A **portfolio of very different technologies** and chemistries often under the same umbrella
- **Each chemistry is at a different TRL** and characterized by specific challenges

The agenda for today

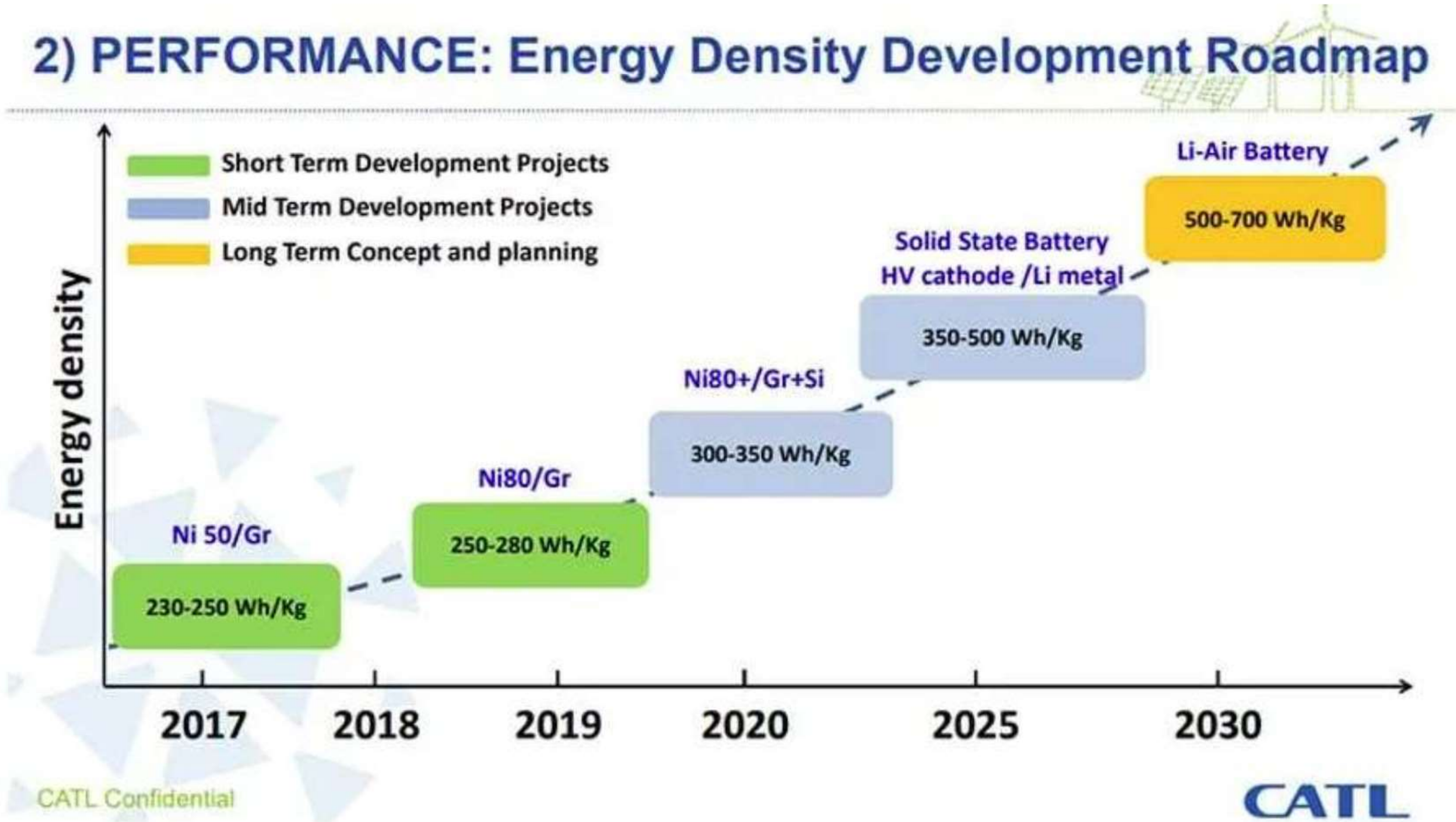
1. **Theory vs. reality**
   Dr. Matthew Lacey
2. **Innovation – Lab to market**
   Dr. Uldercio Ulissi
3. **Why you need to understand markets**
   Dr. James Frith
4. **A proposed solution**
   Dr. Lukas Lutz



