FUTURE BATTERY INDUSTRIES CRC

# FBICRC Participant Summit

11 March 2020

FUTURE BATTERY INDUSTRIES CRC

# Professor Chris Moran

DVCR Curtin University

FUTURE BATTERY INDUSTRIES CRC

# Hon Bill Johnston MLA

Minister of Mines & Petroleum; Energy; Industrial Relations

# Update and Outlook Participants Meeting

Tim Shanahan Chair

FUTURE BATTERY INDUSTRIES CRC

11 March 2020

# AN AMBITIOUS VISION

*FBICRC will help grow Australia's capabilities in future battery industries, capitalising on our competitive advantages and profound shifts occurring globally*

### *Walk …*

- The start up organisation
- Key agreements
- Research governance
- Research projects

### *Run …*

- A "state of play" mapping
- The narrative and advocacy
- Create culture
- Compliance programs
- Independent Board

### *Grow…*

- Build international linkages
- New partners in key areas
- Legacy thinking
- The case for further funding

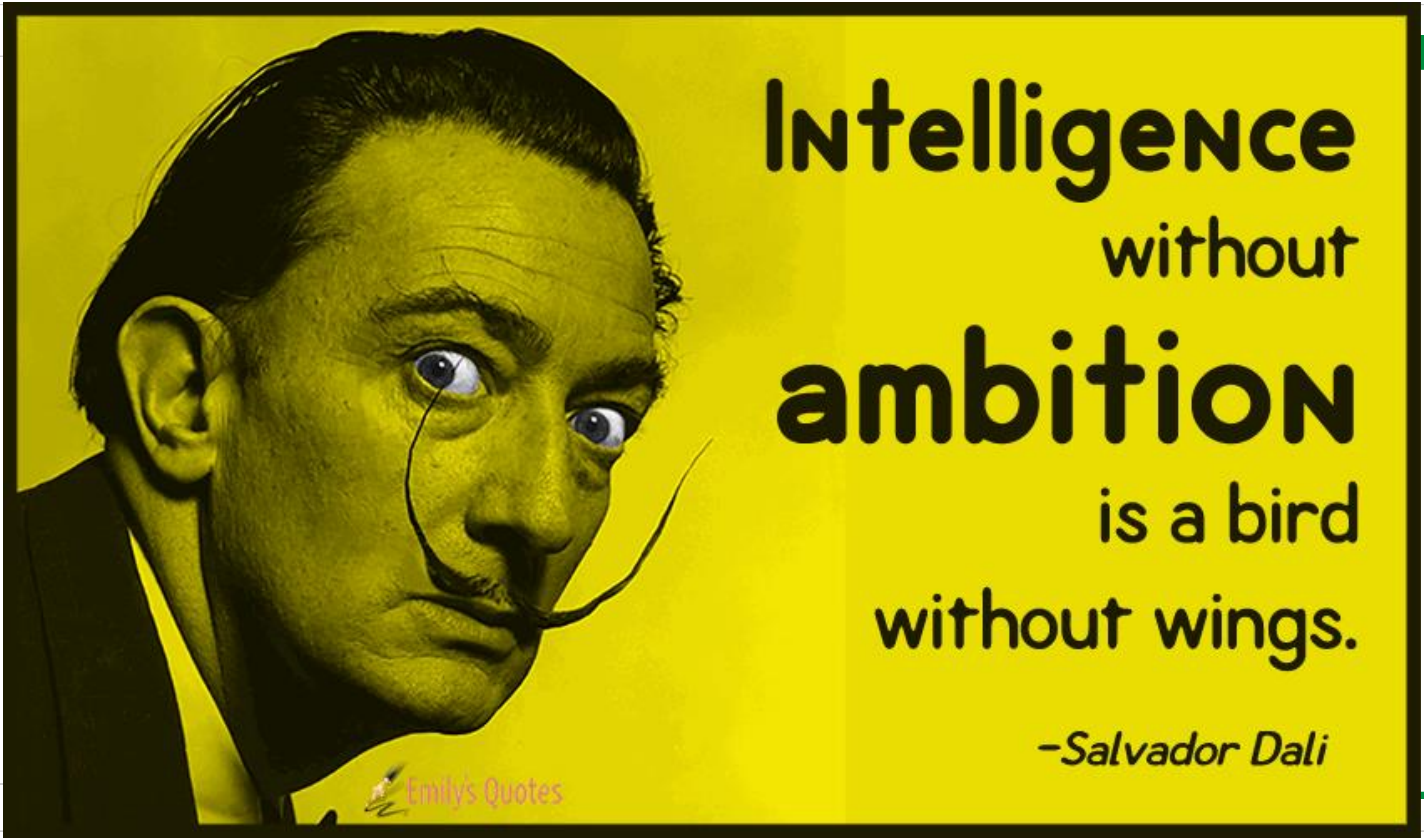
### *Transform…*

- Establish long term options
- Sustain the skills pipeline


I'M GONNA MAKE IT.
I'M GONNA MAKE IT!

# ROLE OF THE FBICRC BOARD

- Establish culture, value and ethics
- Set strategic direction
- Confirm organisation structure
- Appointment of CEO and delegation to management
- Ensure effective risk management, compliance and internal controls in place
- Exercise accountability to Members, Participants and Stakeholders


Intelligence without ambition is a bird without wings.
-Salvador Dali
Emily's Quotes

# A HIGH CALIBRE NATIONAL BOARD & INTERNATIONAL ADVISOR

- Deep expertise to help set direction, ensure compliance and accountability to members
    - Tim Shanahan Chair
    - Lisa Paul AO
    - Mark Woffenden
    - Graeme Hunt
    - Sarah Ryan
    - Bruce Godfrey
- International Board Advisor
    - Christina Lampe-Onnerud
    - A leading battery expert with experience growing businesses in US, Europe and Asia

# MEASURING SUCCESS

- Research in and of itself will not be sufficient
- Building and strengthening Australia's battery industries is our goal:
  - ✓ Economic Growth
  - ✓ Jobs and Opportunity
  - ✓ Capability

# Update and Outlook Participants Meeting

**Stedman Ellis CEO**

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# A FAST DELIVERY OF A SHORT TERM CRC

2018
– Steering committee formed
– Stage 1 & 2 CRC bids submitted
– WA Government commitment of $6M

2019
– CRC selection interview
– Commonwealth announces funding of $25M
– Initial Board appointed
– Participant workshops and a call for research EoIs
– Commonwealth grant agreement execution
– First wave of research proposals
– Inaugural AGM and appointment of full Board

2020
– International battery expert/advisor appointed
– Participant agreements lodged for execution
– Current market conditions present some ST challenges
– A community of 48 participants across value chain
– A pool of over $100M cash and in kind at foundation
– Targeting "steady state" research years by mid-year

*And many stakeholder interactions along the way …*

# A UNIQUE AND GROWING COLLABORATION

- Core and Key Participants (17)
  - Industry players across value chain
  - Seven universities
  - Key international companies
  - WA's Minerals Research Institute
- Associates and Affiliates (35)
  - SMEs and Supporters
  - Research and educational institutions
  - State Governments and Utilities

## STATUS AND OUTLOOK

- Timely delivery of establishment phase
  - Constitution
  - Key agreements
  - Governance
- Start-up phase underway
  - Program and project development
  - Operations
  - Management
  - Board Committees
- Steady–state phase: July 2020 onwards

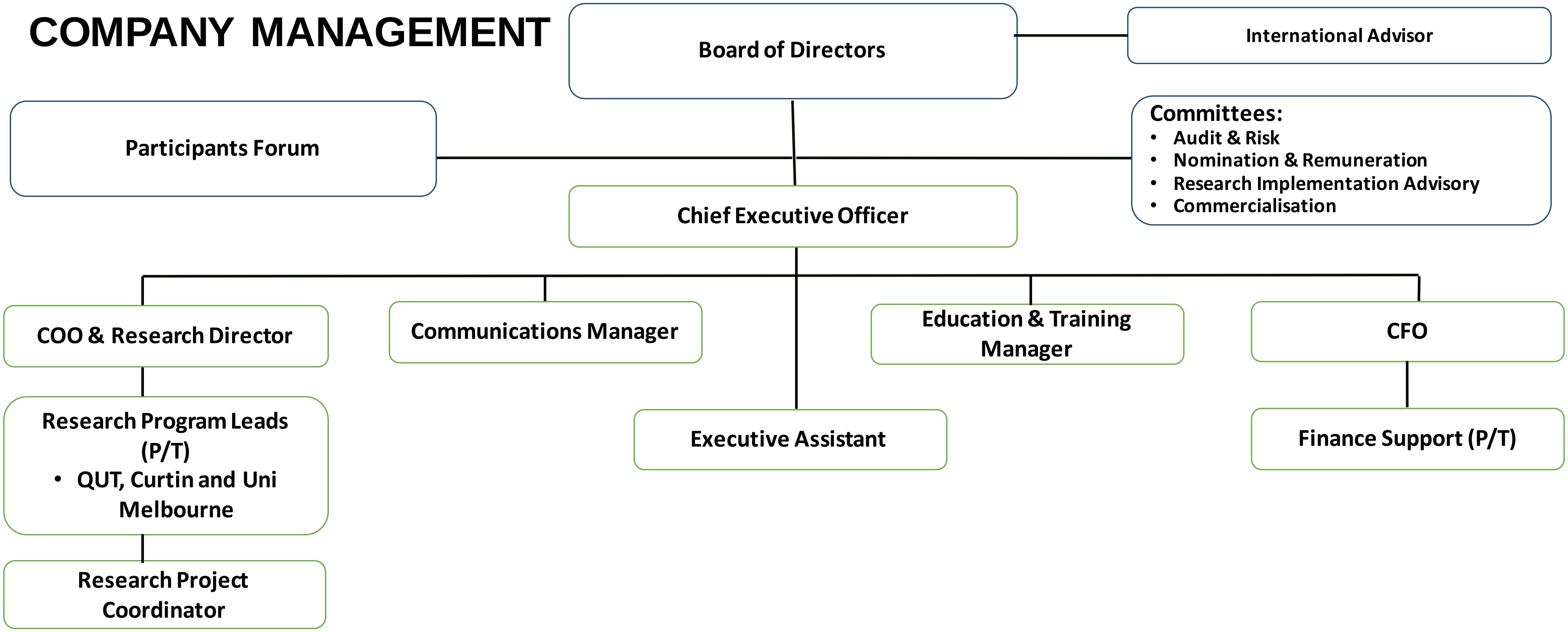
# START UP PHASE UPDATE

- Research governance and investment plan established
- Systems, policies and templates under development
- Scene setting projects commissioned
- Contracting of first round of flagship projects
- Six year capability of circa $2M cash and in kind investment per month
- New website www.fbicrc.com.au

# GRANT AGREEMENT – SCHEDULE 2

- 78 research milestones over six years
    - Related to 13 outputs and useage
- One special condition
    - CRC to take a leadership position regarding environmental management strategies from extraction of material through to end of life
- 12 education and training milestones
    - Related to HDR, vocational and business and leadership capability outputs
- Milestone completion commence 2020 to 2025
- Quarterly reporting on progress to the Commonwealth

# COMPANY MANAGEMENT



# NEXT STEPS

- Official launch of Centre on 13 March by Minister Karen Andrews
- Establish education and training program
- Establish advocacy and communications program
- Establish priorities for international engagement and partnerships
- Shepherd first round priority projects
- Complete organisation structure
- Ramp up participant engagement activities
  - Annual assembly, Annual conference
  - Participants Forum
  - Business and leadership capability development

# Update and Outlook Participants Meeting

Jacques Eksteen COO

FUTURE BATTERY INDUSTRIES CRC

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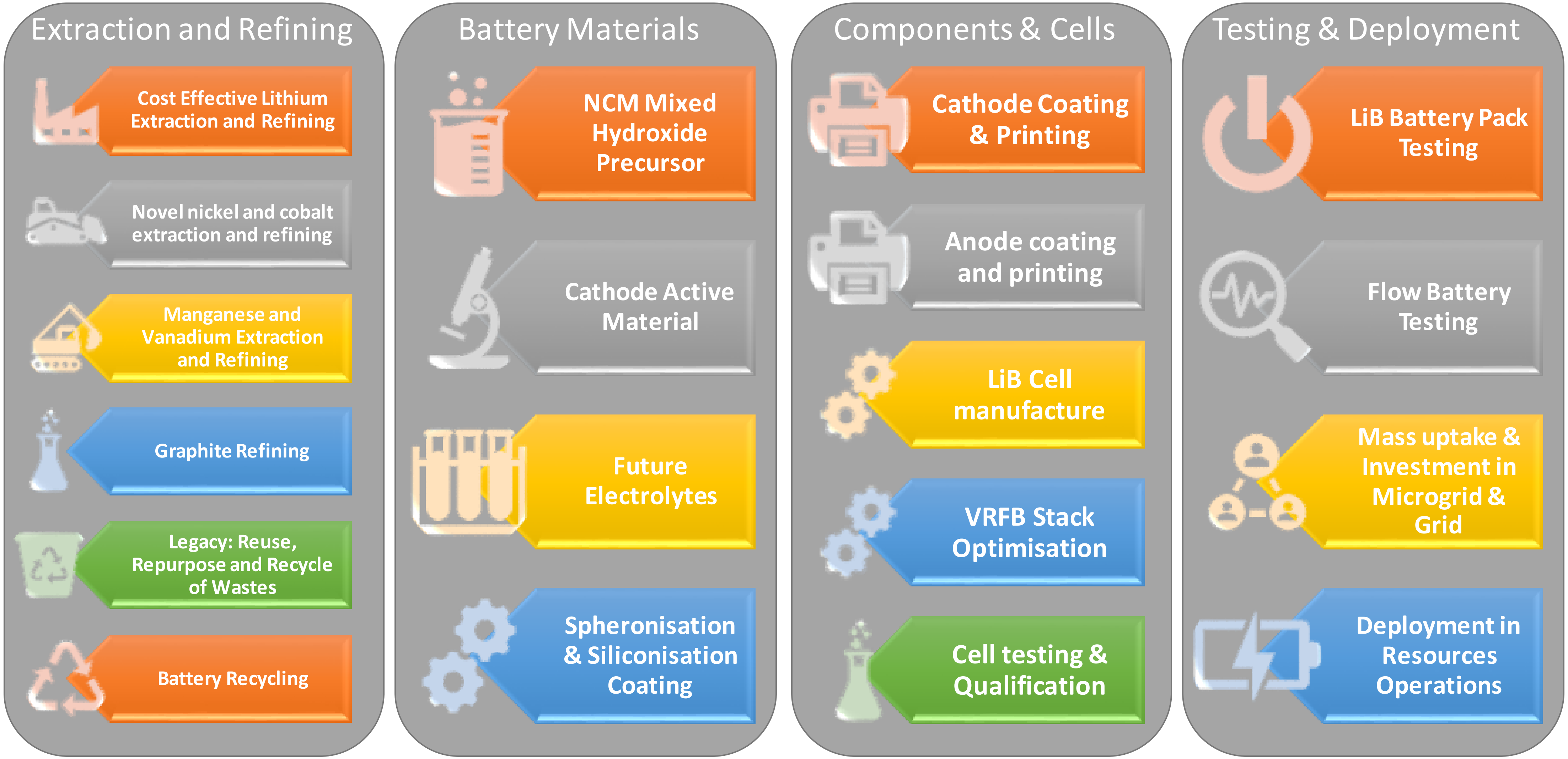
# INTERCONNECTED NATURE OF PROJECTS

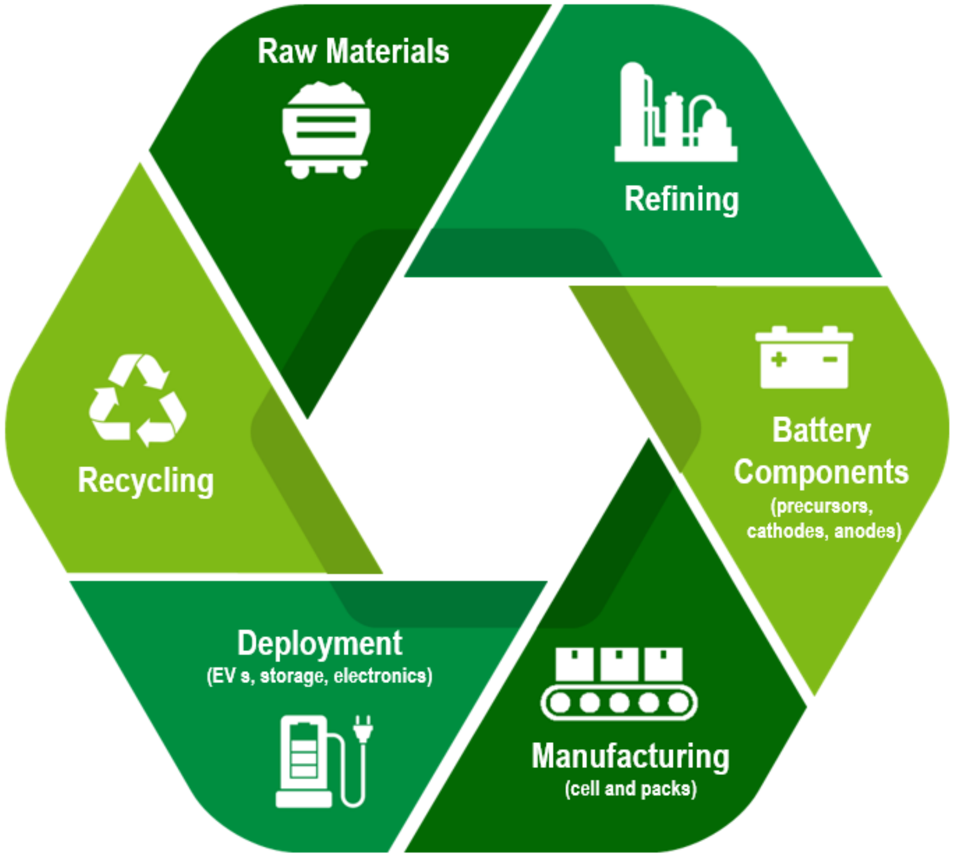


# INTERCONNECTED NATURE OF PROJECTS

| Extraction and Refining | Battery Materials | Components & Cells | Testing & Deployment |
| --- | --- | --- | --- |

- Battery material provenance authentication and traceability
- Environmental footprint certification and life cycle analysis
- State of Play: Positioning Australia in the International Context
- Resilient and Sustainable Processing and Manufacturing Hubs

# HIGH LEVEL RESEARCH STRATEGY ACROSS VALUE CHAIN




Scene setting projects due Q1, 2020:

- Governance of global battery value chains (Perth US Asia Study Centre/UWA)
- Feasibility of WA cathode precursor and cathode active material industry (QUT/Hatch)
- State of Play of Australian battery industries (CSIRO)

# RESEARCH PROJECT PIPELINE

1. Process Legacy (waste reduction, repurposing and reuse)
2. National battery testing facility
3. Innovative nickel and cobalt extraction
4. Enhancing lithium recovery and refining processing efficiency
5. NCM/NCA Cathode precursor and cathode active material pilot plant
6. Development of materials refining and forming processes for high powered anodes
7. Enabling Li-ion Cell manufacture in Australia
8. Processing of manganese and vanadium ores and the optimisation of redox flow batteries
9. Battery material provenance authentication and traceability
10. Market advantage in a circular economy through environmental footprint certification and life cycle analysis
11. Battery recycling, reuse and repurposing

# EXPRESSIONS OF INTEREST UNDER DEVELOPMENT

1. Battery industry hubs and industrial ecosystems
2. Ensuring mass uptake of battery energy storage systems
3. Future Electrolytes
4. Battery supported electrification of mining operations
5. Whole of systems approach for assessment of battery investment options

# RESEARCH IMPLEMENTATION ADVISORY COMMMITTEE

- Board member leading the committee:
  - Mark Woffenden
- Participants representatives providing industry insight:
  - Gary Frampton, BHP
  - Nathan Cammerman, Multicom
  - Stephen Wan, HEC
  - Antonia Cornwall, Synergy
  - Nicole Roocke, MRIWA
- Research program committee leaders providing research insight:
  - Prof Peter Talbot, QUT
  - Dr Mark Aylmore, Curtin University
  - Assoc. Prof Jo Staines, University of Melbourne
- The CEO and COO are ex-officio members

# RESEARCH PROJECT DEVELOPMENT AND EVALUATION

- Projects were develop in response to stated industry needs
  - Expression of Interests (EoI’s) were invited (54)
- Evaluation by Program Committee and RIAC
  - Program Committee detailed review
  - RIAC evaluates and recommends to the Board
- Projects are evaluated according to:
  - Alignment to Programs, Themes and Commonwealth Outputs
  - Impact on growing Australian battery industries
  - Industry cash and in-kind support
  - Technological readiness
  - Extent and breadth of cooperation amongst research institutions, industry and state government

# GROWTH OPPORTUNITIES

- Bringing international partners/expertise to Australia
  - BASF brings expertise in cathode active materials production and battery recycling
  - Targeting battery groups in German vehicle makers and OEMs
- Contributing to an aligned approach around mission with other players
  - CRCs e.g. RACE FOR 2030
  - CRC-Ps
  - Deakin ITRP
  - CSIRO
  - Critical Minerals agenda
- Collaboration with international institutions for exchanges
  - Fraunhofer IST (Germany)
  - Helmholtz Institute Freiberg for Resource Technology (Germany)
  - Faraday Institute (UK)

# QUESTIONS

# National Battery Testing Centre

- **Professor Peter Talbot – QUT**
- **Program Lead, FBI CRC**

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March 11, 2020

*Clean Energy Plug and Play Microgrid*

- Battery Testing Centre
- ARENA Hydrogen Project
- Solar CPV Arrays
- System Microgrid Integration
- 60Ha site

QUT ife Institute for Future Environments

# Key and Emerging Energy Storage Markets in Australia

- Solar
  - 14GW installed as of Sept 2019
  - 3.3GW installed in the preceding 12 months
  - Hydrogen production

- Electric Vehicle
  - US$300B invested in EV

- Mine Electrification
  - Estimated market US$20B annually within 10yrs


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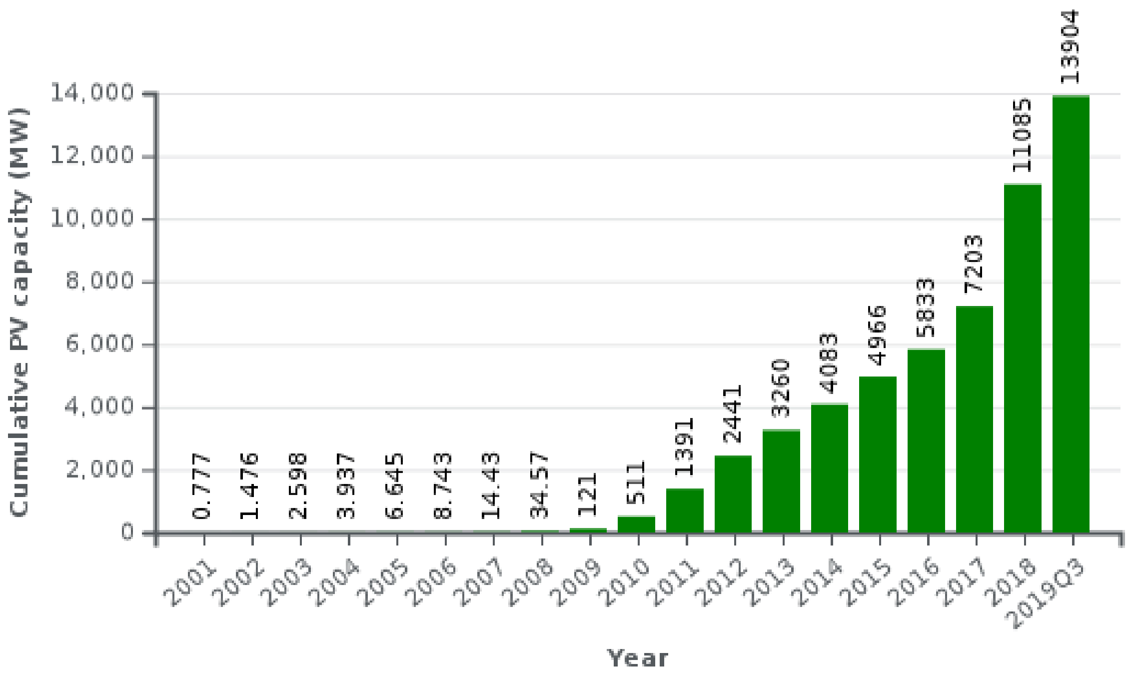
# Solar Installations




*Grid-connected distributed (Residential Roof tops) biggest sector, 2018

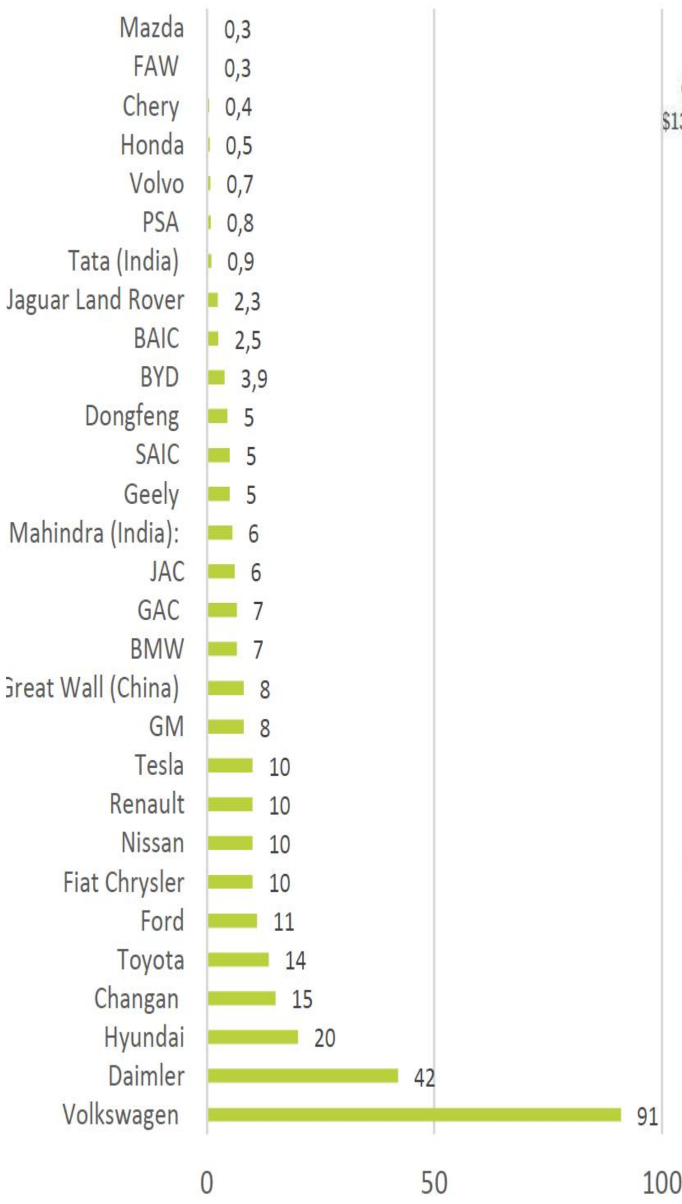
"National Survey Report of PV Power Applications in Australia- 2018"

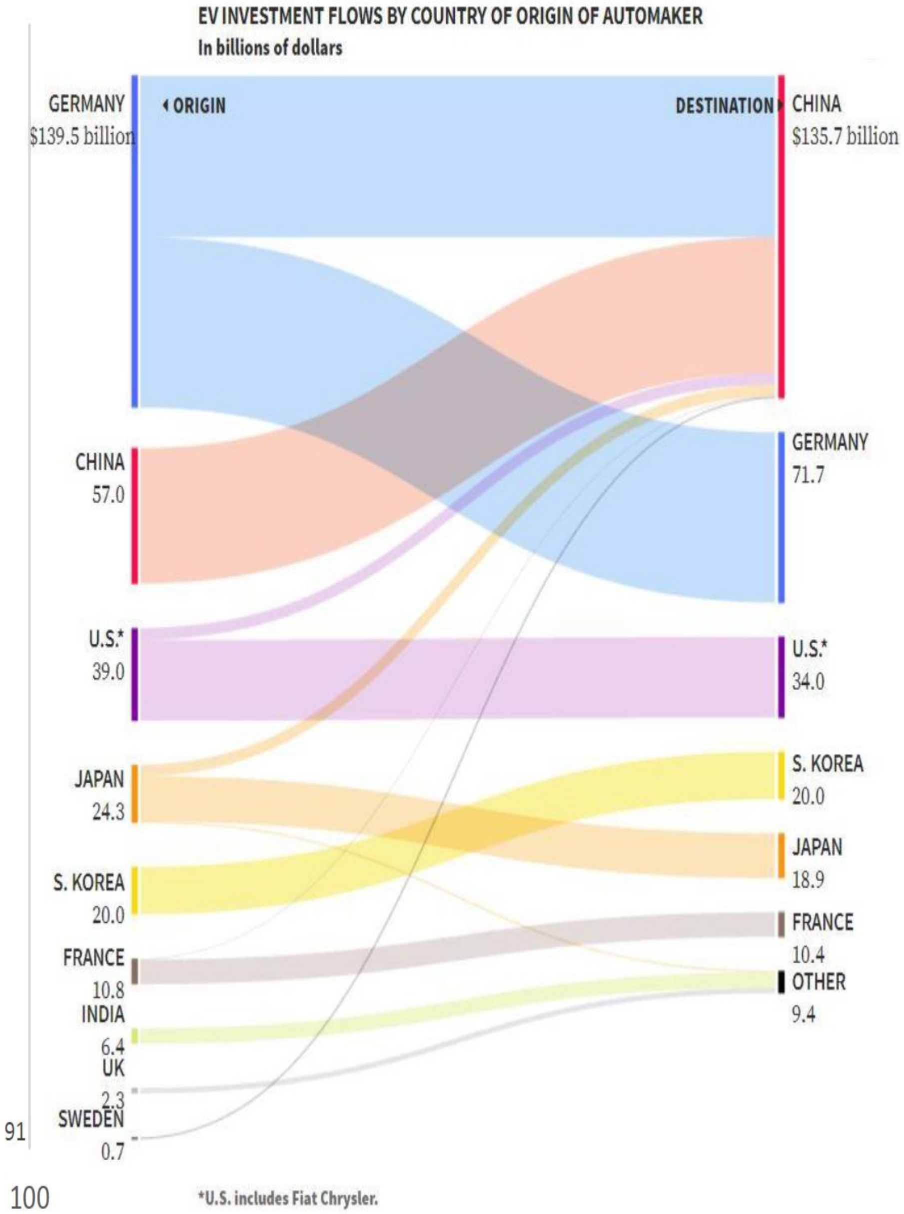
| [14] | Off grid (MW) | Grid-connected distributed (MW) | Grid-connected centralized (MW) | Total (MW) |
|---|---|---|---|---|
| 2015 | 173 | 4,580 | 356 | 5,109 |
| 2016 | 210 | 5,329 | 446 | 5,985 |
| 2017 | 247 | 6,115 | 740 | 7,103 |
| 2018 | 284 | 8,030 | 3,272 | 11,586 |

**Grid connected solar**

- residential systems <9.5 kW,
- commercial systems 9.5 to 99.9 kW
- industrial systems 100 kW to 5 MW.
- utility scale > 5 MW. .

# Car makers Invest over $300 Billion in EV's in 2019

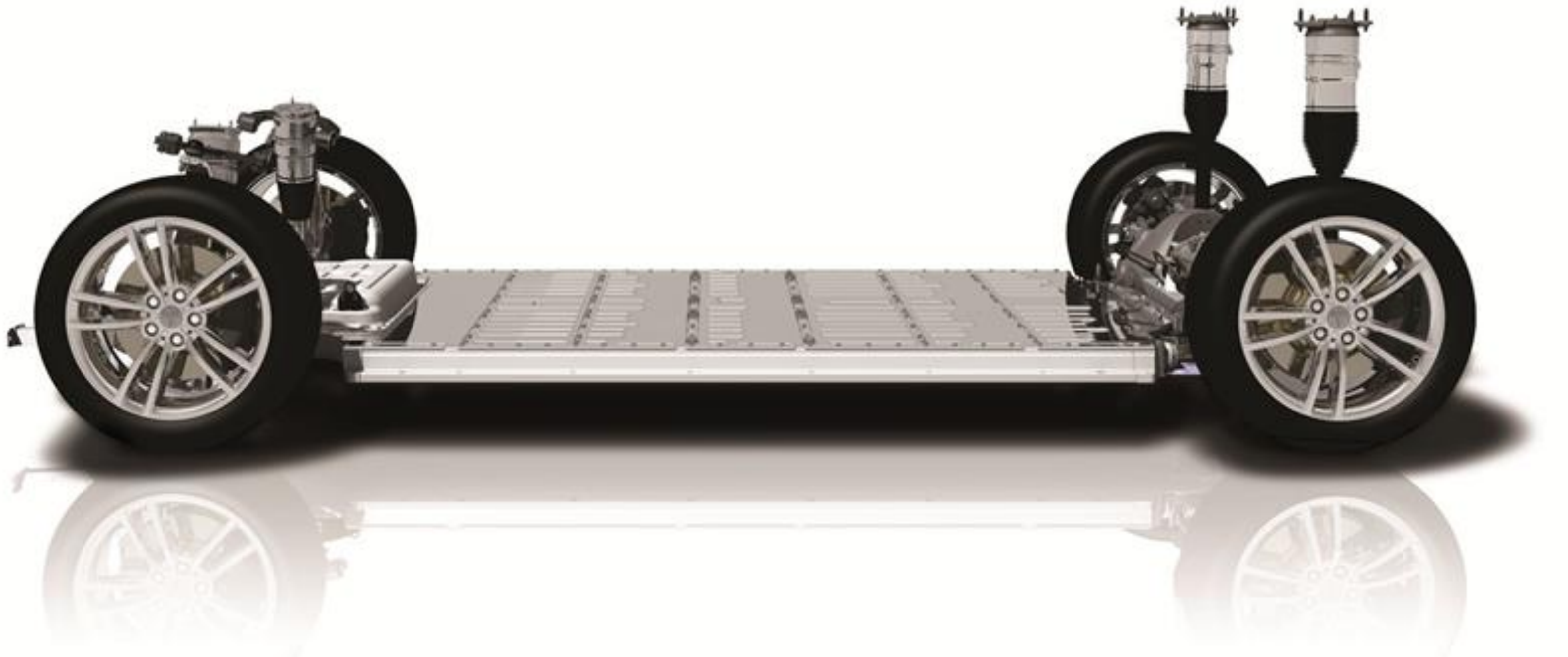



*Source: Reuters January2019, Avicenne Energy*

# Electric Vehicle
# EV

# 100kWhr Battery
# On Wheels



# Batteries (According to Tesla)


**Model 3 Tesla**

- Cells, 2170 3.6V 4.8Ah 17.3W
- Modules, 100V 199Ah 46P25S, 20KWhr

  1150 cells
- Packs, 320V 80kWhr 350KW

  4416 cells

**Grid Storage**

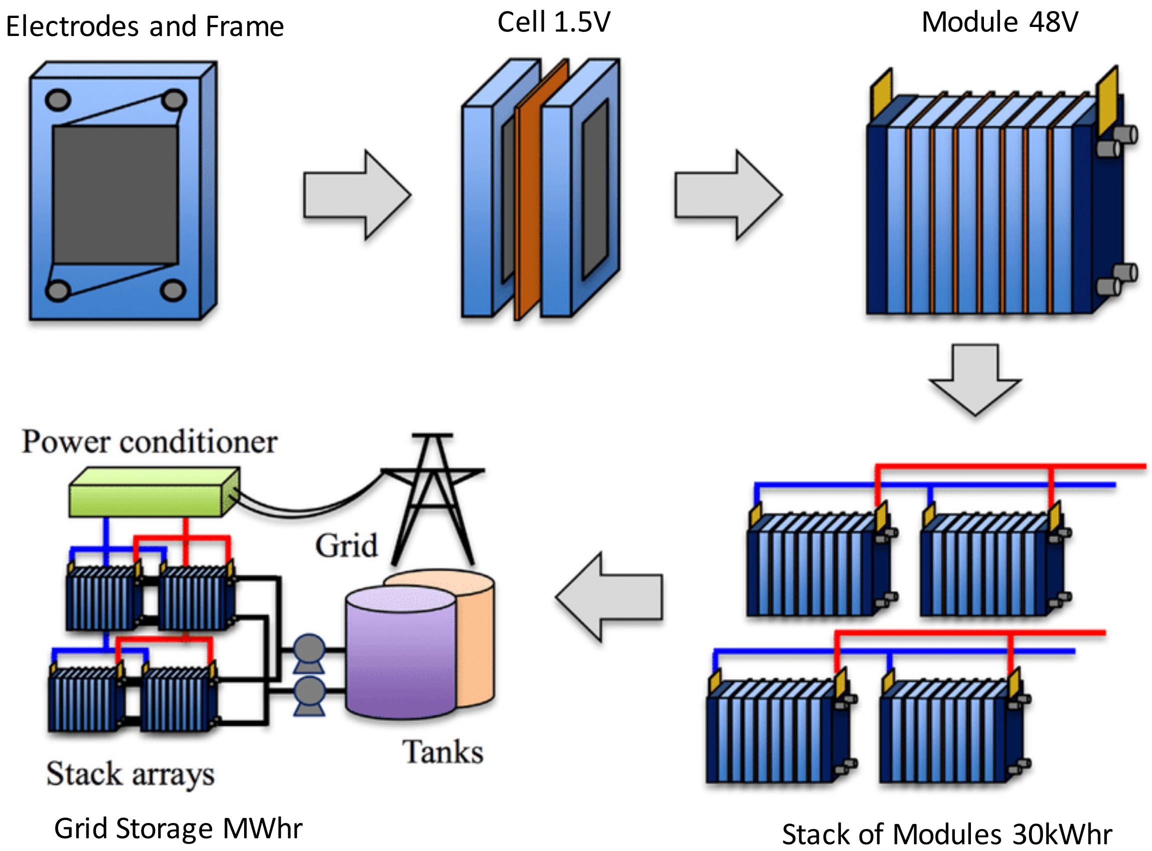
- Storage (Packs of Packs !!)

128MWhr @100MW

**Tesla Model S**

Battery module, 24V, 233Ah, 5.2kWh, 444 Panasonic 18650 3200mAh

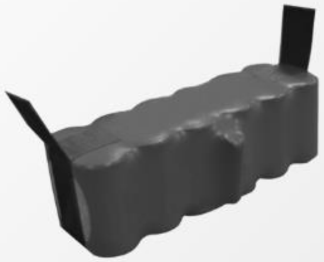
# Vanadium Redox Flow Batteries

# Battery Testing – Cells, Modules and Packs

**BATTERY: CELL TESTING**
**Up to 10V**

**BATTERY: MODULE TESTING**
**Up to 60V**



**BATTERY: PACK TESTING**
**Up to 1000V**



# Cell Testing Equipment

## Up to 10V

# Cell Testing

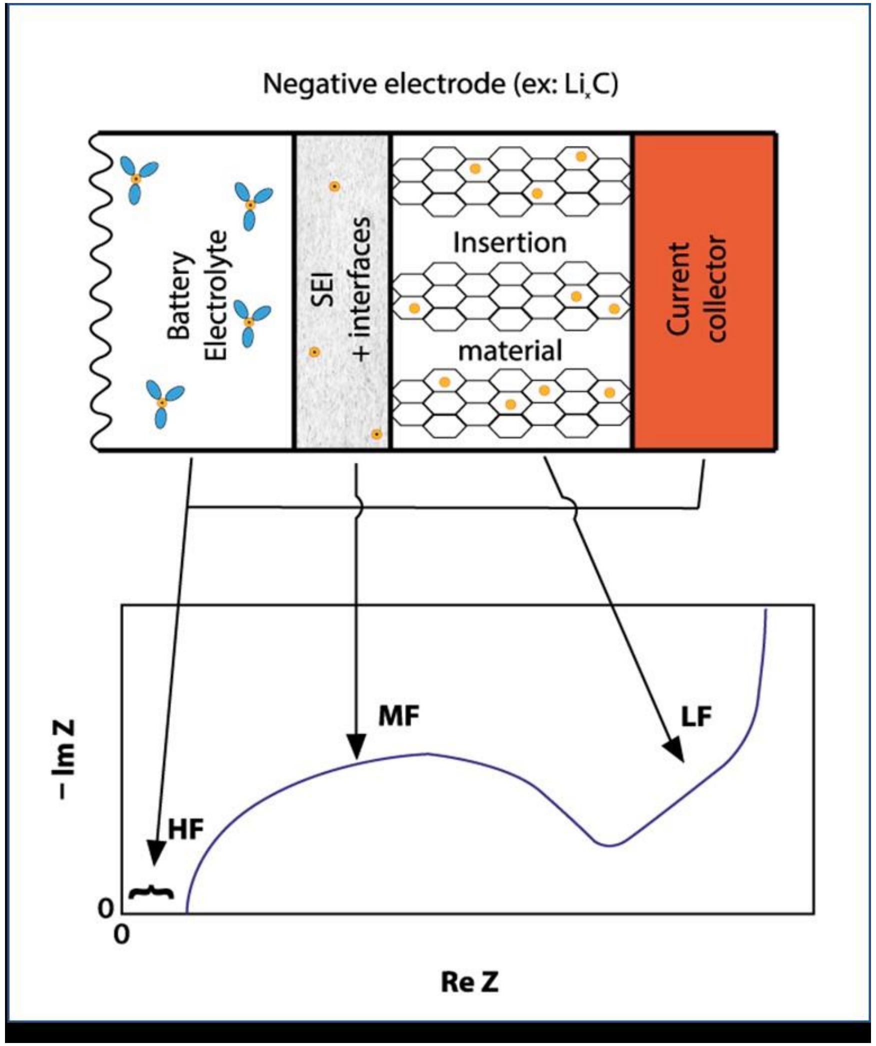
## Cell Performance Measurements

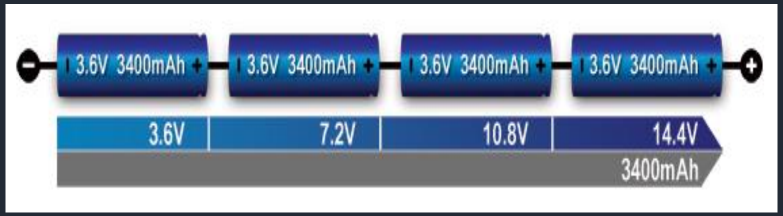
- Cell voltage profile
- Capacity
- Energy Density
- Cycle life
- Coulombic efficiency

## Impedance Spectroscopy

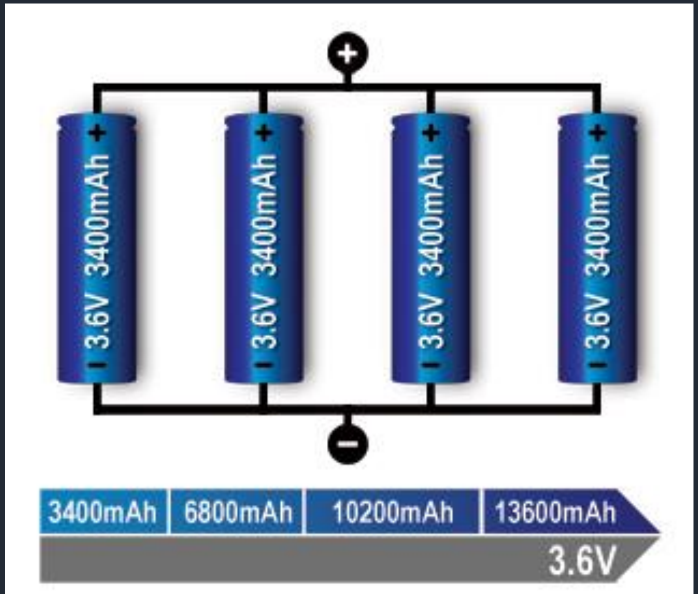
Each component of the half-cell can be characterized.

- High frequencies, one can measure the ohmic resistance of the electrolyte.
- Middle frequencies, one can obtain information concerning SEI capacitance and electron transfer rate.
- Lower frequencies, one may obtain information about diffusion processes of species in the insertion material.






Batteries can be connected in series to increase the voltage (V) of a module




In parallel to increase the Current (A) or runtime (Ah) of a module

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# Module Testing

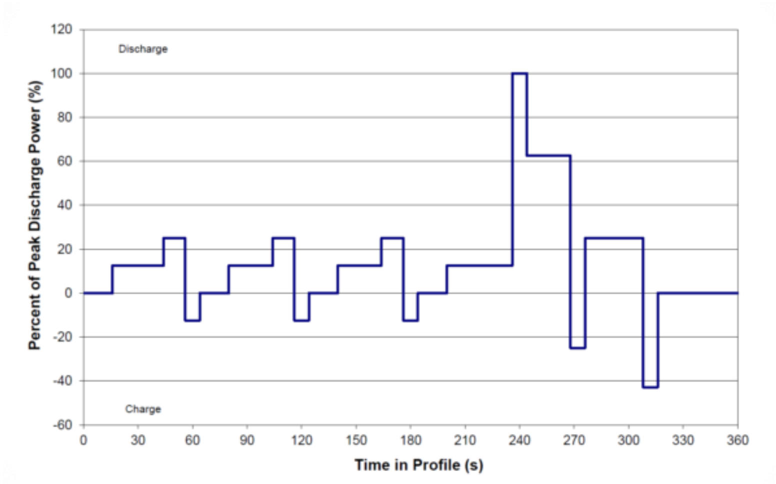
Battery Voltage 60V to 100V
Battery Current up to 2500A

- Life Cycle Testing
- Simulation of advanced real-world test profiles
- R&D of batteries for electric vehicle and grid storage applications
- Validate internal battery management system (BMS)
- Test Smart Battery modules

# Pack Testing up to 1000V

## DRIVE PROFILE (DRIVE CYCLE) SIMULATIONS

- UNITED STATES EV BATTERY TEST STANDARDS
- The Federal Urban Drive Schedule (FUDS), Hybrid Pulse Power Characterization (HPPC), Dynamic Stress Test (DST), and Peak Power Test are some of the most common electric vehicle battery tests performed globally.

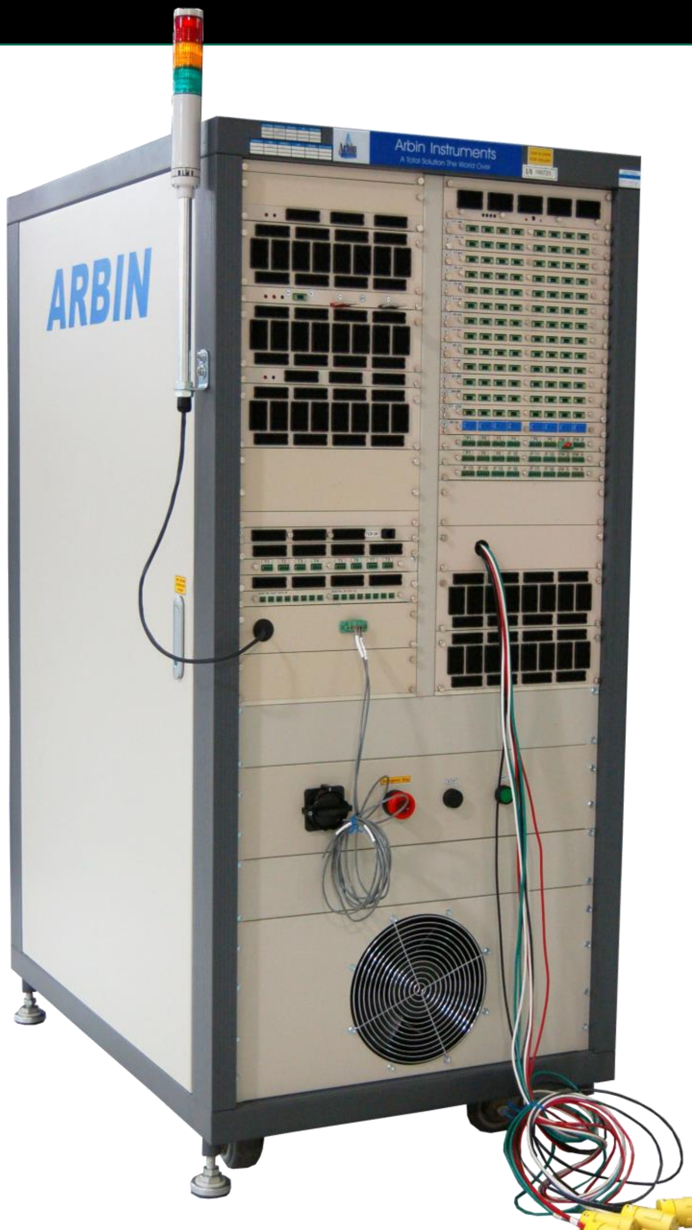



**Dynamic Stress Test Profile**

- Worldwide Harmonized Light Vehicles Test Procedure (WLTP)

# Flow Battery Testing

- Flow Battery Stack Voltage up to 100V
- Flow Battery Stack Power up to 300k
- Each testing system is customized to measure and control all flow battery hardware




**Key Features:**

•Integrate Control of the Flow Battery System
•Compatible with Third-Party Hardware

•Potentiostatic/Galvanostatic Charge/Discharge Functionality
•Modular Plug & Play Design
•Automatic Device Simulation

# Battery Safety Testing

## NITE

National Institute of Technology and Evaluation (Osaka)

- The world's largest testing and evaluating facilities for Large-Scale Battery Energy Storage Systems (BESS)
- The NLAB Testing Facilities can be utilized to conduct various testings on large-scale modules and pack-size batteries such as;
- vibration testing by simulating seismic waves
- vibration in transportation,
- charge/discharge and
- external short-circuit testing under temperature-variable conditions.


