Modular battery design for Automated battery manufacturing in Niche applications: AMPLiFII Project

Mark Ellis
Principal Engineer – Battery Systems
WMG – University of Warwick, UK

Project Objectives

Access to the vehicle electrification market for niche vehicle manufacturers

- Modules for both high power and high energy pack requirements sharing a common footprint to maintain modularity within the pack design.
- Apply the modular 'building block' approach to battery module and pack manufacture to allow high quality, validated multi-applications at lower cost than bespoke designs. Consider extension of battery life, design for remanufacturing, and recycling; essential to sustainability and market acceptance of the process solution.
- Provide the means to **aggregate demand at module level** to allow high quality product development for low volume manufacture.
- The business innovations: **enduring supply chain** through license arrangement, develop a **common software platform** with enduring license for upgrades to both hardware and software
- The **flexible**, **scalable** assembly of the small-cell solution enables a pilot line capable of producing a **variety** of different traction battery types, and a **technology transfer** package output to allow consortium members to **replicate the facility** and scale up for future volume production.
- This project fills a critical gap in the UK supply chain. Enables development of a centralised UK supply chain. This will lead to the increased production of xEVs and the cascaded benefits for the supply chain within the UK.

Collaboration

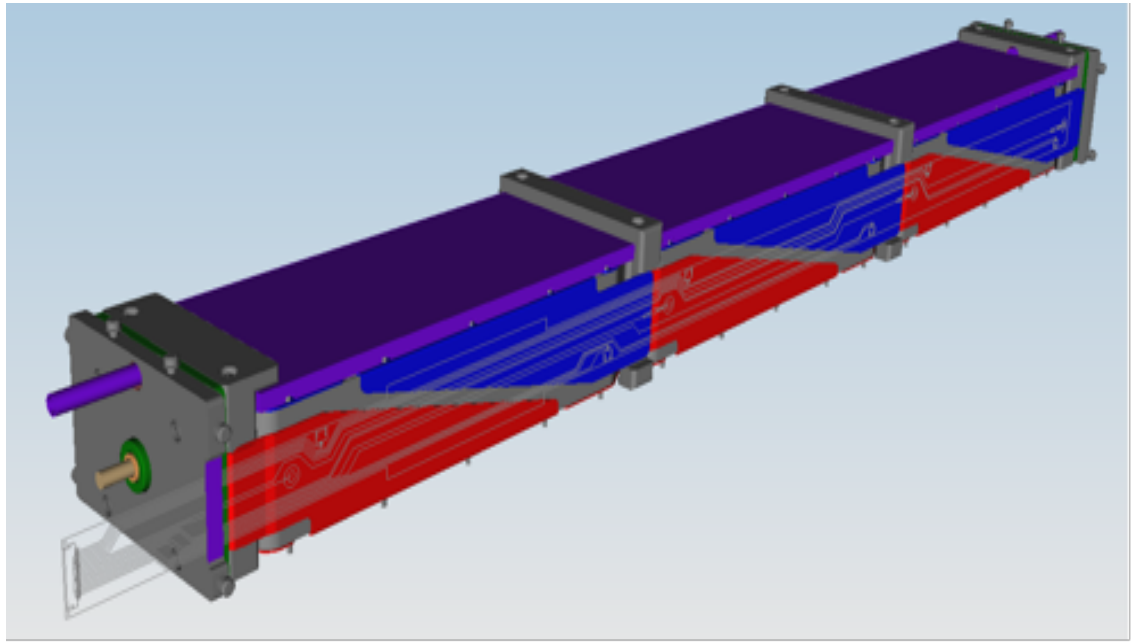
Project Approach

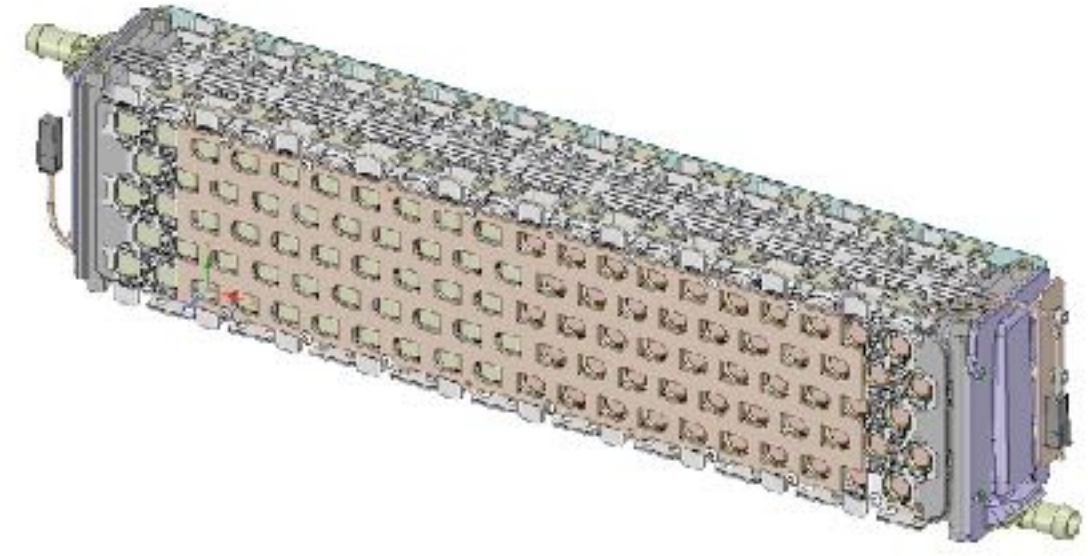
- ***AMPLiFII will create a UK supply chain for fully validated battery packs to suit hybrid and electric vehicles across a broad range of market applications***
- ***The project will design a modular battery architecture, based on 18650 cylindrical cells, for both high power and high energy requirements***
- ***The common architecture will allow supply chain to aggregate demand and benefit from economies of scale***