Why you need to understand markets

Dr. James Frith

Technology roadmaps are misleading

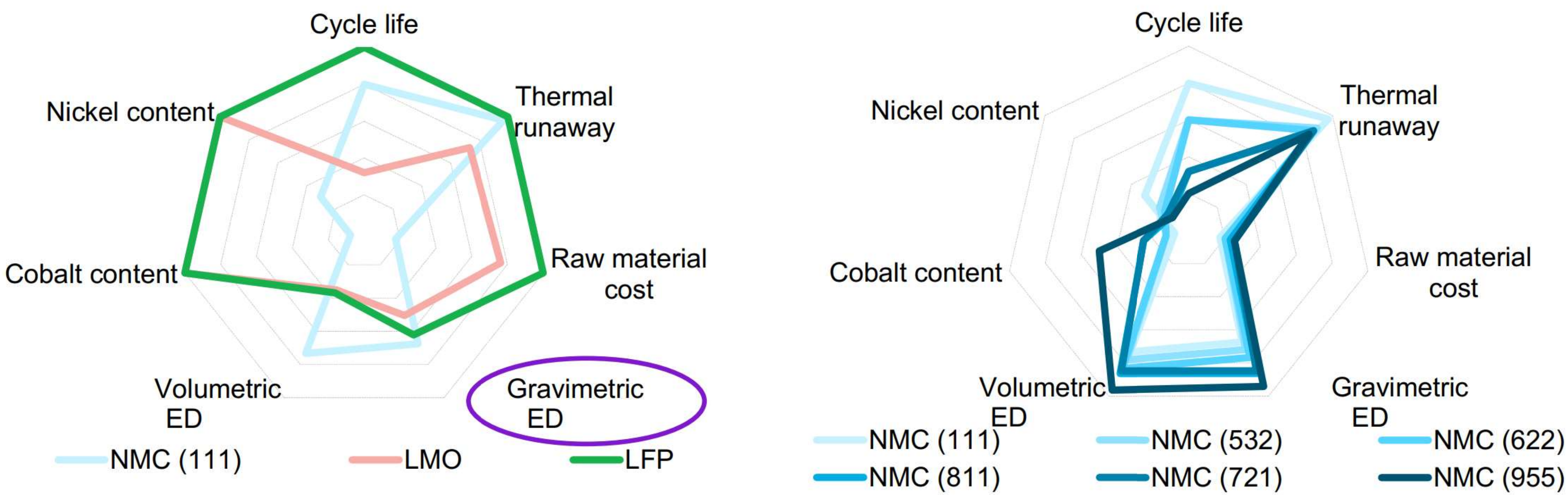


- Industry should be actively helping academia to focus on the **most beneficial lines** of research
- The best guidance industry provides on technology development is its **technology roadmaps**
- New entrants to the field of battery research may misinterpret key takeaways
- Industry wants more energy density, but why?

