Towards Cognitive Digital Twin for Battery Analytics

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SINGAPORE INSTITUTE OF TECHNOLOGY

Outline

- Battery Management
- AI-based Battery Management
- Cognitive Digital Twin
- Use Cases

Battery Management

Traditional Battery Management System

Battery Management System (**BMS**) – A Battery Doctor:

- Electronic system that manages a rechargeable battery.
- Protection & prevention of the system from damage.
- Increase of battery life.
- Maintenance of the battery system in accurate and reliable state.

However, traditional BMS meets several **challenges:**

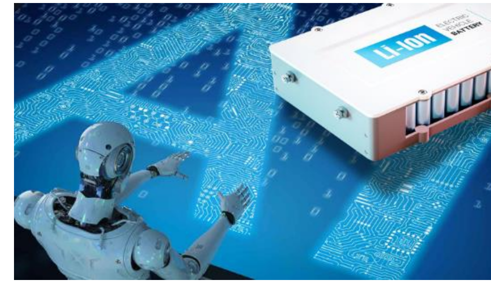
- *Limited data collection*: only current and voltage for charging and discharging.
- *Missing important features*: require probing batteries in action, detecting subtle signals.

- *Complicated battery dynamics*: need more accurate & comprehensive analytic method.
- *Increasing concern on safety and efficiency*: need explainability & real-time reaction.

AI and Data-driven approach are the keys to unlock battery technology

AI-based Battery Management

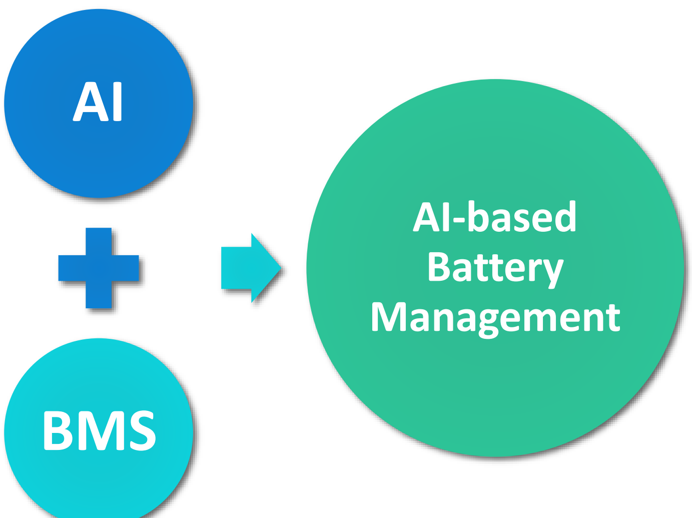
Analytics and AI in Battery Industry



Artificial intelligence (**AI**): the 4th industrial revolution enabled by:

- Data: internet-of-things (**IoT**).
- Communication: **5G** and 6G.
- Computation: high-performance computing and **GPU**-powered edge device.
- **Algorithms**: simulating human intelligence.

Widely adopted in various sectors: **manufacturing**, **transportation**, etc.

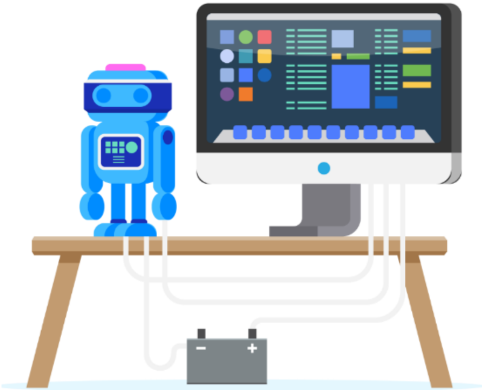


Battery industry definitely is not falling behind.

- AI-based battery gauge for state-of-charge (**SOC**).
- AI to predict state-of-health (**SOH**) in Nature.
- AI to group the **used batteries** into diff. categories.
- AI for battery-enabled **demand response**.

Challenges for AI-based Battery Management

Challenges to be addressed despite the vast research effort.



Data scarcity

- **High-cost**, i.e., 1 battery for 1 cycle life data.
- Numerous **battery types**. Cannot capture all.
- **Privacy**, i.e., battery status of a private car.
- However, many AI algos need **big data** to survive.

Risk-averse mindset

- Most existing AI algorithms are **black-box** in nature.
- No **trust** -> no adoption. **Understand** -> trust.
- Rest assured about the **limits**, i.e., crossing the line?
- Government **regulations**, i.e., EU's GDPR.

Overall, **far** from real-world adoption for battery.

Cognitive Digital Twin

Cognitive Digital Twin for Battery Management

Physical-based digital twin. (1st gen)

- Physical laws, i.e., fluid dynamics, electrical circuit.
- Decades of **effort**. Huge **cost**. Poorly generalized.

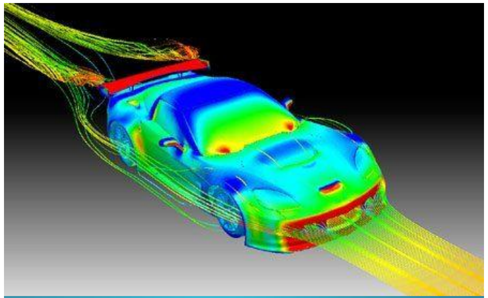
Data-driven digital twin. (2nd gen)

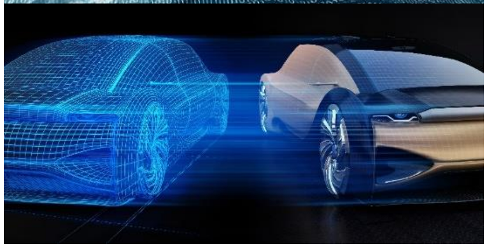
- Machine learning, approximation from data.
- Highly **reliant** on **big data**. But often insufficient.

Overall, virtual replica with **no intelligence**.

AIoT + digital twin. (3rd gen)

- **Far beyond** a virtual **replica** of a real-world entity.
- AIoT: AI-enabled IoT for 3-tier **intelligence**:
  - Descriptive intelligence for **what has happened**.
  - Prescriptive intelligence for **what do we do**.
  - Predictive intelligence for **what will happen**.





Use Cases

1. SOH prediction based on AI: Preliminary Results

State-of-the-art: **Nature Energy** 2019 work for SOH prediction.

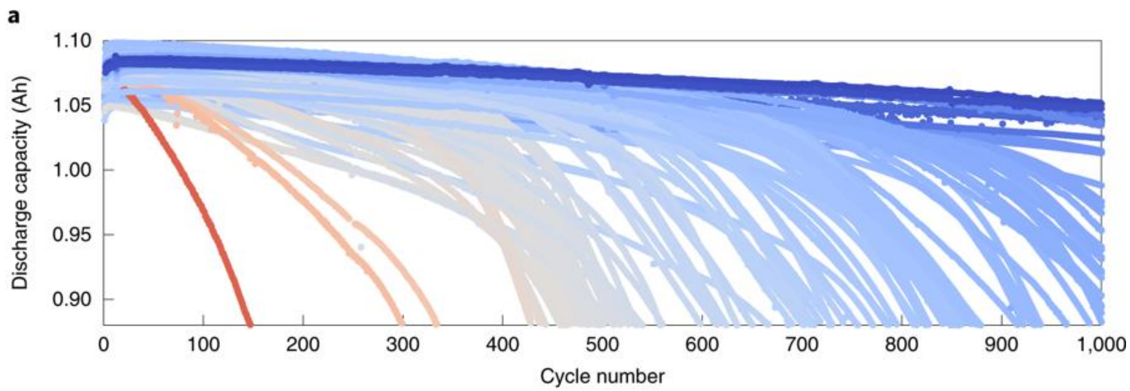
- Linear Regression, 85-87% accuracy.
- Variance model: single feature input.
- Full model: 9-feature input.

	Nat. Energy Liner Reg.	Our Work Neural Net.
Variance Model	85.3%	86.4%
Full Model	85.9%	88.4%

Our AI-based Approaches.

- **Shallow** neural network. Able to **win**.
- Deep Learning. To be explored.

Huge potential with AI + Digital Twin.



2. Use Cases of Digital Twin in Battery Management

TWAICE battery simulation models for lithium-ion batteries.

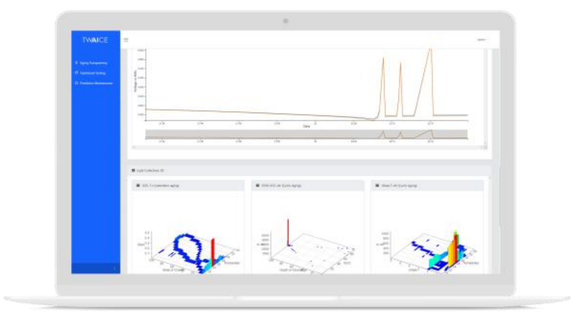
- Speed up **system design** and **replace** lengthy **testing cycles**.
- SOH, Electrical-thermal, remaining storable energy, accessible power, etc.

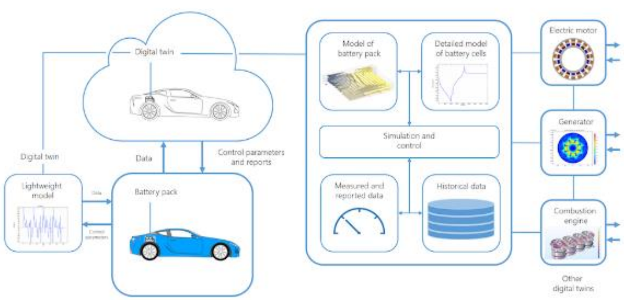
COMSOL digital twin of a battery pack.

- Temperature, SOC, impedance, current versus voltage curves, etc.
- Multiphysics model in COMSOL to alleviate the data reliance.

ION Energy: digital twin to improve Lithium battery life.

- AIoT to predict life, overall performance, and critical issues.
- Prevent breakdowns. Insights, recommendations, and tools for optimization.





Collaboration

To implement the cogitative digital twin in real battery management system needs the effort from multiple agencies.

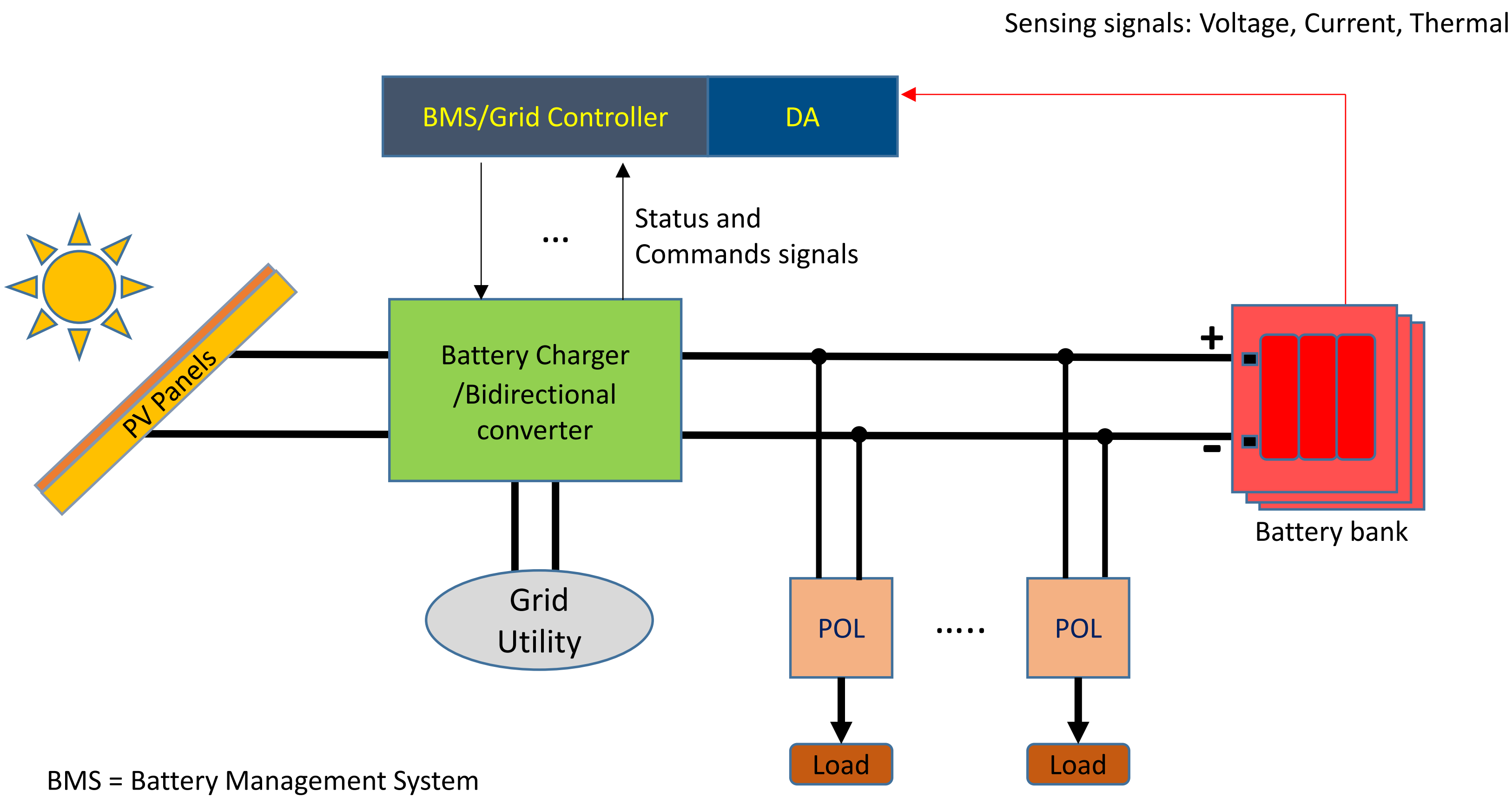
- Enrich the domain knowledge from multiple disciplines.
- Increase creativity and out-of-the-box thinking.

Thank You!

Intelligent Embedded Platform for Battery Analytics

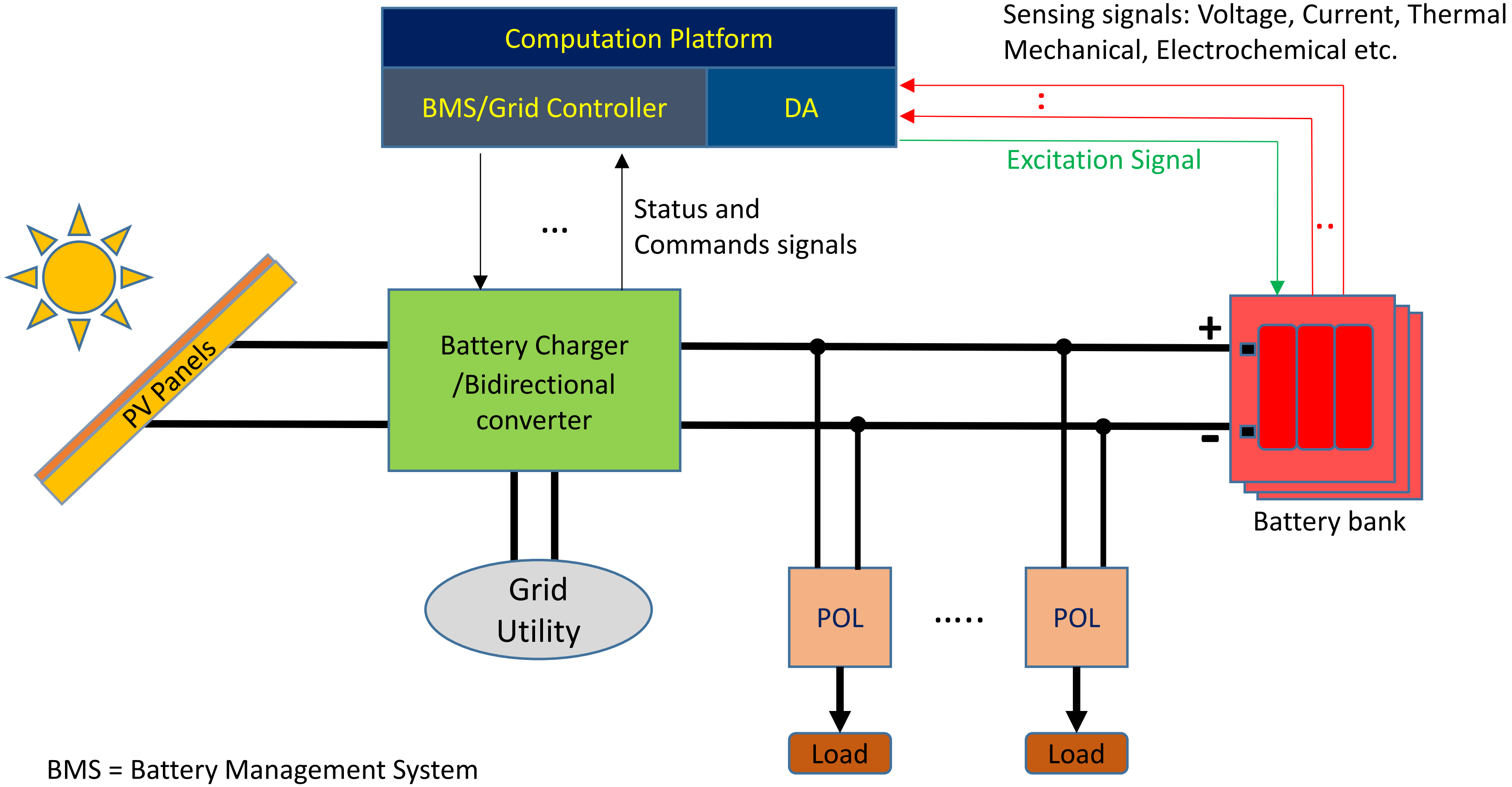
(Nichola Vun)

Conventional Battery Management System



BMS = Battery Management System
DA = Data acquisition module
POL = Point-of-load regulator

Embedded Platform for Battery Analytics



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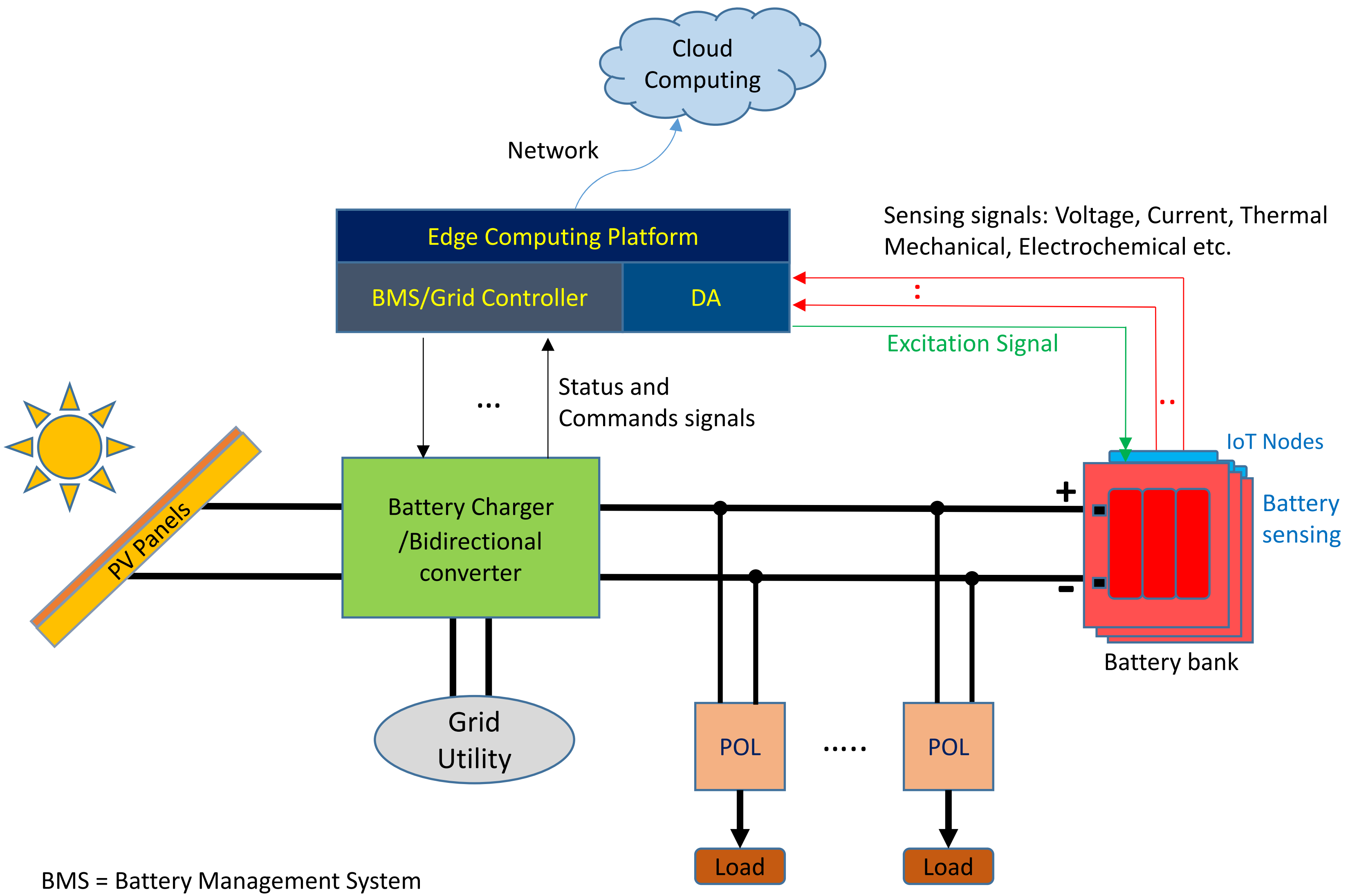
An Intelligent Embedded Platform for Battery Analytics



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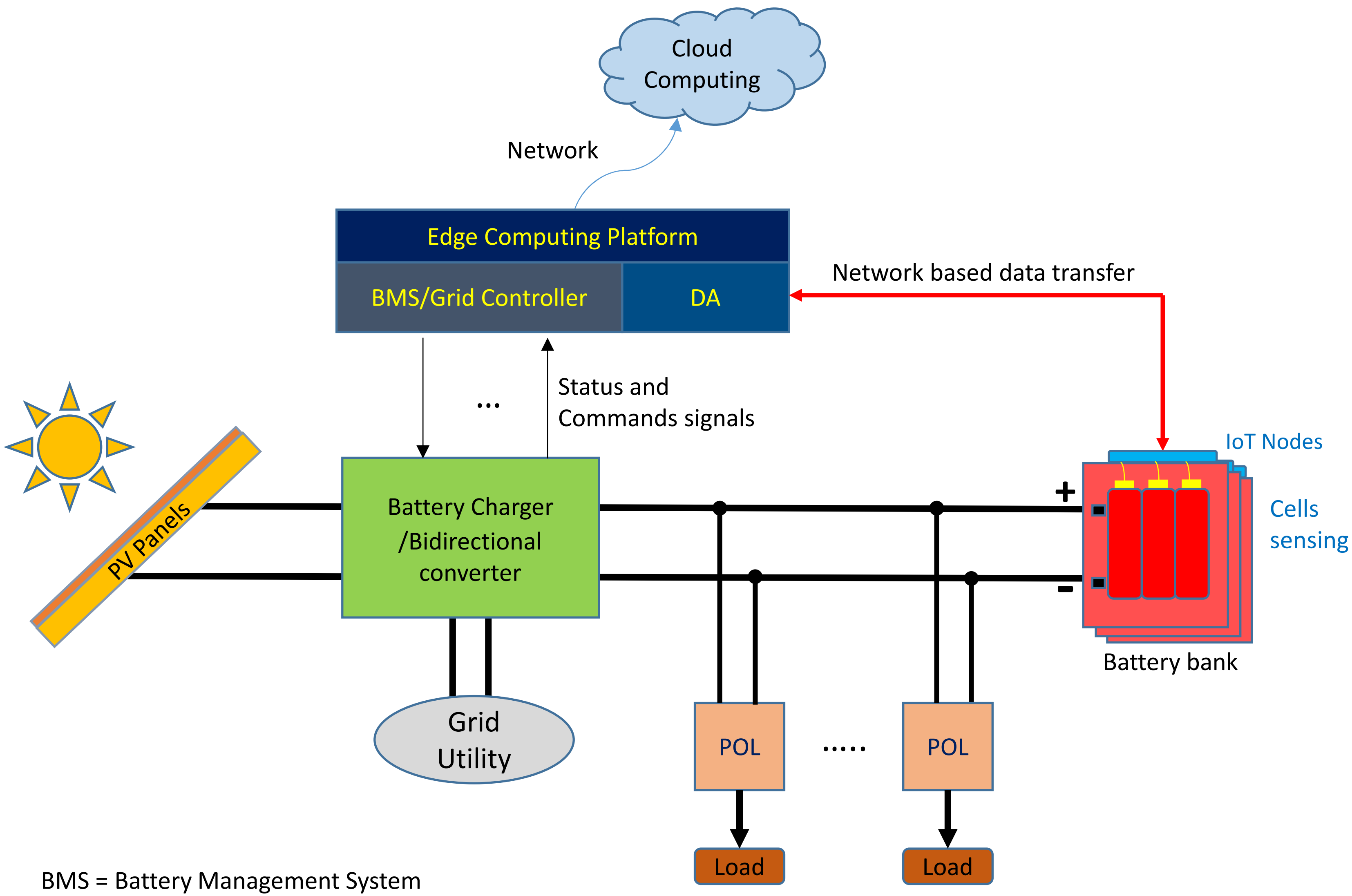

