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Battery requirements coming from aviation

10 October 2017

Siemens eAircraft – Our motivation for electrifying aircraft propulsion

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- Drive systems are going electric – on land, at sea, and in the air
- Electric drive systems are one of the main business domains of Siemens
- The application to aerospace is attractive, technologically challenging, and requires safety and certification
- We are committed to the development and production of hybrid electric aircraft propulsion systems as a future area of business
- Technology spill over for other Siemens businesses

$P_{Mot} \approx 1/2$ MW

$P_{Mot}/m_{Mot} = 0.87$ kW/kg

$P_{Mot} \approx 1/4$ MW

$P_{Mot}/m_{Mot} = 5.2$ kW/kg

The aviation industry is on the verge of a major shift towards electrified propulsion

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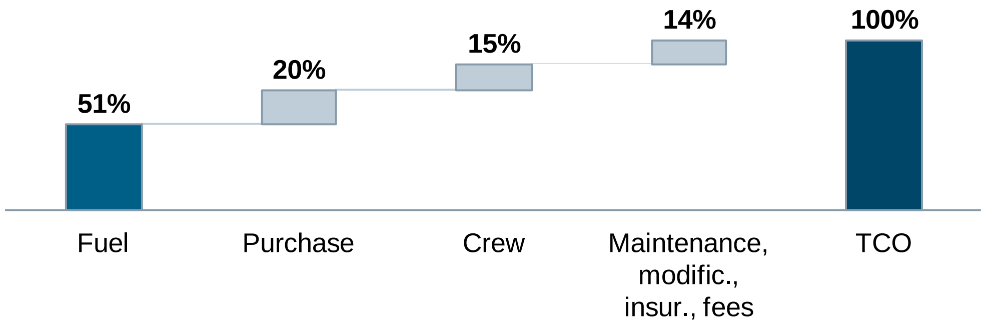
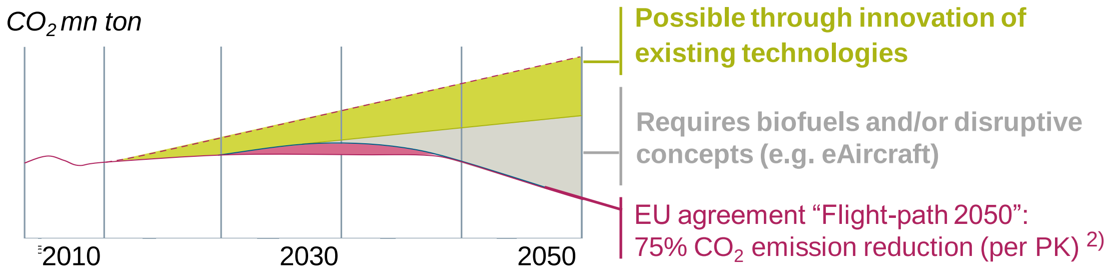
1. **Reduction of fuel consumption:** main lever to reduce aircraft TCO (example 737-800)



2. **Projected emission goals:** can only be reached with disruptive concepts [1)]



3. **Customer perspective:** extension of potential operating hours through noise reduction

Industry: various hybrid electric propulsion roadmap defined for demonstration (TRL's) and product development until 2035, e.g.

2016 – 2020

Hybrid Electric Systems Project

- Hybrid Ground Demonstrator, 10 MW platform
- <2 MW potential platform applications vertical take off and landing (VTOL), door-to-door