https://insideevs.com/news/428508/catl-2-million-km-battery-not-tesla/

These only tell you about one key metrics

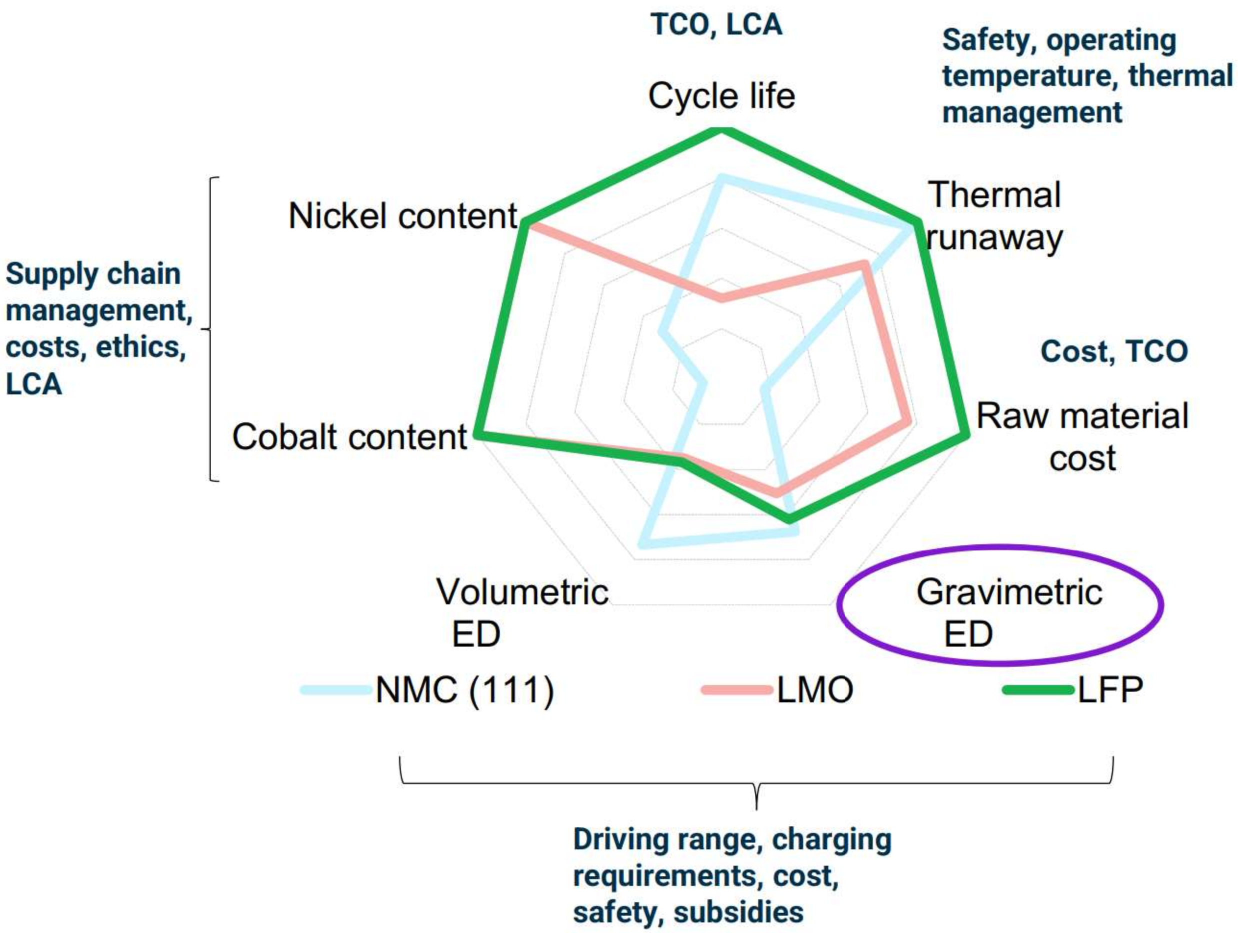
Impact of cathode choice on performance

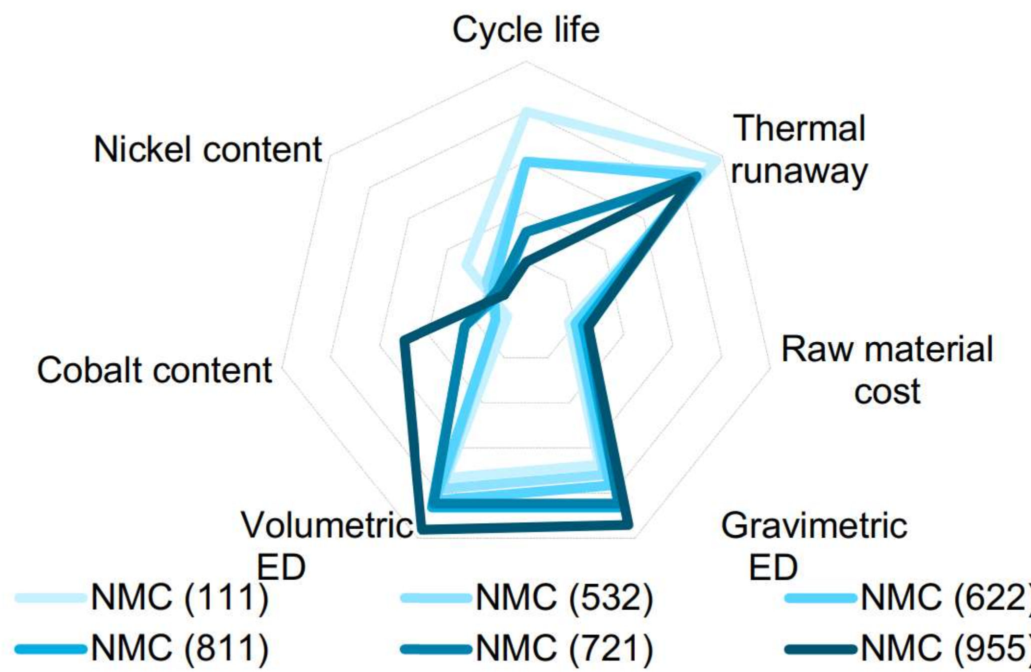


- These roadmaps usually only show gravimetric energy, but **volumetric is often more important** and **difficult to extrapolate** from "materials" or even "gravimetric" cell data.
- They also suggest that **only one or maybe two** types of technology **can achieve this performance**. **volumetric is often more important**