- ***A pilot line hosted at WMG will support the manufacture of high quality pre-production prototypes, combining appropriate levels of manual and automated assembly methods.***
- ***The pilot line will encompass flexible manufacturing technology and will be structured to operate at Industry 4.0 standard.***
- ***The pilot line will become an open facility operating as part of the Energy Innovation Centre located in the International Automotive Research Centre.***
- ***AMPLiFII will develop new knowledge, skills, technology and facilities to support UK industry seeking to implement new processes and technologies for next generation battery systems.***

Work Package Structure

WP0	Project Management
WP1	Vehicle Pack Specification
WP2	System Safety Engineering
WP3	Cost Engineering
WP4	Define Pack Architecture
WP5	Module Design
WP6	Pack Design & Analysis
WP7	Electrical Distribution System
WP8	Pilot Production Line
WP9	BMS Architecture Design
WP10	Module Control Unit (MCU)
WP11	Battery Control Unit (BCU)
WP12	High Level BMS Software
WP13	Multi Pack Controller
WP14	Testing & Characterisation
WP15	Pack Level testing
WP16	Pack Sign Off
WP17	OEM Validation
WP18	Parallel R&D Activities
WP19	Life Cycle Management

Module Design





Series	#	3	2	3	4
Parallel	#	99	50	30	20
		Energy	**Power 1**	**Power 2**	**Power 3**
Cell capacity	Ah	3.38	2.05	2.05	2.05
Cell Nominal voltage	V	3.60	3.60	3.60	3.60
Cell Min Voltage	V	2.50	2.50	2.50	2.50
Cell Max voltage	V	4.20	4.20	4.20	4.20
Nominal Energy	kWh	3.40	0.74	0.66	0.59
Nominal Capacity	Ah	314.8	102.5	61.5	41.00
SOC Window	%	85%	85%	85%	85%
Usable Energy BOL	kWh	2.89	0.63	0.56	0.50
Usable Energy ECL (80% BOL)	kWh	2.31	0.50	0.45	0.40
voltage					
Nominal Voltage	V	10.8	7.2	10.8	14.4
Min Voltage	V	7.5	5	7.5	10.0
Max Voltage	V	12.6	8.4	12.6	16.8

- **Jaguar Land Rover** have explored Energy module configuration to enhance module energy density and better understand manufacturing issues.
- **Delta Motorsport** have led the development of a scalable module which can be readily adapted for different niche applications.
  - Plastic snap-fit module carrier
  - Incorporates an innovative flexible plastic liquid cooling system