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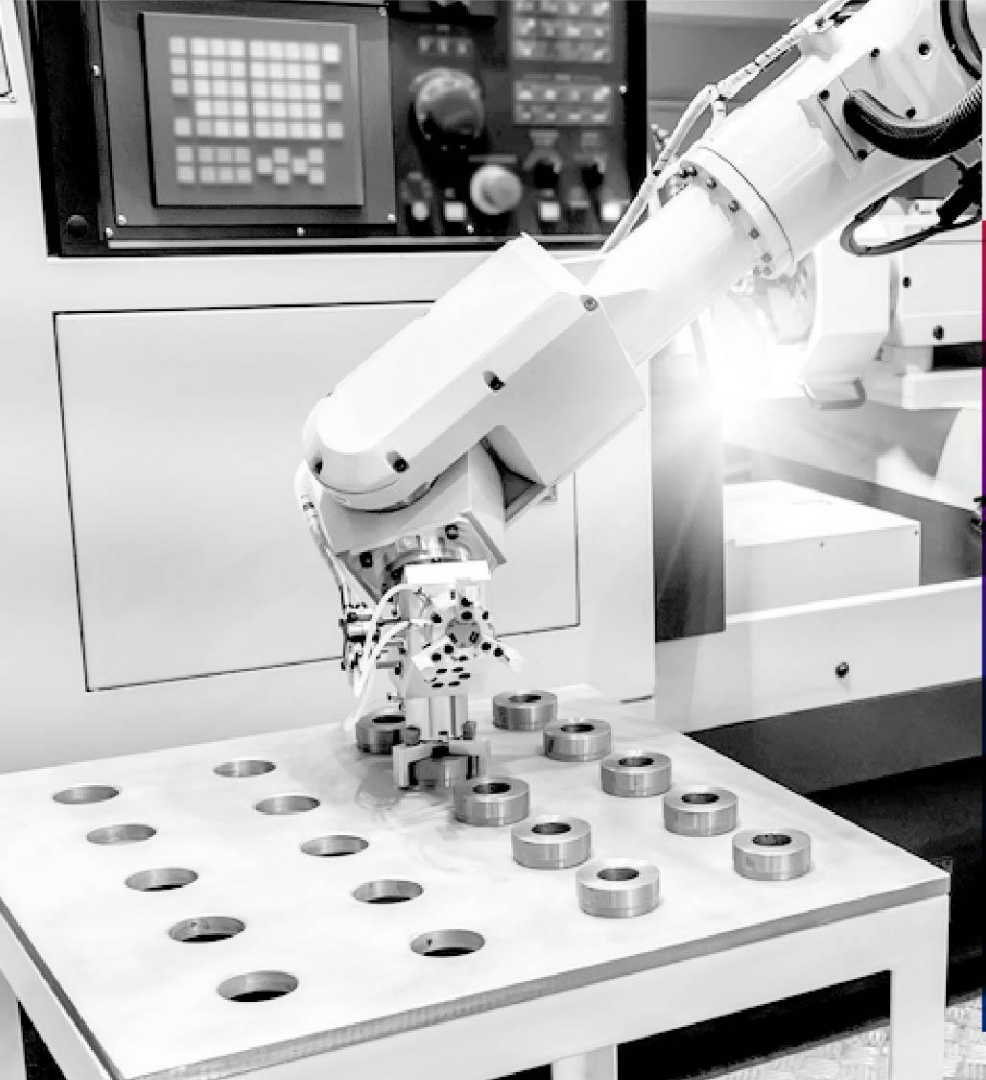

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OPERANDO BATTERY MONITORING AND SENSING FOR BATTERY ANALYTICS

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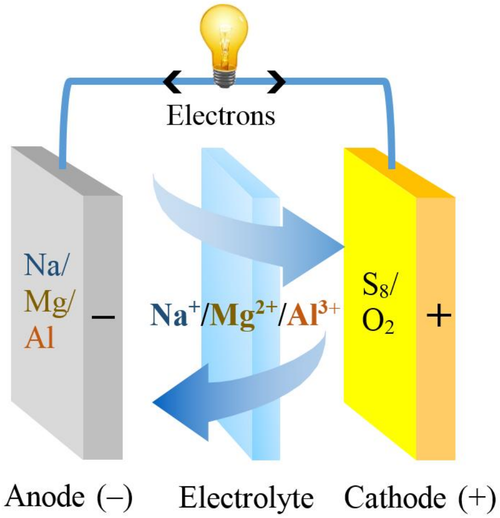
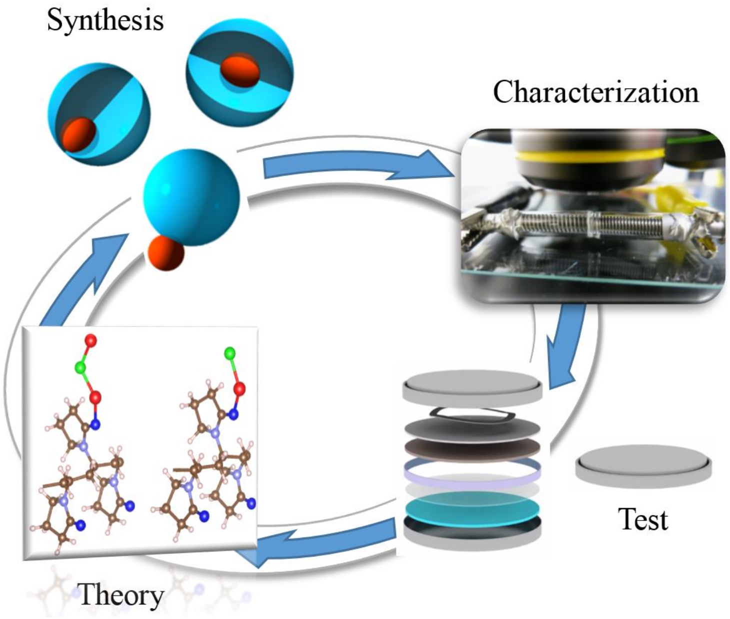
http://www.zwseh.com

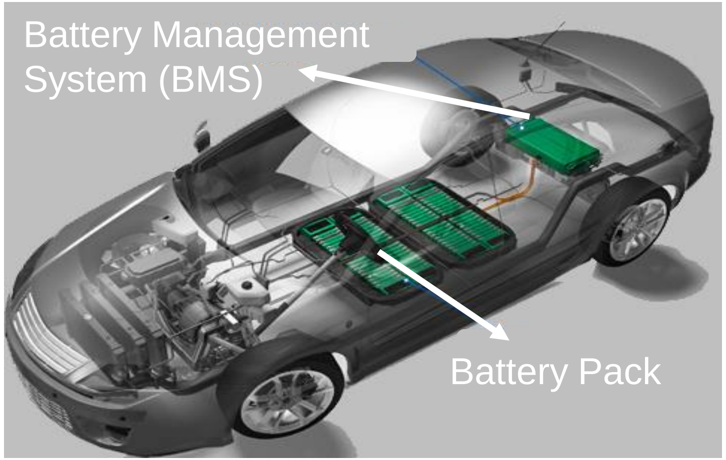
Next-Generation Batteries

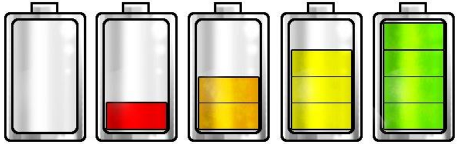




M.-F. Ng, J. Zhao, Q. Yan*, G. J. Conduit*, Z. W. Seh*, ***Nat. Mach. Intell.*** 2020, *2*, 161-170
A. D. Handoko, F. Wei, Jenndy, B. S. Yeo, Z. W. Seh*, ***Nat. Catal.*** 2018, *1*, 922-934
Z. W. Seh, J. Kibsgaard, C. F. Dickens, I. Chorkendorff, J. K. Norskov, T. F. Jaramillo*, ***Science*** 2017, *355*, eaad4998

Operando Battery Monitoring and Sensing





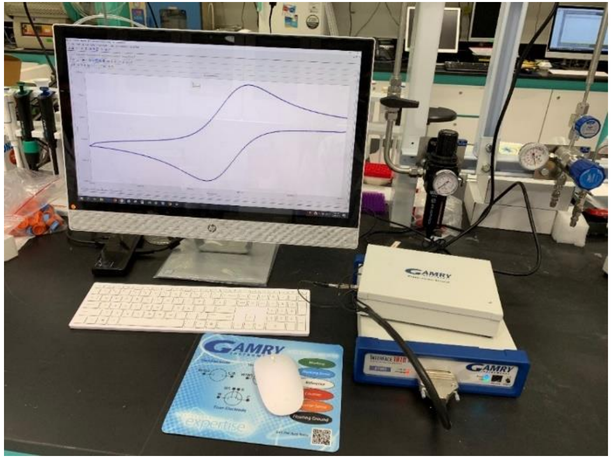
Operando/onboard battery monitoring and sensing is important:

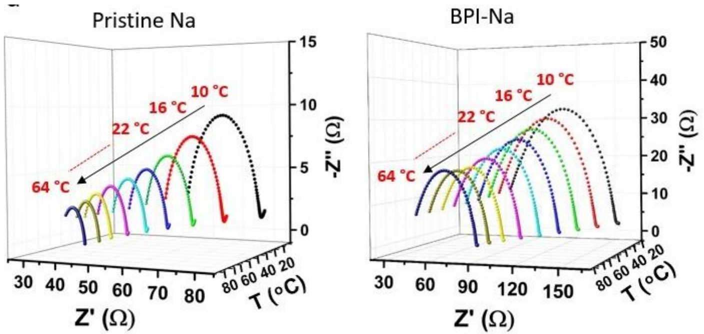
- Determine state of charge
- Determine state of health
- Predict remaining useful life
- Identify catastrophic safety issues
- Enable safe and fast charging
- Optimize battery capacity

Current BMS can measure:
- Current
- Voltage
- Surface temperature

What's next in battery analytics?

Electrochemical Impedance Spectroscopy (EIS)

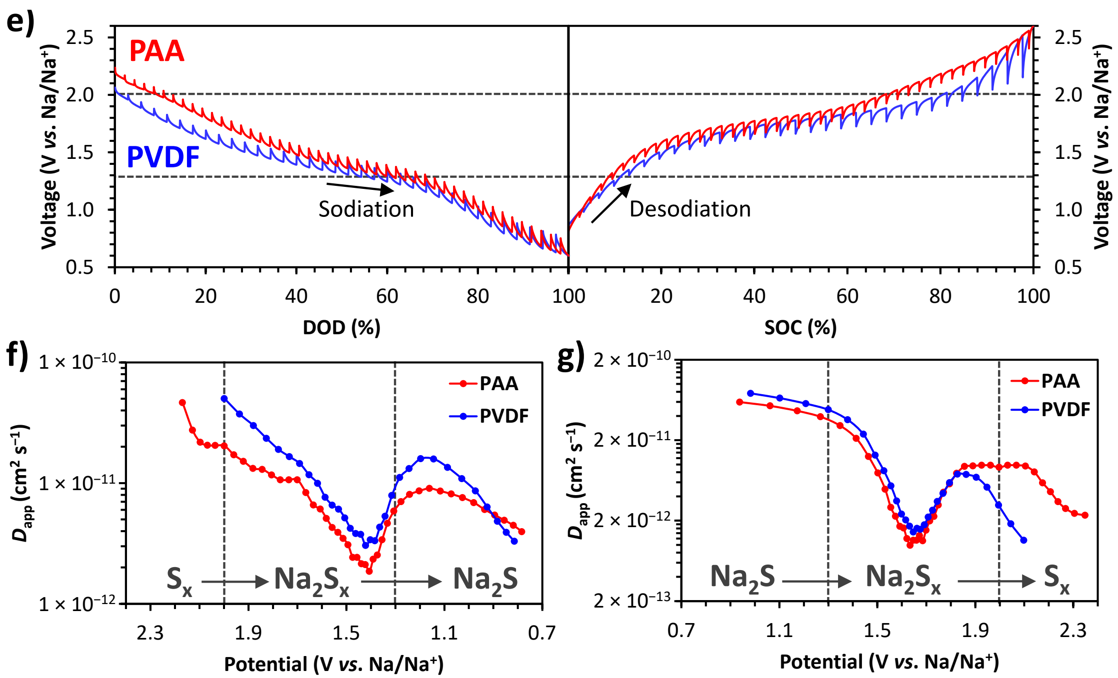




- EIS can give valuable information on internal cell resistance using sinusoidal AC excitation signal
- High internal resistance denotes poor state of health and end of life
- Temperature-dependent EIS can determine activation energy and kinetics for charge transfer

V. Kumar, Y. Wang, A. Y. S. Eng, M.-F. Ng, Z. W. Seh*, ***Cell Rep. Phys. Sci.*** 2020, *1*, 100044
V. Kumar, A. Y. S. Eng, Y. Wang, D.-T. Nguyen, M.-F. Ng, Z. W. Seh*, ***Energy Storage Mater.*** 2020, *29*, 1-8

Galvanostatic Intermittent Titration Technique (GITT)



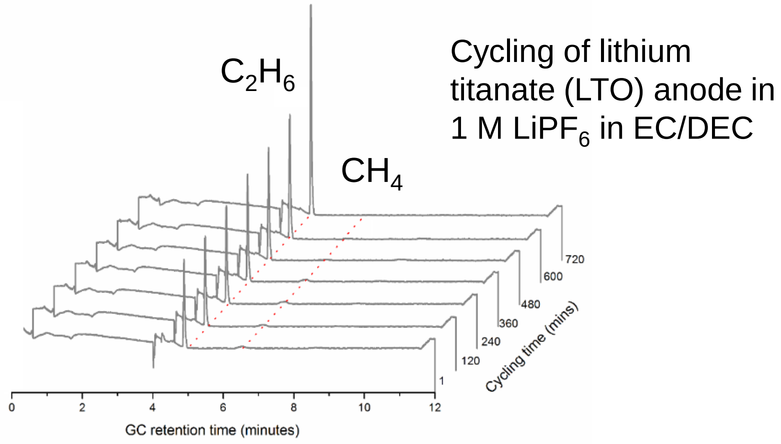
GITT uses current pulses and relaxation times to determine lithium ion diffusion coefficient as a function of battery state of charge

High Precision Coulometry

Courtesy of Novonix

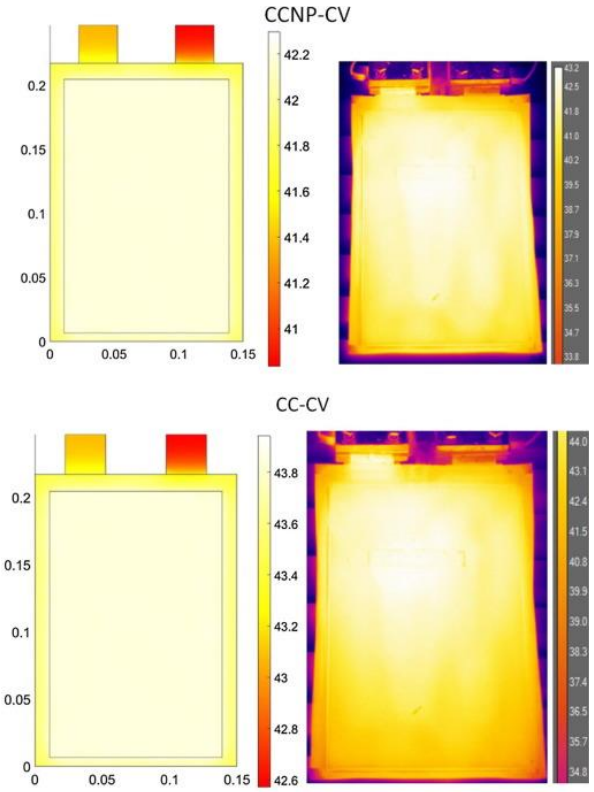
- It is important to have high precision and high accuracy coulometry when evaluating batteries
- Battery cycler can measure coulombic efficiency with a precision of 20 ppm and accuracy of 50 ppm
- High precision coulometry can enable reliable prediction of battery lifetime within short time period

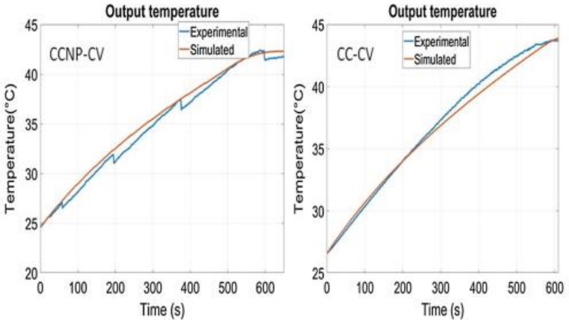
Gas Chromatography (GC)



- GC can measure unwanted gas evolution from electrolyte decomposition during battery cycling
- Flame ionization detector and thermal conductivity detector can perform trace analysis down to ppb levels

Thermal Imaging





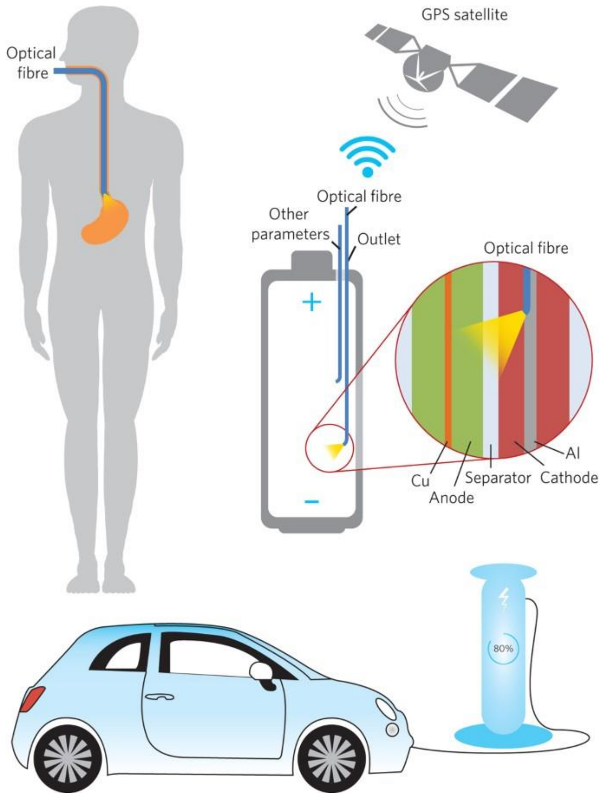
Appl. Therm. Eng. **128**, 1282–1296 (2018)

- Thermocouples and infrared cameras can be used to measure surface temperature of batteries

- However, surface temperature can differ greatly from internal temperature, which is more relevant to safety

CREATING GROWTH, ENHANCING LIVES

Future Prospects and Outlook



Nature Materials 16, 45–56 (2017)

- Implantable smart sensors in batteries in the future?
- Monitor internal processes in batteries during operation, e.g. internal temperature, pressure, strain, etc
- Can determine state of charge and health of batteries
- Can communicate with outside world
- **Ultimate goal:** Incorporate operando battery sensors and data into a smart BMS for the future

CREATING GROWTH, ENHANCING LIVES

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THANK YOU

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In-situ and ex-situ materials characterization for explainable machine learning

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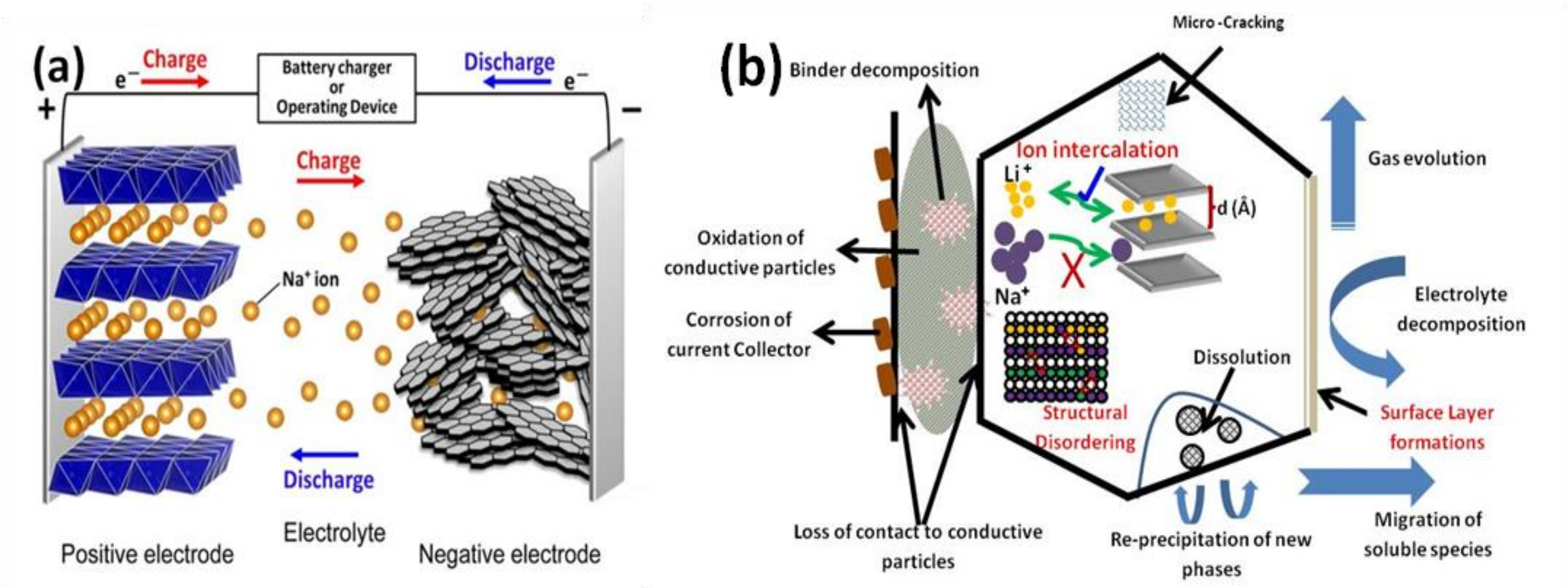
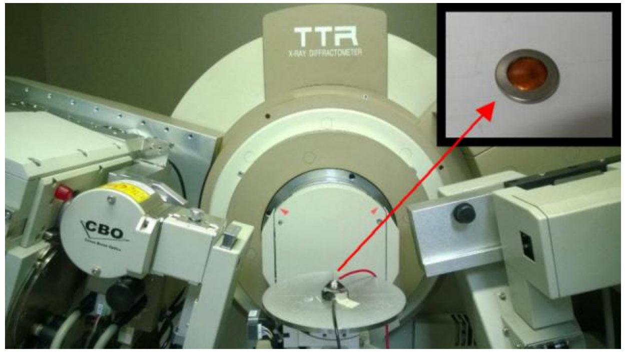
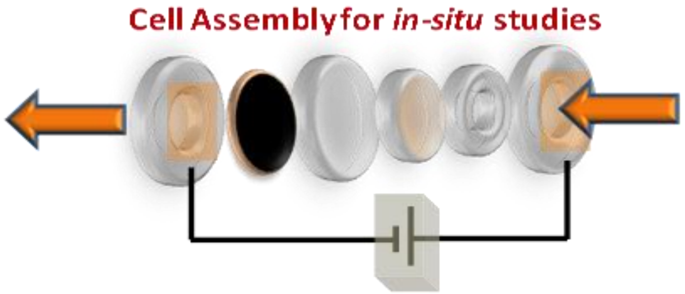
Singapore

Materials changes and electrochemical process in LIBs



Various materials changes and electrochemical process taken place in Li ion batteries and affecting the performance



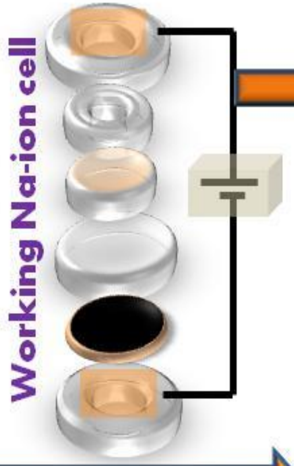


In-situ cells + characterization tools = real time information on material components during battery operation

Working principle of in-situ ex-situ materials characterization

In-situ XAS

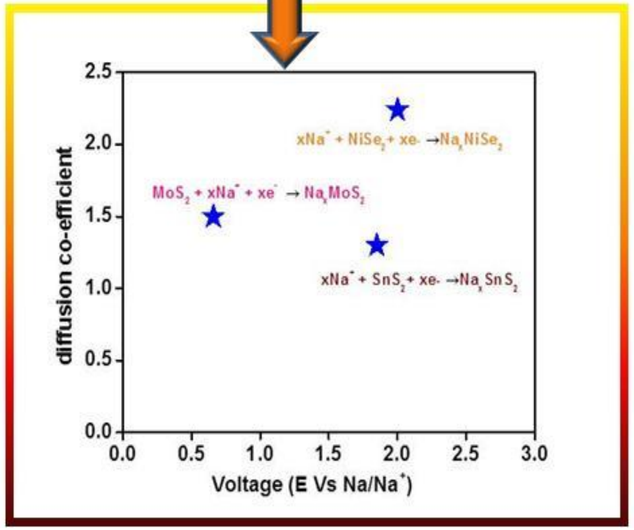
In-situ TEM

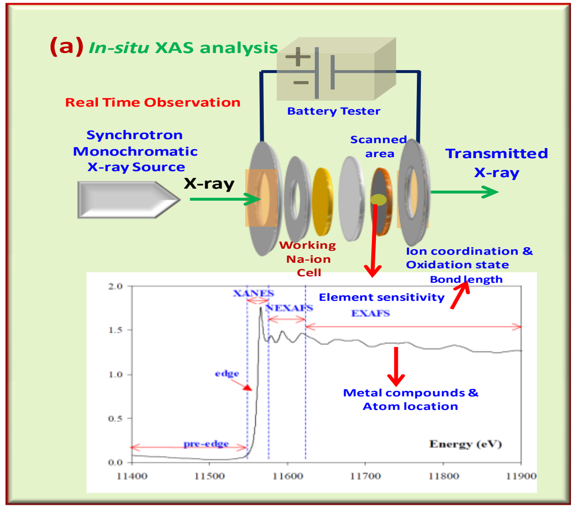


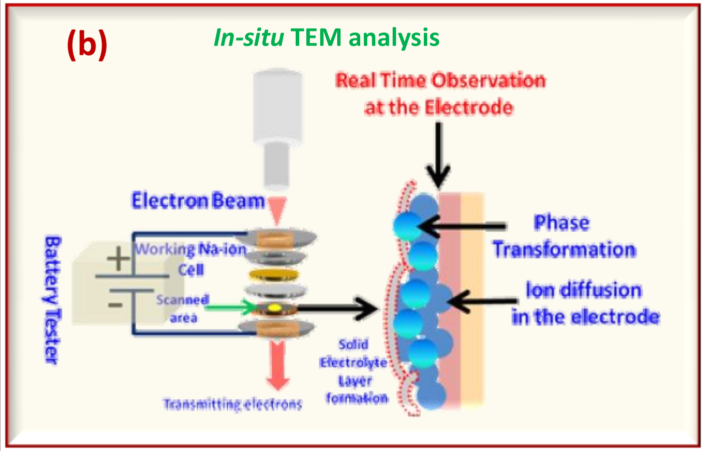
- Na-ion diffusion in various electrode
- Reaction kinetics of Na incorporation into the electrode
- The local structural changes
- the transition bonds/phases formed
- Phase transformation
- Surface Layer formations
- Quantifying of Na ion diffusion

