ilika

Solid-state battery technology

Capital Markets Day 5th December 2019

Disclaimer

The materials being provided to you in connection with this presentation are strictly confidential and intended only for informational purposes and convenient reference.

This document has been prepared by Ilika plc ("Ilika") and is the responsibility of the same and comprises the written materials for a presentation to investors concerning Ilika.

This information is not intended to provide, and should not be relied upon, for accounting, legal, tax advice or investment recommendations. You should consult your tax, legal, accounting or other professional advisors about the issues discussed herein. The descriptions contained herein are summaries and are not intended to be complete and neither Ilika nor any of its subsidiaries or affiliates undertakes any obligation to update or correct any errors or inaccuracies in any of the information presented herein. The information in these materials and any other information discussed at the presentation is subject to change.

These materials do not constitute or form part of any offer or invitation to sell or issue or any solicitation of any offer to purchase or subscribe for any securities of Ilika in any jurisdiction, nor shall it (or any part of it) or the fact of its distribution form the basis of, or be relied upon in connection with, or act as any inducement to enter into, any contract or investment decision in relation thereto.

The distribution of these materials in jurisdictions other than the United Kingdom may be restricted by law and persons into whose possession these materials come should inform themselves about and observe any relevant restrictions. In particular, these materials are not for publication or distribution, directly or indirectly, in, into or from the United States of America, Canada, Australia, the Republic of South Africa or Japan. Any failure to comply with the above restrictions may constitute a violation of such securities laws.

Ilika has not been and will not be registered under the U.S. Investment Company Act of 1940, as amended (the "Investment Company Act") and the holders of its shares will not be entitled to the benefits of that Act. In addition, the offer and sale of the shares mentioned herein have not been, and will not be, registered under the U.S. Securities Act of 1933, as amended (the "Securities Act"). No securities of Ilika may be offered or sold or otherwise transacted within the United States or to, or for the account or benefit of U.S. persons. In connection with the transaction referred to in this presentation the shares of Ilika will be offered and sold only outside the United States to, and for the account or benefit of non U.S. persons in "offshore transactions" within the meaning of, and in reliance on the exemption from registration provided by Regulation S under the Securities Act. No public offer of the shares is being made in the United States and the information contained herein does not constitute an offering of securities for sale in the United States, Canada, Australia, South Africa, the Republic of Ireland or Japan. No money, securities or other consideration is being solicited and, if sent in response to the information contained herein, will not be accepted. Any failure to comply with the above restrictions may constitute a violation of such securities laws.

Neither Ilika nor any of its subsidiaries or affiliates makes any representation or warranty, express or implied as to the accuracy, completeness or verification of the information contained herein, and nothing contained herein shall be relied upon as a promise or representation whether as to past or future performance. In giving this presentation, neither Ilika nor its respective advisers and/or agents undertake any obligation to provide the recipient with access to any additional information or to update this presentation or any additional information or to correct any inaccuracies in any such information which may become apparent.

This material is confidential and distribution of this material to any person other than the person to whom this information was originally delivered and to such person's advisors is unauthorised and any reproduction or redistribution of these materials, in whole or in part, or the disclosure of any of their contents, without the prior consent of Ilika or its affiliates is prohibited.

These materials and any offer mentioned herein if subsequently made are only addressed to and directed at persons in member states of the European Economic Area who are 'qualified investors' within the meaning of Article (2)(1)(e) of the Prospectus Directive (Directive 2003/71/EC). This document is for distribution in the United Kingdom only to persons who are authorised or exempt persons within the meaning of the Financial Services and Markets Act 2000 or to persons who have professional experience in matters relating to investments falling within Article 19(5) of the Financial Services and Markets Act 2000 (Financial Promotion) Order 2005, (all such persons together being referred to as, "relevant persons"). This document is directed only at relevant persons. Other persons should not act or rely on this document or any of its contents. Any investment or investment activity to which this presentation relates is available only to (i) in the United Kingdom, Relevant Persons and (ii) in any member state of the EEA other than the United Kingdom, Qualified Investors, and will be engaged in only with such persons. Solicitations resulting from this presentation will only be responded to if the person concerned is, (i) in the United Kingdom, a Relevant Person, and (ii) in any member state of the EEA other than the United Kingdom, a Qualified Investor.
These materials include statements that are, or may be deemed to be, "forward-looking statements" which are based on current expectations and projections about future events. In some cases, these forward-looking statements may be identified by the use of forward-looking terminology, including the terms "targets", "believes", "estimates", "anticipates", expects", "intends", "may", "will" or "should" or, in each case, their negative or other variations or comparable terminology. They appear in a number of places throughout these materials and include statements regarding the intentions, beliefs or current expectations of Ilika and/or its directors concerning, among other things, the trading performance, results of operations, financial condition, liquidity, prospects and dividend policy of Ilika. By their nature, these forward-looking statements as well as those included in any other material discussed at any roadshow presentation involve risks and uncertainties because they relate to events and depend on circumstances that may or may not occur in the future. Forward-looking statements are not guarantees of future performance. A number of important factors could cause actual results or outcomes to differ materially from those expressed, projected or implied in any forward-looking statements. No one undertakes publicly to update or revise any such forward-looking statement. In light of these risks, uncertainties and assumptions, the events or circumstances referred to in the forward-looking statements may not occur. None of the future projections, expectations, estimates or prospects in this presentation should be taken as forecasts or promises nor should they be taken as implying any indication, assurance or guarantee that the assumptions on which such future projections, expectations, estimates or prospects have been prepared are correct or exhaustive or, in the case of the assumptions, fully stated in the presentation. No one undertakes to publicly update or revise any such forward-looking statement, whether as a result of new information, future events or otherwise. As a result of these risks, uncertainties and assumptions, you should not place undue reliance on these forward-looking statements as a prediction of actual results or otherwise.

Return targets are targets only and are based over the long-term on the performance projections of the investment strategy and market conditions at the time of modelling and are therefore subject to change. There is no guarantee that any target return can be achieved. Investors should not place any reliance on such target return in deciding whether to invest in Ilika.

To the extent available, the industry, market and competitive position data contained in these materials come from official or third party sources. Third party industry publications, studies and surveys generally state that the data contained therein have been obtained from sources believed to be reliable, but that there is no guarantee of the accuracy or completeness of such data. The contents of this document have not been independently verified, are not comprehensive do not contain all the information that a prospective purchaser of securities of Ilika may desire or require in deciding whether or not to offer to purchase such securities and do not constitute a due diligence review and should not be construed as such. No undertaking, representation, warranty or other assurance, express or implied, is made or given by or on behalf of Ilika or any of its directors, officers, employees, agents or advisers or any other person as to the accuracy, completeness or fairness of the information, forward-looking statements or opinions contained in this document and no responsibility or liability is accepted by any of them for any such information, forward-looking statements or opinions or in respect of any omission, and this document is distributed expressly on the basis that it shall not give rise to any liability or obligation if, for whatever reason, any of its contents are or become inaccurate, incomplete or misleading and neither Ilika nor any such persons undertakes any obligation to provide the recipient with access to additional information or to correct any inaccuracies herein which may become apparent.

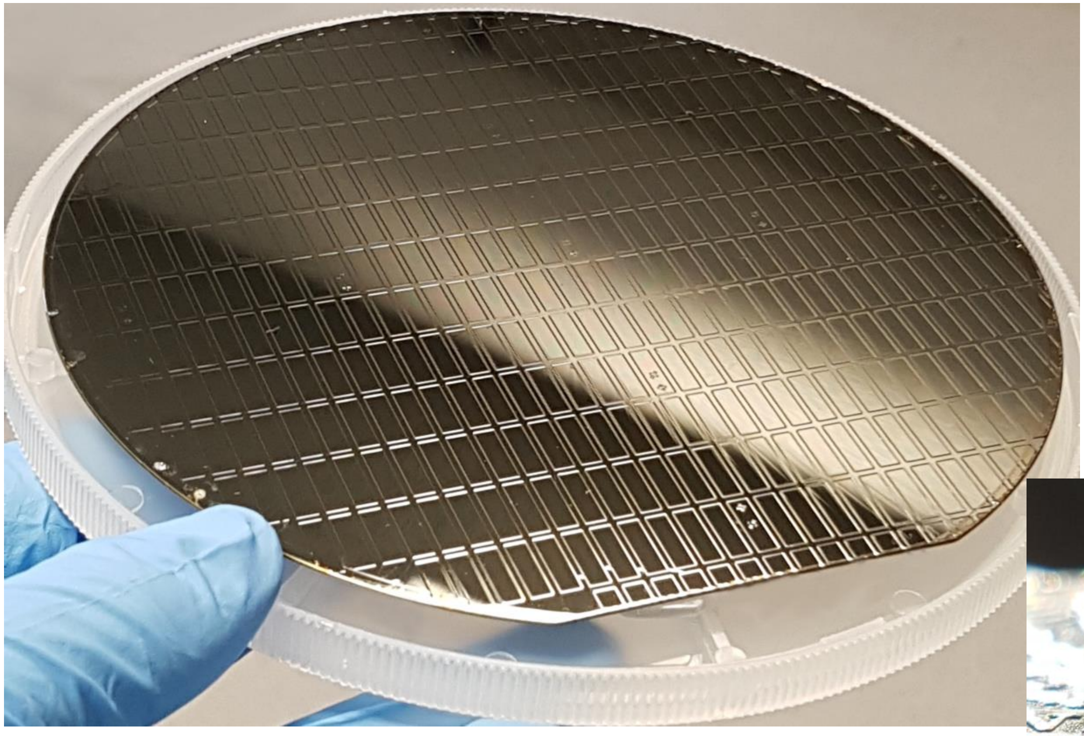
The information and opinions contained in this presentation are provided as at the date of this presentation and are subject to verification, completion and change without notice.

By attending the presentation you agree to be bound by the foregoing limitations.

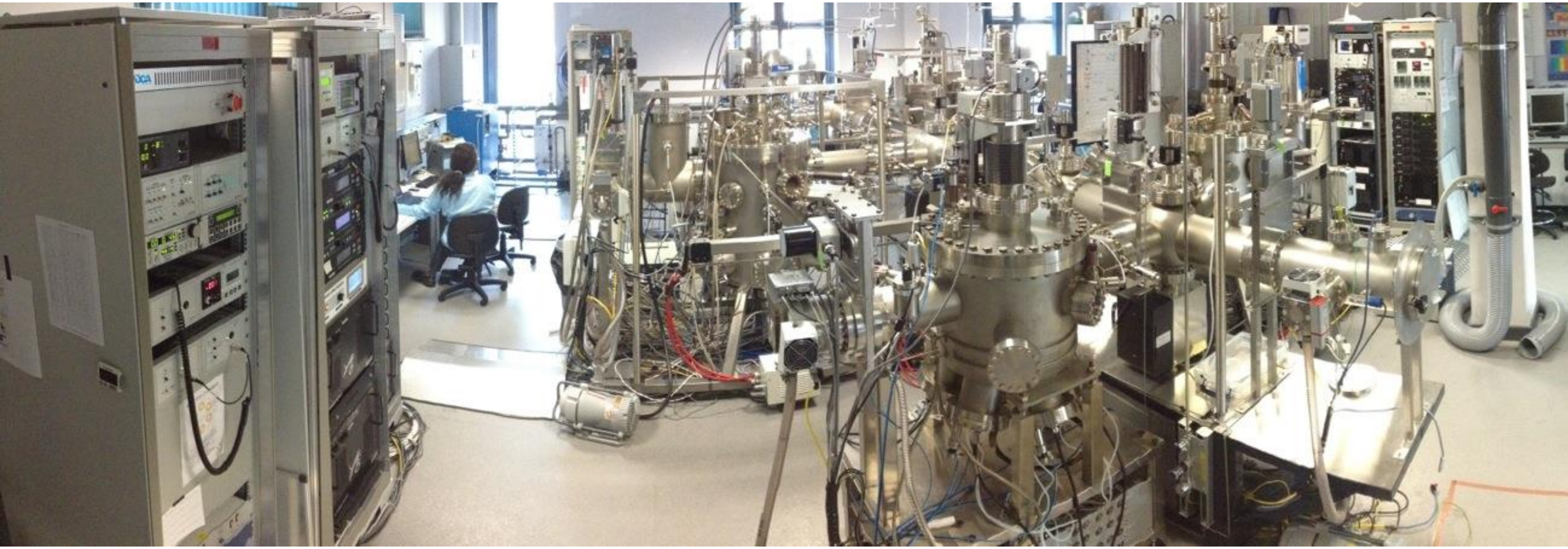
NOT FOR DISTRIBUTION DIRECTLY OR INDIRECTLY INTO THE UNITED STATES, CANADA, AUSTRALIA, SOUTH AFRICA, THE REPUBLIC OF IRELAND OR JAPAN OR ANY OTHER JURISDICTION IN WHICH THE SAME WOULD BE UNLAWFUL. THIS COMMUNICATION IS DIRECTED ONLY AT PERSONS TO WHOM IT IS LAWFUL TO COMMUNICATE TO.

Business overview

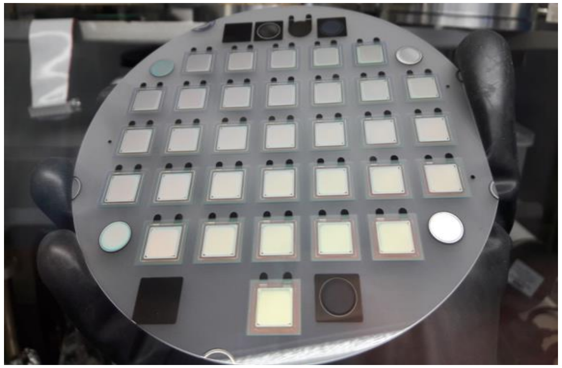
Ilika is a pioneer in solid-state battery technology



Ilika history



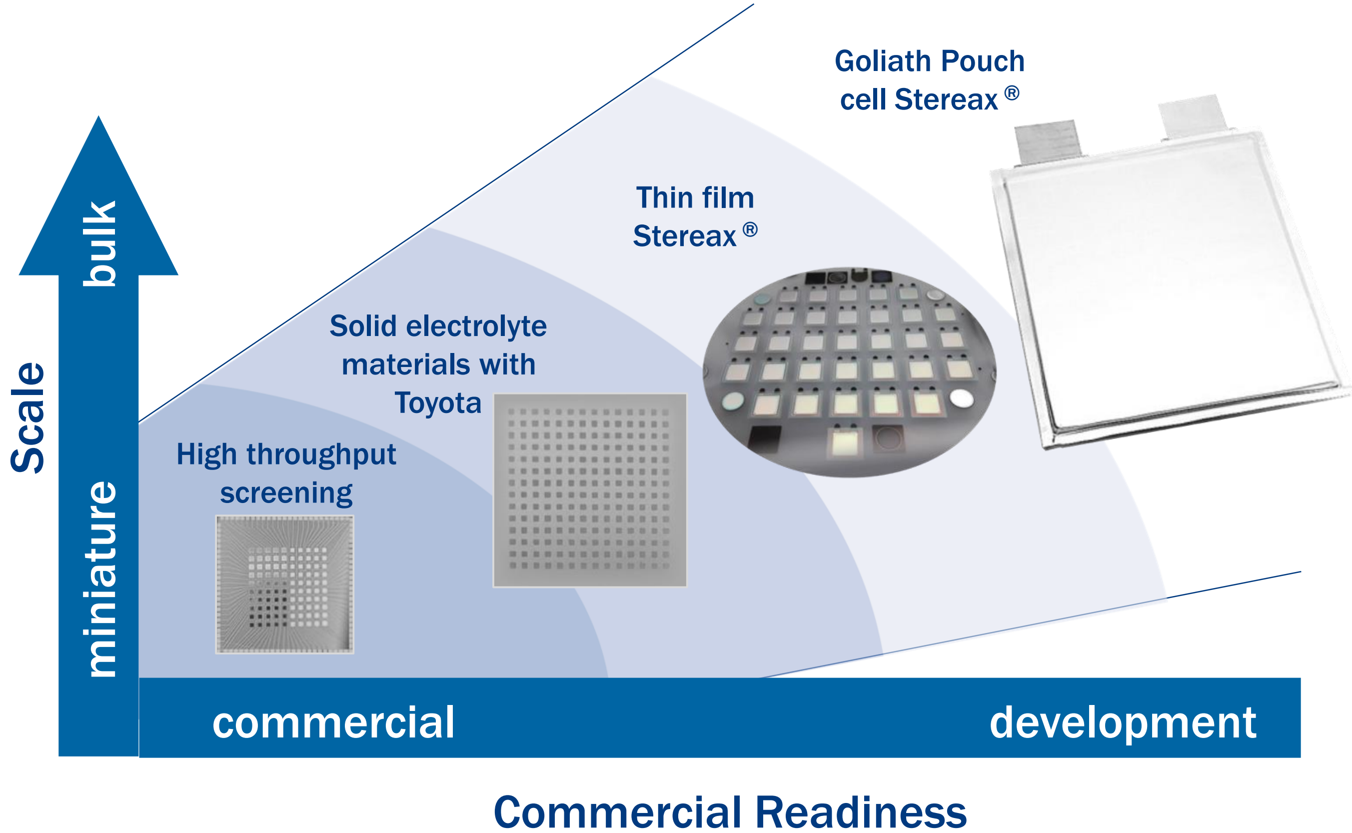
- 15 years in rapid materials innovation
  - Significant early work with Toyota
  - Created & launched mAh scale SSB technology
  - Now developing single cells and pouch cells for EV
  - Automotive Programme (Goliath) Auto industry partners & UK Government funded