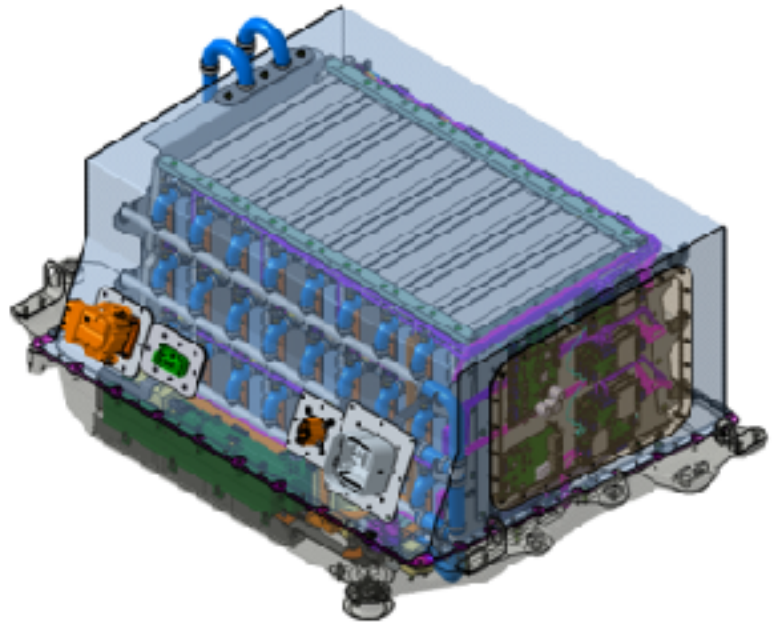
Detail Design

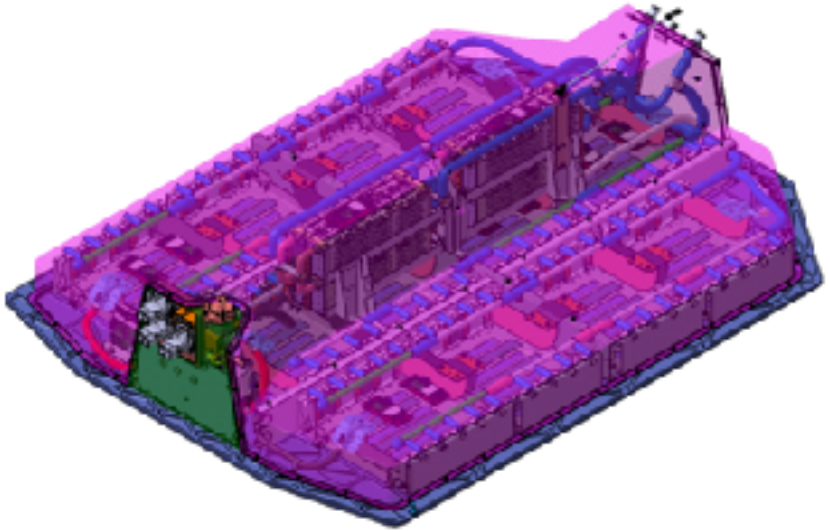
- Flexible structure of the module carrier achieved by injection-moulded snap-fit plastic carrier elements holding ten 18650 cells each.
- End-plates all provide stiffness for the module and allow mounting of the busbar
- Module structure is fixed by ultrasonic welding of upper and lower carriers
- Busbar to cell joining achieved by DC-TIG welding
- Busbar of 0.30mm Cu to achieve reliable welding to Ni-plated steel can. Requires two-piece busbar to balance charge carrying capacity with welding needs.