Electrochemical Studies

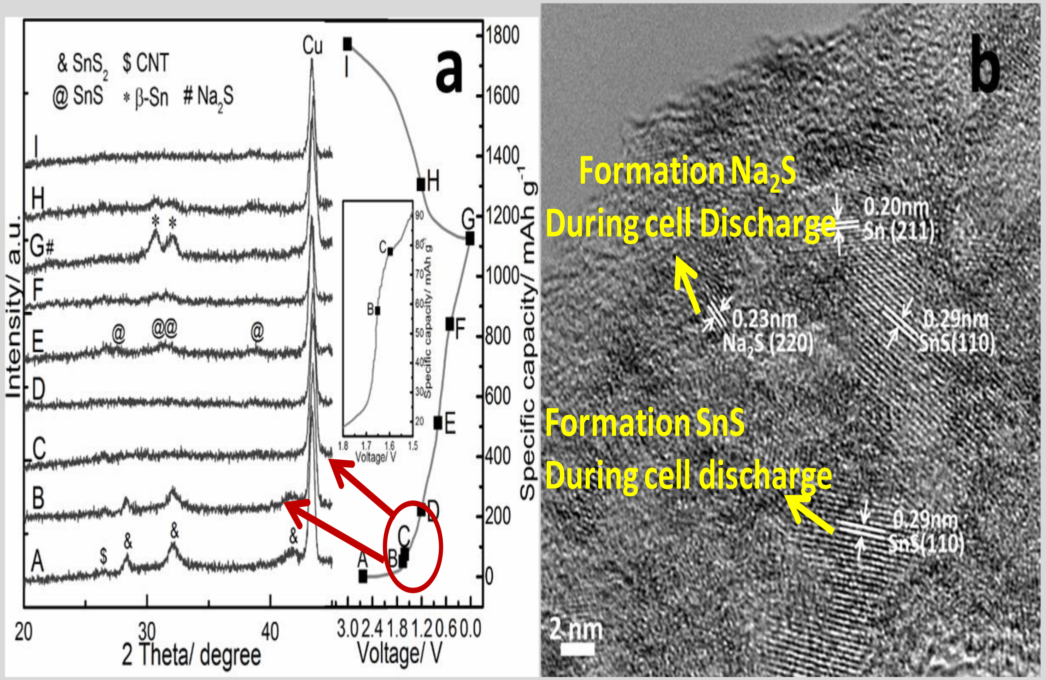
- ❑ Cyclic Voltammetry
- ❑ EIS







Characterization to generate information on monitoring the change of battery components



(1) *spectroscopy tools*

Phase, expansion, electrode dissolution, structure disordering, valence, SEI growth, SEI decomposition, binder decomposition

(2) microscopy

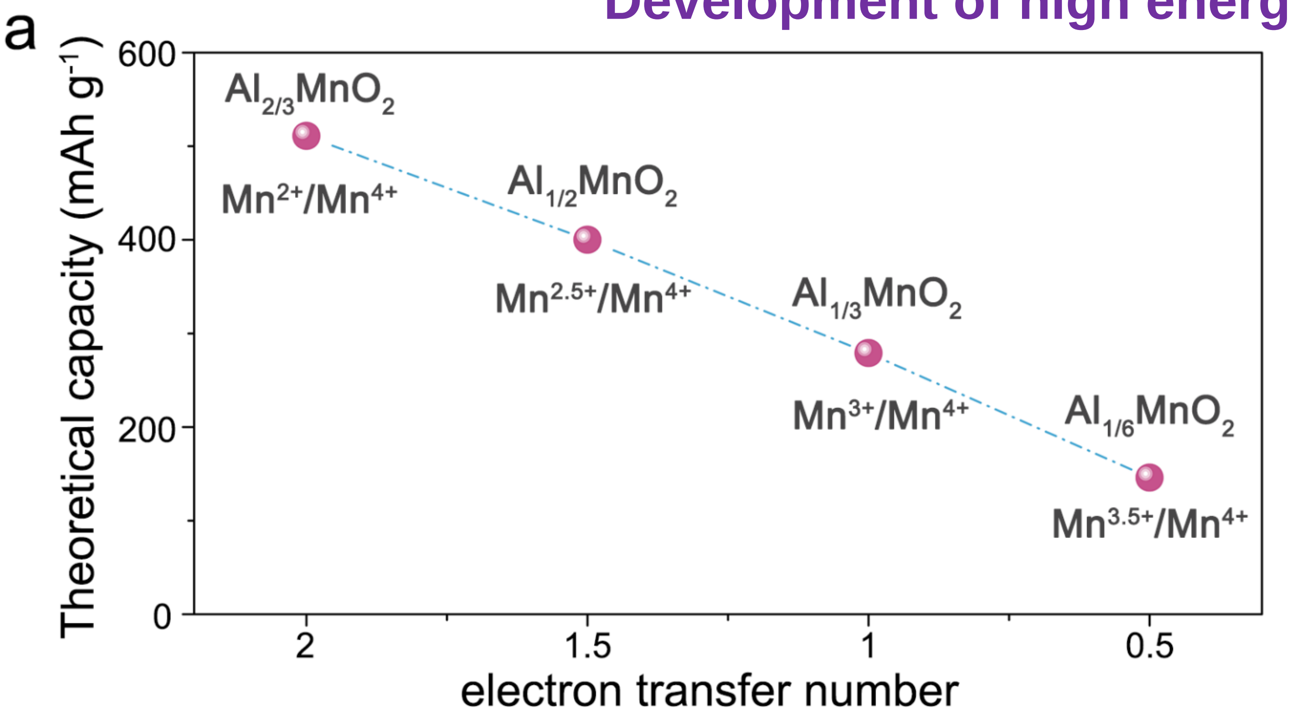
Graphite exfoliation, electrode particle cracking, Li plating/dendrite

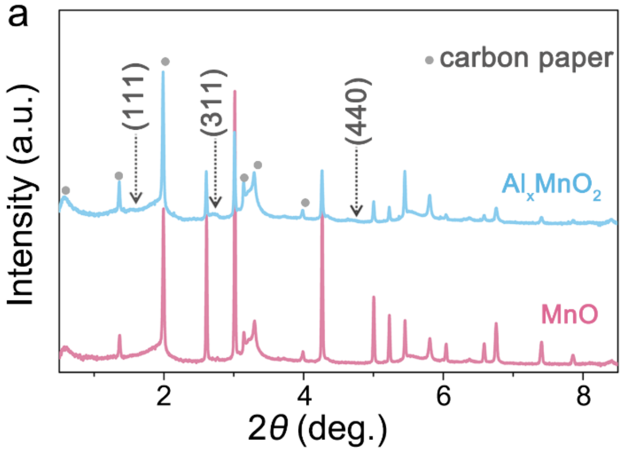
Our studies on the phase change, structural changes of SnS_2 for battery electrode during charge discharge cycling

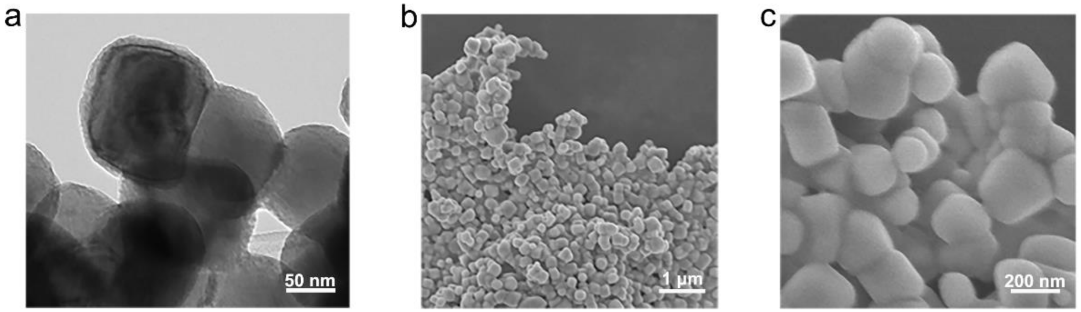
Sun and Yan*,ACS NANO 9 (11), (2015), p11371-11381

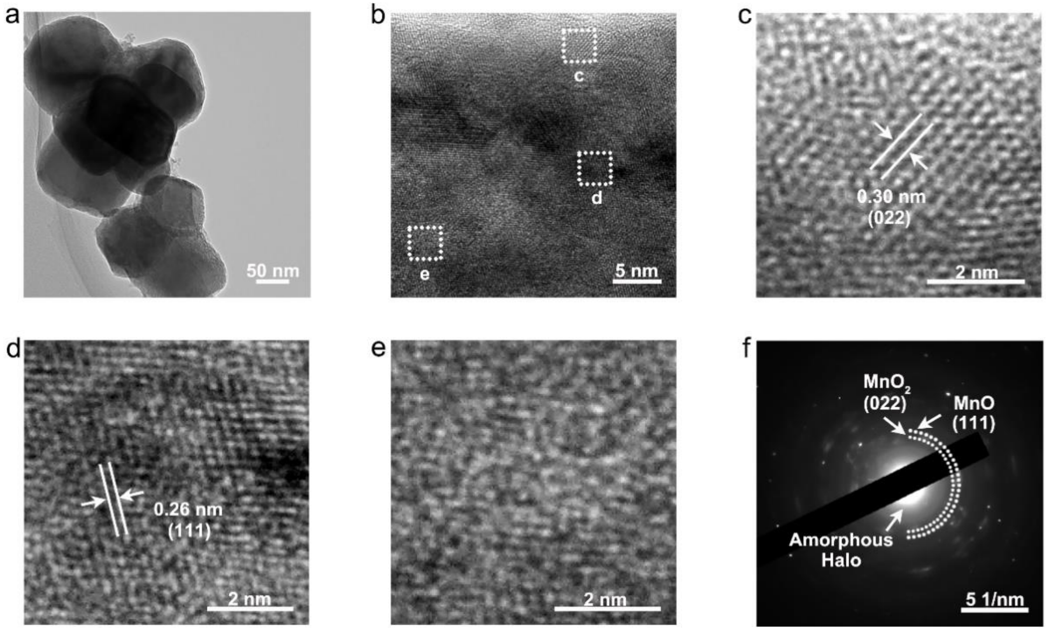
High Energy Density and Stable Rechargeable Aqueous Al ion Battery

Development of high energy density Cathode, MnO → Al_xMnO_2









Yan, Rui*, Yan,* Yu* et al, JACS (2020)

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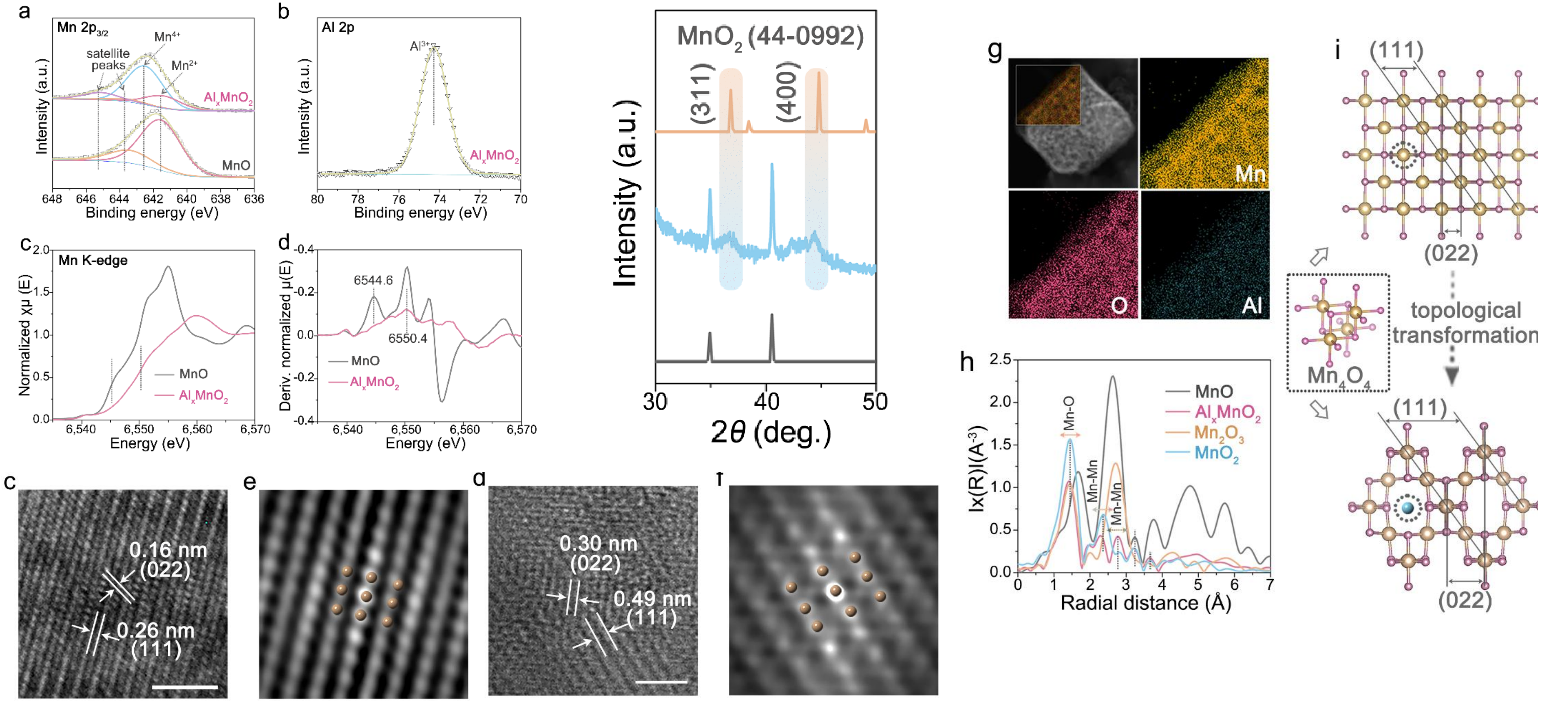

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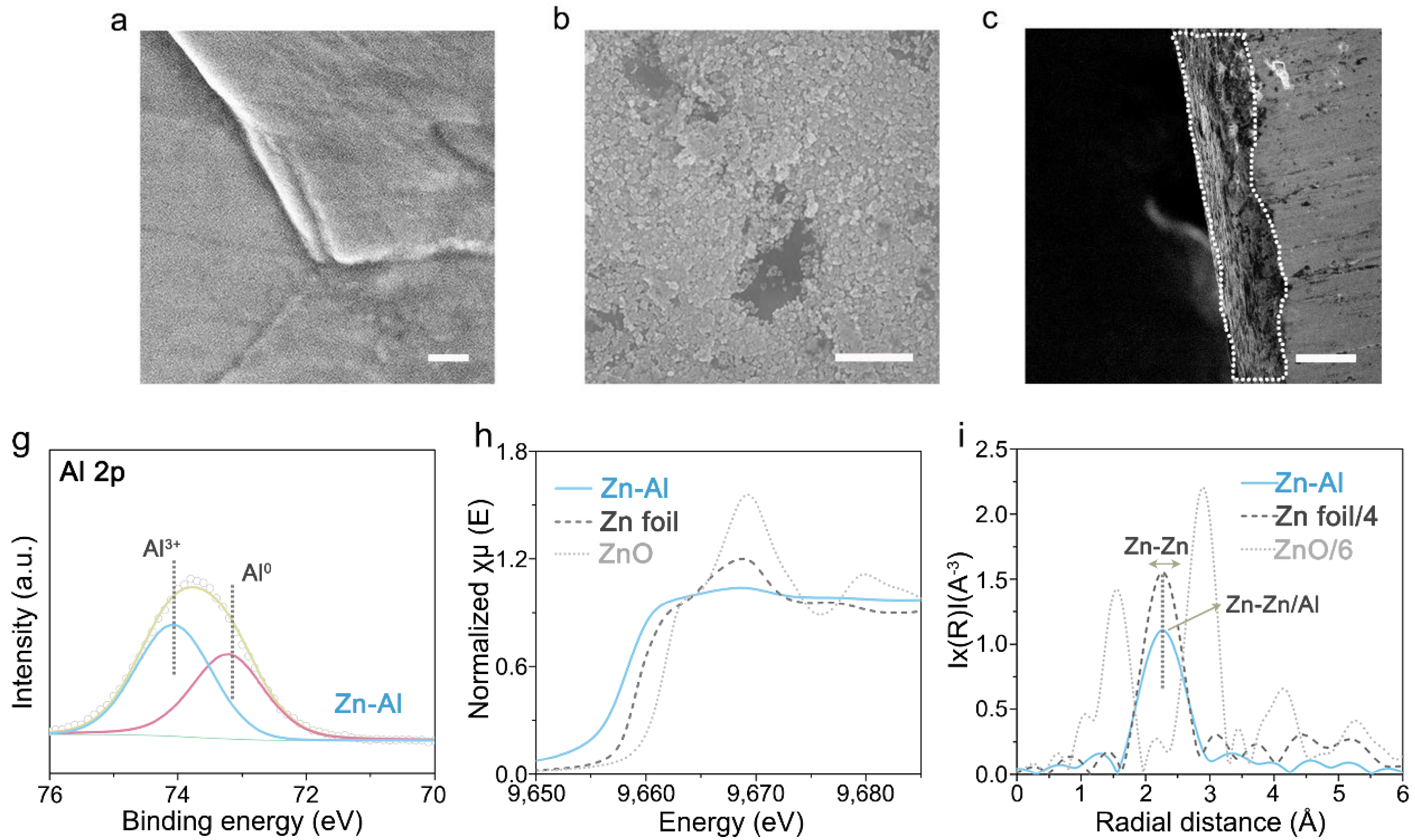

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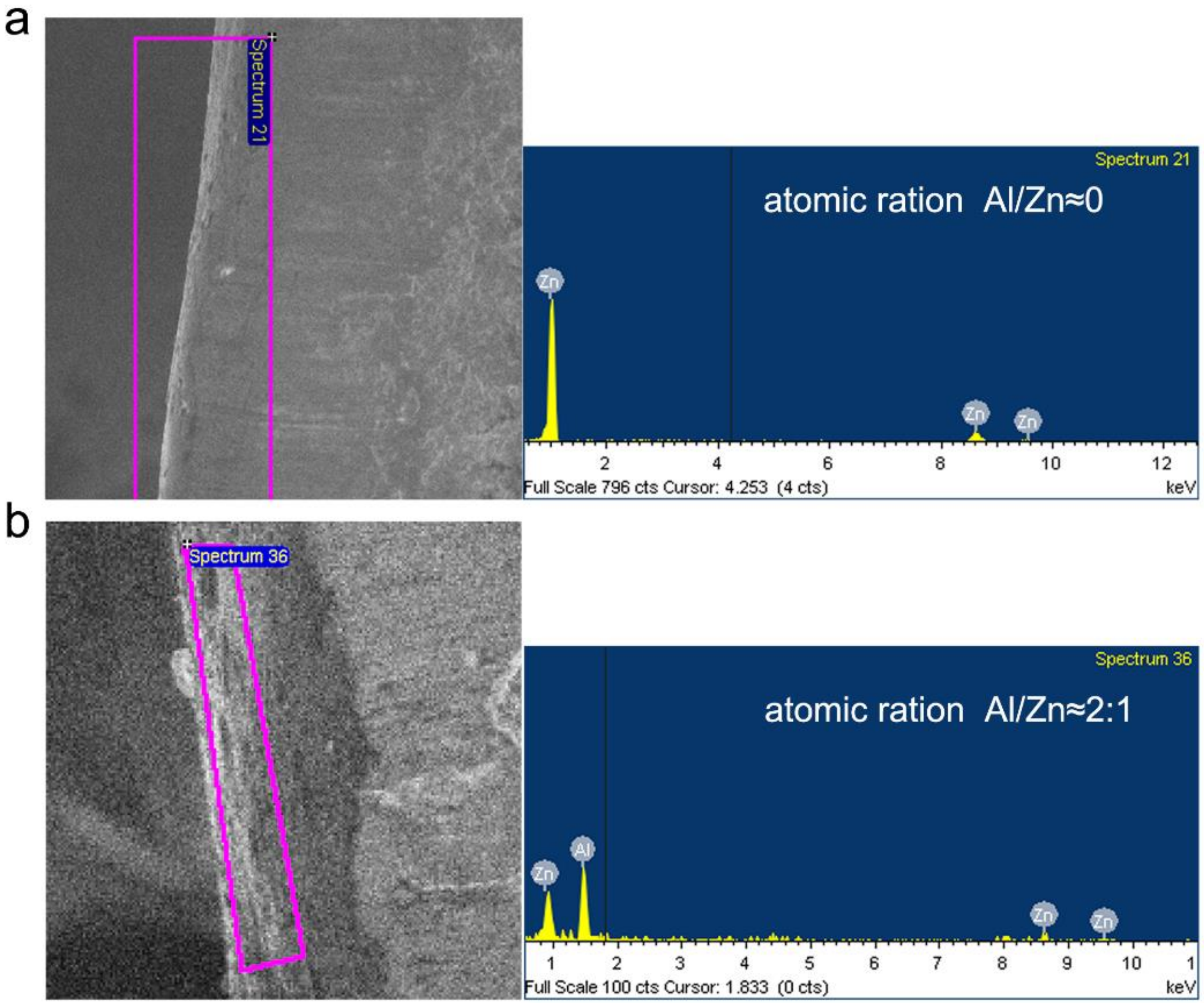
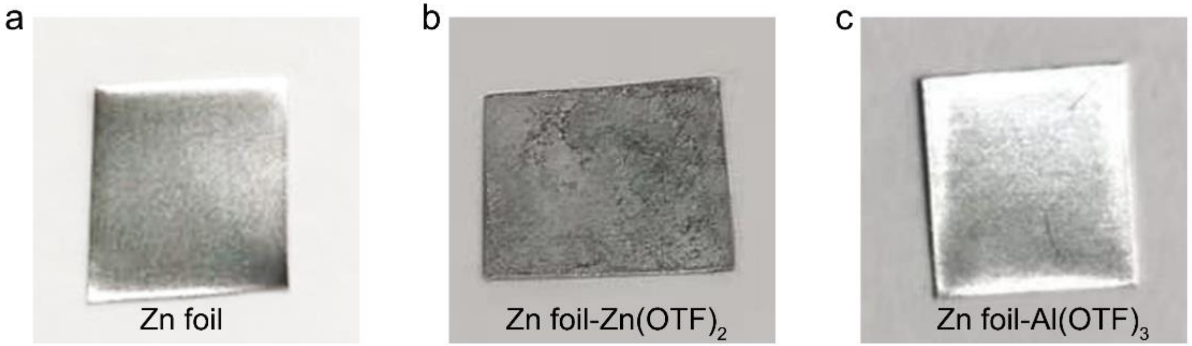
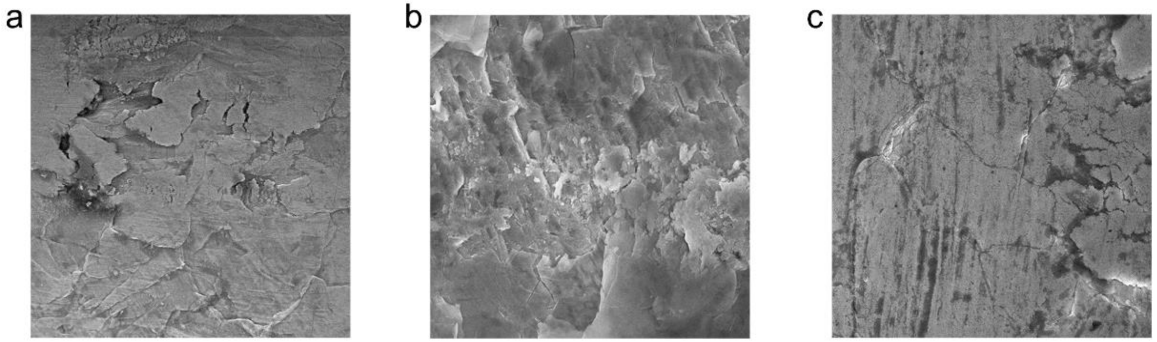
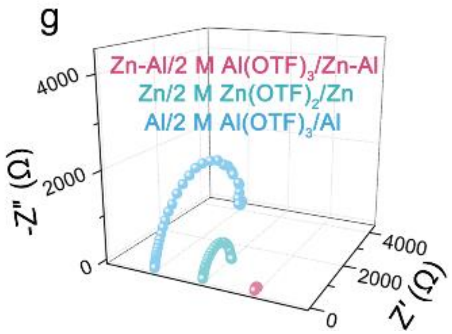
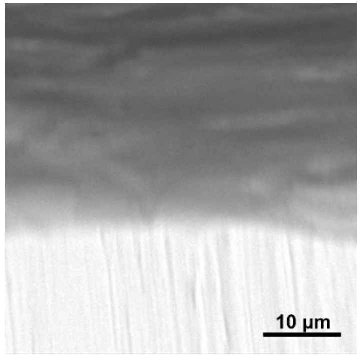