Energy storage solutions

	Conventional Li-ion	Supercapacitors	Ilika Solid-State Batteries
Temperature range	✗	✗	✓✓
Trickle-charging/ Low Leakage	✗	✗	✓
Fast charging	✗	✓	✓✓
Ultra-compact	✓	✗	✓
Safety Profile	✗	✓	✓✓

Stereax ® product evolution



Stereax ® product to market mapping

ilika

M250

Key requirements
- Long life (10 years)
- Integration possible
- Low leakage

Opportunities

Sensors for:
Smart building, smart homes beacons, indoor asset tracking

P180

Key requirements
- High operating temperature
- Long life (10 years)
- Low leakage

Opportunities

Sensors for:
Industrial, automotive, aerospace, infrastructure

M50

Key requirements
- Bio-compatibility
- Long life
- Low leakage

Opportunities

Medical, backup/security

Goliath

Key requirements
- Non-flammable
- High capacity
- High energy density
- High power

Opportunities

Automotive, consumer electronics, wearables

Stereax® commercial highlights

- Delivering a perpetual beacon for high value asset tagging
  - Developing a condition monitor for wind turbine blades
    - Designing a rail-track strain gauge
      - Designing an autonomous environmental sensor card
        - Dispatching batteries for evaluation in miniature medical implants

Stereax ® development partners

ilika

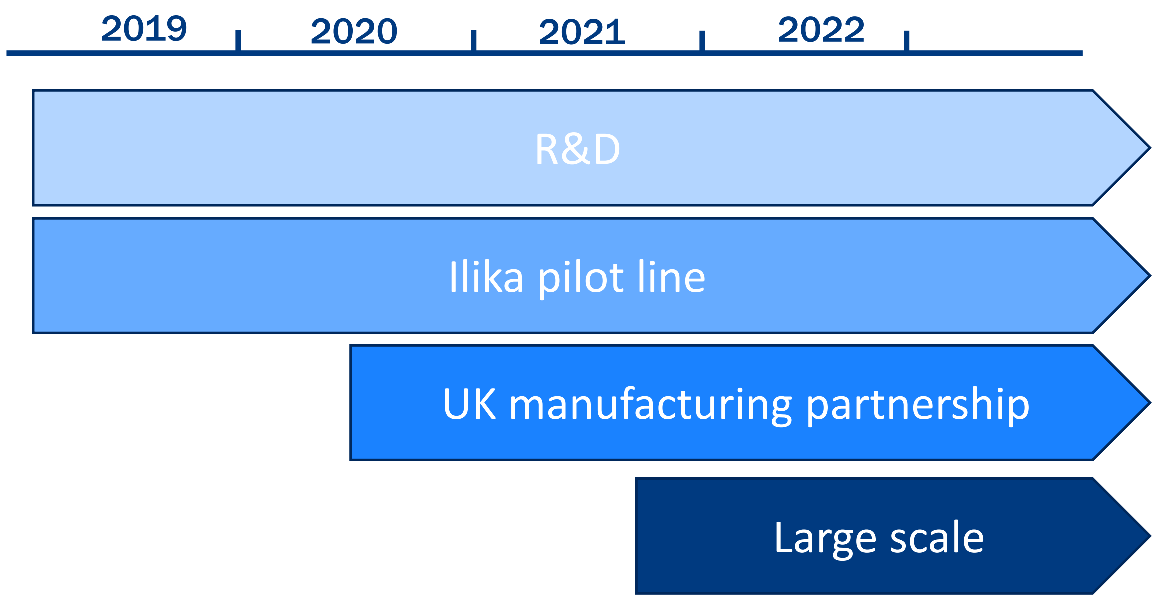
- Asset tagging
- Wind turbine condition monitoring
- Track monitoring
- Environmental monitoring

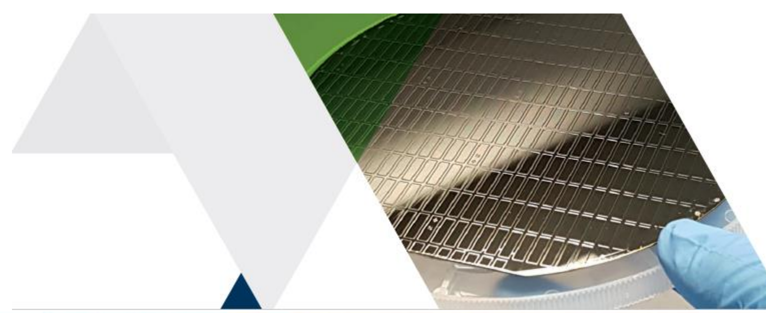
Biomedical partner

- Powering medical implants

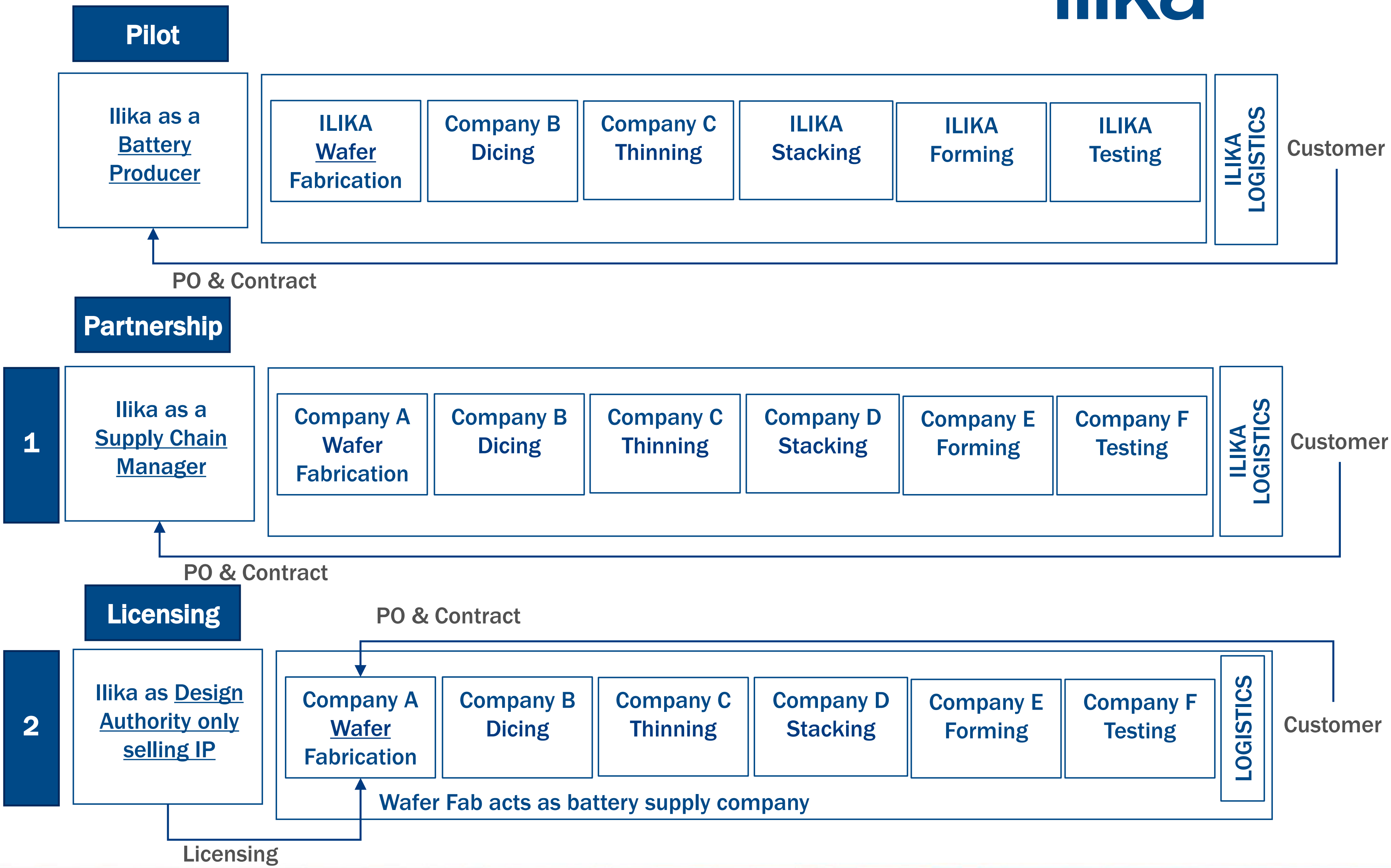
Stereax® manufacturing partnerships

M50 Capacity (Devices/yr)
500
13,500
312,000
1 million+





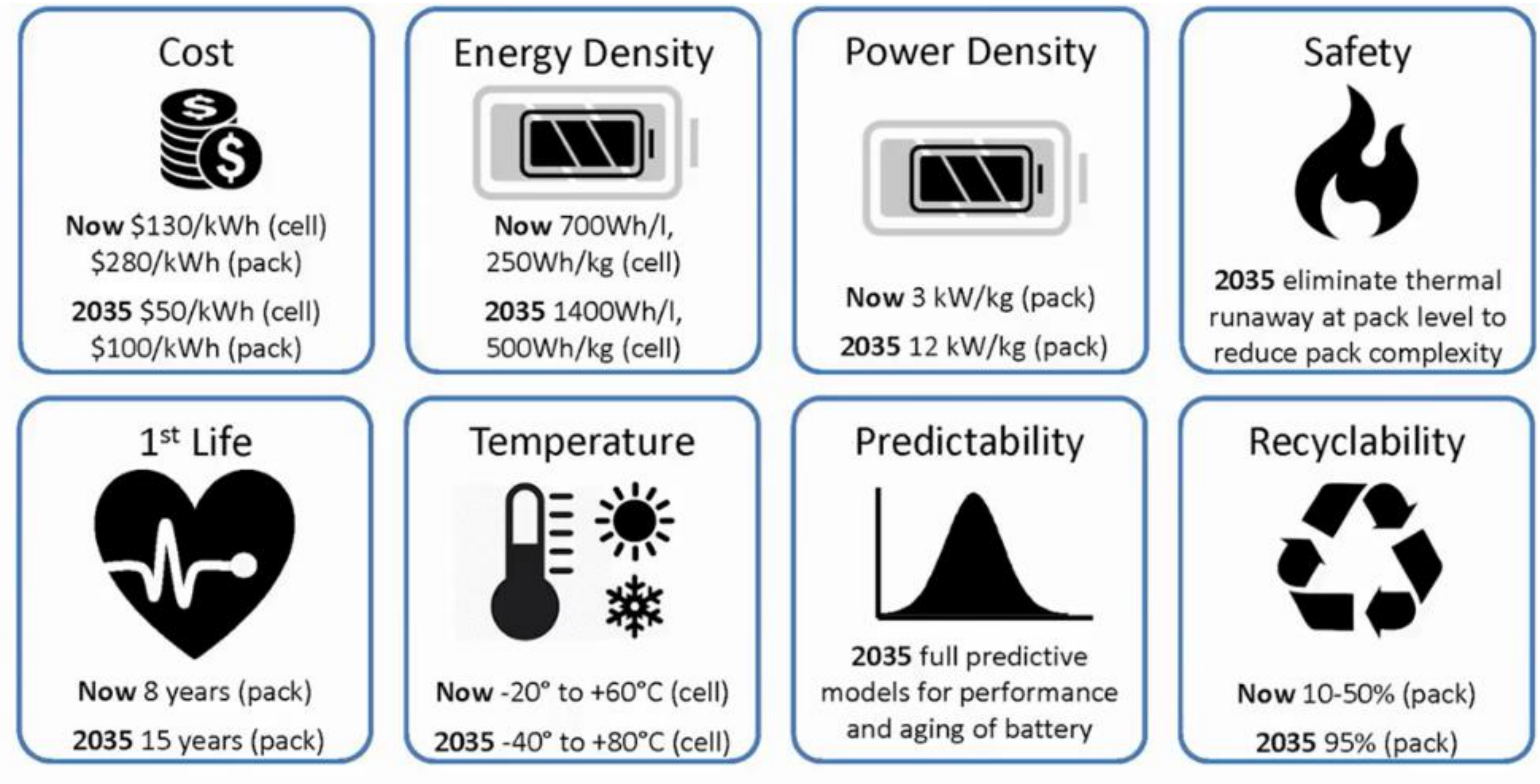
Ilika Business Model



Goliath project

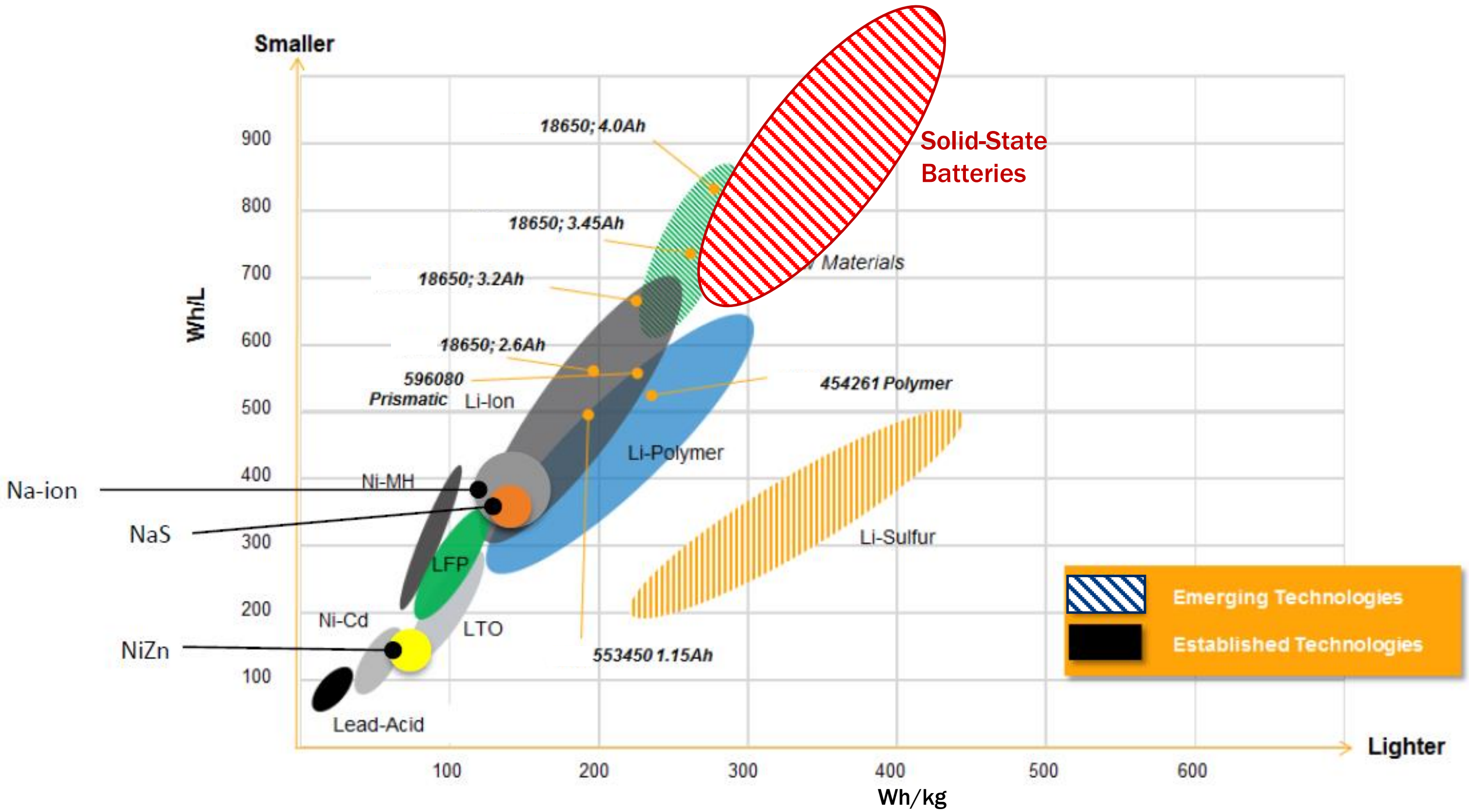
Ilika is developing the Goliath solid-state battery product line to address the growing demand for safe, high performance batteries for Electric Vehicles