# National Battery Testing Centre- Redlands, QLD

- Battery Testing Centre
- ARENA H2Xport Project
- Hydrogen Transport Projects
- System Integration Projects

*Cost Effective Renewable Energy through Materials, Modelling and Process Innovation*

QUT ife Institute for Future Environments

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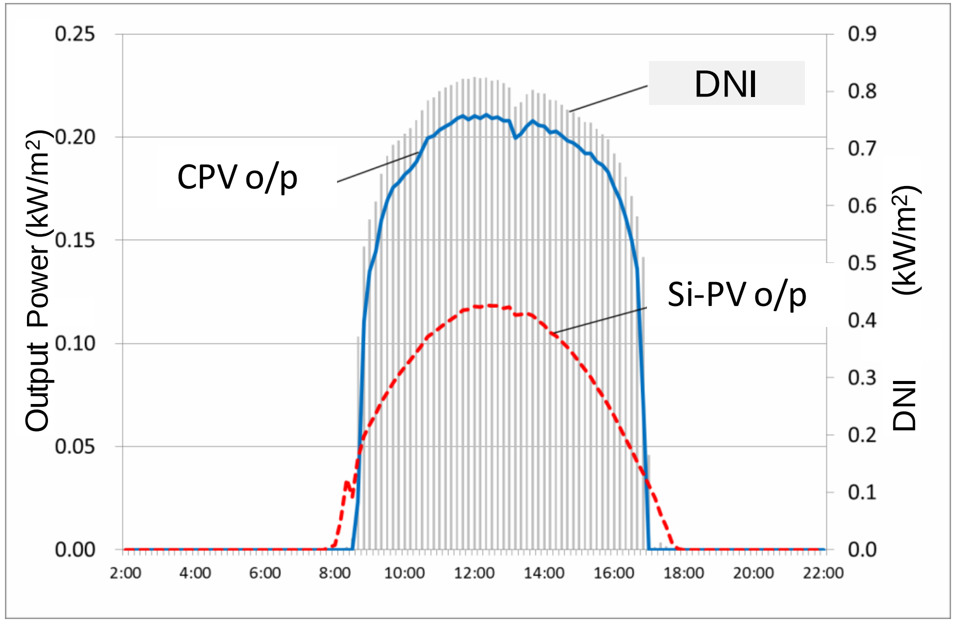
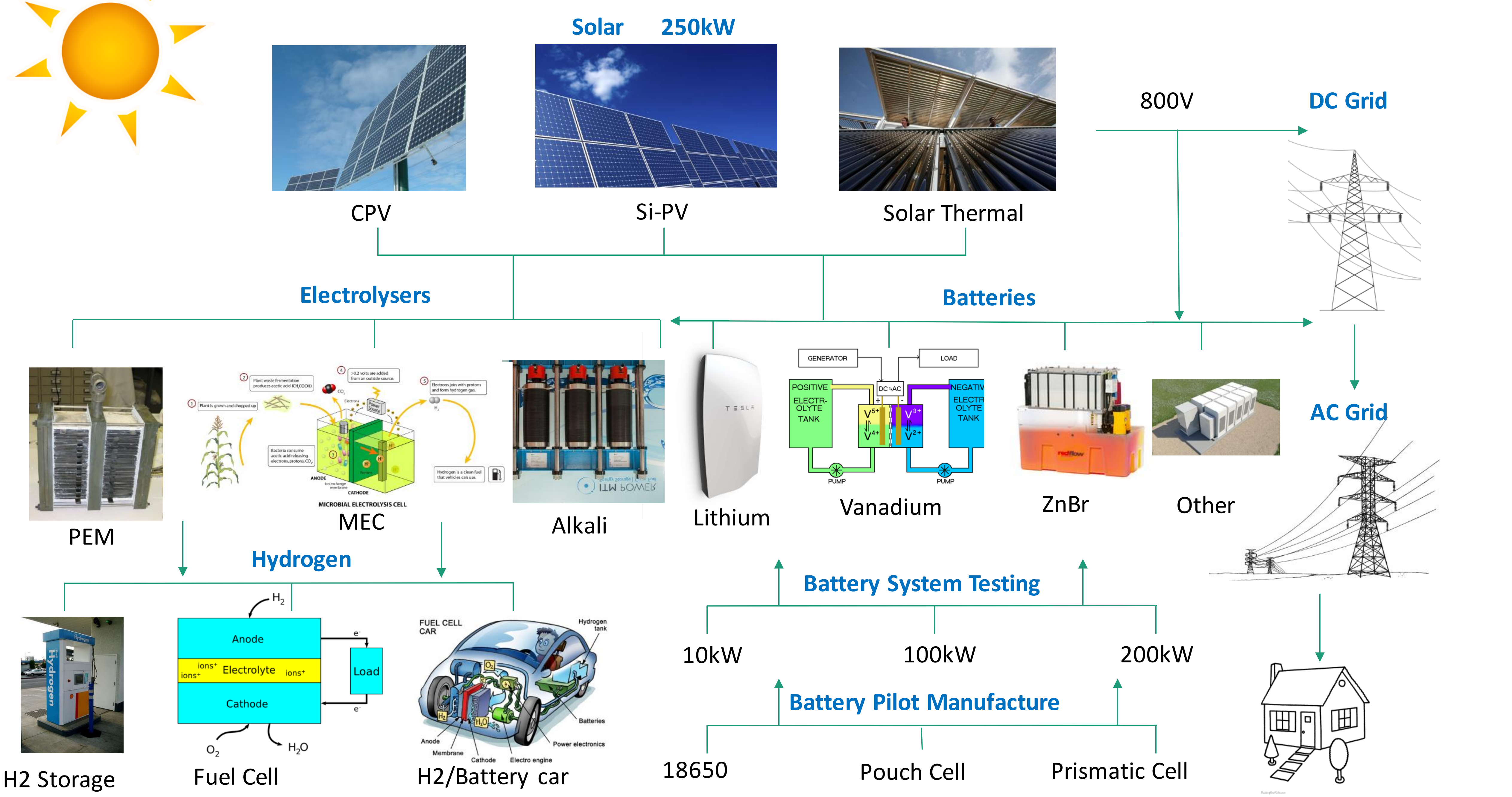
# QUT - New Development Underway

## Proposed Site for National Clean Energy Testing Centre


- ❖ Concentrated Solar Array
- ❖ Battery manufacture and pack construction pilot facility
- ❖ Proposed Clean Energy Testing Centre



# Clean Energy Testing Centre



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## National Battery Testing Centre

# Summary

- support upstream development of battery materials and downstream development of an Australian battery manufacturing industry.
- provide Australian manufacturers with facilities to develop national standards for performance and safety testing of locally developed battery cells and systems
- support skills development in Australian manufacturing
- increase collaboration with between research and industry pooled resources
- result in increased competitiveness against imports
- result in increased exports into the Global Supply Chain

# Process Legacy

Theme 6 (Program 2)

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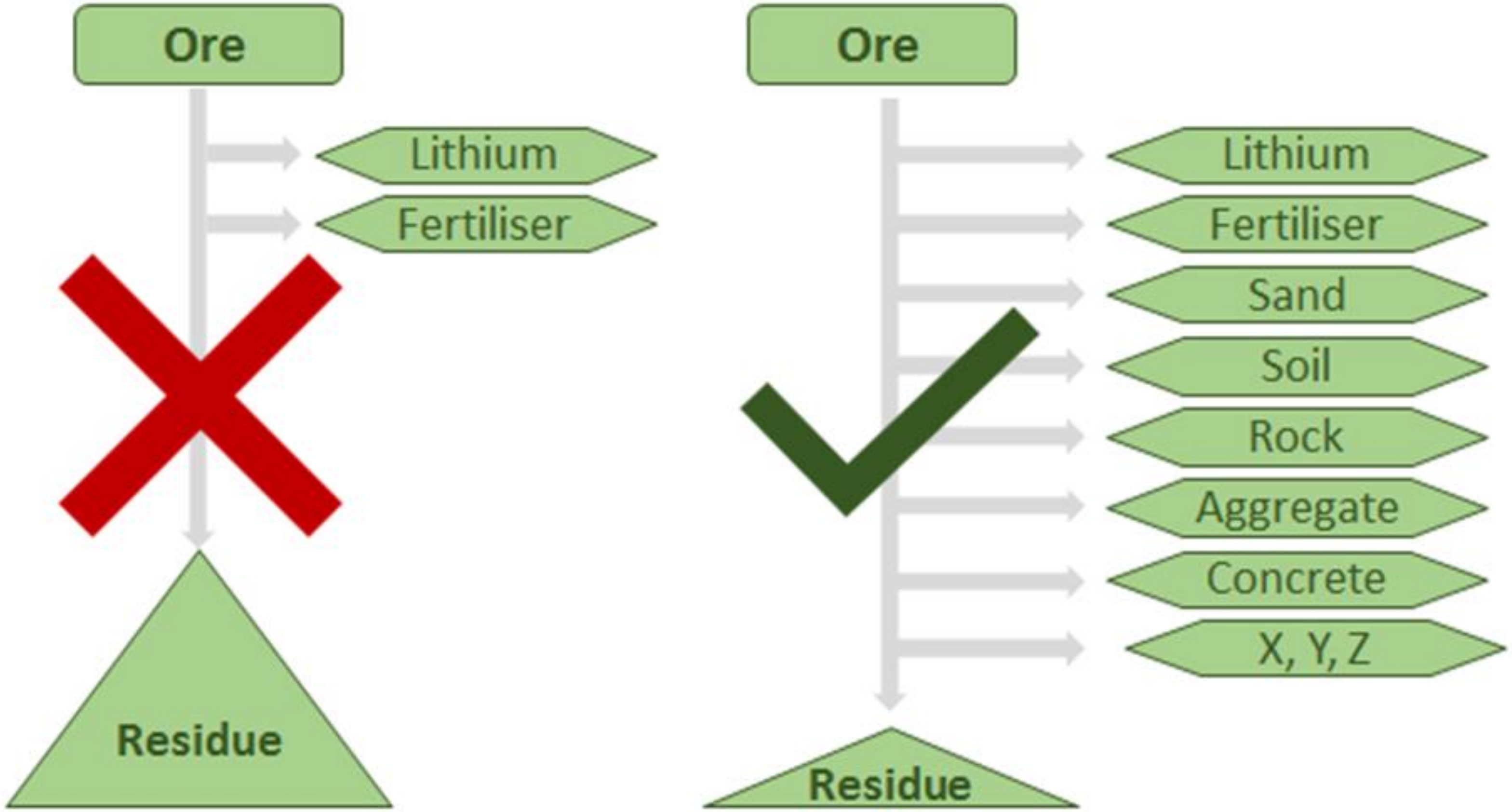
Prof Arie Van Riessen & Prof Evan J Jamieson

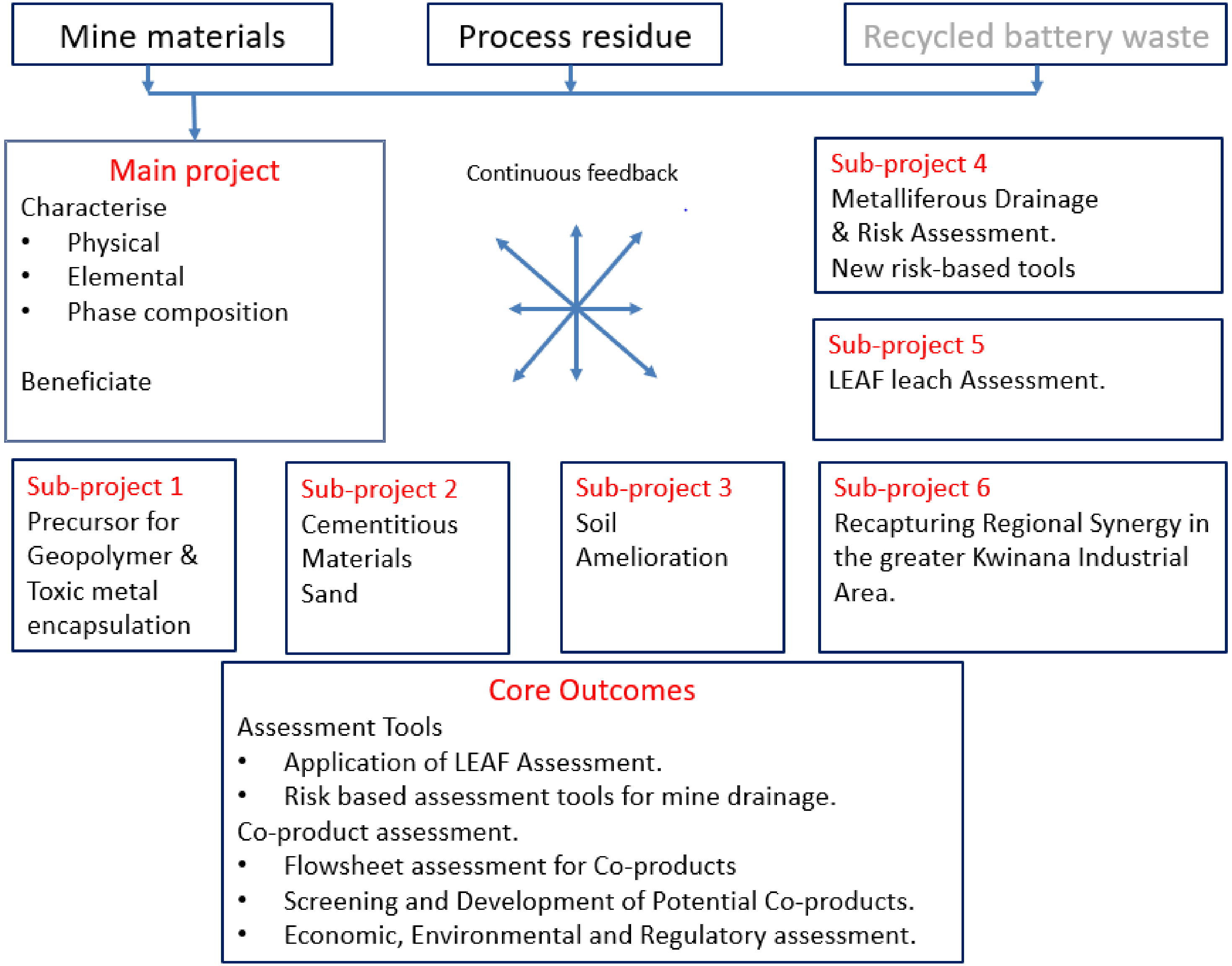
11 March 2020

# “Waste is a product made to poor specifications”

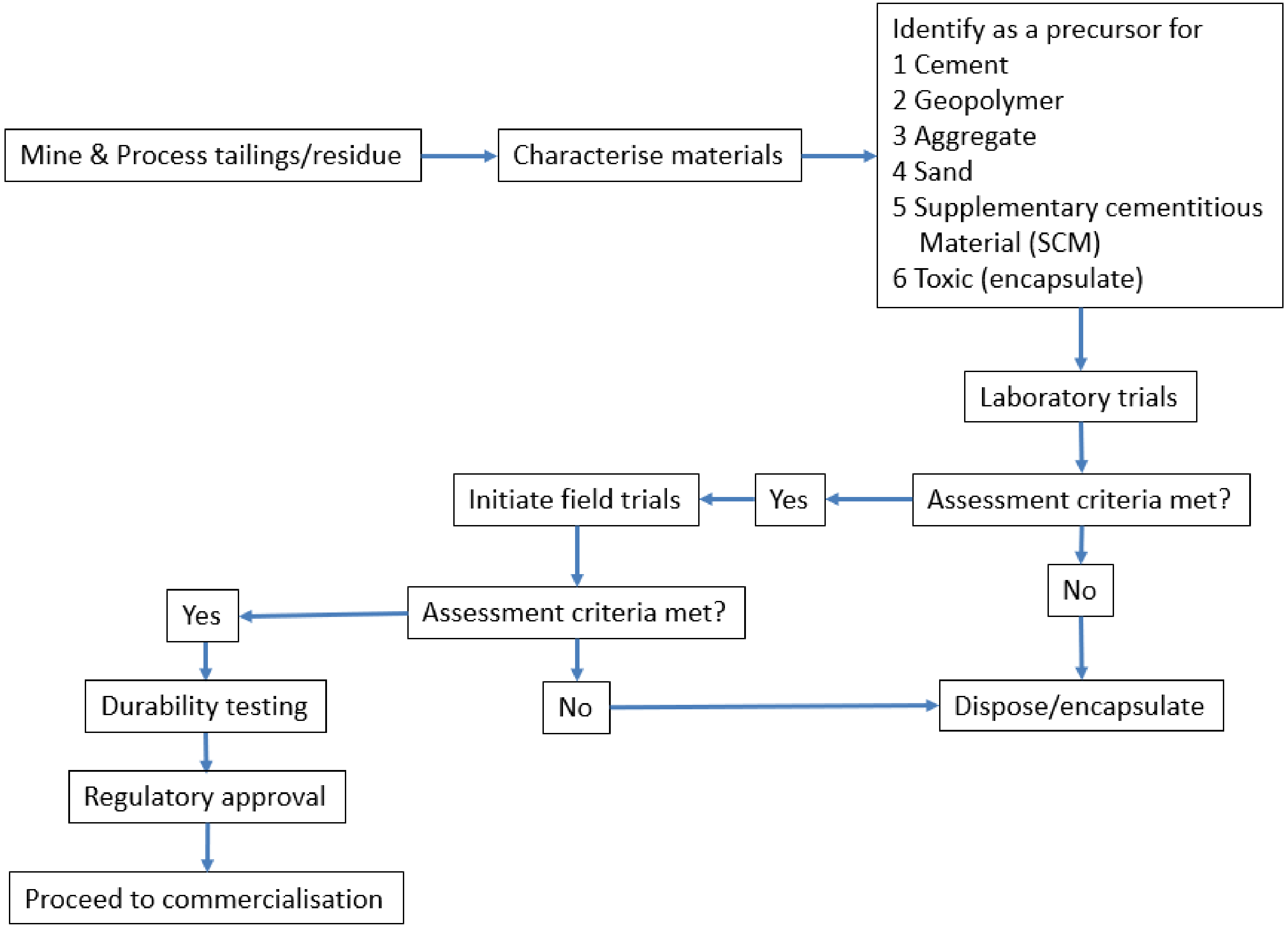
Jamieson 2008



# PROCESS LEGACY



# BY-PRODUCT DEVELOPMENT FLOWCHART



# STRUCTURAL SUPPORT

## Assess Mine-site operation & closure unknowns. SP4

Mine Site Metalliferous Drainage - New Risk Assessment Tools

- Waste Rocks, Li-bearing Pegmatites, Tailings
- Saline & Hypersaline Study
- Water Recycling Through Tailings

## Blue sky opportunity screening. SP5

Utilise the predictive assessment of LEAF leach test data for possible in situ applications.

## Find the low hanging fruit. SP6

Regional synergy in the greater Kwinana Industrial Area.

- Resources
- Water
- Heat

## Support regulatory development. Collaborative

Collaborative workshops

- Provide detailed analysis
- Development and assessment tools
- Collaborative feedback

# OUTCOMES INCLUDE, BUT ARE NOT LIMITED TO…

- Enhanced "Social licence to operate".
- Reduced exposure to maintenance of impoundment sites.
- Reduction in resources being wasted through co-disposal with hazardous materials.
- Potential reduction in hazardous materials through quality specifications and use (e.g. lime).
- Immobilisation of toxic waste via encapsulation in geopolymer.
- New commodity products with reduced embodied energy; lower CO2 footprint.
- Extended life of virgin mine commodities.
- Developed and validated new risk-based tools to better inform mine site operations and mine closure planning.
- New methodologies and scientific knowledge on mining (e.g. lithium) and processing will inform government policy and regulatory guidelines.
- Development of new jobs and workforce.
- Development of technical capability that could provide competitive advantage.
- Potential for development of IP and commercialisation.
- Significant opportunity for student projects improving employee relevance.

## STAGE 1 FUNDING (6 MONTHS)

Mine tailings

Process residue

**Main project**

Characterise

- Physical
- Elemental
- Phase composition

***Indicative Samples Only***

Continuous feedback

**Sub-project 4**
Metalliferous Drainage & Risk Assessment on indicative samples.
New risk-based tools.

**Sub-project 5**
LEAF leach Assessment on indicative samples.

**Sub-project 1**
Precursor for Geopolymer & Toxic metal encapsulation

**Sub-project 2**
Cementitious Materials Sand

**Sub-project 3**
Soil Amelioration

**Sub-project 6**
Recapturing Regional Synergy in the greater Kwinana Industrial Area.

### Core Stage 1 Outcomes

Assessment Tools

- Application of LEAF assessment to indicative samples only.
- Trial risk based assessment tools for mine drainage.

Co-product assessment.

- Flowsheet assessment for co-products
- Preliminary screening of potential co-products based on indicative samples

Engage regulatory assessment authorities.

# PARTICIPANTS

- Curtin University
- Chemistry Centre
- University of WA
- Department of Water and Environmental Regulation: Environmental Protection Authority
- Minerals Research Institute of Western Australia
- APozA
- Galaxy Resources Limited
- FYI Resources Ltd

- Covalent Lithium Pty Ltd
- Pilbara Metals Group Pty Ltd
- Independence Group NL

- Tianqi Lithium

# Innovative nickel and cobalt extraction


Dr. Greg O'Connor

Western Australian School of Mines - Curtin University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11 March 2020

# There are ten participants for the "Innovative Nickel and Cobalt Extraction" project

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THE UNIVERSITY OF WESTERN AUSTRALIA

BLACKSTONE MINERALS

Curtin University

igo

THE UNIVERSITY OF MELBOURNE

MPS MINING & PROCESS SOLUTIONS

BHP

Murdoch UNIVERSITY

NIPPON EIRICH EIRICH GROUP

BASF We create chemistry

# This project sits at the start of the battery value chain, in Program 2: Processing Resources to Precursors


Nickel sulfate

Cobalt sulfate

# We were invited to address the challenge of recovering Ni and Co lost in mineral processing

A Ni tailings storage facility

Kalgoorlie Nickel Smelter

https://cape.com.au/projects/leinster-tsf/
https://www.flickr.com/photos/ppc2000/366939009/in/photostream/

# Losses can be due to magnesium minerals such as talc

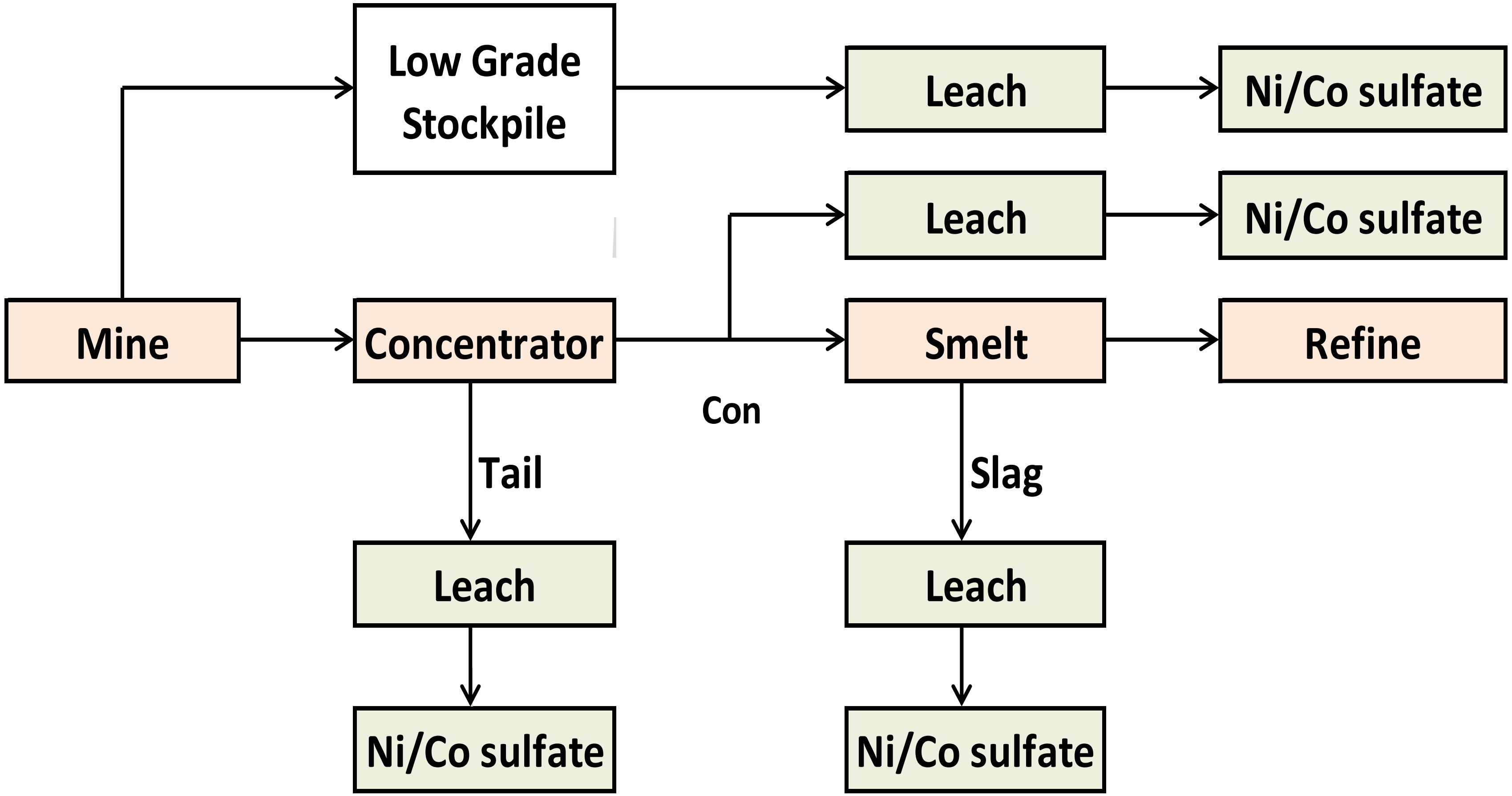
Example of “normal” froth flotation

Float floor after talc hit the plant

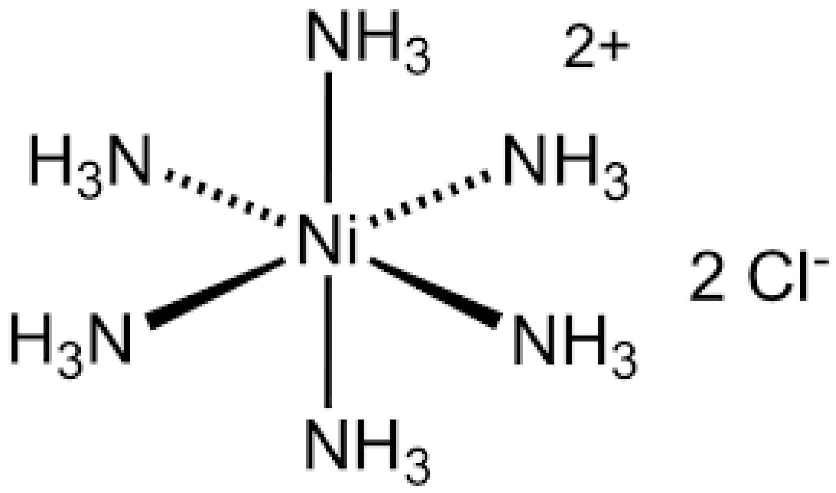
# An established alternative process is leaching, such as Terrafame's Ni heap leach operation

https://www.terrafame.com/

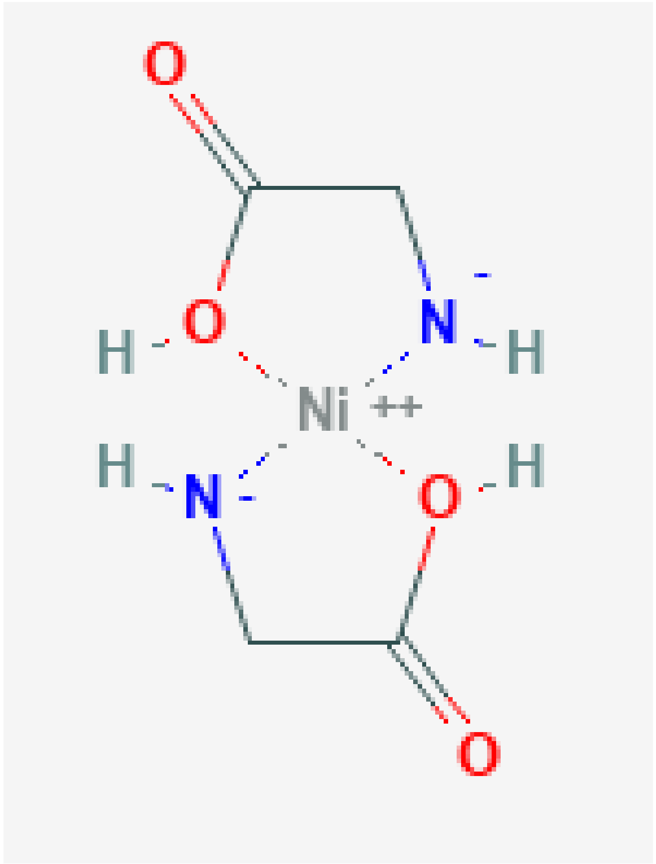
# We can add a leach process to the current flowsheet at a number of points



# The key for success (at alkaline pH) is a *cheap* complexing agent

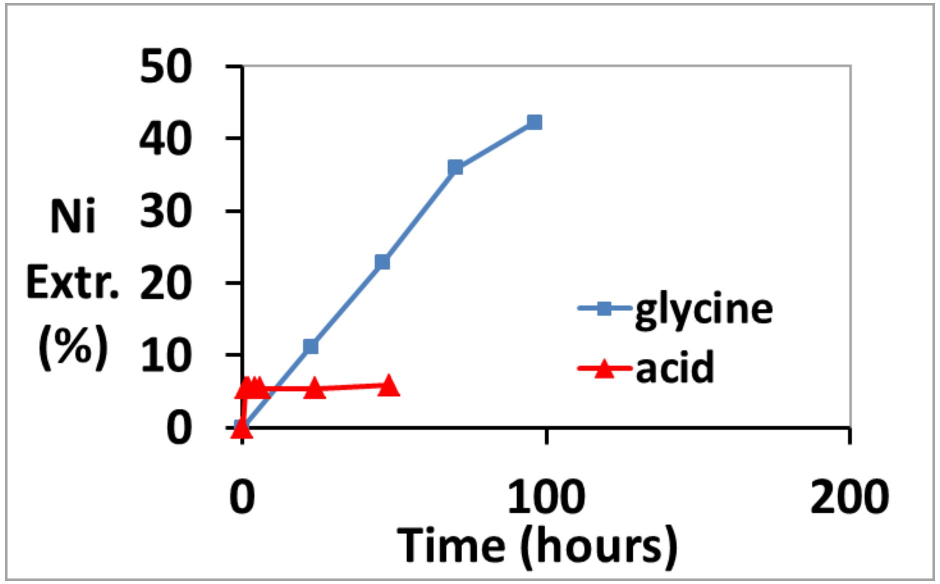



Ammonia complex

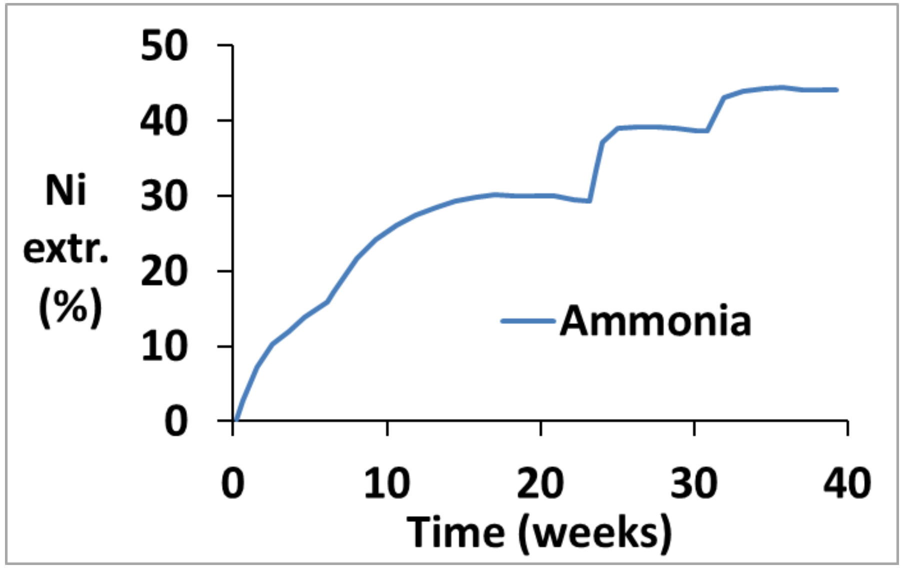



Glycine complex

# Both glycine and ammonia are effective in lab tests, in contrast to acid




Glycine or acid (WASM 2020)

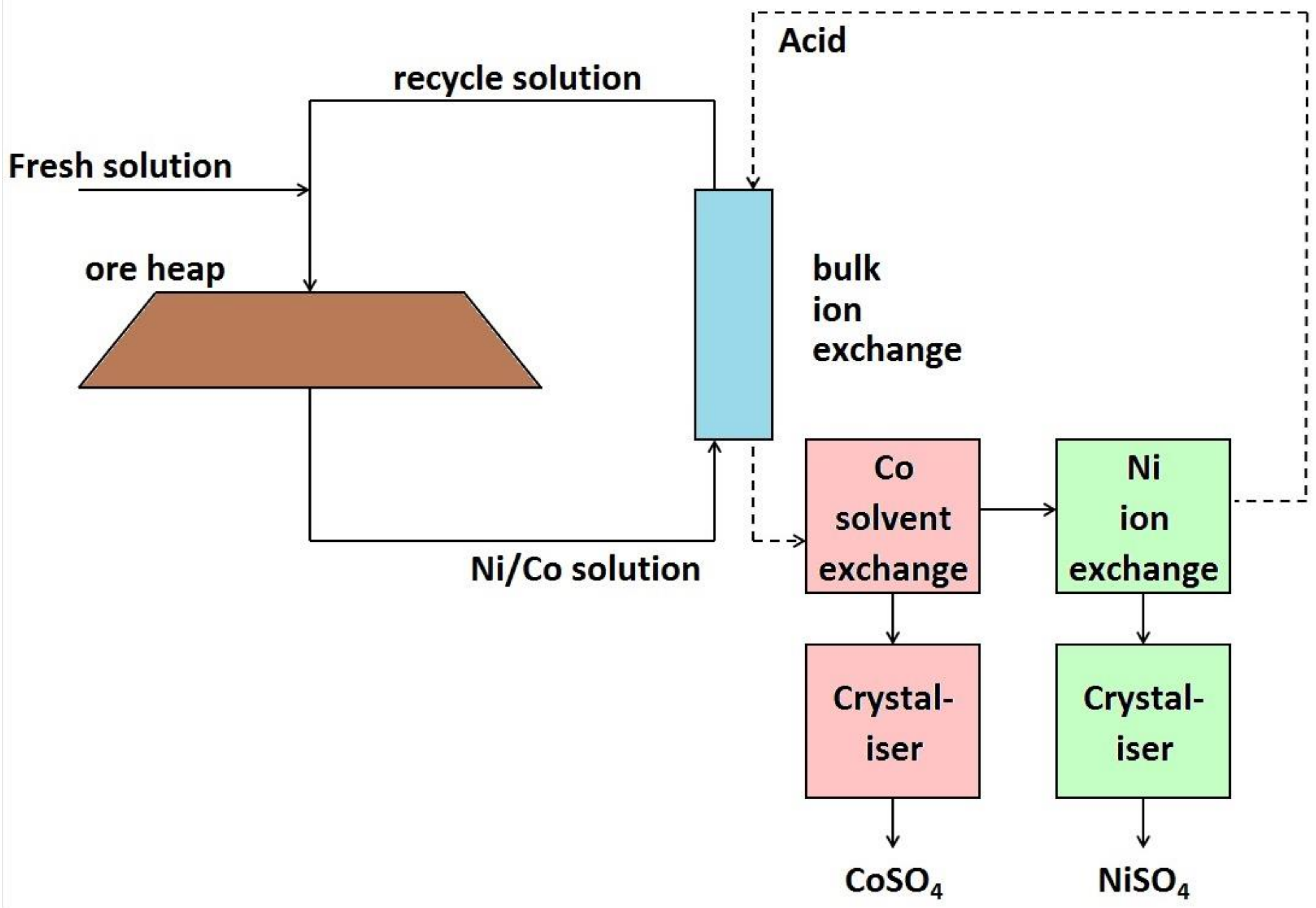



Ammonia (CSIRO 1974)

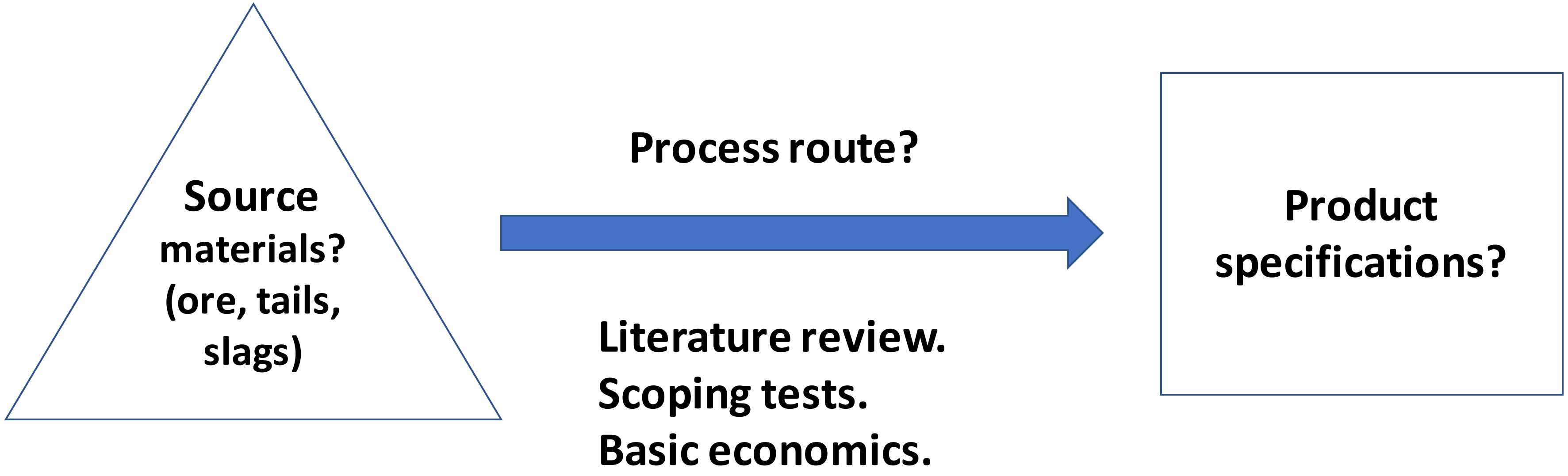

Eksteen J.J., Oraby E.A., Nguyen V.N. 2020 *Leaching and ion exchange based recovery of nickel and cobalt from a low grade, serpentine-rich, sulfide ore using an alkaline glycine lixiviant system*. Minerals Engineering, volume 145

Bennet C. E. G., Parks T. C. 1974. Leaching of low grade nickel sulphide serpentinite ores: a way to chemical mining? The Aus. I.M.M. Conference. Southern & Central Queensland

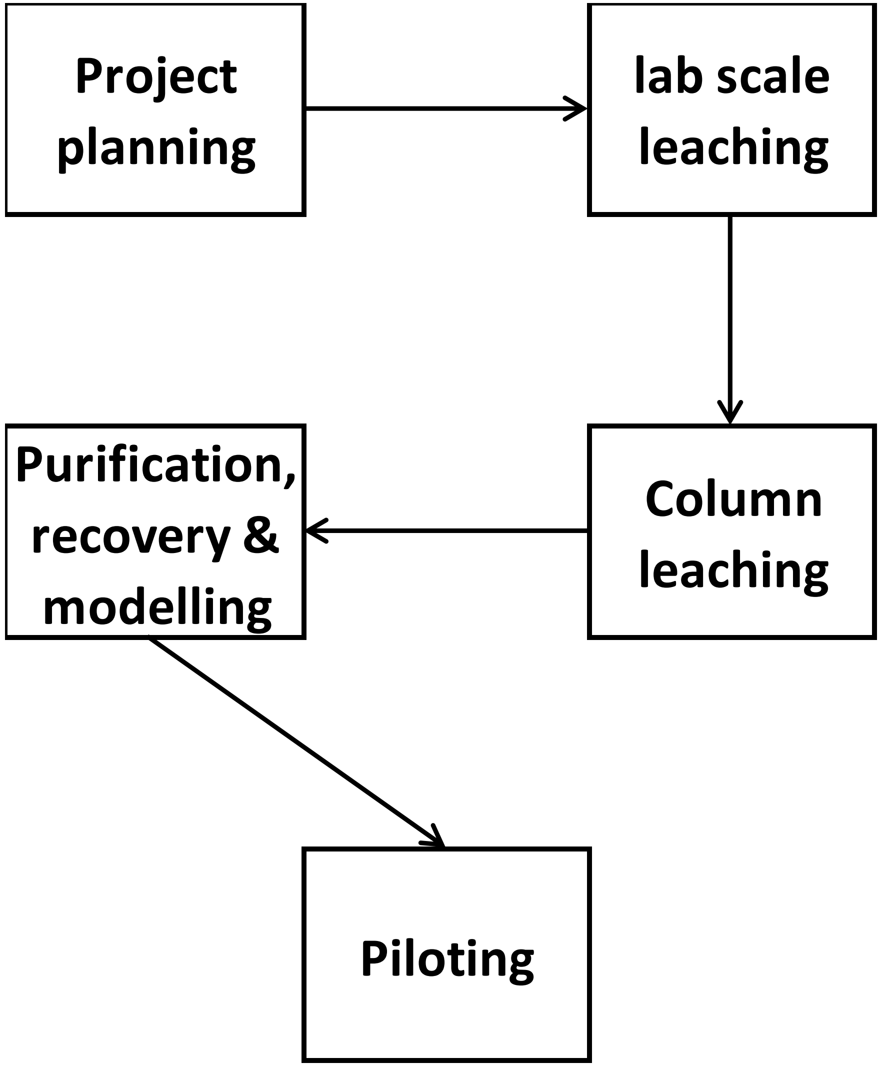
# The dissolved metal is to be recovered by ion exchange/solvent exchange



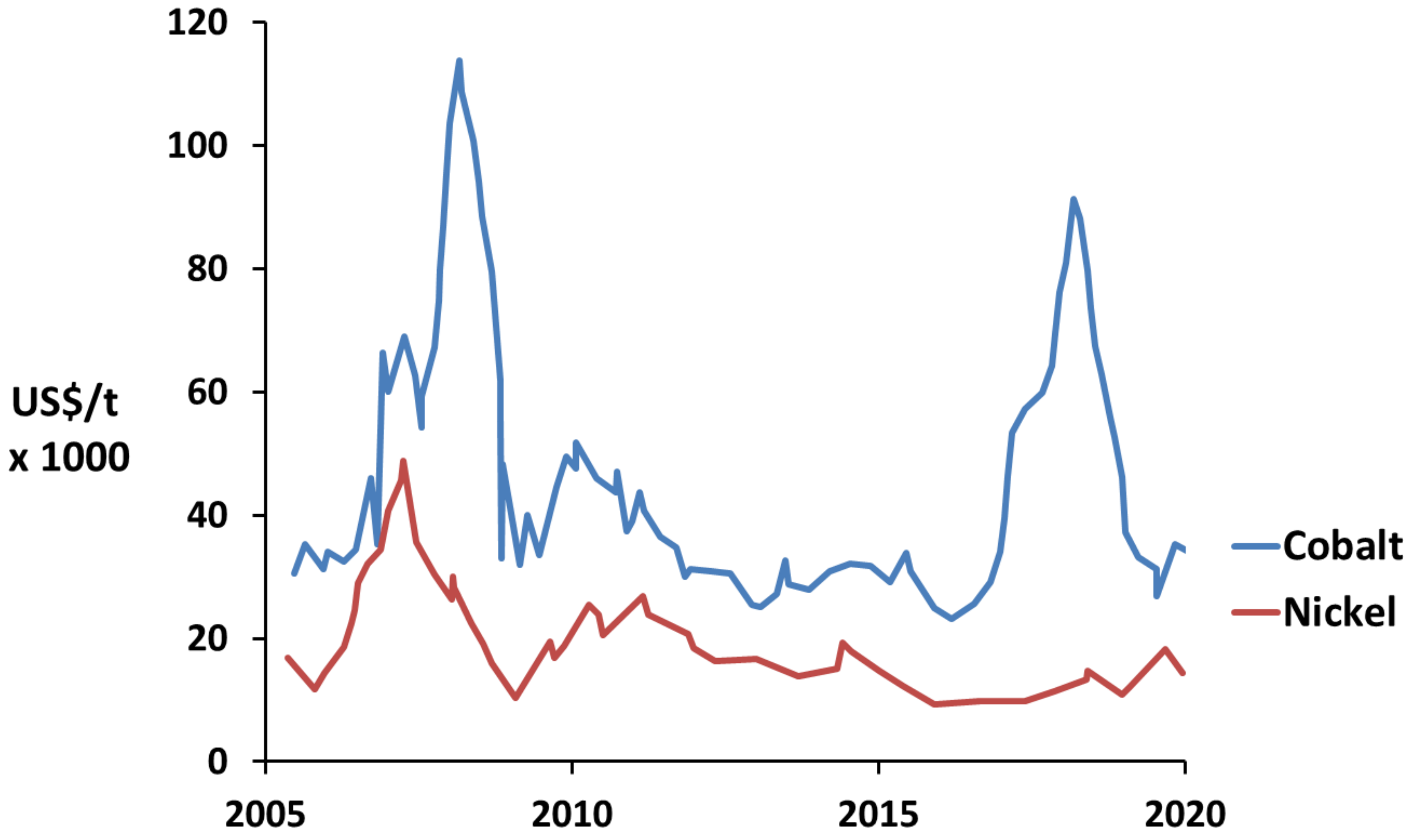
# We will follow a stage-gate project management system. Stage one is “Project Planning”.