2028

Regional Aircraft
100 passengers, 6-8 MW

2035+

Short Range Aircraft
150-200 passengers, 20MW

1) IATA technology roadmap, June 2013

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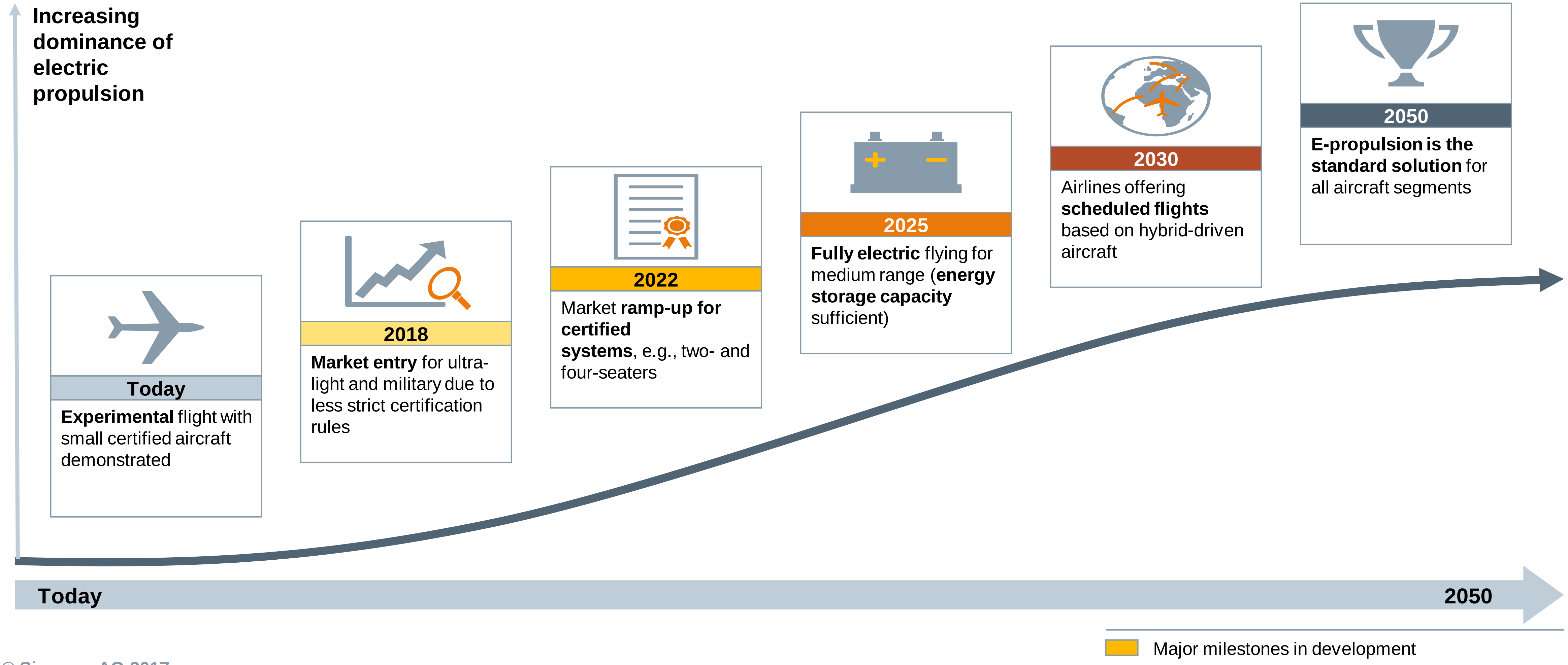
We expect e-propulsion to be the standard solution by 2050

Milestone outlook for e-propulsion market



Our core portfolio – electric propulsion units (EPU) for applications with high power/weight requirements

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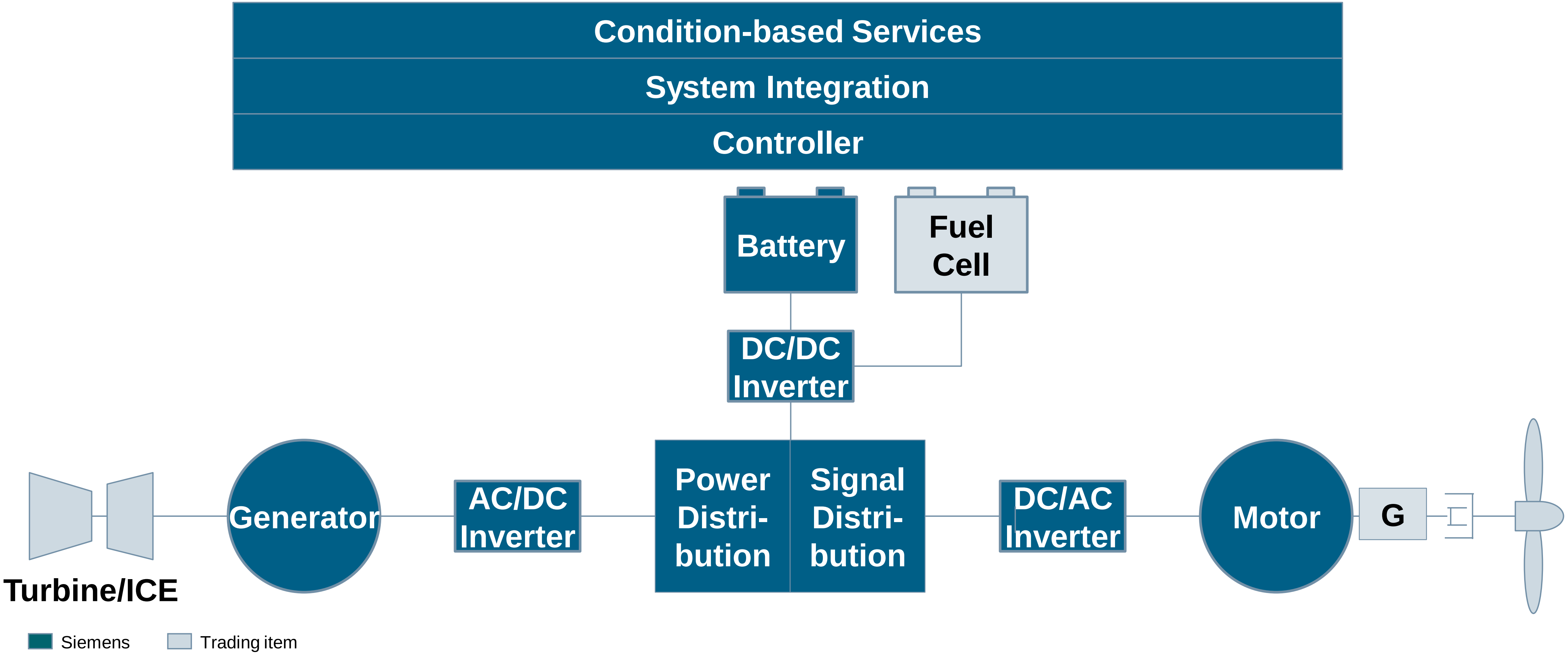