Market needs



Road mapping the EV future - Professor David Greenwood, University of Warwick

Battery technologies: size and weight

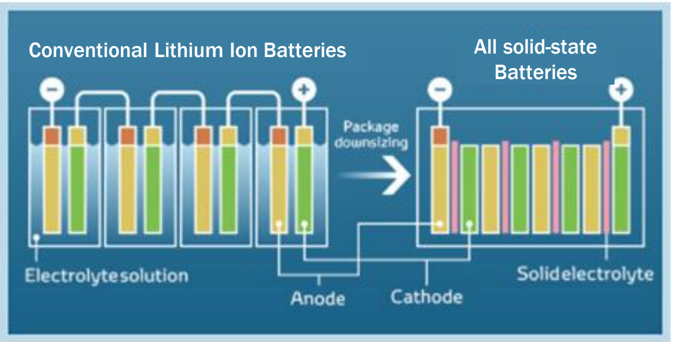


Source: Christophe Pillot - Avicenne

Solid-state batteries

ilika

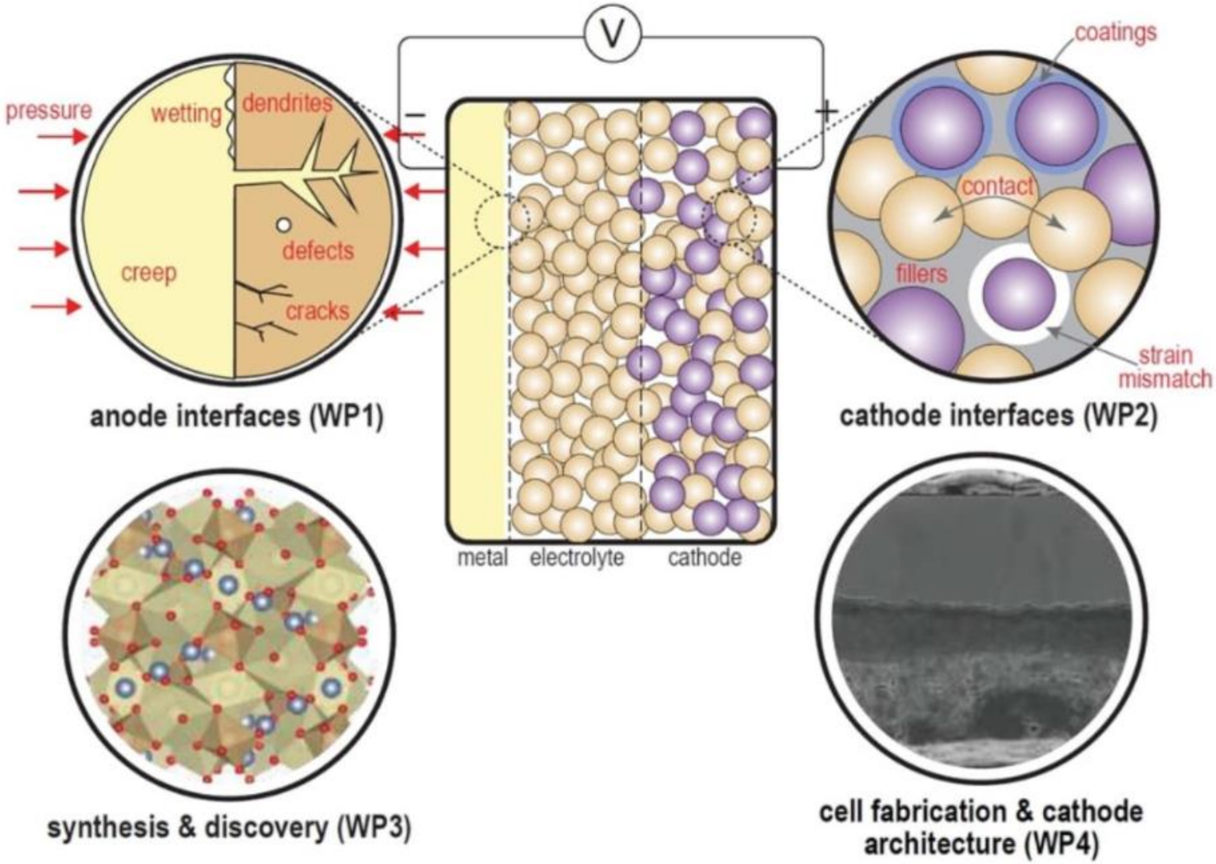
Advantages
Safety
Durability
Fast charge / discharge
High energy density (Wh/L)
High energy density (Wh/kg)
Thermal stability
Simple construction
Low self-discharge
Efficient packaging



Source: Toyota

Challenges
Materials conductivity
Interface reactions and resistance
Manufacturing Methods
Electromechanical Stability

Challenges facing SSB technology

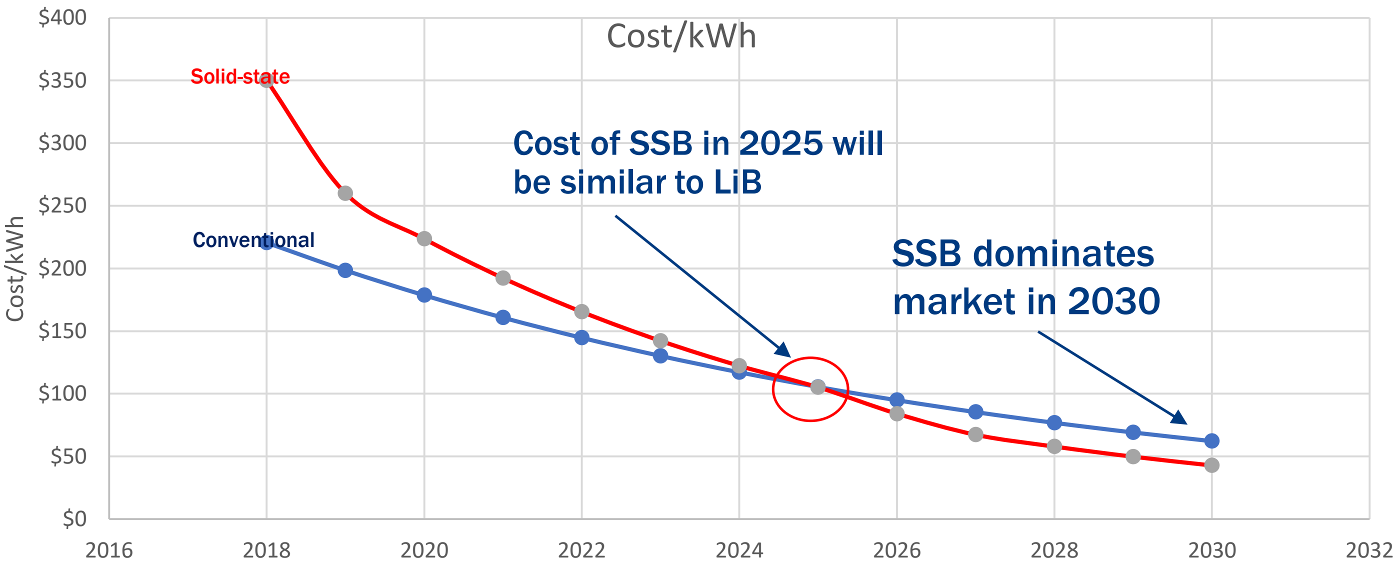


Source: University of Oxford and Faraday Institution

The solid-state battery technologies

Company	Electrolytes	Features
Ilika/Honda/McLaren	Oxide-based electrolyte	Room temp operation (-50°C-150°C),excellent environmental adaptability, scalable printing tech at low cost
Dyson / Sakti 3		Flash evaporation processing, custom equipment, cost appears high
BMW / Solid Power	Sulfide-based electrolyte	Sulfide-based material is toxic and difficult to handle, processing equipment and package are expensive and complicated
Toyota		
Solid Energy	Polymer (PEO)-based electrolyte	Solid polymer ionic liquid, could have some safety issues?
Bathium / Bolloré		Pre-heat to 60°C-80°C for operation, needs complicated and expensive heat management system.
Fisker		

Unit cost analysis (cost/kWh)



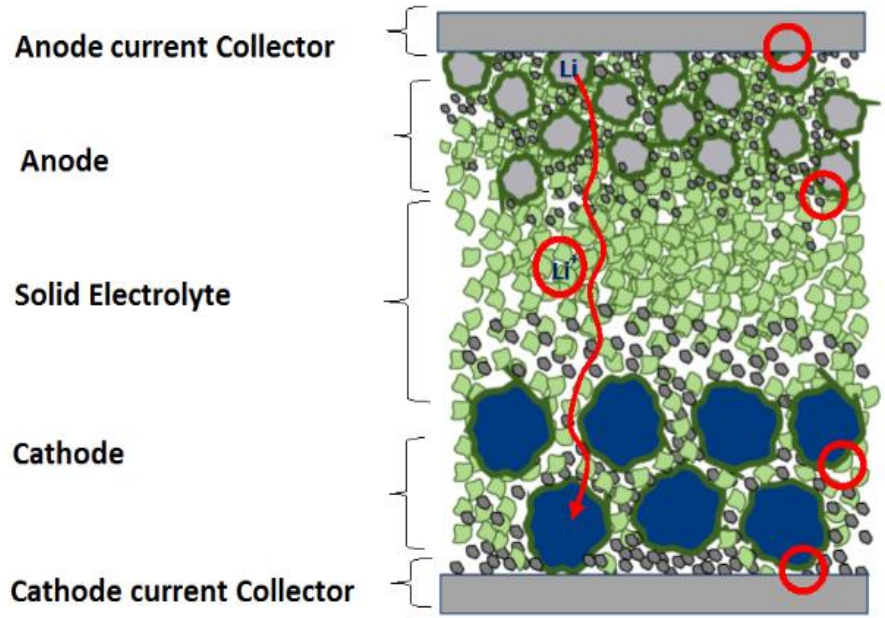
- The unit cost of SSB is around 30-40% higher than LiB in 2021
- Cost expected to be similar to LiB in year 2025
- SSB will dominate market in 2030, taking over 70% market share.

What differentiates Ilika's Goliath programme?

- Use of silicon as anode material
  - Experiences gained from Stereax® SSB programme
- 10 years of materials innovation on solid electrolytes
  - Extensive testing around sulphides and oxides
  - Selection of oxides
  - Development of specific oxides
- Flexibility to use best in class cathode material
  - Supply of advanced NMC grades will evolve over next 5-10 years and Ilika is positioned to take advantage of this

Lessons from Stereax®

- How to deploy a silicon anode
- How to manage interface resistances
- Use of oxide electrolytes
- Formulation of composite structures
- Development of manufacturing processes



Pouch Design

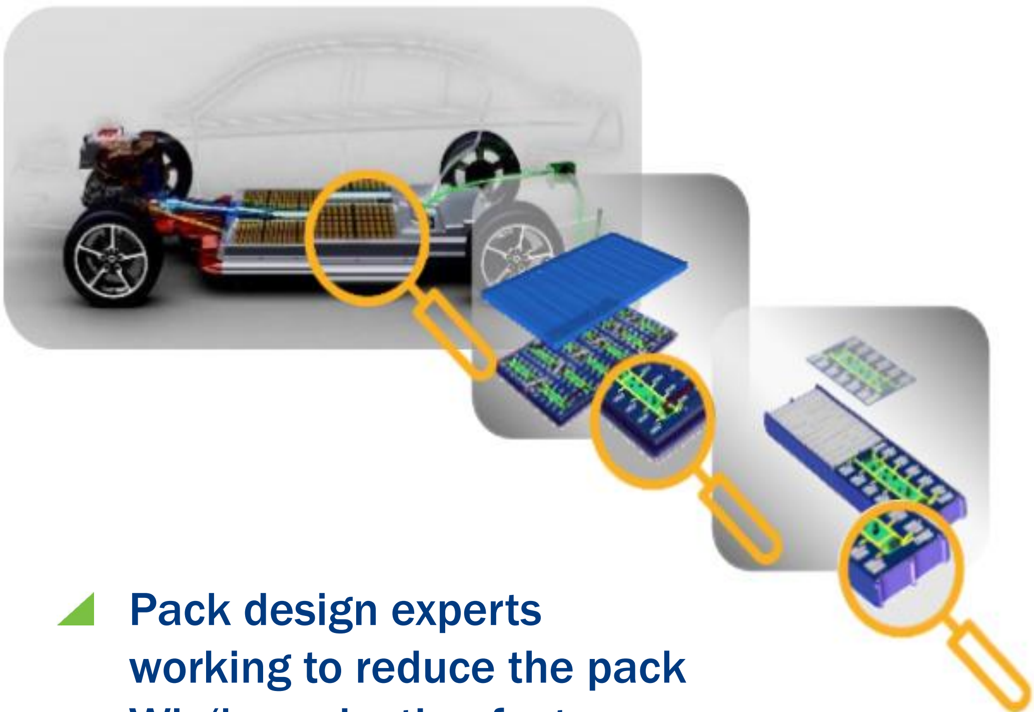
- Selected due to non flexible nature of the ceramics

- Single α cell

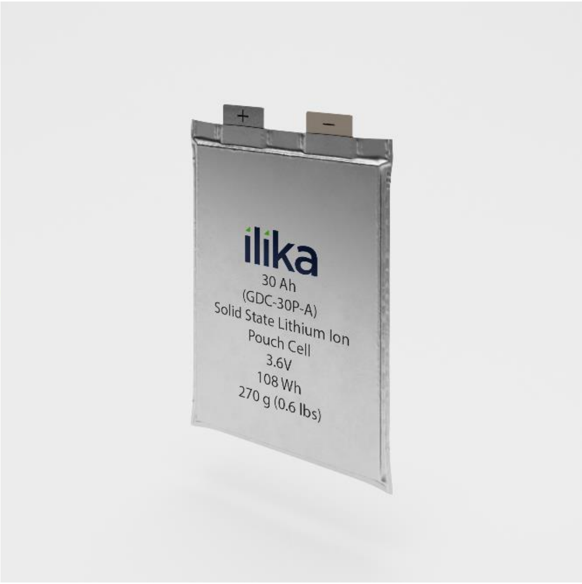
- Zoom on stack

- Multi-Cell Pouch

A6 , 30Ah solid-state pouch cell



- Ilika working with pack design experts to establish the optimum format for a solid-state pouch cell



- Pack design experts working to reduce the pack Wh/kg reduction factor based on the outputs of a solid-state pouch cell

Goliath development programme targets

ilika

1 **Cell Prototype A**

e.g., A6 Sheet Format Using available NMC 111, etc

α - Single Cell
1.5 Ah
0.48 mm
18 g

300 Wh/kg
725 Wh / L

Increased Electrode Thickness
2.5 Ah
0.58 mm
26 g

350 Wh/kg
1000 Wh/L

Mechanical Stacking

α - Multi-cell Pouch
30 Ah
5.0 mm
270 g

400 Wh/kg
1390 Wh/L

2 **Cell Prototype B**

State of art materials at this point (e.g., NMC 811)

Apply all learnings

State of the Art Cathode
36 Ah

480 Wh/kg

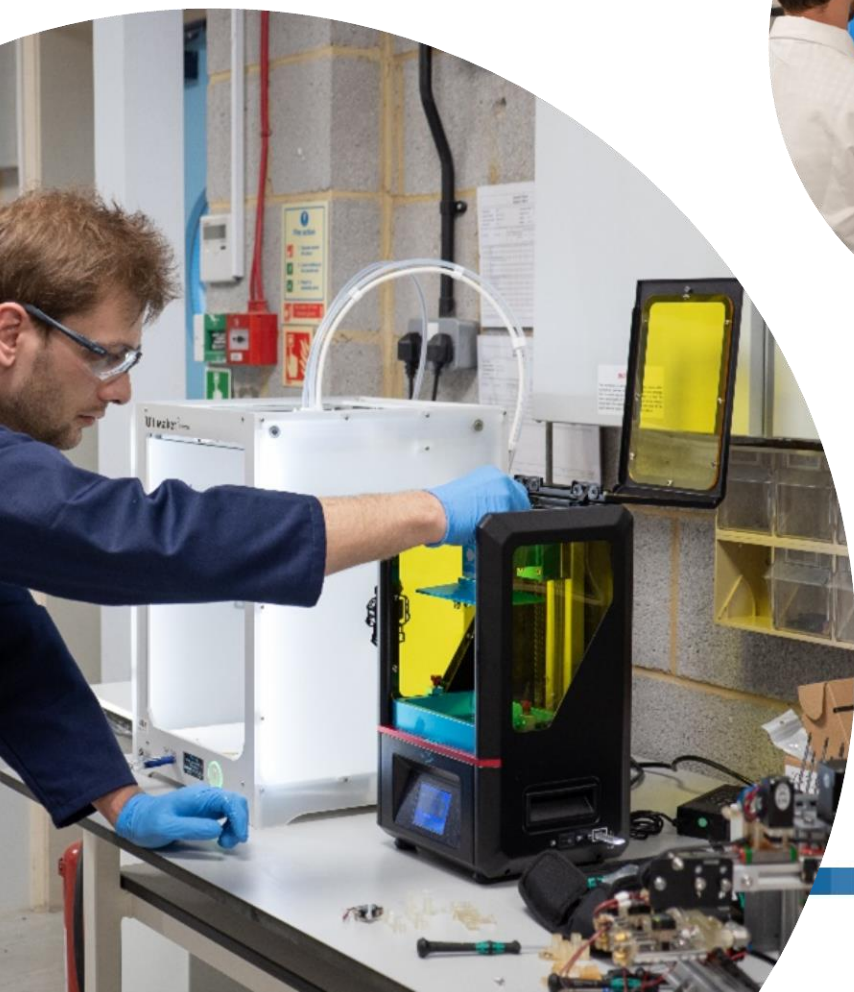
3 **Prototype C**

Bipolar Stacked Pouch

4 **Prototype D**

Practical & Theoretical limits of chemistry for selected process and materials

550 Wh/kg



Ilika pre-pilot line facilities

Goliath Development Partnerships

ilika

Goliath Development Programme:

- Establish Ilika as leader in development of manufacturing methods for production of solid-state batteries
- Commercialise the large format solid-state battery (Goliath)

POWER DRIVE LINE — Innovate UK

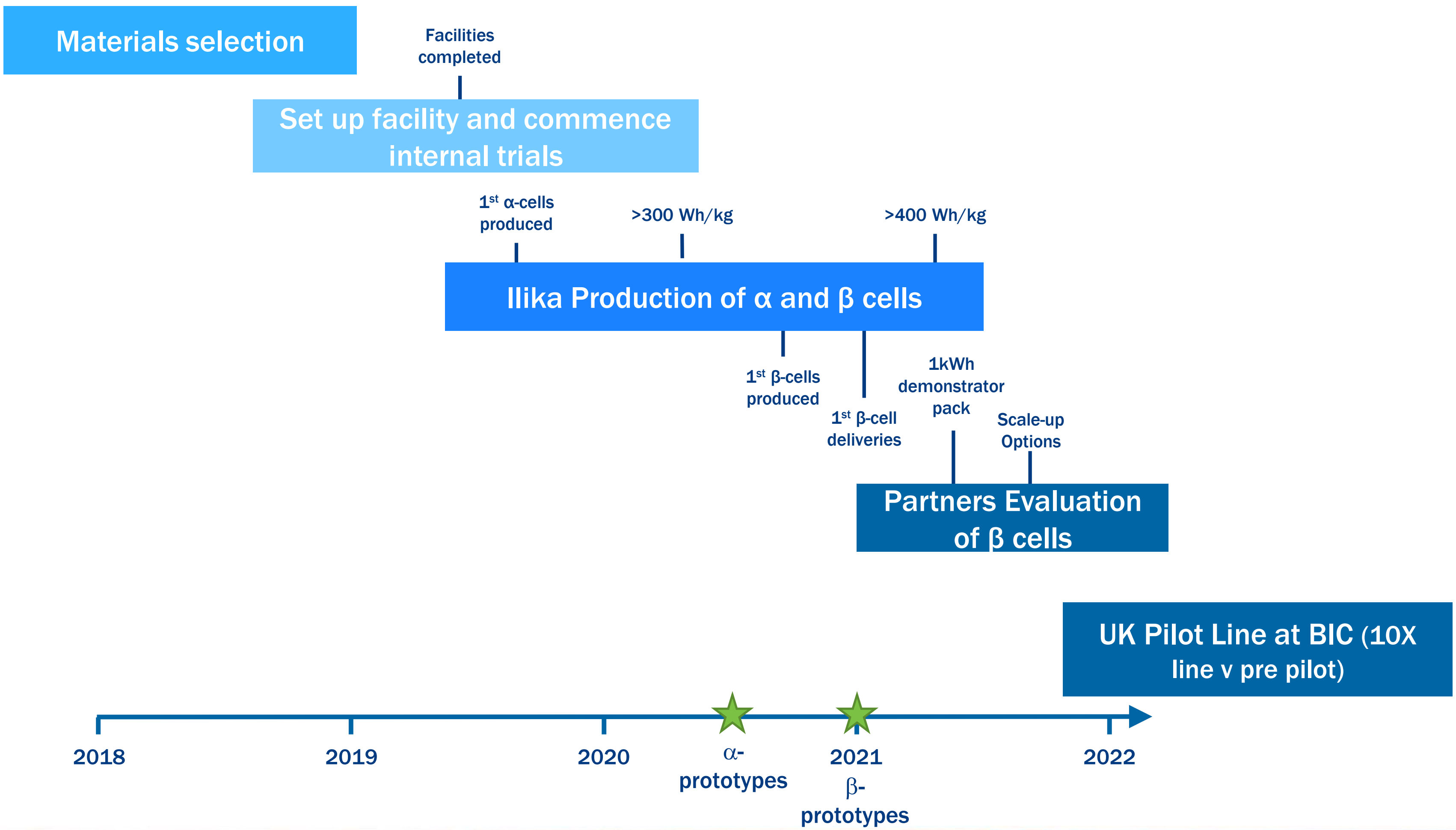
MOSESS — Innovate UK

GRANITE — Innovate UK

Lead Partner Framework

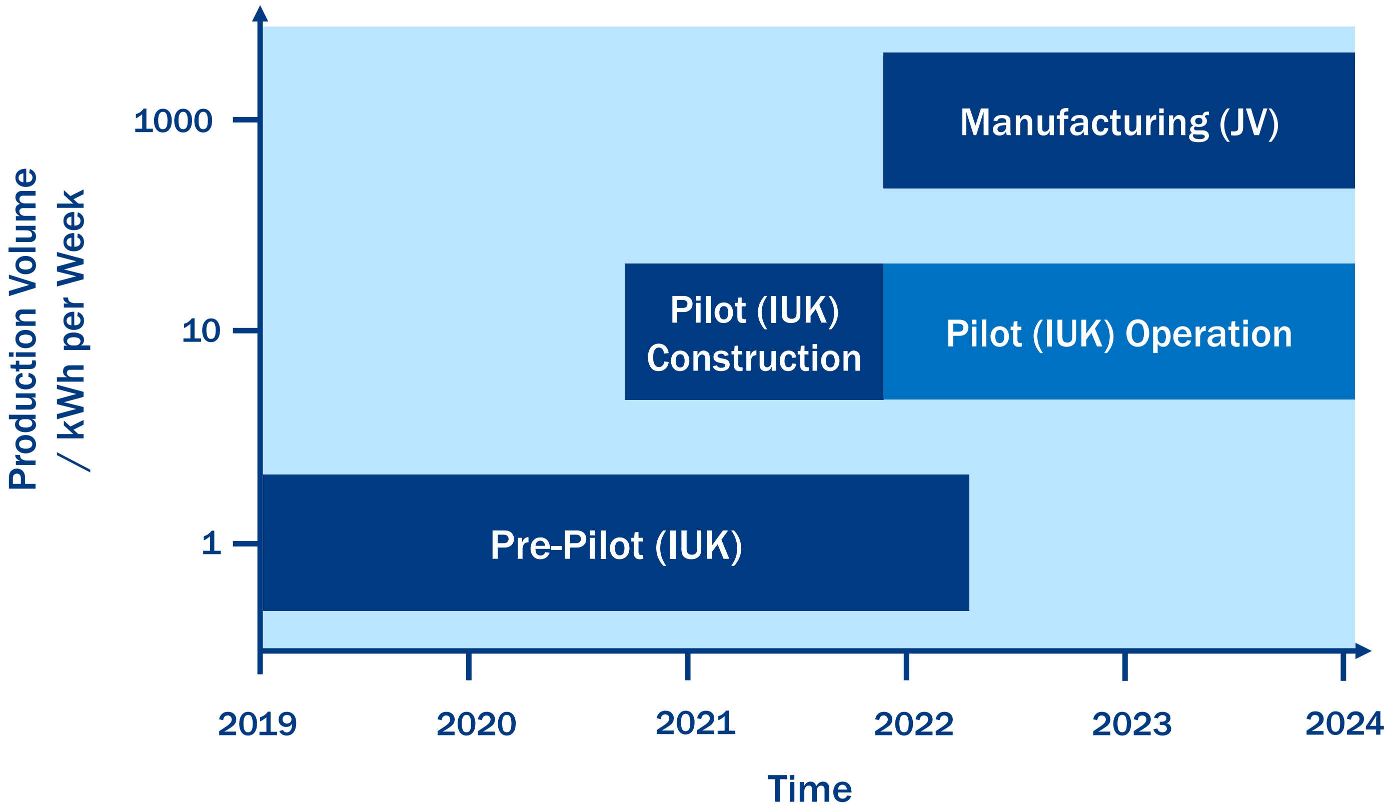
Including consumer cells

Goliath pre-pilot programme



Goliath manufacturing scale-up

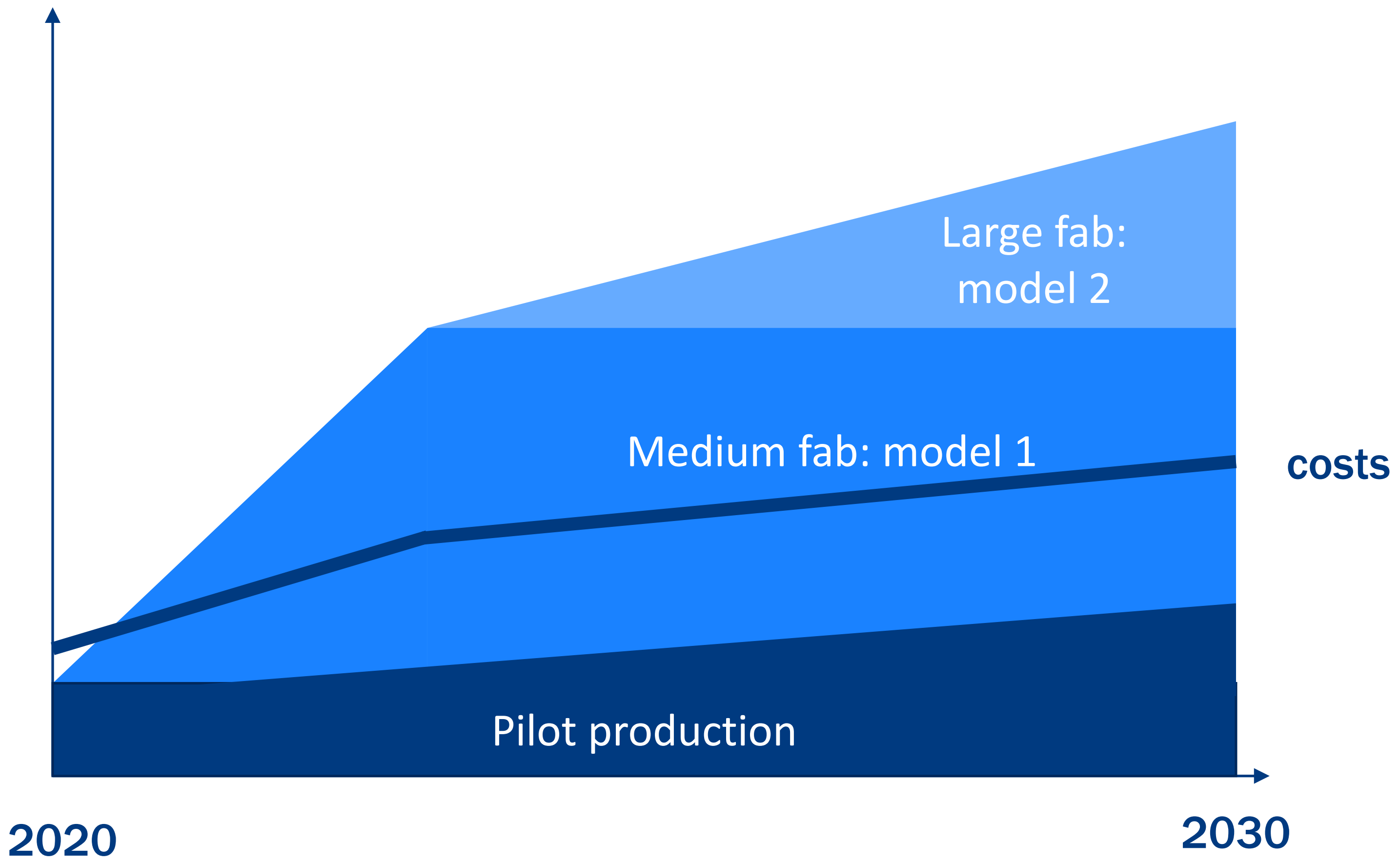
- The technology will be developed and manufactured in three phases



Financial summary for the half year ended 31st October 2019

- Revenue £1.5m (H1 2018: £1.0m)
- EBITDA loss £1m (H1 2018: £1.3m)
- Cash £1.9m with £0.7m received post period end.

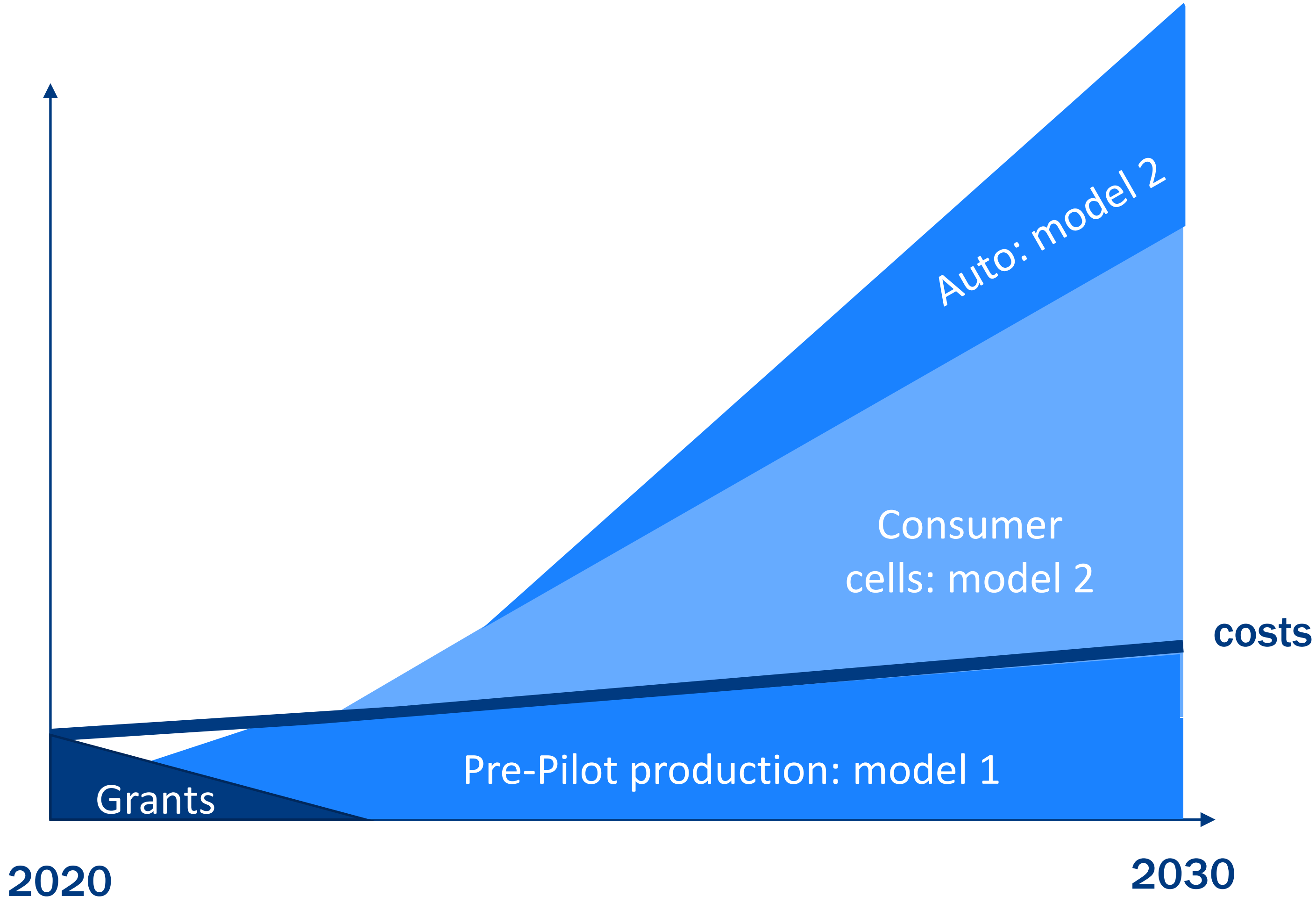
Stereax® Business Growth Profile



Confidential

Goliath Business Growth Profile

ilika



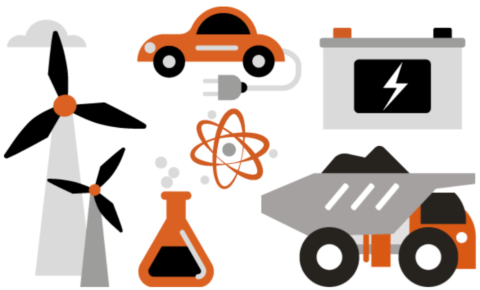
Summary

ilika

- Solid-state batteries will be a significantly disrupting technology
- Investors have been taking positions in the technology via investment in SME's
- Ilika offers a lower risk investment proposition because of:
  - Its demonstrated ability to make miniature solid-state batteries
  - Its capital light commercialisation model
  - Substantial grant support from IUK facilitating partnering and reducing reliance on shareholder capital