# Subsequent stages will depend on the success of the preceding stage.

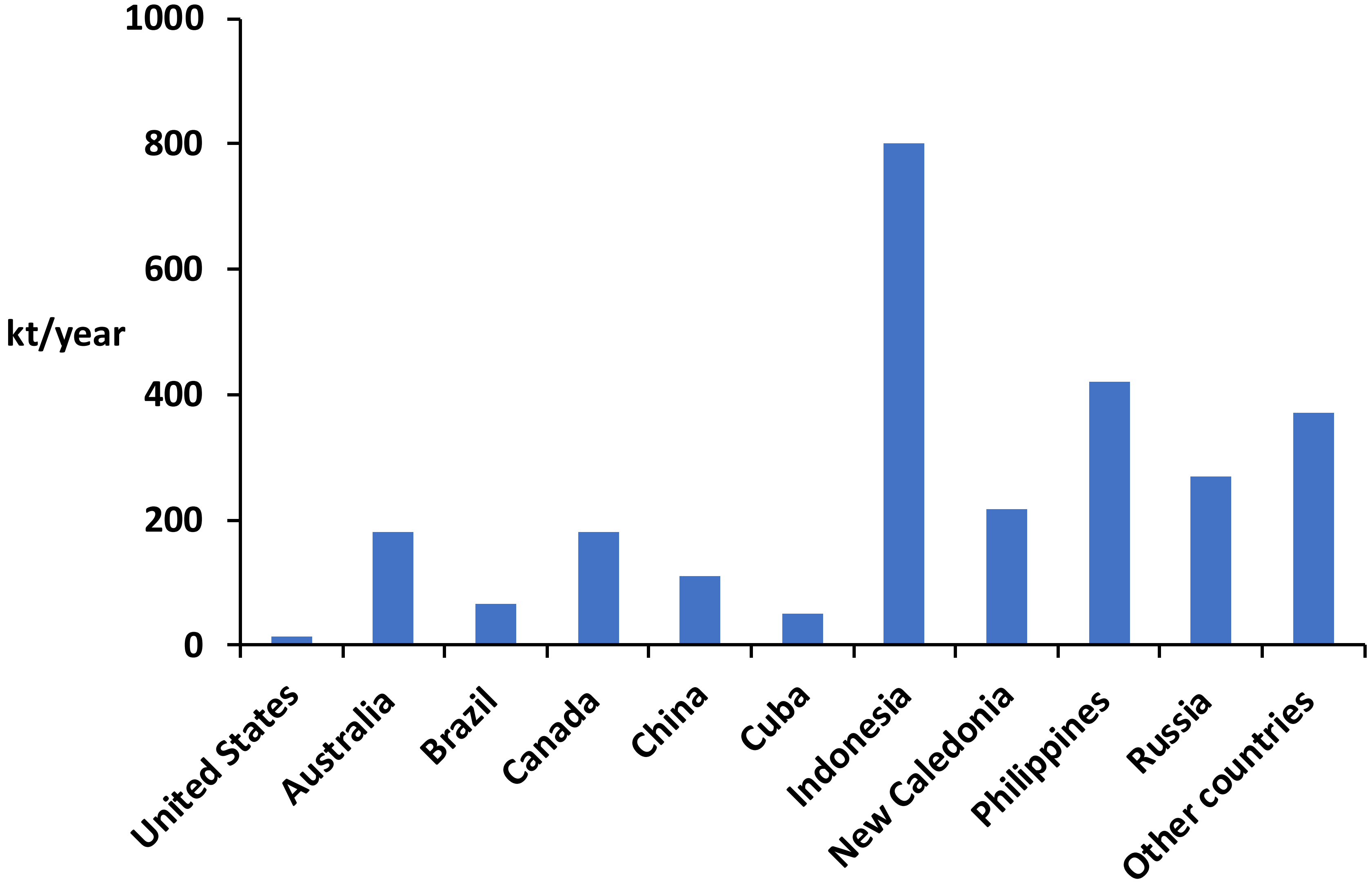



# The viability will depend on the metal price, and the extra value for the sulfate form

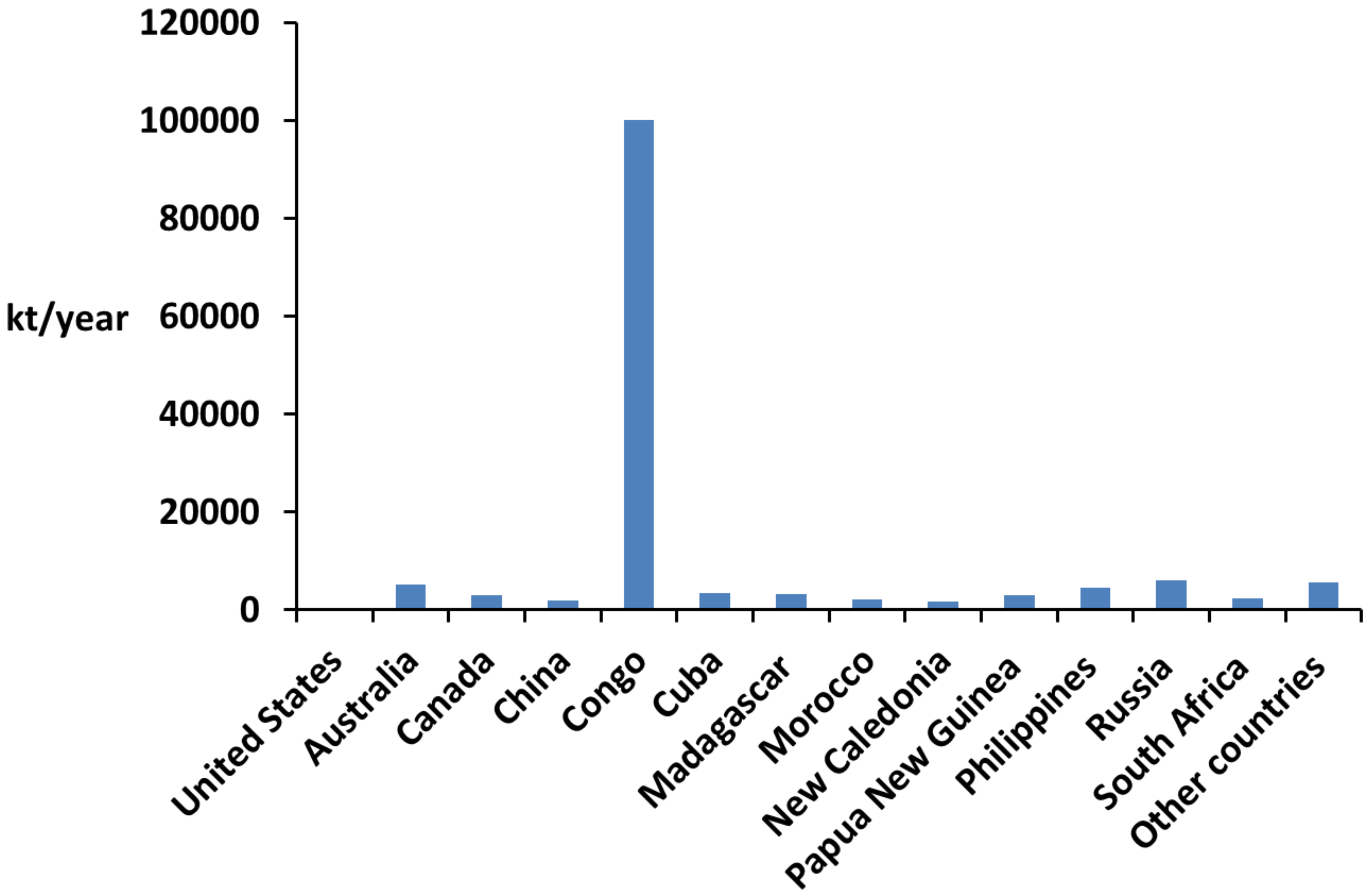



http://www.infomine.com/investment/metal-prices

# Nickel supply is dominated by cheap ferro-nickel

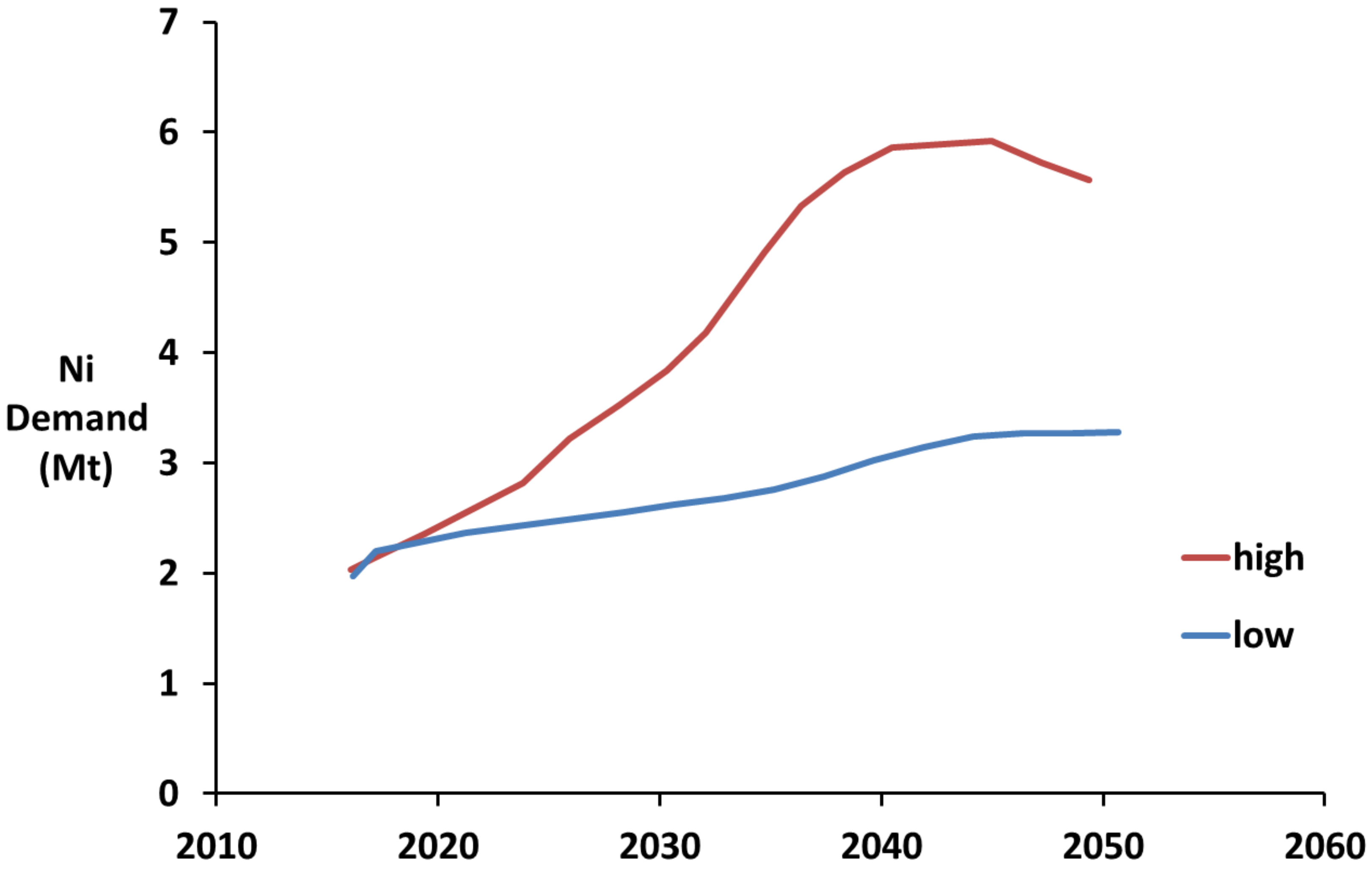


# Cobalt is predominantly from Congo




https://pubs.usgs.gov/periodicals/mcs2020/mcs2020.pdf

# EV sales are expected to grow with an increased demand for Ni and Co

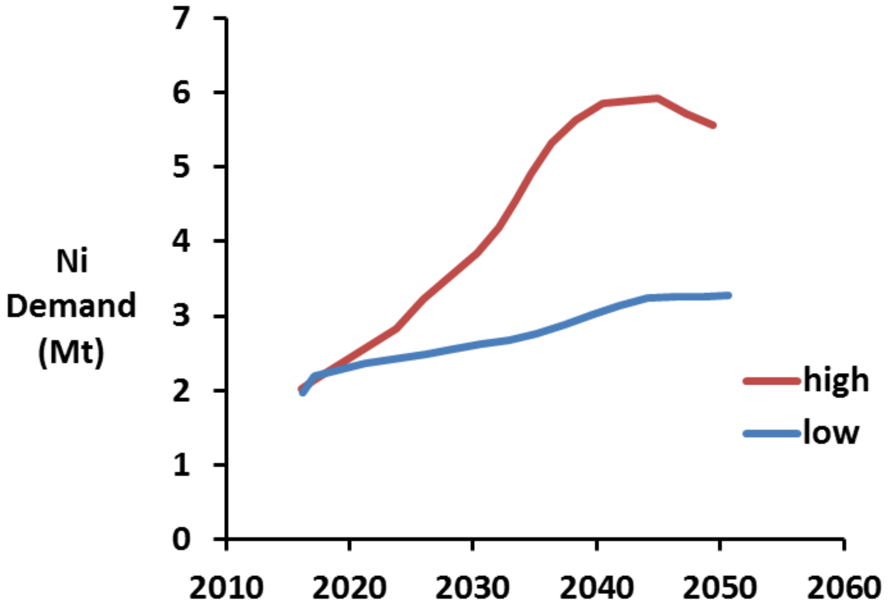



https://www.bhp.com/media-and-insights/prospects/2019/08/the-electrification-of-transport-episode-two/

# In conclusion, the future is promising

Utilises waste

Compliments existing technology




Demand is increasing

Environmentally friendly

# Beneficiation and Chemical Processing of Lithium Minerals

A/Prof Aleks Nikoloski

FUTURE BATTERY INDUSTRIES CRC

March 11 2020

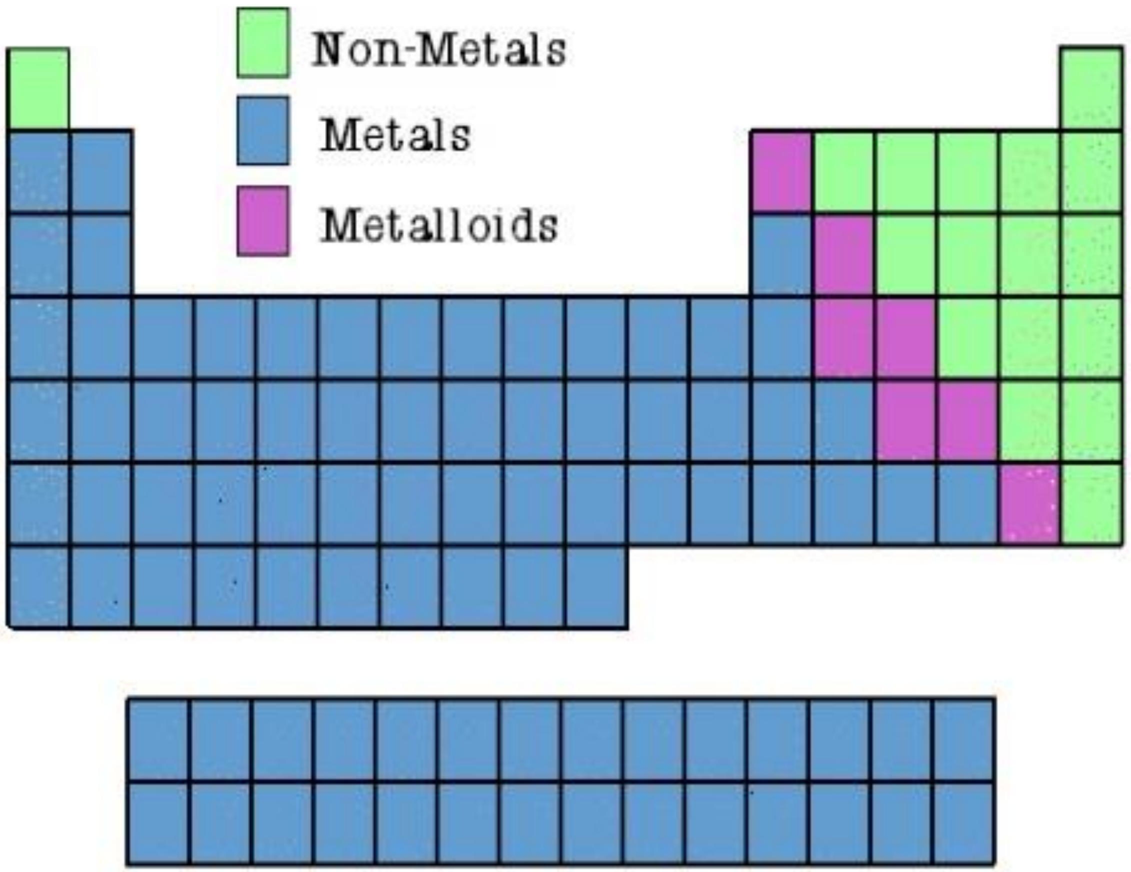
# Context: Why lithium?


- It is the lightest metal
- Has a single valence electron that easily forms a cation
- Efficient conductor of electricity
- A vital ingredient to drive the green energy quest
- **It’s unique and we will need much more of it!**

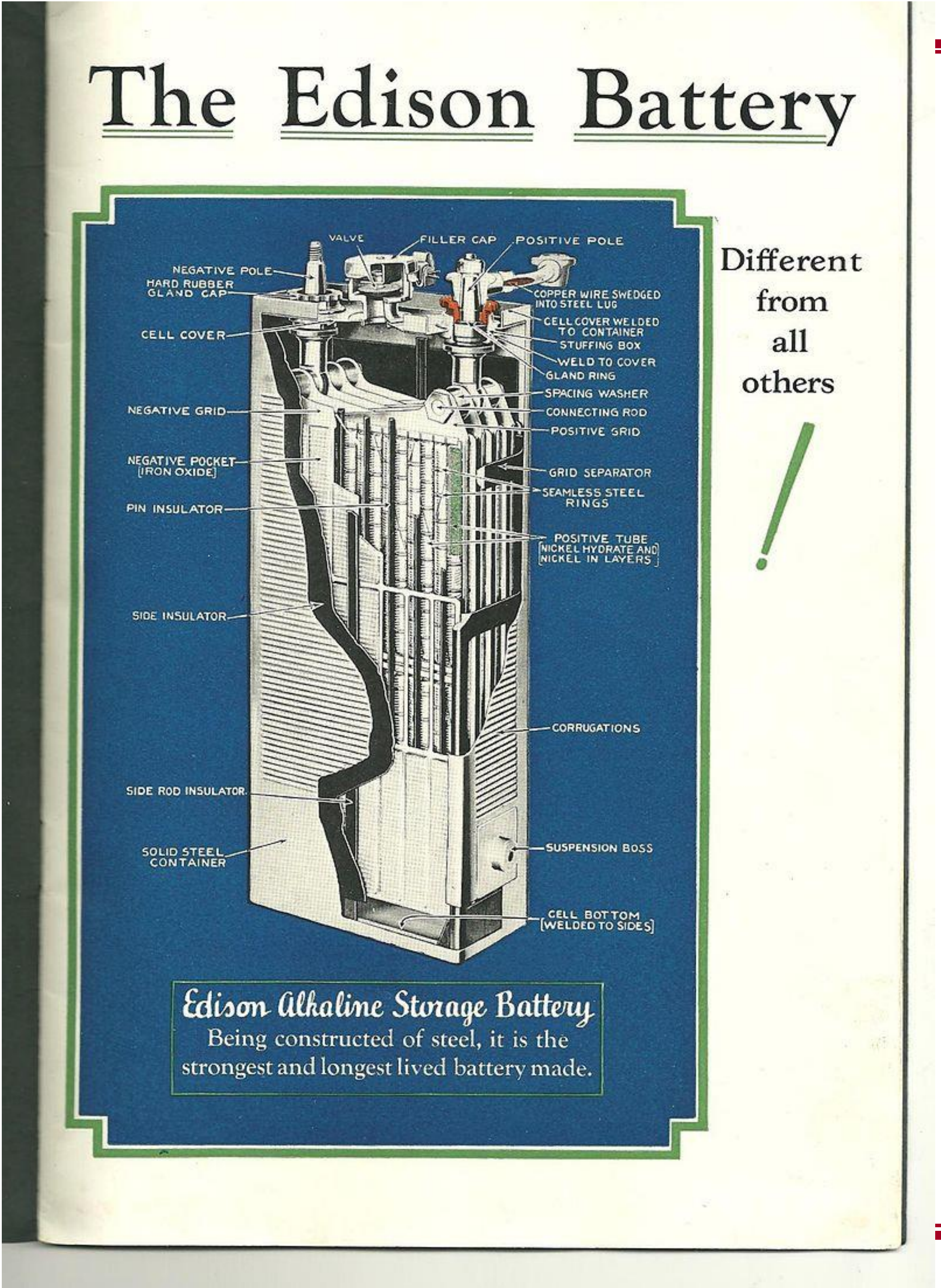
# How did we get here?

- ca 6000 BC – the Stone Age – discovery of gold and copper in native form
- ca 4,000 BC – the Copper Age
- ca 2800 BC – the Bronze Age
- ca 1500 BC – the Iron Age
- ca AD 1800 – the Industrial Revolution, the development of the first processes for production of large volumes of high-grade smelted iron

# AD 1800 to 1950 – Use of physical properties and discovery of new metals and intrinsic properties




- 95 different new metals found
- Each with different physicochemical properties and potential uses
- Discovery of electricity…
- More technological and scientific progress and changes in the 20th century than ever imagined possible – more than in all the other centuries before that, since the dawn of civilization, combined.




# Electrochemistry and the development of rechargeable batteries

- In 1901 Thomas Edison patented and commercialized a NiFe rechargeable battery
- It was promoted for use as the energy source for electric vehicles
- An aqueous solution of potassium hydroxide was used as the electrolyte charge carrier

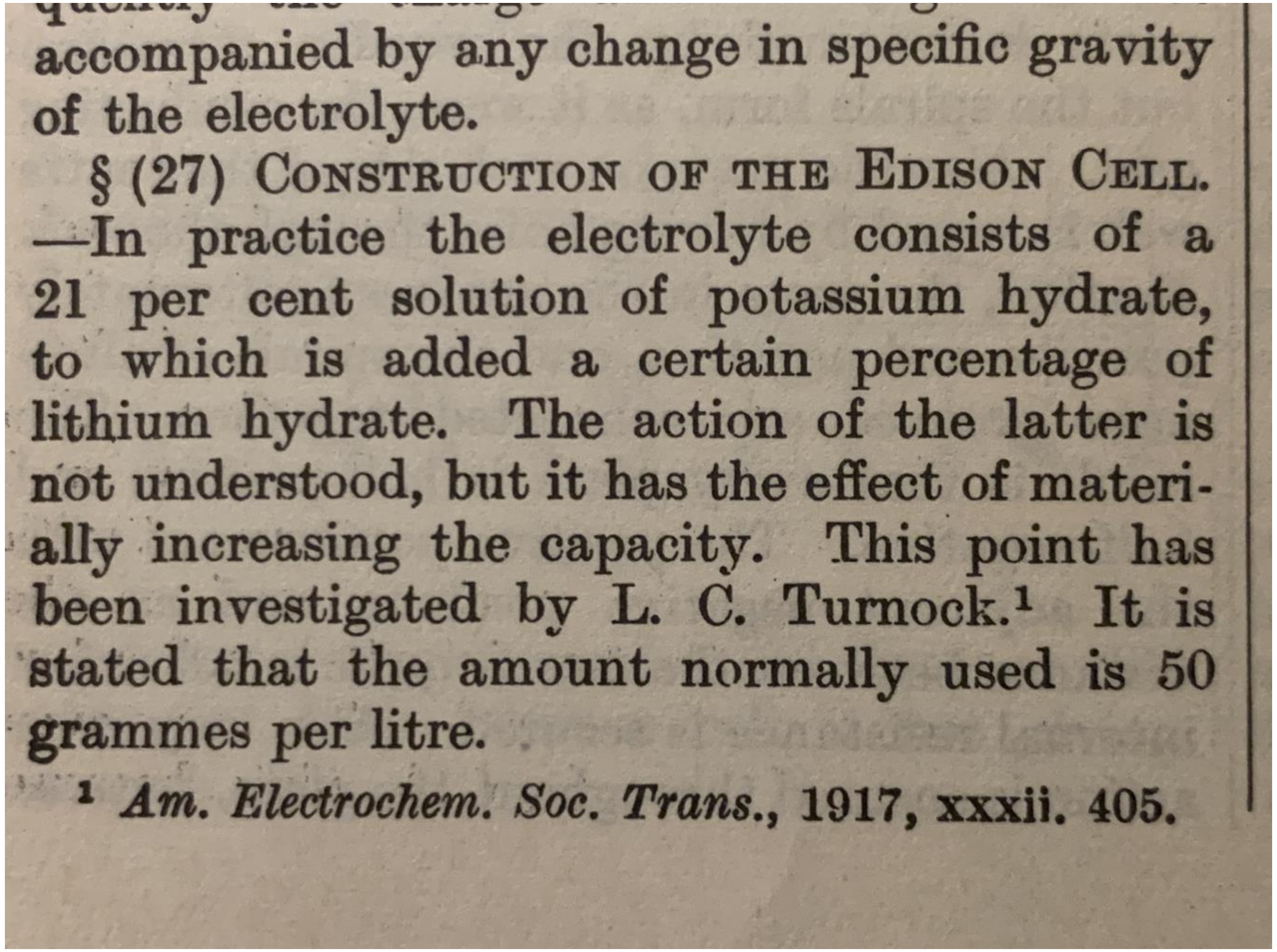
Murdoch
UNIVERSITY


Thomas Edison and an electric car in 1913

MPI
Metallurgical Process
Research Development
and Innovation

# The development of the lithium ion battery

- In 1917 Turnock L. C. published an abstract reporting research findings on the effect of lithium ions on the capacity of the Edison battery
- Tested the addition of lithium to the alkaline potassium electrolyte
- Reported significant improvement in the battery charge capacity
- The chemical mechanism was not understood at the time



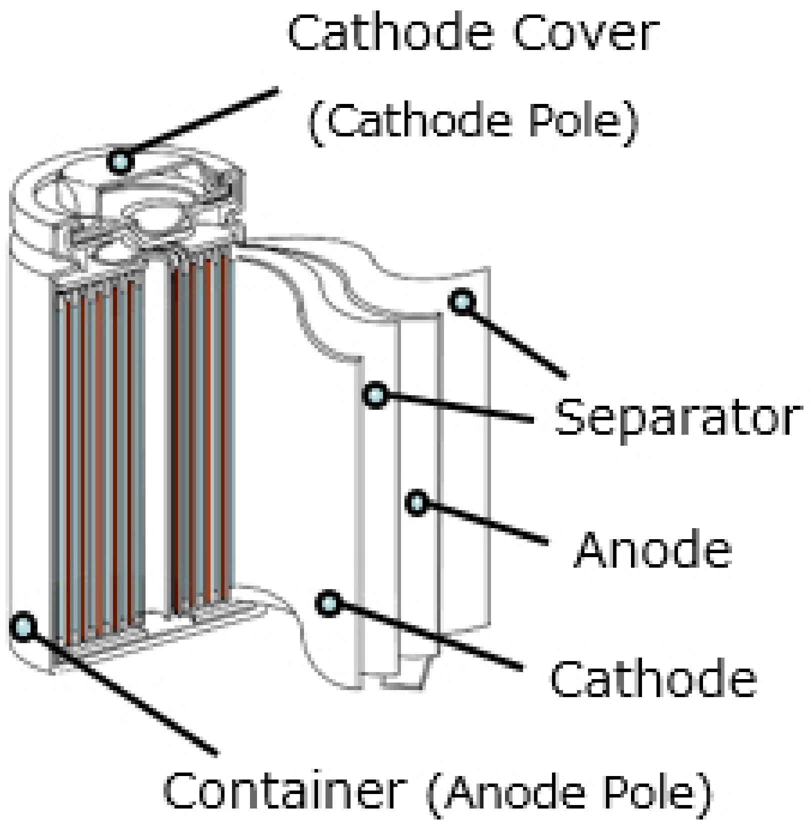
accompanied by any change in specific gravity of the electrolyte.

§ (27) Construction of the Edison Cell.—In practice the electrolyte consists of a 21 per cent solution of potassium hydrate, to which is added a certain percentage of lithium hydrate. The action of the latter is not understood, but it has the effect of materially increasing the capacity. This point has been investigated by L. C. Turnock.[1] It is stated that the amount normally used is 50 grammes per litre.

[1] *Am. Electrochem. Soc. Trans.*, 1917, xxxii. 405.

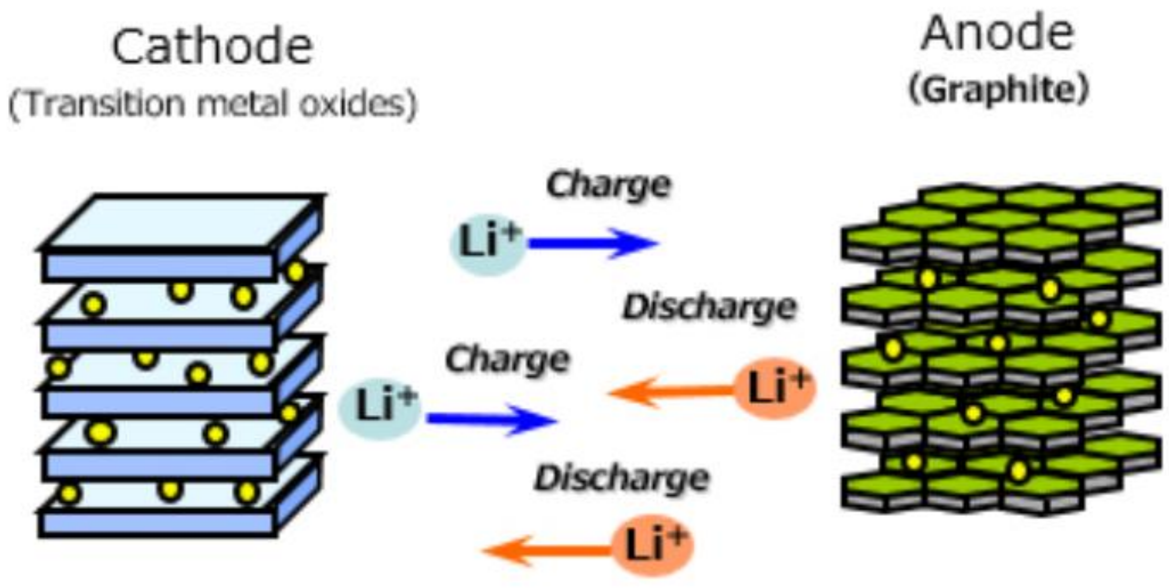
# The rise of lithium

- 1800's – discovered in petalite, spodumene and lepidolite
- 1855 – first isolated
- Initially used for soaps and then for lubricating greases for aircraft engines
- 1950's to 1990's – used to decrease melting temperature of glass, increase conductivity of cryolite in the Hall-Héroult cells and for the production of nuclear fusion weapons
- 1970's to 1980's – Whittingham and Goodenough separately developed rechargeable batteries with electrodes made capable of storing lithium ions
- 1980's – Yoshino made changes to the electrodes that dramatically improved safety and enabled commercial production of the lithium ion batteries
- 2007 – the lithium ion batteries became dominant.



# The development of the lithium ion battery

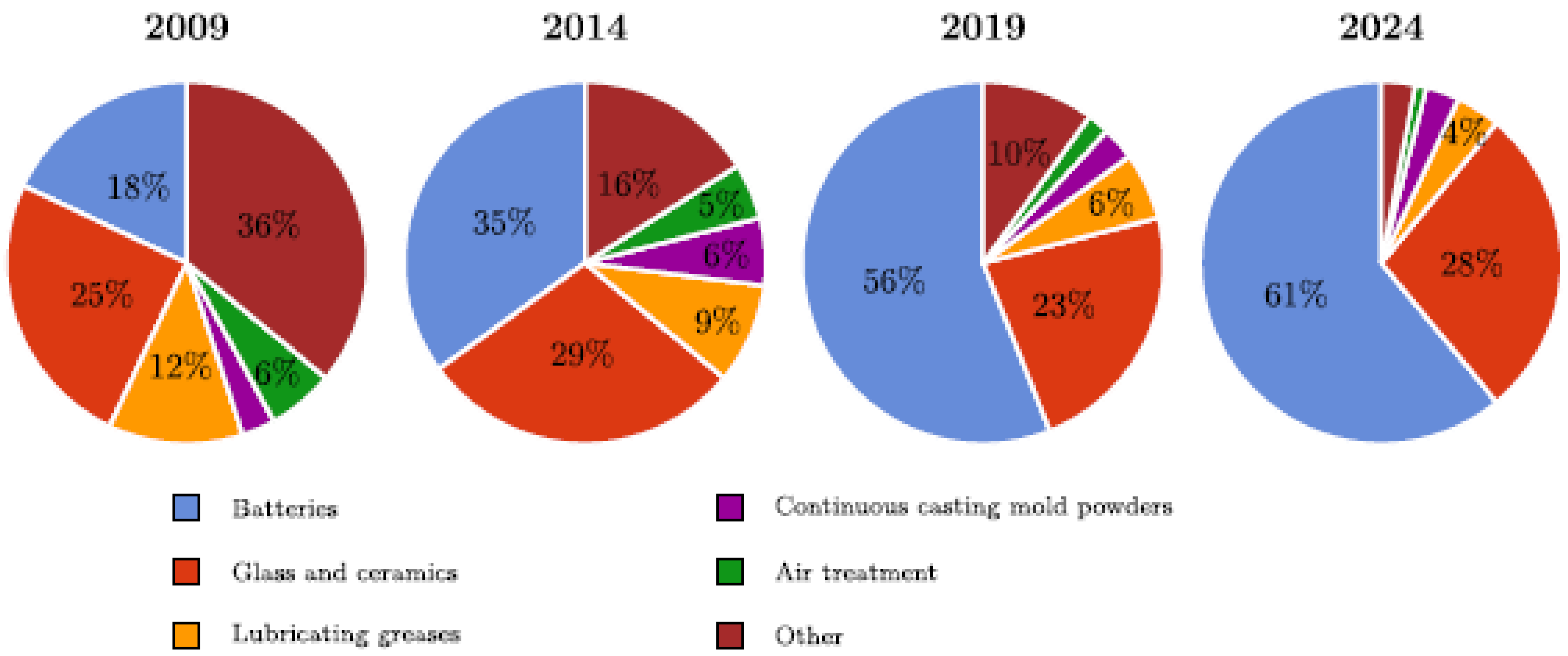
- 2019 Nobel Prize in Chemistry awarded to Whittingham, Goodenough and Yoshino "for the development of lithium-ion batteries“ – by many “overdue”
- The lithium ions are so small that they fit into holes within the crystal lattice of solids (intercalate) and effectively transfer charge



# Today – the Green Energy Revolution

- The Green Energy Revolution is the primary driver for the lithium demand and will fuel its production in the decades to come
- Renewables require batteries and with special conductive propertiers lithium has become the most sought-after ingredient for building the world's modern batteries
- A major increase is required in the production of high purity lithium to enable the transition to a society powered by clean and renewable energy
- Lithium is sourced from either brine lakes or hard rock minerals
- However, the brine sources are being exhausted and harder to purify
- Meanwhile, increased focus is placed on hard rock lithium minerals processing

# How much lithium are we talking about?




- In 2018, the production ramped up to 85,000 tons (an increase of 23% compared to 2017 and of 123% compared to 2016).
- Lithium will be critical in a world running on renewable energy and dependent on batteries
- We need to greatly increase production to meet the demand for the low carbon technologies

# Overview of the proposed research program

## Theme I

### Comminution & beneficiation:

1. Crushing
2. Grinding
3. Coarse particle processing
4. Flotation reagents

## Theme II

### Extraction:

5. Calcination and leaching
6. Direct leaching
7. Mechanochemical extraction

# Overview of the proposed research program

## Theme III

### Impurity separation and purification:

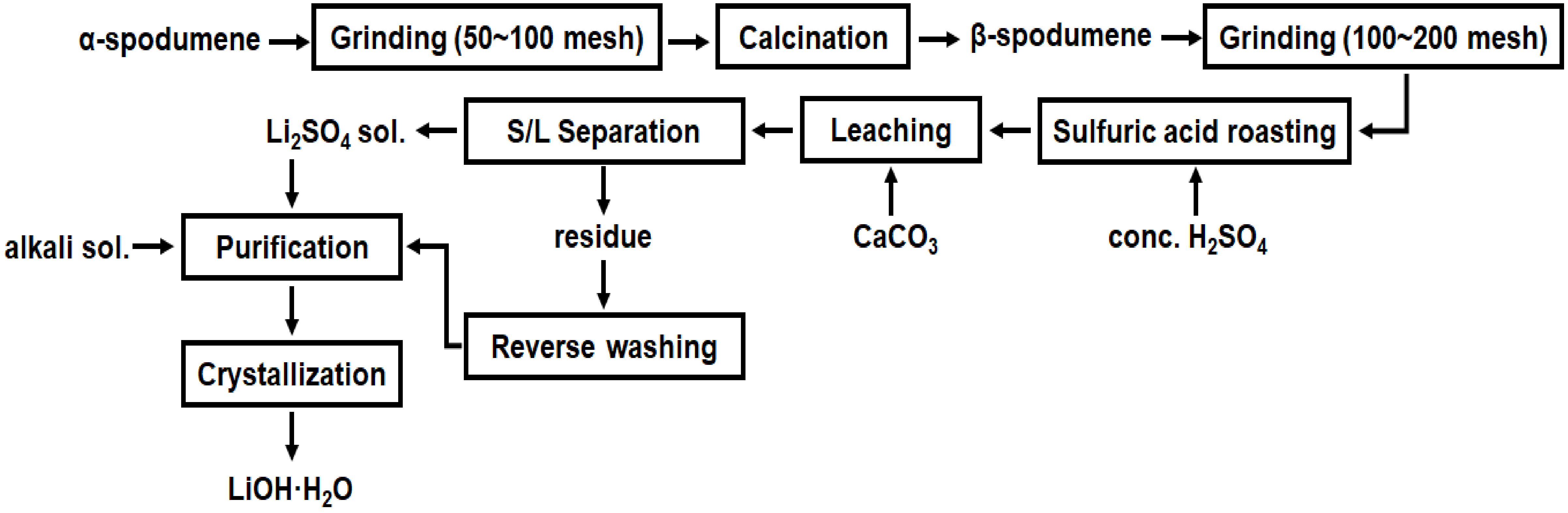
8. Precipitation and ion exchange
9. Crystallisation
10. Electrodialysis

## Theme IV

### Reagent recovery from liquors

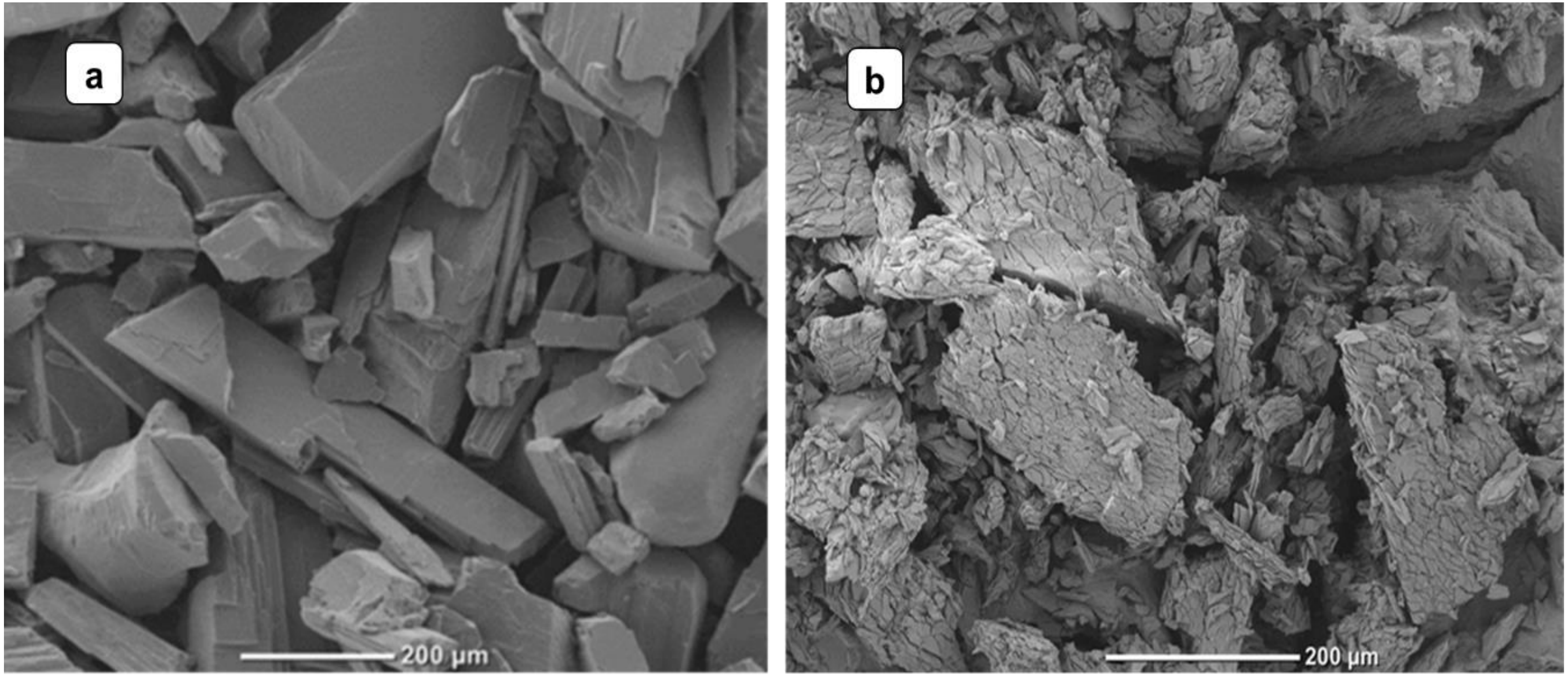
11. Caustic and acid recovery
12. Recovery of other reagents

# Conventional hard rock processing
# - sulfuric acid roasting technology



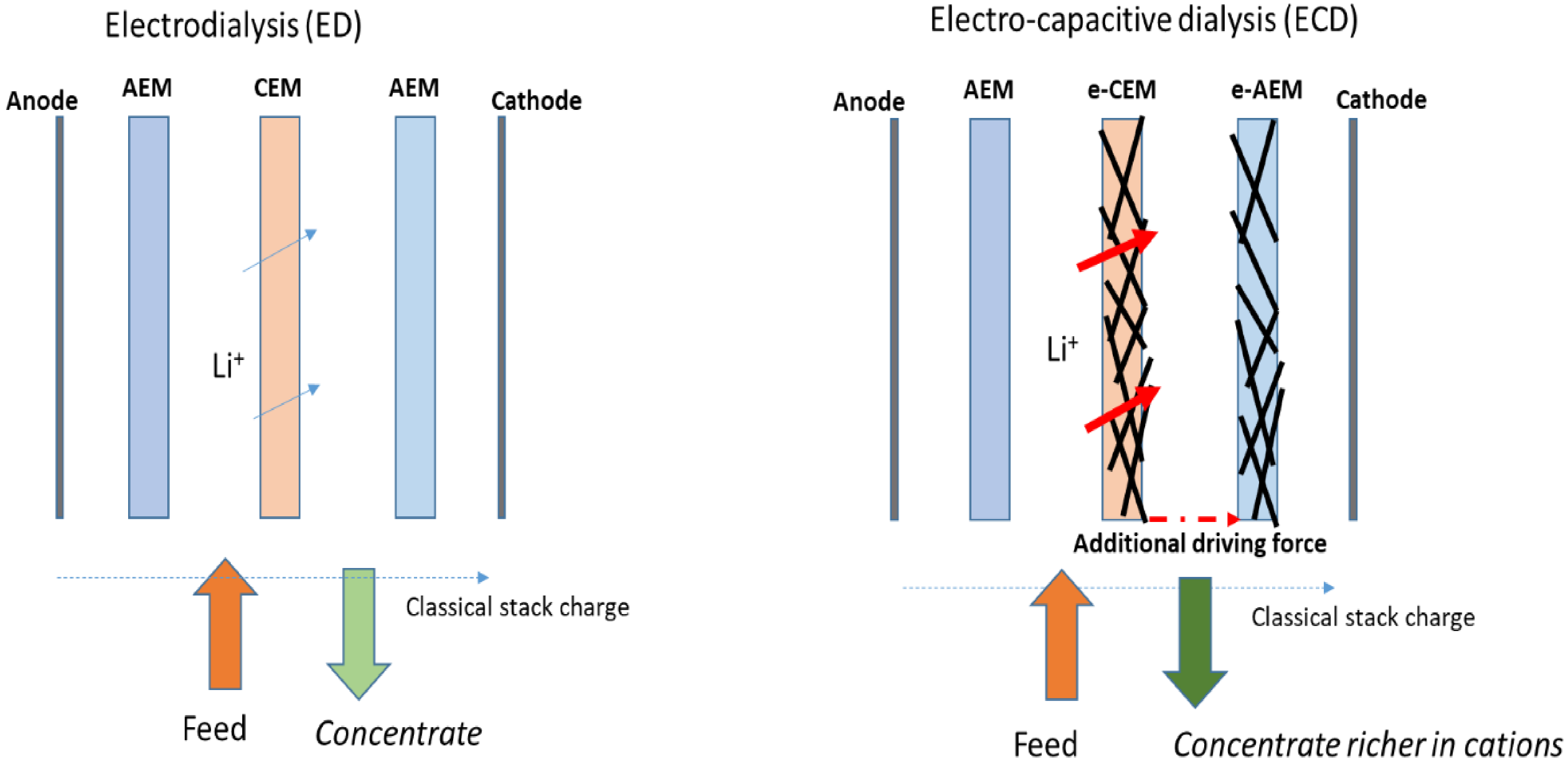

$Li_2O \cdot Al_2O_3 \cdot 4SiO_2$ (β-spodumene) + $H_2SO_4$ (concentrated) => $H_2O \cdot Al_2O_3 \cdot 4SiO_2 + Li_2SO_4$

# Physical changes during calcination

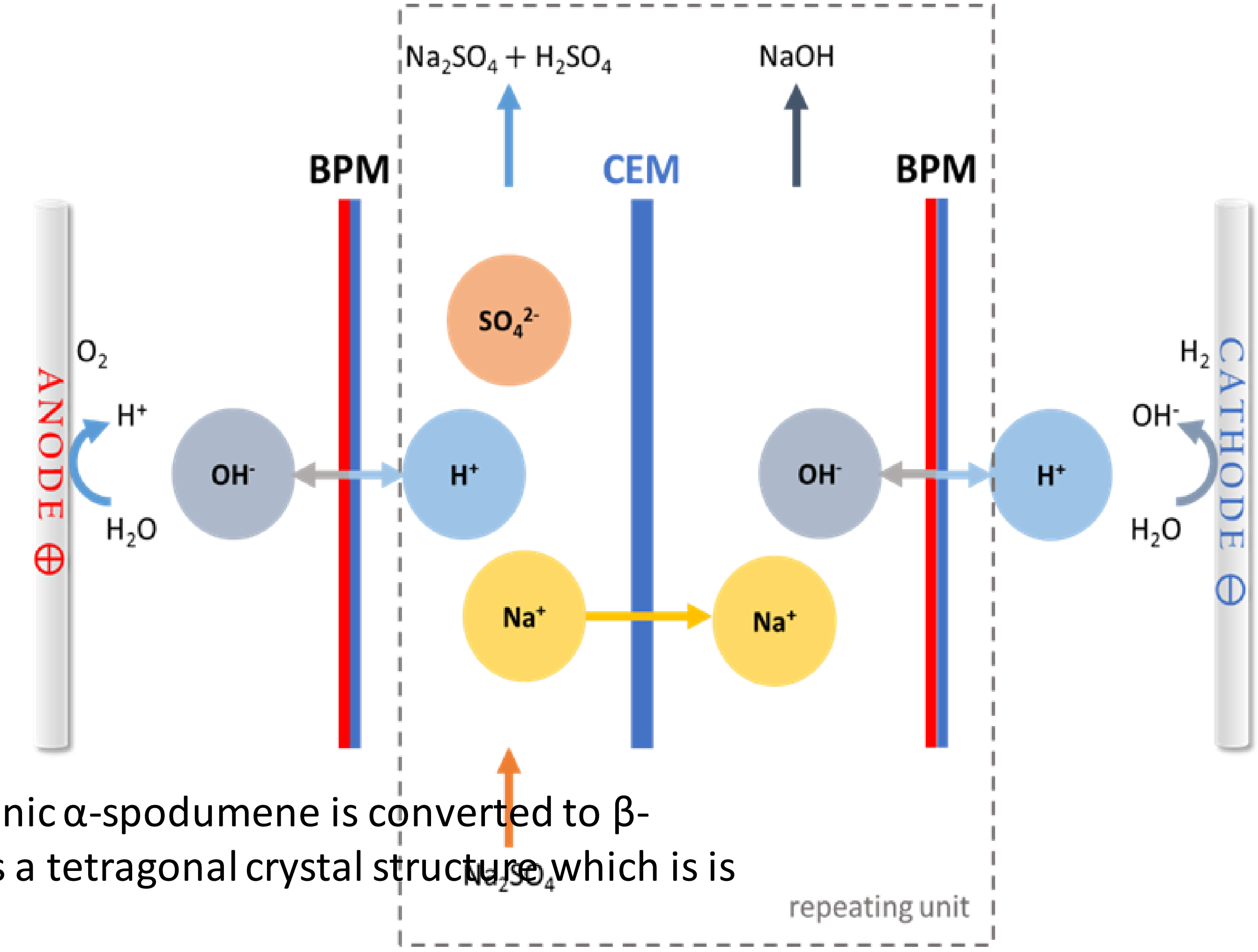



At 1100 C, the monoclinic α-spodumene (a) is converted to β-spodumene (b), which has a tetragonal crystal structure and is less packed.

# Direct recovery of lithium hydroxide using standard electrodialysis (left) and enhancing selective ion diffusion with electrically charged ion exchange membranes (right)



# Bipolar membrane electrodialysis in a two-compartment configuration




At 1100 C, the monoclinic α-spodumene is converted to β-spodumene, which has a tetragonal crystal structure which is is not as packed.

# Theme I. Comminution and beneficiation

- **Crushing (Topic 1, CU led):** The impact of hard rock breakage mechanism on liberation characteristics of lithium minerals and tantalum minerals by using various crushing techniques (Bogale Tadesse, Boris Albijanic, George Franks, Mark Aylmore)
- **Grinding (Topic 2, UTS led).** Development of energy efficient grinding technology and grinding additives to effectively break and grind lithium ore to fine powders with desired size and optimised size distribution (Guoxia Wang at UTS and JdLT at CU)
- **Coarse particle processing (Topic 3, CU led):** Optimization of by wet and dry separation including (i) gravity (jigs and dense media separation techniques), (ii) magnetic and (iii) coarse particle flotation (HydroFloat technology) for lithium ores (Boris Albijanic, Bogale Tadesse, Postdoc, George Franks, Greg O'Connor, Laurence Dyer, Mark Aylmore)
- **Flotation (Topic 4, CU led):** Development and optimization of collectors for fresh and saline water flotation of hard rock lithium minerals (i) spodumene, (ii) petalite and (iii) lepidolite (George Franks, Boris Albijanic, Postdoc, Bogale Tadesse, Chris Aldrich, Laurence Dyer, Richard Alorro, Aleks Nikoloski)

# Theme II.
# Extraction of lithium from hard rock minerals

- **Calcination and leaching (Topic 5, CU and UTS led).** Development of (ii) alternative roasting processes for spodumene and petalite (Greg O'Connor and Jim Cupitt at Curtin and Post Doc at Murdoch) and (i) optimisation of the production parameters for conventional calcination and roasting (Guoxia Wang at UTS) as pre-treatment to extraction by leaching.
- **Direct leaching (Topic 6, MU led).** Development of fully hydrometallurgical process for extraction of lithium from hard rock minerals (high temp & pressure) (Aleks Nikoloski, Post Doc at Murdoch, Post Doc at Curtin)
- **Mechanochemical processing (Topic 7, CU led).** Mechanochemical processing of hard rock lithium bearing minerals (Richard Alorro at Curtin).

# Theme III.
# Impurity separation, purification and recovery

- **Precipitation and ion exchange (Topic 8, MU led).** Impurity separation lithium leach solutions by (i) precipitation and (ii) IX for product and by-product recovery (Post Doc at Murdoch, Richard Alorro and Postdoc at Curtin).
- **Crystallisation (Topic 9, UTS led).** Exploration and establishing of crystallisation technologies using new chemicals and reagents for production with maximum rate of high purity battery grade lithium containing chemicals (including lithium hydroxide monohydrate) obtained from the lithium ore (Guoxia Wang and Postdoc at UTS).
- **Electrodialysis (Topic 10, MU led).** Electrodialysis production of $LiOH.H_2O$ from different product liquors by (Aleks Nikoloski, Post Doc and MPhil student at Murdoch and Ludovic Dumee and Post Doc at Deakin).

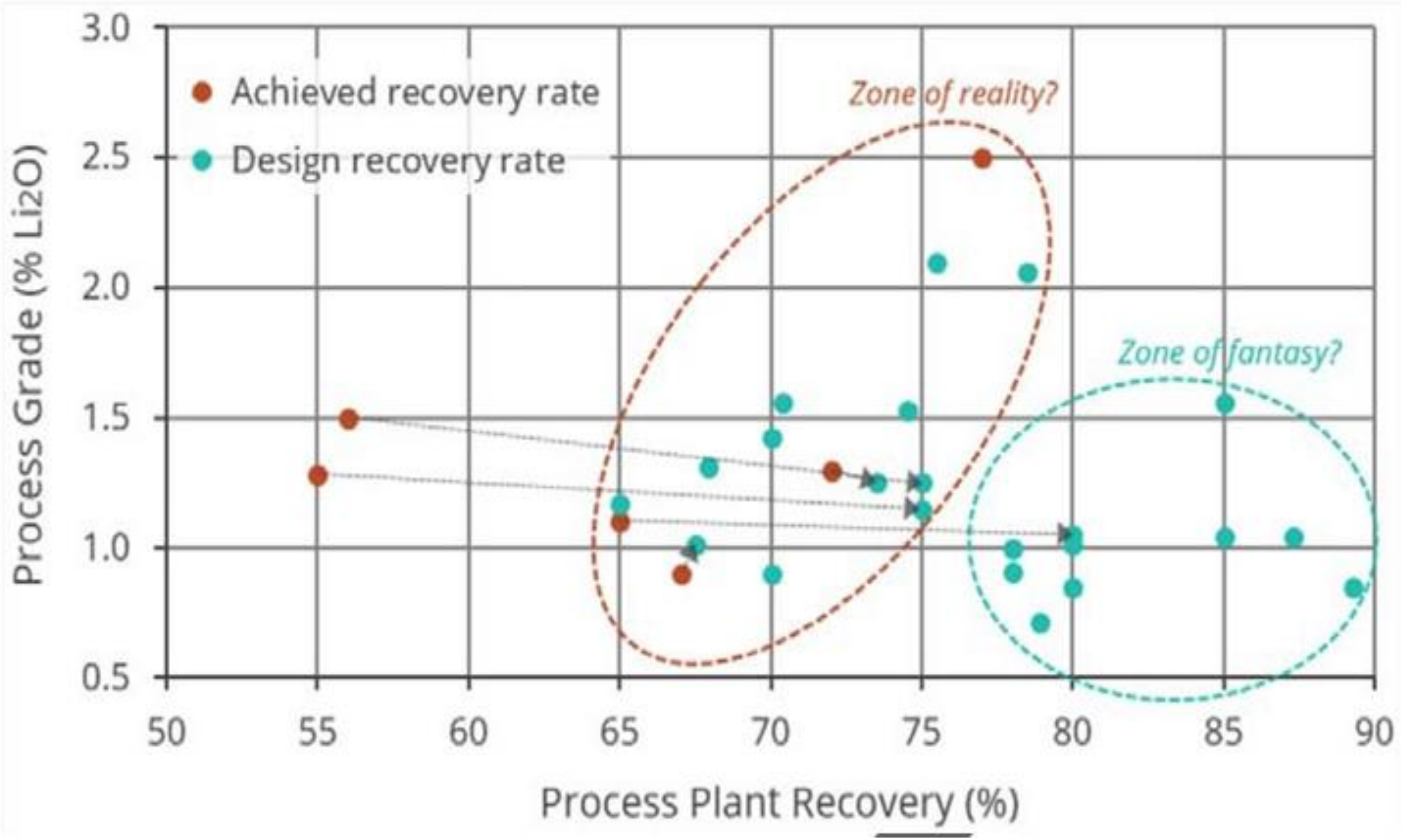
# Theme IV.
# Reagent recovery and regeneration from waste

- **Caustic recovery and acid regeneration (Topic 11, MU led).** Electrodialysis of $Na_2SO_4$ for reagent regeneration and waste treatment (Aleks Nikoloski, Post Doc at Murdoch).
- **Fluorine recovery by precipitation (Topic 12, CU led).** Regeneration of reagents such as fluorine by precipitation, following the recovery of lithium from the final product liquors (Laurence Dyer and Postdoc at Curtin).