Two active test platforms running

Sub- 100kW electric propulsion units	¼ MW and greater electric propulsion units
	

Extra 330LE – Flying Testbed for ¼-MW class electric propulsion systems

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Extra 330LE – maiden flight summer 2016

Aircraft Data	
MTOW	1000 kg
Wingspan	8.0 m
Height	2.6 m
Length	7.5 m
Wing area	10.7 m^2
Propulsion System Data*	
$P_{cont.}$	230 kW
N_{max}	2250 rpm
$M_{cont.}$	1000 Nm
U_{zk}	580 VDC
η_{Motor}	max. 95%
$m_{motor\ including\ propeller\ bearing}$	50 kg

* As rated in the Extra 330LE

Magnus eFusion - fully electric aircraft propulsion system installed firewall-forward

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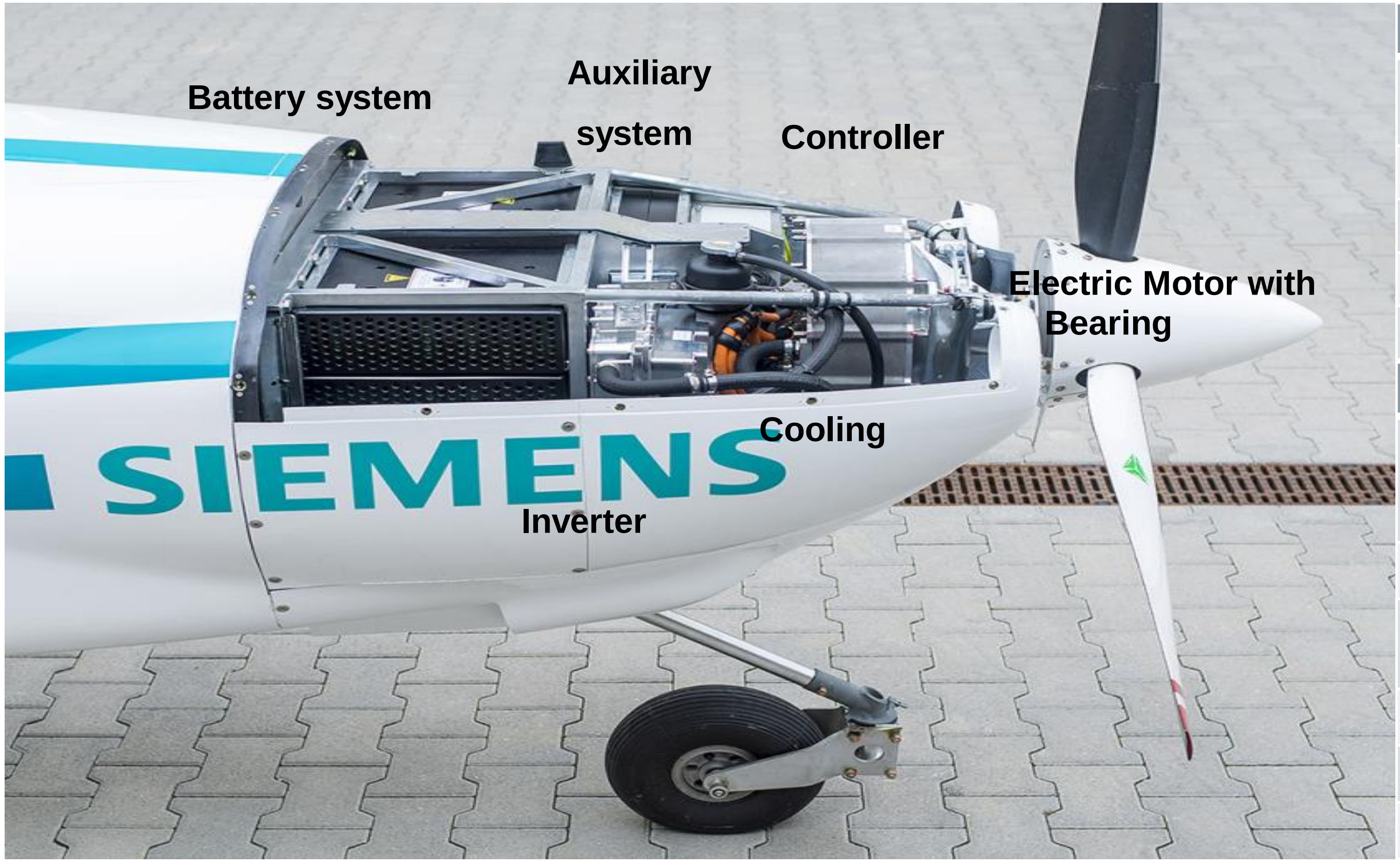
Magnus eFusion – maiden flight Summer 2016