Contact details

- www.ilika.com
- @ilikaplc
- /ilika-plc



Battery technology

Battery costs and technology

Asad Farid
Analyst
+44 20 3207 7932
asad.farid@berenberg.com

Chris Armstrong
Specialist Sales
+44 20 3207 7809
chris.armstrong@berenberg.com

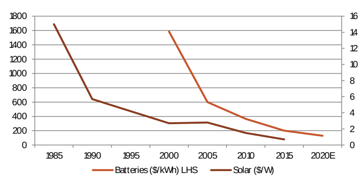
Battery technology – drivers and implications

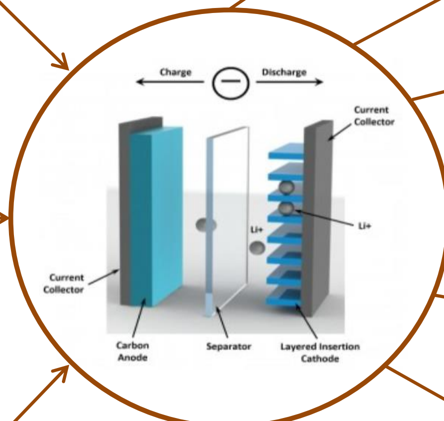
3 factors driving battery adoption

Regulations for emissions control
Direct/indirect financial support for EVs, charging infrastructure & stationary storage

Rising renewable generation
Storage requirements for renewable electricity integration rising

Battery costs falling
Battery costs are falling by half every 5 years as manufacturing scale rises





Multiple sectors headed towards electrification

Automotive

Stationary storage

Electric buses

Vans & trucks

Industrial

Mining

Constructi on

Battery technology – drivers and implications

BERENBERG
PARTNERSHIP SINCE 1590

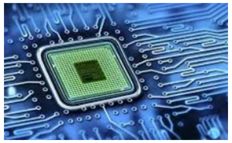
Sectors which will benefit | **Sectors which may be disrupted**

1. Lithium and Nickel miners
Albemarle
AMG, Lithium Americas
SQM, FMC
Orocobre
Norilsk Nickel

2. Cathode manufacturers and Silicon rich anodes
Umicore
JMAT
SGL Carbon
Wacker

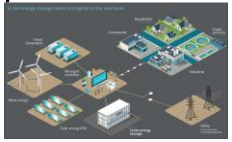
3. Next gen flourinated electrolytes
Solvay
Arkema

4. Semiconductor suppliers
Infineon
Renesas
STMicro
NXP



5. Automation players
Siemens
Manz
Bhuler

6. Micro-grid control providers
Siemens
Schneider
ABB
PSI
EPS



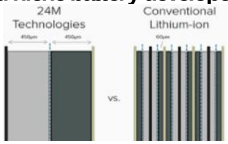
7. Battery manufacturers moving into VPP
Tesla
Sonnen
SMA
BYD

8. Automotive OEMs focussed on EVs/ buses
Tesla
BYD

9. Large scale battery manufacturers
Panasonic
LG Chem
Sony
Samsung SDI
CATL

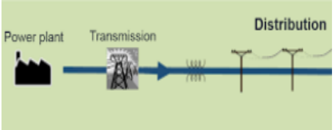
10. Battery recycling
Umicore
Veolia Group
Aurubis
Eramet
Boliden
CATL
BYD

11. Next generation and niche battery developers
Ilika
Maxwell
RedT
Ceres



1. Auto OEMs lacking EV technology
Toyota
Peugeot
Fiat

2. Centralised utilities
Fortum
Engie
Verbund
EDF



3. Gas/ diesel peaker plant manufacturers
GE
Alstom
Siemens
MHI

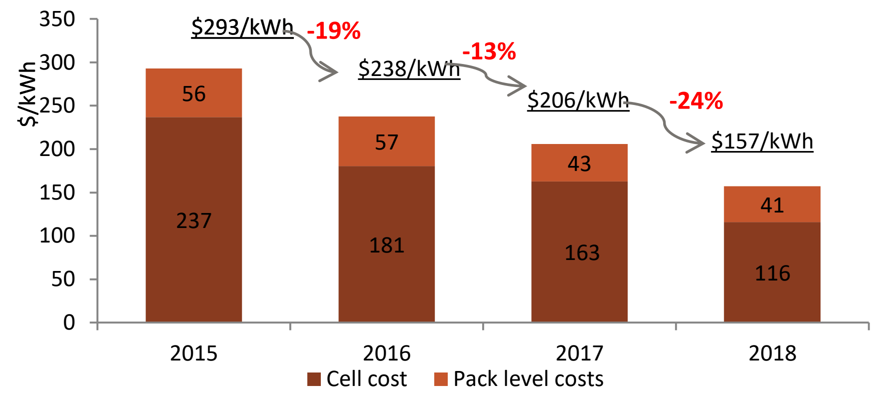
4. Micro gas turbine/ diesel manufacturers
CAT
Cummins
Kohler (Kraft Power)

Battery costs fell sharply in 2018

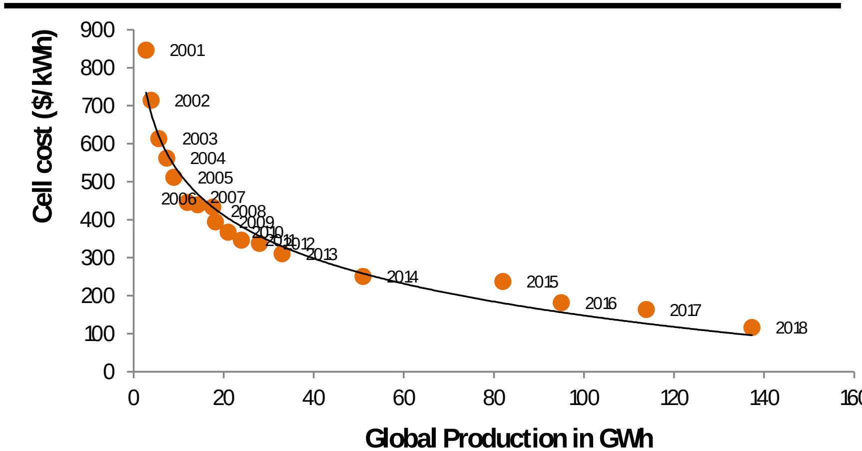
- In 2018 lithium ion battery costs declined sharply by only 24%.
- Cell costs fell by ~29%

- **Why?**
- **Reason #1: Rapid decline in raw material prices.** Down ~30% overall.
- **Reason #2: Rising manufacturing scale.** Plant capacities rose to 18-20GWh for Panasonic, CATL, BYD
- **Reason #3: Poor profitability for cell manufacturers.** Cells being sold below or at cost.

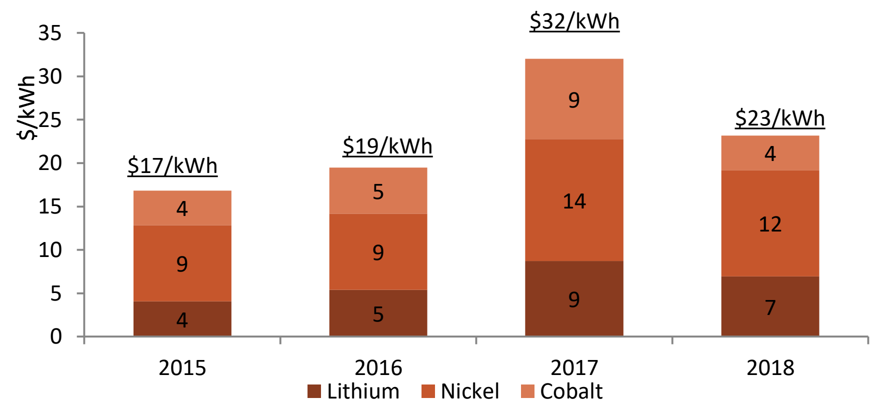
Battery costs declined sharply in 2018



Rising manufacturing scale helped lower cost



Sharp reduction in metal prices contributed 1/3rd of the cost reduction in lithium ion cells

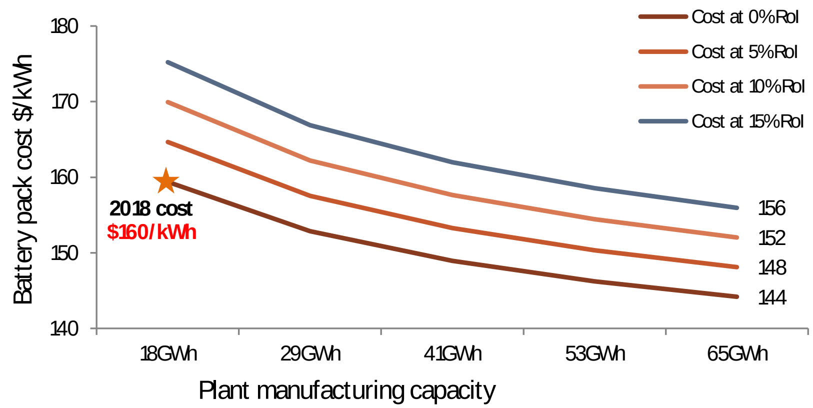


Is linear cost reduction sustainable? Not really

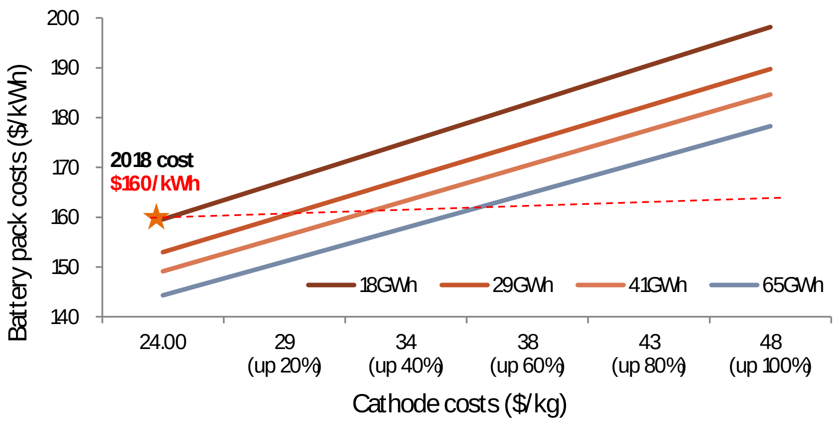
BERENBERG
PARTNERSHIP SINCE 1590

- Three risks in our view could emerge which could result in battery cost bottoming our higher than expected
- **Risk #1: Pricing power returning to the cell manufacturers.** If after tax RoI for cell manufacturer rises to 10%, battery costs will only fall to $152/kWh despite a >3X increase in manufacturing capacity.
- **Risk #2: Raw material risk:** If input metal costs double over the next 5 years, it will neutralise the benefits of a >3 fold increase in manufacturing capacity
- **Risk #3: Processing cost increase:** Higher nickel cathodes beyond NMC622 will be more expensive because of the higher processing costs

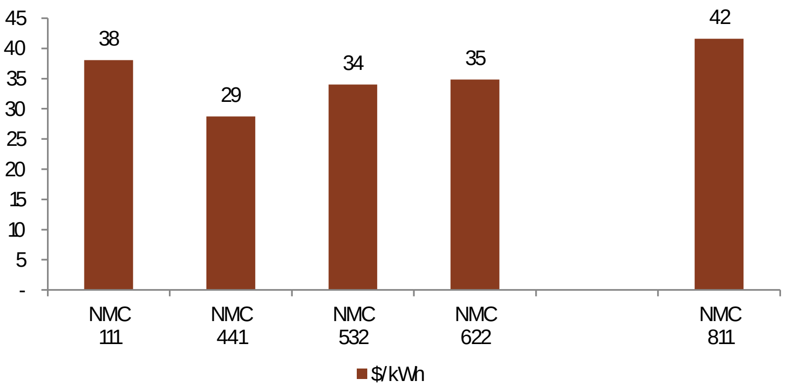
Cell manufacturers currently selling cells below/at cost. Rising consolidation in cell manufacturing and plant utilization rates could raise margins



Batteries are made of expensive metals. Increase in lithium, nickel and cobalt prices will have an impact on overall costs



Technological innovations will increase battery costs rather than decrease it. High nickel cathode materials will be more expensive

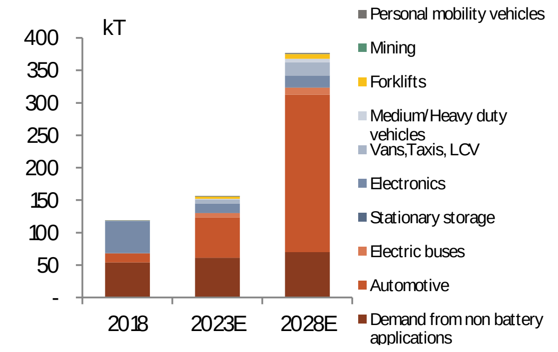


Cost Risk #1: Cobalt price increase is a major risk

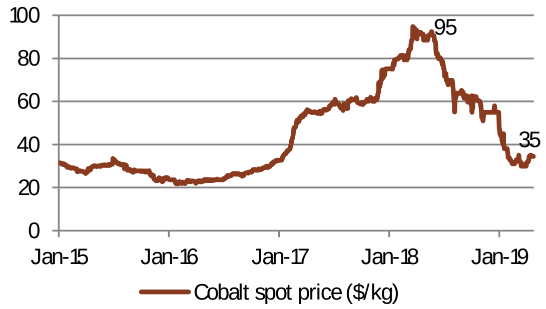
BERENBERG
PARTNERSHIP SINCE 1590

- **Sector #2: Cobalt miners/recyclers – Umicore, Glencore**
- Cobalt spot price is down by 63% from its peak at start of 2018. Our "cobalt crash" thesis has largely played out.
- We now **change our negative view on cobalt**
- Expect a bottoming of cobalt pricing and tightening of supply-demand balance over 2019-25. This is because of:
  1. a shift to NMC from LFP in electric buses in China (subsidies require higher energy densities),
  2. increased processing costs for nickel rich NMC
  3. preference for long life (and safe) cobalt rich NMC for commercial vans, trucks and off road vehicles.
- Cobalt supply from the Katanga project is at risk.

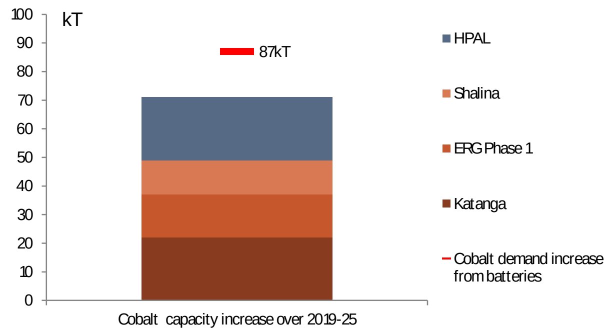
Over the next 10 years, we expect global demand to rise by more than 3 fold to 307kT



Tightening of the cobalt market could result in a partial recovery in cobalt prices in our view



Global cobalt demand to rise by 90kT over 2019-25 while cobalt production to rise less than 70kT because of Katanga (25% of total increase)



Cobalt will not disappear from lithium ion batteries

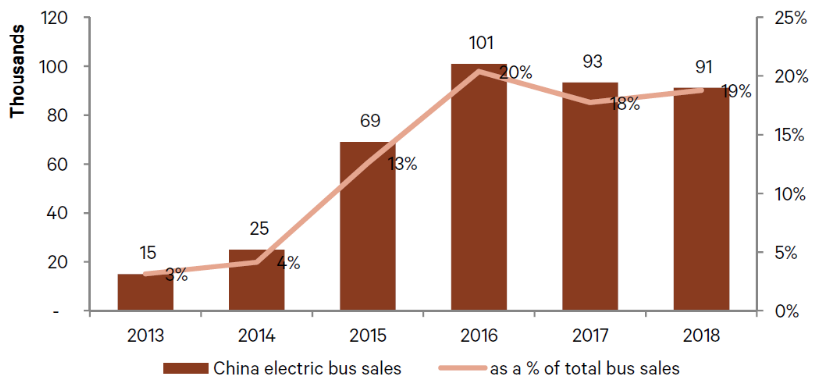
- **Reason #3: NMC and cobalt demand will rise from electric buses and other end markets**

- **NMC market growth will be supported by:**
  1. Rapid shift to NMC in electric buses,
  2. Demand from commercial road and off road vehicles,
  3. Complete shift tom NCA to NMC.