# Gantt Chart illustrates the start and end dates for each sub-project in the overall project

| Theme | Sub-project | 2020 | | | | 2021 | | | | 2022 | | | | 2023 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3 | 6 | 9 | 12 | 3 | 6 | 9 | 12 | 3 | 6 | 9 | 12 | 3 | 6 | 9 | 12 |
| I | 1 | | G1 | | | | | | | | | | | | | | |
| | 2 | | G1 | PD | | | | | | | | | | | | | |
| | 3 | | | PD | | G2 | | | | | | | | | | | |
| | 4 | | G1 | | | G2 | | | | | | | | | | | |
| II | 5 | | G1 | PD | | | | | | | | | | | | | |
| | 6 | | G1 | | | | | | | | | | | | | | |
| | 7 | | | | | G2 | | | | | | | | | | | |
| III | 8 | | | PD | | | | | | | | | | | | | |
| | 9 | | | PD | | | | | | | | | | | | | |
| | 10 | | G1 | PD | | G2 | | | | | | | | | | | |
| IV | 11 | | | | | | PD | | | | | | | | | | |
| | 12 | | | | | G2 | | | | | | | | | | | |

# Lithium recovery rates versus feed grade during spodumene processing



# Some relevant publications by the research team


1. Salakjani, N.K., Nikoloski, A.N., Singh, P., (2020) 'Production of Lithium – A Literature Review Part 1: Pretreatment of Spodumene', Mineral Processing and Extractive Metallurgy Review, Article in Press,
2. Karrech, A., Azadi, M.R., Elchalakani, M., Shanin, M.A., Seibi, A.C. (2020) 'A review on methods for liberating lithium from pegmatites', Minerals Engineering, 145, 106085.
3. Zhou, Y. Albijanic, B., Tadesse, B., Wang, Y., Yang, J., Zhu, X., Rezvani, A. (2019) 'Predicting sliding times of a particle over a bubble surface under various chemical conditions.' Minerals Engine ering, 137, pp. 177-180.
4. Zhou, Y., Albijanic, B. Tadesse, B., Wang, Y., Yang, J. (2019) 'Investigation of bubble-particle attachment interaction during flotation.' Minerals Engineering, 133, pp. 91-94.
5. Zhou, D., Shanmukaraj, D., Tkacheva, A., Armand, M., Wang, G. (2019) 'Polymer Electrolytes for Lithium-Based Batteries: Advances and Prospects.' Chem, 5(9), pp. 2326-2352
6. Tadesse, B., Makuei, F. Abijanic, B., Dyer, L. (2019) 'The beneficiation of lithium minerals from hard rock ores: A review', Minerals Engineering, 131, pp. 170-184.
7. Zhang, J., Sun, B., Zhao, Y., Tkacheva, A., Liu, Z., Yan, K., Guo, X., McDonagh, A.M., Shanmukaraj, D., Wang, C., Rojo, T., Armand, M., Peng, Z., Wang, G. (2019) 'A versatile functionalized ionic liquid to boost the solution-mediated performances of lithium-oxygen batteries.' Nature Communications, 10 (1), Article number 602
8. Allioux, F.M., Balme, S., Dumée, L.F. (2018) 'Smart electrically responsive hybrid ion-selective membranes for selective gated transport of ionic species', Materials Forisons, 6, pp. 1185-1193.
9. Albijanic, B., Zhou, Y., Tadesse, B., Dyer, L., Xu, G., Yang, X., (2018) 'Influence of bubble approach velocity on liquid film drainage between a bubble and a spherical particle.' Powder Technology, 338, pp. 140-144.
10. Allioux, F.M., Kapruwan, P., Milne, N., Kong, L., Fattaccioli, J. Chen, Y., Dumée, L.F. (2018) 'Electro-capture of heavy metal ions with carbon cloth integrated microfluidic devices', Separation and Purification Technology, 194, 26-32.
11. Nikoloski, A.N. and Kyle, J. (2017) 'Literature Review: Production and Purification of Products from Lithium Sources'. (MRIWA Project M479 - Final Report, Prepared for MRIWA, Lithium Australia Ltd. and Venus Metals Ltd.). Murdoch University, February. 72 p.
12. Salakjani, N.K., Nikoloski, A.N., Singh, P., (2017) 'Mineralogical transformations of spodumene concentrate from Greenbushes, Western Australia. Part 2: Microwave heating', Minerals Engineering, 98, pp. 71-79.
13. Harrison, H. (2016) 'The Electrodialysis of Lithium Sulphate to Lithium Hydroxide". Research Thesis, Supervised by Nikoloski, A.N.; Murdoch University, November 2017. 93 p.
14. Nikoloski, A.N. and Kyle, J. (2017) 'Experimental Findings in Phases 1 & 2: Solution Purification and Valuable By-Product Formation'. (MRIWA Project M479 - Final Report, Prepared for MRIWA, Lithium Australia Ltd. and Venus Metals Ltd.). Murdoch University, November. 140 p.
15. Yao, J., Bewlay, S., Konstantionv, K., Drozd, V.A., Liu, R.S., Wang, X.L., Liu, H.K., Wang, G.X., (2016) 'Characterisation of olivine-type LiMnxFe1-xPO4 cathode materials.' Journal of Alloys and Compounds, 425 (1-2), pp. 362-366
16. Salakjani, N.K., Singh, P., Nikoloski, A.N., (2016) 'Mineralogical transformations of spodumene concentrate from Greenbushes, Western Australia. Part 1: Conventional heating', Minerals Engineering, 98, pp. 71-79.
17. Nikoloski, A.N. (2016) 'Testing of impurity separation options and purification of lepidolite leach solution'. (Project report, Prepared for Lithium Australia). Murdoch University, October. 45 p.
18. Nikoloski, A., Barmi, M. and Ang, K.L. (2013) 'The Development of a Method for Production of LiOH.H2O from a LiCl solution by Electrodialysis and Crystallization,' (Project report, Prepared for Reed Industrial Minerals Pty Ltd). Murdoch University, December. 61 p.
19. Wang, G., Liu, H., Liu, J., Qiao, S., Lu, G.M., Munroe, P., Ahn, H. (2010) 'Mesoporous LiFePO4/C nanocomposite cathode materials for high power lithium ion batteries with superior performance.' Advanced Materials, 22 (44), pp. 4944-4948

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# THANK YOU

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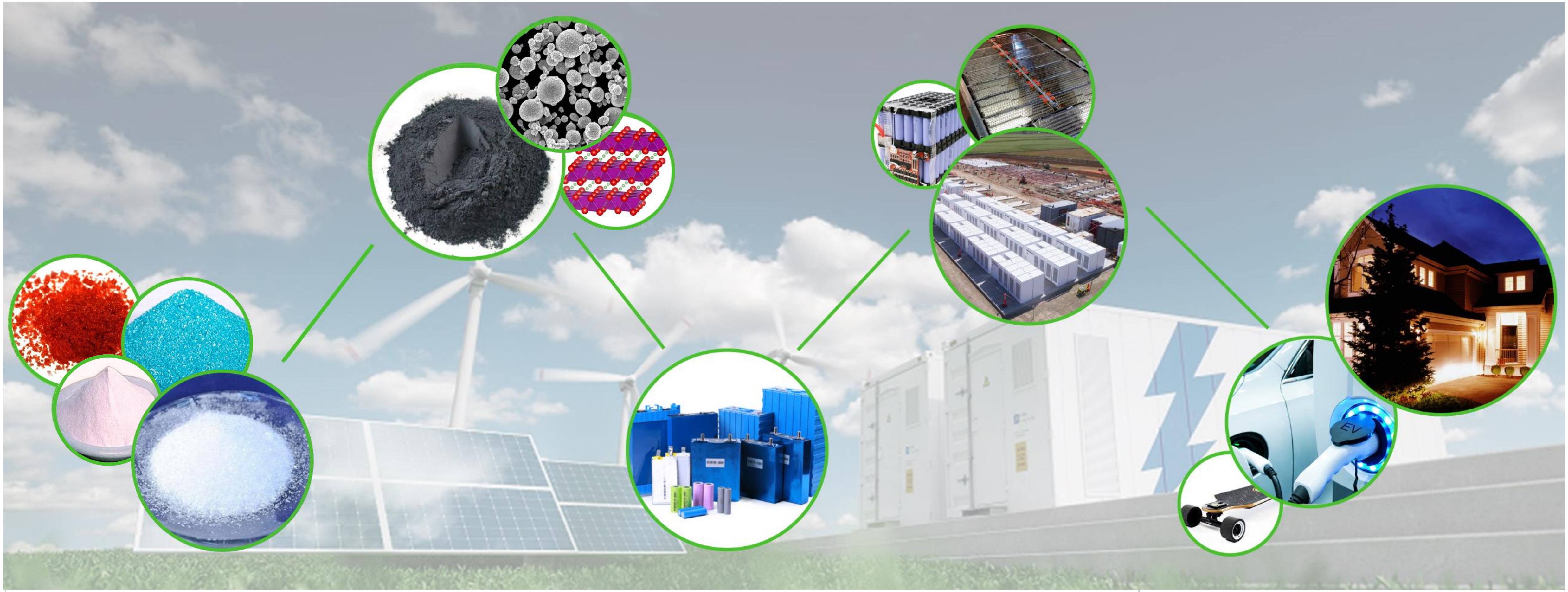


# Battery Precursor Manufacture in Australia

FUTURE BATTERY INDUSTRIES CRC

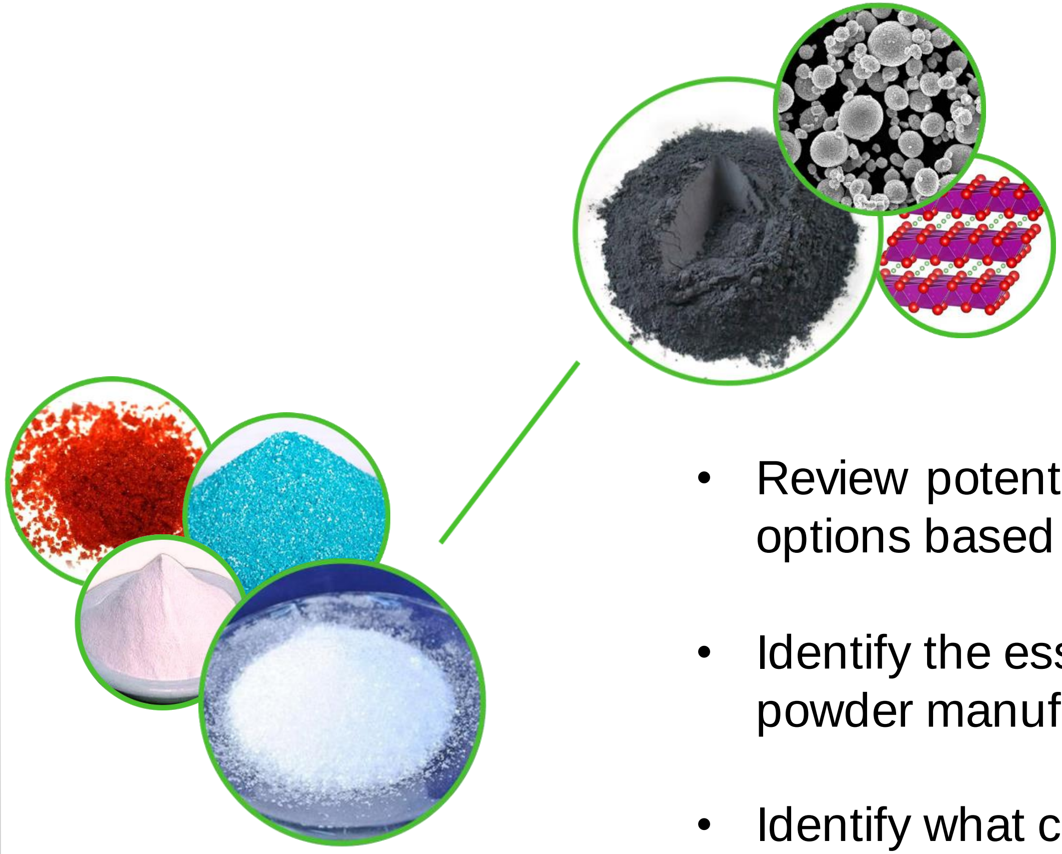
QUT

Curtin University

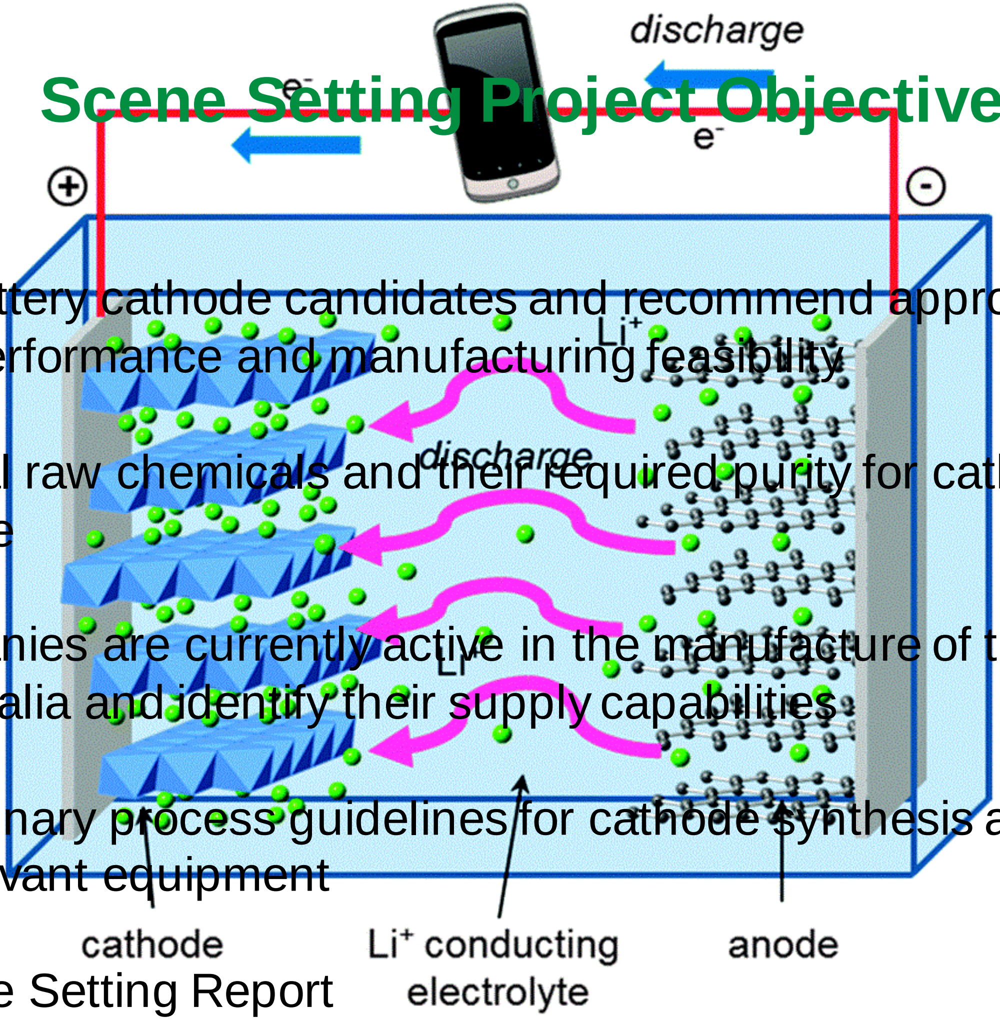

Scene Setting Project – Dr Joshua Watts (QUT)

Cathode Precursor Pilot Plant – Erin Ireland (Curtin University)


MARCH 11 2020



# Scene Setting Project Objectives




- Review potential battery cathode candidates and recommend appropriate options based on performance and manufacturing feasibility
- Identify the essential raw chemicals and their required purity for cathode powder manufacture
- Identify what companies are currently active in the manufacture of these compounds in Australia and identify their supply capabilities
- Recommend preliminary process guidelines for cathode synthesis and processing with relevant equipment
- Generation of Scene Setting Report

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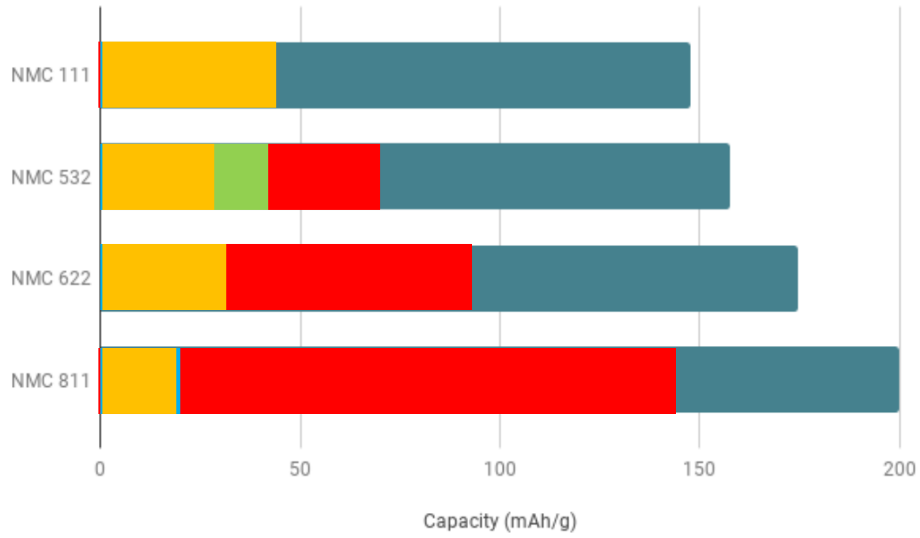
# NMC

($LiNi_xMn_yCo_zO_2$) (LiNiMnCoO$_2$)

Specific Energy




Performance

Ni Stability/ Cyclability

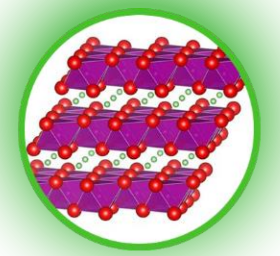
LFP ($LiFePO_4$)

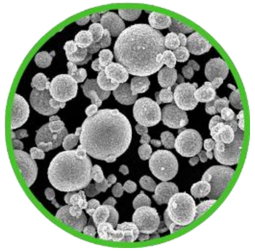
LMO ($LiMn_2O_4$)

LCO ($LiCoO_2$)

NCA ($LiNiCoAlO_2$)

NMC ($LiNiMnCoO_2$)





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# NMC Cathode Precursors


99.98% purity minimum

Expected to surpass lithium carbonate as primary lithium precursor over next 5 years

Manganese sulphate monohydrate (HPMSM)

Primary precursor in NMC/NCA




99.0%

**Appearance**

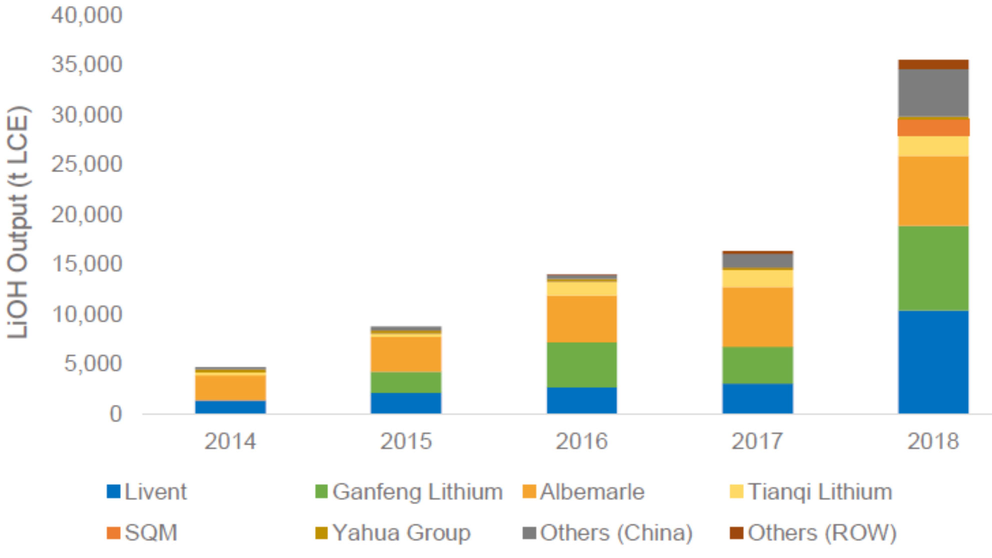
Pink-Red odorless crystalline powder

**Chemical Analysis**

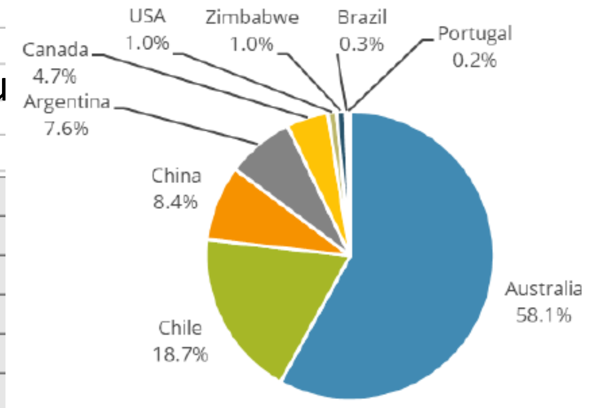
| | Spec | Typical |
|---|---|---|
| Cobalt, as Co, wt % | > 21.00 | 21.06 |
| Manganese, as Mn, ppm | < 3 | 0.5 |
| Iron, as Fe, ppm | < 3 | 2.0 |
| ...l, as Ni, ppm | < 80 | 22.0 |
| ...er, as Cu, ppm | < 3 | ND |
| ...um, as Na, ppm | < 10 | 1.5 |

...t 28 kt in 2017

| ... | ...2 | Chi... | China 2 | China 3 | WA 1 | Others |
|---|---|---|---|---|---|---|
| | 22.3 | 22.2 | 22 | 22.2 | 22.3 | 22.2 |
| | 10 | 30 | 10 | 30 | 80-120 | 100-250 |

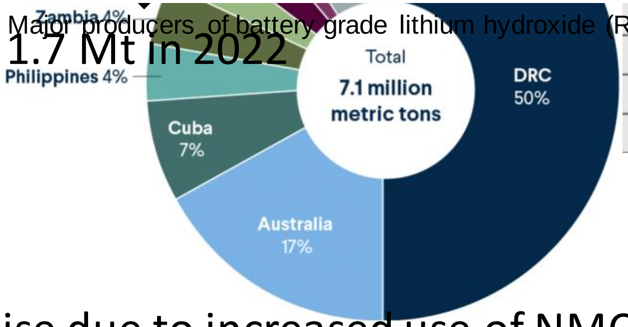



Major producers of battery grade lithium hydroxide (Roskill, 2019)




Mined lithium production (Roskill, 2019)

1.7 Mt in 2022




| | | |
|---|---|---|
| ppm | | |
| ppm | 50 max | |
| ppm | 50 max | 2 - |
| ppm | 10 max | 1 5 |
| | 10 max | |
| | 10 max | |

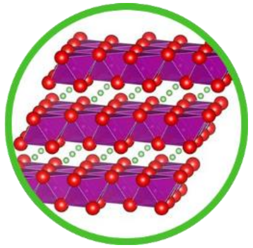
(IGO, 2019)

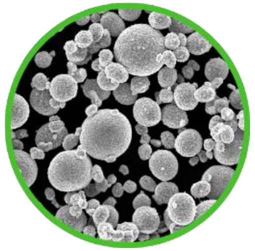
(ISKY,2020)

| | | |
|---|---|---|
| | 56.5 | min |
| | 0.35 | max |
| | 0.003 | max |
| | 0.05 | max |
| Fe2O3, wt% | 0.03 | max |
| | 0.003 | max |
| NaOH, wt% | 0.05 | max |
| Acid Insolubles, wt% | 0.005 | max |

(Livent,2020)

Rise due to increased use of NMC and NCA batteries and introduction of nickel-rich cathode compositions (such as NMC811 and NMC622).





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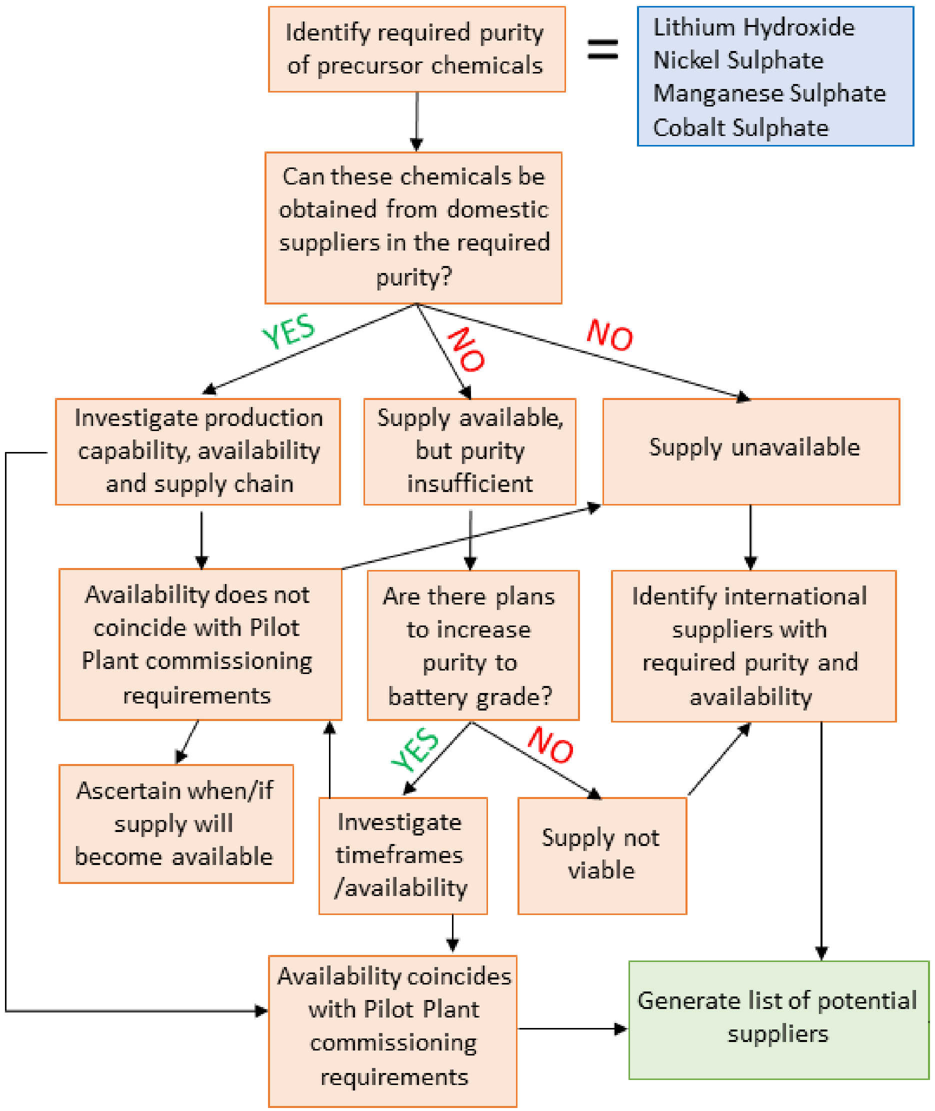
# Australian Supply

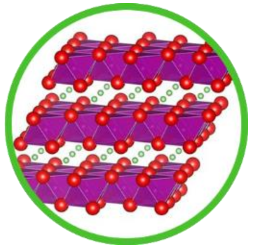

BHP Nickel West, Cobalt Blue

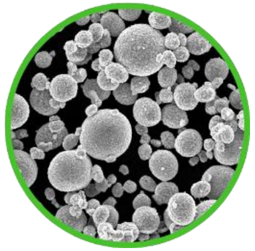

BHP Nickel West, IGO


Pilbara Metals Group


Tianqi Lithium, Covalent Lithium





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# Cathode Manufacture Process

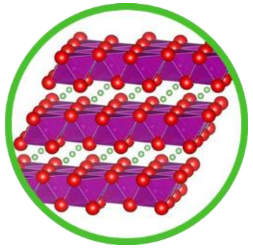


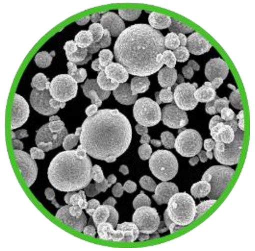


Cathode materials synthesized in different ways:

- solid state
- spray/solution combustion
- sol-gel
- hydrothermal
- carbonate/oxylate co-precipitation
- hydroxide co-precipitation

Hydroxide co-precipitation method is one of the most economical and effective approaches to prepare NCA/NMC cathode materials with controlled particle size distribution via a continuously stirred tank reactor.





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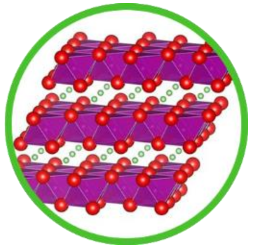
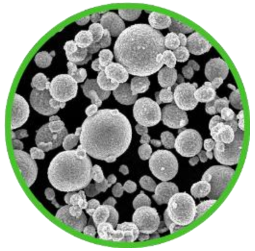
# Hydroxide Co-precipitation







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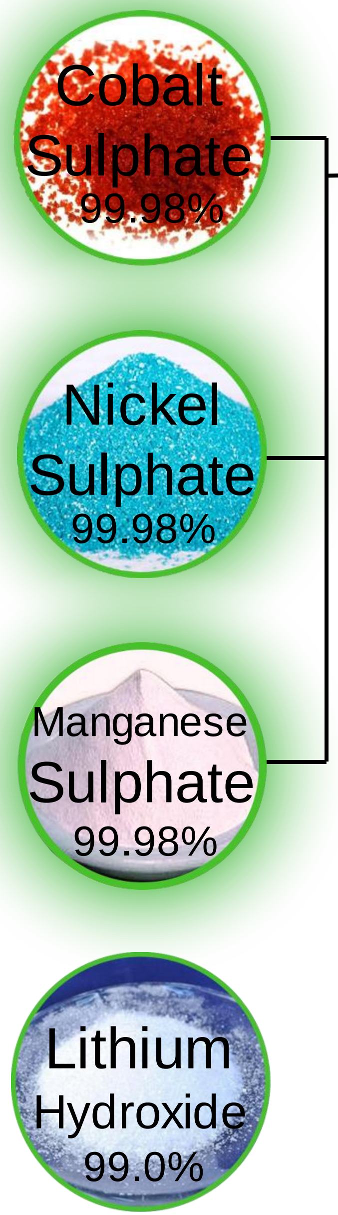
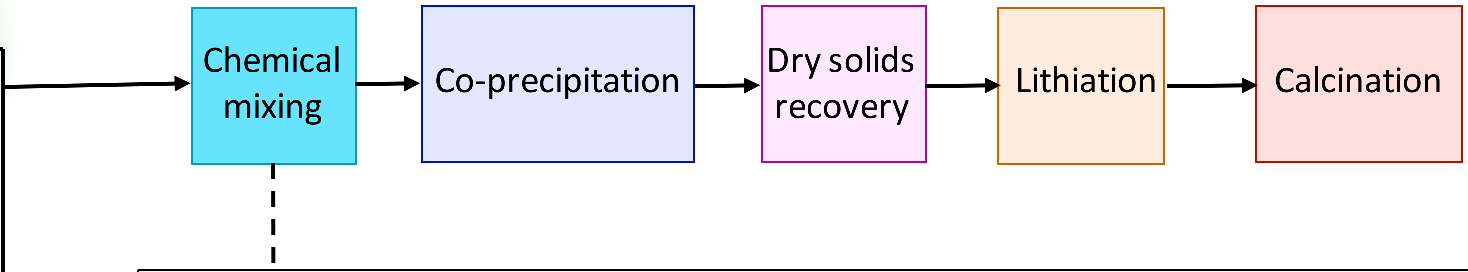
# Cathode Manufacture Process: Co-precipitation



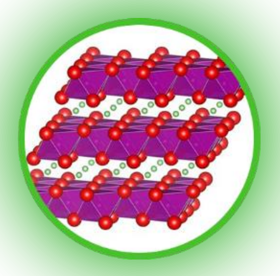



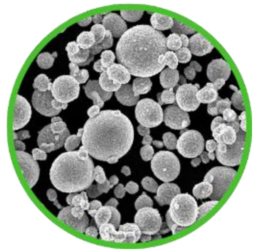

**Design Criteria**

- Ratio of metal sulphates determined by desired stoichiometry
- Target mixed sulphate (aq) solution concentration of 2.0 mol/L
- Stirring required for full dissolution of precursor chemicals
- Deionised water required a solvent

**Equipment**

- Stirred mixing tank with cooling/heating capability





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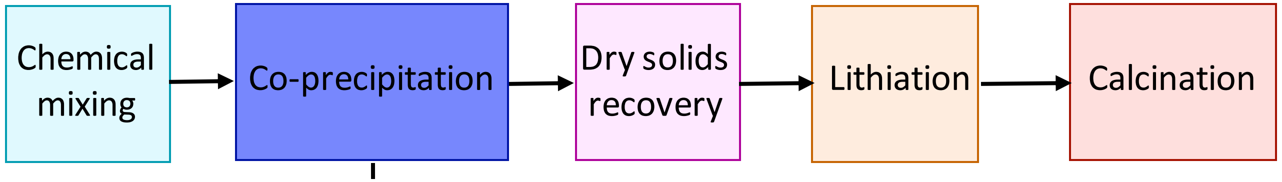
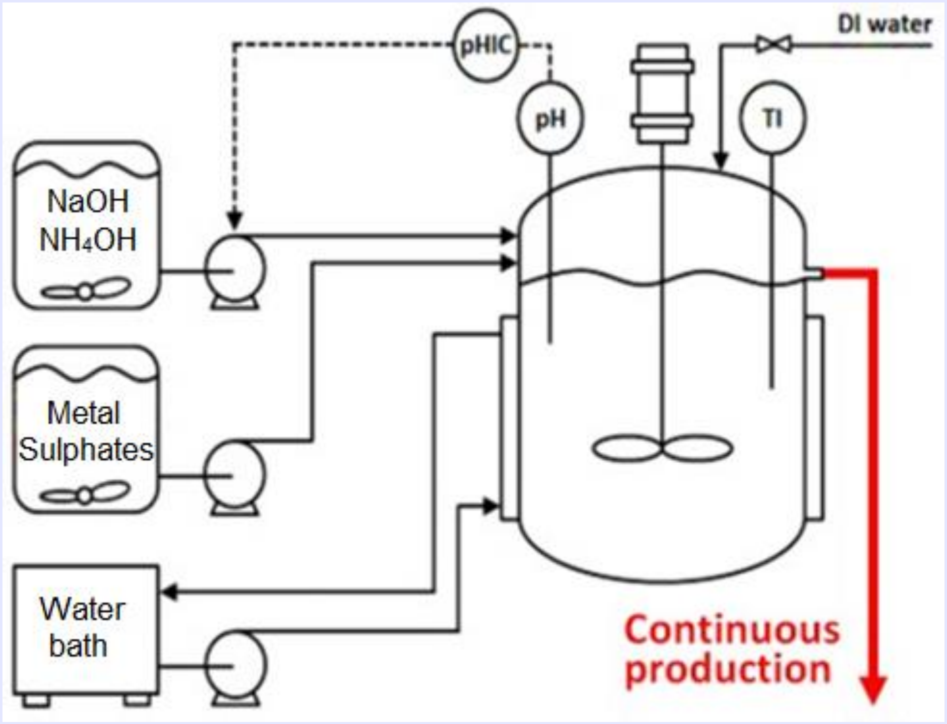
# Cathode Manufacture Process: Co-precipitation

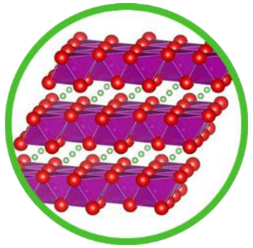


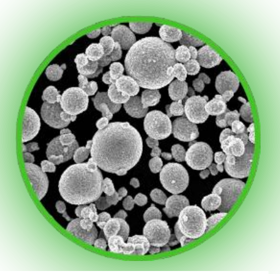





Metal Sulphates





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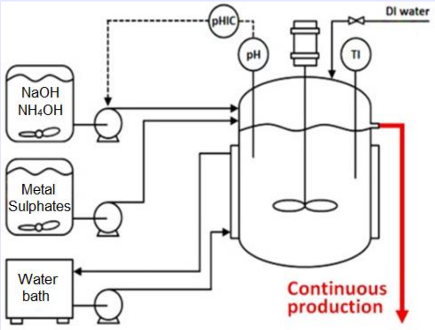
# Cathode Manufacture Process: Co-precipitation





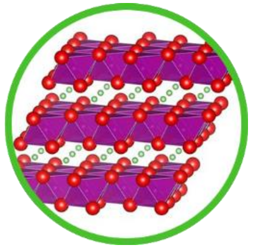
Chemical mixing → Co-precipitation → Dry solids recovery → Lithiation → Calcination

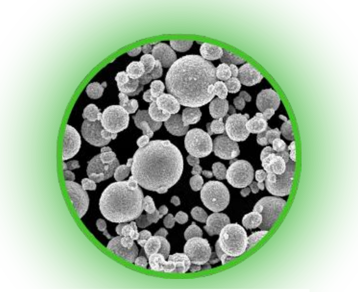
## Design Criteria




- pH of reaction vessel must be precisely controlled – mitigate impurity, morphology control
- For NMC111; pH 11, for NMC811; pH 11.5-11.6
- Constant temperature of reaction vessel required (50-60ºC)
- Constant stirring required; increased speed facilitates narrow secondary particle size distribution with increased density
- Concentration of NaOH (aq.) may vary between 2.0 and 4.0 mol/L.
- Concentration of $NH_4OH$ (aq.) may vary; increased concentration promotes uniform spherical secondary particles
- Inert atmosphere required to mitigate formation of impurity oxides; nitrogen or argon may be used

Metal Sulphates





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# Cathode Manufacture Process: Co-precipitation





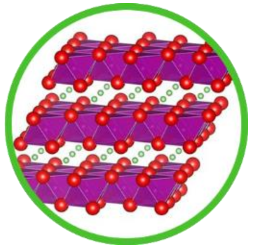
Chemical mixing → Co-precipitation → Dry solids recovery → Lithiation → Calcination

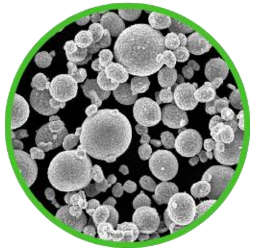
## Design Criteria

- Washing with DI water to remove any residual sulphate impurity.
- Drying to occur in a vacuum oven at 80-120ºC for 12-24 hrs.

## Equipment

- Filter press





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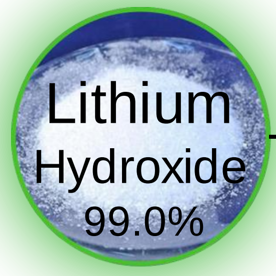
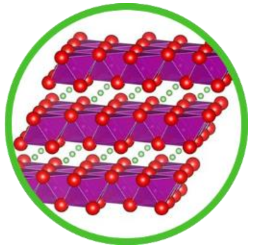
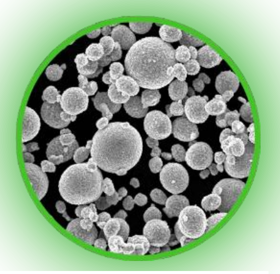
# Cathode Manufacture Process: Co-precipitation




Chemical mixing → Co-precipitation → Dry solids recovery → Lithiation → Calcination





**Design Criteria**

- Thorough mixing of dry $Ni_xMn_yCo_z(OH)$ powder with LiOH achieved by gentle dry mixing so as to not destroy particle morphology
- 2% excess LiOH used to mitigate calcination losses

**Equipment**

- Powder mixer

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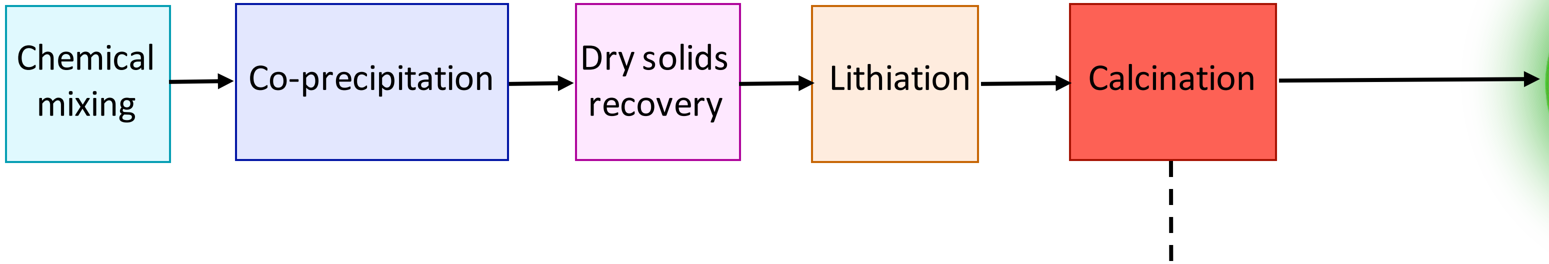
# Cathode Manufacture Process: Co-precipitation





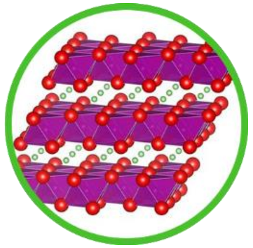


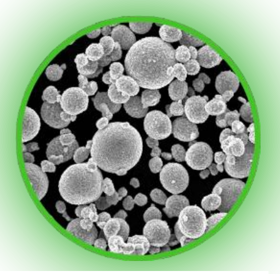

**Design Criteria**

- Calcination 2 stage process; 450-480ºC for 3-5 hrs under flowing oxygen followed by 750ºC for 12-15 hrs
- Final $Li(Ni_xMn_yCo_z)O_2$ powder is susceptible to oxidation (especially high-Ni content powders) and must be stored under inert conditions

**Equipment**

- Rotary furnace





# Cathode Pilot Plant Objectives

- **This program is a large D small r project with objective to:**
  - develop cost-effective, sustainable production of superior quality battery precursors for cathodes whilst minimising processing wastes
  - establish technical and processing capabilities in Australia to manufacture nickel-rich hydroxide precursors
  - reduce risk for Cathode Precursor Production Pilot Plant in Western Australia
  - increase the value chain of battery manufacturing in Australia

# Stage Gate Approach

**Stage 1**

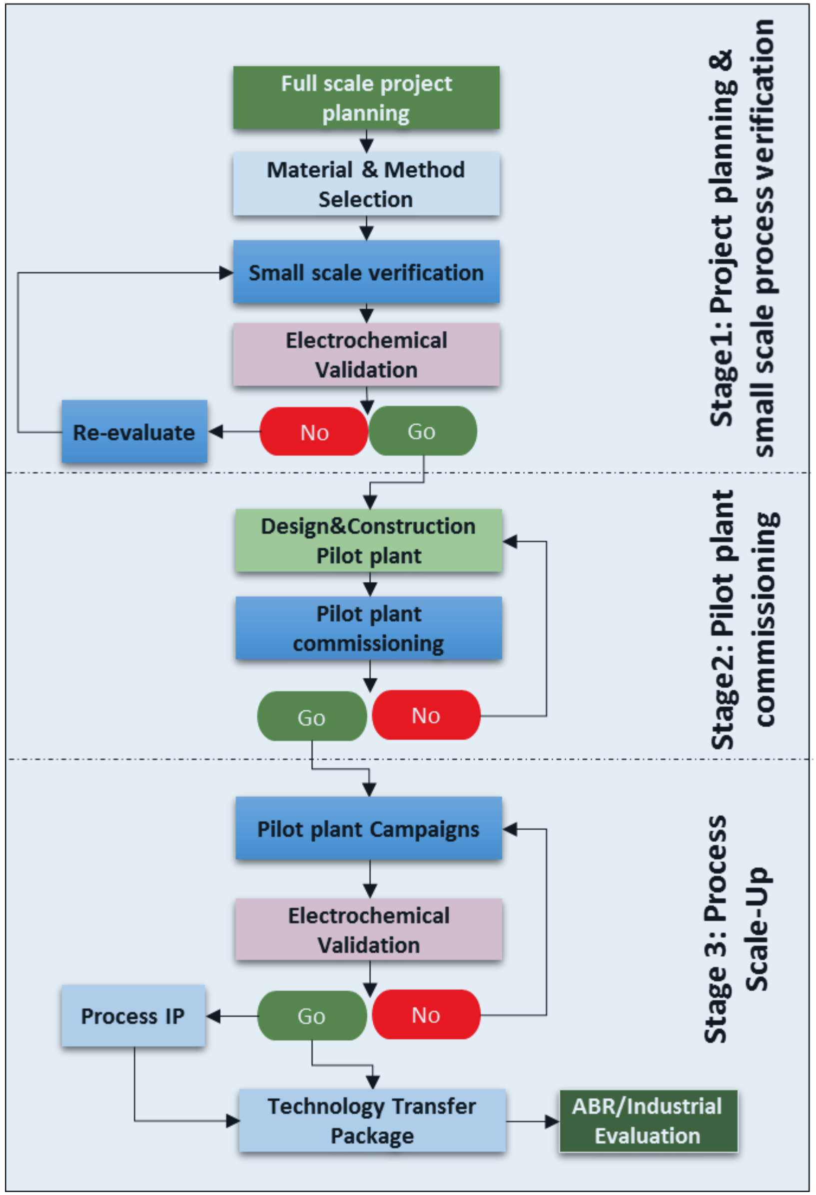
- Full scale budget and project planning for four years
- Stock-take of pilot plant components and industry engagement to determine In Kind contributions
- Identification of candidate materials, method and cathode active materials
- Develop experimental work planning and Quality Control (QC) procedures
- Small-scale verification of process (Design of experiments, kilograms)
- Process modelling and production cost estimation
- Final impact and commercialisation plan
- State of play review

**Stage 2**

- Pilot plant design and construction
- Pilot commissioning and verification

**Stage 3**

- Pilot plant campaigns for scale-up/process verification (kilogram scale synthesis)
- Create Technology Transfer Package
- Mate the materials available for industrial evaluation
- Project closing

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# Deliverables

- **For each cathode material selected we will:**
  - Develop a scalable manufacturing process.
  - Develop analytical methods and QAQC procedures.
  - Prepare a “technology transfer information package” which will include:
    - Summary of the original process used by discovery researchers to synthesize the material
    - Summary of the scalable process suitable for large scale manufacturing
    - Detailed procedure of the revised process for material synthesis
    - Analytical data/Certificate of Analysis for the material
    - The material impurity profile
    - Electrochemical performance test data
    - Preliminary estimates of production costs
    - Material safety data sheet for the material
  - Make kilograms quantities of the material available for evaluation.
    - The material will be fully characterized chemically and electrochemically

# Project Completion

- **Scoping Level Study:**
  - PFD’s
  - Mass/Water/Energy Balance
  - Pilot design, construction and operation
  - Verification and qualification of the final precursor
  - Process modelling and scale-up verification of final process design
  - CAPEX and OPEX estimates (±40%)
  - Environmental, safety and business benefits/risks
  - Prove the viability of the production of ultra-stable NCM/NCA cathode materials
  - Pathway to Commercialisation

FUTURE BATTERY INDUSTRIES CRC

Curtin University

## THANK YOU

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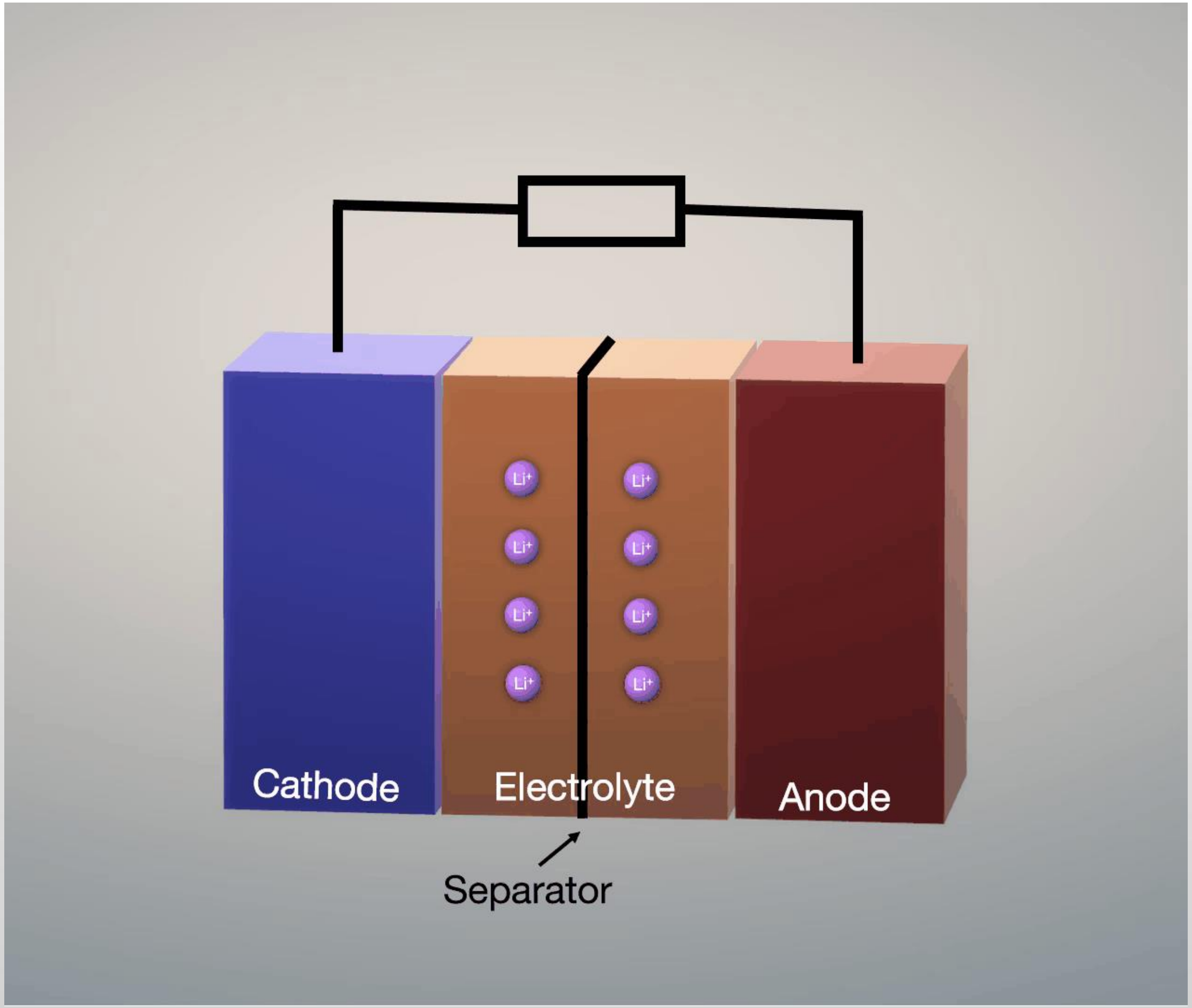
# Super Anode Project