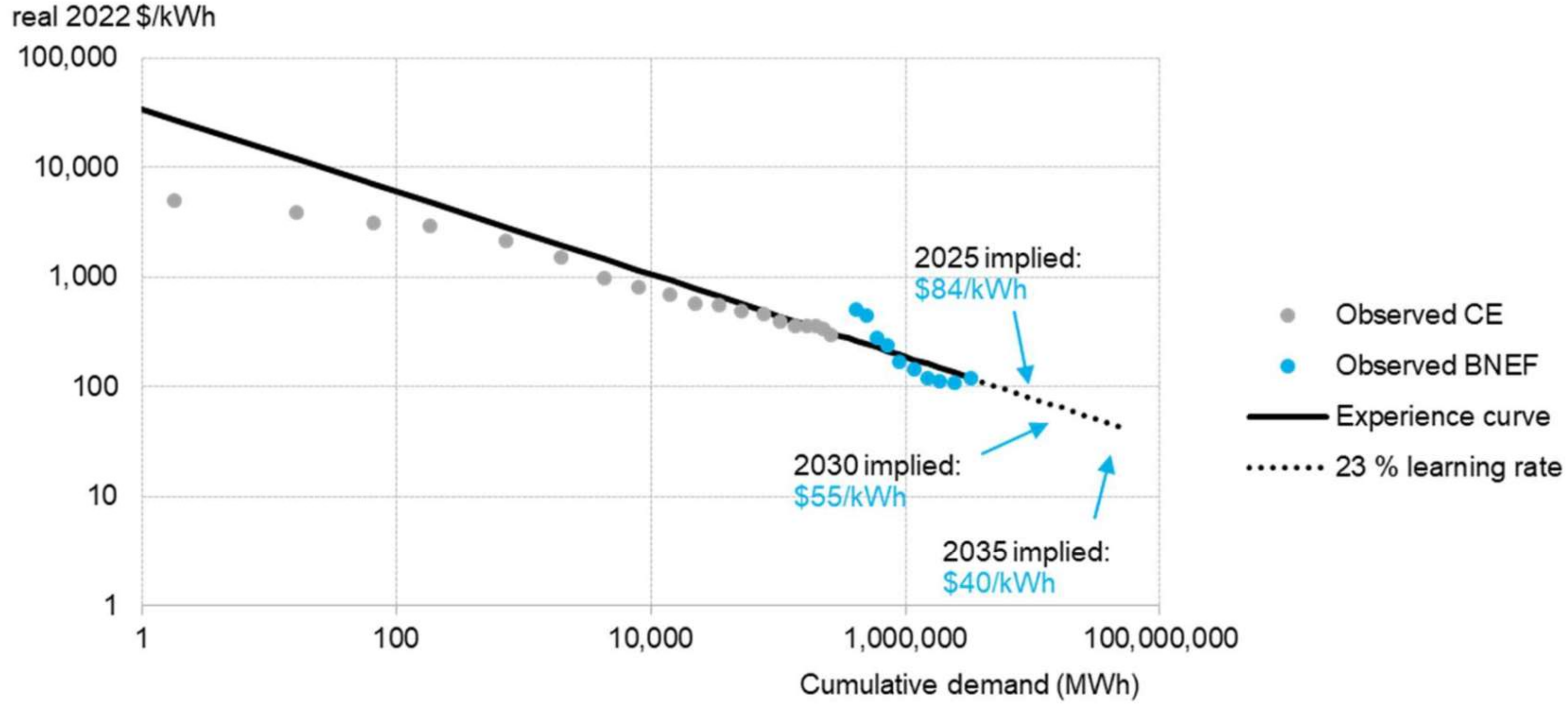
BloombergNEF, 2022 Lithium-Ion Battery State of the Industry