Aircraft Data	
Empty weight including batteries and parachute	410 kg
MTOW	600 kg
Wingspan	8.4 m
Length	6.6 m
Height	2.4 m
Propulsion System Data	
Power	45 kW MCP 60 kW MTOP 85 kW max.
N_{max}	2500 rpm
DC-link voltage (nominal)	350 VDC (300 …450 V)
Torque M_{Boost}	324 Nm
Battery	10.1 kWh
Max. airspeed	97 KIAS

Siemens eAircraft – located at the heart of Europe

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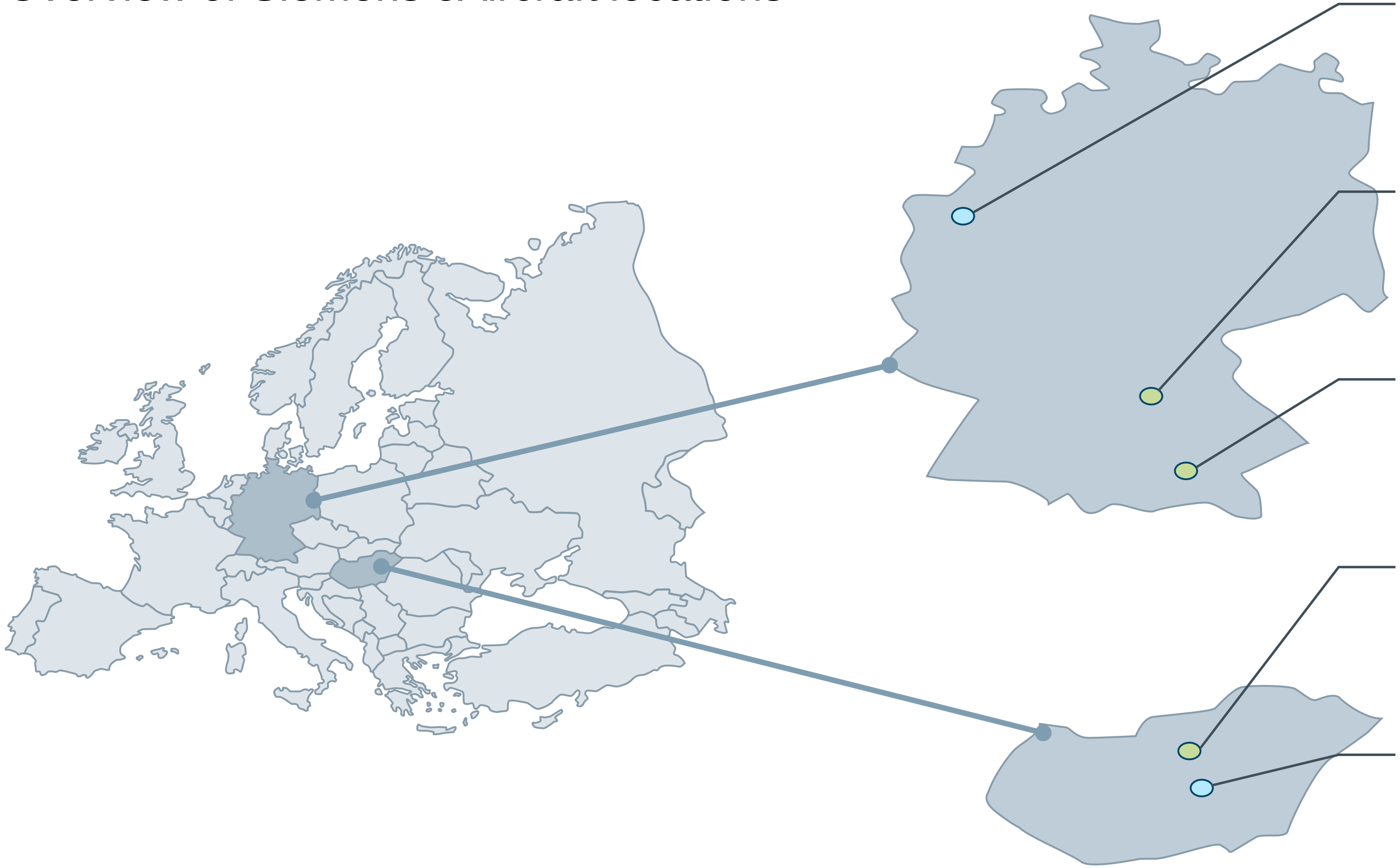
Overview of Siemens eAircraft locations