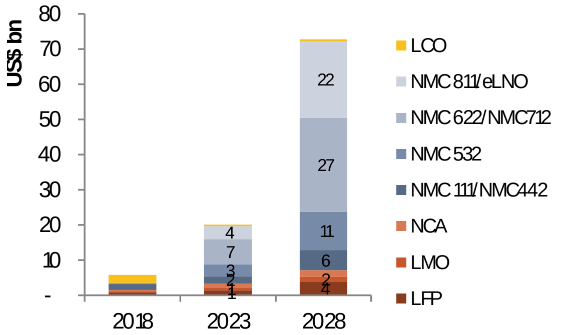
- We think that nickel rich NMC will primarily be used for premium cars because of their higher processing costs.

- NMC622 will likely be the dominant cathode chemistry for the next 10years.
  - The biggest player in NMC622 is Umicore

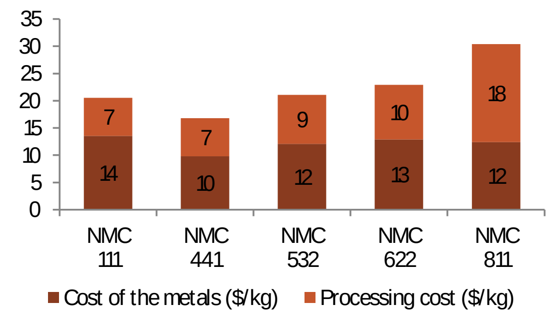
Over the last three years, 18-20% of buses sold in China have been electric



We expect global NMC cathode market to grow from $2bn in 2018 to $16bn by 2023



High cobalt chemistries will grow strongly because of their long cycle life and higher processing costs for high nickel NMC chemistries

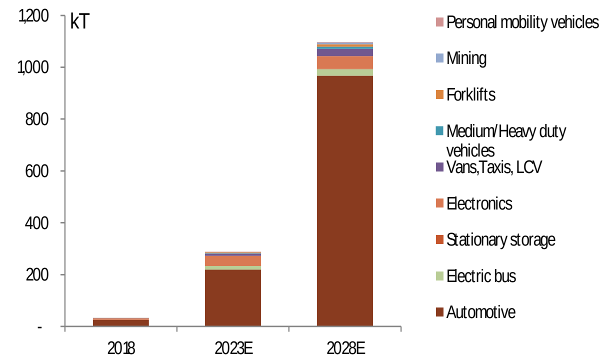


Cost risk #2: Nickel has now peaked and will likely remain at current levels

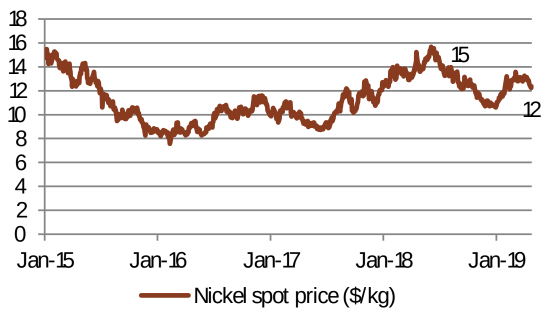
BERENBERG
PARTNERSHIP SINCE 1590

- Nickel market has been in structural deficit since 2016 and inventories have been declining.
- Demand for class 1 nickel will grow sharply.
  - ➢ Demand from batteries to rise from 32kT in 2018 to 288kT by 2023 and more than 1mn tonnes by 2028.
  - ➢ Currently global class 1 nickel is ~1mn tonnes p.a.
- Most of the new nickel projects are based on laterite ores ion places like Indonesia and Philippines. These require expensive HPAL process to convert it into battery grade nickel.
  - ➢ According to Norilsk Nickel, HPAL project need more than $20/kg incentive pricing.
  - ➢ According to Umicore, incentive pricing for HPAL processing is $25-26/kg. This is double where nickel is trading currently.

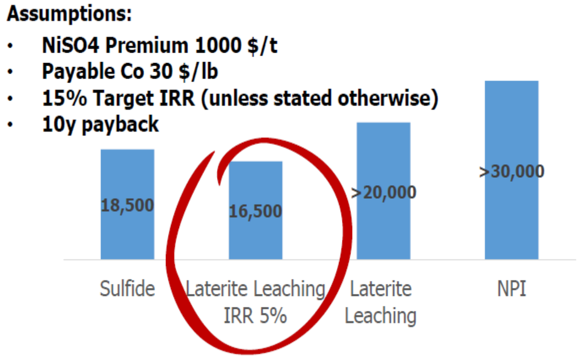
We project class 1 nickel demand from batteries to rise from 32kT in 2018 to 288kT by 2023 and more than 1mn tonnes by 2028



Nickel prices need to double if incremental class 1 nickel supply is to come from HPAL based laterite ores



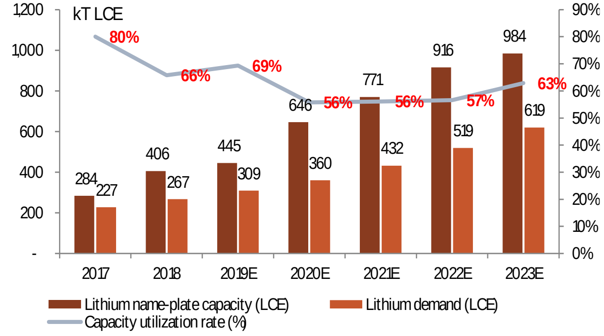
Nickel prices need to be above $20/kg for HPAL laterite projects to make 15% IRR



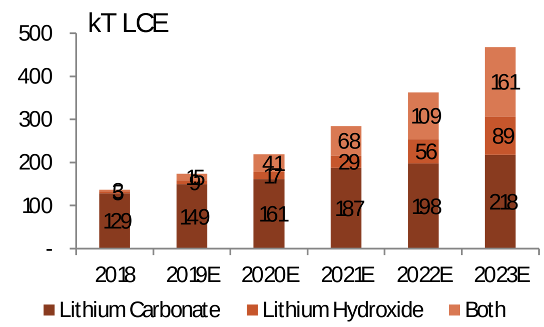
Cost Risk #3: Lithium – price has now bottomed

- Electrification commercial end market can add 78kT to the global demand for lithium by 2023 and 194kT by 2028. We project that global lithium demand will grow to 619kT by 2023 and 1.8mT by 2028
- Based on projects currently under development, we project global lithium mining capacity to rise to ~1mn tonnes LCE by 2023 which is more than double versus 0.4mn tonnes LCE capacity at the end of 2018.
- **Capacity utilization rate for the sector to drop further and on average remain below 60% over the next 5 years.**
- **We expect price erosion especially in lithium hydroxide and for spodumene.**
- We think that lithium carbonate will remain the dominant feedstock for cathode manufacturing and lithium hydroxide premium will come off.
- **Lowest cost players Tianqi, Ganfeng, SQM, Albemarle and Livent will likely strengthen control of the lithium market but they too will suffer as pricing remains weak.**

Capacity utilization rate for the sector to drop further and on average remain below 60% over the next 5 years. We expect price erosion especially in lithium hydroxide and for spodumene



We think that lithium carbonate will remain the dominant feedstock for cathode manufacturing and lithium hydroxide premiums will come off



Cost Risk #4: Pricing power will go to the cell makers – a key risk to battery cost reduction

BERENBERG
PARTNERSHIP SINCE 1590

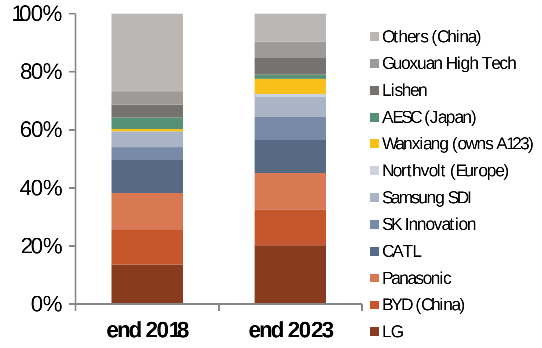
- **Sector #5: Large cell manufacturers – CATL, LG Chem**

- We strongly expect cell manufacturing to gain pricing power over the next five years due to:
  1. Need for localization,
  2. Captive nature of capacity additions,
  3. Change in Chinese subsidy regime incentivizing consolidation
  4. Delays in cell gigafactories in Europe and the US and
  5. Rising capacity utilization rates for large cell manufacturers

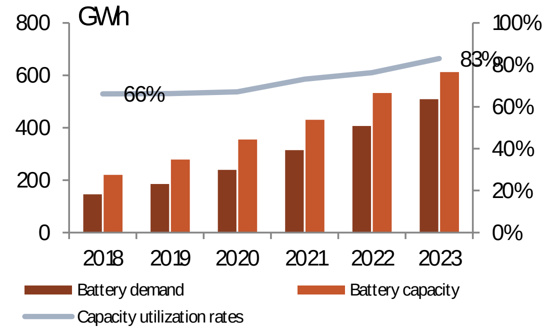
- The companies with the largest scale will likely win in the long term in our view.

- **Three companies which are likely to come out on top are CATL (China), LG Chem (Korea) and Samsung (Korea).**

We expect the top 7 players in the market to control 80% of the global cell market by 2023



We expect capacity utilization rate for the cell manufacturers to rise over the next five years



Cost Risk #5: No Moor's law here. Shift to fluorinated electrolytes will improve energy density but will add to battery costs

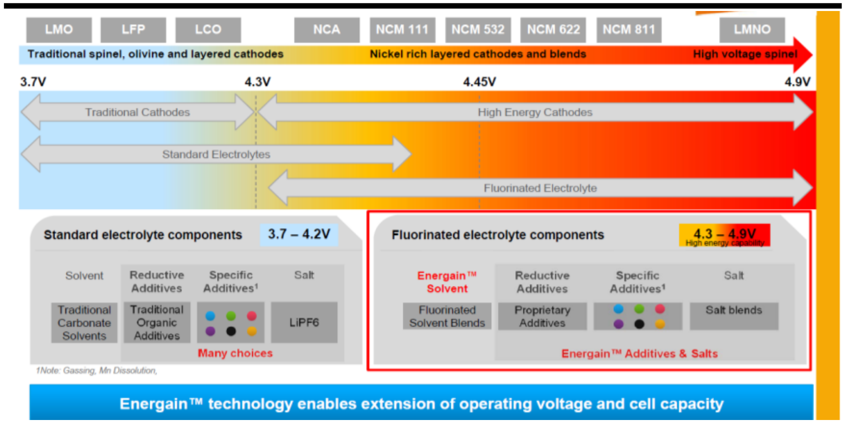
BERENBERG
PARTNERSHIP SINCE 1590

Electrolyte

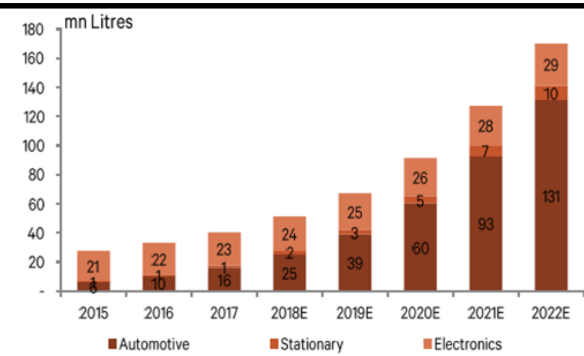
- Traditional electrolyte degrades with high nickel and high silicon in the anode
- We think we will shift to "fluorinated electrolytes".
    1. These work at higher voltages
    2. result in longer cycle life

- Fluorinated electrolytes cost more than double versus traditional electrolytes but they result in energy density rising by more than 30%

Solvay's fluorinated electrolytes use high-nickel NMC-based lithium-ion cells to operate at high voltages without compromising on cycle life; this can result in at lest a 30% improvement in the cell's energy density



We project demand for electrolytes to rise to 170m litres by 2022 from 40m litres in 2017



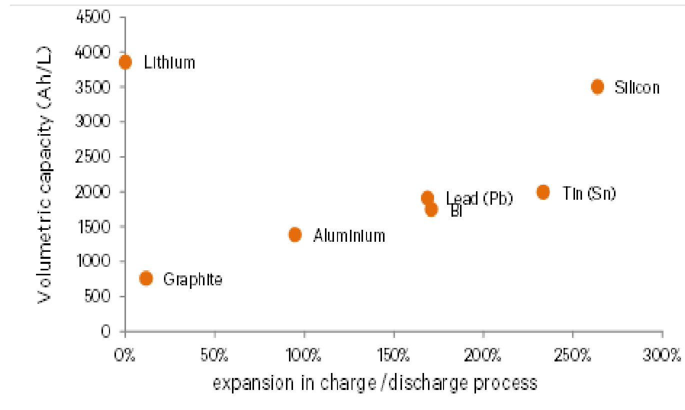
Solid-state batteries based on lithium ion will be horrendously expensive. Silicon could be a solution

BERENBERG
PARTNERSHIP SINCE 1590

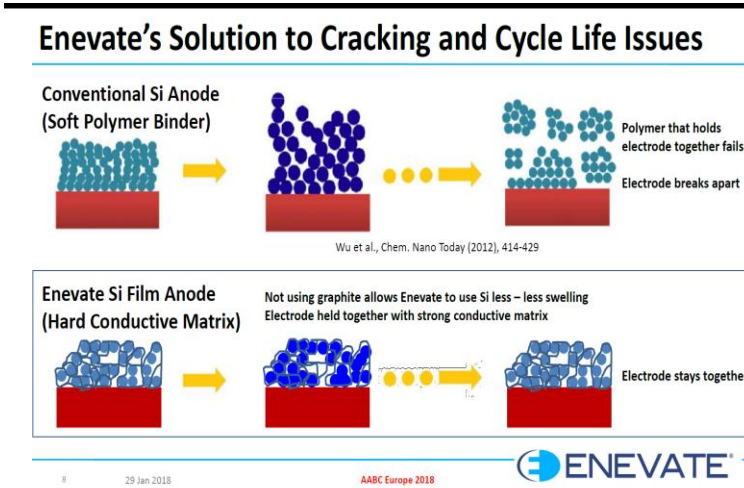
Anode

- Shift to lithium metal anode in mainstream EVs unlikely to occur
- Silicon content in batteries and EVs will rise

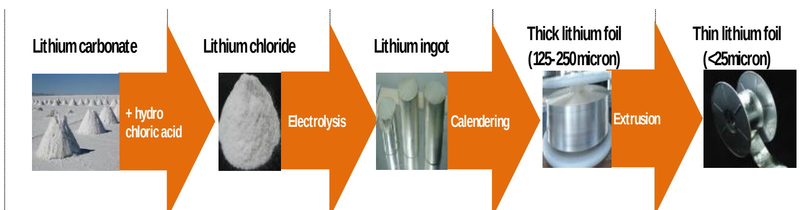
Alternative anode materials, lithium metal and silicon hold the most promise for increase energy density and EV range



Silicon might be the preferred route to improve the anode



Lithium metal anode is not economic with lithium prices rising



	Lithium carbonate	Lithium chloride	Lithium ingot	Thick lithium foil (125-250micron)	Thin lithium foil (<25micron)
Cost ($/kg)	$12/kg		$100/kg	$500/kg	$2000/kg
Cost ($/kWh)			$6/kWh	$30/kWh	$120/kWh

Disclaimers

Publication date: 3 December, 2019

Please note:

This document has been prepared by Equity Research Analysts of Joh. Berenberg, Gossler & Co. KG (hereinafter referred to as the "Bank") and opinions contained in this presentation represent those of the Bank's Research Department at the stated date of publication.

The recommendations referred to in the presentation are not, nor shall they be construed as, investment advice by Berenberg. For recommendations and relevant disclosures issued by the Berenberg Research department, as part of investment research, please see Compliance Disclosures | Berenberg

If you would like to view our research reports, these can be found at Equity Research or you can request a copy by emailing crm@berenberg.de.

Valuation basis/rating key

The recommendations for companies analysed by Berenberg's Equity Research department are made on an absolute basis for which the following three-step rating key is applicable:

Buy: Sustainable upside potential of more than 15% to the current share price within 12 months;

Sell: Sustainable downside potential of more than 15% to the current share price within 12 months;

Hold: Upside/downside potential regarding the current share price limited; no immediate catalyst visible.

NB: During periods of high market, sector, or stock volatility, or in special situations, the recommendation system criteria may be breached temporarily.