Metrics need to be translated into **device performance**





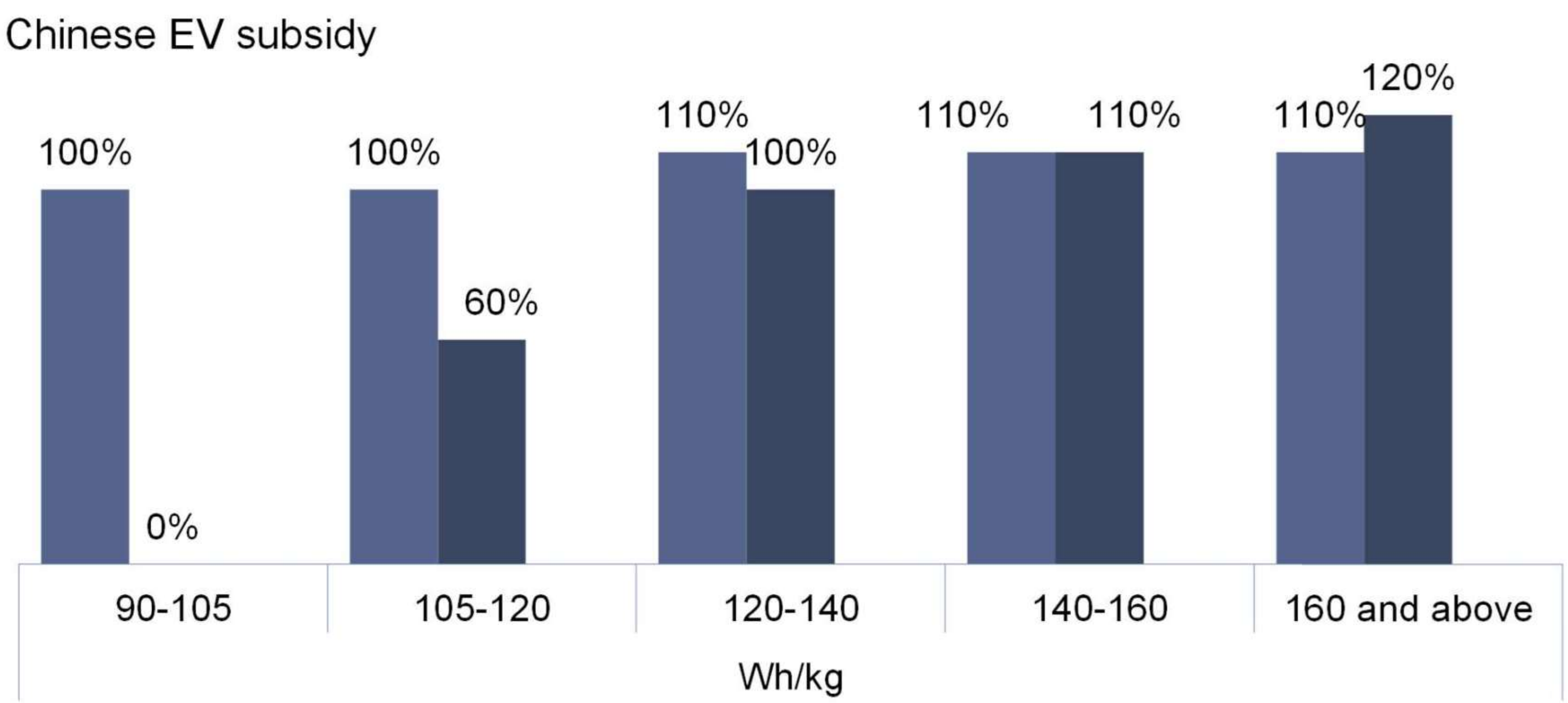
Metrics need to be translated into device performance



- Even when they say it is not about the money.... **it is all about the money**.
- Technological advances are generally only adopted if they are **lower-cost** than the incumbent technology **or have a viable cost-down trajectory**.