Dinslaken, Germany

Airfield for Extra 330LE flying testbed

Erlangen, Germany

Headquarters, development and future design organization for certified applications

Munich, Germany

Airbus-Siemens collaboration
Testing labs

Budapest, Hungary

Development for non-certified applications

Matkópusztai airfield, Kecskemét, Hungary

Airfield for eFusion flying testbed

Airfield   Office location

eAircraft Airbus-Siemens Collaboration – joint development agreement signed April 2016

"Siemens is determined to establish hybrid-electric propulsion systems for aircraft as a future business."

"We believe that by 2030 **passenger aircraft** below 100 seats could be propelled by **hybrid propulsion systems**..."

- Both companies take a significant joint development decision
- Demonstrate the technical **feasibility of various hybrid-electric propulsion systems by 2020**
- Assemble **joint development team** of some 200 employees

- Prototype propulsion systems ranging from a few **100 kW up to 10 MW** and more
- for short, local trips with aircraft below 100 seats, helicopters or UAVs up to classic short and medium-range journeys.
- Target: breakthrough innovation in **aerospace e-mobility**

The most important requirements for energy storage

SAFE

- Fire safety — catastrophic event
- Loss of power

POWERFUL & **LIGHTWEIGHT**

1 kW/1kg and 600 Wh/kg — MTOW* limit

EFFICIENT

All systems from battery until e-motor shall be high efficient

EASY TO INTEGRATE

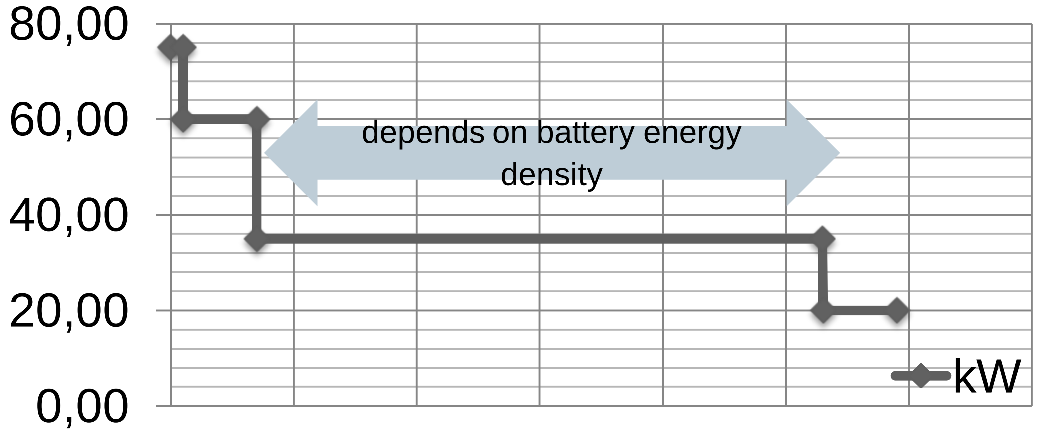
mechanical replacement of battery is an advantage. Integration in fire designated zones.

Both requirments are equally important

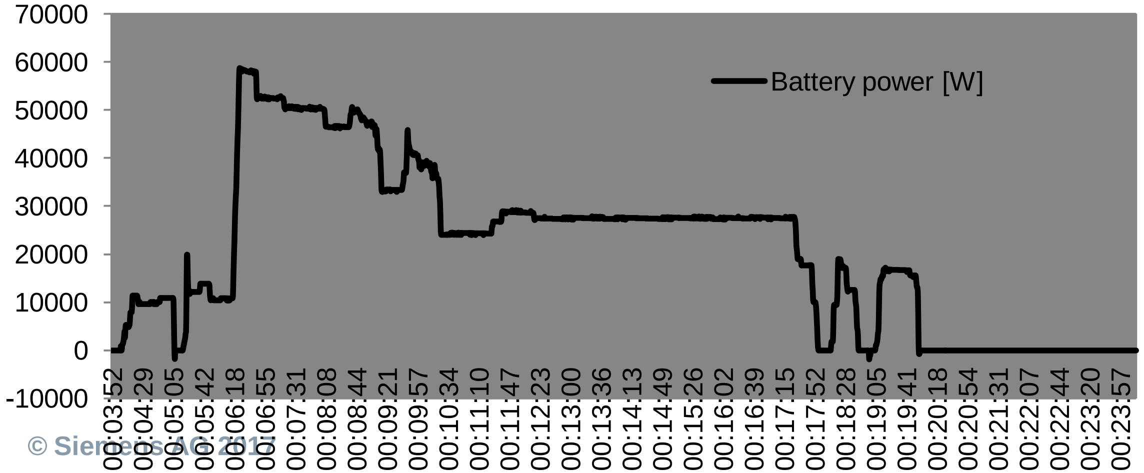
- light technology enables takeoff
- safe technology is necessary for landing