FUTURE BATTERY INDUSTRIES CRC

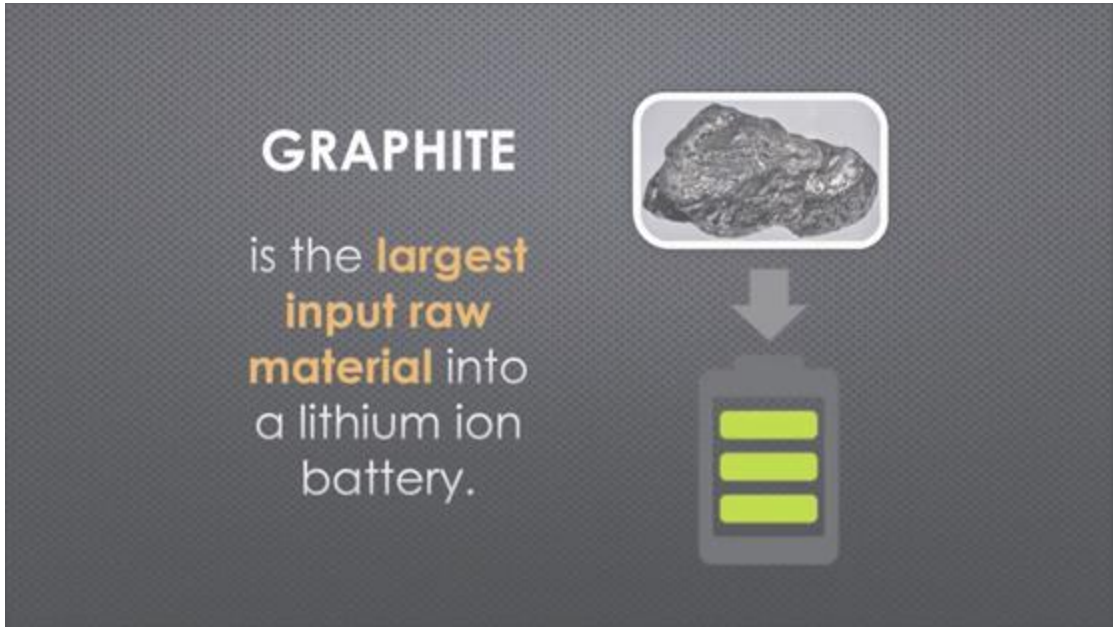
Project Lead: Amanda Ellis – Chemical Engineering, The University of Melbourne

March 11 2020

# Li ION BATTERY



# Graphite Anode



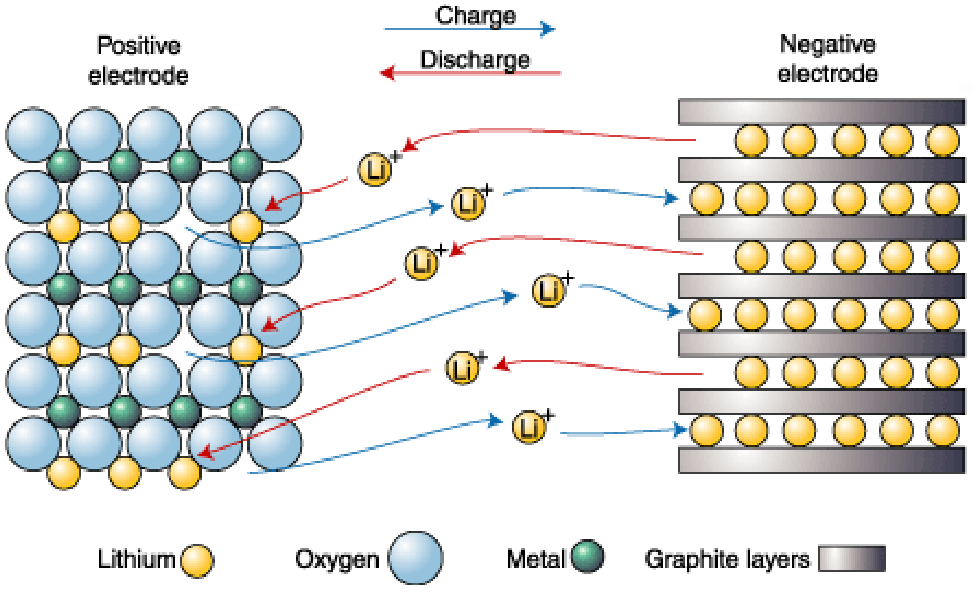

## Program 2:

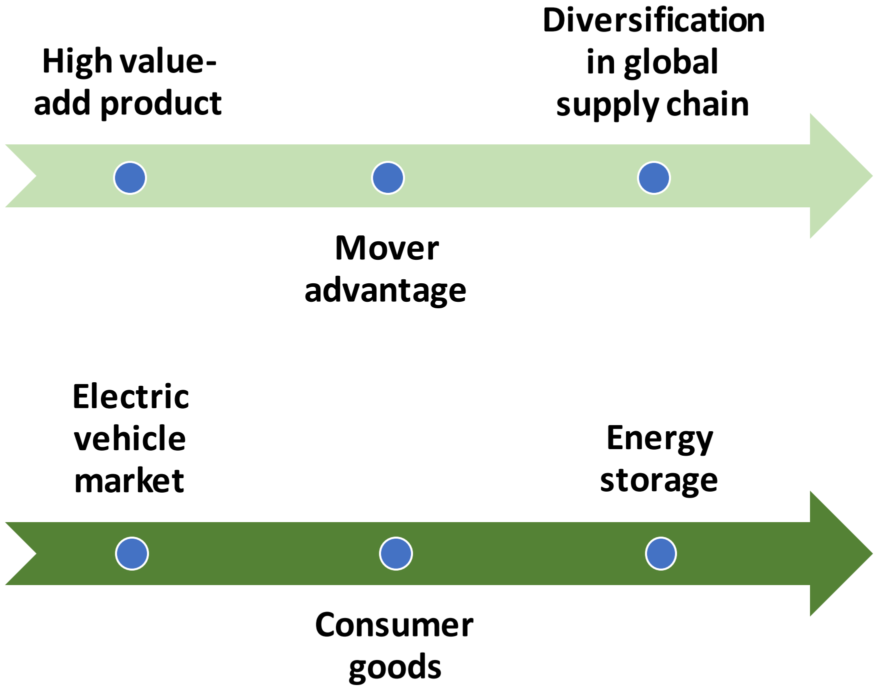
## Processing Resources to Precursors

6. Environmental and waste management strategies
7. Cost-competitive resources processing of battery minerals to chemicals (Li, Ni, Co, Mn, Graphite, V, Al, HPA, REE)
8. Premium quality battery grade chemicals
9. Battery recycling, repurposing and reuse
10. Develop battery component precursor production

# Goal

- Directly support the build-up of expertise and capability to **produce value added anode materials and anodes in Australia**, with a focus on natural graphite as a key precursor material
- **Develop high capacity, high energy anode** production. Silicon/graphite anodes (>1000 mAh/g (theoretical 4200 mAh/g))
- **The challenge:** that any efforts made to make the cathode−electrolyte interface should be compatible with the graphite anode and cathode



## Research providers

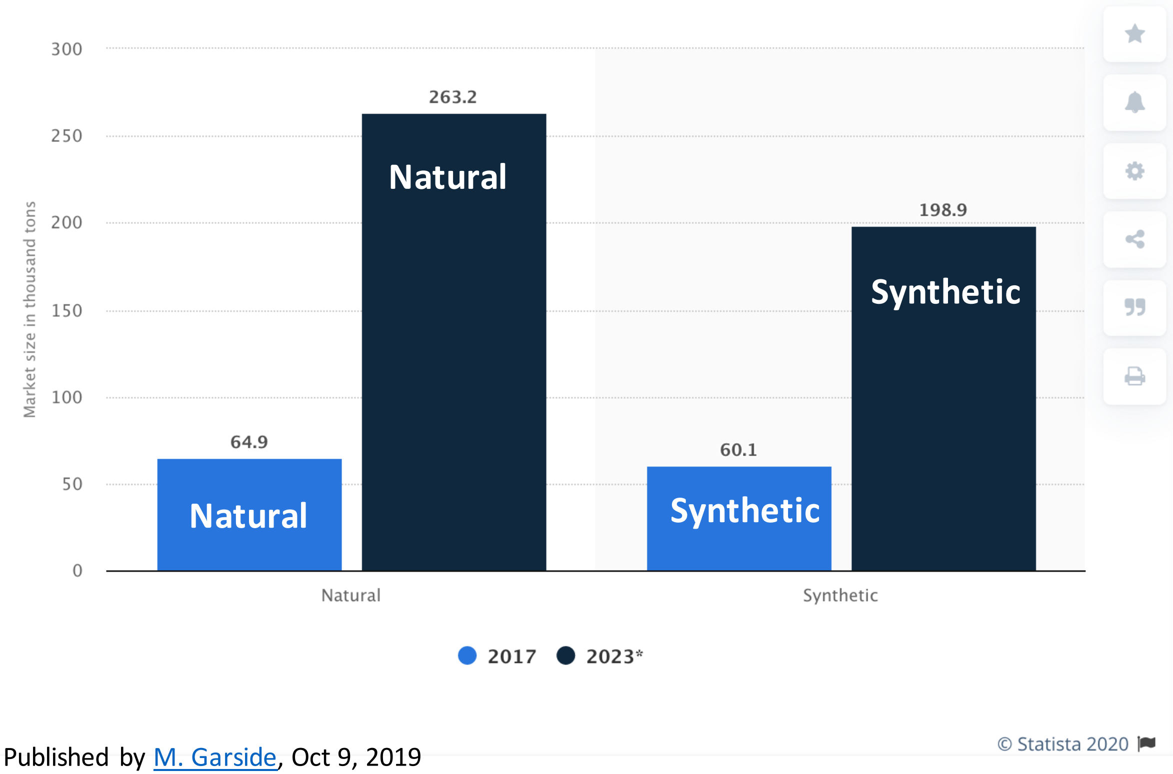
## Current industry partners

## Collaborators

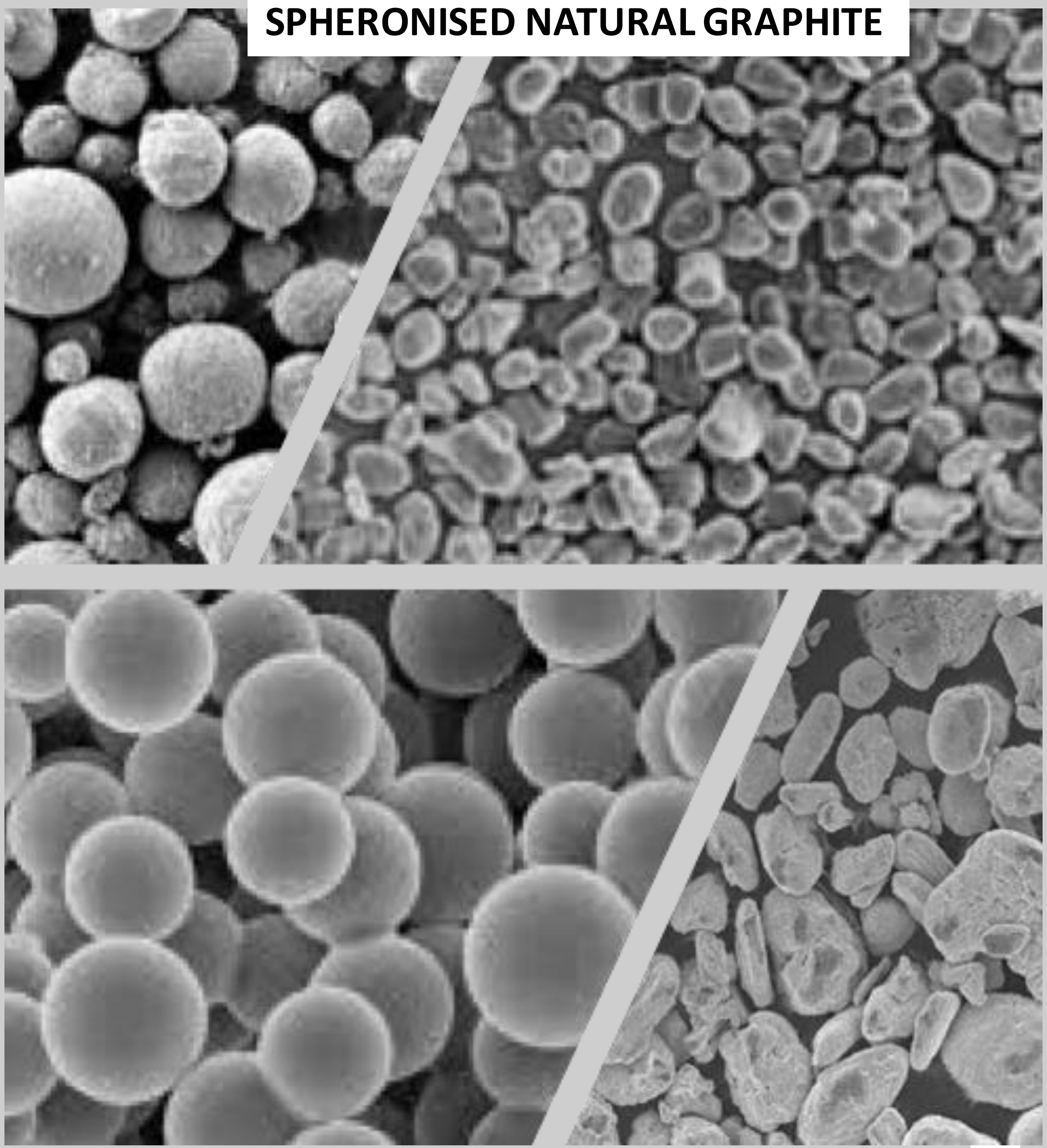
# Graphite to remain the anode material of choice

- New era of growth needs increase capacity
- Lithium ion demand for anode materials increase to 1.9 million tonnes by 2028
- Annualised growth rates of 26.5% (natural) and 20.5% (synthetic) graphite
- Mining in China, new supply coming from Mozambique and Tanzania
- Current low-price environment for flake graphite make project economics challenging. Global pipeline of development companies ready to support future supply challenges

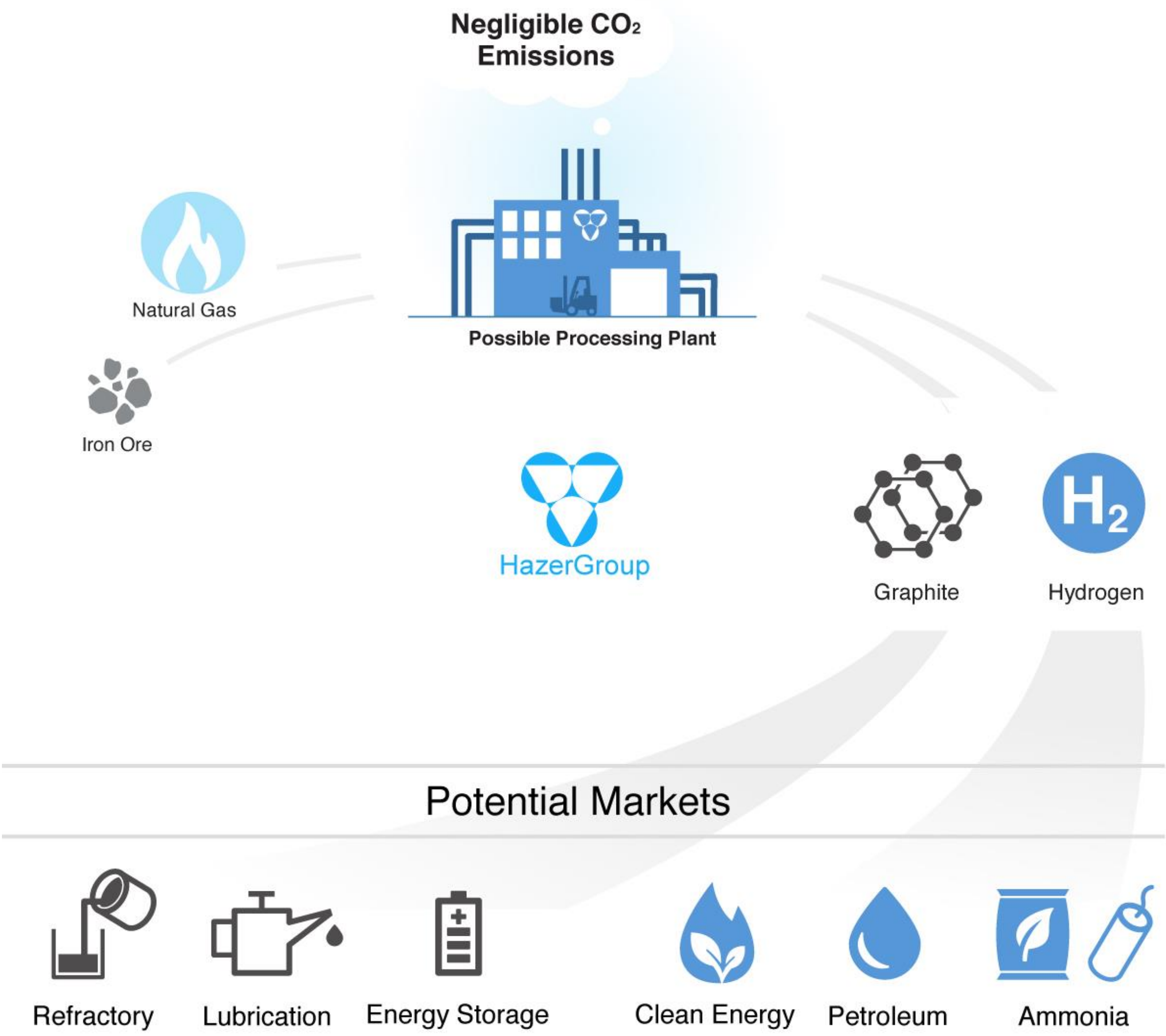
# Market volume of spherical graphite worldwide



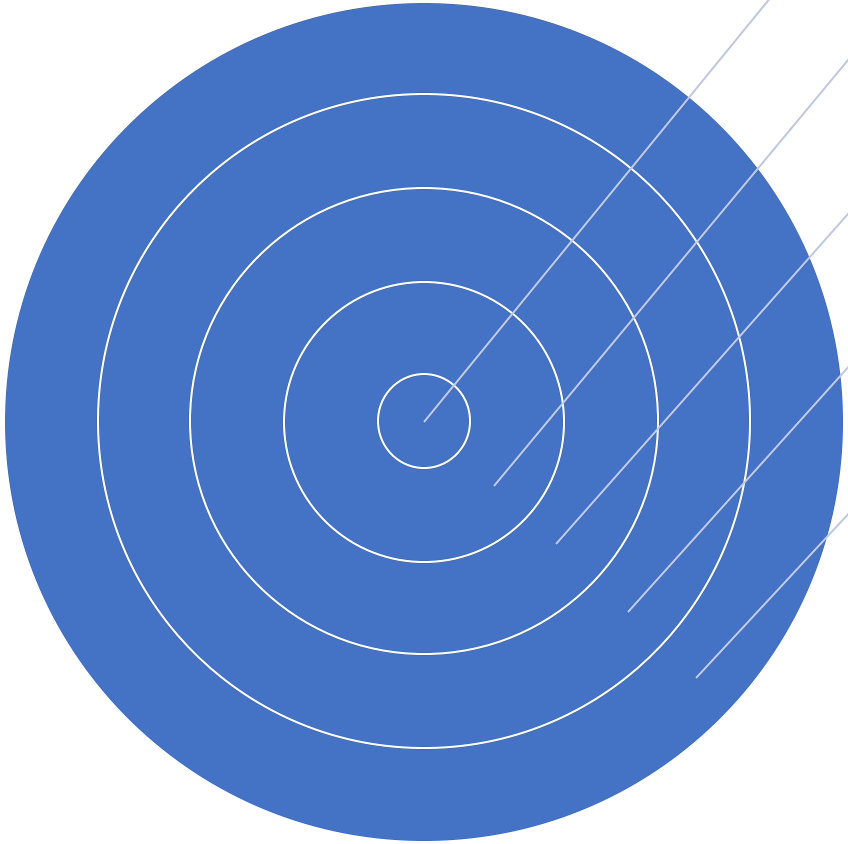

Published by M. Garside, Oct 9, 2019



## Synthetic graphite



# Project Outline



**Graphite Purification**

- Minimisation of toxic solvent (e.g., HF)

**Spheronisation**

- Crystallinity
- Shape and particle size distribution
- Modelling packing densities
- Surface area

**Silicon Composites**

- Capacity (performance)
- Modeling

**Coatings**

**Hybrid Natural and Synthetic Graphite**

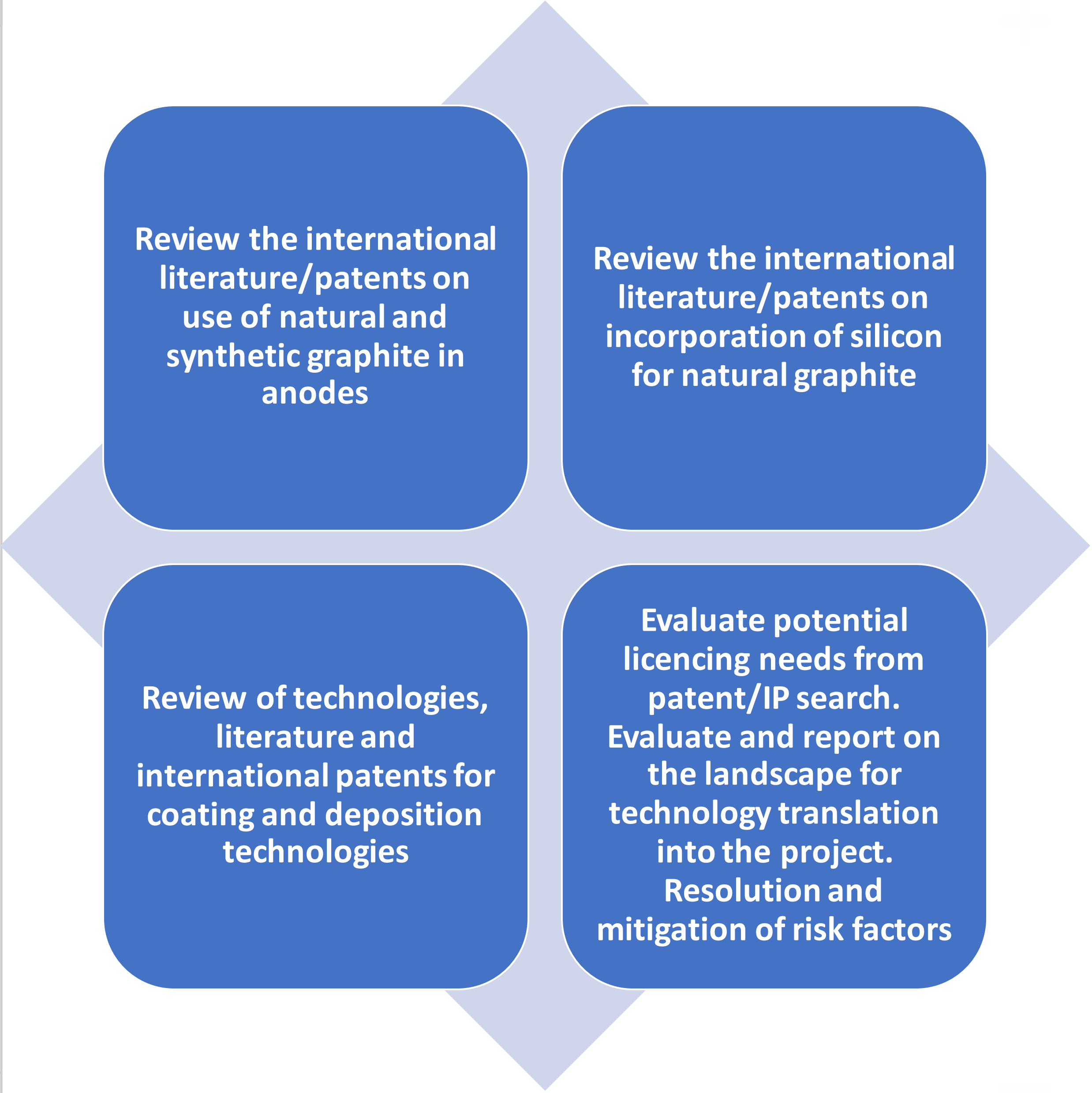
Optimisation and anode testing – matching electrolyte/cathode materials

Program 3

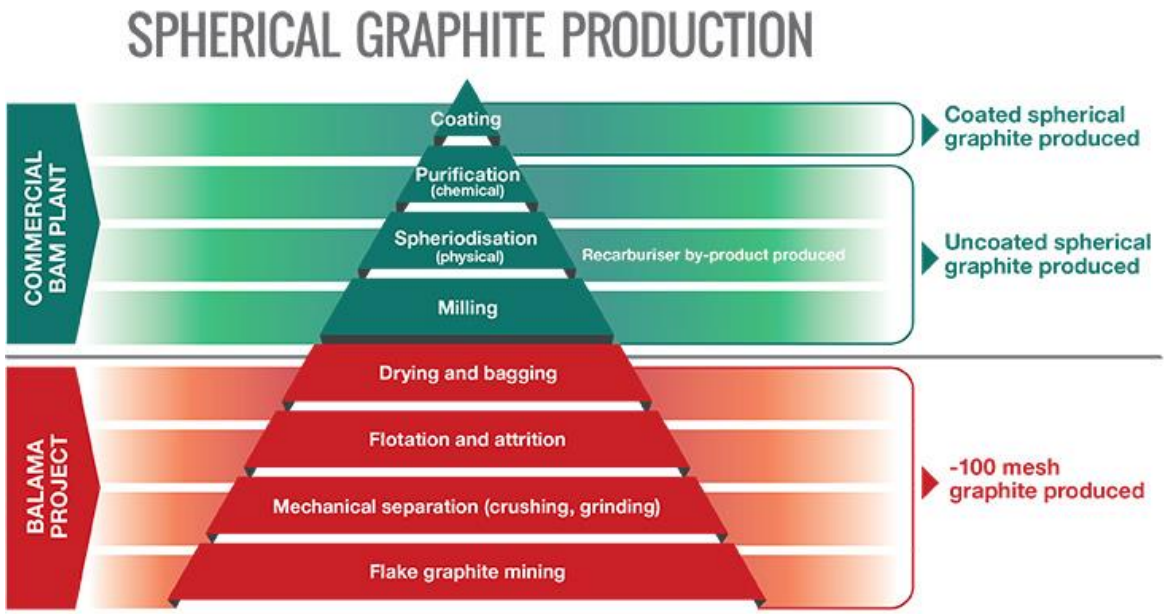
11. Cell manufacturing and testing
12. Battery energy storage systems development and testing

# Stage 1 (6 months)

- Set up and establish the team and employee the required expertise. Demonstrate value generation, and quantify risks and scope within Australia by:



# Battery Anode Material (BAM)




http://www.syrahresources.com.au/spherical-graphite-project

# Objectives

- Establish current best practice in natural graphite processing
- Benchmark Australian graphite as competitive against Chinese or African graphite
- Develop capability in the evaluation and processing of quality natural graphite and graphite-based anode materials and manufacture of graphite anodes
- Reduce the wastage of natural graphite in anode production by 30%, specifically targeting the spheronisation process
- Improve the performance of assembled anodes using silicon (macro and nanomaterials) and potentially other novel additives.
- Complete a full life cycle analysis for natural graphite-based anode systems.

# Stage 2 (1-4 years)

- Research, development, and translation to industry of processing technologies

## Natural graphite - BAM

Maximisation of high value product production during spheronisation of graphite

Evaluate novel green graphite purification strategies

Mesoscale modelling of particle packing and

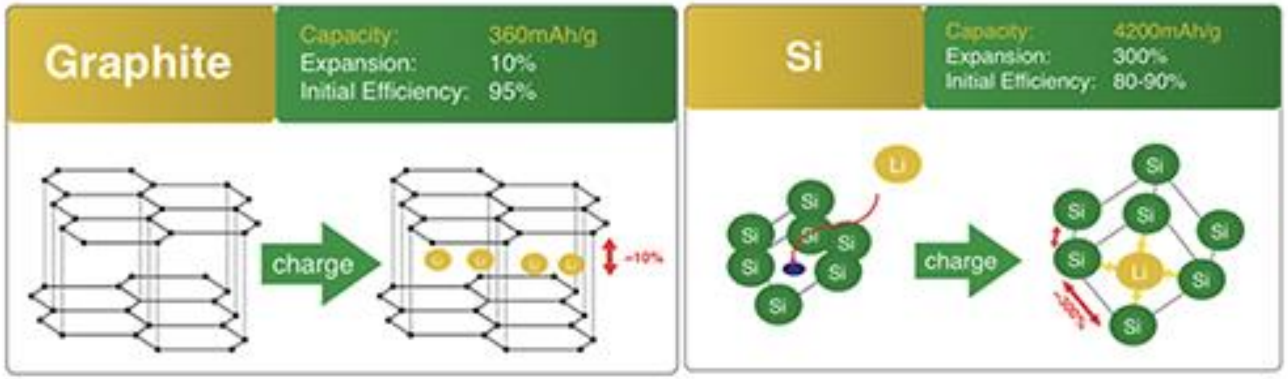
Testing of anode

Optimise coating and deposition technologies as defined by Stage 1

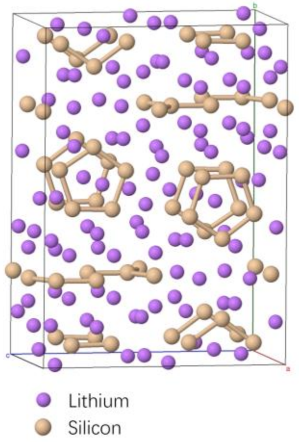
Prototyping of anode for pilot plant applications for the 8-1-1 and 6-2-2 projects

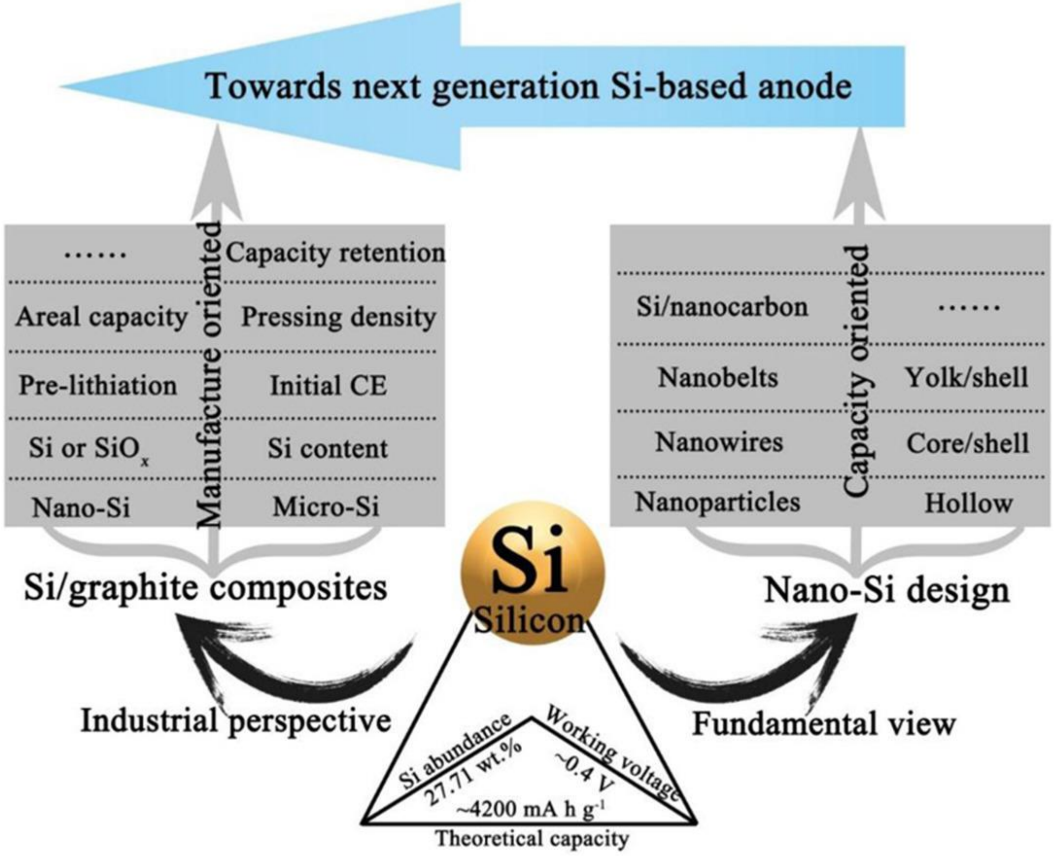
Ongoing knowledge transfer to the CRC and appropriate industry partners

# Silicon Battery Anode Material (SiBAM)




SiBAM most promising next-generation anodes due to its substantially higher capacity (~ 4200 mA h $g^{-1}$ for $Li_{4.4}Si$) than traditional graphite anode (~ 372 mA h $g^{-1}$). Coating graphite so volumetric expansion of silicon/Li complex is within tolerance



# Silicon and Natural graphite - SiBAM

Material and electrode benchmarking of commercial grade materials (Graphite, SiOx, mSi)

Develop and refine specification of silicon composite active material particle

Develop silicon composite/graphite anode with specific storage capacity up to 1000 mAh/g

Small-scale production of silicon composite material and demonstration trials and cost-model refinement

Prototyping of anode for pilot plant applications for the 8-1-1 and 6-2-2 projects

Ongoing knowledge transfer to the CRC and appropriate industry partners

## Graphite will maintain dominance for the foreseeable future and natural graphite will increase market share as cost pressure increases

| **Artificial Graphite**<br>Anode material<br>xEV, grid | **Natural Graphite**<br>Anode material<br>xEV, portable electronics | **Silicon Alloy Anodes**<br>Emerging but mixed with graphite presently |
|---|---|---|

more energy →

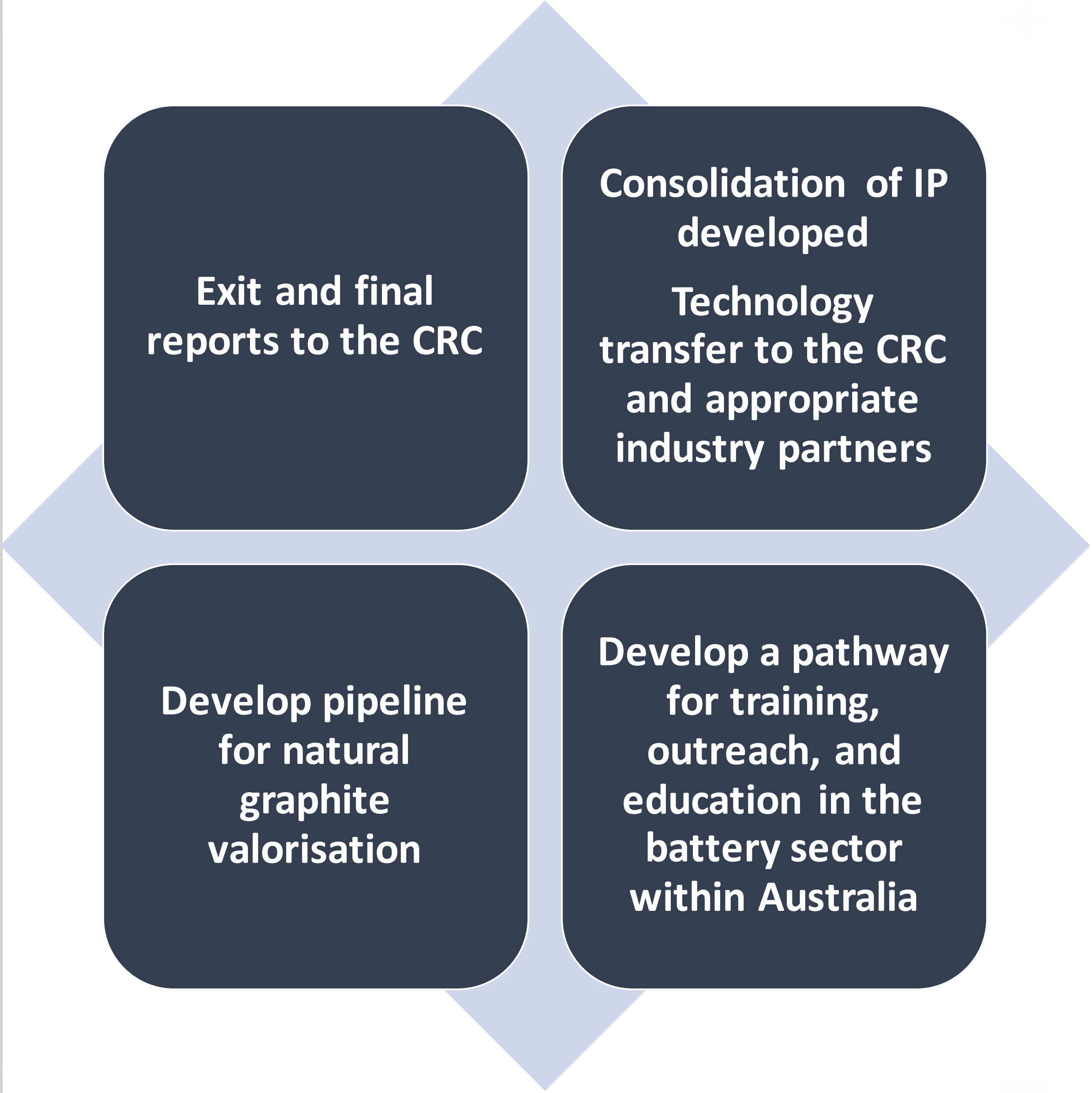
← better cycle life

| | | |
|---|---|---|
| **Key issues**<br>• High cost<br>• High graphitisation energy use | **Key issues**<br>• Low temperature performance<br>• Historical environmental impact | **Key issues**<br>• Cycle life<br>• Electrode expansion/cell dimensional stability<br>• Low first cycle efficiency |
| **Mitigating solutions**<br>Mix with natural graphite<br>Develop graphitization process | **Mitigating solutions**<br>Surface coating/modification<br>Particle morphology design | **Mitigating solutions**<br>Si-nano-particles composite<br>Mix with larger percentage of natural and/or artificial graphite<br>Limit discharge cut-off voltage |

Source: Cadenza Innovation

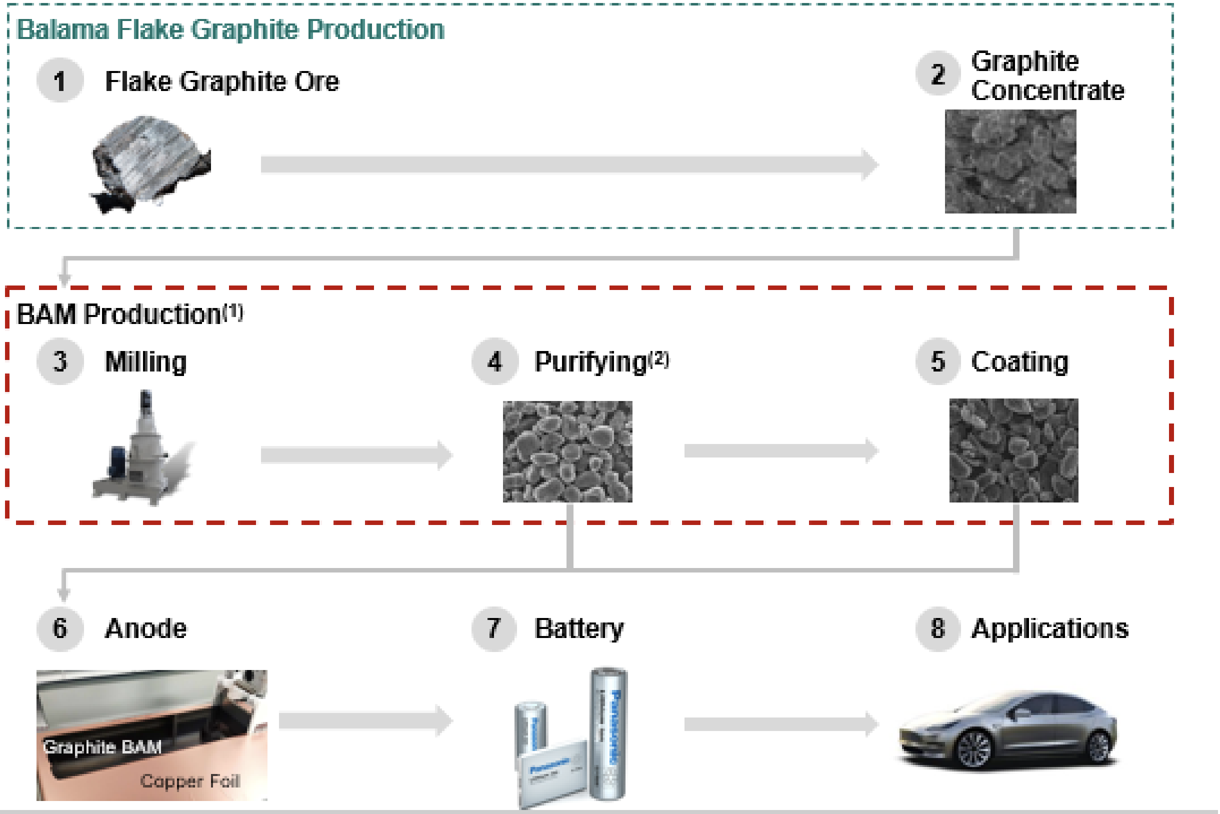
## Stage 3 (6 months)

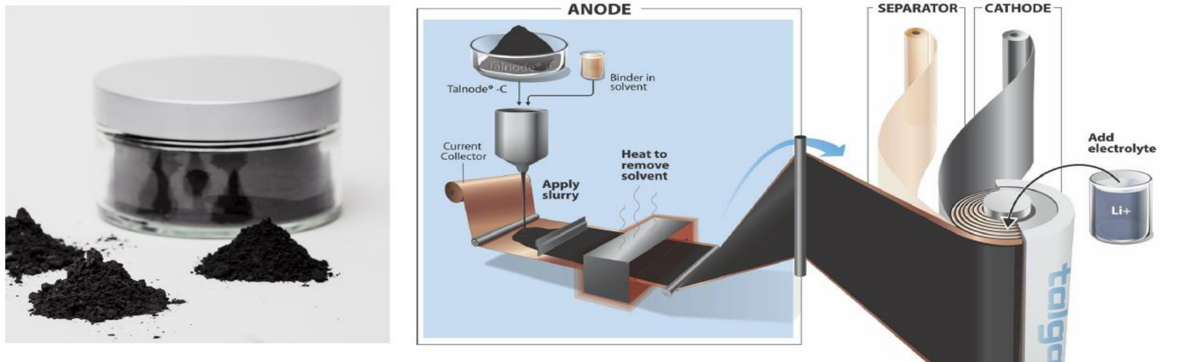
- Finalisation of technology and IP outputs and incorporation into pilot plant projects



# Commercial outcomes

- Connecting relevant research and industry players.
- Green and sustainable high purity graphite
- Establishing required testing protocols to compare the efficacy of different anode materials and production approaches.
- Optimising the sub processes of graphite purification, spheronisation and coatings, and overall system optimisation.
- Developing novel “composite” anode formulations, including the use of silicon and/or artificial graphite additives.
- Increasing the Australian expertise base in anode battery materials.




A fully coated anode powder ready for mixing and coating on current collector in Li-ion battery production line

Benchmark Minerals Intelligence World Tour / 24 June 2019, London, UK / © Talga Resources Ltd

FUTURE BATTERY INDUSTRIES CRC

Research providers

THE UNIVERSITY OF MELBOURNE

CSIRO

QUT

Current industry partners

SYRAH RESOURCES

EcoGraf

anteo technologies

talga

Collaborators

UTS

DEAKIN UNIVERSITY

WARWICK

# THANK YOU

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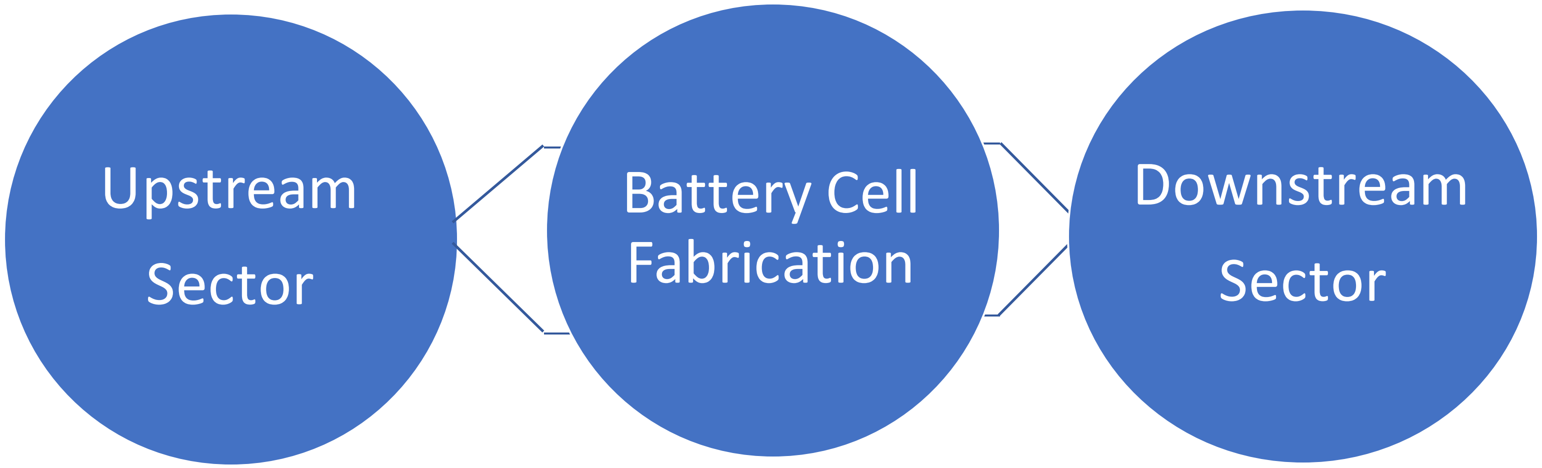
# Advanced Li Ion Cell Fabrication Facility


QUT

Prof. Jose Alarco on behalf of
Dr. Jawahar Nerkar
Queensland University of Technology

# Project Theme

FBI CRC's Vision: *Establishment of a sustainable and complete Li-ion battery (LIB) supply chain in Australia by supporting the upstream battery raw materials/component developers to downstream battery energy storage deployment.*



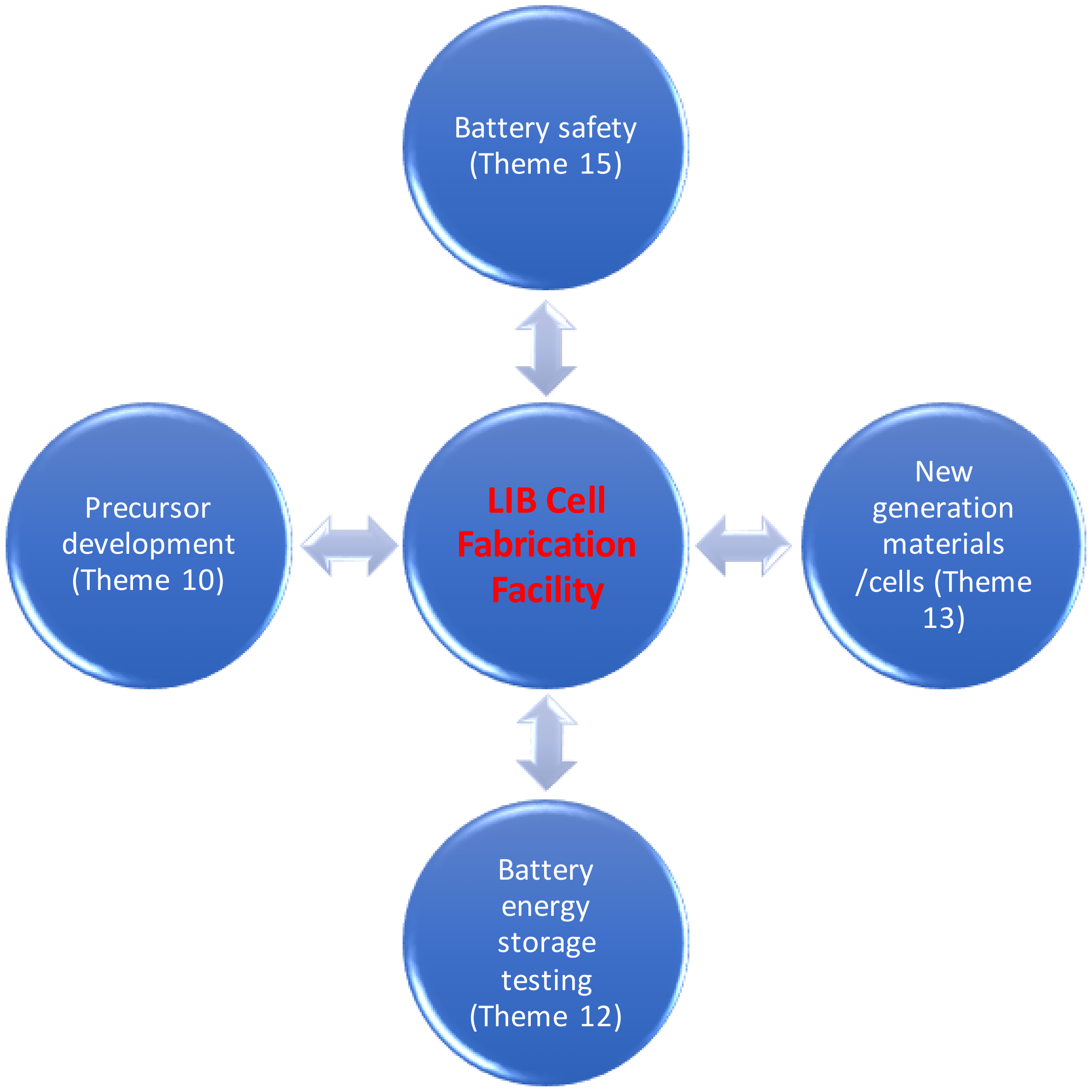

*Establish a state-of-the-art national LIB cell fabrication facility in Australia for the rapid prototyping of LIB cell formats from Australian produced energy materials (four-year project)*

## Project Description

- A generic pilot capability and capacity to fabricate commercially representative high performance, high quality Li ion cells of different sizes from a range of Li ion chemistries.

- This project will integrate the aspects of different FBI CRC themes.

- Full cell testing will provide iterative feedback to relevant projects in different themes for the final validation/ optimisation work.



## Project Objectives

- To develop a *state-of-the-art* national LIB cell fabrication facility.

- To integrate current and next generation battery raw materials and components produced from Australian developers in the final battery cell format.

- To develop and implement best practices compliant to international standards for the fabrication and finishing of battery cells incorporating different chemistries for real-world operation.

- To establish a capability to rapidly adapt to new developments, meeting the overall performance, quality, safety and economic efficiency criteria for commercial deployment in Australian conditions and worldwide commercial markets.

- To assist in developing skilled workforce to support the establishment and growth of future LIB manufacturing industry in Australia.