BloombergNEF, 2022 Lithium-Ion Battery Price Survey

The industry needs to be reactionary

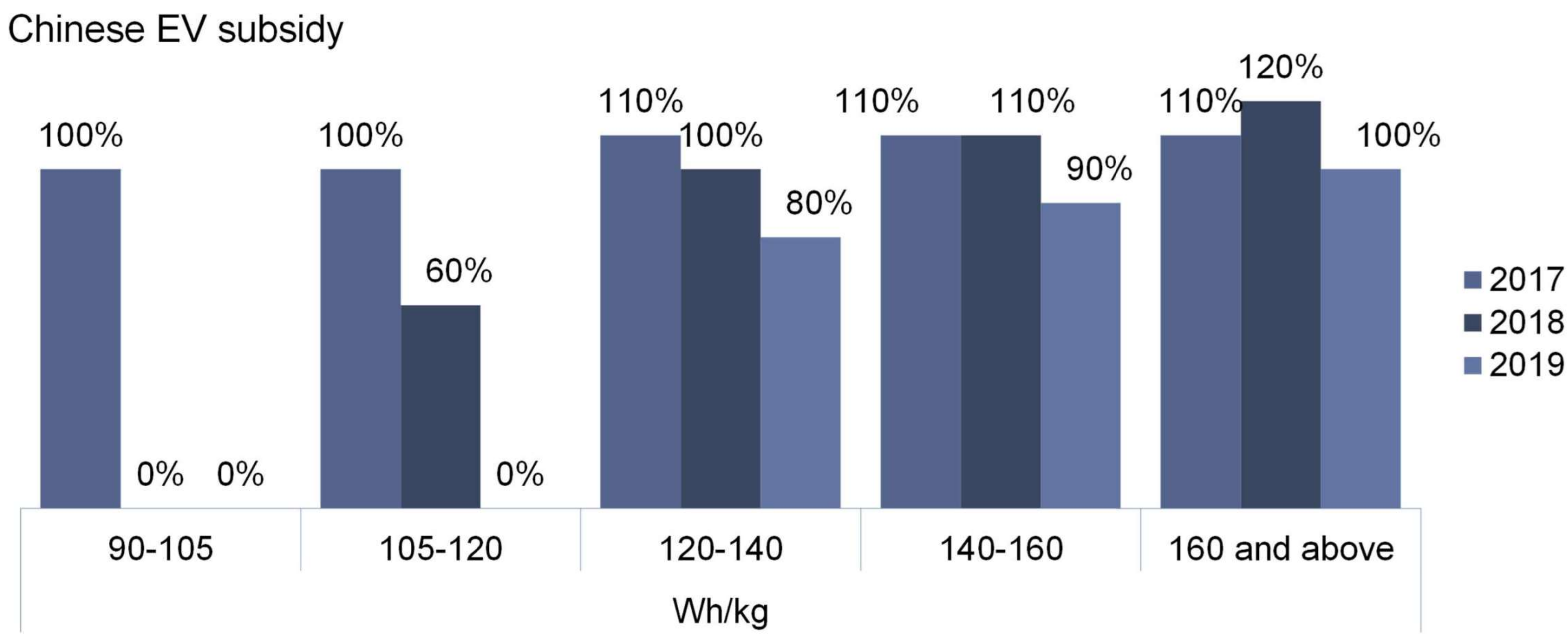


The percentage indicates the max. subsidy amount EVs with this performance can receive.

- Chinese subsidies varied depending on the battery pack size, energy density and vehicle range.
- In 2019, subsidies were slashed from a maximum of $6,600 to ~$3,700.
- The percentage indicates the maximum subsidy amount EVs with this performance can receive.