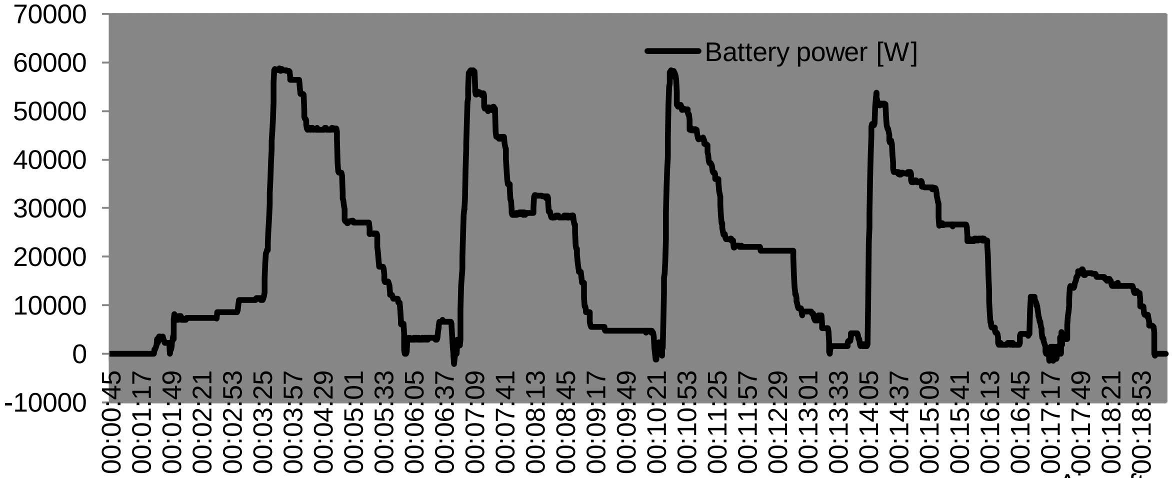
Power and energy requirements can be estimated acc. to mission profile, MTOW and aircraft weight balance