General investment-related disclosures

The Bank has made all efforts to carefully research and process all information. The information has been obtained from sources which we believe to be reliable such as, for example, Thomson Reuters, Bloomberg and the relevant specialised press. However, we do not assume liability for the correctness and completeness of any information given. The provided information has not been checked by a third party, especially an independent auditing firm.

Disclaimers

BERENBERG
PARTNERSHIP SINCE 1590

The following internet link provides further remarks on our financial analyses: Berenberg Research

Legal disclaimer

The information given can become incorrect due to passage of time and/or as a result of legal, political, economic or other changes. We do not assume responsibility to indicate such changes and/or to publish an updated document. The forecasts contained in this document or other statements on rates of return, capital gains or other accession are the personal opinion of the author and we do not assume liability for the realisation of these. Forward-looking forecasts or future results, estimates of amounts not yet determinable, and therefore involve known and unknown risks, uncertainties and other factors which may cause the actual results, performance or achievements of their subject matter to be materially different from current expectations. The Bank accepts no responsibility and no representation or warranty, express or implied, is made as to the accuracy, reliability or completeness of the source of information on these webpages. To the fullest extent permitted by law, the Bank accepts no responsibility for and shall have no liability for any loss (including without limitation direct, indirect, consequential and loss of profit), damages, or for any liability to a third party however arising in relation to the information on these webpages. The Bank has no obligation to update, modify or amend the information.

This presentation is only for information purposes only. It does not constitute investment advice or recommendation to buy financial instruments. It does not replace consulting independent advisors regarding legal, tax or financial matters.

Opinions, estimates and projections constitute the current judgment of the author when this document was compiled.

Recommendations issued should not necessarily be considered to be either objective or unbiased. The Bank may engage in transactions, for its own account or with customers, in a manner inconsistent with the views taken in a recommendation. the Bank may (i) act as a market-maker (ii) deal as principal (iii) have managed or co-managed a public offering for the issuer, which is the subject of a recommendation (iv) be party to an agreement with the issuer, that is the subject of a recommendation, relating to the provision of services of investment firms (v) provide liquidity in instruments referred to in any recommendation and (vi) have, or be seeking to develop, an investment banking or corporate banking relationship with issuers mentioned in a recommendation. The Bank or its employees may from time to time have long or short positions in such instruments referred to in a recommendation. Accordingly, information referred to in a recommendation may not be independent from the proprietary interests of the Bank and its affiliates, which may conflict with your interests and affect the objectivity of relevant recommendations.

This document is not a solicitation or an offer to buy or sell the mentioned stock.

Disclaimers

Remarks regarding foreign investors

The preparation of this document is subject to regulation by German law. The distribution of this document in other jurisdictions may be restricted by law, and persons into whose possession this document comes should inform themselves about, and observe, any such restrictions.

United Kingdom

This document is meant exclusively for institutional investors and market professionals, but not for private customers. It is not for distribution to or the use of private investors or private customers.

United States of America

This document has been prepared exclusively by Joh. Berenberg, Gossler & Co. KG. Although Berenberg Capital Markets LLC, an affiliate of the Bank and registered US broker-dealer, distributes this document to certain customers, Berenberg Capital Markets LLC does not provide input into its contents, nor does this document constitute research of Berenberg Capital Markets LLC. In addition, this document is meant exclusively for institutional investors and market professionals, but not for private customers. It is not for distribution to or the use of private investors or private customers.
Please contact Berenberg Capital Markets LLC (+1 617.292.8200), if you require additional information.

Competent supervisory authority
Joh. Berenberg, Gossler & Co. KG is a Kommanditgesellschaft (a German form of limited partnership) established under the laws of the Federal Republic of Germany registered with the Commercial Register at the Local Court of the City of Hamburg under registration number HRA 42659 with its registered office at Neuer Jungfernstieg 20, 20354 Hamburg, Germany. A list of partners is available for inspection at our London Branch: 60 Threadneedle Street, London EC2R 8HP, United Kingdom.

Joh. Berenberg, Gossler & Co. KG is authorised by the German Federal Financial Supervisory Authority (BaFin) and subject to limited regulation by the Financial Conduct Authority, firm reference number 222782. Details about the extent of our regulation by the Financial Conduct Authority are available from us on request. For further information as well as specific information on Joh. Berenberg, Gossler & Co. KG, its head office and its foreign branches in the European Union please refer to http://www.berenberg.de/en/corporate-disclosures.html.

Contacts - Research

BERENBERG
PARTNERSHIP SINCE 1590

JOH. BERENBERG, GOSSLER & CO. KG

Internet www.berenberg.com

E-mail: firstname.lastname@berenberg.com

EQUITY RESEARCH

GENERAL MID CAP

MID CAP - DACH

Carl-Oscar Bredengen	+44 20 3753 3160
Marta Bruska	+44 20 3753 3187
Charlotte Friedrichs	+44 20 3753 3077
Gustav Froberg	+44 20 3465 2655
James Letten	+44 20 3753 3176
Alexander O'Donoghue	+44 20 3207 7804
Gerhard Orgonas	+44 20 3465 2635
Benjamin Pfannes-Varrow	+44 20 3465 2620
Lasse Stueben	+44 20 3753 3208

MID CAP - EU core

Beatrice Allen	+44 20 3465 2662
Fraser Donlon	+44 20 3465 2674
Remi Grenu	+44 20 3207 7806
Christoph Greulich	+44 20 3753 3119
Andreas Markou	+44 20 3753 3022
Anna Patrice	+44 20 3207 7863
Trion Reid	+44 20 3753 3113
Jan Richard	+44 20 3753 3029

MID CAP - UK

Calum Battersby	+44 20 3753 3118
Joseph Bloomfield	+44 20 3753 3248
Robert Chantry	+44 20 3207 7861
Sam Cullen	+44 20 3753 3183
Ned Hammond	+44 20 3753 3017
Tom Horne	+44 20 3207 7913
Edward James	+44 20 3207 7811
Kieran Lee	+44 20 3465 2736
Lush Mahendrarajah	+44 20 3207 7896
Benjamin May	+44 20 3465 2667
Alex Medhurst	+44 20 3753 3047
Anthony Plom	+44 20 3207 7908
Eoghan Reid	+44 20 3753 3055
Owen Shirley	+44 20 3465 2731
Donald Tait	+44 20 3753 3031
Sean Thapar	+44 20 3465 2657

BUSINESS SERVICES, LEISURE & TRANSPORT

BUSINESS SERVICES

Tom Burlton	+44 20 3207 7852

LEISURE

Jack Cummings	+44 20 3753 3161
Stuart Gordon	+44 20 3207 7858
Annabel Hay-Jahans	+44 20 3465 2720

TRANSPORT & LOGISTICS

Conor Dwyer	+44 20 3753 3216
William Fitzalan Howard	+44 20 3465 2640
Joel Spungin	+44 20 3207 7867
Adrian Yanoshik	+44 20 3753 3073

CONSUMER

BEVERAGES

Javier Gonzalez Lastra	+44 20 3465 2719

FOOD MANUFACTURING AND HPC

Ebba Bjorklid	+44 20 3753 3247
Fulvio Cazzol	+44 20 3207 7840
James Targett	+44 20 3207 7873

FOOD RETAIL

Thomas Davies	+44 20 3753 3104

GENERAL RETAIL

Michael Benedict	+44 20 3753 3175
Oliver Anderson	+44 20 3753 3173
Graham Renwick	+44 20 3207 7851
Michelle Wilson	+44 20 3465 2663

LUXURY GOODS

Lauren Molyneux	+44 20 3207 7892

ENERGY

OIL & GAS

Baha Bassatne	+44 20 3753 3158
John Gleeson	+44 20 3465 2716
Ilkin Karimli	+44 20 3465 2684
Edward Pizzey	+44 20 3753 3185
Henry Tarr	+44 20 3207 7827

ENERGY (cont'd)

UTILITIES

Andrew Fisher	+44 20 3207 7937
Lawson Steele	+44 20 3207 7887

FINANCIALS

BANKS

Adam Barrass	+44 20 3207 7923
Frederick Brennan	+44 20 3753 3171
Michael Christodoulou	+44 20 3207 7920
Andrew Lowe	+44 20 3465 2743
Eoin Mullany	+44 20 3207 7854
Peter Richardson	+44 20 3465 2681

DIVERSIFIED FINANCIALS

Panos Ellinas	+44 20 3753 3149
Chris Turner	+44 20 3753 3019

REAL ESTATE

Kai Klose	+44 20 3207 7888

HEALTHCARE

Scott Bardo	+44 20 3207 7869
Michael Healy	+44 20 3753 3201
Tom Jones	+44 20 3207 7877
Odysseas Manesiotis	+44 20 375 3200

INDUSTRIALS

AEROSPACE & DEFENCE

Andrew Gollan	+44 20 3207 7891
Ross Law	+44 20 3465 2692
George McWhirter	+44 20 3753 3163

AUTOMOTIVES

Cristian Dirpes	+44 20 3465 2721
Asad Farid	+44 20 3207 7932

CAPITAL GOODS

Philippe Lorrain	+44 20 3207 7823
Joel Spungin	+44 20 3207 7867

MATERIALS

CHEMICALS

Sebastian Bray	+44 20 3753 3011
Xian Deng	+44 20 3753 3014
Kai Lux	+44 20 3753 3202
Anthony Manning	+44 20 3753 3092
Rikin Patel	+44 20 3753 3080

METALS & MINING

Richard Hatch	+44 20 3753 3070
Laurent Kimman	+44 20 3465 2675
Michael Stoner	+44 20 3465 2643

TMT

TECHNOLOGY

Tammy Qiu	+44 20 3465 2673
Tej Sthankiya	+44 20 3753 3099
Lou Ann Yong	+44 20 3753 3159

MEDIA

Jamie Bass	+44 20 3753 3217
Robert Berg	+44 20 3465 2680
Keisi Hysa	+44 20 3207 7817
Laura Janssens	+44 20 3465 2639
Sarah Simon	+44 20 3207 7830

TELECOMMUNICATIONS

David Burns	+44 20 3753 3059
Usman Ghazi	+44 20 3207 7824
Laura Janssens	+44 20 3465 2639
Abhilash Mohapatra	+44 20 3465 2644
Carl Murdock-Smith	+44 20 3207 7918

THEMATIC RESEARCH

Steven Bowen	+44 20 3753 3057
Julia Schrameier	+44 20 3753 3172

ECONOMICS

Florian Hense	+44 20 3207 7859
Kallum Pickering	+44 20 3465 2672
Holger Schmieding	+44 20 3207 7889

Contacts - Sales

BERENBERG
PARTNERSHIP SINCE 1590

EQUITY SALES

SPECIALIST SALES

AEROSPACE & DEFENCE & CAPITAL GOODS
Cara Luciano +44 20 3753 3146
AUTOS, CHEMICALS & TECHNOLOGY
Edward Wales +44 20 3207 7815
BANKS & DIVERSIFIED FINANCIALS
Eleni Papoula +44 20 3465 2741
BUSINESS SERVICES, LEISURE & TRANSPORT
Rebecca Langley +44 20 3207 7930
CONSUMER DISCRETIONARY
Pauline Chevalier +44 20 3753 3209
CONSUMER STAPLES
Ramnique Sroa +44 20 3753 3064
HEALTHCARE
David Hogg +44 20 3465 2628
MEDIA & TELECOMS
Jonathan Smith +44 20 3207 7842
METALS & MINING, OIL & GAS AND UTILITIES
Jason Turner +44 20 3753 3063
THEMATICS
Chris Armstrong +44 20 3207 7809

SALES

BENELUX
Miel Bakker +44 20 3207 7808
Bram van Hijfte +44 20 3753 3000

SALES (cont'd)

FRANCE
Alexandre Chevassus +33 15844 9512
Dalila Farigoule +33 15844 9510
Kevin Nor +33 15844 9505
Guillaume Viret +3315844 9507

SCANDINAVIA
Marco Weiss +49 40 3506 0719

UK
Thomas Baker +44 20 3753 3062
James Burt +44 20 3207 7807
Marta De-Sousa Fialho +44 20 3753 3098
Katie Jackson +44 20 3753 3041
Robert Floyd +44 20 3753 3018
David Franklin +44 20 3465 2747
Sean Heath +44 20 3465 2742
Stuart Holt +44 20 3465 2646
James Hunt +44 20 3753 3007
James McRae +44 20 3753 3036
David Mortlock +44 20 3207 7850
Bhavin Patel +44 20 3207 7926
Kushal Patel +44 20 3753 3038
Richard Payman +44 20 3207 7825
Christopher Pyle +44 20 3753 3076
Adam Robertson +44 20 3753 3095

SALES (cont'd)

UK (cont'd)
Mark Sheridan +44 20 3207 7802
George Smibert +44 20 3207 7911
Paul Walker +44 20 3465 2632

GERMANY
Simone Arnheiter +49 69 9130 90 740
Nina Buechs +49 69 9130 90 735
André Grosskurth +49 69 9130 90 734

SWITZERLAND, AUSTRIA & ITALY
Duncan Downes +4122 317 1062
Andrea Ferrari +4144 283 2020
Gianni Lavigna +4144 283 2038
Jamie Nettleton +4144 283 2026
Yeannie Rath +4144 283 2029

CRM

Megan Connelly +44 20 3753 3244
Laura Cooper +44 20 3753 3065
Beau Dibbs +44 20 3753 3048
Jessica Jarmyn +44 20 3465 2696
Madeleine Lockwood +44 20 3753 3110
Vikram Nayar +44 20 3465 2737
Fenella Neill +44 20 3207 7868

CORPORATE ACCESS

Lindsay Arnold +44 20 3207 7821
Sally Fitzpatrick +44 20 3207 7826
Maz Gentile +44 20 3465 2668
Robyn Gowers +44 20 3753 3109
Dipti Jethwani +44 20 3207 7936
Phoebe Lindsay +44 20 3753 3246
Ross Mackay +44 20 3207 7866
Stella Siggins +44 20 3465 2630
Lucy Stevens +44 20 3753 3068
Abbie Stewart +44 20 3753 3054

EVENTS

Miranda Bridges +44 20 3753 3008
Charlotte David +44 20 3207 7832
Suzy Khan +44 20 3207 7915
Natalie Meech +44 20 3207 7831
Eleanor Metcalfe +44 20 3207 7834
Sarah Weyman +44 20 3207 7801

COO Office

Greg Swallow +44 20 3207 7833

SALES TRADING

LONDON
Charles Beddow +44 20 3465 2691
Mike Berry +44 20 3465 2755
Joseph Chappell +44 20 3207 7885
Stewart Cook +44 20 3465 2752
Mark Edwards +44 20 3753 3004
Tom Floyd +44 20 3753 3136
Tristan Hedley +44 20 3753 3006
Peter King +44 20 3753 3139
AJ Pulleyn +44 20 3465 2756
Paul Somers +44 20 3465 2753
Frans Van Wakeren +44 20 3753 3079

PARIS
Vincent Klein +33 158 44 95 09

EQUITY TRADING

HAMBURG
David Hohn +49 40 350 60 761
Lukas Niehoff +49 40 350 60 798
Lennart Pleus +49 40 350 60 596
Marvin Schweden +49 40 350 60 576
Philipp Wiechmann +49 40 350 60 346
Christoffer Winter +49 40 350 60 559

LONDON
Christopher Brown +44 20 3753 3085
Edward Burlison-Rush +44 20 3753 3005
Jack Clayton +44 20 3753 3166

LONDON (cont'd)
Will Kain +44 20 3753 3167
Chris McKeand +44 20 3207 7938
Ross Tobias +44 20 3753 3137
Robert Towers +44 20 3753 3262

ELECTRONIC TRADING

Frederik Bröker +49 40 3506 0463
Jonas Doehler +44 40 3506 0391
Matthias Führer +49 40 3506 0597
Sven Kramer +49 40 3506 0347

Contacts - BCM

BERENBERG CAPITAL MARKETS LLC — Member FINRA & SIPC

Internet www.berenberg-us.com — E-mail: firstname.lastname@berenberg-us.com

EQUITY RESEARCH

CONSTRUCTION	
Robert Muir	+1646 949 9028
Daniel Wang	+1646 949 9025
GENERAL MID CAP - US	
Samuel England	+1646 949 9035
Alex Maroccia	+1646 949 9033
Brett Knoblauch	+1646 949 9032
FOOD MANUFACTURING	
Donald McLee	+1646 949 9026
HEALTHCARE	
BIOTECH/THERAPEUTICS	
Shanshan Xu	+1646 949 9023
MED. TECH/SERVICES	
Ravi Misra	+1646 949 9028
SPECIALTY PHARMA/BIOTECH	
Iris Long	+1646 949 9029
Patrick R. Trucchio	+1646 949 9027
CAPITAL GOODS	
Andrew Buscaglia	+1646 949 9040
INDUSTRIAL MATERIALS	
Paretosh Misra	+1646 949 9031
REAL ESTATE	
Keegan Carl	+1646 949 9052
Nate Crossett	+1646 949 9030
Connor Siversky	+1646 949 9037
SOFTWARE & IT SERVICES	
Joshua Tilton	+1646 949 9036
Francois Yoshida-Are	+1646 949 9152
TECHNOLOGY HARDWARE	
Andrew DeGasperi	+1646 949 9044