BloombergNEF, China Slashes EV Subsidies by Half

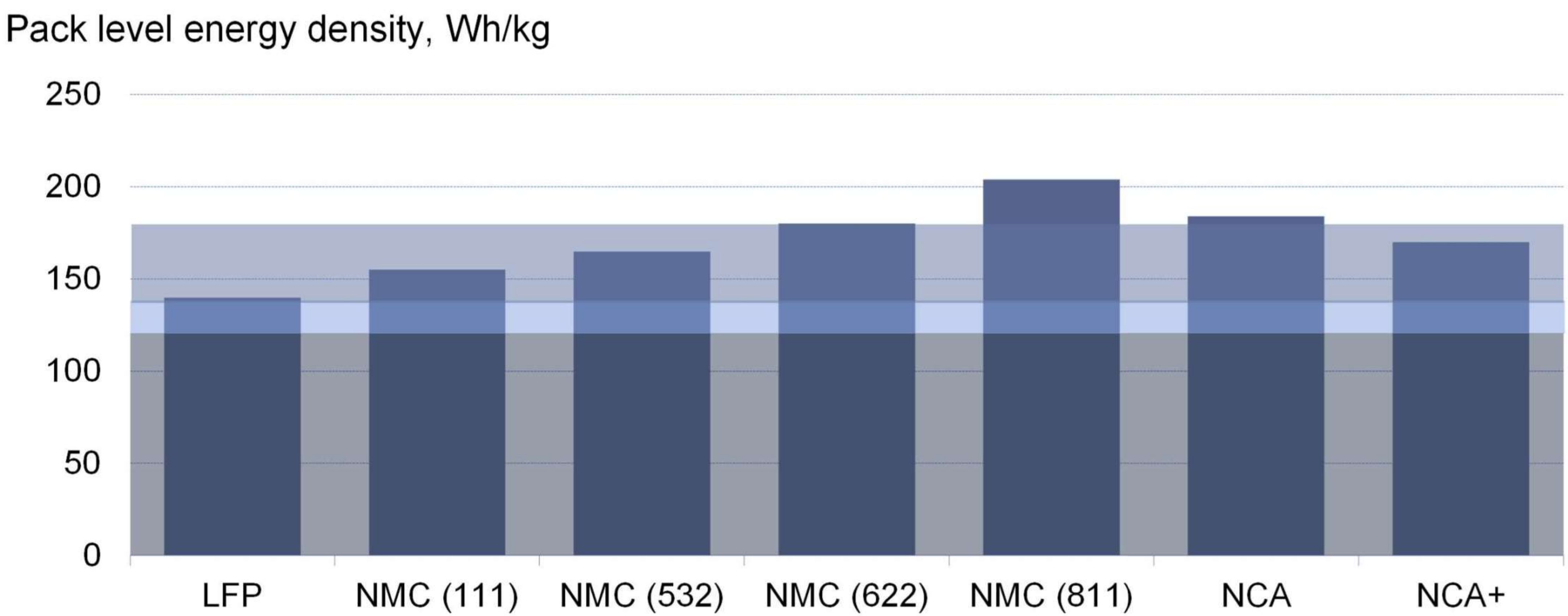
The industry needs to be reactionary



- In 2019, China's subsidy regime was tightened, meaning EVs with a battery pack of less than 120Wh/kg, would get no subsidy.
- Even high energy density packs received a lower subsidy on a $ basis, as the total subsidy level was reduced as well as the subsidy multiplier.

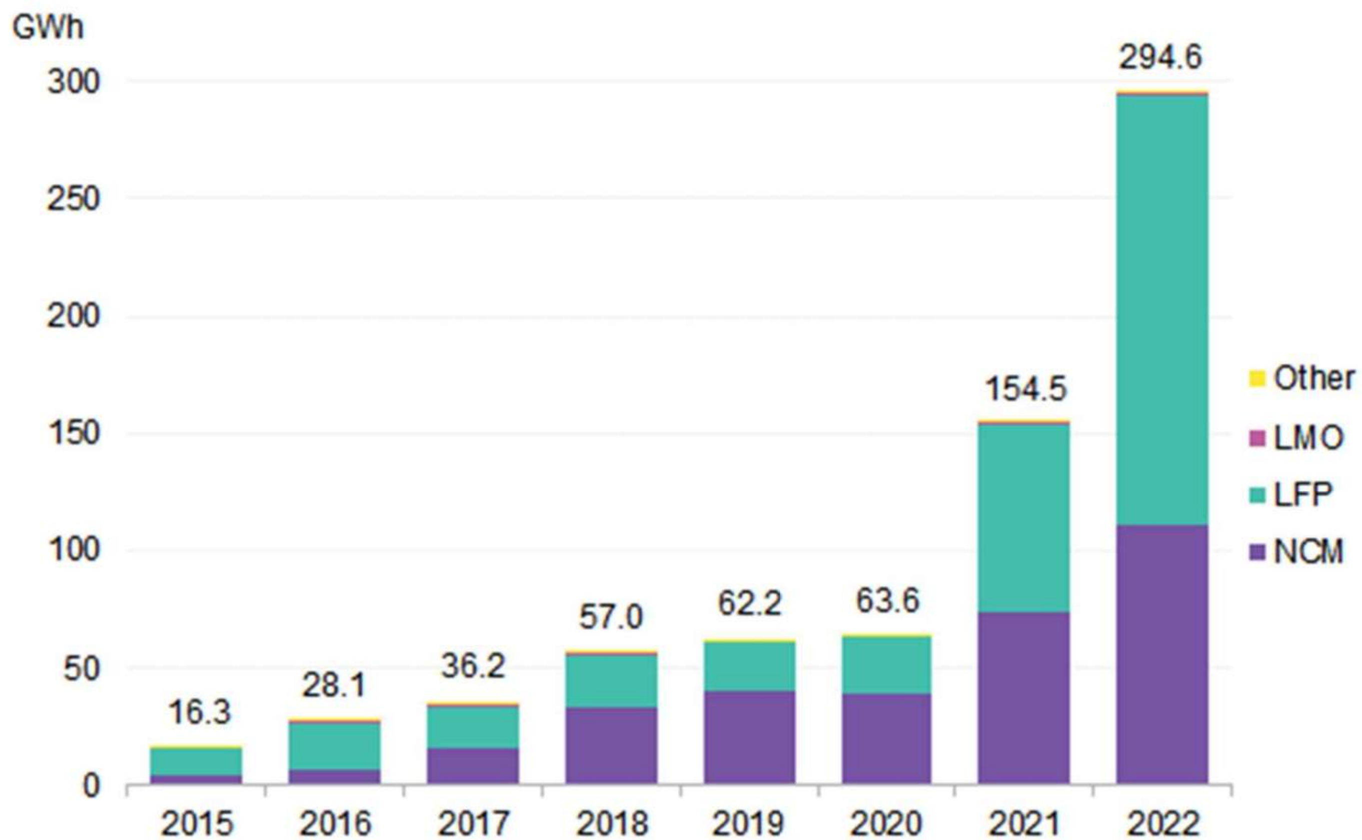
BloombergNEF, China Slashes EV Subsidies by Half