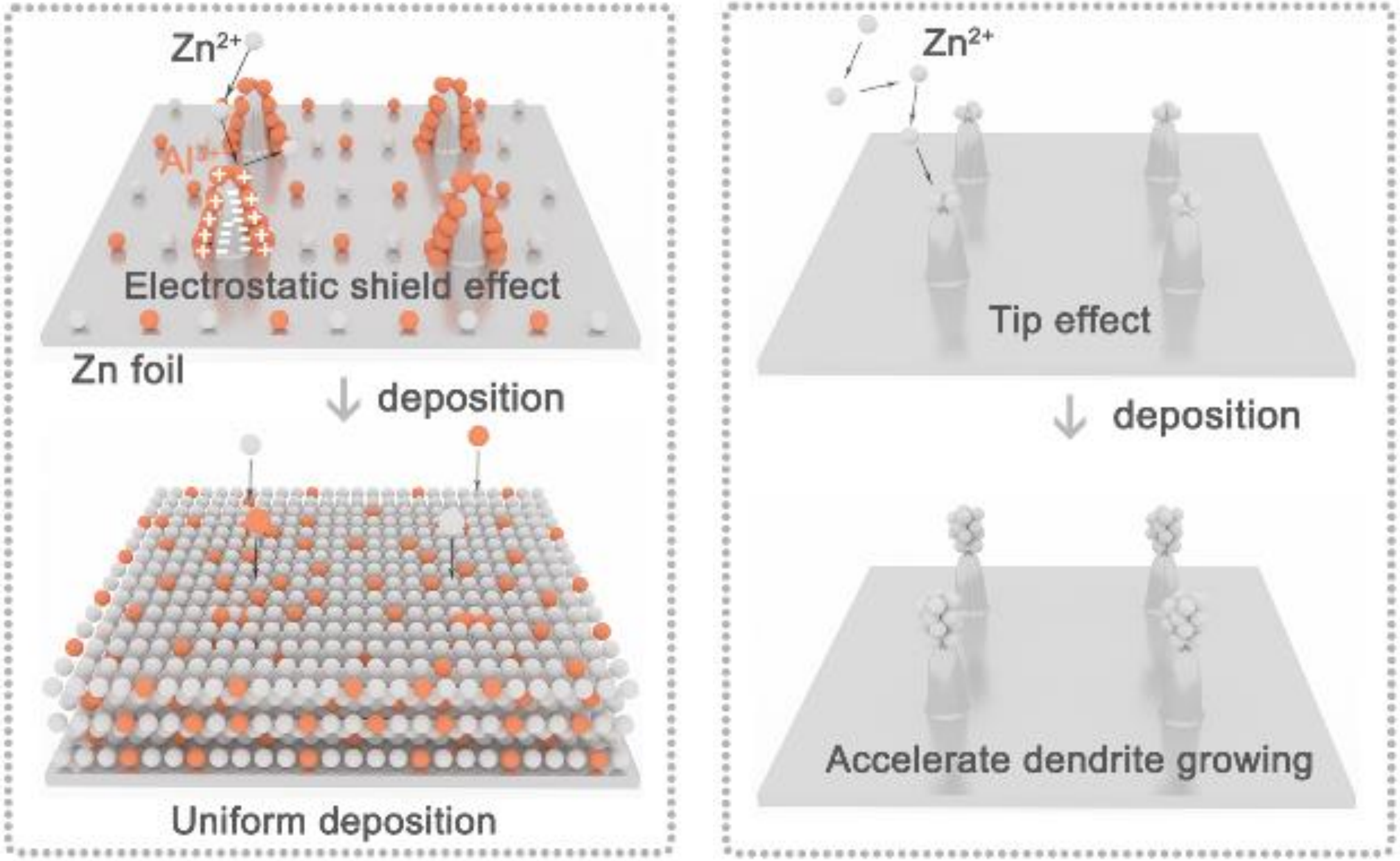


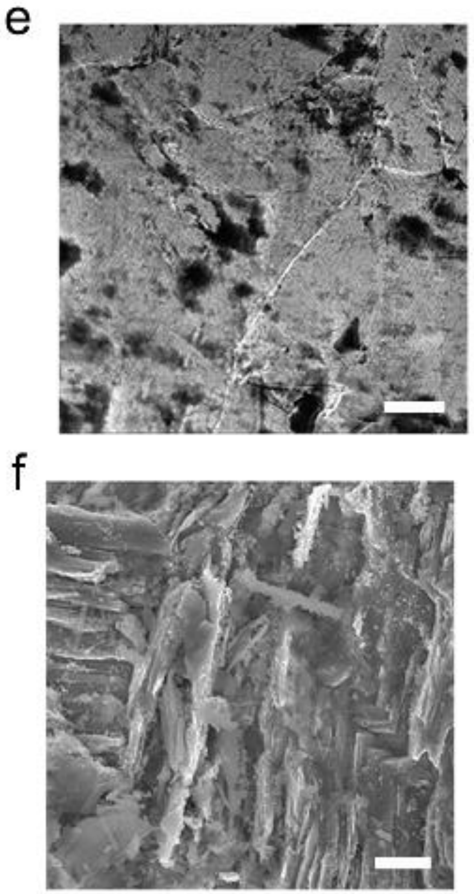


Yan, Rui*, Yan,* Yu* et al, *JACS* (2020)

High Energy Density and Stable Rechargeable Aqueous Al ion Battery

Symmetric cells comparison, inhibition of dendrite and side reaction





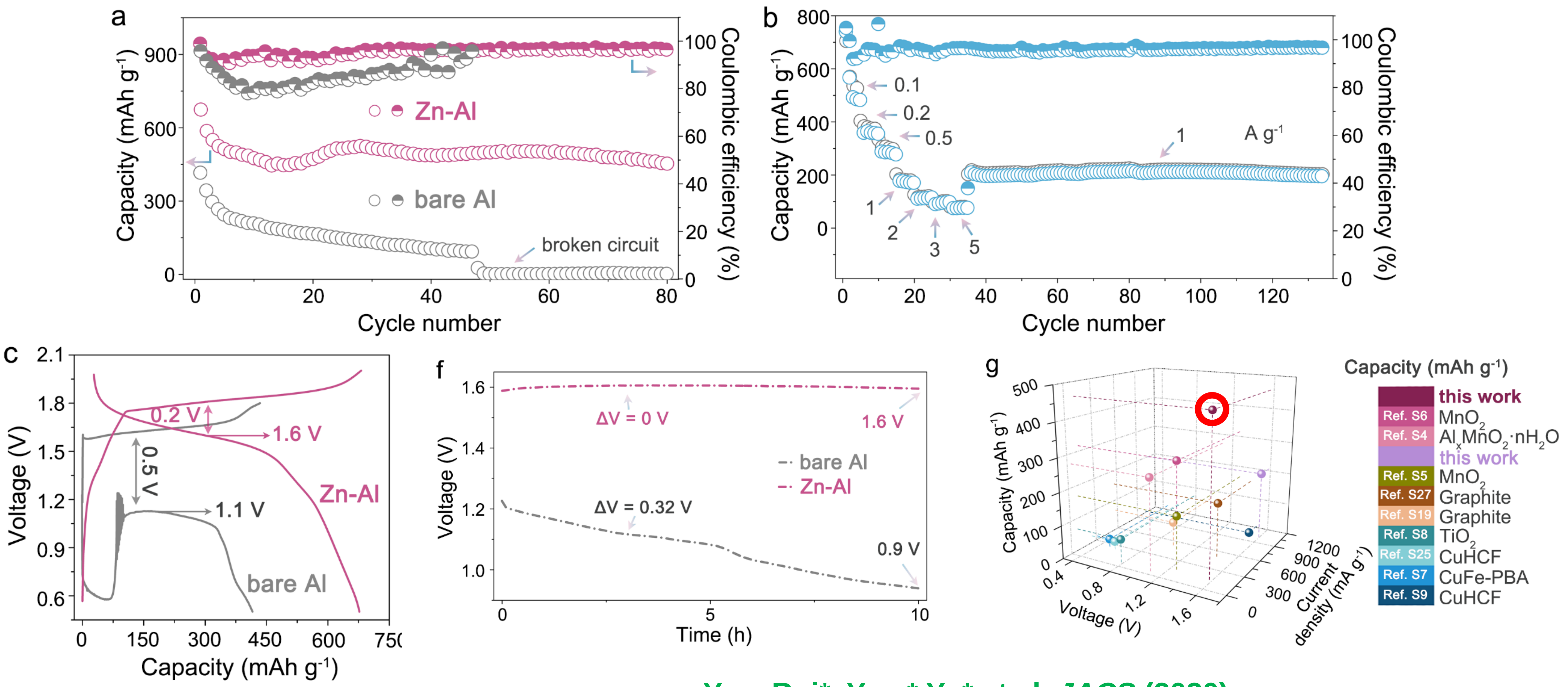
Zn-Al alloy after plating 100 cycles

Zn alloy after plating 100 cycles

Yan, Rui*, Yan,* Yu* et al, *JACS* (2020)

High Energy Density and Stable Rechargeable Aqueous Al ion Battery

Full Cell battery performance: 460 mAh/g with Columbic efficiency ~98% upon cycling (highest achieved so far in the world), high discharge voltage (1.6 V), stable cycling, no dendrite formation, no side reaction, good rate (fast charging) performance, long shelf life.



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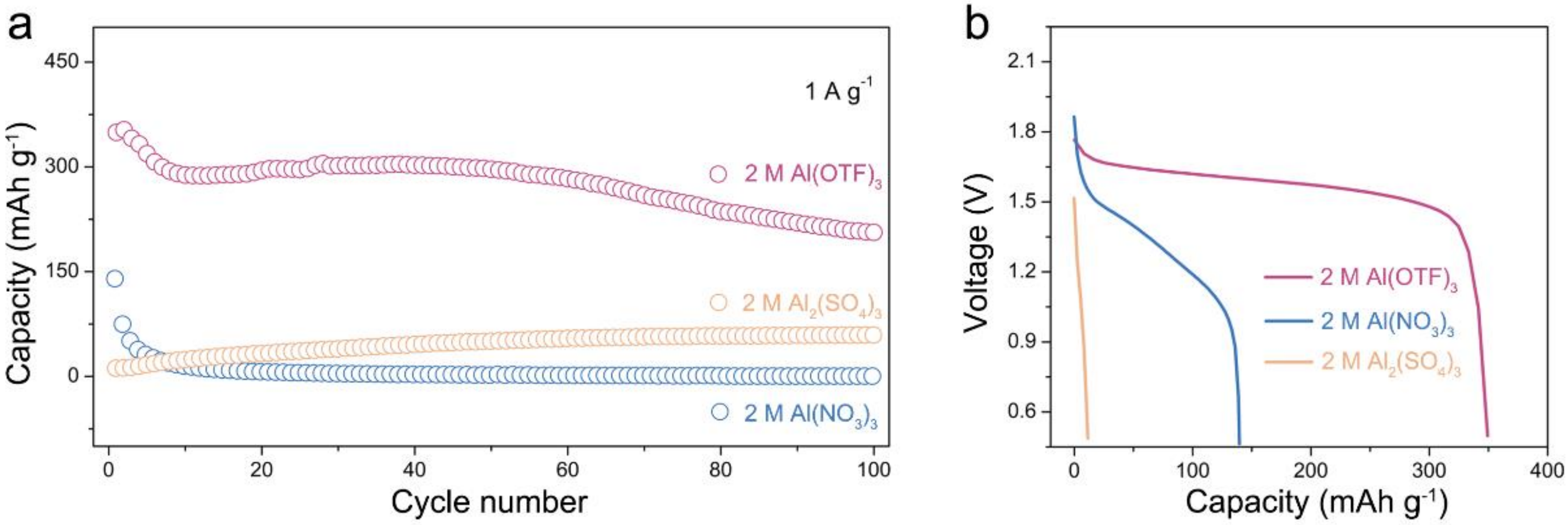
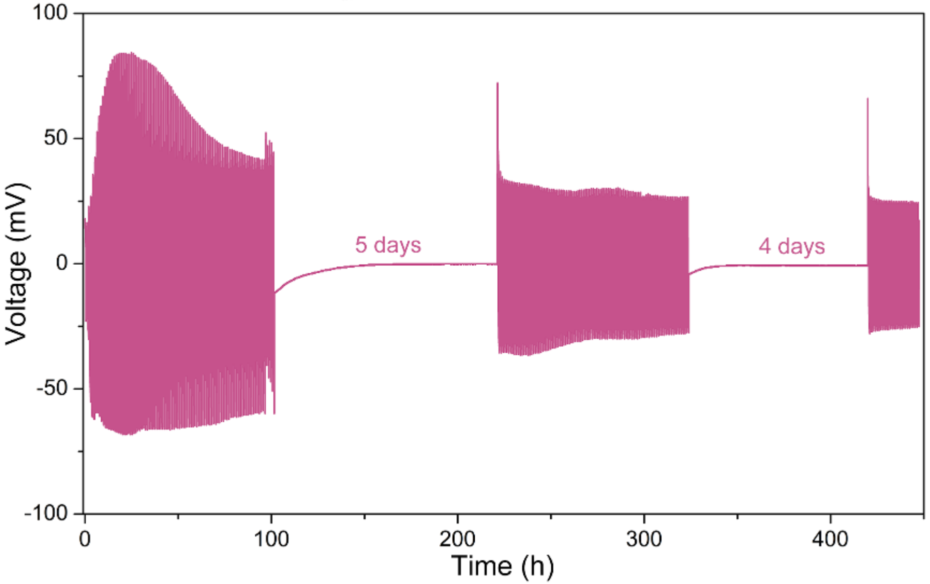
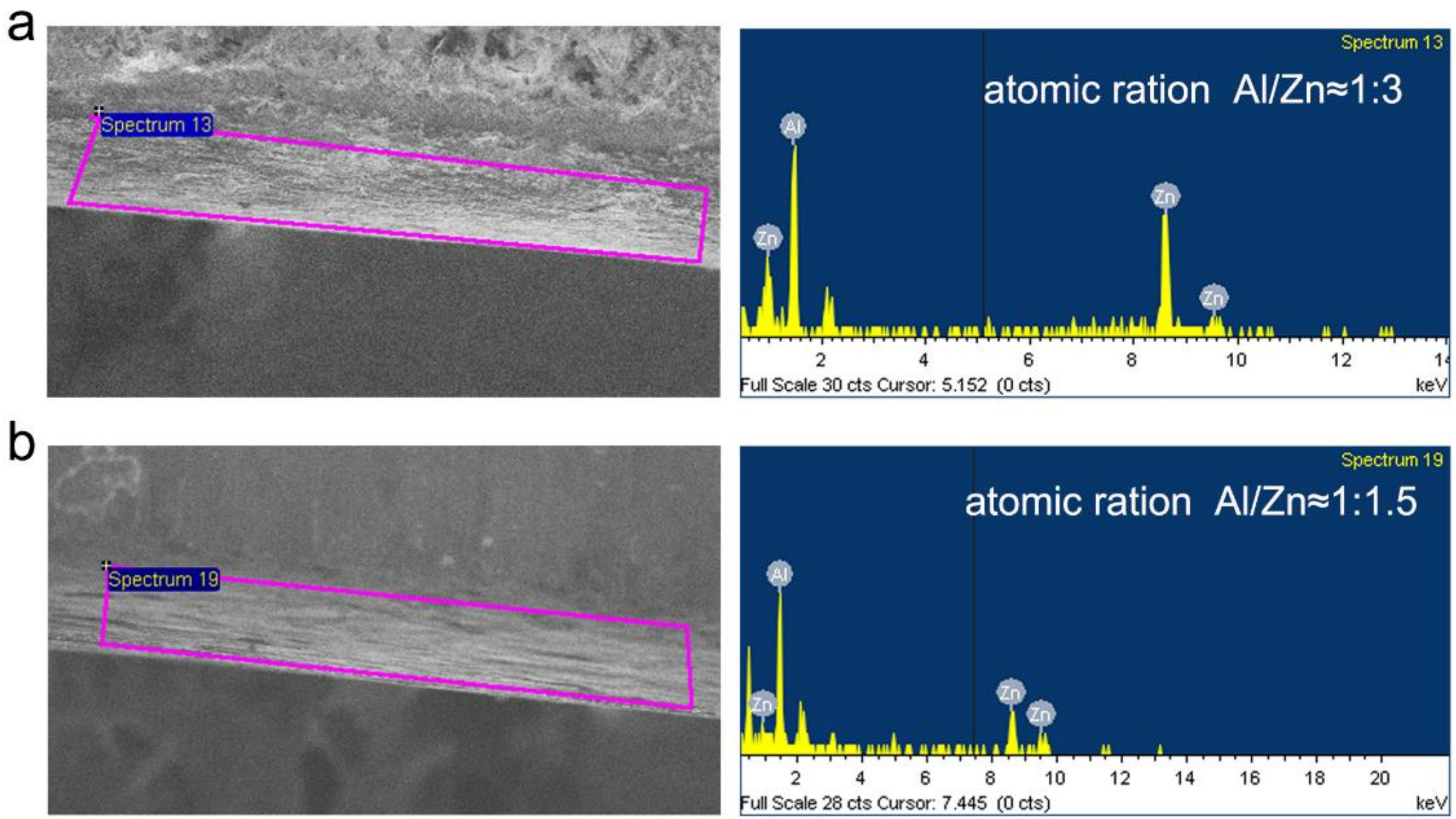




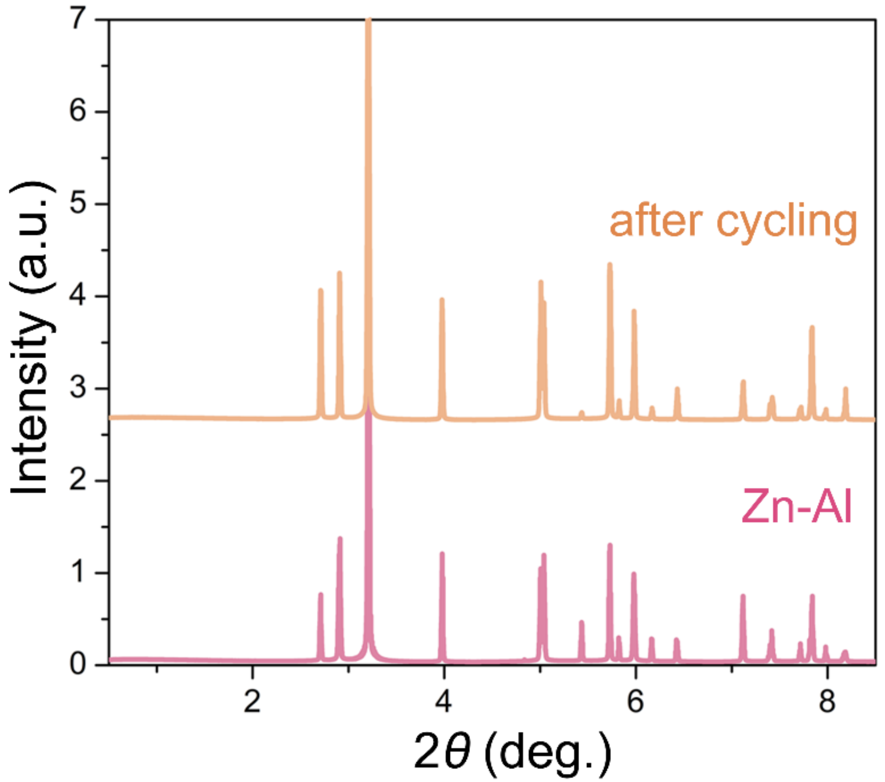
Zn is selected based on capacity, Voltage, CE and self-discharge

Yan, Rui*, Yan,* Yu* et al, *JACS* (2020)

High Energy Density and Stable Rechargeable Aqueous Al ion Battery



SEM and EDS images of Zn-Al anode at different states after 10 cycles. (a) Discharge. (b) Charge.



High energy synchrotron XRD patterns of Zn-Al anodes before and after cycling. No observable phase change

Yan, Rui*, Yan,* Yu* et al, *JACS* (2020)

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INNOVATION FACTORY
SEP 2020

Mission

To support SMEs from ideation to design and engineering stage, and migrate them to product owners in order to venture into higher value markets.

Vision

The one-stop design and solution centre for Singapore SMEs.

Objectives and Intent of the Innovation Factory

Objectives

- To **plug** the current gaps in companies looking to develop new products
- **Catalyse** innovative design and **Scale up** to Pilot production

Target Group

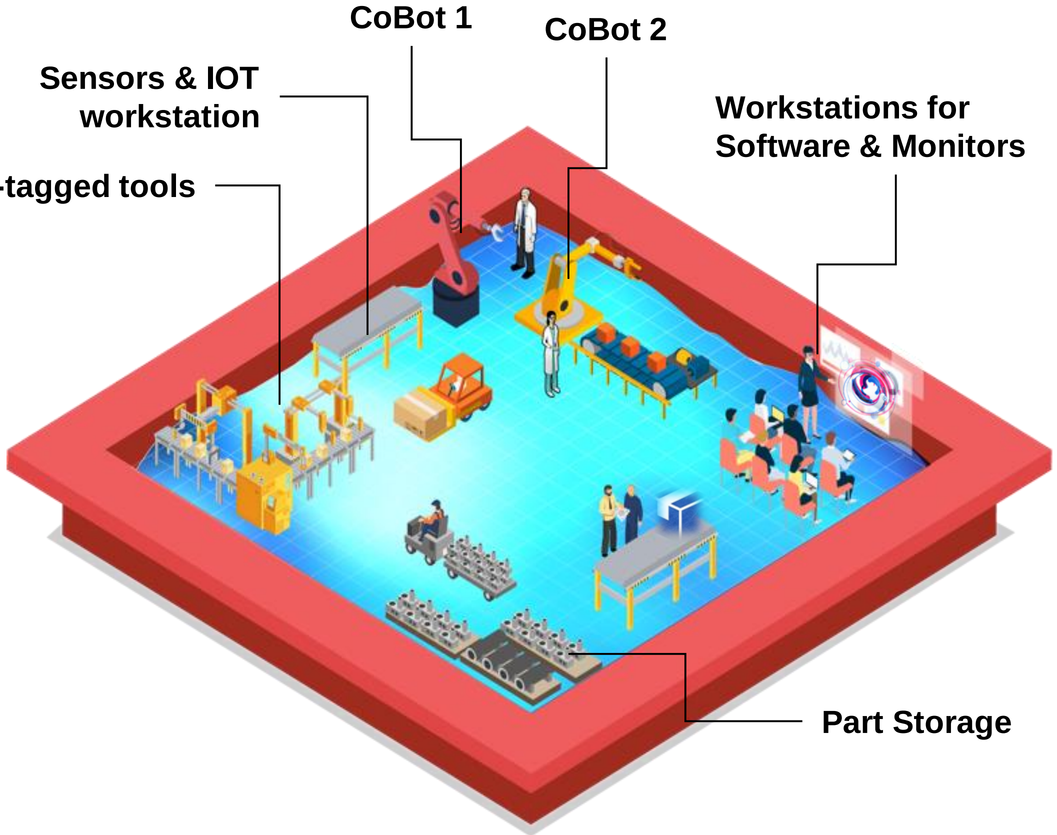
- Product and Equipment Distributors
- Companies curated via Operational & Technology Roadmap (OTR) process
- PE company aspiring to be an Original Device Manufacturer (ODM)
- 2nd generation SME owners who plan to branch into new areas
- **Lifestyle, Retail and consumer products companies**

Value Capture

- Enable local SMEs to move up the value chain and broaden business opportunities
- Migrate SMEs from component / module manufacturer to product owner
- Form network of hardware & software companies to co-develop product

Differentiators

- Enable SMEs to 'Fish' (from Ideation to Pilot Production) via the Product Development journeys



The Innovation Factory

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SIMTech Innovation Factory – The IDEA Model

Target Companies

- Precision Engineering
- MedTech
- Distributors
- A*STAR OTR

Stage 1 IDEATION

Ideation Journey Program

- Creating an ecosystem with application of **Design Thinking** methodologies
- Exchange of ideas between demand and supply drivers
- Design Bootcamp
- Focus Areas:
  - MedTech
  - PE and Industrial Equipment
  - Lifestyle, Consumer and Retail

Start Design Thinking early (core competency)

Stage 2 DESIGN

Design Journey Program

Outsourced projects to Design Companies:

- Advanced Product & Engineering design
- New Product Development
- Embedded Systems
- Network of Designers & Consultants

Stage 3 ENGINEERING

Engineering Journey Program

Access pool of experts from **RIs, IHLs, COIs**:

- Robotics
- Additive Manufacturing
- AI, Sensors & IoT
- Vision & Inspection
- Advanced Materials
- AR, VR, Simulation

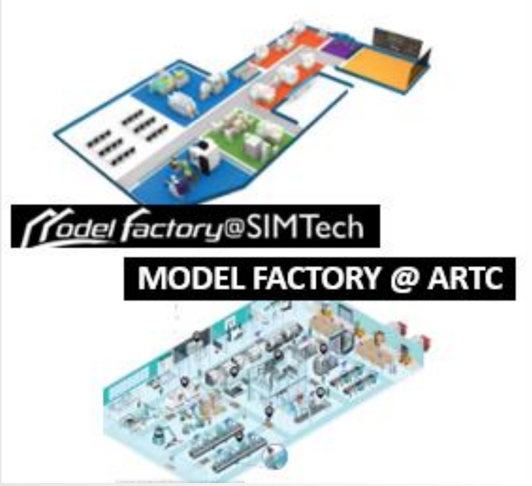
PE COI Precision Engineering Centre Of Innovation – Sustaining and Advancing PE Industry

Nanyang Technological University Singapore; NUS National University of Singapore; SUTD Singapore University of Technology and Design; SIT Singapore Institute of Technology; Singapore Polytechnic SP; Republic Polytechnic; Temasek Polytechnic; Ngee Ann Polytechnic; NYP Nanyang Polytechnic

Stage 4 APPLICATION

Scale-up to Pilot production program

- Assist SMEs to set up Pilot Production line
- Model Factory Digital Solutioning
- Product / Module Performance Validation and Assessment



Innovation Labs to address today's Gap

Innovating with COIs, IHLs and A*STAR RIs

Collaboration with COIs and the Larger Ecosystem

Supply Drivers

Distributors
OTR Companies
PE Companies
2^{nd} Owners

Innovation Factory

1. Provide Design Thinking, human-centered consulting
2. First stage project filtering (Go/~~No Go~~)
3. Leverage on the network of **COIs**, RIs, IHLs for R&D consulting, **train** new talents, job redesign
4. Coordination & Link up with design companies
5. Outsource projects to successful time-to-market;

Demand Drivers

Productisation
Co-ordinate, manage and perform product focused design and development activities to transform ideas into market ready products/

MNCs/LLEs

Public Agencies

TACs

SPETA
Singapore Manufacturing Federation
SME Centre@SMCCI
SME Centre@SMF
SME Centre@SCCCI
SME Centre@ASME
SME Centre@SICCI

Outsource Projects to Design Partners

UXC user experience centre
AGENCY
chemistry
STUCK
ThinkPlace
DESIGN SOJOURN
designinsight
ideactio
we are perspective
orcadesign
XENTIQ

3lagytech
AVNET Reach Further
dk engineering
Synergy Design Solutions
opulent
L&T Technology Services
Aztech

Partner COIs and Research Performers

SG:D OPEN INNOVATION PLATFORM

A*STAR
- SIMTech Precision Engineering COI
- IMRE Materials COI

Nanyang Technological University Singapore – EcoLabs COI for Energy

Singapore Polytechnic – Food Innovation Resource Centre

Temasek Polytechnic
- Aquaculture Innovation Centre
- COI for Complementary Health Products

Nanyang Polytechnic – Centre of Innovation for Electronics & IoT (COI-EIoT)

Republic Polytechnic – COI for Supply Chain Management (COI-SCM)

Ngee Ann Polytechnic
- Environmental and Water Technology
- Marine and Offshore Technology

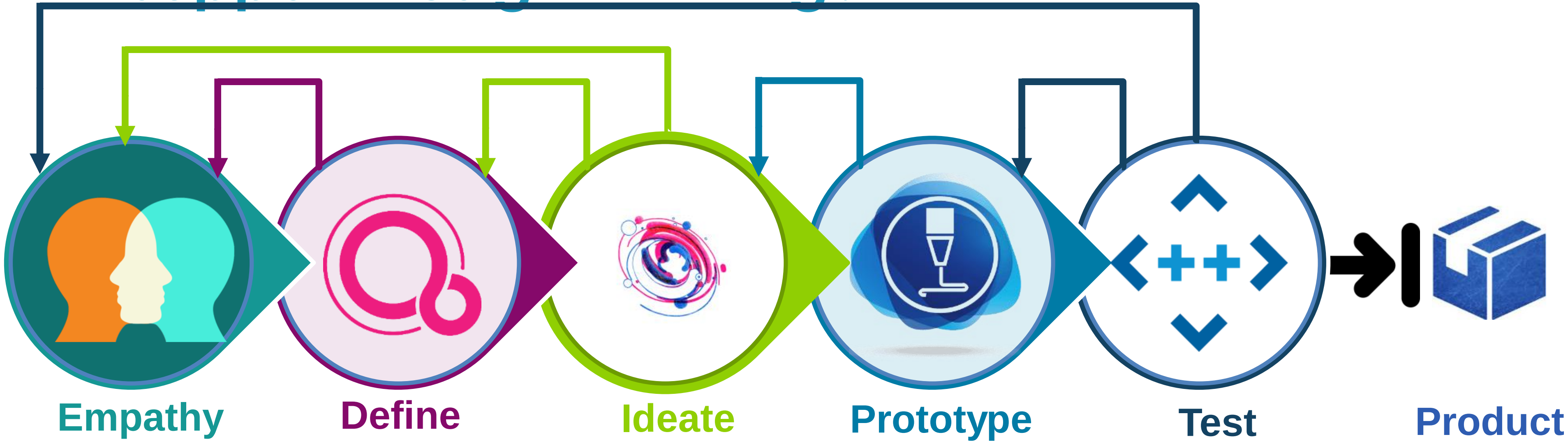
Singapore University of Technology and Design

Singapore Institute of Technology

NUS National University of Singapore

ndustry

How IF support Design Thinking?