ECONOMICS

Mickey Levy	+1646 949 9099
Roiana Reid	+1646 949 9098

EQUITY SALES

SALES	
David Alonso	+1415 802 2523
Albert Aguiar	+1646 949 9218
Jason Cantrell	+1415 802 2523
Daniel Claeys	+1646 949 3144
Nate Emerton	+1617 292 82 11
Kelleigh Faldi	+1617 292 8288
Ted Franchetti	+1646 949 9231
Rich Harb	+1617 292 8228
Zubin Hubner	+1646 949 9202
Jessica London	+1646 949 9203
Anthony Masucci	+1646 949 9217
Ryan McDonnell	+1646 949 9214
Emily Mouret	+1415 802 2525
Peter Nichols	+1646 949 9201
Kieran O'Sullivan	+1617 292 8292
Rodrigo Ortigao	+1646 949 9205
CRM	
Alexandra Angove	+1646 949 9211
Sammy Chea	+1646 949 9241
CORPORATE ACCESS	
Michelle Backmann	+1646 949 9215
Adriane Klein	+1617 292 8202
Olivia Lee	+1646 949 9207
EVENTS	
Meridian Della Penna	+1646 949 9208
Laura Hawes	+1646 949 9209

SALES TRADING

Marc Castagnera	+1646 949 9107
Ronald Cestra	+1646 949 9104
Mark Corcoran	+1646 949 9105
Chris Davidson	+1617 292 9140
Michael Haughey	+1646 949 9106
Christopher Kanian	+1646 949 9103
Lars Schwartau	+1646 949 9101
Bob Spillane	+1646 949 9102
Donato Tierno	+1646 949 9109

ATLAS

ALPHA • THOUGHT LEADERSHIP • ACCESS • SERVICE

BERENBERG

PARTNERSHIP SINCE 1590

The EV battery roadmap

December 2019

Adam Collins **Research**
+44 (0) 20 3100 2075
adam.collins@liberum.com

Ropemaker Place, 25 Ropemaker Street,
London EC2Y 9LY / T: +44 (0)20 3100 2000
www.liberum.com

The competition

Perfected over 100 years of mass production

UK's top selling Ford Focus petrol car

Fuel economy	Range	Fuelling time	Price
WLTP: 50mpg, 6L/100km.	~500 miles, 800km	<2 minutes	From £20,000

The EV starting point

2008 reva G-Wiz

- Best selling electric car in world 2008. 1,000 on UK roads 2009
- Eight 6v lead acid batteries. Upgraded to 15KWh Li-ion 2009
- Advertised top speed and range of 45mph/48 miles … when heater off. 0-60mph 54 seconds…
- Auto Express – ''One of 10 worst cars ever''

2011 Nissan Leaf

- Best selling UK 'pure electric' car 2012. MSRP £29,000
- 24KWh L-ion (LMO) battery costing $20,000 (e). 73 mile EPA (real driving) range. 100 miles driving carefully, 50 miles in extreme heat or cold
- 20hrs to full charge @ home 6-12 hours at best stations

What the auto industry needs

Acceptable range, cost and charging times with similar safety and longevity to ICE's

1. **A profitable fully electric Golf segment car priced at a small premium to todays ICE cars i.e. £20k-£25k**

2. **Battery specs: range >300 miles, preferably 500. Battery cost <1/3 cost of car i.e. <£8,000**

3. **10 year effective battery life**

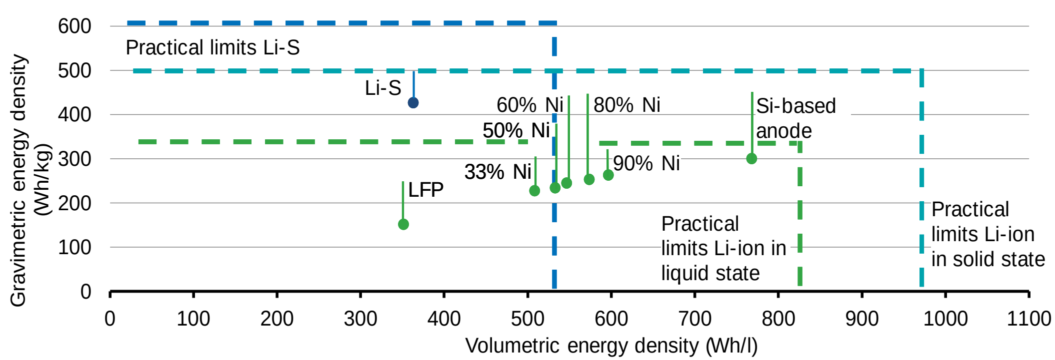
4. **30 minute or less fast charging**

Battery assembly costs will benefit from giga investments

Producer	Location	Status	Capacity GWh	Timing	Source
CATL	China	Greenfield	37-42	2020	Financial Times, 2017
Tesla	Shanghai, China	Greenfield	35	2020-2025	Electrek.co, 2017
LG	Nanjing, China	Greenfield	32	2019	Koreajoongangdaily.joins.com, 2018
Lishen	China	Greenfield	17	2020	Financial Times, 2017
BYD	China	Greenfield	24	2019	Bloomberg.com, 2018
BPP	Liyang, China	Brownfield	7	2020	Financial Times, 2017
LG	Nanjing, China	Brownfield	6	2018	Financial Times, 2017
CALB	Luoyang, China	Brownfield	2	2020	Financial Times, 2017
China total			163		
Tesla	Europe	Greenfield	35	2020-2025	Electrek.co, 2016
Northvolt	Sweden	Greenfield	32	2020-2025	Europe.autonews.com, 2017
GSR	Sweden	Greenfield	30	2020-2025	Tu.no, 2018
LG	Wroclaw, Poland	Brownfield	9	2020-2025	Manager-magazin.de, 2017
SKI	Hungary	Greenfield	7.5	2020	Electrive.com, 2017
LG	Wroclaw, Poland	Greenfield	6	2018	Koreaherald.com, 2018
SDI	Hungary	Greenfield	2.5	2018	SDI News, 2017
CATL	Germany	Greenfield	14	2022	Reuters.com, 2018
Europe total			136		
Tesla	Nevada, US	Greenfield	35	2018	Tesla, 2017
Tesla	TBD	Greenfield	35	2020-2025	Electrek.co, 2017
LG	Michigan, US	Brownfield	3	2018	Electrive.com, 2018
LG	Ochang, South Korea	Brownfield	10	2019	Financial Times, 2017
SKI	Seosan, South Korea	Brownfield	25	2020	Koreaherald.com, 2017
SDI	Ulsan, South Korea	Brownfield	2	2020	Financial Times, 2017
Saft/Siemens/Solvay/Mans	TBD	Greenfield	1	2020	Saft, 2018
Rest of world total			111		
Global Total			410		

Innovations in cell materials

	Current	2020	2025	2030
Gravimetric Energy Density (Wh/kg)	210	230	330	500
Volumetric energy density (Wh/l)	530	600	830	1000
Cost ($/kWh)	230	150	150	150
Main technology driver		80 – 90% Ni cathodes	Silicon doped anodes	Solid electrolyte



Source: Liberum estimates, Bloomberg NEF, Umicore

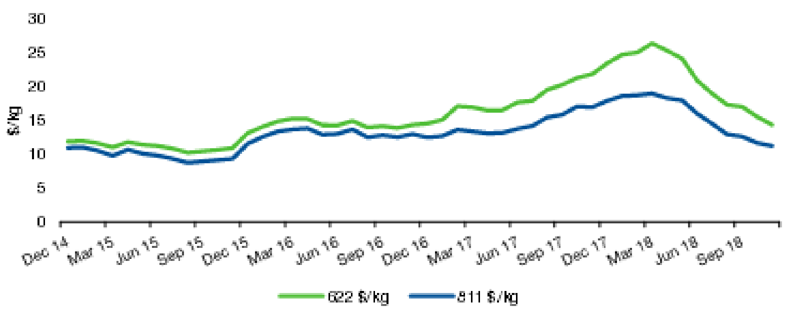
Higher nickel cathodes

- The current EV cathode materials of choice are multi-layered transition metal oxides – Lithium NMC or NCA
- First generation NMC is 333 (30% each of nickel, manganese and cobalt +10% lithium). Latest generation NMC is >50% nickel. Future generation NMC >80% or 90% nickel. NCA is already high nickel

The transition to high nickel cathodes drives down cathode ($/Kg) because nickel is 1/3 the cost of cobalt today…

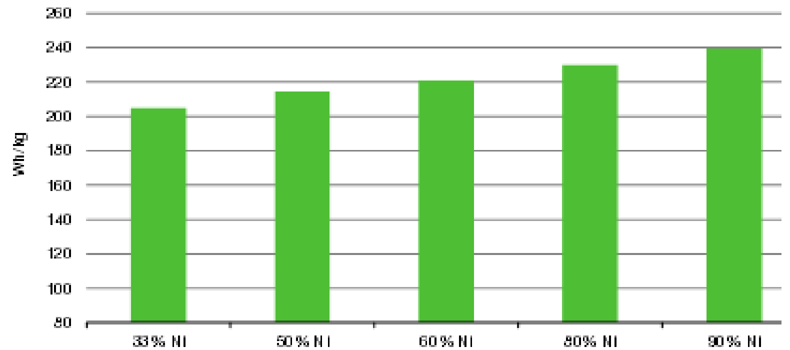
….and drives up energy density (Wh/Kg) because nickel has higher voltage than manganese

NMC 622 and 822 estimated costs at January 2019 prices



Source: Bloomberg spot metal prices, Liberum for content estimates

As nickel displaces manganese energy density (KWh/kg) rises



Source: Umicore

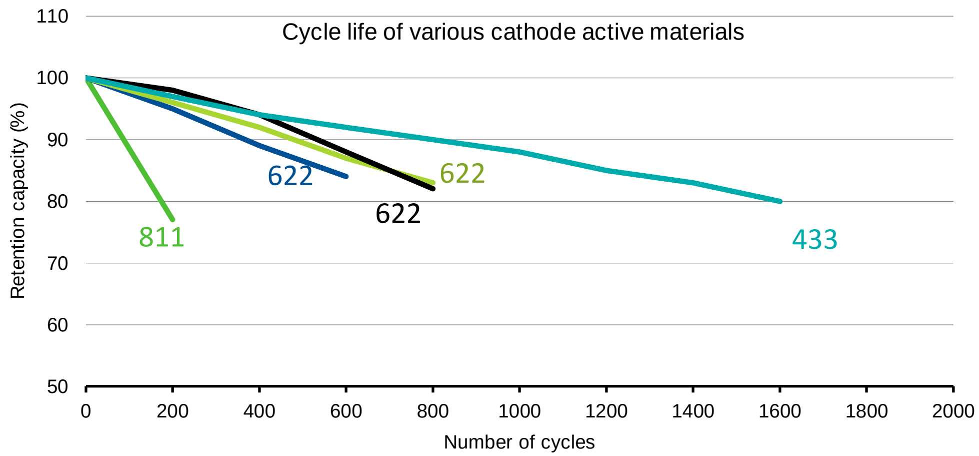
LIBERUM

The bumpy road to high nickel NMC

The transition to high nickel NCA or NMC involves some cost and performance trade-offs so is happening slower than previously anticipated

Performance trade-offs: Poorer cycle life

Cost trade-offs: Lithium hydroxide better than Lithium carbonate for high nickel NMC but higher cost. Costlier, enhanced battery-management systems (BMS) may be required

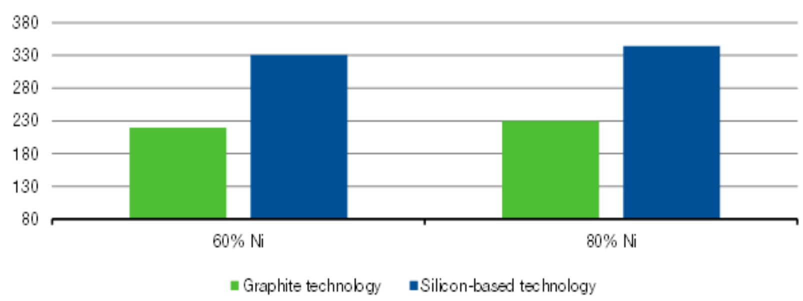


Source: Umicore 2018 industry presentation

Silicon doped anodes

- **The single largest improvement in EV battery energy density through 2025 is likely to come from the doping of graphite anodes with silicon.** Silicon has a specific capacity c.10x that of graphite and we expect 5-10% silicon doped anodes to be in widespread use by 2025. Si-C is already in use in some Japanese consumer applications
- **Key development challenge with Si-C is 3x volume expansion when cycled leading to cracking:** Solutions under development include the use of nano particle-Si, Si nano-wires, porous Si and Si graphite blends.

Anodes with 5-10% silicon offer up to 50% cell energy density uplifts when combined with NMC 622 or 811 cathodes



Source: Umicore 2018 CMD

Graphite vs. silicon anodes compared

	Graphite	Silicon
Type	Intercalation	Alloy
Theoretical capacity (mAh/g)	330	4200
Current collector	Copper	Copper
Main drawback	Capacity	3x expansion
Development status	In use from 2012	2% Si/C in Japanese consumer

Source: Liberum

Pure lithium anodes

Lithium metal anodes also offer 10x the specific capacity of graphite and are the preferred anode materials for some solid-state batteries under development

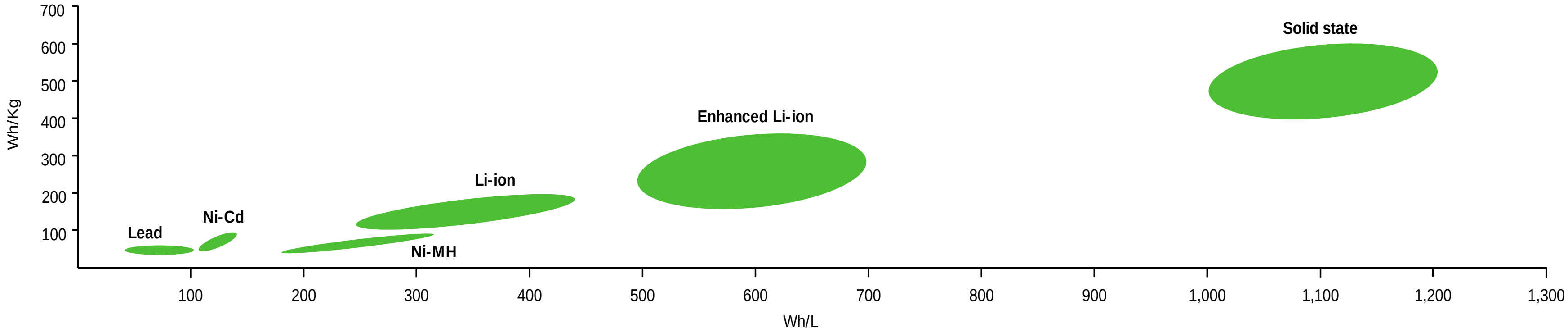
The principal development challenge with lithium metal anodes relates to the interaction of reactive lithium with the liquid electrolytes resulting in the creation of lifetime compromising dendrites. Research efforts to minimise dendrite electro-deposition use surface coatings to create a protective solid electrolyte interface (SEI) layer.

Lithium metal anode adoption may also trigger a switch back to lithium brines

Solid-state batteries

- Solid-state batteries have a solid electrolyte rather than solvent liquid electrolyte. Absent a flammable solvent electrolyte, they are less vulnerable to combustion. Energy density promises to be higher thanks to the absence of the separator, less cell packaging and an opportunity to use high energy electrodes. There is also the possibility to configure for fast charging.

- However they will likely require a different battery manufacturing approach to the expensive deposition processes used for micro SSB production and many producers may use lithium metal for the anode, which is rarely produced today.



Source: Liberum estimates

What else is out there?

A couple of other battery technologies have attracted research interest but are not serious contenders for EVs

Lithium sulfur and near relations Na-s and Mg-s

Have sulfur cathodes and lithium, sodium or manganese anodes.

PROS	CONS
Batteries use low cost sulfur, seem very safe and have attractive gravimetric energy density (Wh/Kg)	Low volumetric energy density due to low voltage and have cycling issues
Interesting for aircraft and military applications	Too bulky for cars

Lithium air

Batteries have a high capacity lithium anode and a porous carbon cathode which draws in oxygen from ambient air.

PROS	CONS
Potentially offer 5x-10x ED of today's LiBs	No tangible progress in developing cycling capability despite extensive academic R&D efforts

LIBERUM

Disclaimer