Small changes can have big impacts



- At the time, commercial LFP packs had a maximum energy density of ~120Wh/kg, so were not eligible for any subsidy.
- Theoretically, pack energy density could be increased up to ~140Wh/kg

Small changes can have big impacts



- The introduction of LFP CTP designs resulted in LFP packs with >120Wh/kg.
- With 80% of the subsidy available, LFP packs were ~$800 cheaper than high-nickel packs, for a 70kWh pack.
- This contributed to the resurgence of LFP in China but was driven by industry looking at the economics.

The agenda for today

1. **Theory vs. reality**
   Dr. Matthew Lacey
2. **Innovation – Lab to market**
   Dr. Uldercio Ulissi
3. **Why you need to understand markets**
   Dr. James Frith
4. **A proposed solution**
   Dr. Lukas Lutz

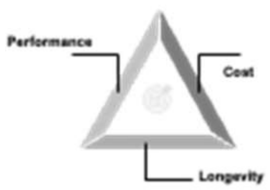
A proposed solution – Technology Assessments

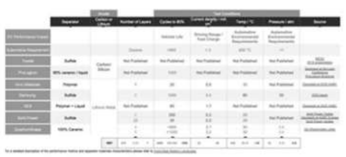
Dr. Lukas Lutz

A complex technology is disruption the markets

The entire value chain is dependant on high quality data – and we are lacking that!

Innovative Materials + **New Battery Manufacturers** + **Large Demand & Expectations** + **Non-standardized Data** = **Hype & Confusion**





Step 1: Approaching the battery field with the right mindset

Separating hype from facts

I

Having realistic expectations

II

Understanding physical limitations

III

Embracing the complexity of science & engineering

Besides all the excitement for a sustainable future, lets be realistic about our expectations!

Step 2: Understanding Trade-offs

There is no silver bullet - it's always a trade-off

Higher performance ≡ **Sustainability** | **Cycle Life** | **Cost** | **Safety**

Innovation is needed to measure these trade-offs

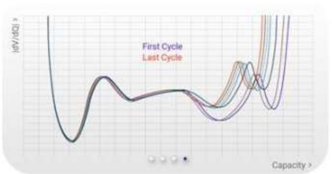
...text fixtures

Cell pressure & swelling

...benchmarking & partners

Thermal Management

...software & data



Aging & degradation analysis

Step 3: Comprehensive performance testing of new innovations

Standardized data is key fully understand the potential and the area of impact of new innovations

Key Performance Indicator (KPI)	Relevant Unit	Priority (EV)	Priority (ESS)	Priority (Power Tool)
Specific Energy	**Wh/kg**	■■■■■■□□□□	■■□□□□□□□□	■■■■□□□□□□
Energy Density	**Wh/L**	■■■■■■■■□□	■■■■□□□□□□	■■■■■■□□□□
Power Capability (Discharge)	**W, C-rate**	■■■■■■□□□□	■■■■■■□□□□	■■■■■■■■■■
Power Capability (Charge)	**W, C-rate**	■■■■■■■■□□	■■■■■■■■■■	■■■■■■■■■■
Cost	**$/kWh**	■■■■■■■■□□	■■■■■■■■■■	■■■■■■□□□□
Cycle life and lifetime	**Cycle n., years**	■■■■■■□□□□	■■■■■■■■■■	■■■■□□□□□□
Safety	**Std. testing**	■■■■■■■■■■	■■■■■■■■□□	■■■■■■■■□□
End-of-Life cost, sustainability	**$/(kWh CO_{2e}), Rec. content**	■■■■■■□□□□	■■■■■■□□□□	■■■■■■□□□□

Sphere’s contribution

Standardized data and rational decision making along the battery value chain.

Understand technology to drive business opportunities

Standardised test equipment

Test cells for next generation batteries enabling high quality data acquisition in academia

Battery test service & technology validation

Validation of innovation & prototypes, benchmarking of commercial cells.

Technology consulting

Understanding technology from a industrial perspective to drive the right strategic decisions.

R&D

Engineering

Strategy

Thank you!

It would be great if you could take 1 min to participate in our feedback survey – see you next time!

Thank you for your time and attention!

Questions?