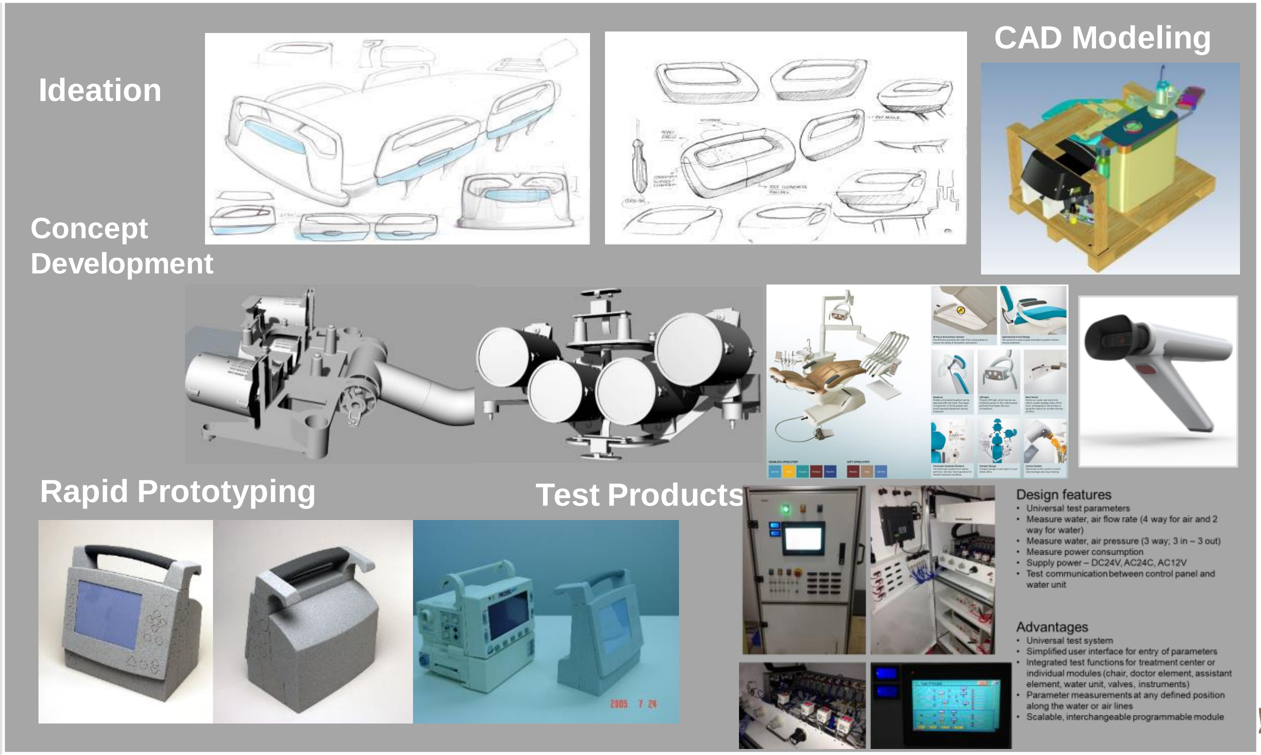


DESIGN RESEARCH
Study the real challenges that users are facing using descriptive or exploratory research methods.

Define the problem statement, unearth issues and unmet needs.

TRANSLATE
Use different types of data analysis tools to study the collected data, translate the findings into design direction that could generate high value propositions.

CONCEPT
No idea is bad idea, concepts were explored and developed in early phase, build prototypes rapidly for quick tests to proof the concept and validate the value proposition.



Innovation Factory Consultancy in Design Thinking

Value of our approach

During the consultancy process, all the key design elements such as **design language, CMF, UX/UI, branding**, and relevant design or quality standards will be carefully implemented and refined rigorously.	Design Language	▪ Branding and style guidelines ▪ Corporate brand value ▪ Ergonomic, Usability ▪ CMF management
	Styling Tiers	▪ Primary ▪ Universal ▪ Specialized ▪ Functional
	Visual Perception UX UI	▪ Critical model ▪ Versatile model ▪ Primary model
	Ergonomics	▪ Low risk ▪ Good to have ▪ Baseline
	Color and Finishes	▪ Corporate theme with composition ▪ Non-corporate
	Design and Quality Standards	

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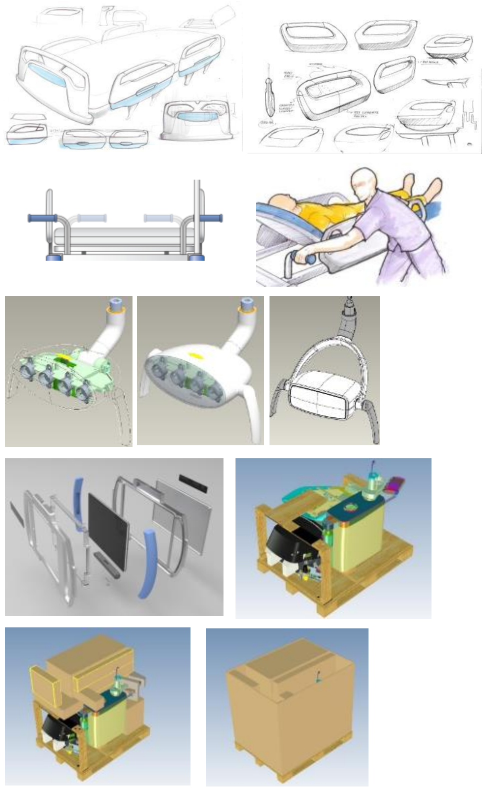
Building Design Capabilities to narrow Market Gaps

PDP → Product & Industrial Design → Technology R&D/ Adoption / Product engineering → Prototype → Design Verification → DFM/ Clinical Validation → Tooling → Mass Production → Market Entry

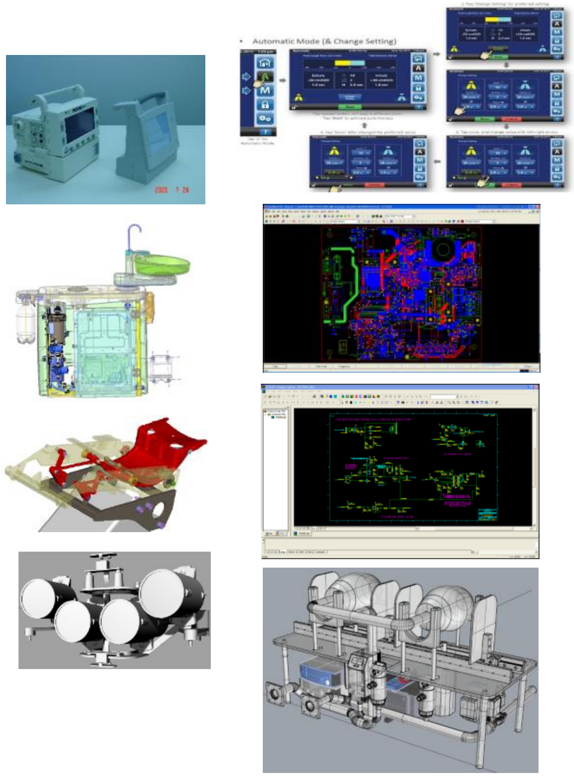
KeyShot, KeyVR, Rhinoceros

- Rhino 3D
- Adobe Creative Cloud, Photoshop, Illustrator
- Luxion KeyShot 3D photorealistic



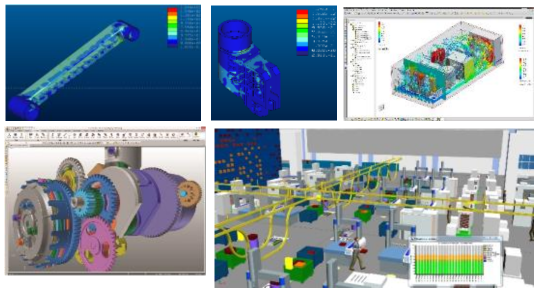
LTspice, STM32Cube, Arduino, Altium Designer 20, KEIL Tools by ARM, Autodesk Eagle, PADS, Micrium, Windows Embedded Compact, python, ThreadX, SolidWorks, Siemens NX, creo, Solid Edge

- 3D concepts
- Go-To-Market Strategy
- R&D (EE, ME, SW)
- Design Reviews

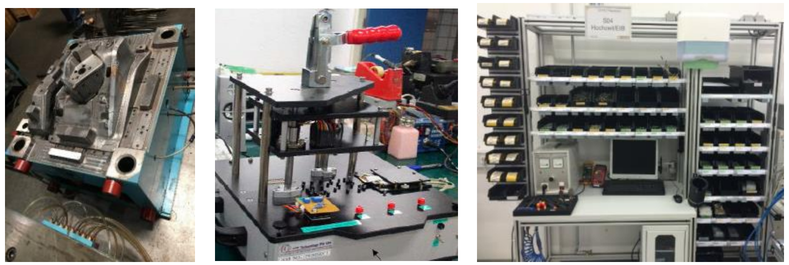


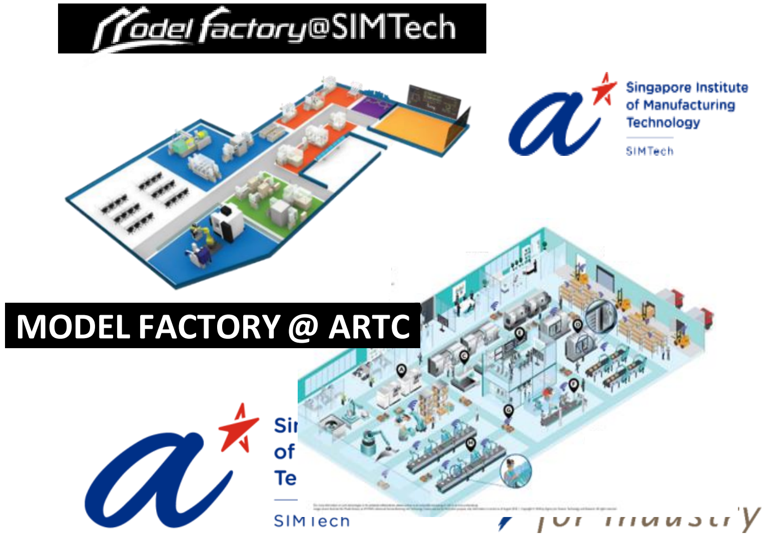
Simcenter™, COMSOL, Ansys, MATLAB, LabVIEW, RecurDyn

- Mold flow analysis
- Simulation (Vibration, Frequency, Buckling, Thermal, Drop Test, topology optimisation, non-linear materials, large deformations)
- Pipe, tube, duct and wire routing
- Environmental Impact Analysis
- Structural part and assembly analysis
- Advanced surface flattening
- Advanced motion simulation
- Advanced stress simulation



- Blow Moulding
- 2k Injection Moulding
- ODM
- CM
- Finished goods
- Shipment
- Logistics
- Product Lifecycle management
- Lessons learned





Stage 2
DESIGN

Innovation Factory Collaboration with Design Houses/RIs/IHLs/COIs

Scope of Design Services

NPD	Scope	Design Activities	Tools and Deliverables
Transform the finalized design concept into design for manufacturability, cost- effective and reliable product throughout the established product development process. Proposed designs will be reviewed in an iterative manner at every stage to ensure technical problems are solved without compromise the design requirements. Continual refinement of ideation sketches, detail design drawing, 3D CAD modeling and rapid prototyping within the planned project timeline will transform the fuzzy frontend and early thoughts into a high quality and attractive product.	General	▪ Requirement Management ▪ Defect Tracking ▪ GTM strategy ▪ Test Management ▪ Document Control ▪ Project Management	windchill, PLM Software SIEMENS NX, IBM Rational DOORS Next Generation, IBM Rational ClearCase, ClearQuest, FUSION 360
	1.0 Industrial Design	▪ As previous slides on Phase 1	▪ Rhino 3D ▪ Adobe Creative Cloud ▪ Luxion KeyShot 3D Photorealistic Rendering KeyShot, KeyVR, Rhinoceros
	1.1 Electrical Design	▪ 8/16/32 bit processors ▪ Motor controls, robotics ▪ Analog and Digital ▪ Power mgt. ▪ Audio and video ▪ PCB Design ▪ Simulation ▪ Programmable Logic	▪ Linear Tech LTSpice ▪ Keil ▪ STMCube ▪ Code Composer ▪ Arduino LTspice, KEIL Tools by ARM, STM32Cube, ARDUINO
	1.2 Schematics and PCB Design		▪ Mentor Graphics ▪ Altium Designer ▪ Autodesk Eagle ▪ DDS Circuit Works, Part Libraries PADS®, ALTIUM DESIGNER20, AUTODESK EAGLE

Stage 2
DESIGN

Innovation Factory Collaboration with Design Houses/RIs/IHLs/COIs

Scope of Design Services

NPD	Scope	Design Activities	Tools and Deliverables
Transform the finalized design concept into design for manufacturability, cost-effective and reliable product throughout the established product development process. Proposed designs will be reviewed in an iterative manner at every stage to ensure technical problems are solved without compromise the design requirements. Continual refinement of ideation sketches, detail design drawing, 3D CAD modeling and rapid prototyping within the planned project timeline will transform the fuzzy frontend and early thoughts into a high quality and attractive product.	1.3 Embedded software design	▪ Coding/Editing ▪ Compiler ▪ Debugging ▪ Defect Management ▪ Automated Tests ▪ Code analysis ▪ Version control ▪ Code generation ▪ Database management ▪ Packaging	▪ C/C++ language ▪ ThreadX ▪ Micrium OS ▪ Win CE OS ▪ Raspbian ▪ System/Server software ▪ Multithreaded server-based software using C# and the Microsoft .NET Framework ▪ C# application software using Microsoft .NET Compact Framework

Stage 2
DESIGN

Innovation Factory Collaboration with Design Houses/RIs/IHLs/COIs

Scope of Design Services

NPD	Scope	Design Activities	Tools and Deliverables
	1.4 Mechanical Design (Packaging, Plastics, electronics packaging with metal work)	▪ Geometric Dimensioning and Tolerancing ▪ Data import and reuse ▪ Advanced 3D part and assembly design ▪ **AR** and export to third party AR/VR/MR ▪ Sheet metal design ▪ Design for cost ▪ Frame & weldment design ▪ Surface modelling and Plastic part design ▪ Jig & fixture design ▪ Conceptual assembly layout ▪ Cam and Gear design ▪ Pulley & shaft, Spring design ▪ Beam & column design ▪ Electrical routing ▪ PCB collaboration ▪ Pipe and tube routing	▪ Automated 2D drawings ▪ Standard parts library (includes machinery content) ▪ Animation and Advanced photorealistic rendering ▪ IFC import & export for Building Information Modelling **(BIM)** ▪ Mesh data reuse (Convergent Modelling) ▪ Reverse engineering (3D scanning) ▪ 3D print preparation and service ▪ Generative design and Data management ▪ Inventor data migration ▪ Pro/Engineer / Creo data migration ▪ Cloud-ready productivity (log-in license, cloud-based collaboration, free viewing tools)

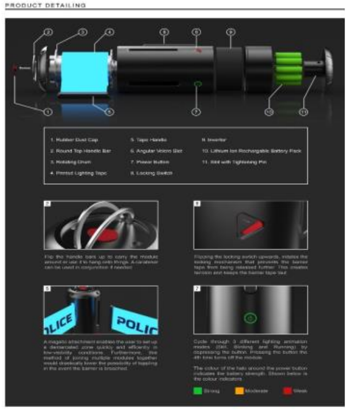
Stage 2
DESIGN

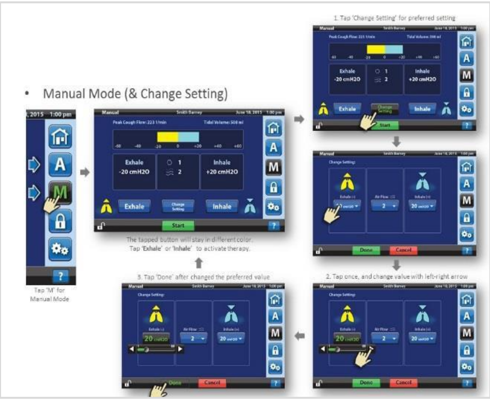
Innovation Factory Collaboration with Design Houses/RIs/IHLs/COIs

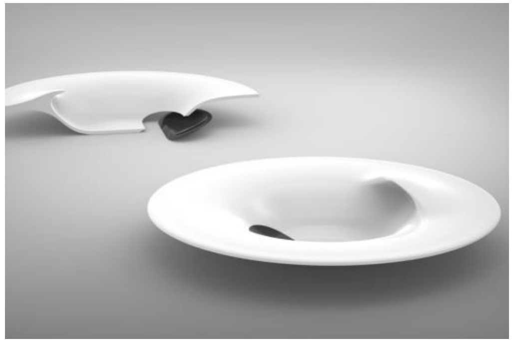
Scope of Design Services

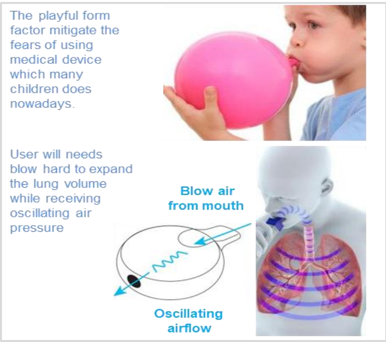
NPD	Scope	Design Activities	Tools and Deliverables
	1.5 Simulation software tools	▪ Mold flow analysis ▪ Simulation (Vibration, Frequency, Buckling, Thermal, Drop Test, topology optimisation, non-linear materials, large deformations) ▪ Pipe, tube, duct and wire routing ▪ Environmental Impact Analysis ▪ Structural part and assembly analysis ▪ Advanced surface flattening ▪ Advanced motion simulation ▪ Advanced stress simulation	▪ Comsol Multiphysics (complex multiphysics interactions e.g. thermal, electrical, mechanical, fluids) ▪ Matlab Simulink (dynamic simulation of systems, Hardware in the loop simulation) ▪ Labview (Real-time simulation and control) ▪ Recurdyn (Multibody dynamic simulation) ▪ Ansys – Fluent (CFD analysis) ▪ Ansys – Maxwell (EM analysis) ▪ Ansys – MotorCAD (Electric machine)

Examples - Design Thinking Approach to Product Design









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Artist Impression of IF@CT2B (Front View)

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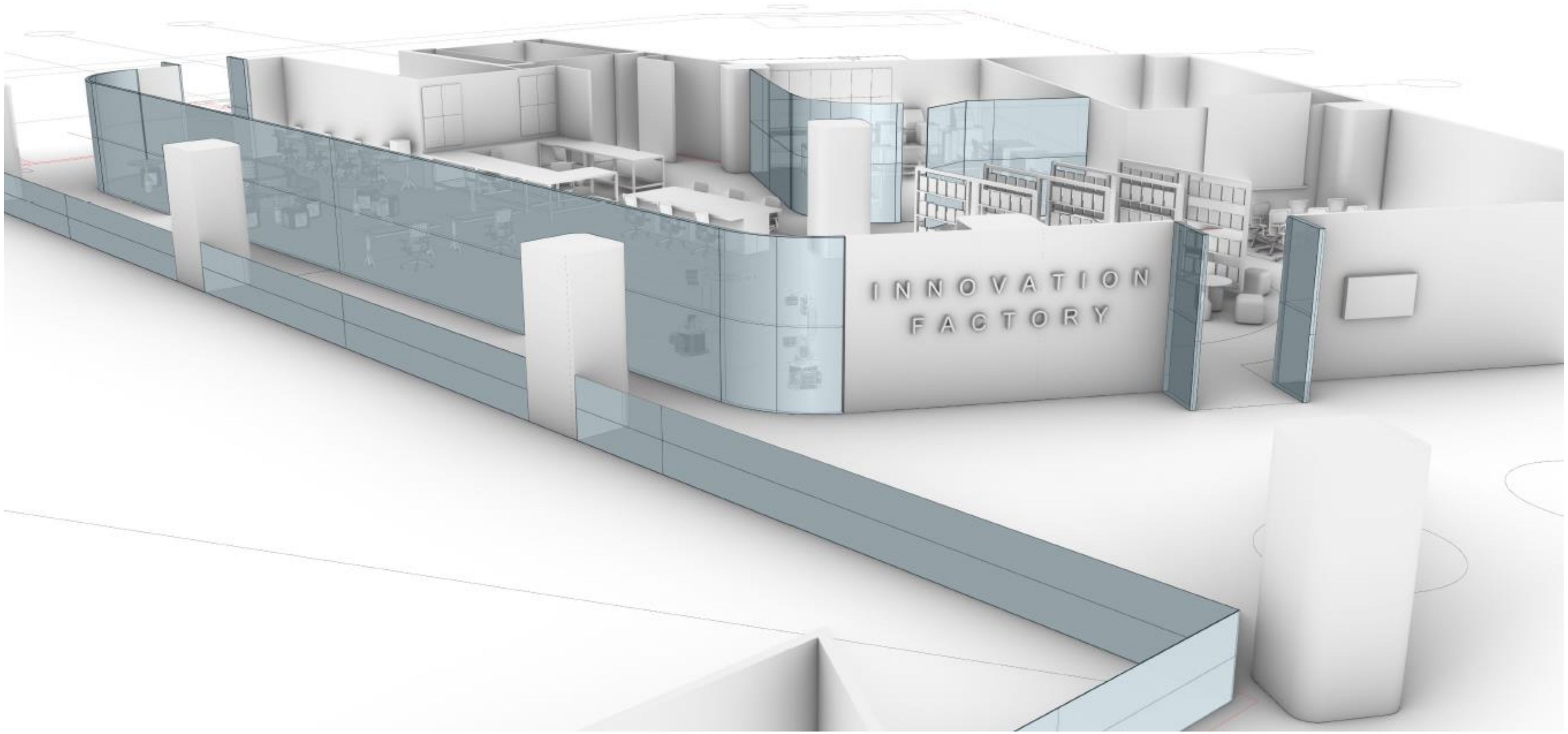
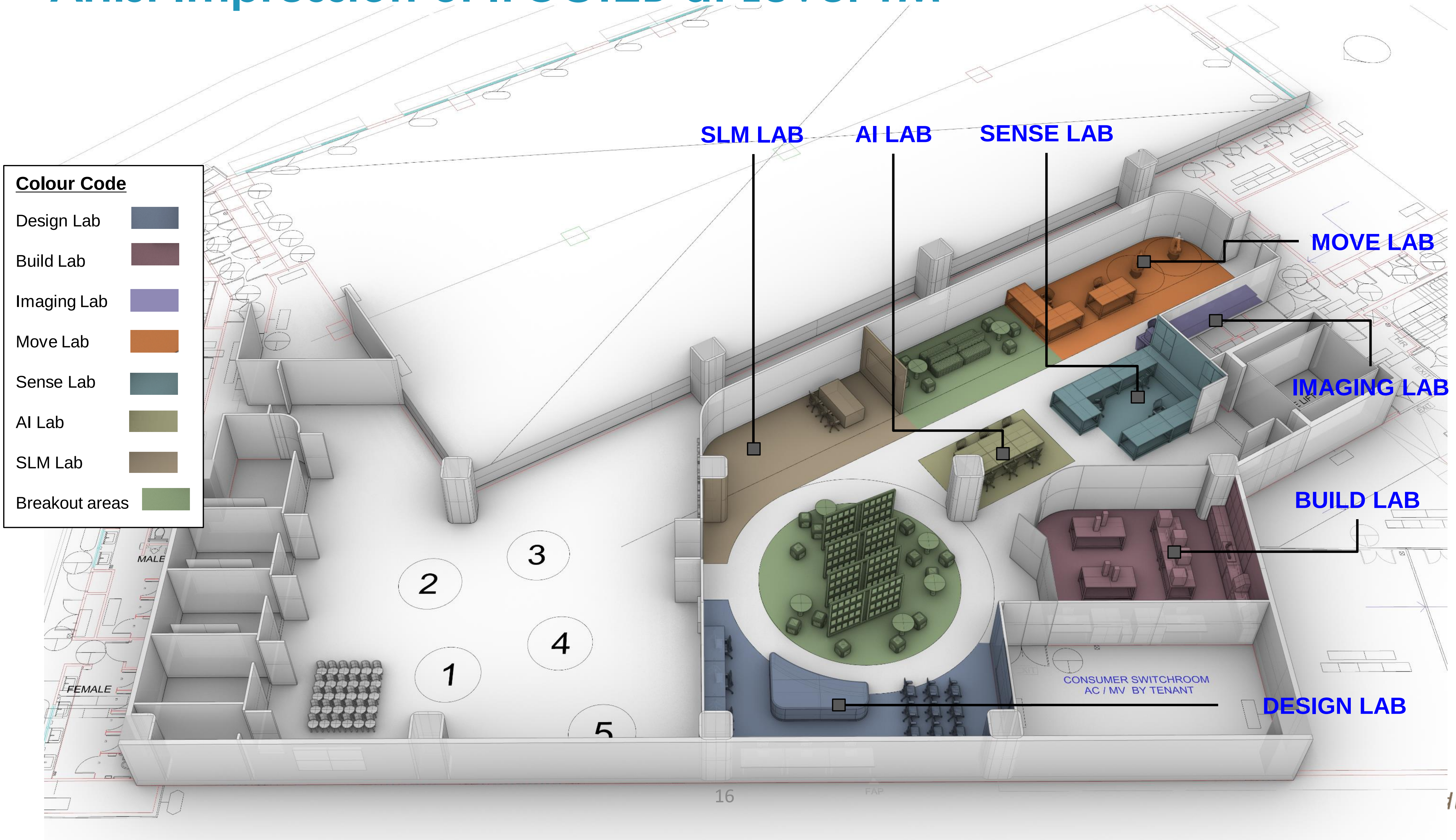
Artist Impression of IF@CT2B (Side View)

Artist Impression of IF@CT2B at Level 1M

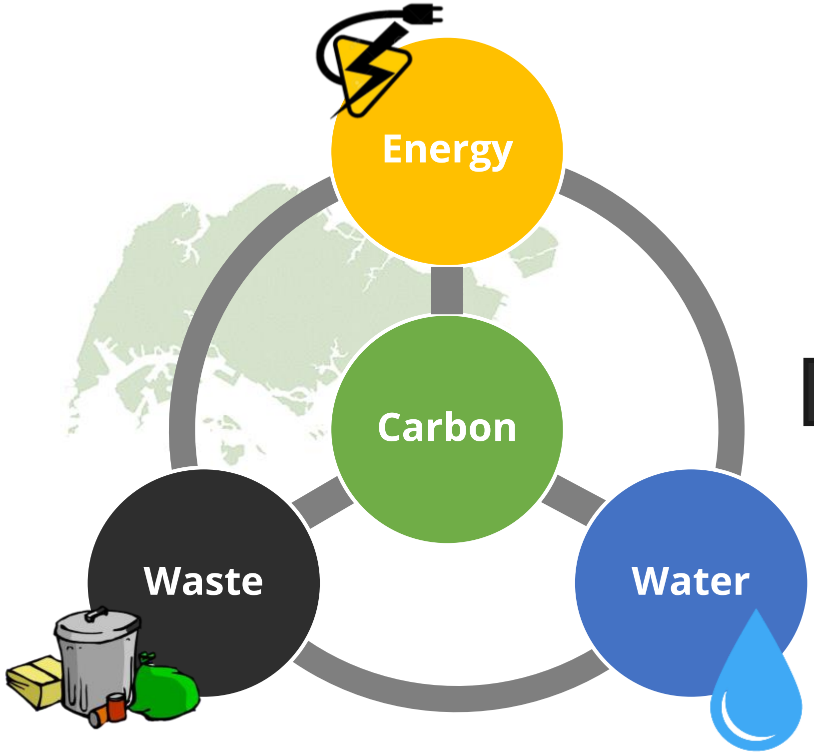


Artist Impression of IF@CT2B at Level 1M



Sustainability and Life-Cycle Management Lab Offering
Underlying Technology Themes

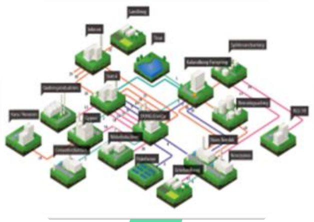
In addressing the nexus of carbon-energy-water-waste, **technologies will be demonstrated through 3 themes**: 1) **sustainable operations**, 2) **industrial ecology**, and 3) **design for sustainability**.