# Project Approach/Strategy

**Planning /Feasibility**
- Literature review of Li ion cell manufacturing best practices

**Sub-project 1**
- Upgrade and extension of QUT pilot scale facility

**Sub-project 2**
- Validation and benchmarking of the (upgraded) cell fabrication facility to establish standard protocols using commercially available materials

**Sub-project 3**
- Cell fabrication integrating Australian battery components

**Sub-project 4**
- Investigate adaptation and modification of cell fabrication incorporating new materials for deployment in Australian conditions

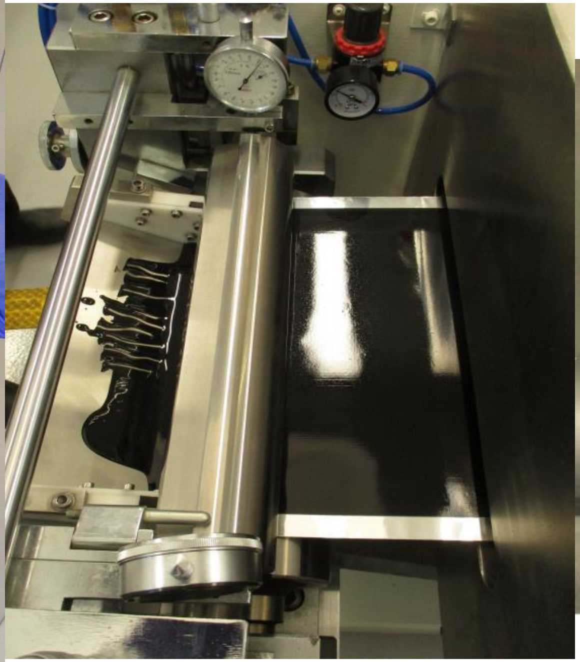
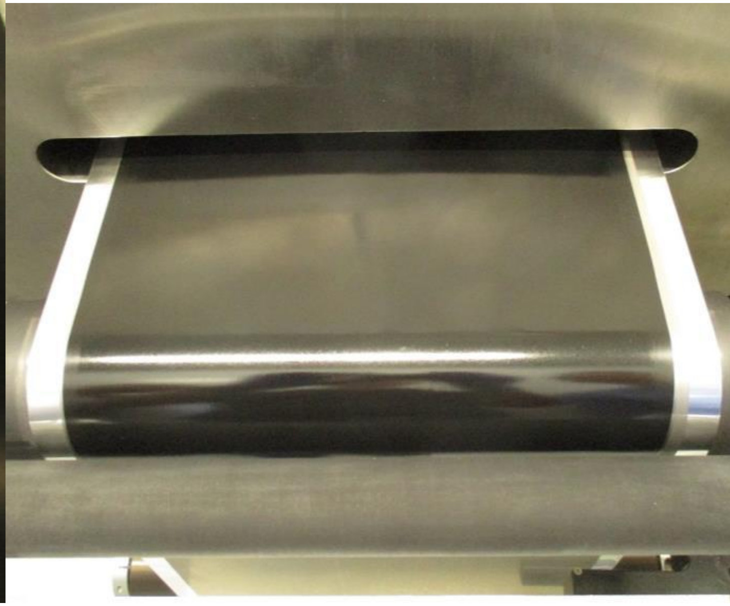
# Sub-project 1: Upgrade and extension of QUT pilot scale facili

- QUT's battery cell fabrication facility with dedicated dry-rooms (Demonstration)

- Pilot-scale electrode fabrication and cell assembly/cell finishing equipment (Commercially representative)

# Sub-project 1: Upgrade and extension of QUT pilot scale facility

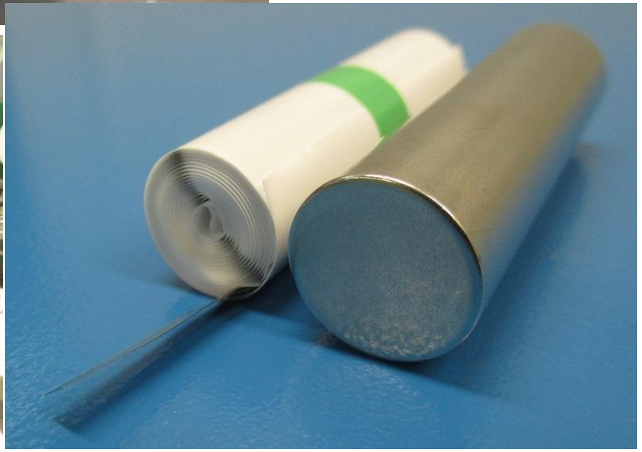


- Verification of operational specifications of the electrode fabrication and cell assembly equipment

# Sub-project 1: Upgrade and extension of QUT pilot scale facility

**Cell fabrication and assembly**



# Sub-project 2: Validation and benchmarking of the cell fabrication facility to establish standard protocols

- Identify optimum electrode configuration for a range of commercially available key Li ion cathode and anode chemistries
  - ➢ active materials with different particle morphology, different coating thicknesses, electrode slurry viscosity, calendaring steps etc. → final electrode loading and density/porosity characteristics.

- Develop best practices for cell conditioning and cell formation protocols for a range of Li ion chemistries incorporated in different cell formats. → eg cell longevity.

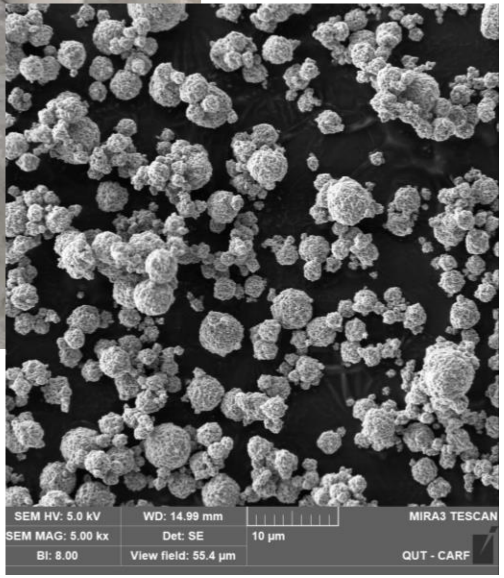
- Develop prototype cells and conduct preliminary electrochemical cell testing to evaluate key performance criteria (voltage, specific capacity, rate capability, energy and power densities, cycle life etc.) to establish standard protocols.

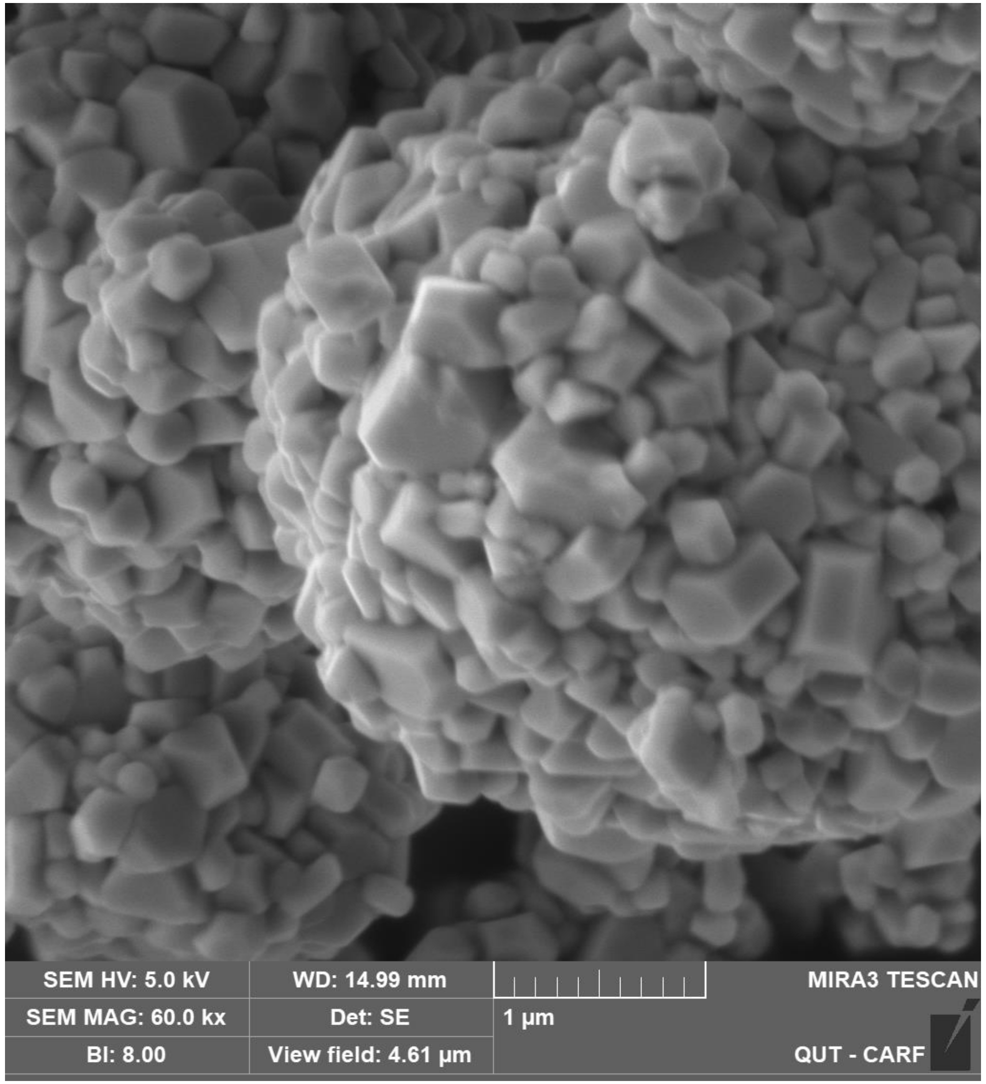
# Sub-project 3: Cell fabrication integrating Australian battery components

- Systematic evaluation and validation of high energy/high power precursor/active components in the final cell format
  - Cathode precursors with different compositions and impurities in optimising the desired particle morphology and the electrochemical performance
  - Systematic evaluation of anode materials, such as spheroidal coated graphite with different material specifications e.g. particle size etc.
  - Evaluate the safety aspects of Alumina ($Al_2O_3$) coated separator membranes on the longevity of the cell

- This sub-project will compliment the work of precursor pilot plant by rapidly validating the precursors into cells for testing.

# Demonstrated Prototype of Precursor Validation

# Sub-project 4: Investigate adaptation and modification of cell fabrication incorporating new materials for Australian conditions

- Integrate and evaluate the outcomes (new materials/formulations) of other FBI CRC flagships to be tested in full LIB cell against high energy/high power cathode compositions developed at the precursor pilot facility
  - Thermally stable advanced electrolytes
  - Speciality high energy anodes
  - Alumina coated separator

- Suitable for high current, high voltage, high temperature use in Australian deployment conditions.

# Project Outcomes

- Advanced pilot facility with the capability and capacity for rapid designing, developing and prototyping of representative state of the art, commercial style LIB cells.

- This facility will provide preferential access to key Australian battery component developers (cathodes, anodes, electrolyte, separator membrane etc.), especially for validation of precursor materials made in Australia.

- Best practices will be established for electrode fabrication, cell assembly and cell finishing, incorporating safety, for a range of formats and chemistries.

# Acknowledgement

Research Institutes:

- QUT
- Curtin University
- University of Melbourne
- Deakin University

Industry Participants:

- BHP Ni West
- IGO
- EcoGraf Limited
- Pilbara Metals Group
- Lava Blue

# Thank You!

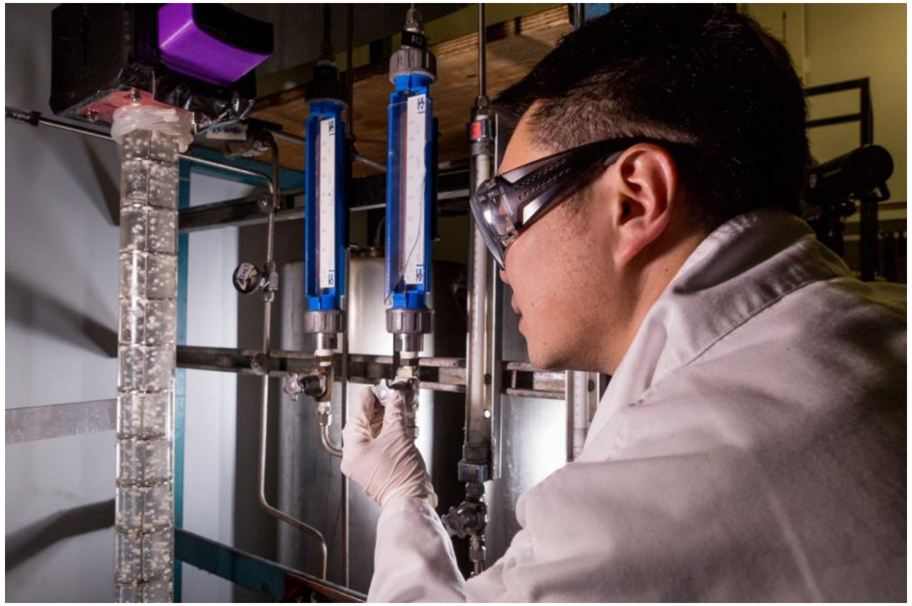

QUT

Dr. Jawahar Nerkar

Email: jawahar.nerkar@qut.edu.au

# Vocational workforce skills for the future battery industries in Western Australia

11 March 2020



# WA Future Battery Industry skills project

- Driver: Western Australian Government *Future Battery Industry Strategy.*

- Aim: Assess and develop strategies to address current and future skills gaps in the FBI in Western Australia.

- Scope:
  - WA vocational sector
  - VET skills focus
  - current activities in WA FBI with some medium term requirements in refining
  - July – February 2020

# Project methodology

- What are the key vocational job roles with skills that are unique to battery minerals and BESS? Any other VET workforce issues anticipated?
- Qualitative interviews due to industry size and technical information required.
- 17 employers interviewed across FBI value chain. Included: mining and refining of Li, LiOH, Ni, $NiSO_4$, Vn, Mn, HPA, graphite and rare earths; bulk chemicals manufacturing, battery design and assembly, electricity network operators (training arms) and one retailer.
- 25 peak industry groups, local government and training providers also interviewed.
- Employer information analysed for commonalities then mapped against national Training Package curriculum to identify gaps. Data on training rates reviewed.

# Key findings

1. Mine and concentrate

    - Battery minerals mining skill requirements are similar to other hard rock mining operations.
    - General resource sector workforce supply issues also apply.
    - Contextualised training can benefit new operations.

# Key findings

2. Refine and process

- Gaps in national Training Packages for Process Operators and Technicians, to achieve battery grade product quality.
  - implement specialised processes to ensure very high purity
  - awareness of contamination risks
  - maintaining a clean environment
  - cultural mindset of precision, attention to detail

- Gaps for working with automation, Industry 4.0 technologies and working as part of a value chain – explore application of existing resource sector training.

**Total course enrolments in process operations qualifications in Western Australia between 2015 – 2019[1].**

| | Certificate II Process Plant Operations | Certificate III Process Plant Operations | Certificate IV Process Plant Technology |
|---|---|---|---|
| 2015 | 278 | 273 | 121 |
| 2016 | 381 | 350 | 150 |
| 2017 | 258 | 256 | 108 |
| 2018 | 315 | 339 | 49 |
| 2019* | 211 | 208 | 8 |

- As employers described requiring between approximately 10 – 30 Process Operators and/or Technicians per operation, close monitoring required as battery chemical plants become established to determine extent of workforce demand.

[1] Customised data request provided by the Western Australian Department of Training and Workforce Development.
*to September only

**Key findings**

3. Refine and process

   - Gaps in national Training Packages for Laboratory Technicians to:
     - achieve battery grade product quality (specialist sampling and testing of high purity products);

     - use specific testing methodologies relevant to battery chemical refining and processing; and
     - have knowledge of crystallisation customised for battery minerals.

Employers described requiring relatively small numbers (10 or less) Laboratory Technicians in refineries.

# Key findings

4. Battery pack and system assembly

   1 employer interviewed.

   No additional or unique skill requirements for Electricians and Technicians for this industry currently.

   Future expansion may require skills in working with automation.

   Skill needs to be monitored and revisited as the industry grows.

# Key findings

5. Battery system installation


- Current national Training Package skills sets are meeting skill requirements for Electricians to install and maintain.
- Existing training partnerships for SPS training.
- Network operators are defining skill requirements for operating and maintaining grid-connected battery systems in distributed energy trials.
- Uptake of battery energy storage systems will directly impact requirement for accredited installers and hence requires close monitoring.

# Next steps

- Findings and suggested actions to address for Government consideration as part of *WA Future Battery Industry Strategy*.

- National skills project comprising:

- national training needs analysis; and

- training development as required.

Nhi Do

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# State of Play

Dr Chris Vernon, CSIRO

CSIRO

FUTURE BATTERY INDUSTRIES CRC

11 March 2020

FUTURE BATTERY INDUSTRIES CRC

# State of Play

Purpose: Measure the baseline of activity in the industry as at the start of the CRC.

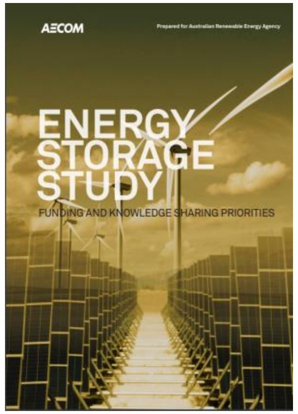
Repeat at 3y and 6y to demonstrate progress.

Not a forecasting or research planning tool.

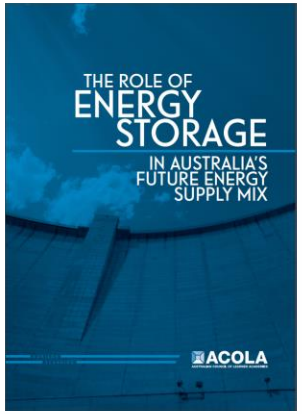
(It may occasionally look that way,
but that's for others to do.)

**FUTURE BATTERY INDUSTRIES CRC**

# Others have considered the potential

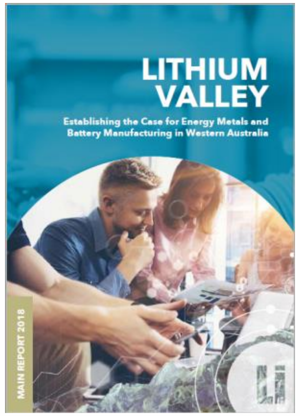



AREA/AECOM 2015

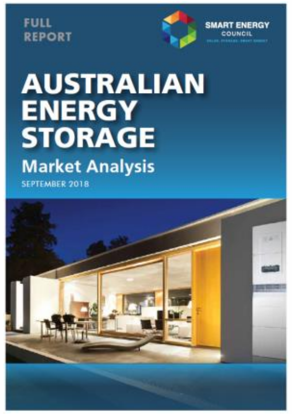



ACOLA 2017

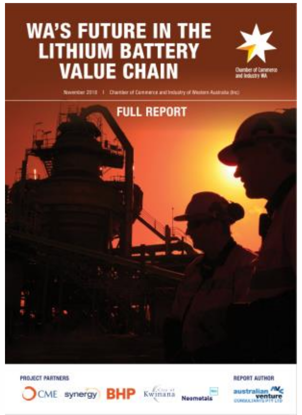

AMEC 2018



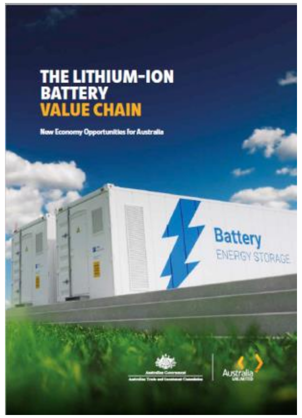

Regional Development Australia 2018



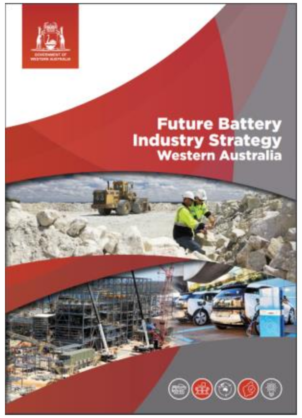

Smart Energy Council 2018




CCIWA 2018




Austrade 2018




WA Govt. 2019

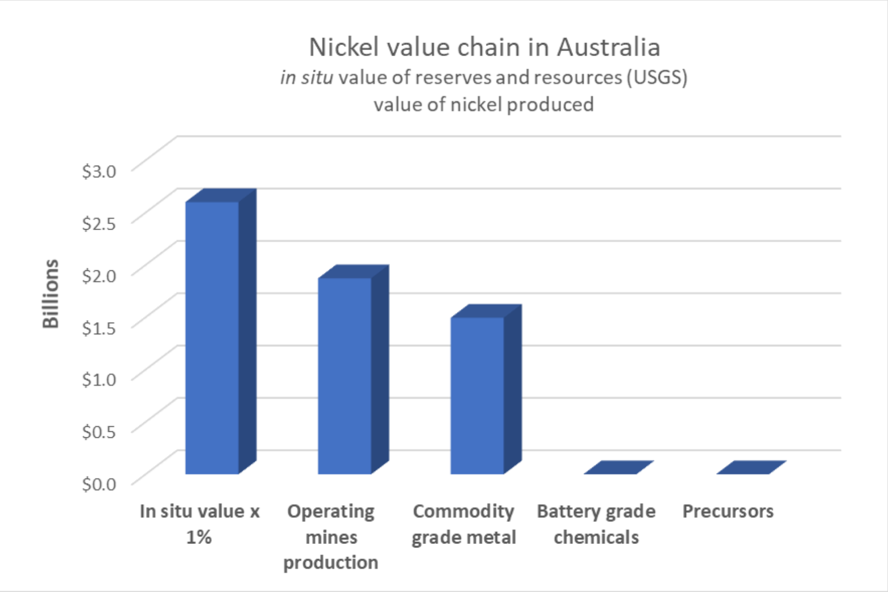
FUTURE BATTERY INDUSTRIES CRC

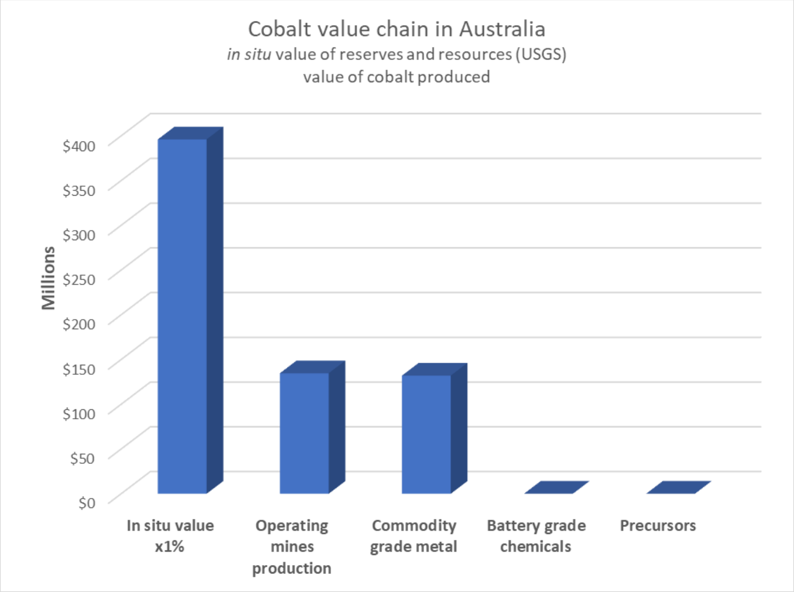
Australia has the resources but does not yet take advantage of them.

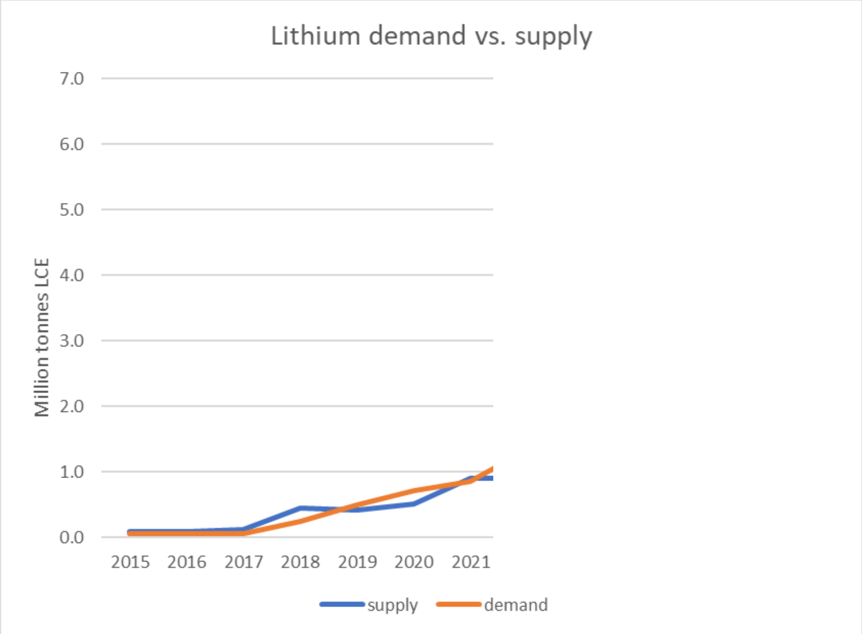
Beyond basic refining it's still dig and ship.

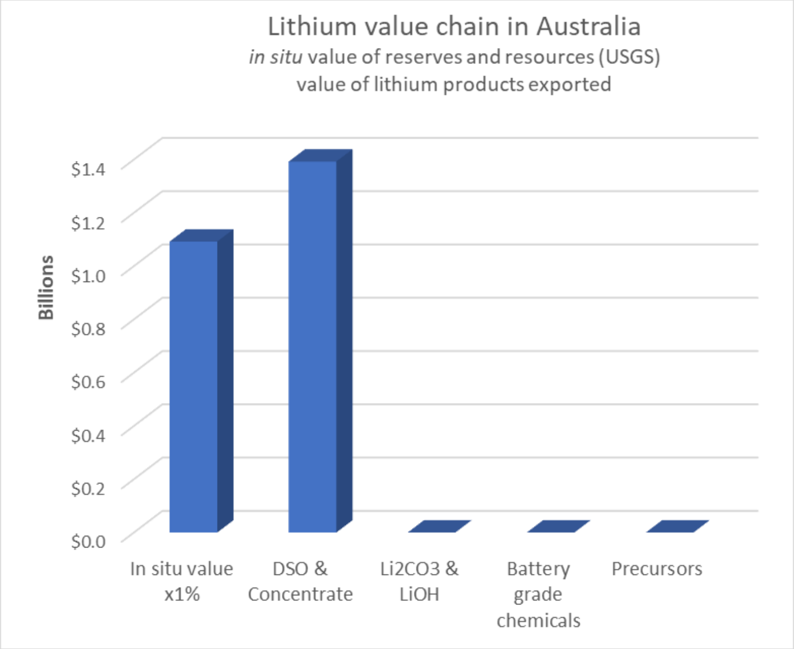
Ni and Co are at least refined to metal.

Untapped opportunities:
- HPA
- Graphite
- Vanadium
- Manganese



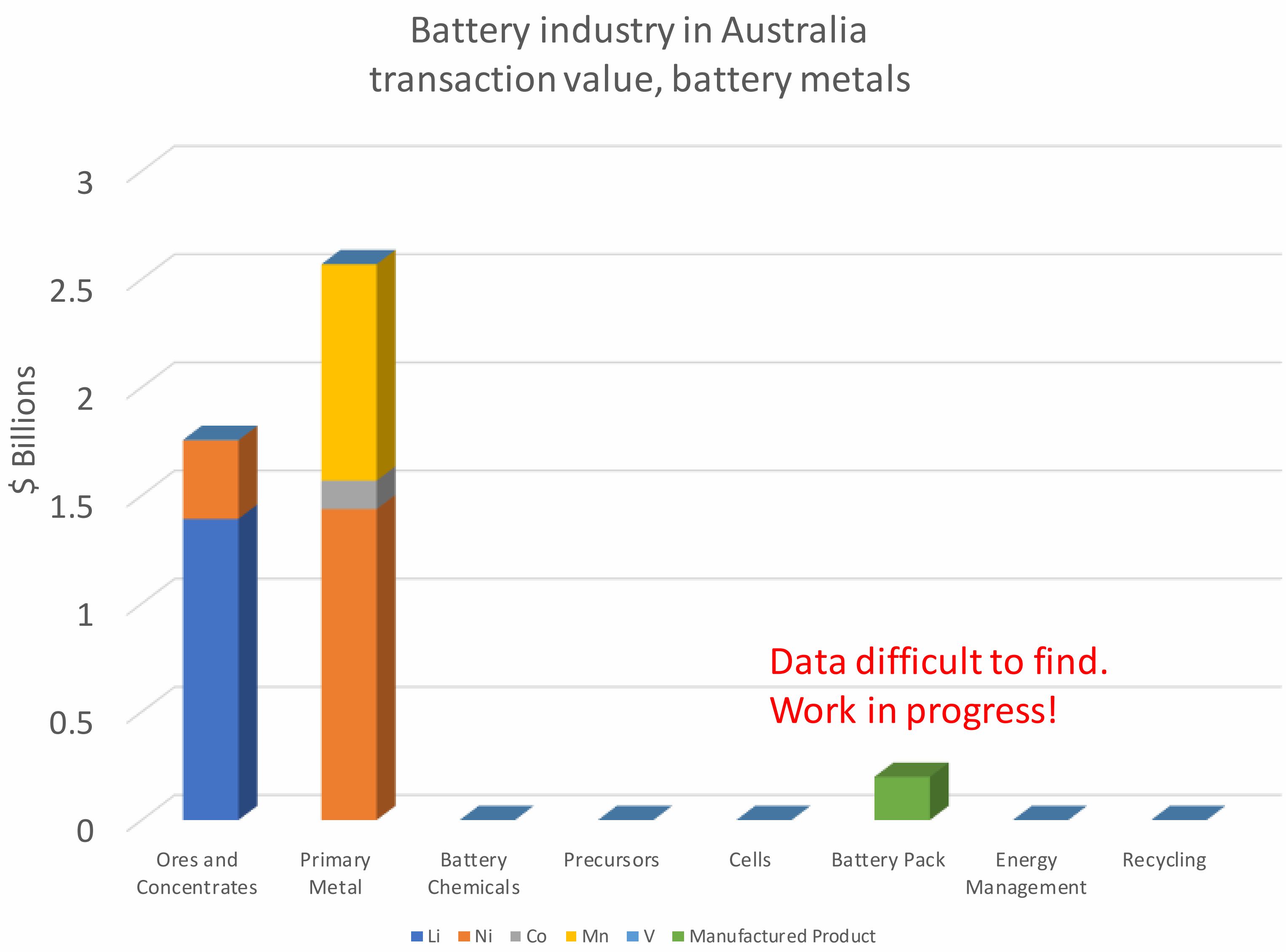
FUTURE BATTERY INDUSTRIES CRC

Ores/concentrates dominated by spodumene concentrates.

Primary metal dominated by manganese and nickel.

A little cobalt too.

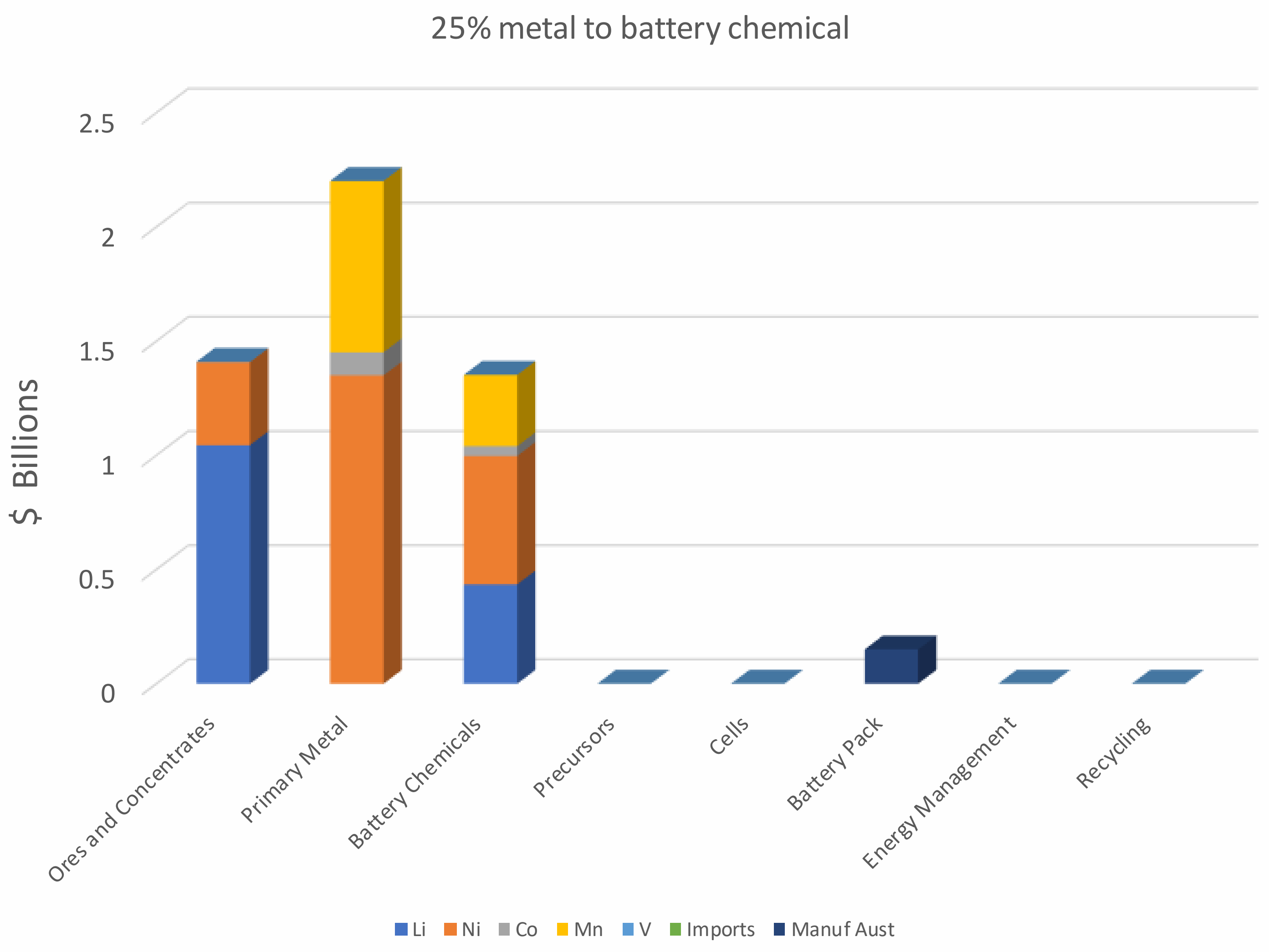
A $4.4b export industry



FUTURE BATTERY INDUSTRIES CRC

Converting just 25% of our *current* output to battery grade chemicals would add ~$0.65 billion nett to the economy.

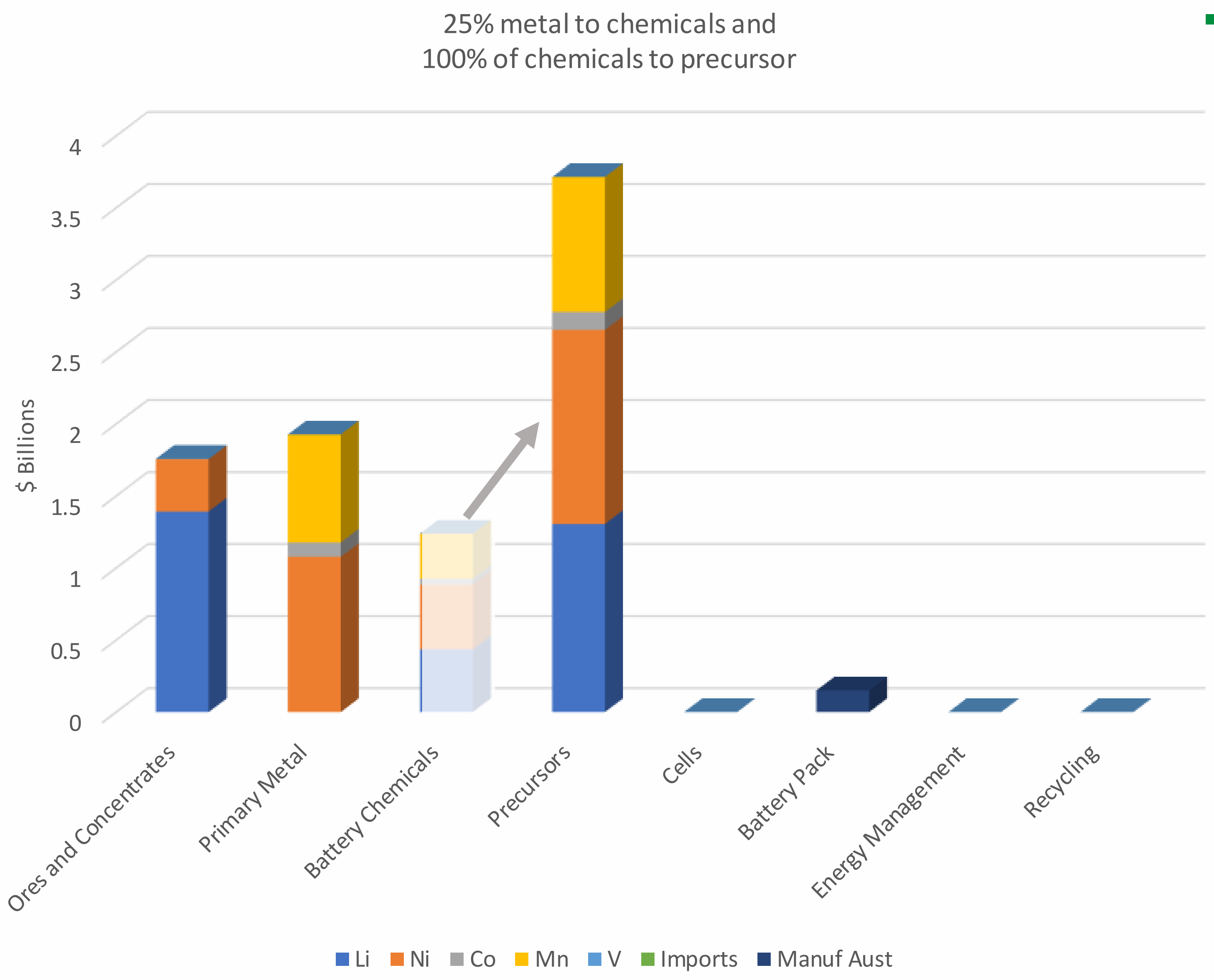
Total exports ⇨ ~$5b



FUTURE BATTERY INDUSTRIES CRC

Converting that 25% at battery grade all to cathode precursor would add ~$3.1b nett to the economy.

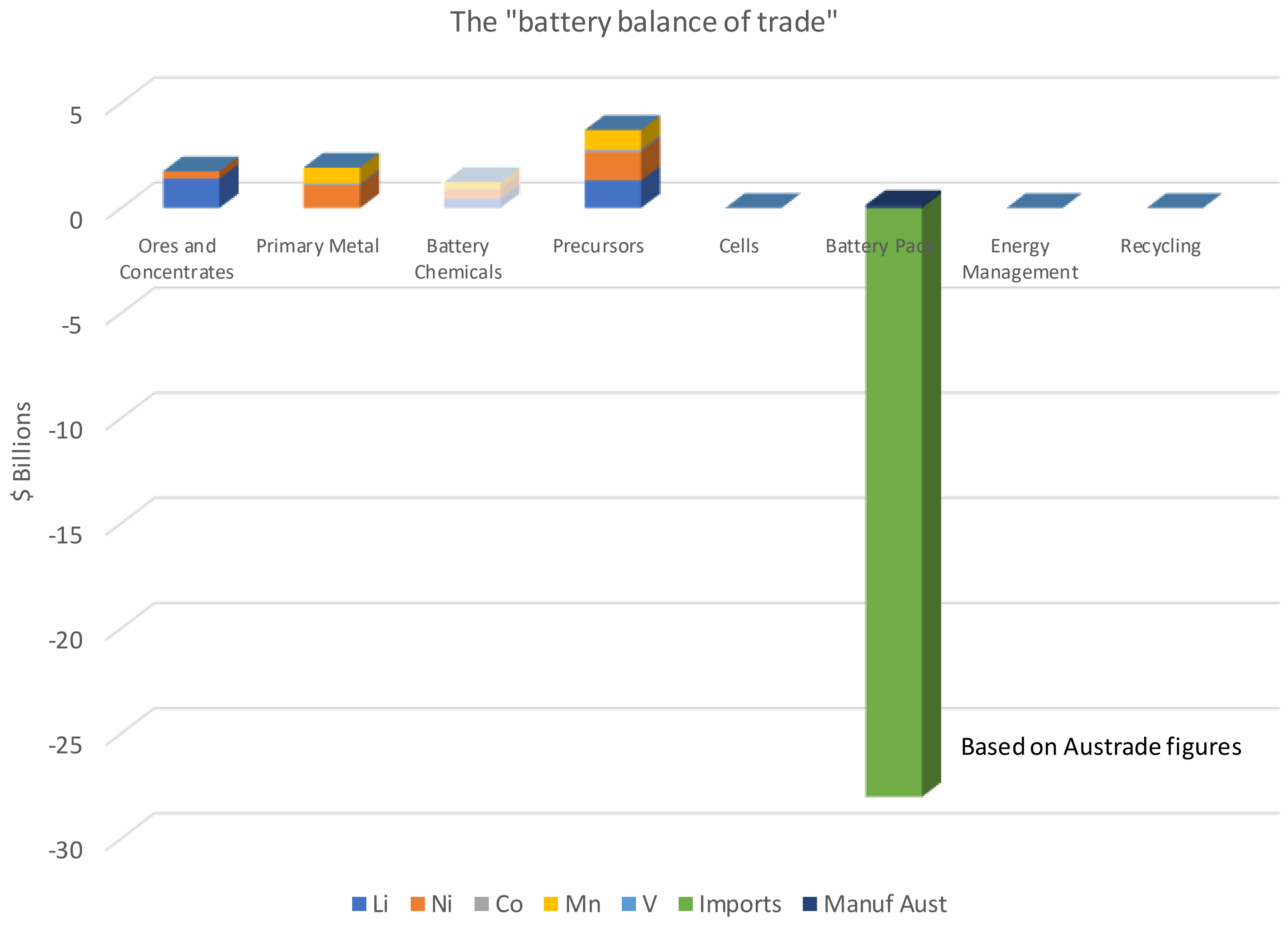
Total value ~$8.6b



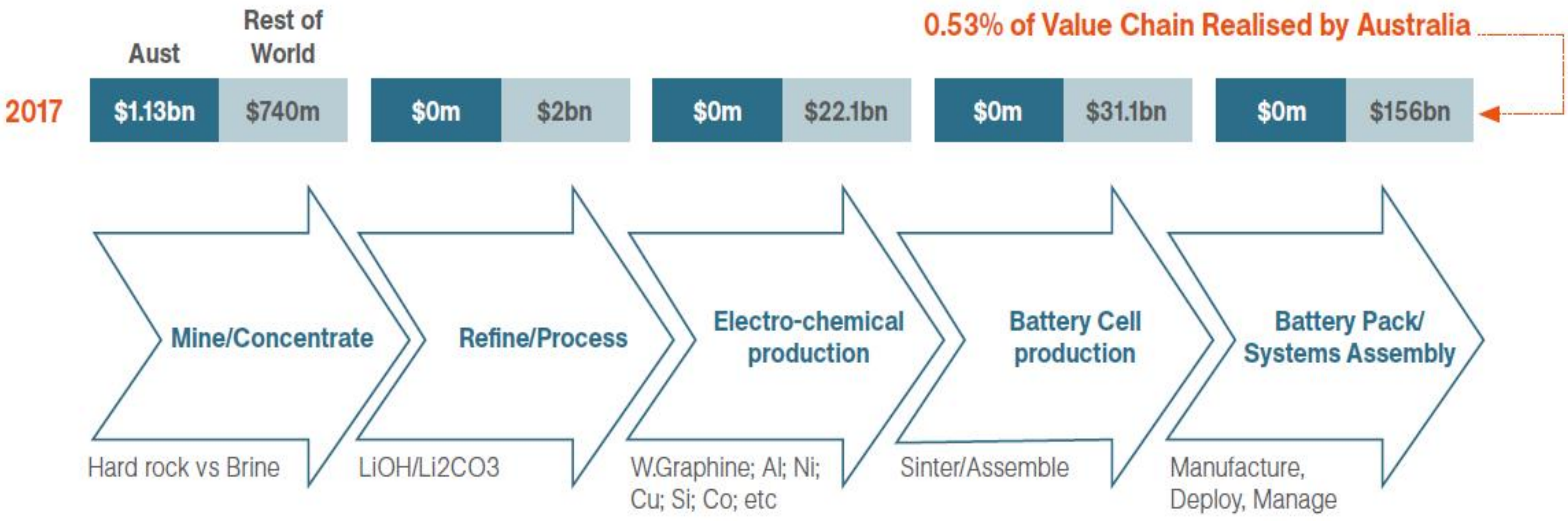
**FUTURE BATTERY INDUSTRIES** CRC

Even going to precursors, we still miss out on a lot.

We would have nearly $9b of exports
*vs.* $28b of battery imports



These are large multipliers

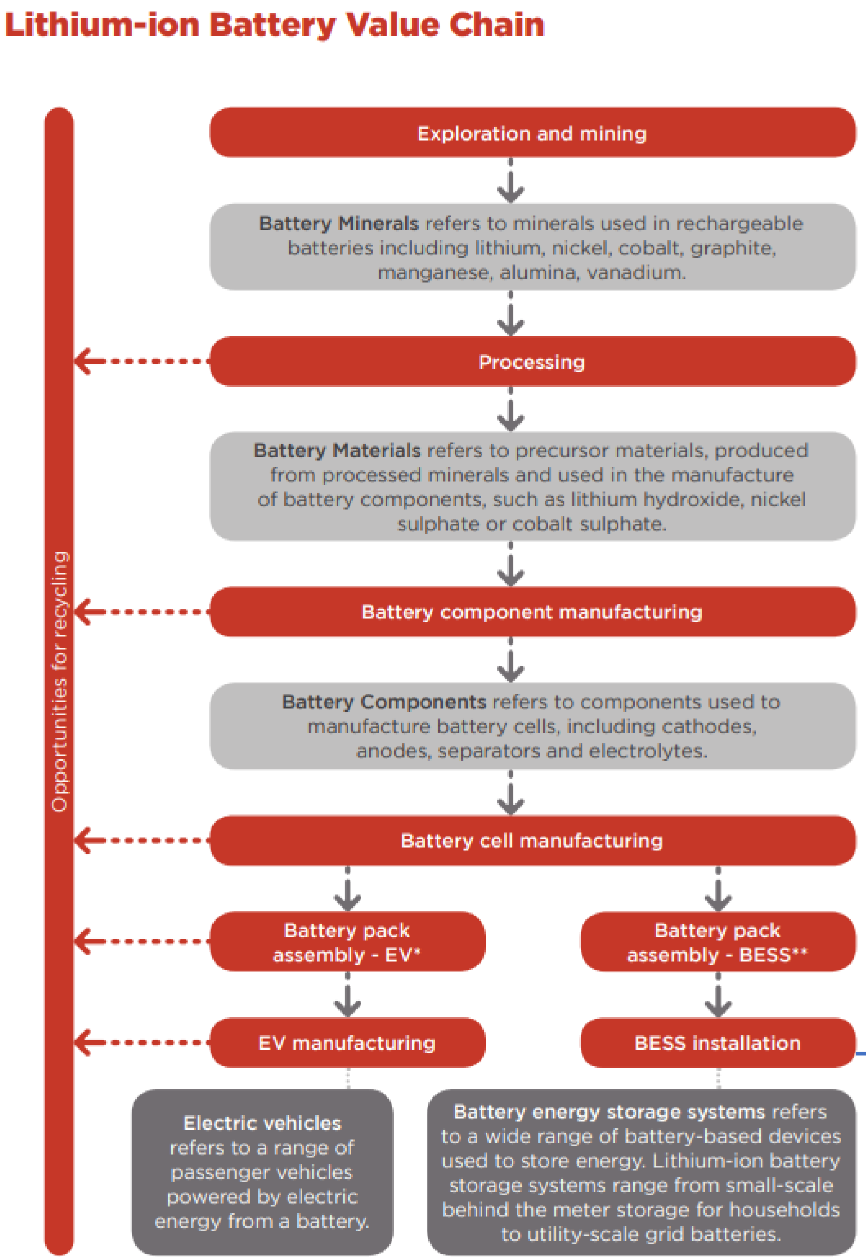


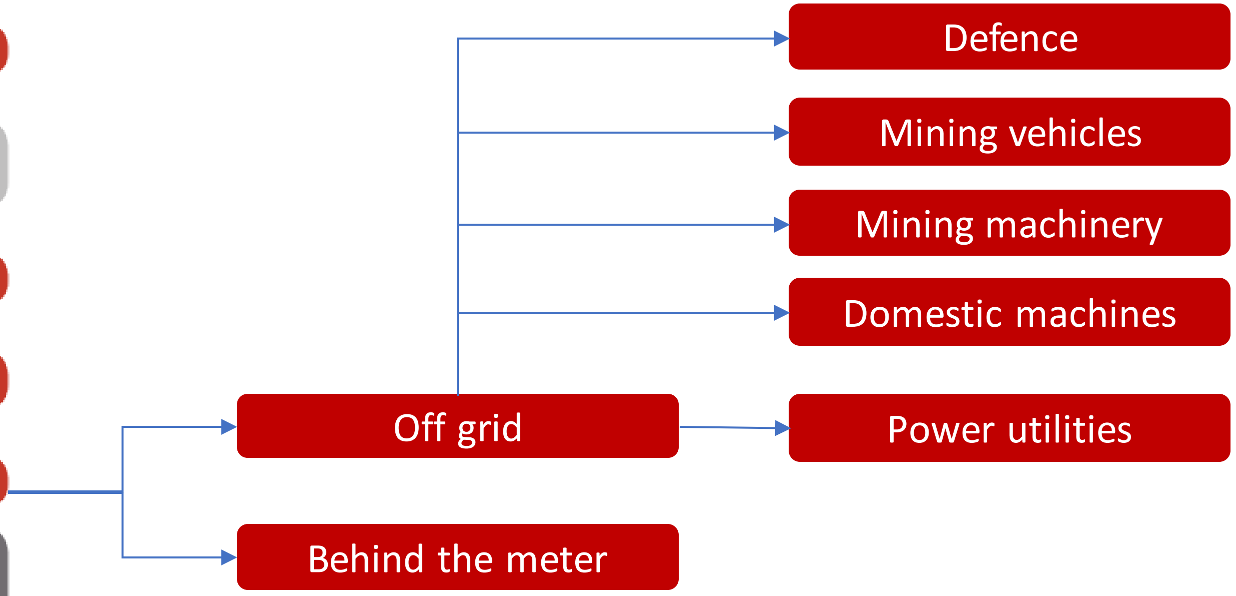

Source: Future Smart Strategies (2018)

## The value chain splits again after cell manufacturing.

Battery pack use is varied and there is value differentiation in this part of the chain.

e.g. mining and defence – performance & safety are paramount
power utilities – storage cost & reliability
domestic machines – safety & cost are the main consideration



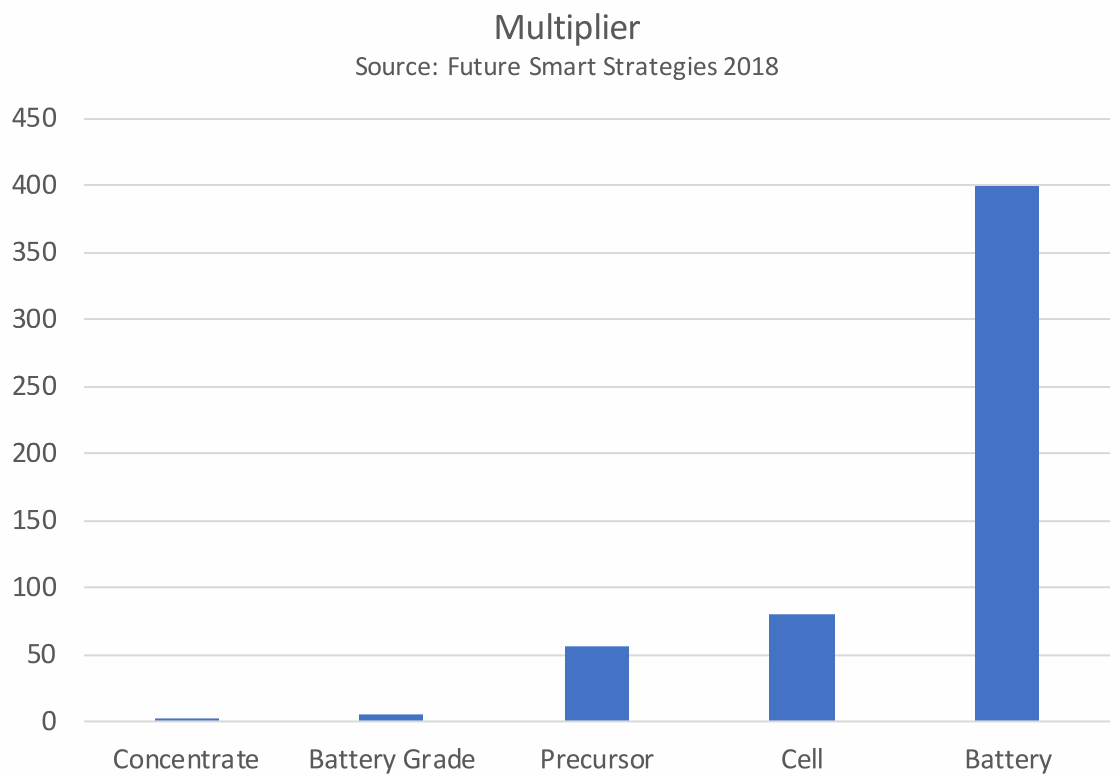
FUTURE BATTERY INDUSTRIES CRC

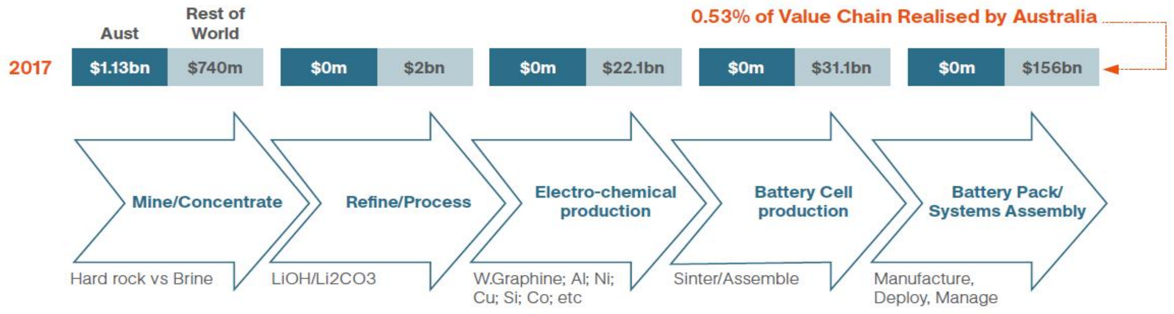
Not surprisingly, value is created at each step in the chain.