- Busbar formed by etched cell tab sheet (0.3mm), laser welded to water jet cut & formed 2.0mm current carrier

Battery Packs

Specification	Unit	Pack	Pack	Pack	Pack
Cell Chemistry		NCA	NMC/Gr+SiO	NMC/Gr+SiO	NMC/Gr+SiO
Form Factor		Cylindrical	Cylindrical	Cylindrical	Cylindrical
Type		High Energy	High Power	High Power	High Power
Energy		**Energy**	**Power 1**	**Power 2**	**Power 3**
Cell capacity	Ah	3.18	2.05	2.05	2.05
Cell Nominal voltage	V	3.60	3.60	3.60	3.60
Cell Min Voltage	V	2.50	2.50	2.50	2.50
Cell Max voltage	V	4.20	4.20	4.20	4.20
Max Energy	kWh	126.94	10.33	46.49	19.29
Nominal Capacity	Ah	314.8	102.5	61.5	41.0
SOC Window	%	90%	85%	90%	85%
Usable Energy BOL	kWh	114.2	8.8	41.8	16.4
Usable Energy EOL (80% BOL)	kWh	91.4	7.0	33.5	13.1
Voltage					
Nominal Voltage	V	345.6	86.4	648	403.2
Min Voltage	V	240	60	450	280
Max Voltage	V	403.2	100.8	756	470.4
Cell Architecture		**32s modules**	**12s modules**	**60s modules**	**28s modules**
Series	#	3	2	3	4
Parallel	#	99	50	30	20
Module Cell count	#	297	100	90	80
Modules	#	32	12	60	28
(Sub) Packs	#	1	1	1	1
Total Cell Count	#	9504	1200	5400	2240

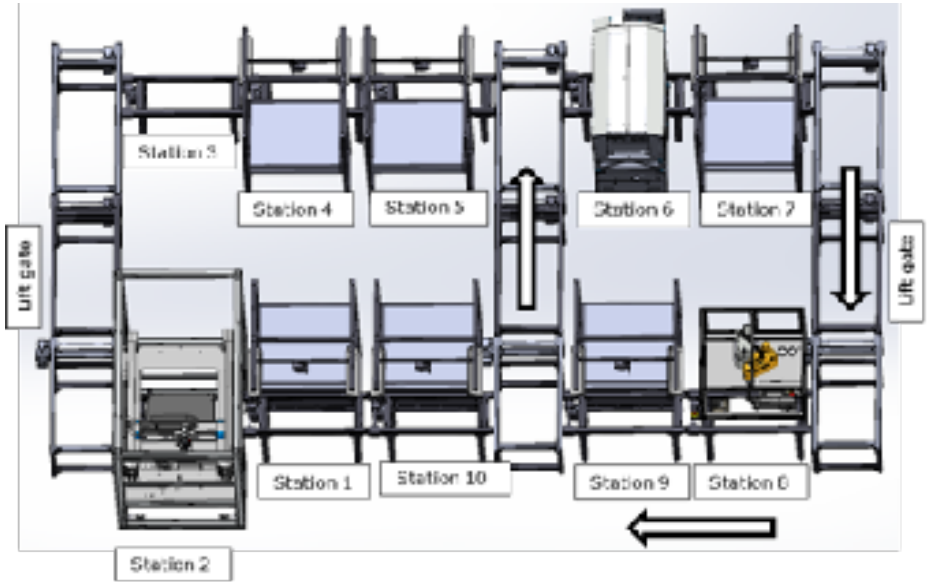




- Pack applications: eBike to Buses
- Voltage: 100 – 750v (36 – 48v eBike & L7)
- Capacity: 10 – 128kWh (360Wh to 290kWh)
- Power: 35kW – 550kW (360W to 600kW)