Carbon-energy-waste-waste nexus

Sustainability and Digital Solutions @ CleanTech 2B

1) Sustainable Operations
Improving carbon and resource efficiency through advanced manufacturing and I4.0-enabled technologies **at the shop floor and across the factory**



2) Industrial Ecology
Improving carbon and resource efficiency through collaboratively closing carbon and resource loops **within and across supply chains**

3) Design for Sustainability
Improving carbon and resource efficiency through **product and system design**

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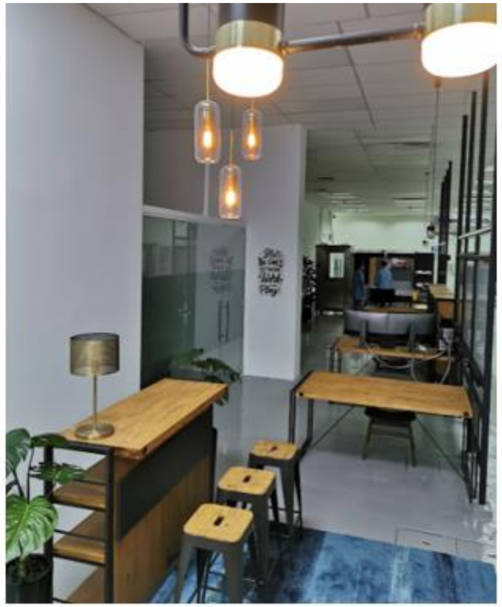
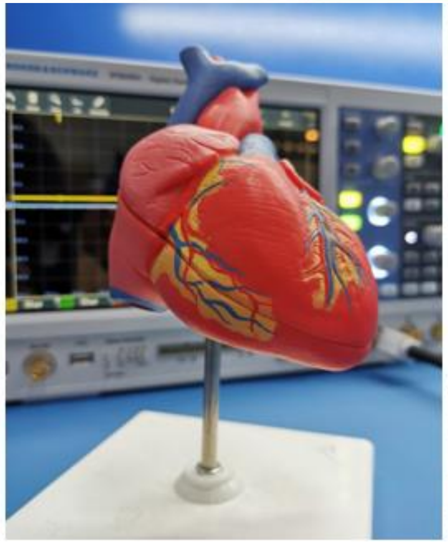
Pilot Innovation Factory @ Valley Block

Total Space:
126sqm / 1357sqft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Proposed Designs for the Workshops for IF@CT2B

General guidelines:
-Dark theme
-Tools must be easily accessible
-All things must be visible, use glass cabinets
-All tables must be on wheels
-All dusty operations in dust room
-Small painting booth
-Maximum storage space everywhere
-No fumes, no dust allowed
-No exposed wires on the floor
-Storage rack of raw materials
-Bright lighting
-Ample power point and compressed air outlet
-Storage locker with lock and key
-Partitions on wheels
-Small discussion area
-Water basin and chemical sink
-Fume hood for 3D printer to exhaust
-Large dustbins











https://www.wallcontrol.com/







://www.the5sstore.com/perfo-stor-tool-system.html





Proposed Designs for the Workshops for IF@CT2B

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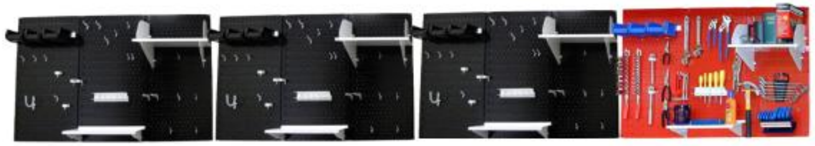

General tools General tools General tools Power tools

https://www.diytools.sg/index.php

Proposed Designs for the Workshops for IF@CT2B

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Innovation Factory Build Lab Facilities and Services

<u>Markforged X7</u> Continuous carbon fiber

- Fused filament fabrication, Continuous Filament Fabrication
- Top-of-the-line industrial grade platform with strengthened dual nozzle print system that supports **Continuous Carbon Fiber** and **Kevlar** reinforcement.
- Build Volume **330 mm x 270 mm x 200 mm**
- Layer Height 50 µm
- Onyx, Onyx FR, Nylon White Fibers, Carbon fiber, fiberglass, Kevlar®, HSHT fiberglass
- Tensile Strength **800 MPa** (25.8x ABS, 22.2x Onyx)
- Flex Modulus **51 GPa** (24.8x ABS, 14.2x Onyx) *

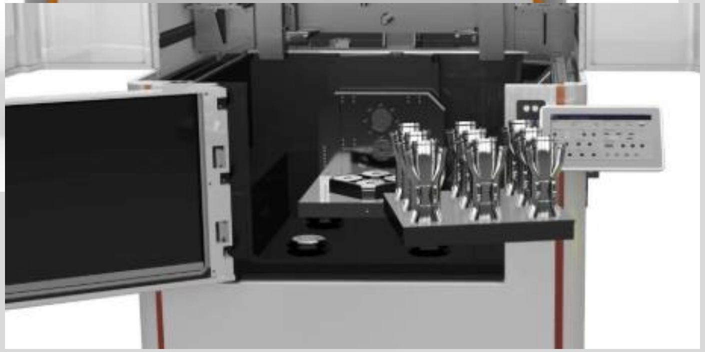
<u>Metal X</u> Metal 3D

- Atomic Diffusion Additive Manufacturing (ADAM)
- Top-of-the-line industrial grade **metal** printing platform featuring 17-4 PH Stainless Steel PH, Tool Steel, Inconel 625 and Copper materials.
- Build Volume **300 x 220 x 180 mm** (11.8 x 8.7 x 7.1 in)
- Max Post-Sinter Part Size 188 x 54 x 52 mm
- Metal material with ceramic release layer
- Layer height 125 µm and 50 µm, post-sinter

Innovation Factory Build Lab Facilities and Services

Georg Fischer +GF+ DMP Flex 350

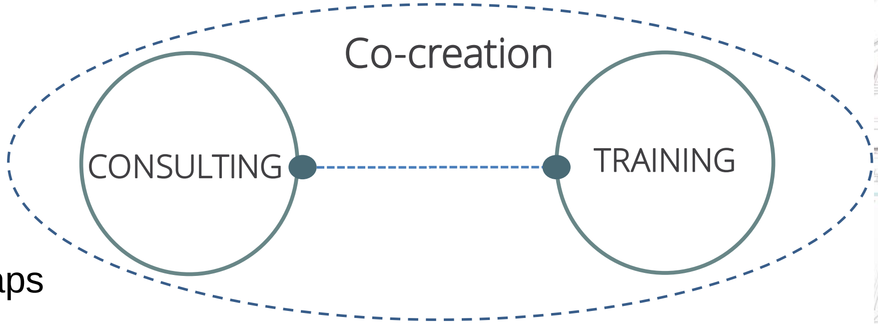
- Laser Powder Bed Fusion system
- Build Volume: 275mm x 275mm x 420mm
- Layer thickness: 10-100µm
- Laser: 500W Fiber Laser
- Efficient **Bidirectional Recoating** system
- Time-saving **Removable** Print **Module**
- Seamless All-In-One **Integrated Software**

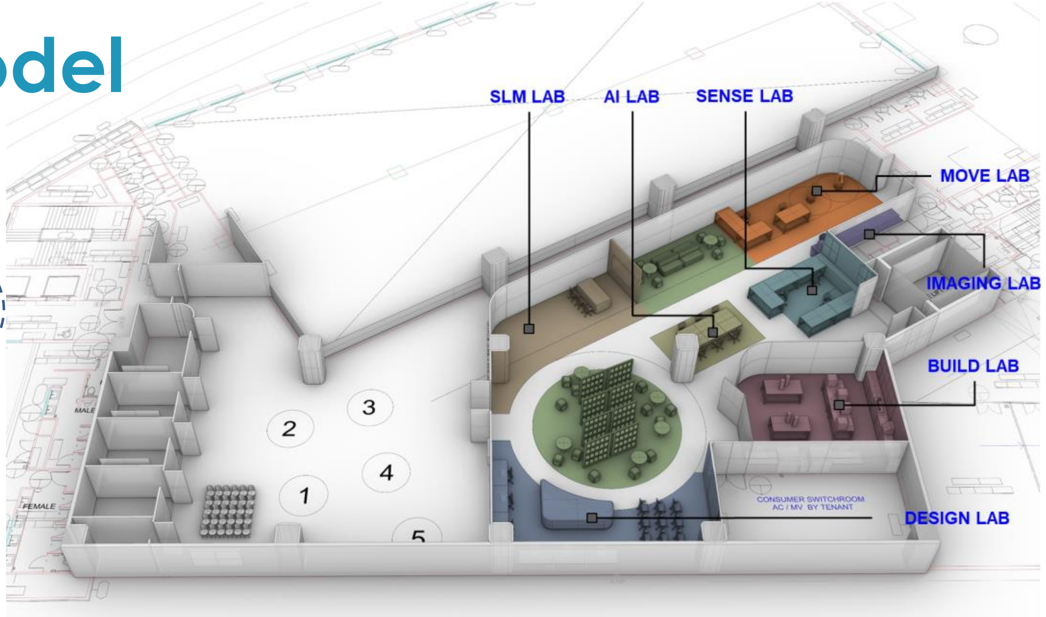


+GF+ CUT AM 500

- Wire Electrical Discharge Machining (EDM) system
- Cut Volume: 510mm x 510mm x 510mm
- Cutting Speed: 280 mm²/min
- Accuracy: ±0.1mm
- **Horizontal** EDM, **Tilting table, Rotary axis** and **collection basket** prevent damage of cut parts
- Cost-saving and Efficient **Double Spool Concept**
- **Integrated Clamping system** for easier referencing

Innovation Factory Collaboration Model





Train R&D talent, address gaps

- Develop I&E talent (OJT)
- Expand pool of deep-tech talent

(e.g. Innovation and Enterprise Fellowship Programme (IFP)

Labs	Expertise	Subject Matter Experts (Current)	Plans – Engaging Beyond SERC
Design	Design Thinking and AM; Human Centered Innovation with Design Thinking; NX for design; Simcenter; PLM	Rayner Ng, Duane Lye, Chikashige Kiyoshi, YY, Thaddie, Tnay Guan Leong, Kentaroh Toyoda (S&A), Clive Stanley Ford (IHPC), Lai Szu Cheng, YIN Xuesong, Chiam Sing Yang (IMRE)	
SLM	Design & Simulation Software	Johnathan Low, Daren Tan, Yeo Zhiquan (SIMTech)	
Sense	Industrial IoT; Analytics Software Sensors & IoT hardware	Liu Wei, Wen Rong, Xiao Long (SIMTech); Cui Shan (NMC), Kwok Yuen Sam, Wong Kok Wai (I2R); YIN Xuesong (IMRE)	
AI	Autonomous AI platform, Brain-Machine, Neural Interfaces, Digital Manufacturing	Liu Wei (SIMTech); Clive Ford, Gao Fei (IHPC); Xue Yang (I2R)	
Move	Process and Plant Simulation; Cobots & AIV	Tnay Guan Leong, Tao Ming (SIMTech), Tijo Thayil (ARTC)	
Build	AM; Machining, Regenerative processes	Wiria Florencia, Soh Fang Hui, Thang & Liu Kui (SIMTech), Alin Pa[illegible]an, Matthew King (ARTC)	
Imaging	Inspection tools	Leon Li Xiang (SIMTech), Shihua (NMC)	

Pilot Innovation Factory Membership

Category	Member's Benefits	Membership Types: Gold	Membership Types: Platinum
	MNCs, LLEs, (fee per annum[1])	$4,000	$6,000
	SMEs, Start-ups (fee per annum[2])	$2,000	$3,000
Membership Services	Recognition[3]	✓	Priority[4]
	Complimentary Hot desking	✓	Priority[5]
	Lounge Access	✓	✓
	Reward points do not expire	✓	✓
	Exclusive membership access card	✓	✓
	Complimentary parking	✓	Priority[6]
	Special offers and invitation to events and promotions	✓	Priority[7]
	Standard subscription[8]	✓	✓
R&D	Access to Innovation Factory	✓	Priority[9]
	Consultation	✓	Priority
	Use of design tools and equipment	✓	Priority
Further Education	Training and Workshop Discounts (where SkillsFuture Credits or other SMEs funding or similar scheme does not apply)	20%	30%

All figures before GST

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Engaging Interested Companies

Product & equipment distributors	Ops & Tech Roadmap (OTR) exercise	PE company aspiring to be ODM	2nd GENERATION SME OWNERS	Others
TAT CHUAN ACOUSTIC ESTABLISHED 1966	HAKKO	Metal Component Engineering Limited	CHONG FONG	Fong's
Ban Leong Technologies Limited	DMS DELPHIC	ATC	CKE MANUFACTURING	PROLINK
LAU	SEIKO Architectural Wall Systems Pte Ltd	MPT	FONG LEE	Dornier MedTech
FLEXON	YEAKIN PLASTIC INDUSTRY PTE LTD Shaping The Future...	ASTech	Kay Kay Plastic Industries Pte Ltd	ALT
		CentiFORCE	ELITE SPRINGS INDUSTRIES Springs | Forming | Cutting	FUCHSIA CREATIVE
		Aurigin technology	Portal Phenom	Swirl.GO
		CSE		SOLU STAR
		Automation Technology Center Pte Ltd		mtech
		AS		FOH FOH
				HYLAX TECHNOLOGY
				COVE
				FIBRE
				SENTRON ENGINEERING (S) PTE LTD

Members

JM Vistec System "Our Vision, Tomorrow's Innovation" - The Machine Vision Specialist; DATATERMINATOR Security with Confidence; LINE8; design; GINLEE

LOI secured

AITECH ROBOTICS; Brain Domain; dk engineering; DESIGN SOJOURN; SANWA; GETECH "Performance, Value, Integrity"; chemistry; MSV Systems & Services; XENTIQ; 3lagytech; PHAOS TECHNOLOGY

Partners

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE; NUS National University of Singapore; SUTD SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN; SIT SINGAPORE INSTITUTE OF TECHNOLOGY; UXC user experience centre SINGAPORE POLYTECHNIC; DesignSingapore Council; SG:D; PIXEL; CAD-IT CONSULTANTS; pd SOLUTIONS; SKYMECH; rion5 MONITORING INTELLIGENCE; NHIC National Health Innovation Centre; Singapore Manufacturing Federation 新加坡制造商总会; SPETA; TÜV SÜD; UL; Standard; SIEMENS; AUTODESK; L&T Technology Services; formlabs

CREATING GROWTH, ENHANCING LIVES

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SIMTech

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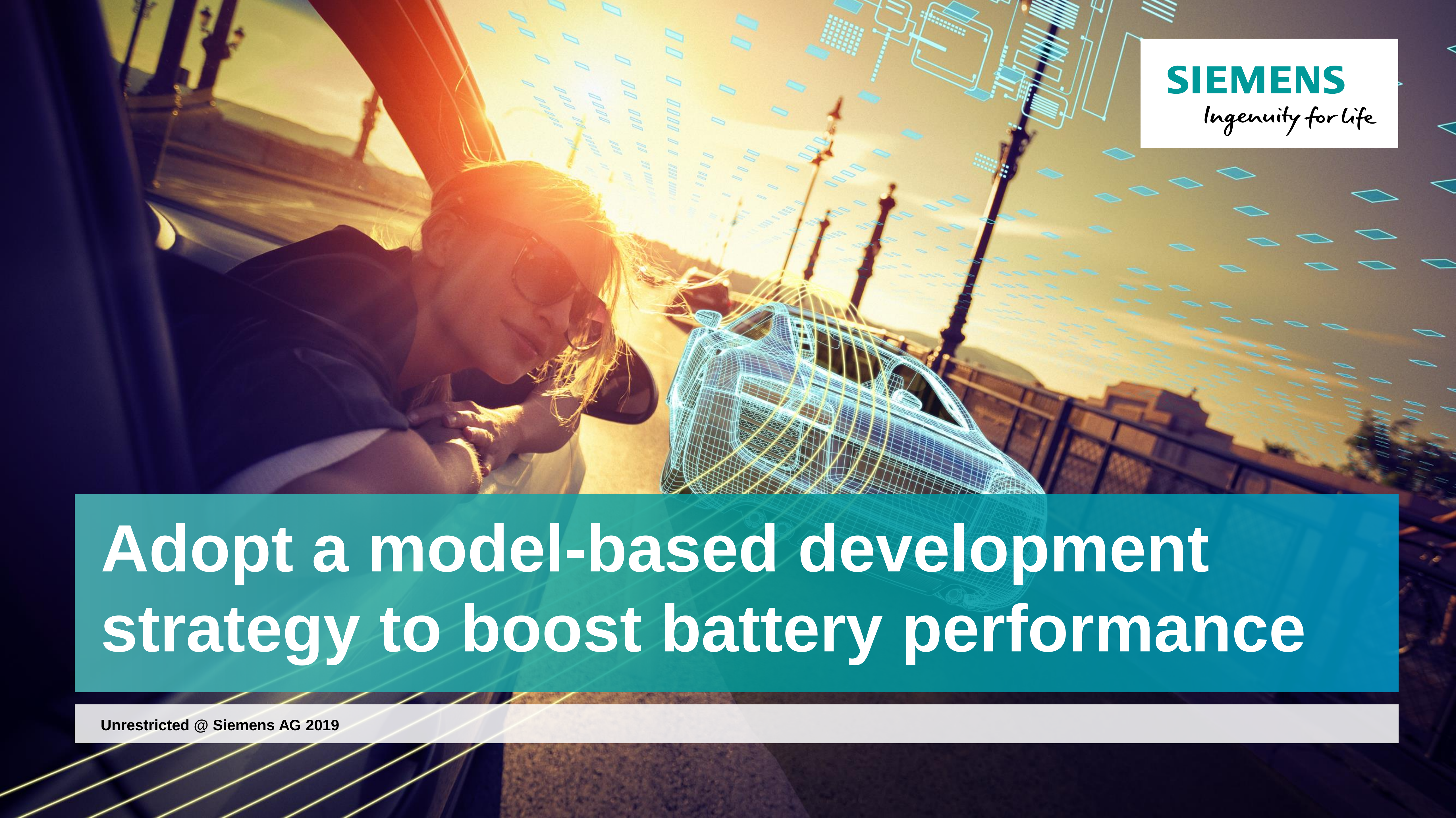
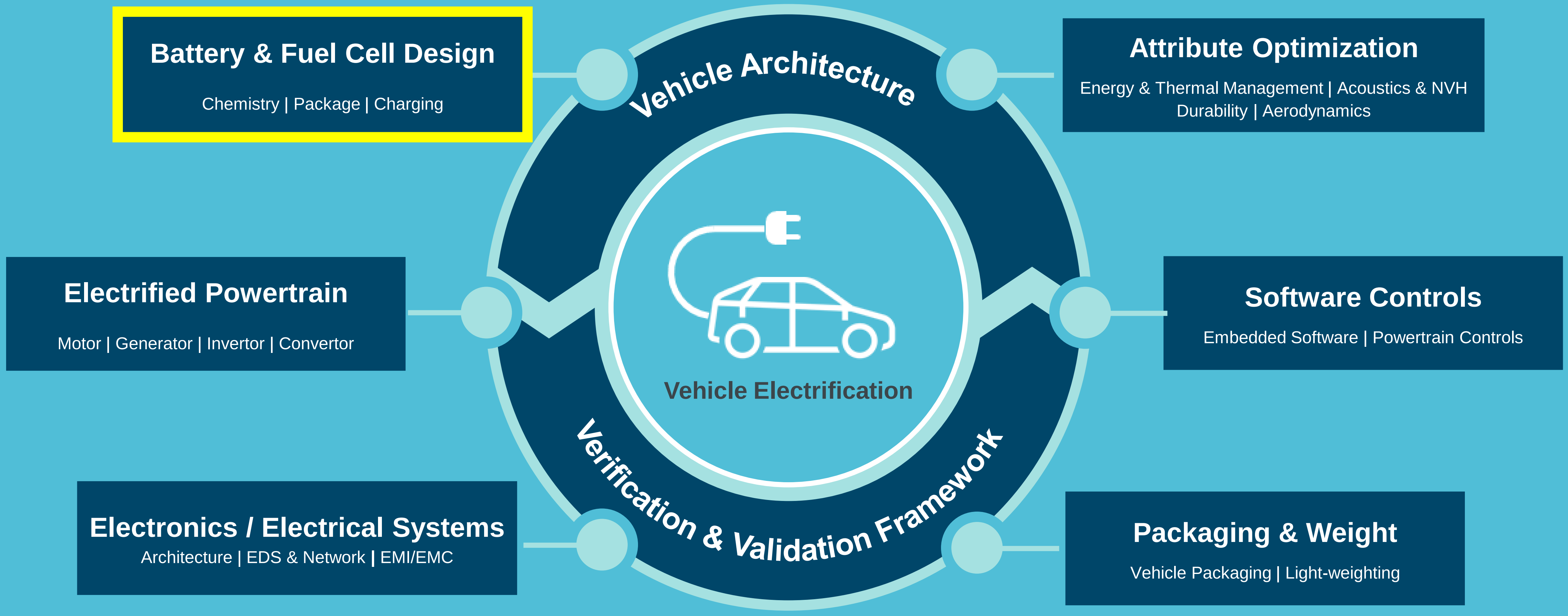


Adopt a model-based development strategy to boost battery performance

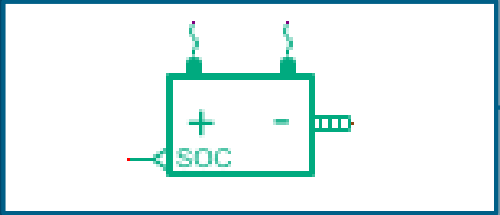
Siemens Digital Industries Software engineering solutions

Catering to a wide range of vehicle electrification needs

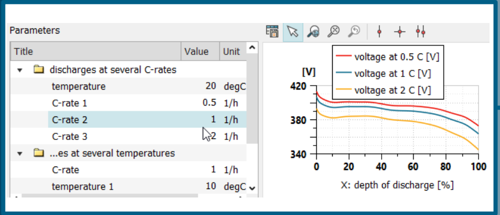


Simcenter simulation solutions for battery design

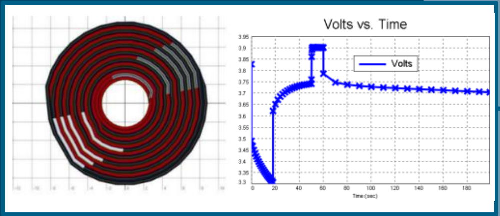
Scalable solutions for tiered collaboration



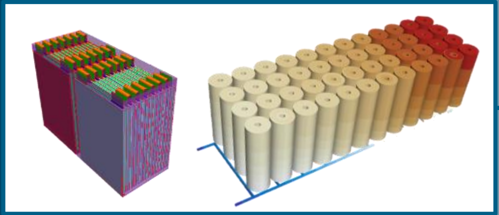
Determine battery requirements for vehicle performance and fuel consumption/range targets



Get a first battery design meeting the requirements starting from a database of commercial Li-ion cells



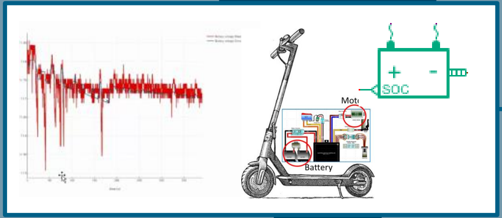
Design and analyze electrochemical reactions and detailed geometry of battery cells



Calculate 3D thermal, fluid and electrochemical properties of battery modules and packs

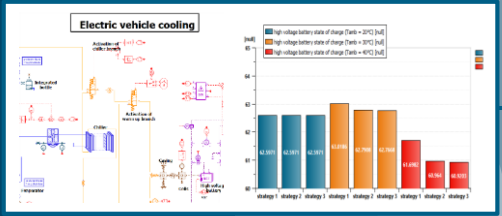
Simcenter simulation solutions for battery design

Scalable solutions for tiered collaboration

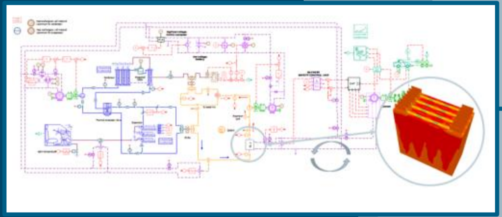


Smart mobility fleet management, preventive / predictive maintenance, product upgrades