Chemicals to precursor is a 10-fold increase.

The major value arises in battery system production.

If we turned just 25% of our Li, Ni, Co, Mn exports into batteries, it would be worth >$400b



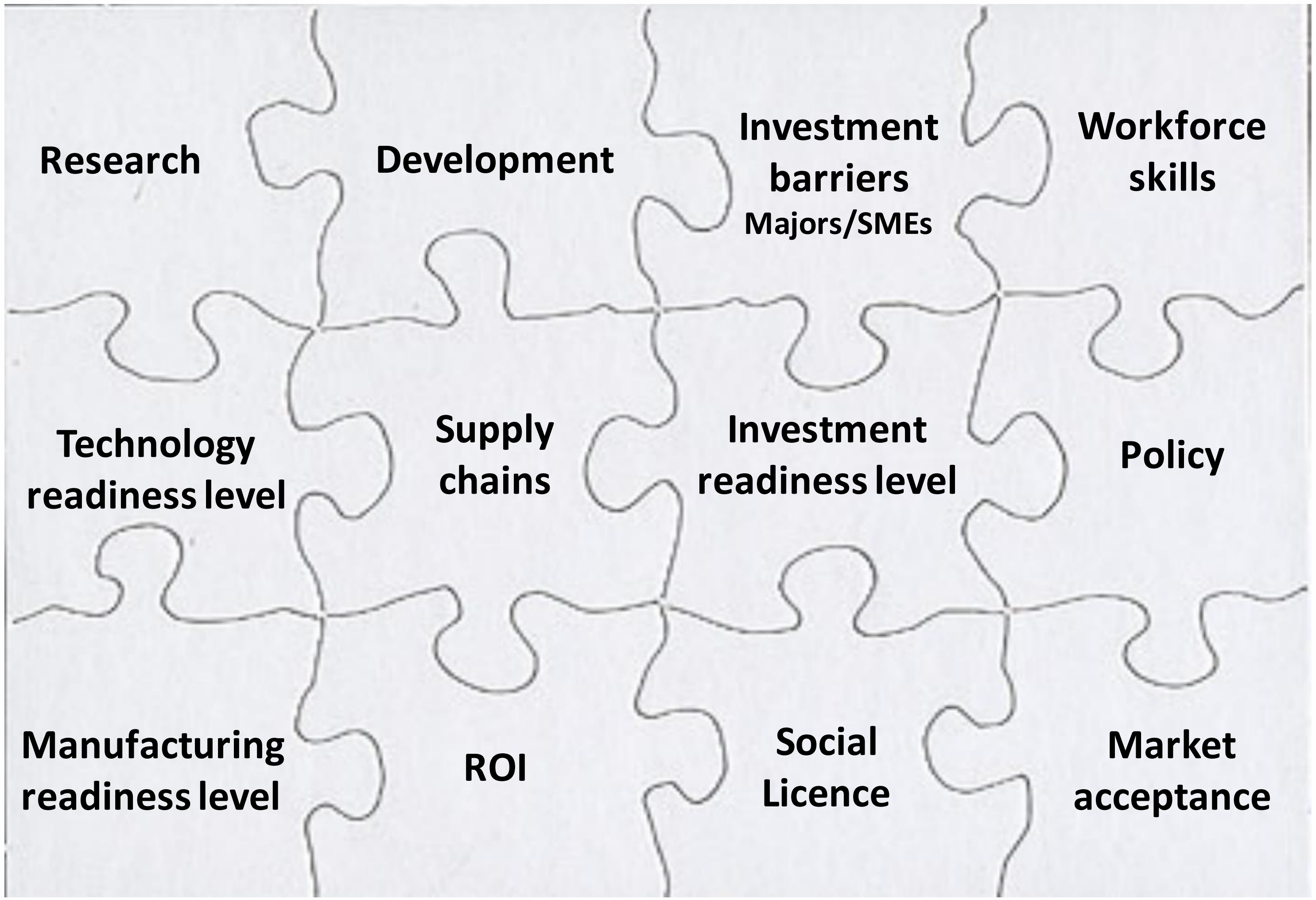

Source: Future Smart Strategies (2018)

We can identify the gaps but R&D is only a small part of the answer.

A major gap in investment for SMEs:

- Can SMEs afford to participate?
- Supply chains are not built yet.
- Manufacturing industries not ready.

Access to funding is critical.

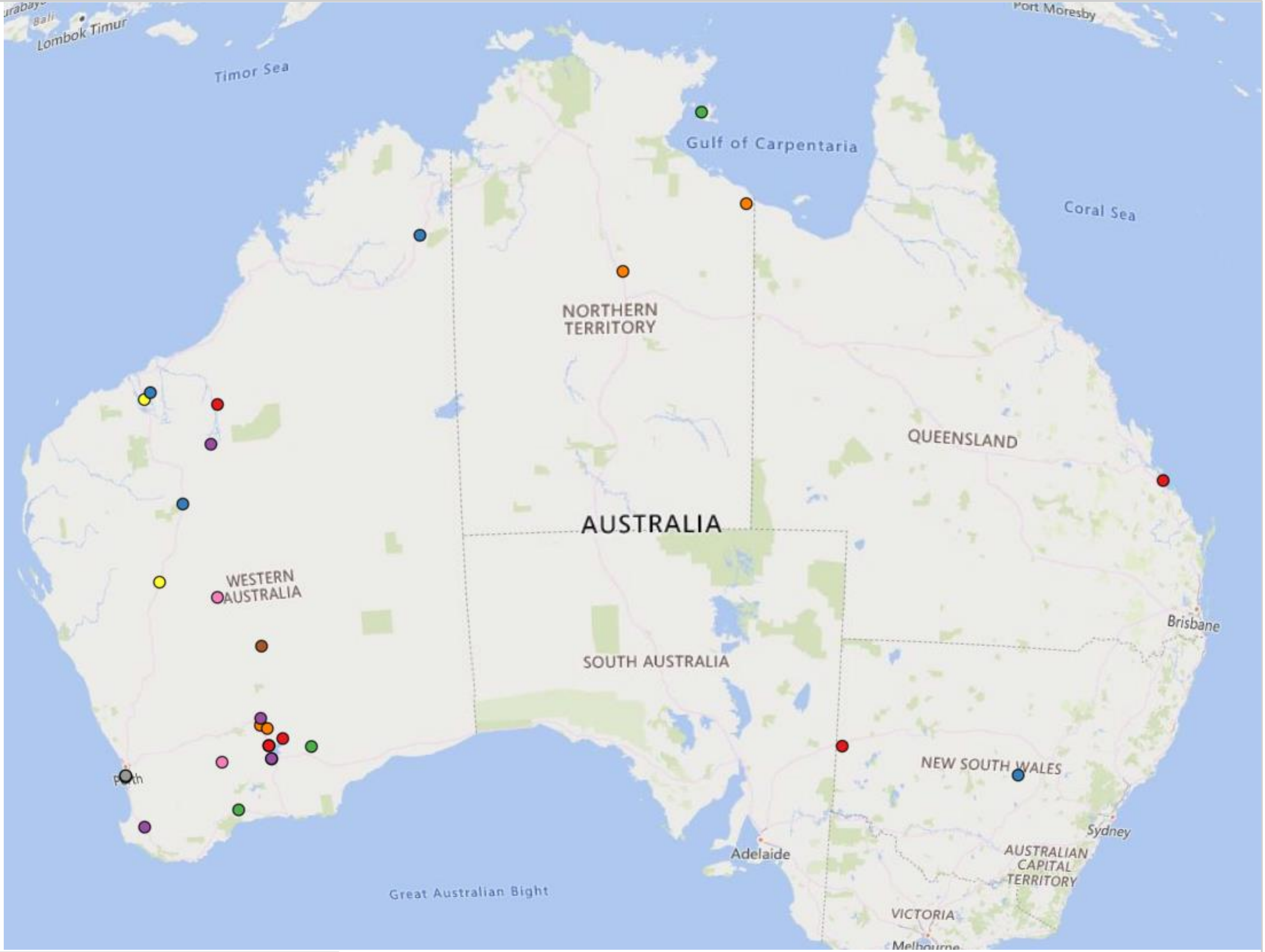


FUTURE BATTERY INDUSTRIES CRC

# Living map project

Creating an interactive geo-tagged database of Australian battery activity.

Updated over time to show evolution of the industry.



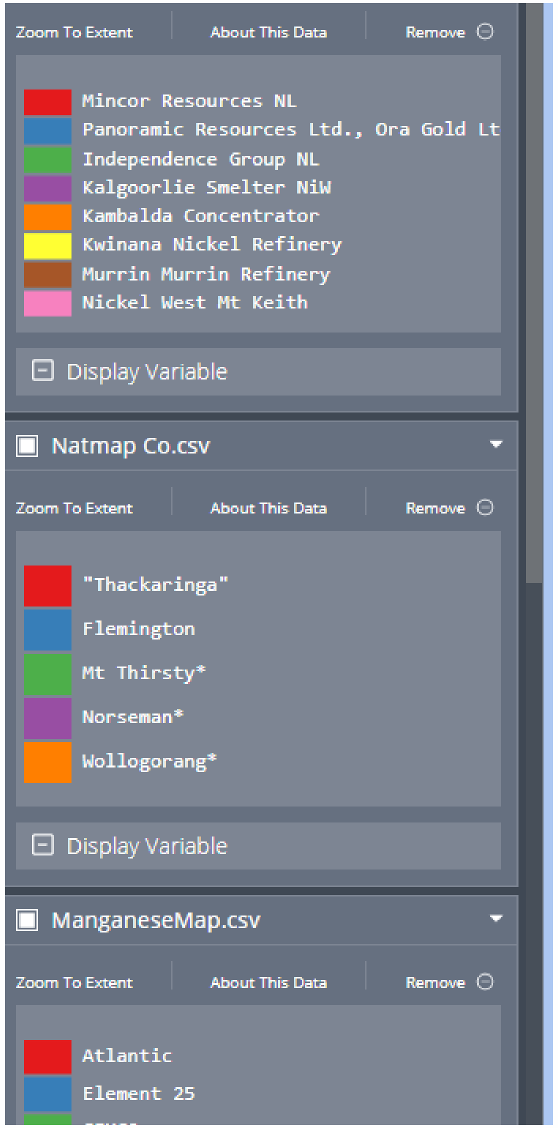
FUTURE BATTERY INDUSTRIES CRC

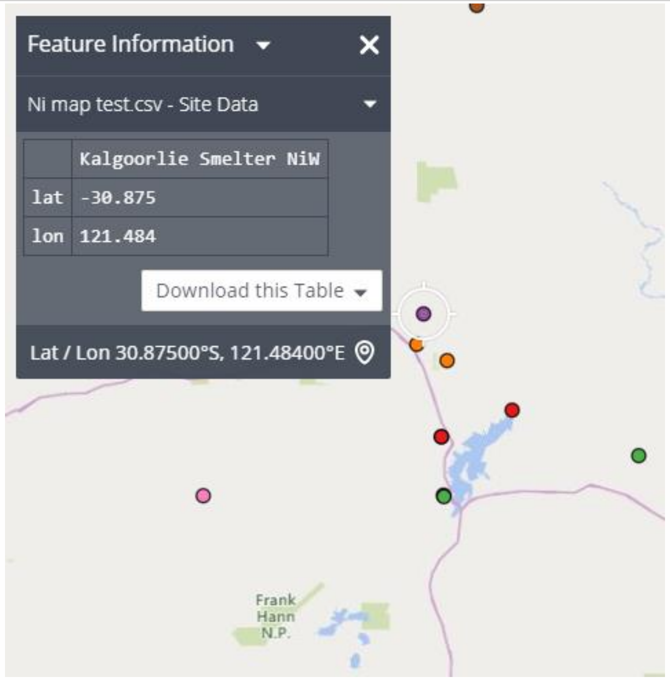
# Living map project

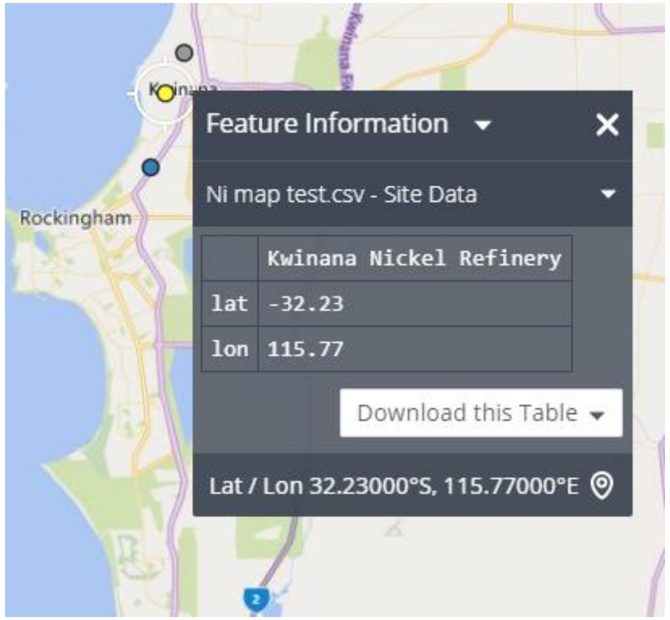
Ability to click on a spot to reveal database information

Sort on commodity/business, size of business, location etc

(under development)



# Thankyou

# Thoughts on the Global Energy Transition

# - and the critical role for battery technology

Cadenza INNOVATION

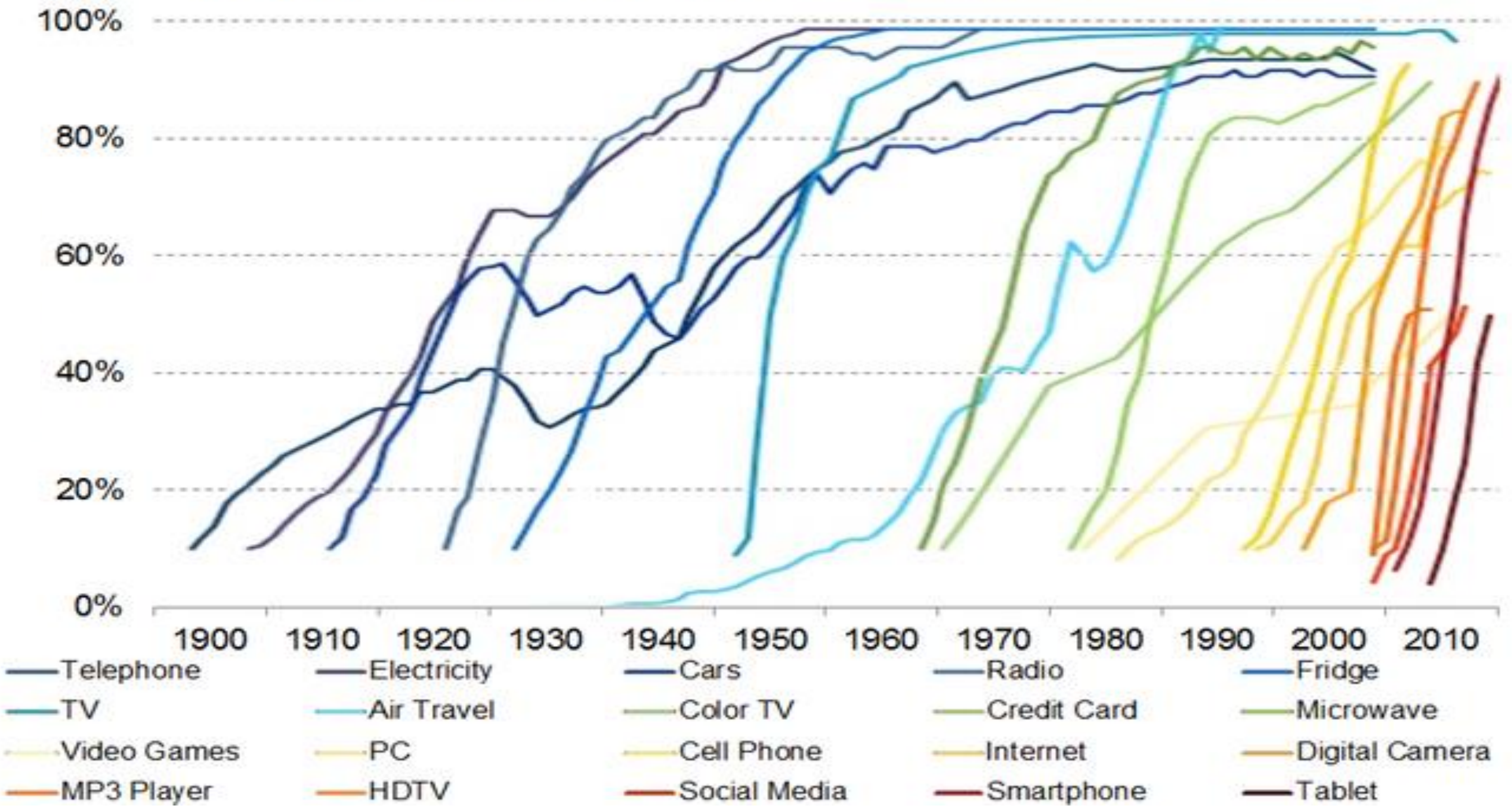

**Dr. Christina Lampe-Onnerud**

Founder and CEO, Cadenza Innovation

Co-Chair, Global Future Council on Energy, World Economic Forum

Special Board Advisor to FBICRC

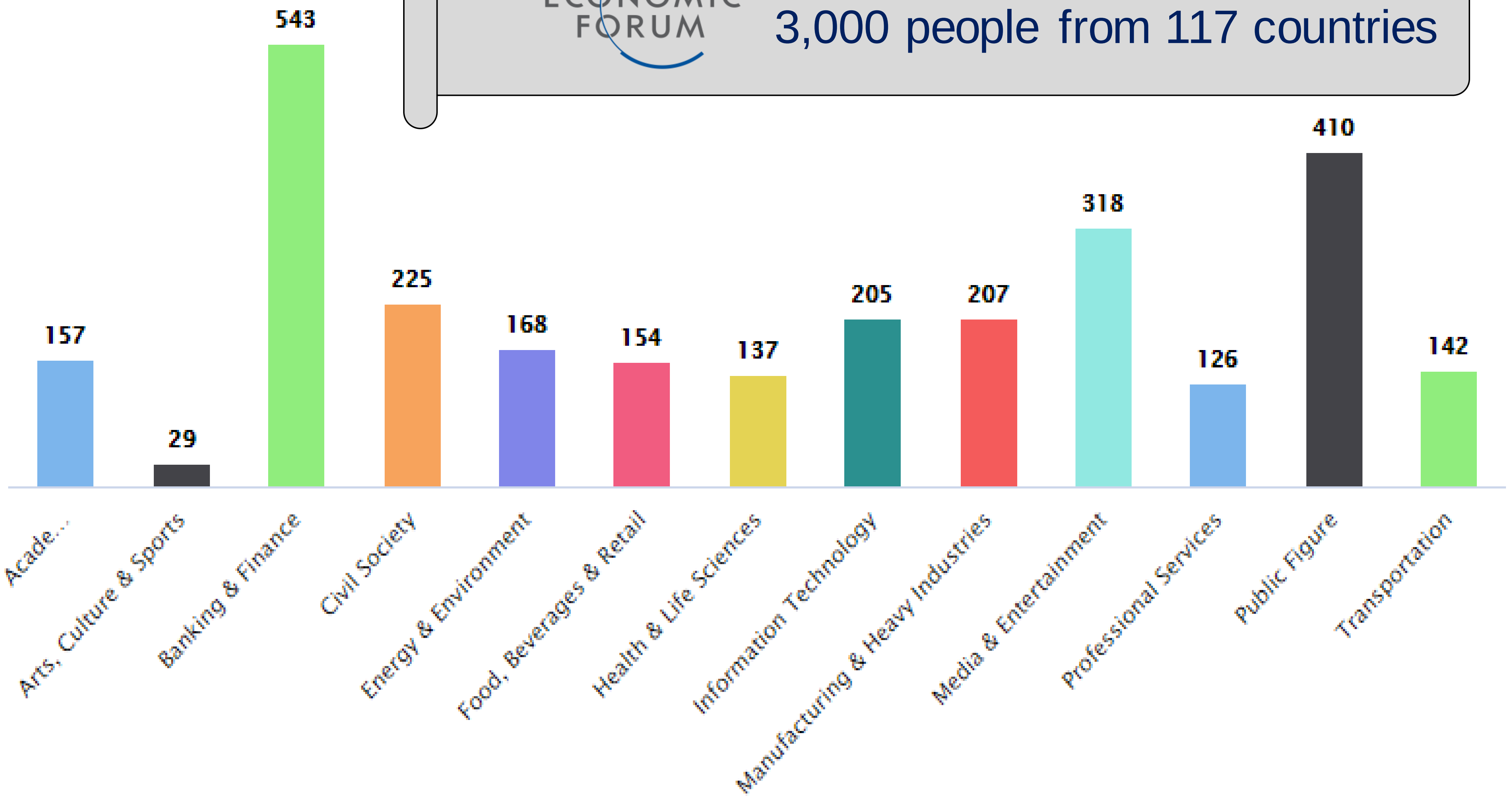
# Adoption of Technology in the US




Source: Market Realist 2018, BlackRock

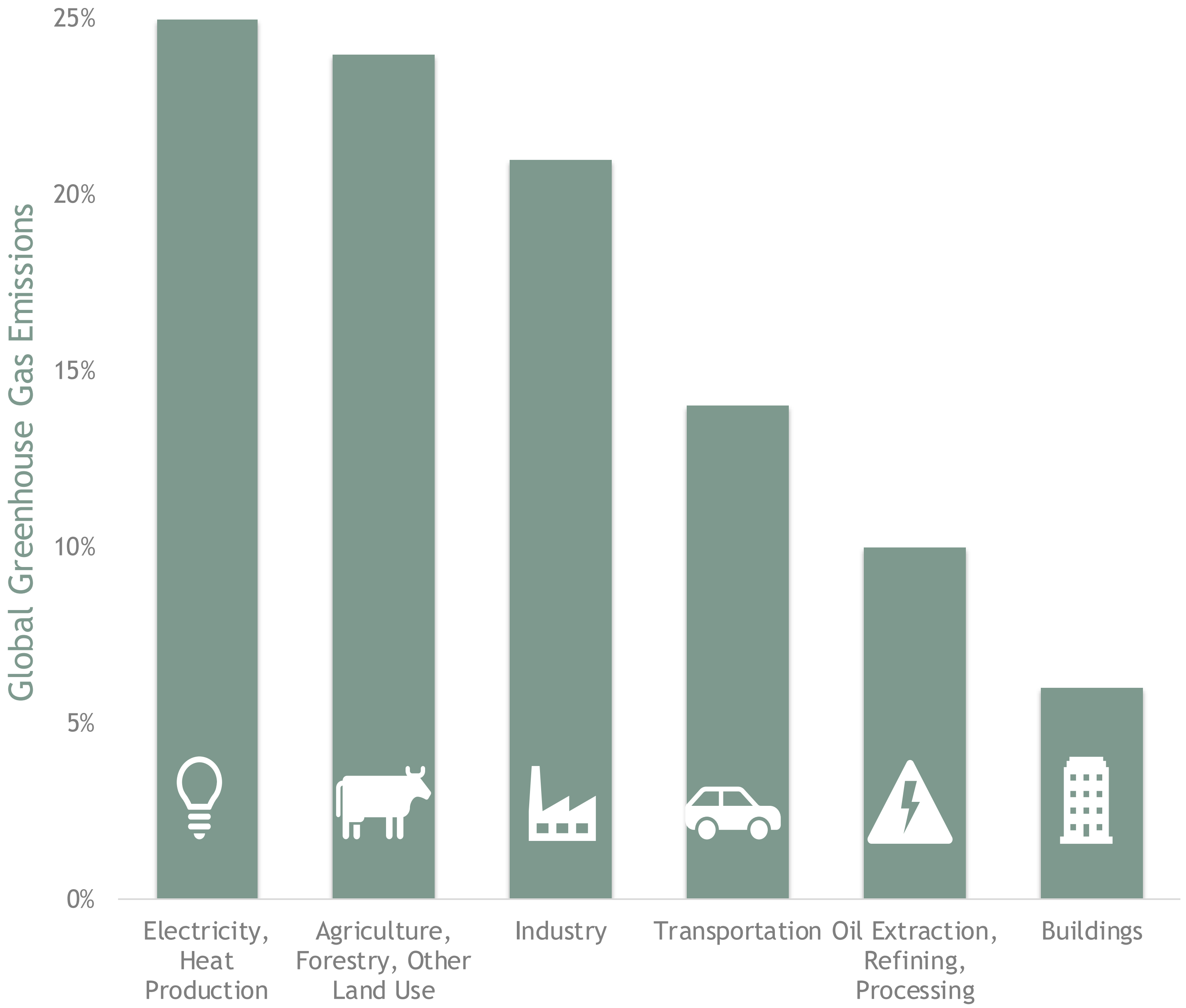

Global Ag
World
Annual
"With the world at such a critical crossroad, this year we must develop a 'Davos Manifesto 2020' to reimagine the purpose and scorecards for companies and governments."
—Klaus Schwab, Founder and Executive Chairman, World Economic Forum
WORLD ECONOMIC FORUM
COMMITTED TO
IPROVING THE STATE
OF THE WORLD

## January 2020:
## 3,000 people from 117 countries

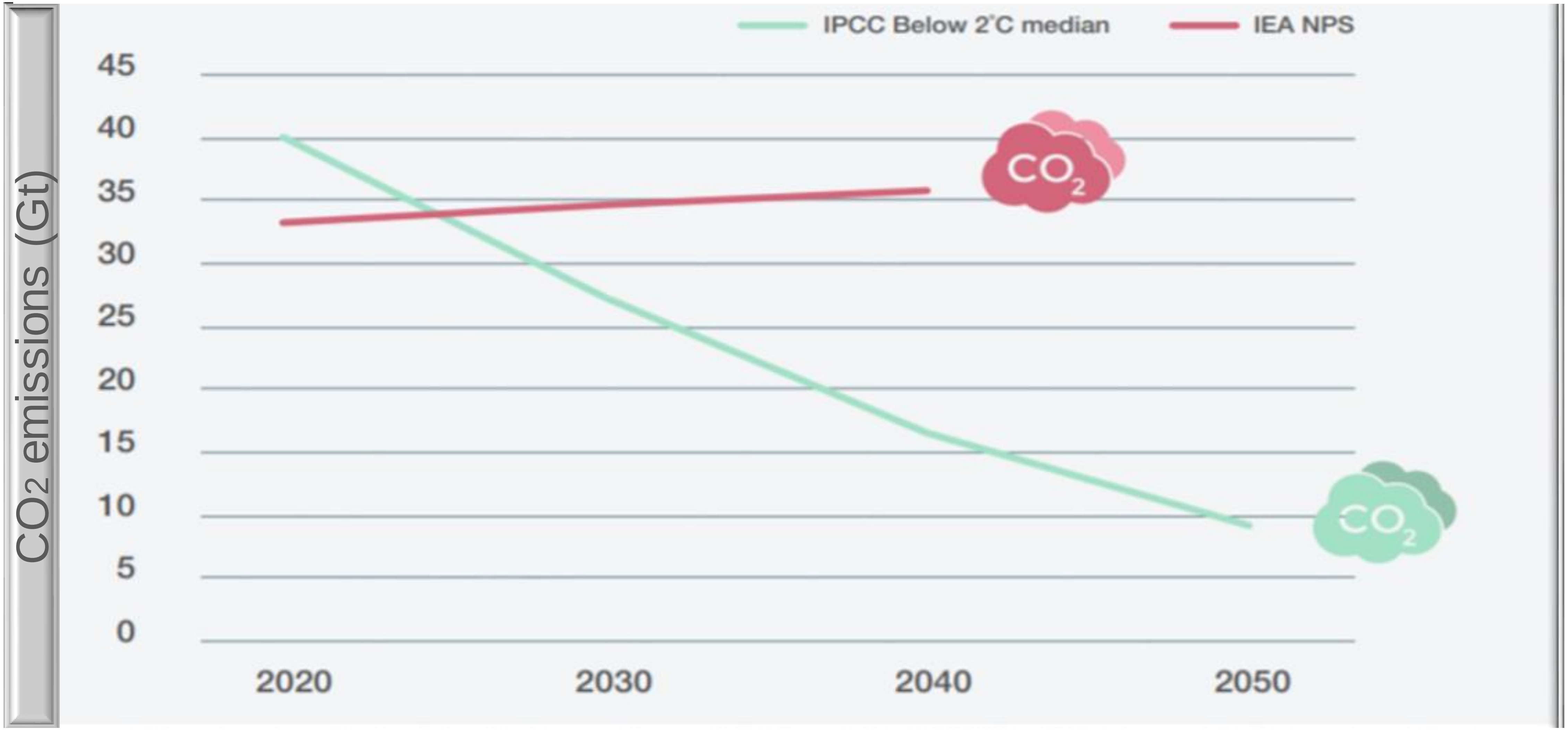


## Sessions Focused on Climate Change

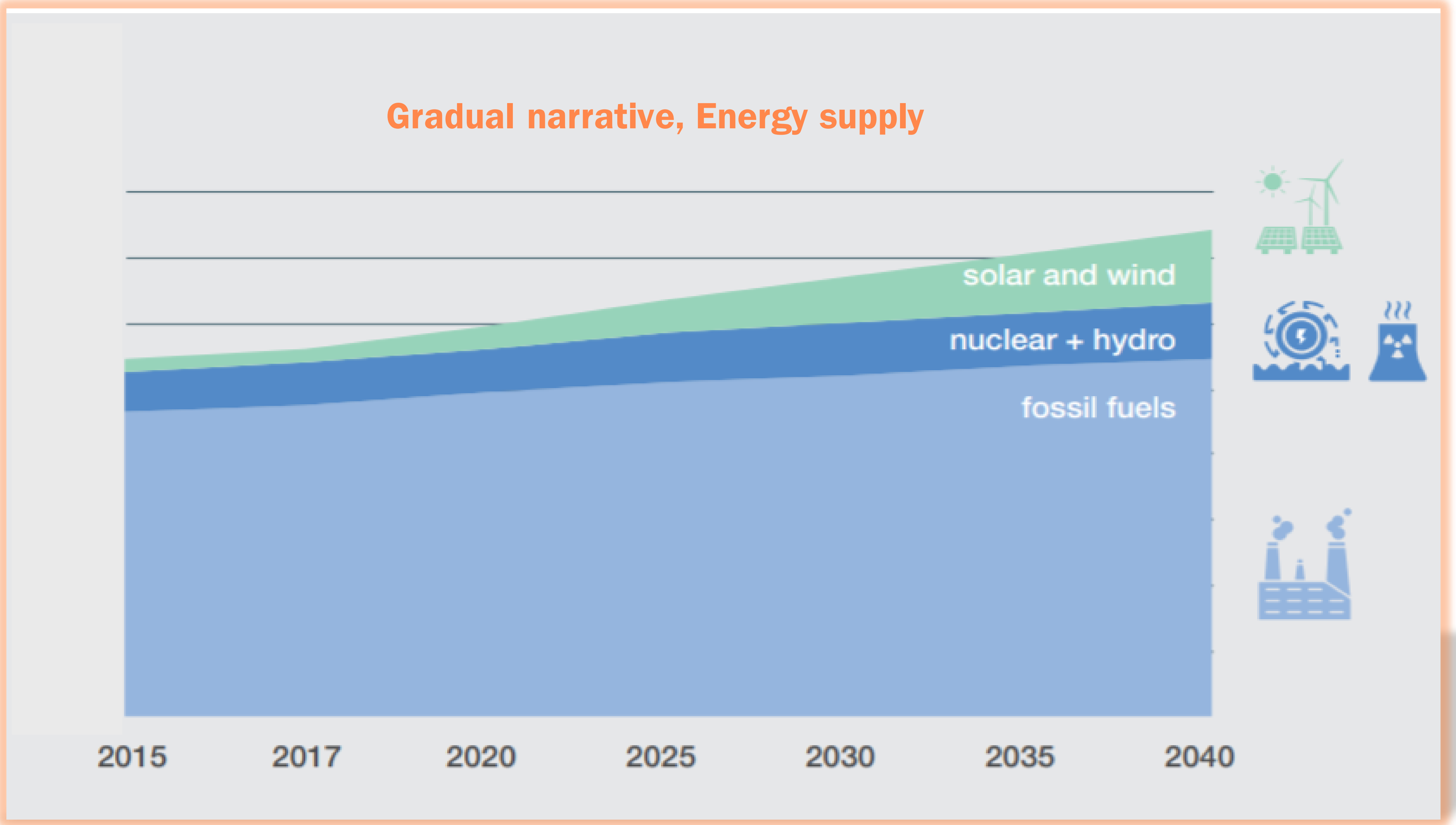

Source: AT&T Abandons Puerto Rico and US Virgin Islands, SDX Central News October 2019




Ref. Global Emissions by Economic Sector US EPA 2016

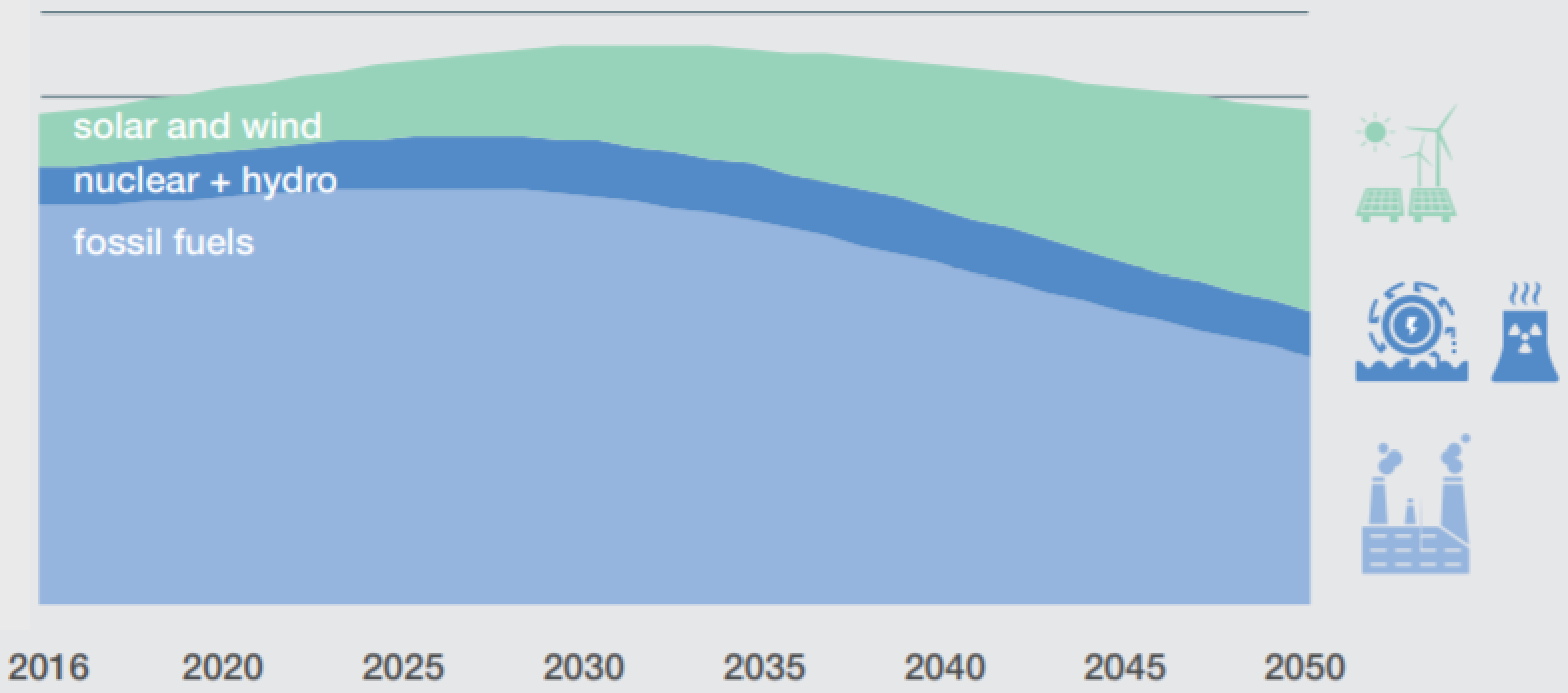



Source: 2019 World Economic Forum (WEF) report: The Speed of the Energy Transition Gradual or Rapid Change?

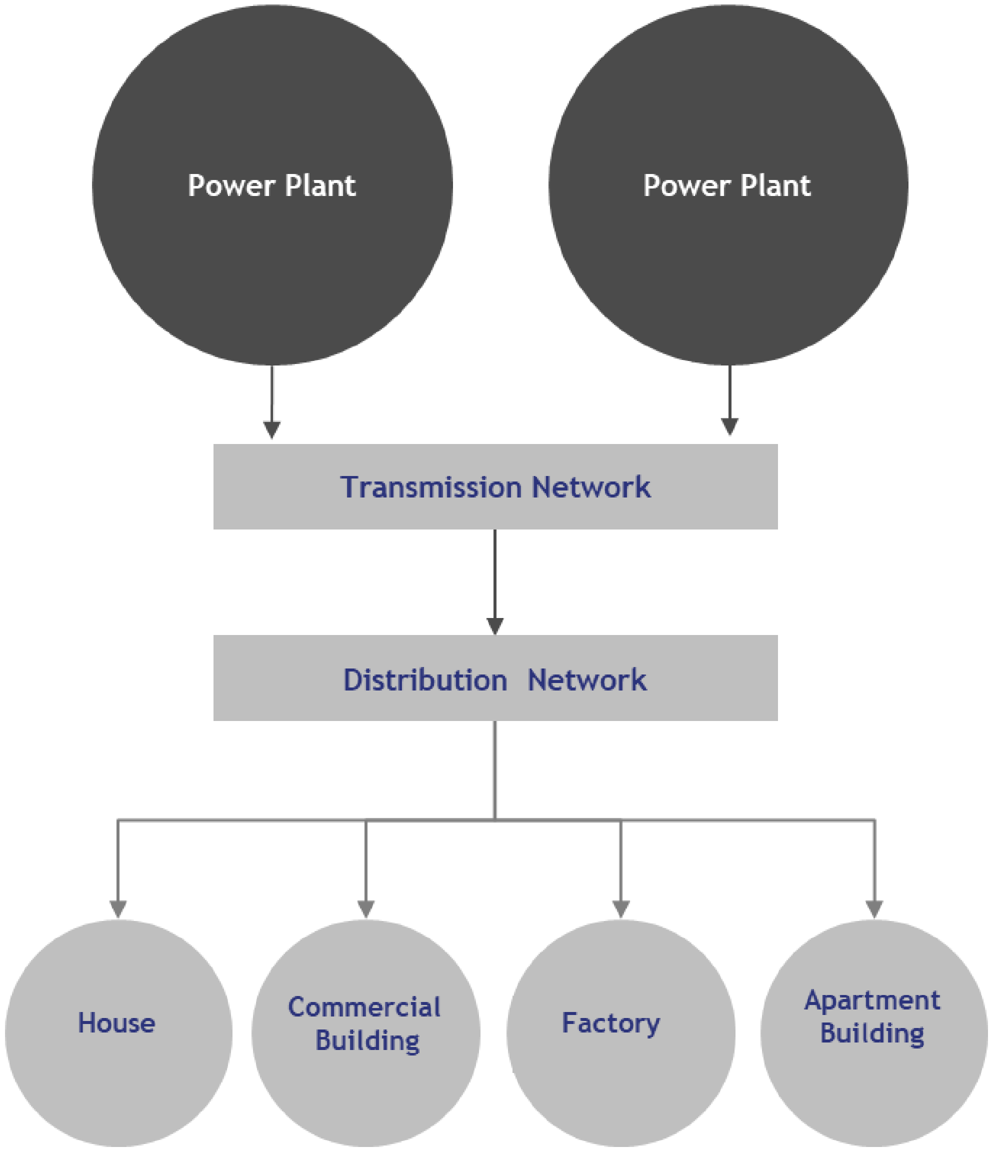


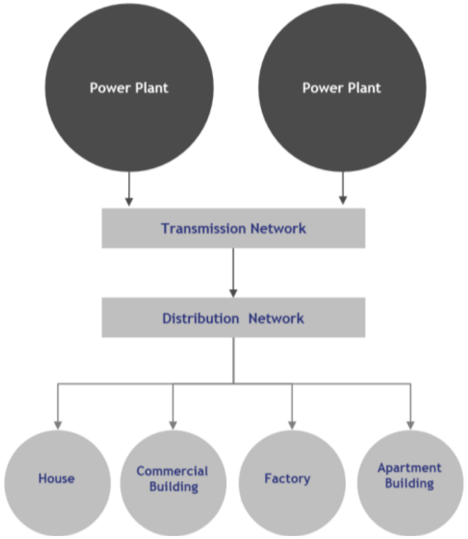

Source: 2019 World Economic Forum (WEF) report: The Speed of the Energy Transition Gradual or Rapid Change?

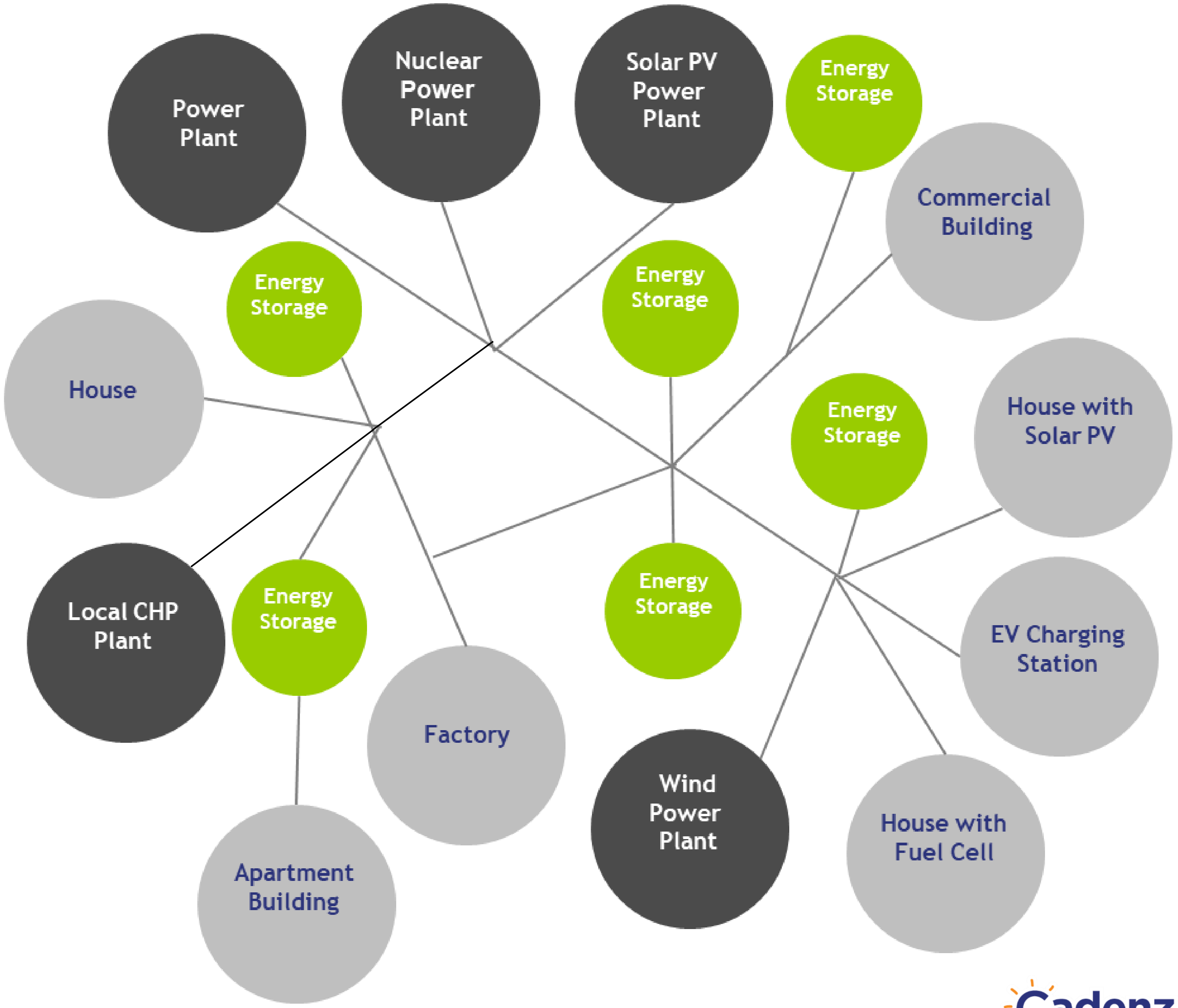
## Rapid narrative, Energy supply

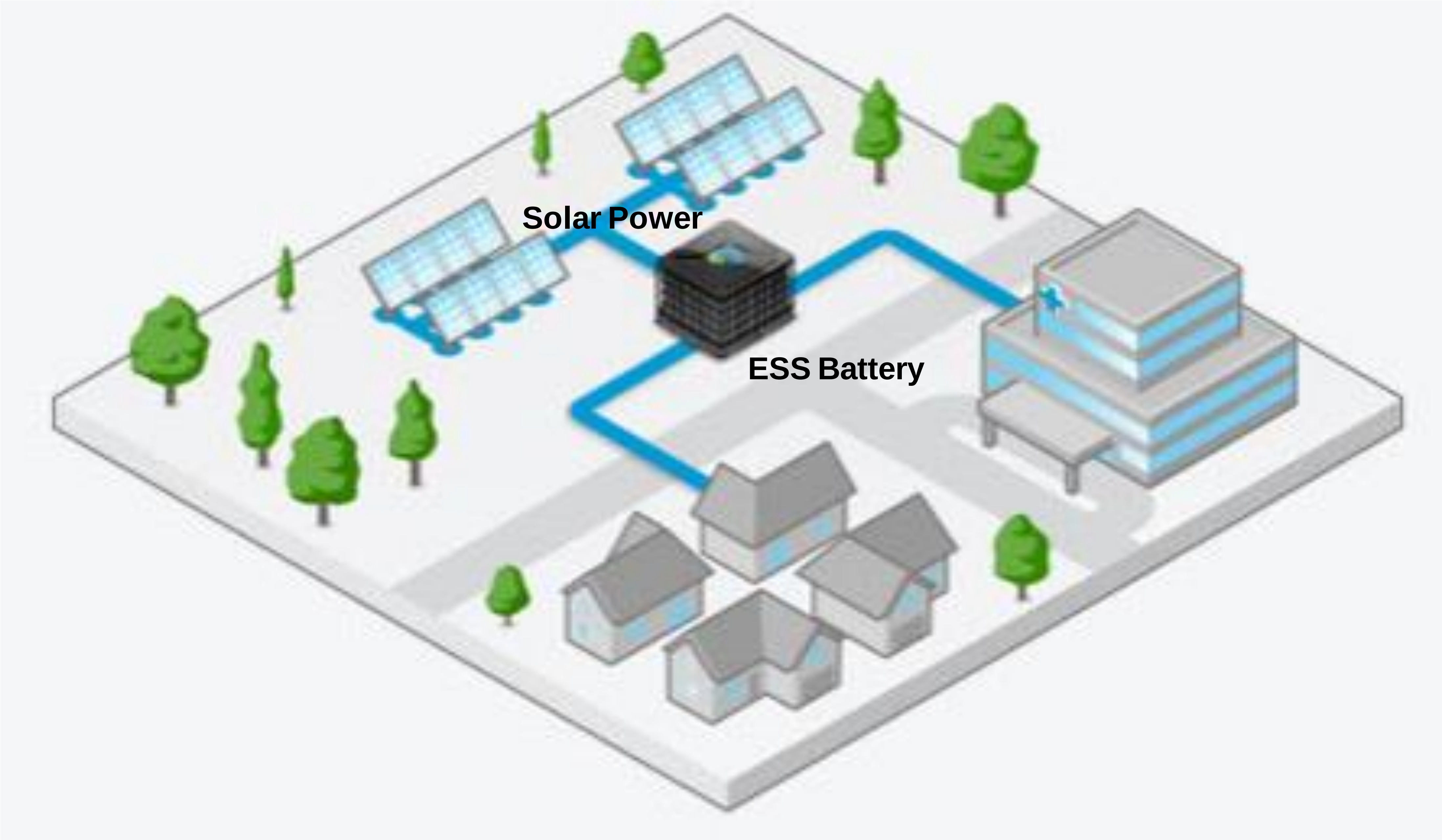



Source: 2019 World Economic Forum (WEF) report: The Speed of the Energy Transition Gradual or Rapid Change?