Mission profile for design

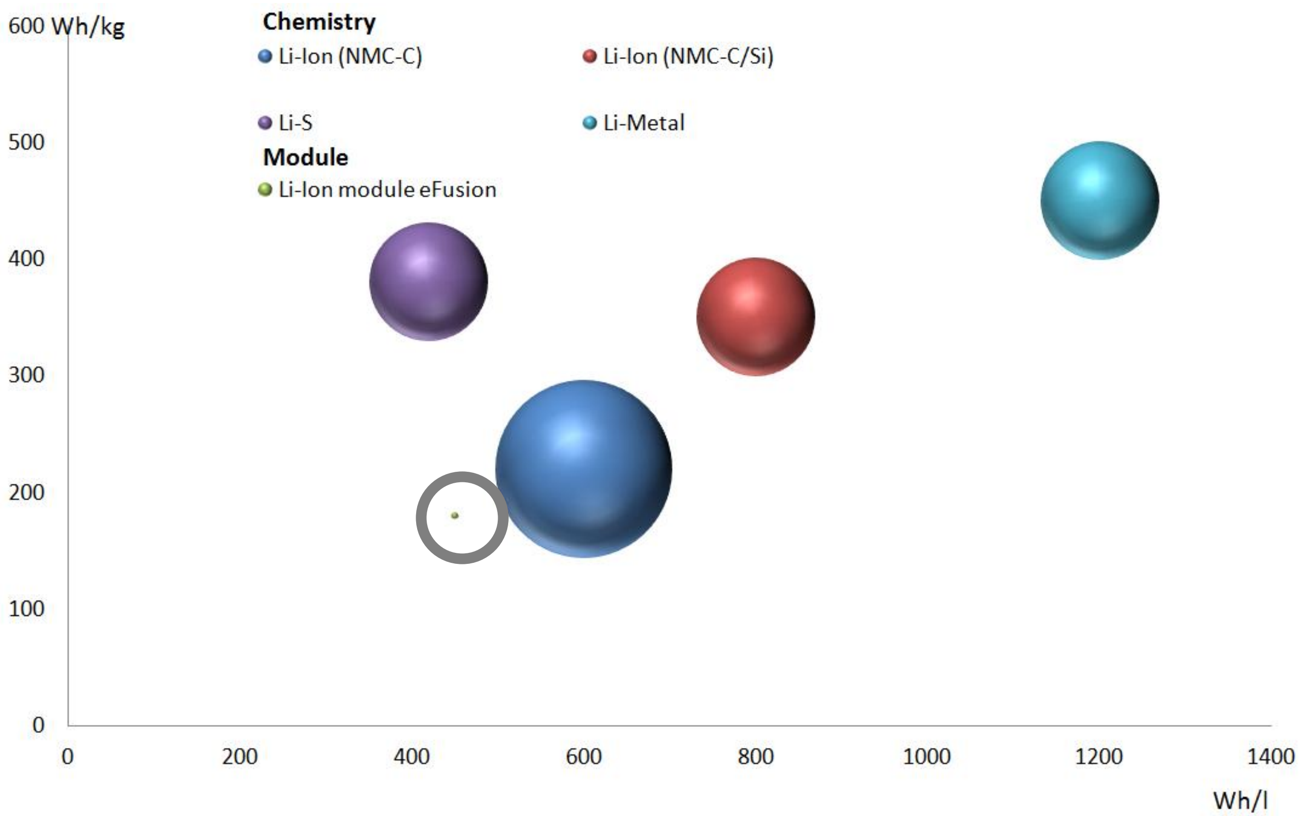


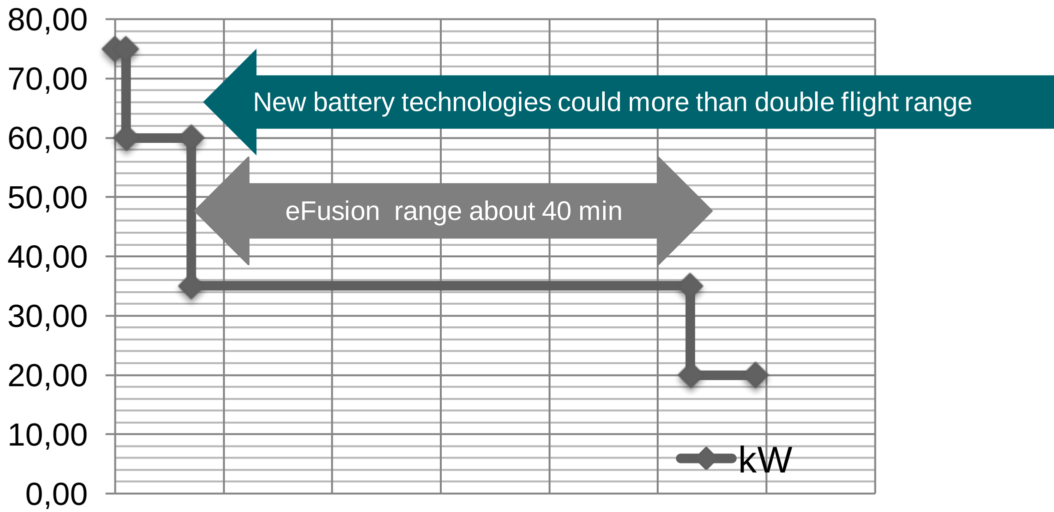
Real mission profiles (examples eFusion)





Flight range vs. energy density





Battery safety requirements and thermal runaway

When handled improperly, or if manufactured defectively, Li-ion battery can experience thermal runaway resulting in overheating.

Such Incidents in li-ion batteries can occur because of:

- inadequate understanding of the chemistry and thermochemistry; ✓ BMS
  - overcharging, overvoltage, undervoltage
- inadequate design for heat removal; ✓ critical
- inadequate control systems and safety systems (BMS); ✓ critical
- inadequate operational procedures, including training,
- manufacturing failures in the batteries or mechanical stress inside or outside of battery cell ✓ critical