Vehicle physical testing for energy management and control validation

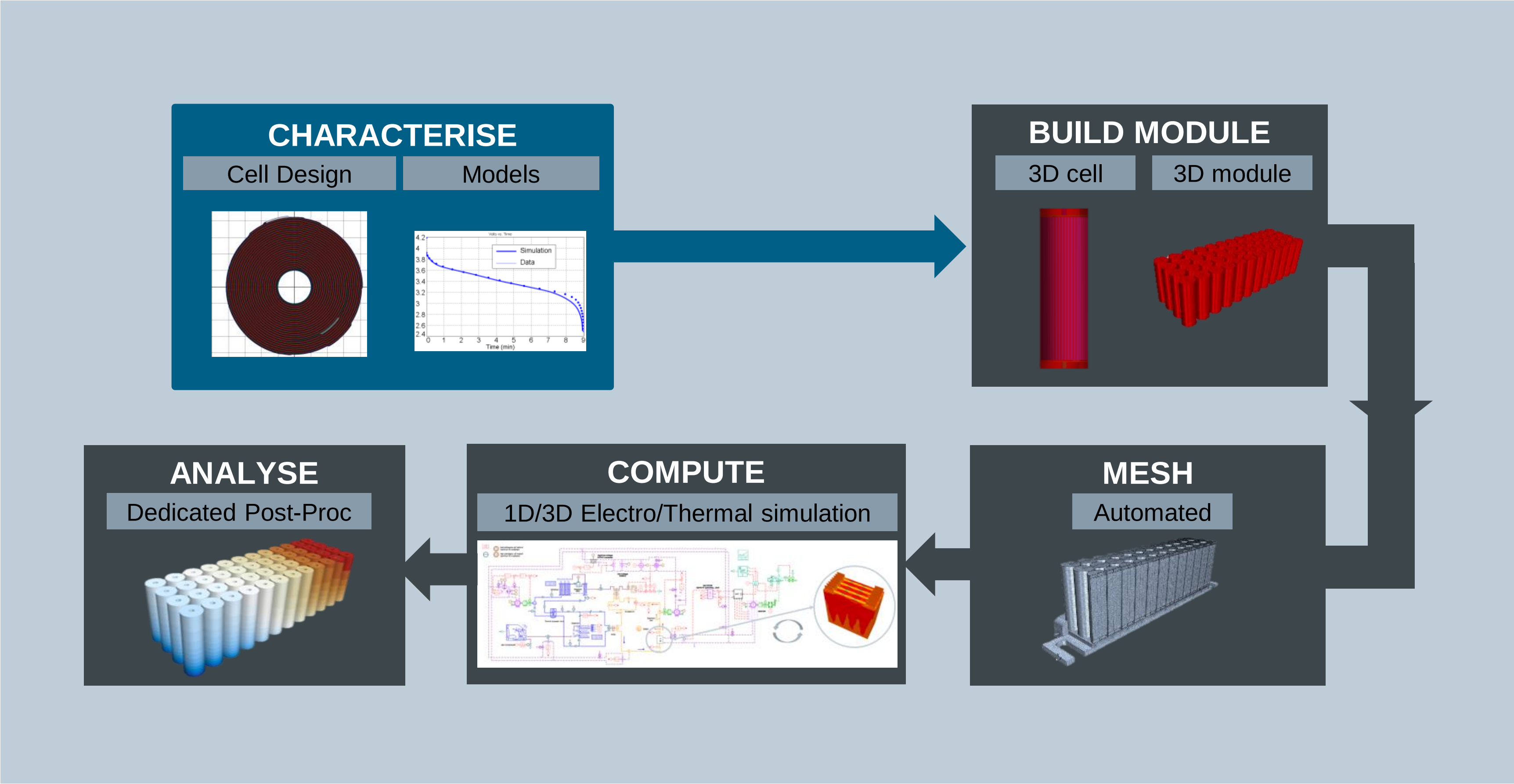


Balancing between battery cooling, range and thermal comfort at vehicle level



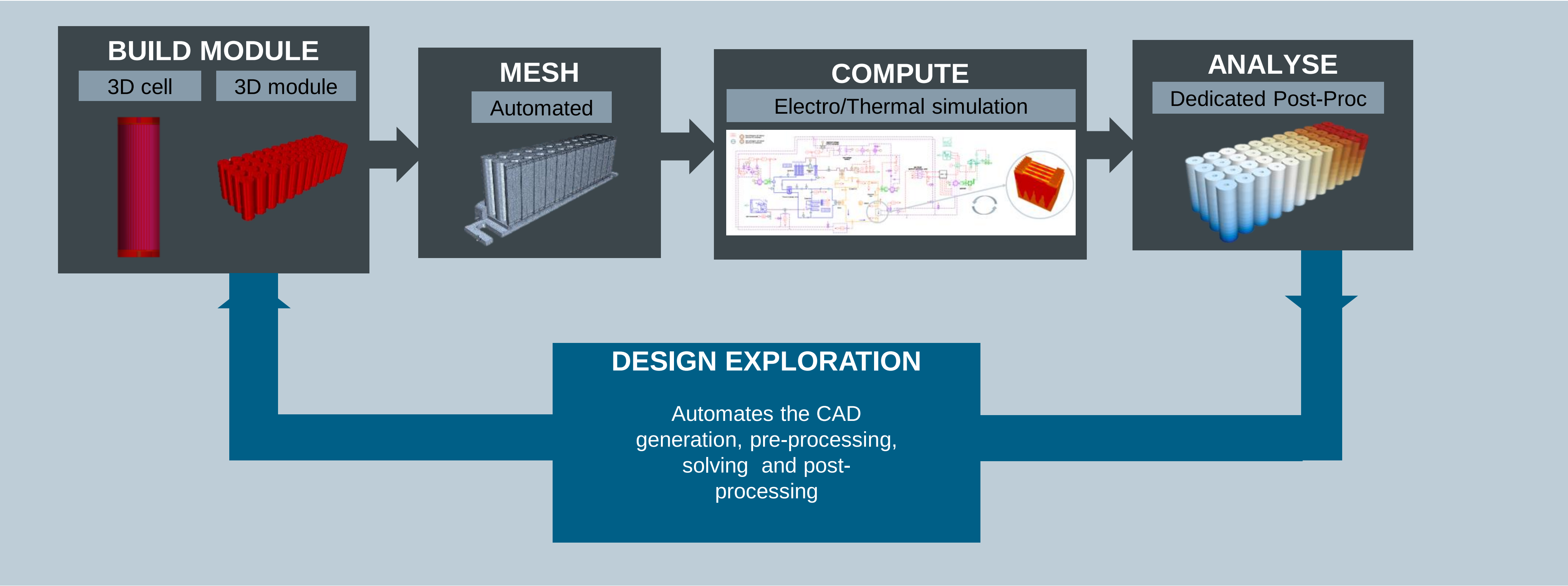
Validate battery pack and cooling loops on realistic drive cycles and environmental conditions (1D-3D coupling)

Drive Battery Innovation
Design Exploration



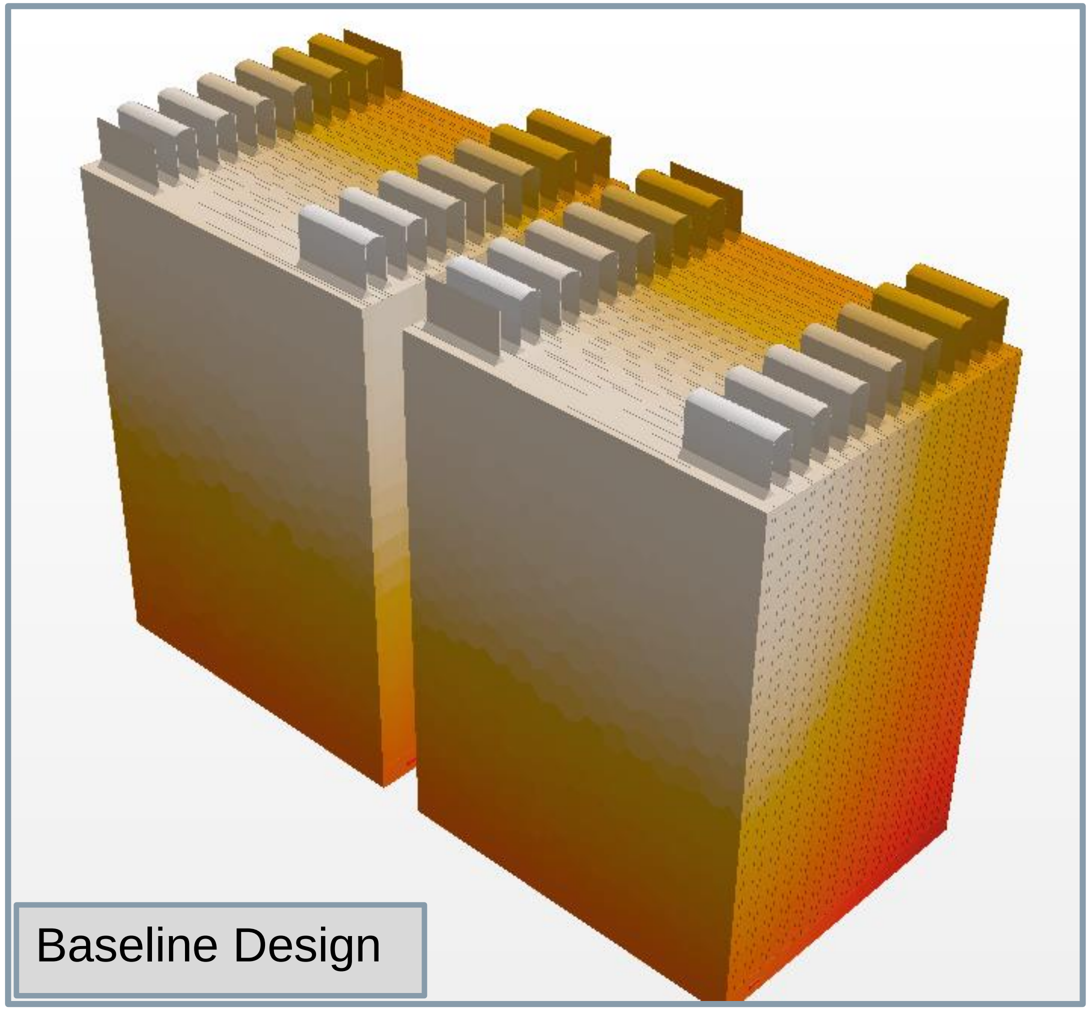
Engineer Innovation

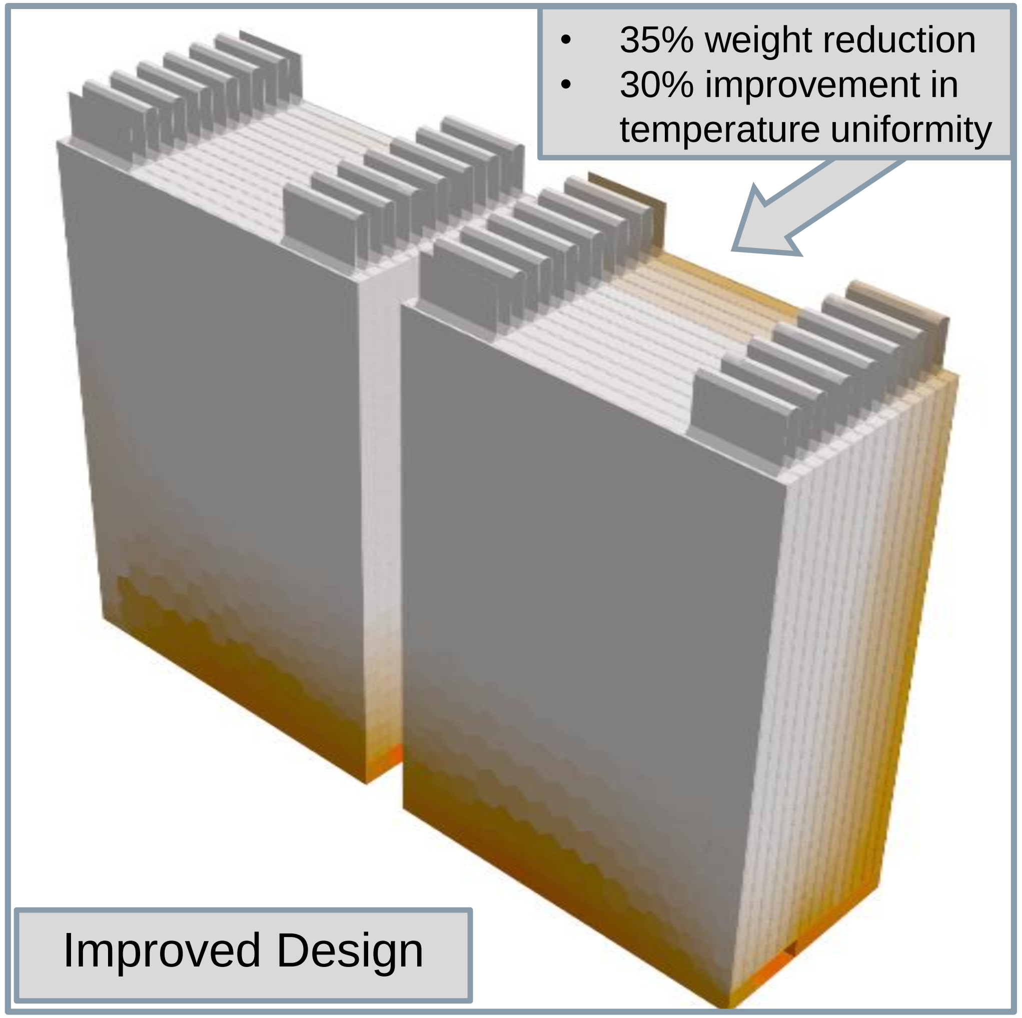
Drive Battery Innovation
Design Exploration



Engineer Innovation

Drive Battery Innovation
Design Exploration

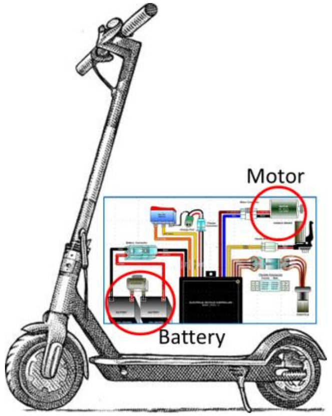




Preventive/predictive maintenance, product upgrades

Smart mobility fleet management example

SIEMENS
Ingenuity for life



Simulation Analyst

Fleet Business Analyst

mx mendix

Simcenter webapp

Cloud based innovation

mx mendix

Fleet management app

Rest API / Service

Rest API / Service

Simulation

Simcenter

Systems of Record

IoT device connectivity

MindSphere

Mentor
A Siemens Business

Digital Twin

Predictive Analytics

IoT

Smart Mobility Fleet Management

SIEMENS

Devices

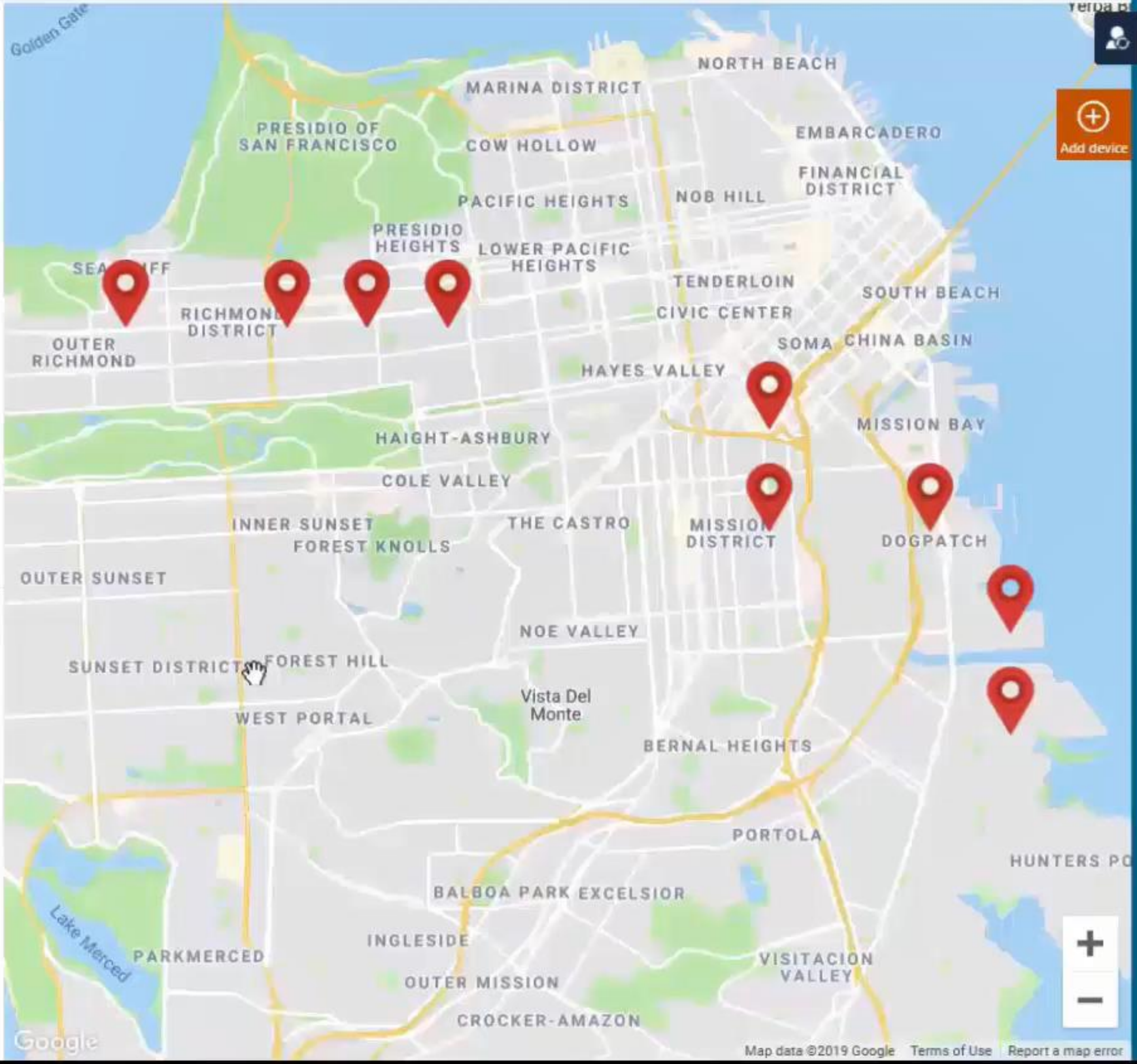
Rules

Config

Critical	Warning	Connected	Offline
3	16	7	2

The fleet

Device	Last Connected	Target status	Device Status
Bike1004	6/5/2019	Running	Alert
Bike1001	6/5/2019	Running	OK
Bike1002	6/5/2019	Running	OK
Bike1003	6/5/2019	Running	OK
Bike1005	6/5/2019	Running	OK
Bike1006	6/5/2019	Running	OK
Bike1007	6/5/2019	Running	OK
Bike1008	6/5/2019	Offline	OK
Bike1009	6/5/2019	Offline	OK

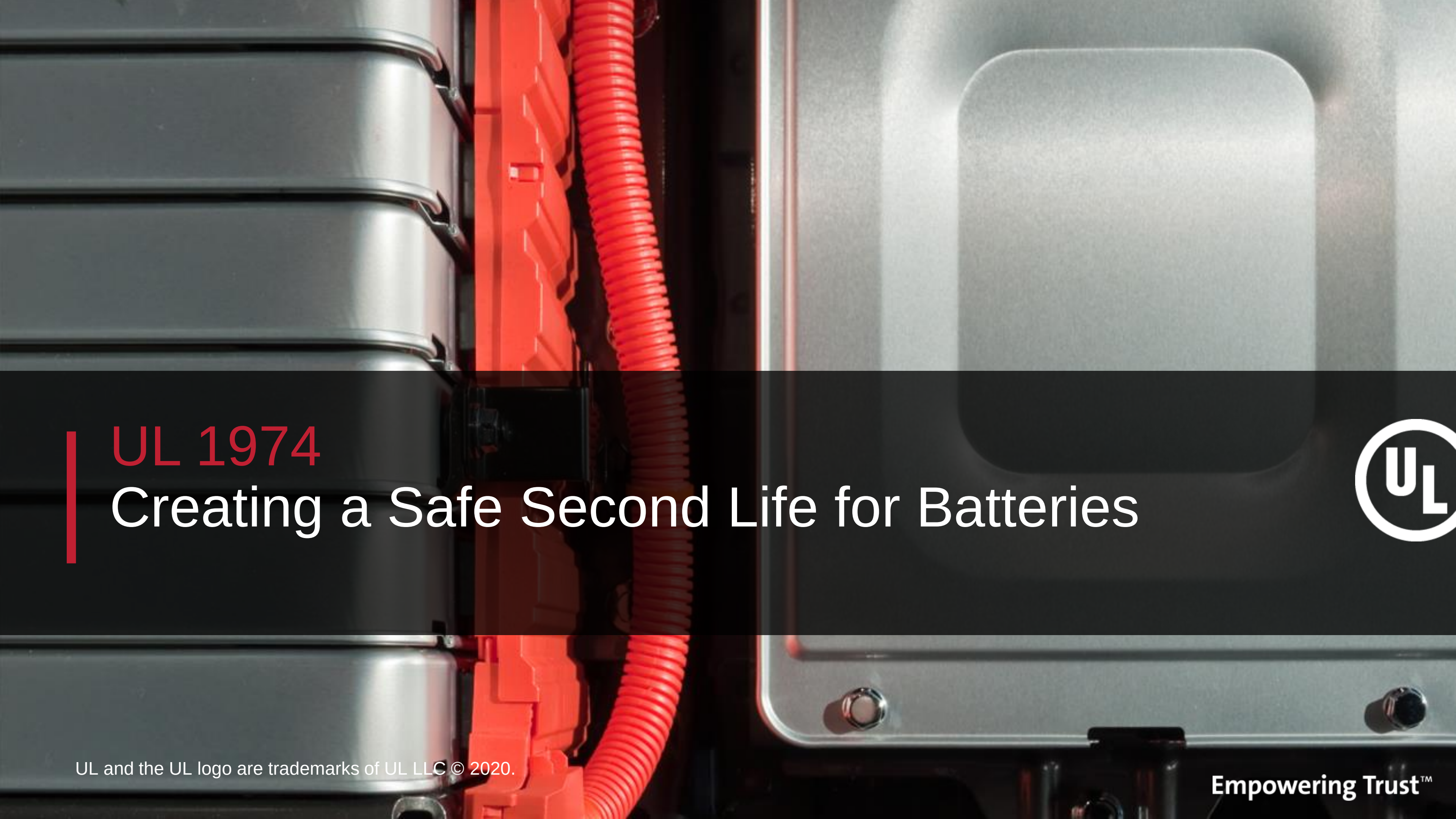


localhost:8080/index.html#

Simcenter solutions
Unique value proposition for electrified powertrain development

SIEMENS
Ingenuity for life

Reduce development cost and time with fewer prototypes	Analyze vehicle/powertrain architectures earlier in the development cycle	Virtually assess systems interactions
Study the influence of control strategies on fuel consumption, emissions and performances	Balance critical attributes: fuel economy, performances, passenger comfort and range	Find the best comprise to fit both regulations and market requirements



UL 1974

Creating a Safe Second Life for Batteries

Empowering Trust™

UL, a Global Safety Science Organization

OUR MISSION

Working for A Safer World

Since 1894

UL Empowering Trust

Underwriters Laboratories (Nonprofit)

UL - Business Solutions

Testing, Inspection & Certification
Software as a Service
Advisory Services

Why UL standard for Repurposing Battery?

- Electric vehicle (EV) battery system is expensive with high performance requirements.
  - 20-30% energy loss means it may not be able to support the EV performance needs
- Sustainability and environmental protection. Li-ion batteries are not readily recyclable.
- Public and regulator misperception of “2nd hand” batteries being unsafe.
- If recertify every repurposed end-product, it is highly ineffective, expensive, both time- and sample-consuming.
- Strong industry need and no standard back then.

UL 1974 Standard Scope

- Covers the sorting and grading process of battery packs, modules, and cells that were originally configured and used for other purposes—such as electric vehicle propulsion—and that are intended for a repurposed use application, such as for use in stationary energy storage and other applications
- The process of sorting and grading these devices is essentially determining the state of health and other parameters to identify continued viability and the rating mechanisms the manufacturer may use for those that are determined suitable for continued use
- Published in Oct 2018. Also recognized as a US and Canada binational standard

JOINT CANADA-UNITED STATES NATIONAL STANDARD

STANDARD FOR SAFETY

ANSI/CAN/UL 1974, Evaluation for Repurposing Batteries

ANSI/UL 1974-2018

Standards Council of Canada
Conseil canadien des normes

Evaluating and Repurposing Batteries

- UL 1974 is a “**manufacturing process**” standard that looks at the methods used to determine the safety and performance of batteries, modules, and cells from used EV battery systems (i.e. repurposing process)
- Assembled batteries need to meet the end product requirements when re-assembled into a 2nd use battery
  - e.g. UL 1973 is used for stationary batteries

Construction — Examination Of Incoming Samples — Performance — Packing & Markings Instructions

Standards Technical Panel of UL 1974 – Repurposing Batteries

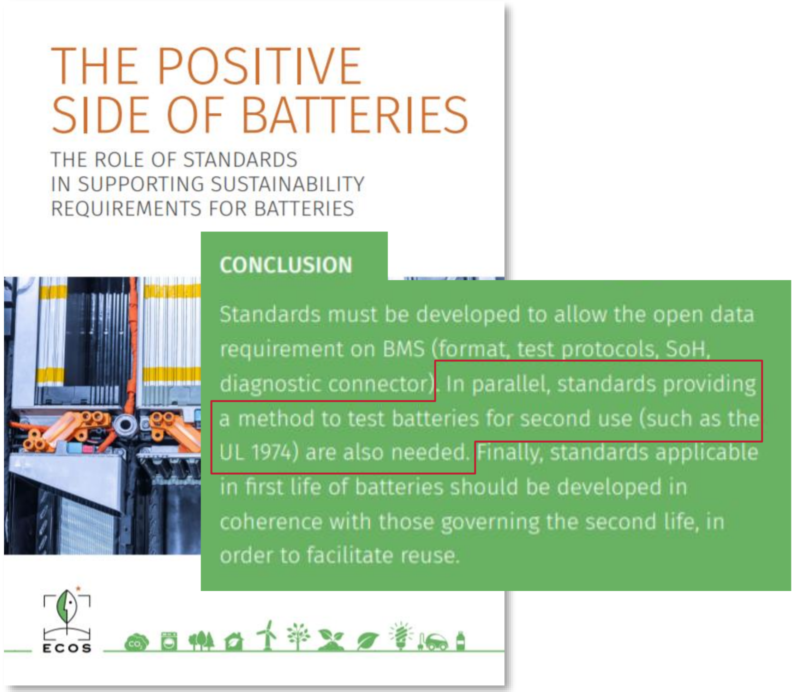
Interest Category	Number of STP members	%
Producer	11 – Manufacturers from US, Canada, Japan and Taiwan	27.5%
Testing & Stds Org	7 – Incl. UL and other international testing bodies from US, China and Taiwan	17.5%
Supply Chain	2 – BMW and Rejoule Energy from Germany and US	5.0%
General	11 – Institutions, Associations and Consulting firms from US, Canada, China and Taiwan	27.5%
Government	3 – US Army, National Research Foundation of Canada and Pacific Northwest National Laboratories	7.5%
Commercial & Ind Users	1 – from US	2.5%
Regulators/AHJ	1 – NY City Dept of Buildings, Alberta Municipal Affairs, etc, from US and Canada	12.5%

- Approved by independent panel of volunteers from 6 countries/territories in North America, Asia and Europe
  - **Commitment of STP member**: Vote, provide comments, provide inputs to comment resolutions, help develop proposals to the standard.
- Balanced representation - no category with 1/3 of total representation
- **Open for participation by Singapore expert at no cost**

Link: STP Member Code of Ethics

Gaining traction globally

As one of its kind of standards, UL 1974 received global interests, e.g.