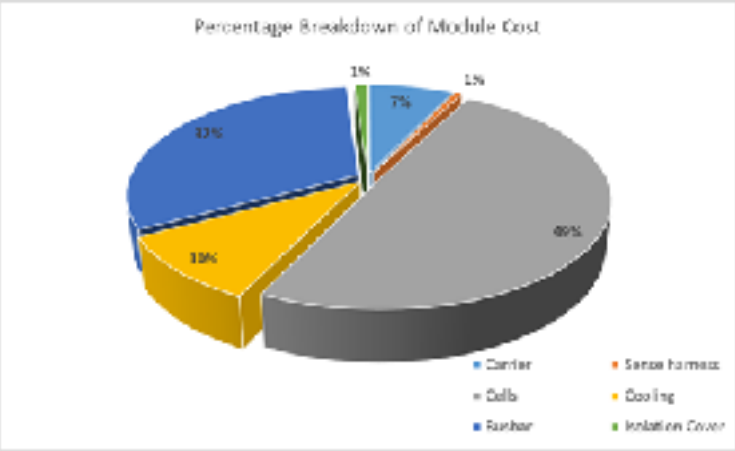
Manufacturing

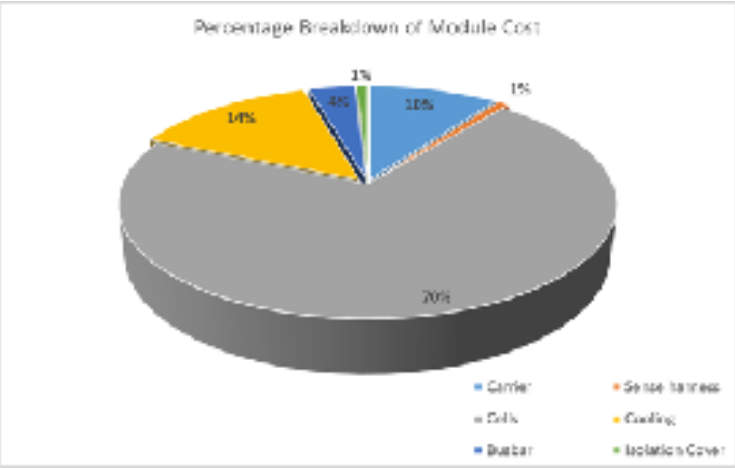
- Automated stations at bottlenecks:
  - Cell-loading & test (OCV & Impedance)
  - Joining cell to busbar
    - Pulsed Arc: DC-TIG
- Moderate manufacturing line investment: £1.3m
- Module end-of-line test:
  - Electrical: short charge / discharge cycle
  - Sensor check: voltage & thermal
  - Pressure test



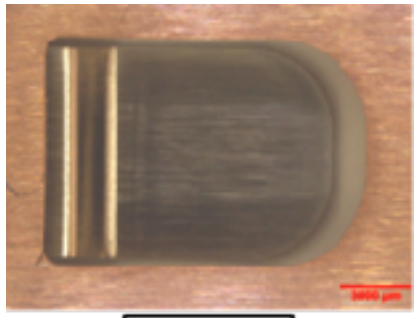
Station	Energy module	Power module
1	Load top tray	Assemble cell carriers
2	Automated cell test and load	
3	Install thermistor, top tray	Install cooling, wiring, assemble cell carriers
4		Cell carriers welding
5	Bus bar fitment	
6	Ultrasonic wedge bonding	
7	Rotate module, bus bar fitment	Rotate module, bus bar fitment
8	Pulsed arc welder	
9	Fit harness, thermal pad, cover	Weld test, fit cover
10	Module test and unload	

Cost reduction

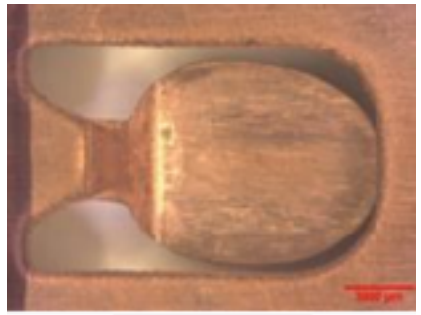




- **Significant efforts made to drive down module cost**
- Use of plastic mouldings for module carrier & cooling
- Prototype parts
- Example: Busbar cost a large focus – high cost material, critical to quality process – tab joining (0.3mm)
  - Laminated 2-piece laser welded
  - Coined 1-piece solution
- Requires tooling investment, but large cost saving
- Supplier developing process capability