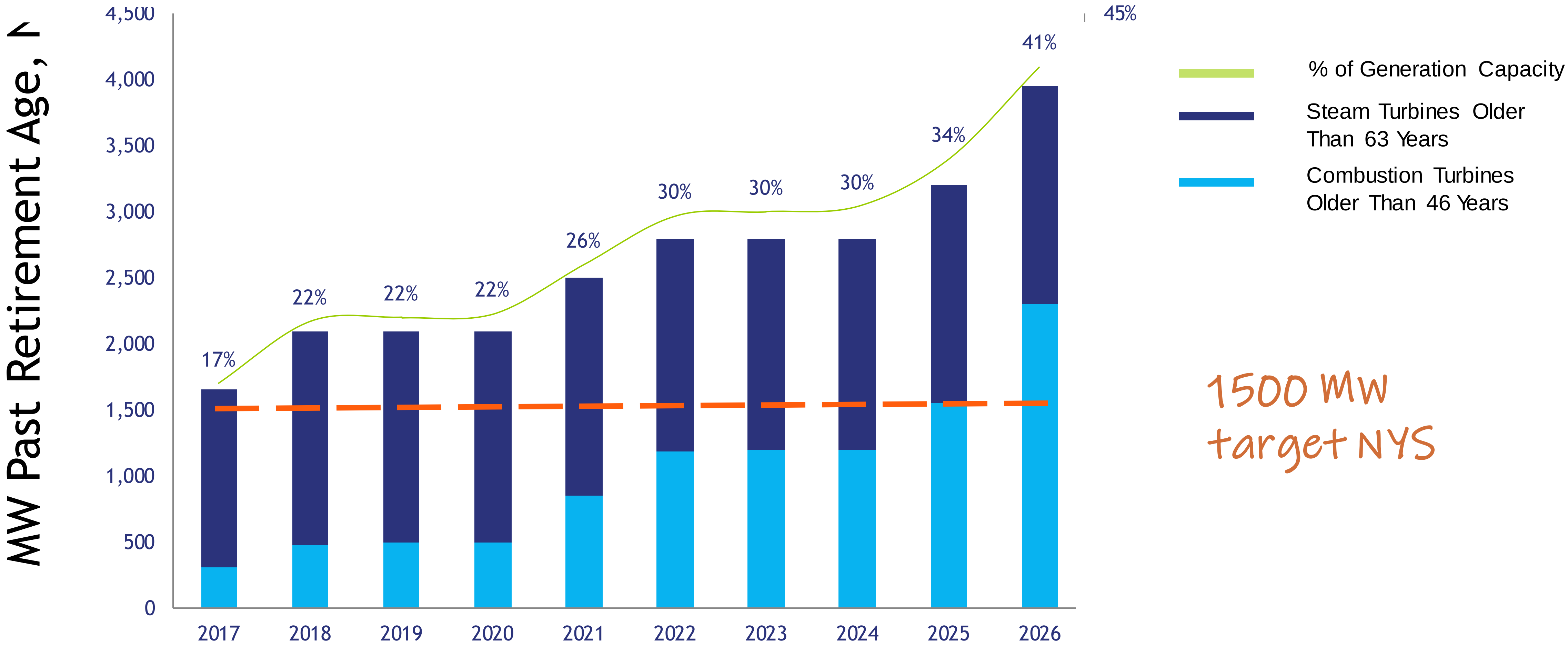

Power Plant
Power Plant
Transmission Network
Distribution Network
House
Commercial Building
Factory
Apartment Building


Power Plant
Power Plant
Transmission Network
Distribution Network
House
Commercial Building
Factory
Apartment Building


Power Plant
Nuclear Power Plant
Solar PV Power Plant
Energy Storage
Commercial Building
Energy Storage
Energy Storage
House
Energy Storage
House with Solar PV
Local CHP Plant
Energy Storage
Energy Storage
EV Charging Station
Factory
Wind Power Plant
House with Fuel Cell
Apartment Building


Solar Power
ESS Battery

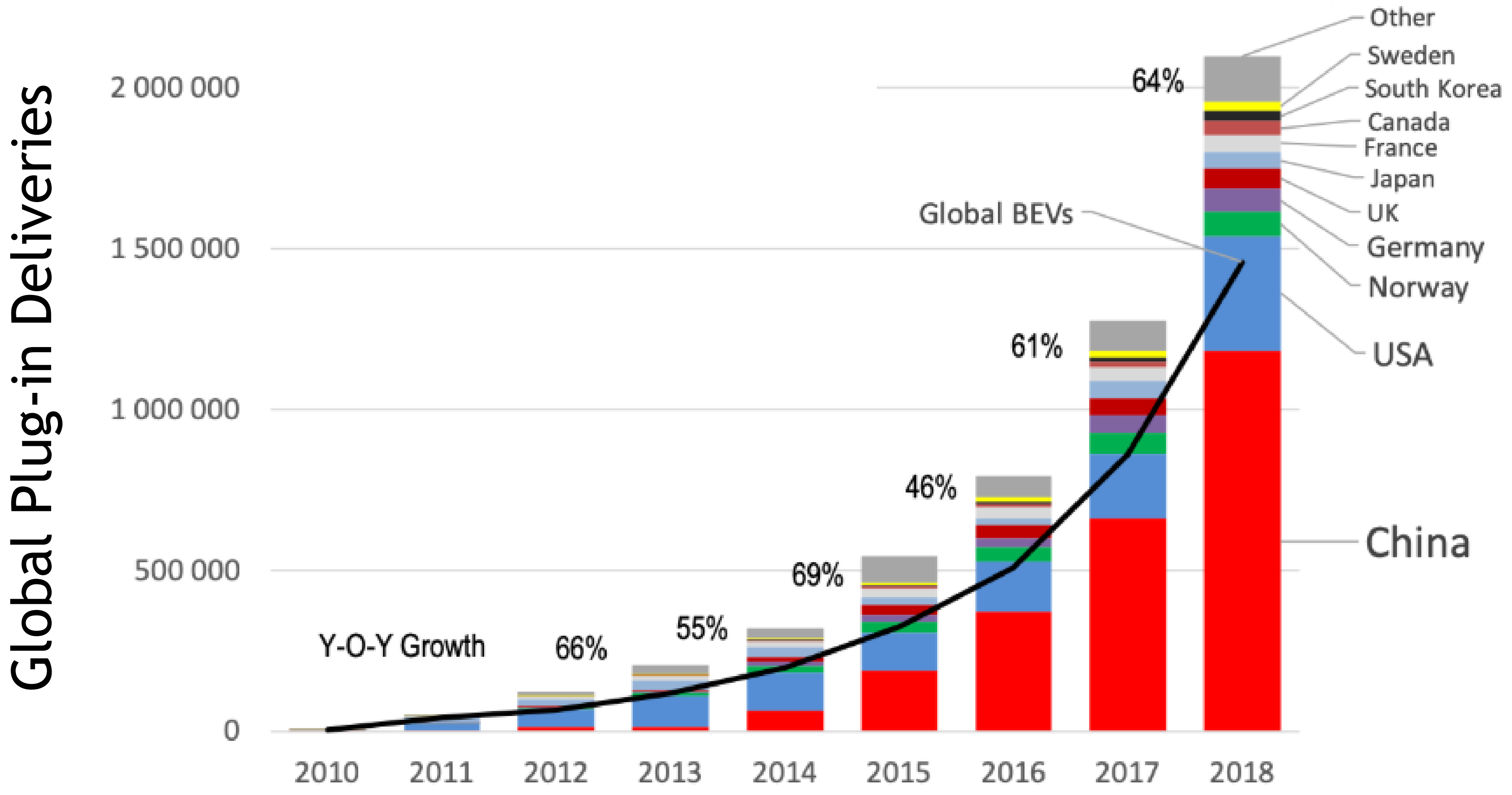
Source: Tesla's massive Powerpack battery in Australia, Electrek 2018


MW Past Retirement Age, M
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
17%
22%
22%
22%
26%
30%
30%
30%
34%
41%
45%
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
% of Generation Capacity
Steam Turbines Older Than 63 Years
Combustion Turbines Older Than 46 Years
1500 MW target NYS


1984


福田交通枢纽公交加电
深圳市公交行业新能源汽车应用示范基地

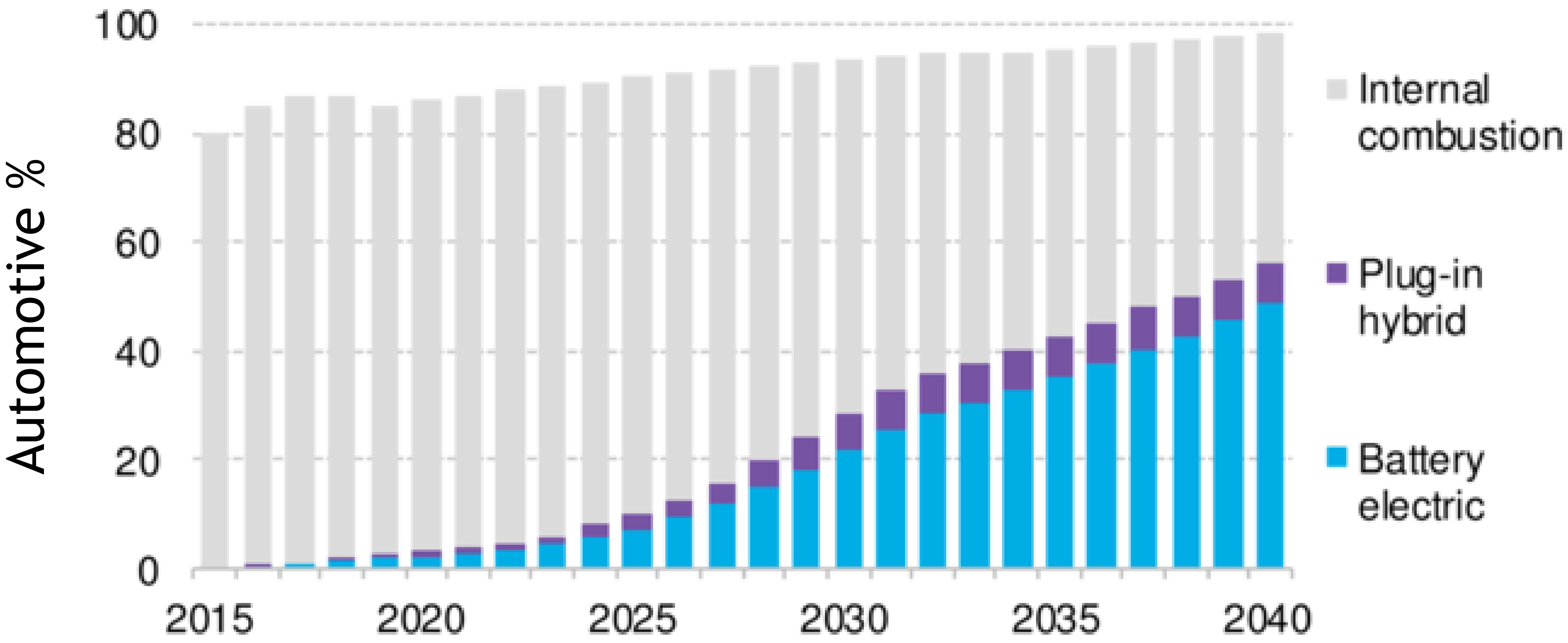
EV VOLUMES.COM
THE ELECTRIC VEHICLE WORLD SALES DATABASE



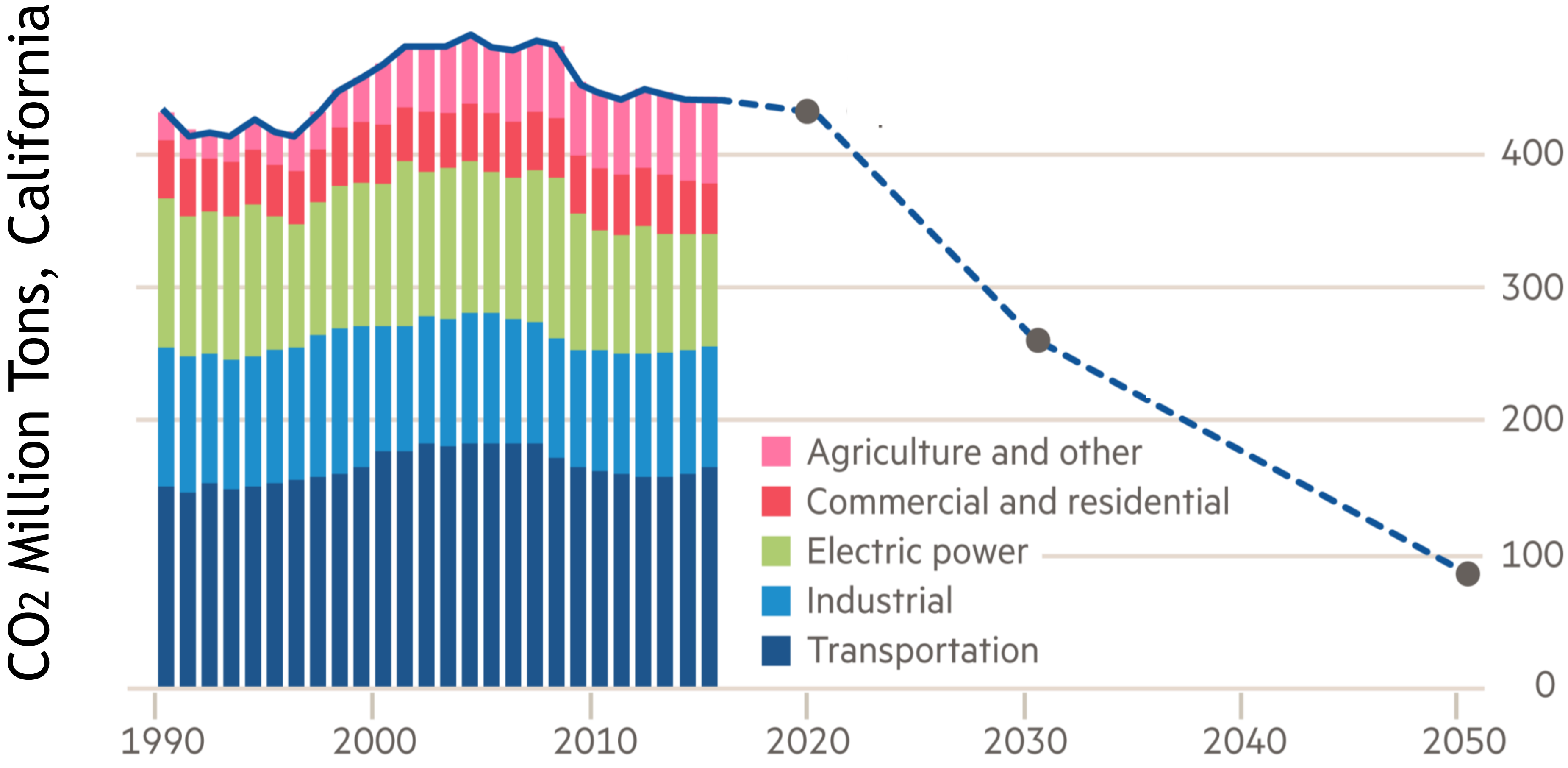

Source: EV Volumes.com2019
2020-02-11 CLO Keynote FBICRC Summit

Cadenza INNOVATION

BloombergNEF




Source: Drive train to go electric, BloombergNEF 2019




Source: US Energy Information Administration 2018

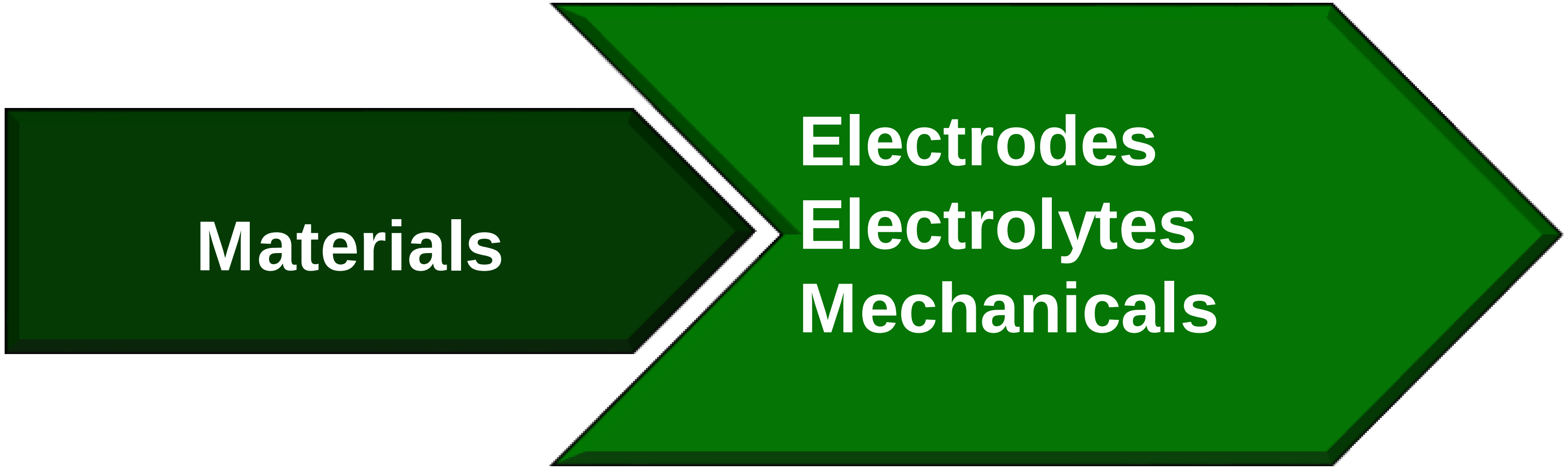
# Critical Role of Batteries:

- increase efficiency and profitability in current electrical grids

- accelerate profitability and deployment of renewable energy generation

- enable low or no emission mass transportation and industrial applications

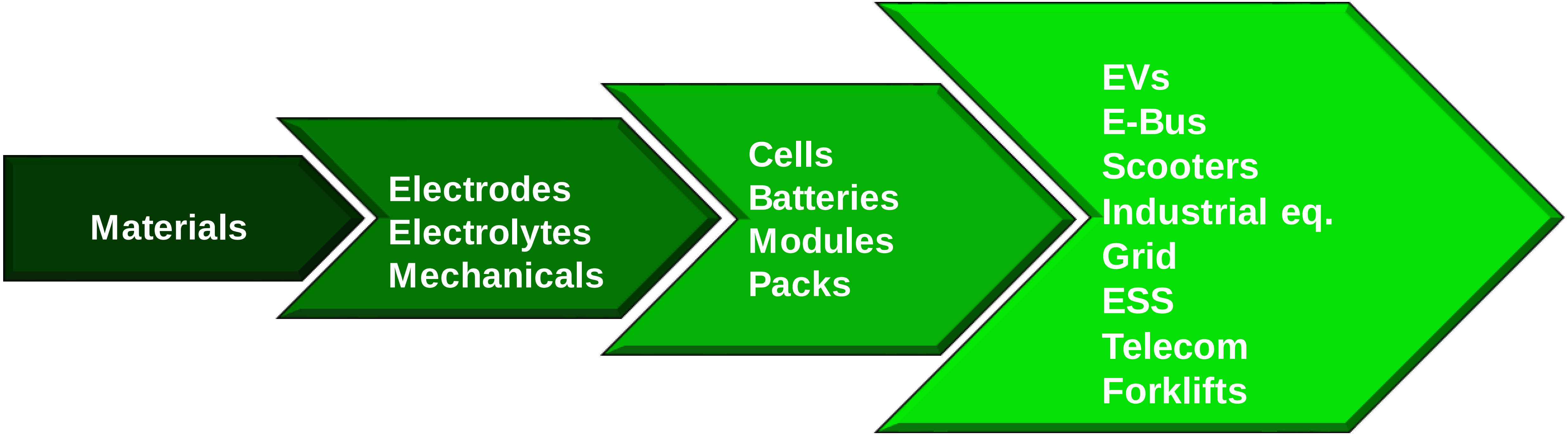
# Materials

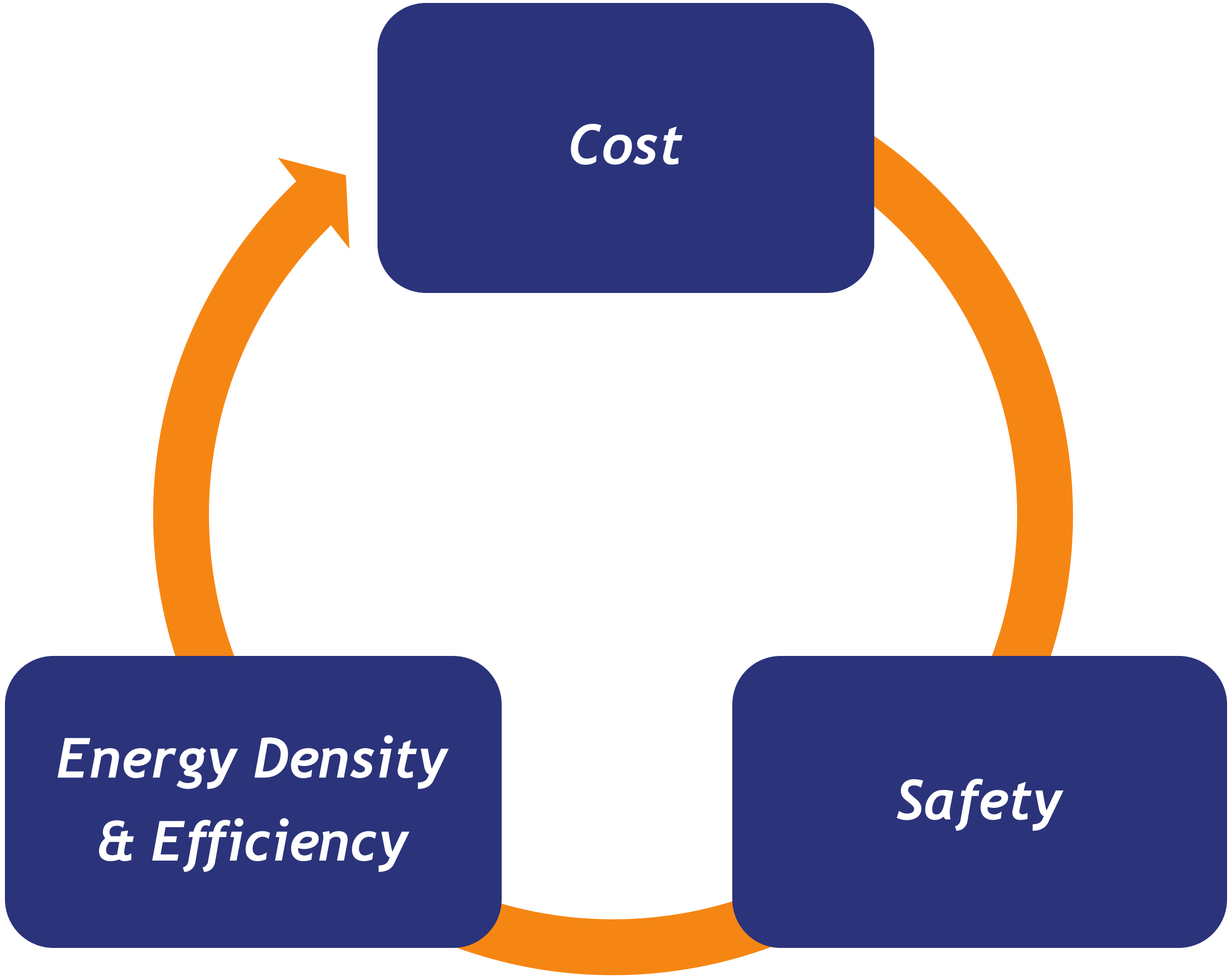

Materials
Electrodes
Electrolytes
Mechanicals

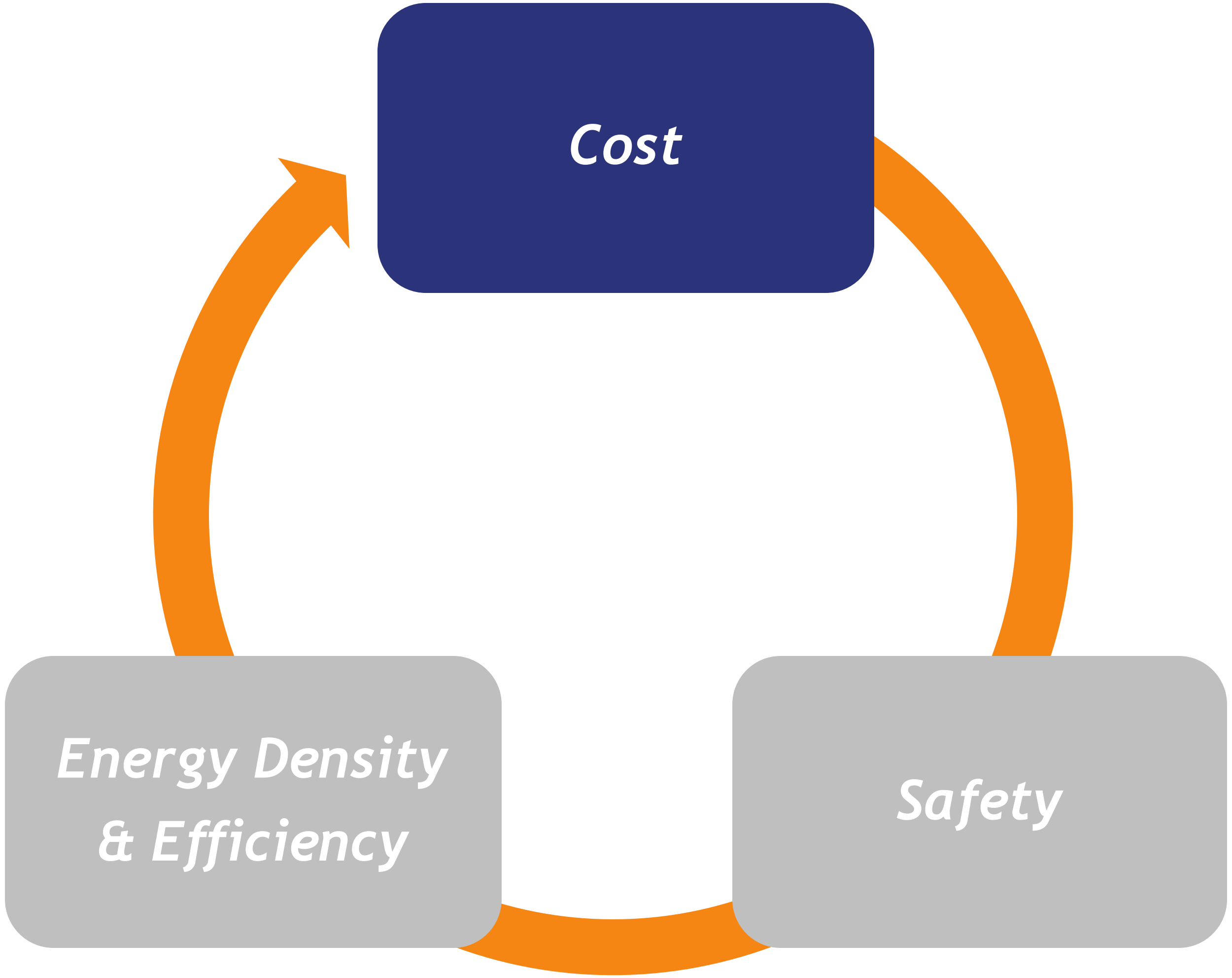
Materials

Electrodes
Electrolytes
Mechanicals

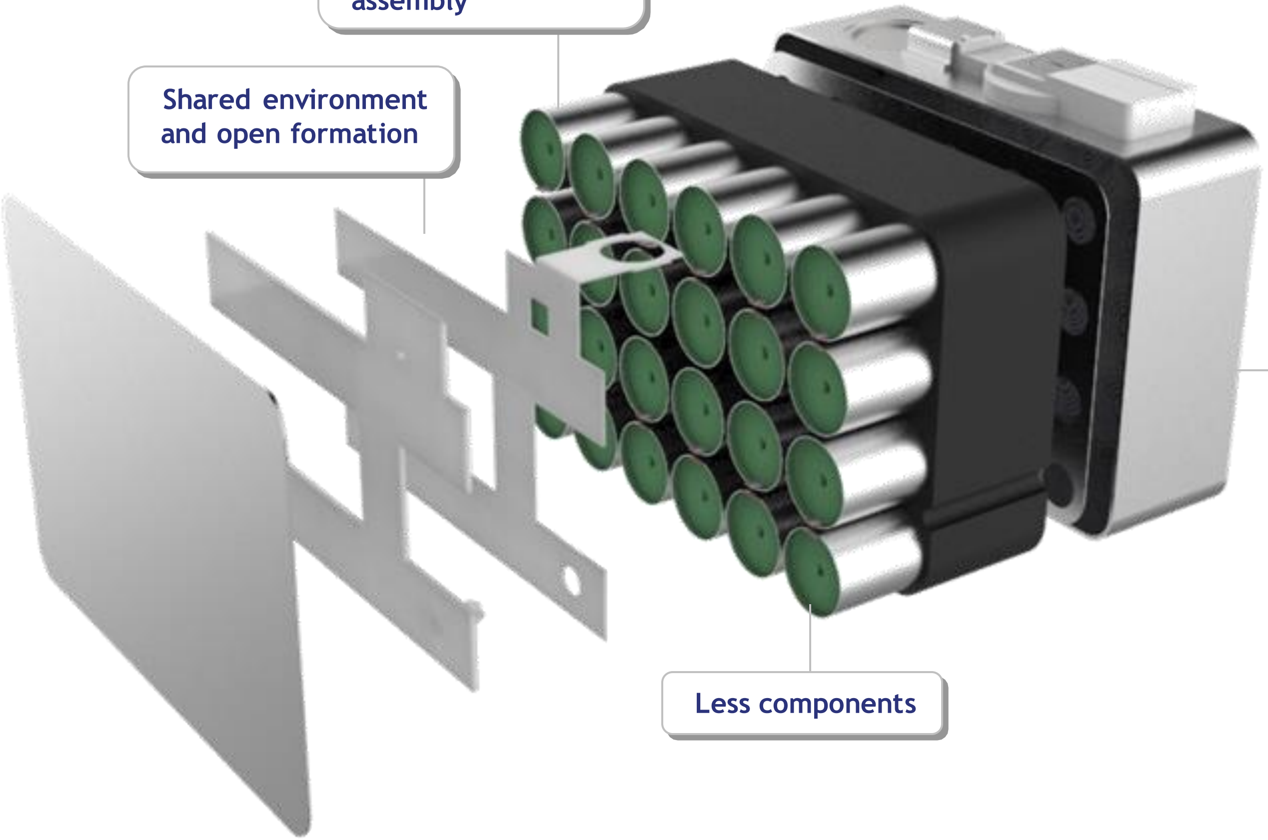
Cells
Batteries
Modules
Packs

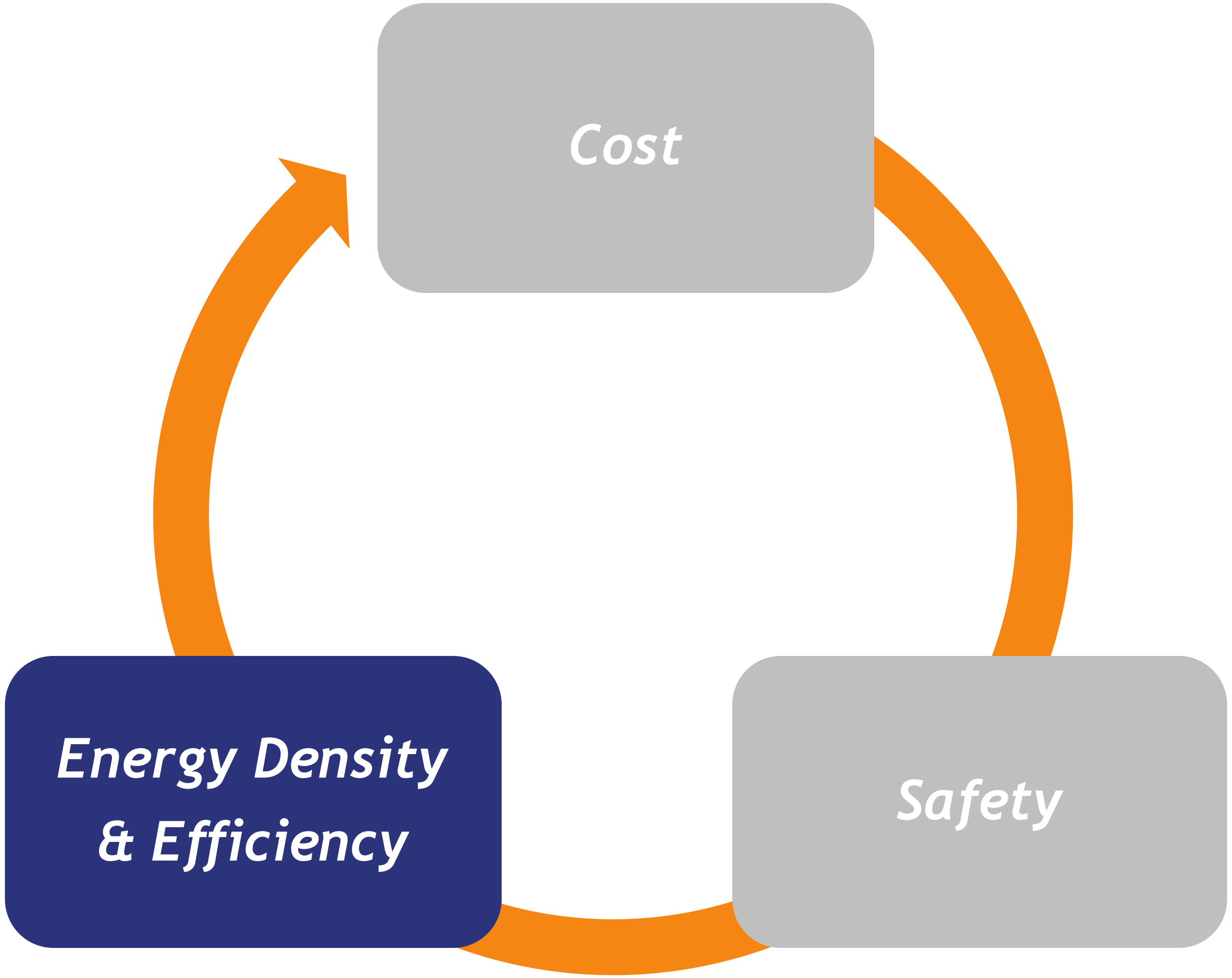

Materials
Electrodes
Electrolytes
Mechanicals
Cells
Batteries
Modules
Packs
EVs
E-Bus
Scooters
Industrial eq.
Grid
ESS
Telecom
Forklifts


Cost
Energy Density & Efficiency
Safety

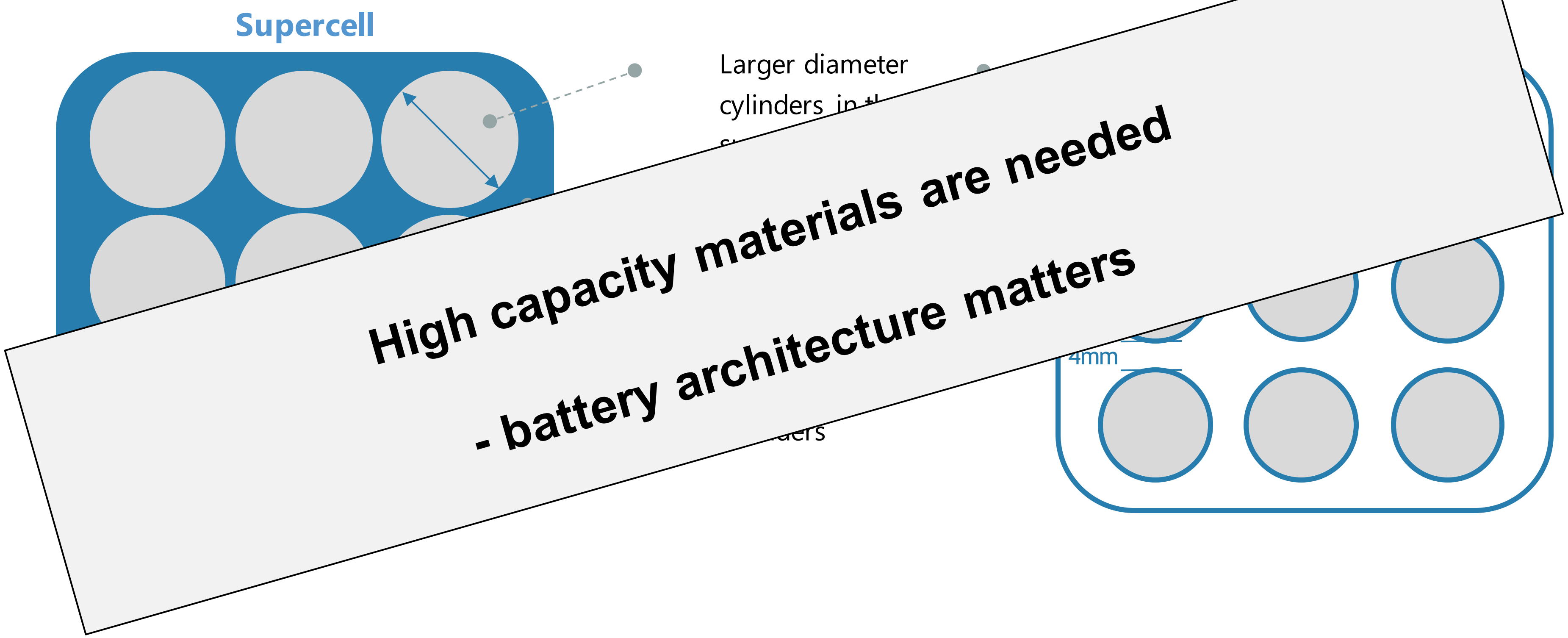

Cost
Energy Density & Efficiency
Safety

Cost dominates opportunity in each use case
- leverage innovation with massive infrastructure and global supply chain



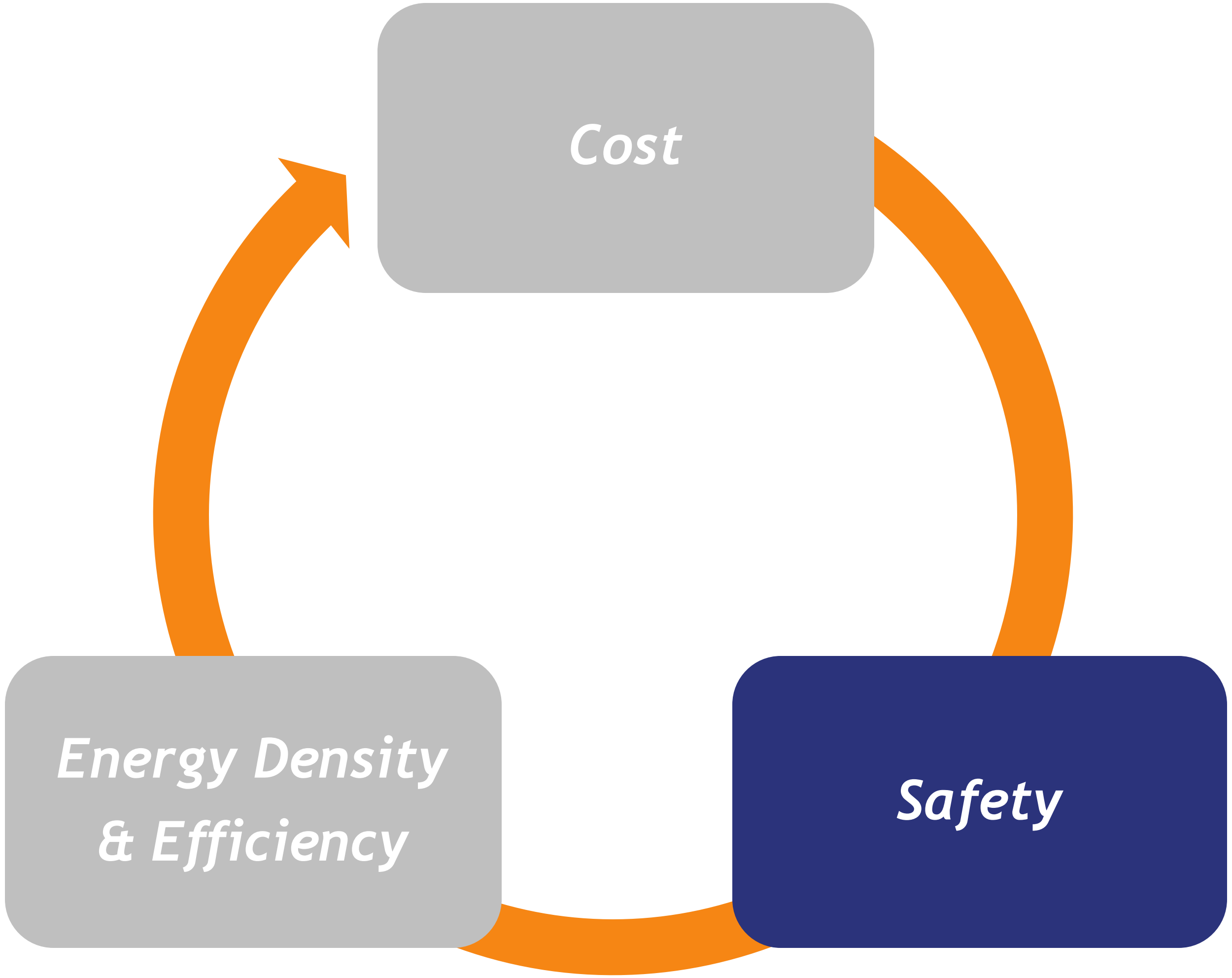

Cost
Safety
Energy Density & Efficiency

# Chemistry and Mechanical Engineering Collaboration Critical to Achieve High Energy Safely




**High capacity materials are needed**

**- battery architecture matters**

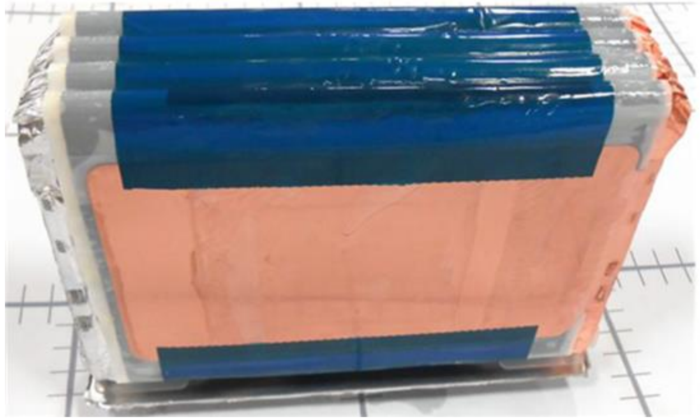

Cost
Energy Density
& Efficiency
Safety

# Success Criteria for Getting to Safe and Reliable Battery Deployment

- Allow data a voice
  - "Hear-say" is simply not good enough
  - One component will never dominate a system design

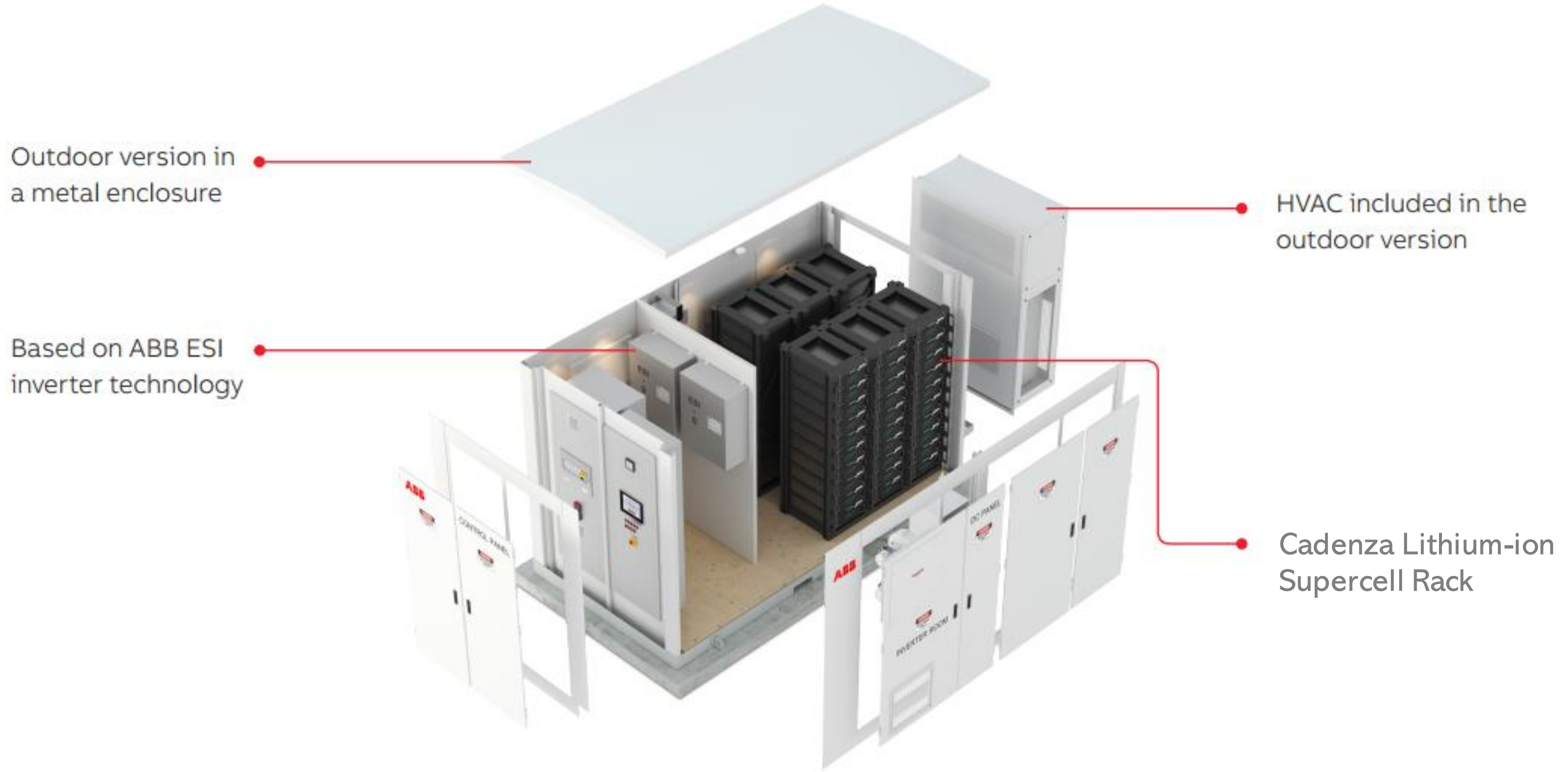
- Accurate testing requirements to validate product claims
  - Police against work-around-solutions

*Interior of prismatic cell electrode stack with copper plate intended to bypass nail penetration*



- Participate in the public arena
  - Public demonstration projects drive multiple stake holders

# Demonstration with New York State stakeholders at New York Power Authority



## Grid

2025 ESTIMATE:

$23.5Bn

## Vehicles

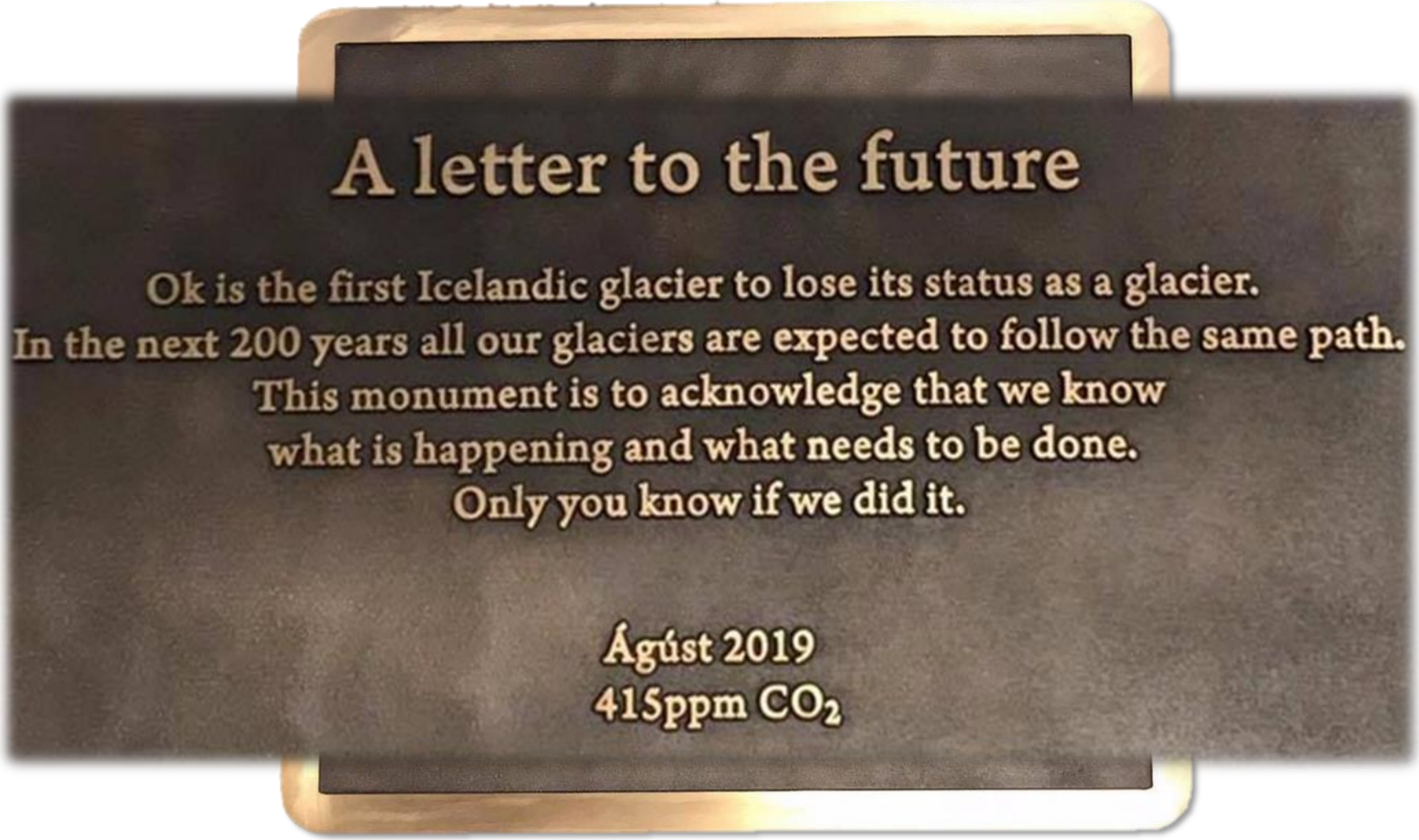
2025 ESTIMATE:

$55.1Bn

## Specialty Battery

2025 ESTIMATE:

$16.2.0 Bn




Source: A letter to the future. Monument for the former Okjökull glacier in Borgarfjörður, Iceland, text by Andri Snaer Magnason 2019

# Massive Opportunity in the Global Energy Transition

# - how will you help to shape it?

**Dr. Christina Lampe-Onnerud**
Founder and CEO, Cadenza Innovation
Co-Chair, Global Future Council on Energy, World Economic Forum
Special Board Advisor to FBICRC

FUTURE BATTERY INDUSTRIES CRC

# Q & A

with FBICRC Executive and Program Leads