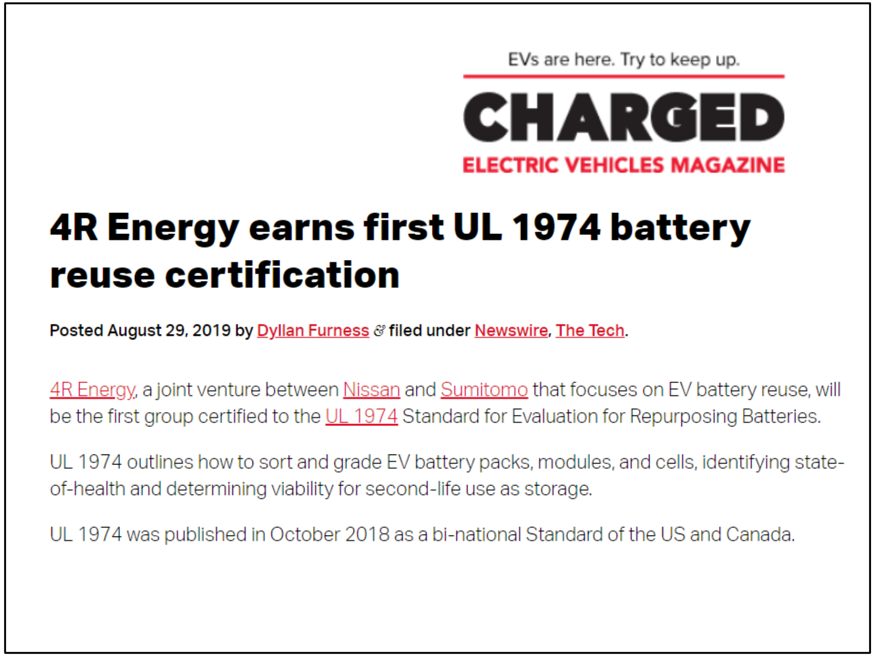
THE POSITIVE SIDE OF BATTERIES

THE ROLE OF STANDARDS IN SUPPORTING SUSTAINABILITY REQUIREMENTS FOR BATTERIES

CONCLUSION

Standards must be developed to allow the open data requirement on BMS (format, test protocols, SoH, diagnostic connector). In parallel, standards providing a method to test batteries for second use (such as the UL 1974) are also needed. Finally, standards applicable in first life of batteries should be developed in coherence with those governing the second life, in order to facilitate reuse.

ECOS



EVs are here. Try to keep up.

CHARGED

ELECTRIC VEHICLES MAGAZINE

4R Energy earns first UL 1974 battery reuse certification

Posted August 29, 2019 by Dyllan Furness & filed under Newswire, The Tech.

4R Energy, a joint venture between Nissan and Sumitomo that focuses on EV battery reuse, will be the first group certified to the UL 1974 Standard for Evaluation for Repurposing Batteries.

UL 1974 outlines how to sort and grade EV battery packs, modules, and cells, identifying state-of-health and determining viability for second-life use as storage.

UL 1974 was published in October 2018 as a bi-national Standard of the US and Canada.

ECOS, European Environmental Citizen's Organisation for Standardisation, is officially recognised in the EU as one of the four organisations whose work is supported to ensure standards serve society. Link to study

Wish to learn more?

SINGAPORE BATTERY CONSORTIUM

Joint Webinar on Repurposing Batteries Standards
(Coming soon)

Or contact me directly:
Kolin Low
Regional Standards Manager
Underwriters Laboratories
Kolin.low@ul.org

Thank you!

UL Standards Recognition

Organization Legacy

- A leading standards developer with strong legacy and track records

- Open, Research-based standards with quick response to market needs

International Level

- Supports implementation of WTO TBT agreement and other multilateral systems
- Coherence with other International Standards Developers e.g. ISO and IEC

WORLD TRADE ORGANIZATION

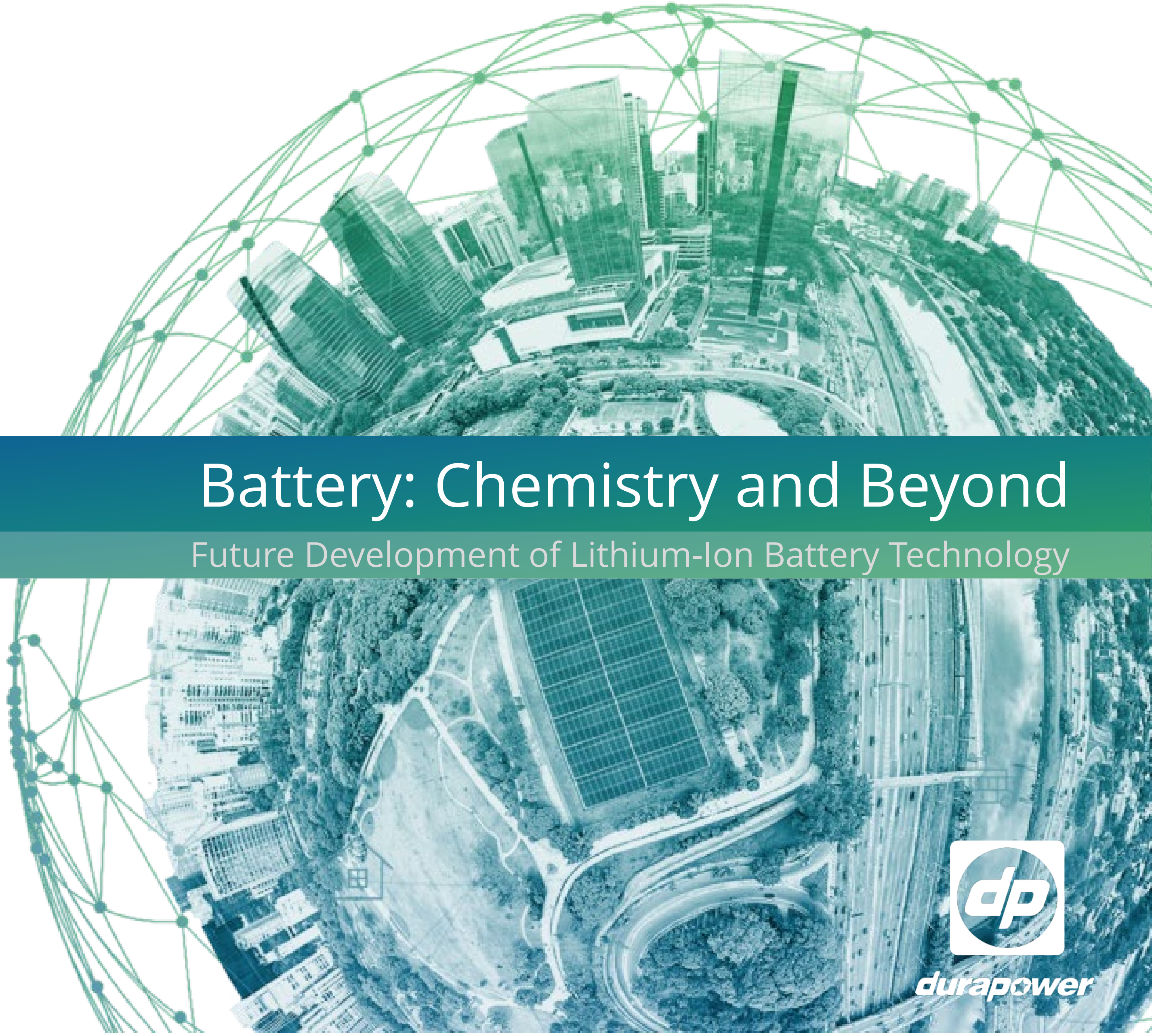
ISO IEC

National Level

- Developing national standards in the US, Canada and Mexico

- Support development & adoption of UL standards globally

UL



Battery: Chemistry and Beyond

Future Development of Lithium-Ion Battery Technology

Dr. Shen Nan
September 2020

durapower

01 ABOUT DURAPOWER

02 CURRENT TECHNOLOGY

03 RESEARCH FOCUS AND CHALLENGES

04 Q & A

01 ABOUT DURAPOWER

02 CURRENT TECHNOLOGY

03 RESEARCH FOCUS AND CHALLENGES

04 Q & A

WHO WE ARE

Established in 2009, Durapower offers a closed-loop, end-to-end energy storage solution for the electric mobility and renewable energy ecosystem. The company is focused on research and design of Lithium-ion battery (LIB) materials, battery cell manufacturing, and integration of battery systems, delivering state-of-the-art energy storage solutions for electric vehicles and renewable energy globally.

With professionals in the automotive and renewable industry of more than 15 years of experience and a wholly-owned battery cell manufacturing facility, Durapower is a tier-one supplier to vehicle manufacturers and has its battery systems integrated into thousands of Electric Vehicles (EVs), Hybrid Electric Vehicles (HEVs) and Plug-In Hybrid Electric Vehicles (PHEVs). The company has achieved a remarkable safety track record over the years, covering hundreds of million kilometers of operational mileage and deployed various scales stationary storage solutions for on and off Grid applications. Headquartered in Singapore and with subsidiaries in China, Europe, and Thailand, Durapower works closely with government agencies, blue-chip customers, and partners to deliver our solutions to over 20 countries and 45 cities globally.

Proud member of :

EVAAP Electric Vehicle Association of Asia Pacific

SEAS Sustainable Energy Association of Singapore

SINGAPORE BATTERY CONSORTIUM

EUROPEAN BATTERY ALLIANCE EBA250

durapower

MANUFACTURING AND R&D FOOTPRINT

OUR GLOBAL MARKET PRESENCE

durapower

20 Countries,
45 Cities & Growing

01 ABOUT DURAPOWER

02 **CURRENT TECHNOLOGY**

03 RESEARCH FOCUS AND CHALLENGES

04 Q & A

KEY PRODUCTS & APPLICATIONS

NMC Battery Cells

NMC High Power Cell Product

- 16Ah HEV/ESS(1)
- **2,600W/kg (high power density)**

NMC High Energy Cell Product

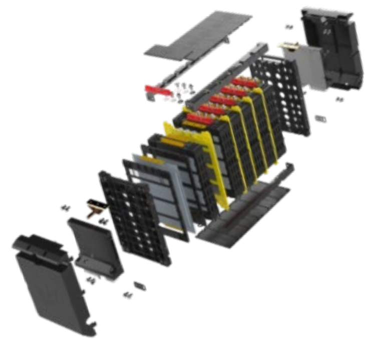
- 25/30/48Ah PHEV/EV/ESS(1)
- **160/190/200 Wh/kg (high energy density)**

LFP Battery Cells

LFP Cell Product

- 25Ah ESS(1)
- **135wh/kg (high energy density)**

High Performance Battery Modules



Materials R&D	Separator R&D Cathode/Anode Material R&D
Cell	Pouch Type cell design Laminated high power structure design
Unit	Cell Frame Protection Flexible Pack Design
Module	Standard modularity design Connection of high reliability
System	System Integration Technology Thermal Management

Market Segments

E-mobility

Specialty Platforms

Stationary

(1) HEV: Hybrid Electric Vehicle, PHEV: Plug-in Hybrid Electric Vehicle, ESS: Energy Storage System

01 ABOUT DURAPOWER

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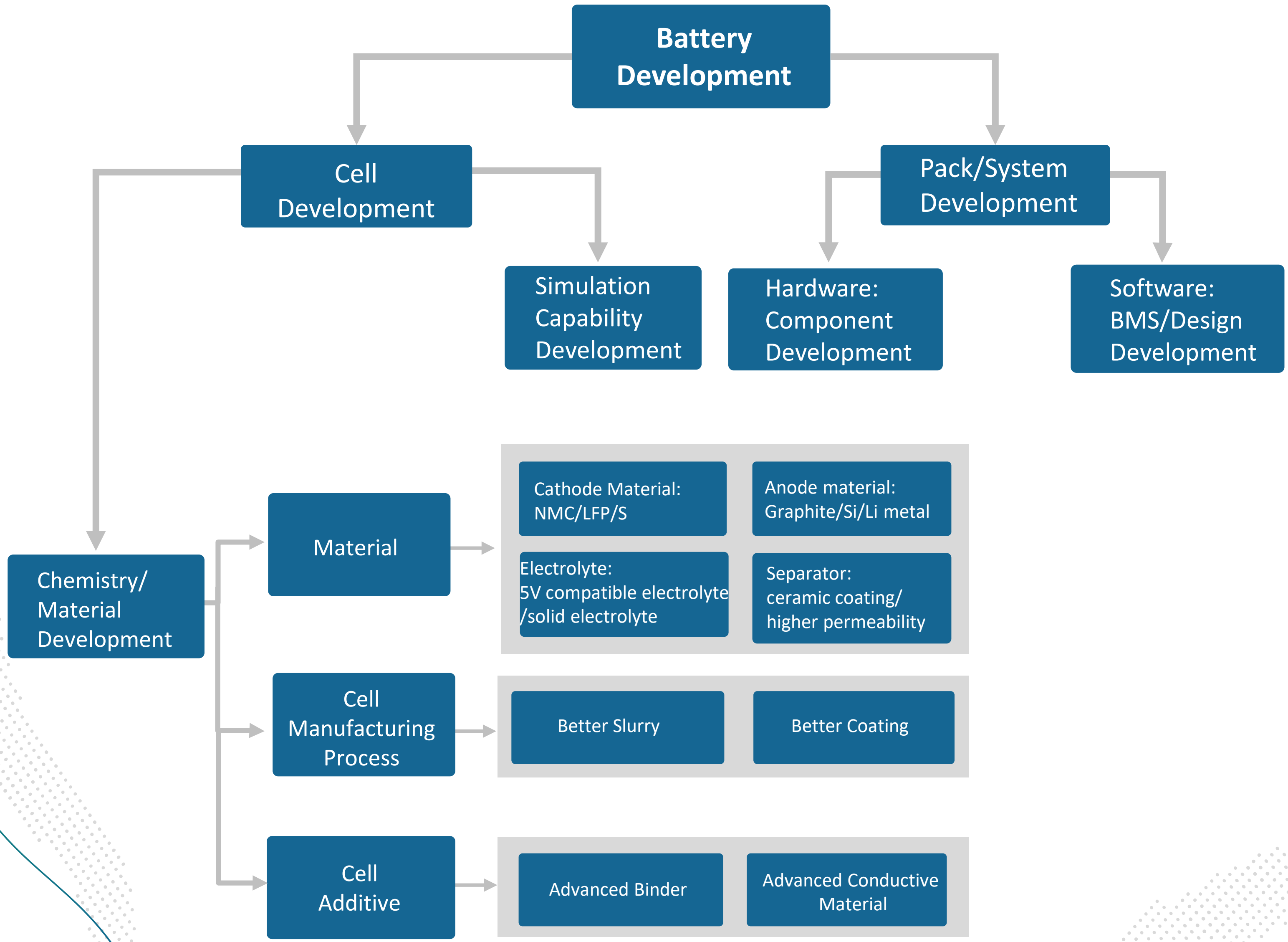
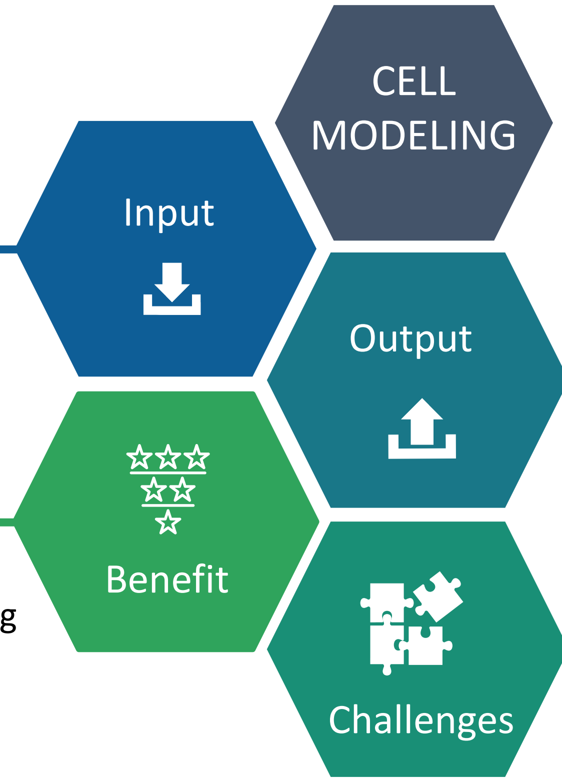
RESEARCH FOCUS AND CHALLENGES



RESEARCH FOCUS AND CHALLENGES



- Raw material property
- Design parameter
- Process parameter

- Fasten R&D process
- Avoid long term test
- Help in module/pack modeling

- Cell parameter
- Electrochemical performance
- Factors that affect the electrochemical performance

- Require expertise from both chemistry and modeling
- A long term effort needed
- Need a strict validation process, hence need collaboration

RESEARCH FOCUS AND CHALLENGES

durapower

PACK

BMS

- Monitor SoC/SoH more accurately
- Adopt more accurate balancing strategy
  - Active balancing
- AI based technology to active predict the future behavior of the battery
- Remote upgrade and diagnose technology

PACK

SIMULATION

Mechanical/ thermal simulation to predict battery behavior

2ND LIFE BATTERIES

- Life cycle prediction: need to anticipate the behavior of battery after 80% EoL
- Redesign and optimize of battery system:
  - Efficient sourcing strategy to pick up “similar” batteries
  - Special BMS development:2nd life battery is supposed to have larger variation; hence, a more powerful balancing strategy would be required.
  - System design: due to change of application, the system component such as thermal design needs to be restructured

01 ABOUT DURAPOWER

02 CURRENT TECHNOLOGY

03 RESEARCH FOCUS AND CHALLENGES

04 Q & A

Q & A

THANK YOU

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Durapower Holdings Pte Ltd

High-precision current pulse for fast battery diagnostics

SBC Battery Analytics roundtable

Andreas Hauser – Deputy Head, ESS

Singapore, 24th September 2020

VDE

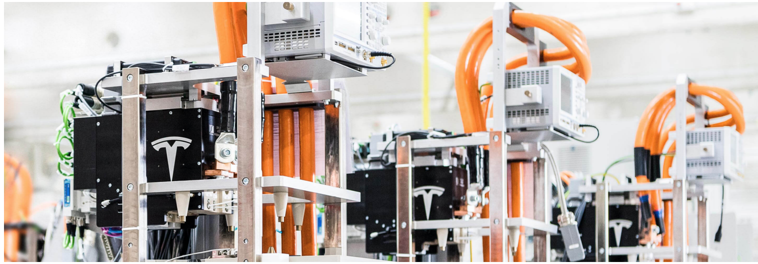
Intro: Where is (fast) battery diagnostic especially relevant?

Battery system production line

- Assembly of individual cells to (large scale) battery systems involves many steps
- Substandard welds / connections can lead to performance loss / safety issues
  - Challenging to check every weld – how?

Second life applications

- Usage of ”still good” batteries after a primary application usage (in e.g. EVs)
- Determination of ”still good” difficult
  - Different usage leads to different remaining capacity / internal resistance
  - Is it still save to use?



Source: Tesla

Source: BMW

VDE

Intro: What methods are typically used today?

Resistance measurement (R_{AC}), e.g. 1 kHz

- Fast, flexible and easy to understand result (an impedance value)

→ Significance of result not clear, difficult to compare results from two systems (what does it mean? capacity?)

→ Little link of single impedance to SoH / SoF

Impedance spectroscopy (EIS)

- Takes long to measure, needs expert to understand
- Correlation between SoH / SoF and EIS to some degree, requires study with multiple samples

→ Difficult to derive single pass / fail criteria

High-power pulse (HPPC & R_{DC})

- Needs accurate cyclers and expert to evaluate correctly (automatic evaluation possible, but no ready solution on market)
- Gives good picture of dynamic behaviour but no information about residual capacity

→ What does the result mean regarding SoH?

Cycling (e.g. discharge performance)

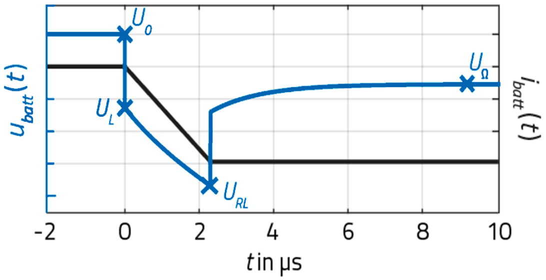
- Takes very long (> 2h), but gives accurate residual capacity
- Requires expensive cyclers, no classification of the internal resistance

→ Test duration and cost makes it not feasible for large-scale (i.e. mass-) production

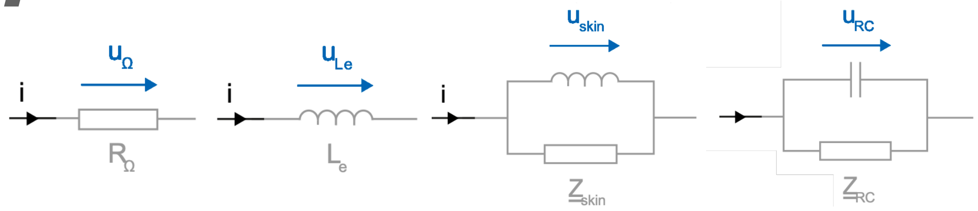
Novel high-speed approach based on precision current pulse

- Usage of a single high-precision current pulse of a few µs duration and high-accuracy recording of battery cell / -module or -pack voltage response
- Equivalent battery circuit components contribute to voltage response, in connection with novel algorithms and battery database allows to assess & classify battery cell / -module / -pack accurately, with high significance and repeatability
- Automatic post-processing & evaluation possible, enables usage by technicians as well as experts and in automated environments, making this approach highly flexible, low cost and time efficient

1 single current pulse of a few µs



100 % analytical parametrization of any battery system



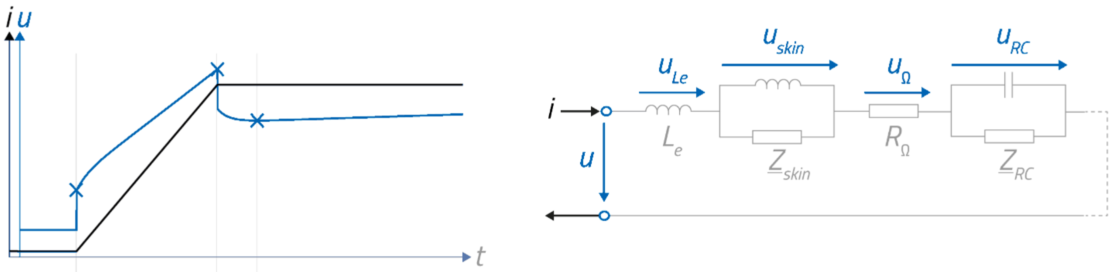
R_Ω L_e R_{skin} R_{RC}

Technology in detail

current pulse *i* and

voltage response *u*

at battery terminals

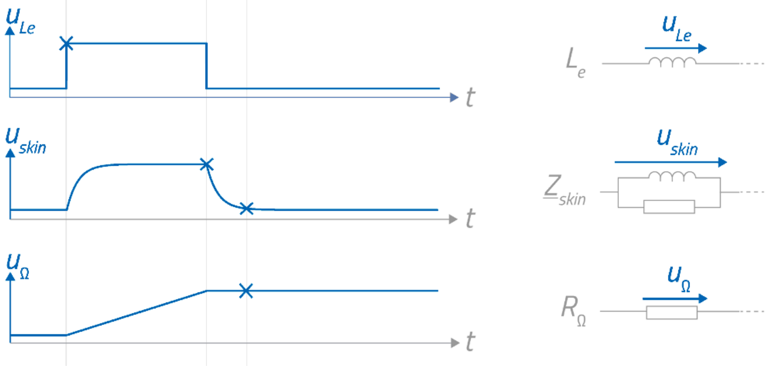


single contributions

u_{Le} , u_{skin} ,u_{Ω}

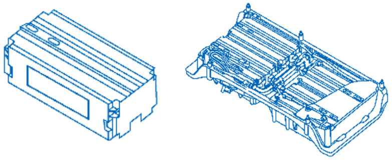
to overall voltage

response *u*



Use cases for battery module / -pack industry

production



operation

2nd life

A Solution by VDE RE & partners

- Standalone hardware + software
- Contacting units + multiplexers
- Contract research + battery database
- Quality certificates for each system

Module / pack test (End of Line)

- Welding spots / connectors / plugs
- Electronics
- Mech. structure & integrity

Service / Maintenance

- Functionality / safety
- Error detection & predictive maintenance
- Valuation

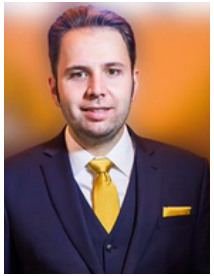
Reuse & Recycle

- Assessment
- Classification
- Valuation

Thank you for your attention!

We shape the e-dial future.
Experience it with us.

Your contact:



Andreas Hauser
Deputy Head, Energy Storage Systems

Phone: +65 9151 1798
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Our services:

- *R&D for industrial clients*
- *Testing & certification on cell-, module-, and pack / system level (including BMS)*
  - *Performance and lifetime testing with 200+ test channels for various system sizes (all chemistries)*
  - *Safety testing in specially designed bunker*
- *Inspections (Factory, ESS sites, pre-shipment)*
- *Accident investigations (battery forensics)*
- *Consulting, due diligence and development support*