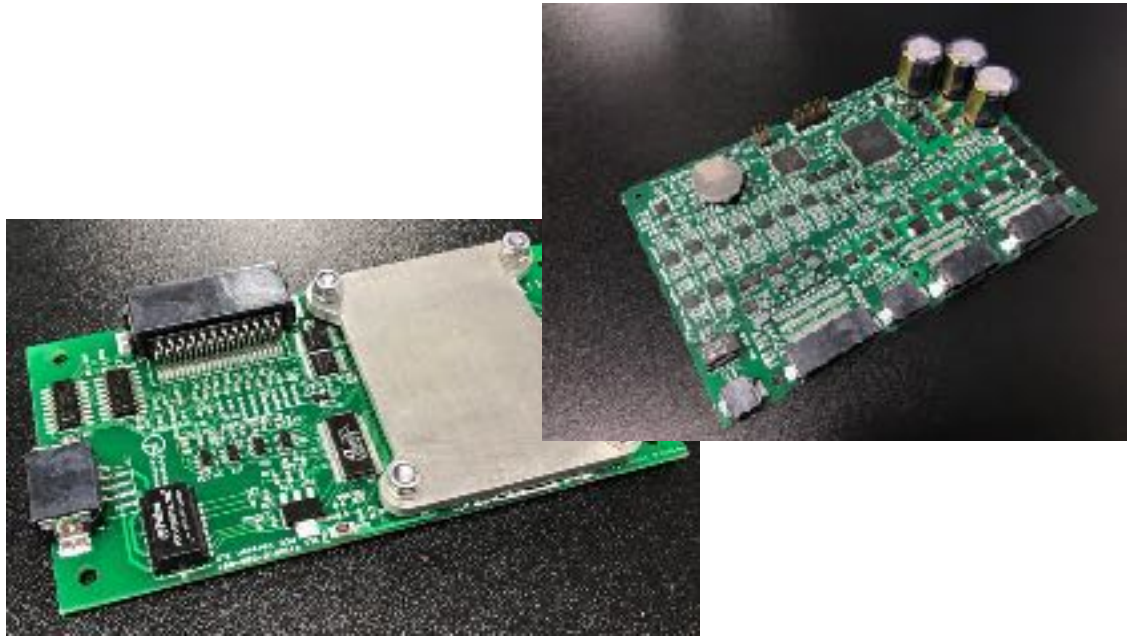
Laminated



Coined

Outcomes: BMS & Material Recovery

- **Potenza** have undertaken a significant development in the production of a flexible and cost effective BMS in both software & hardware
  - Battery Control Unit
  - High Voltage Module
  - Module Control Unit
  - Sub-pack control unit (for multi-pack system)
- ISO 26262 compliant



- **Axion & Augean -** exploring processes for dealing with end of life battery waste within an automotive recycling context
- Addressing safety issues & process considerations for a chemical material recovery process

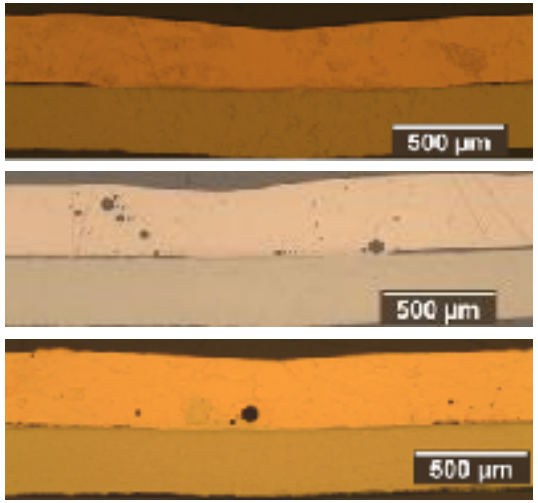
Outcomes: Scientific

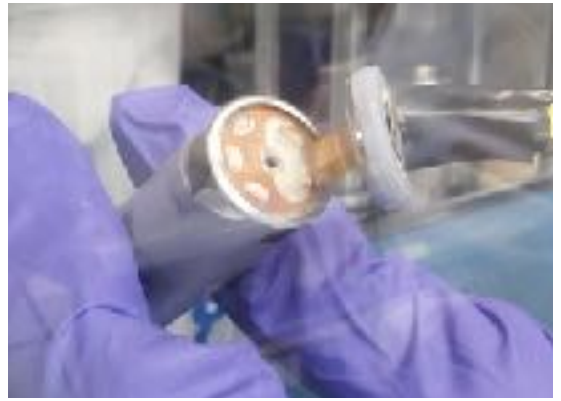
- **Manufacturing** – architecture of module manufacturing line. Balance & capacity constraints for different use-cases

- **Welding** –
  - Suitability of differing welding technologies for module architecture & productivity
  - Metallurgical compatibility of coatings & pre-treatment for weldment reliability
  - Influence of weld heat input on active material performance
- **Sensors** –
  - In-situ highly spatially resolved sensing within cells and modules to better understand high-rate transient thermal behaviour
  - In-situ reference electrode to determine electrochemical performance limits & maintain safety

- **Thermal performance** – modelling and correlation of module thermal performance & relationship with BMS thermal sensors

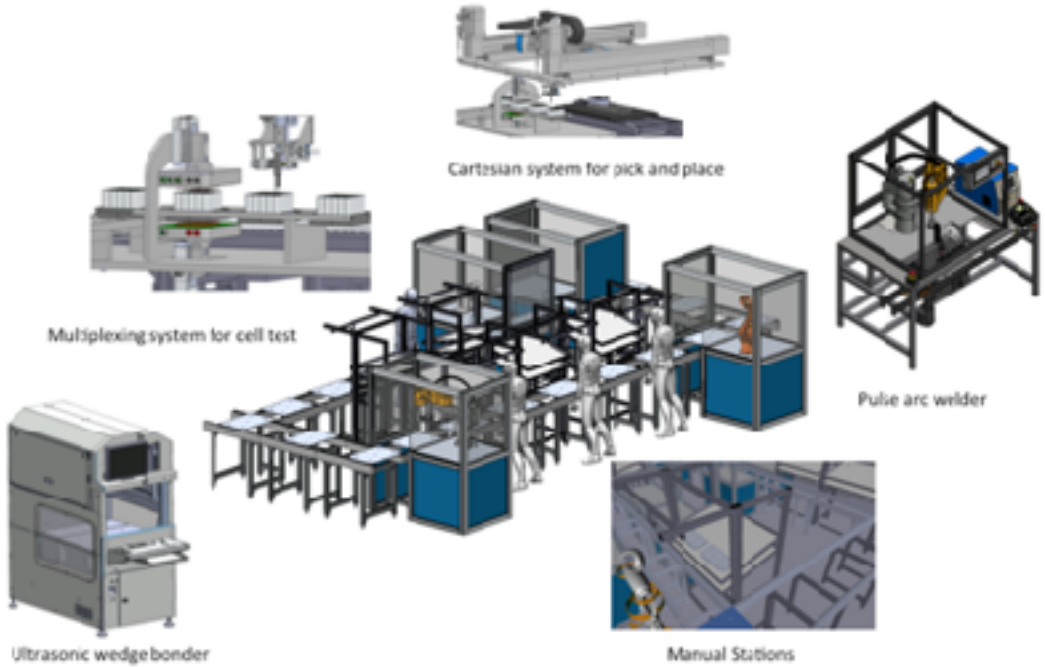
Over 30 papers published or accepted & seven patents applied for





Exploitation: Module Line

- **AMPLiFII** will provide a **UK resource for battery module manufacture. Available for use.**
- Based on 18650 cells; can be reconfigured easily for any small format cylindrical
- Ideal facility to prove manufacturing concept, economics or technical study - reconfigurable for other technologies
  - Modular design. Common station pitch of 1.2m
  - Three fully automated stations (Cell loading / test, Ultrasonic wire-bonding, Pulse arc TIG welding)
  - Six assisted manual stations
  - Each pallet will be equipped with workpiece carrier
  - Common pallets for both modules. Maximum working available area: 540mm in length and 300mm wide
  - Operational information will be gathered via pallet mounted RFID tags, collated to central database – available for analysis



Further Work

- Reduce part cost
  - Busbar - Alternative manufacturing process
  - Optimised material usage

- Improved joining productivity
  - Laser welding cell to busbar (for high volume)
  - Takt-time per cell < 0.2 sec

- Improved Right First Time

- Support of 21700 cell format
  - Adaptation to module carriers & tooling

Further collaborative projects

Summary

- Enable access to electrification market for niche vehicles
- Robust engineering & good science – driving innovation
- Stimulus to new opportunities in supply chain
- Build on strengths – motorsport connections
- Eye on cost
- Leveraging the skills in Universities through collaboration
- Provide a platform for further growth & innovation
  - Facility for development
  - Technology transfer to de-risk investment
  - Learning: to enable new directions

Thank you for your attention

Danke für das Hören meiner Präsentation

Office for Low Emission Vehicles

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