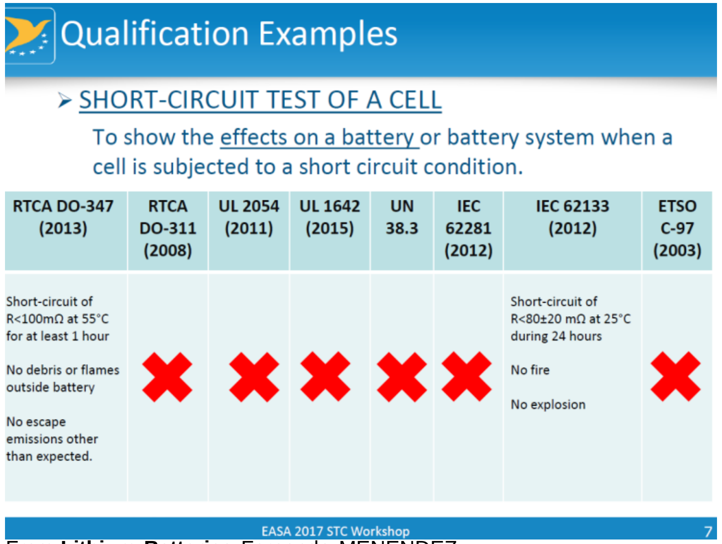
Battery safety requirements and thermal runaway

Battery management system keeps the li-ion cells in their application range acc. to data sheet and performs battery shutdown in case of overcurrent or over-temperature.

Both incidents can cause thermal runaway, which once it starts in the cell → it cannot be stopped any more (Single failure)

In case TR happens to one cell (single failure) it is important **to prevent the cell to cell thermal runaway propagation and keep aircraft operation in failure mode**

EASA requires non propagation demonstration in case of cell short circuit


Qualification Examples

➢ SHORT-CIRCUIT TEST OF A CELL

To show the effects on a battery or battery system when a cell is subjected to a short circuit condition.

RTCA DO-347 (2013)	RTCA DO-311 (2008)	UL 2054 (2011)	UL 1642 (2015)	UN 38.3	IEC 62281 (2012)	IEC 62133 (2012)	ETSO C-97 (2003)
Short-circuit of R<100mΩ at 55°C for at least 1 hour No debris or flames outside battery No escape emissions other than expected.	✖	✖	✖	✖	✖	Short-circuit of R<80±20 mΩ at 25°C during 24 hours No fire No explosion	✖

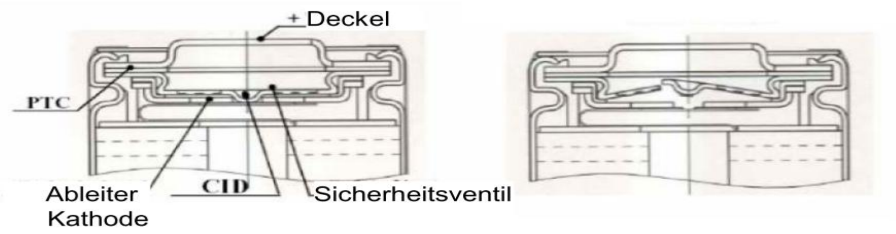
EASA 2017 STC Workshop 7

From **Lithium Batteries** Fernando MENENDEZ

STC WORKSHOP May 17th/18th2017

Types of shorts

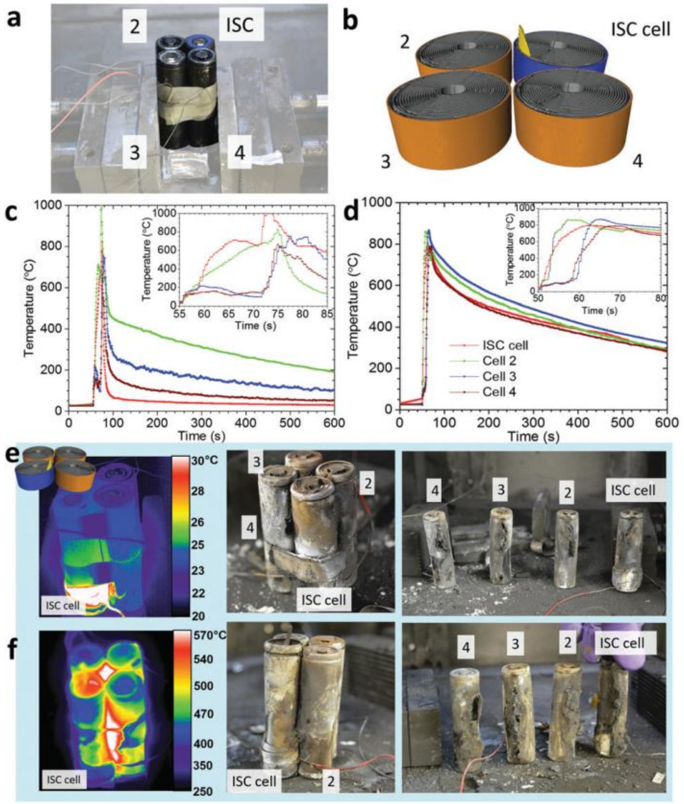
External short



- can be easily cutoff by PTC in case of most cylindrical cells
- Is critical for pouch cells

Internal short (shortcut in the cell itself)

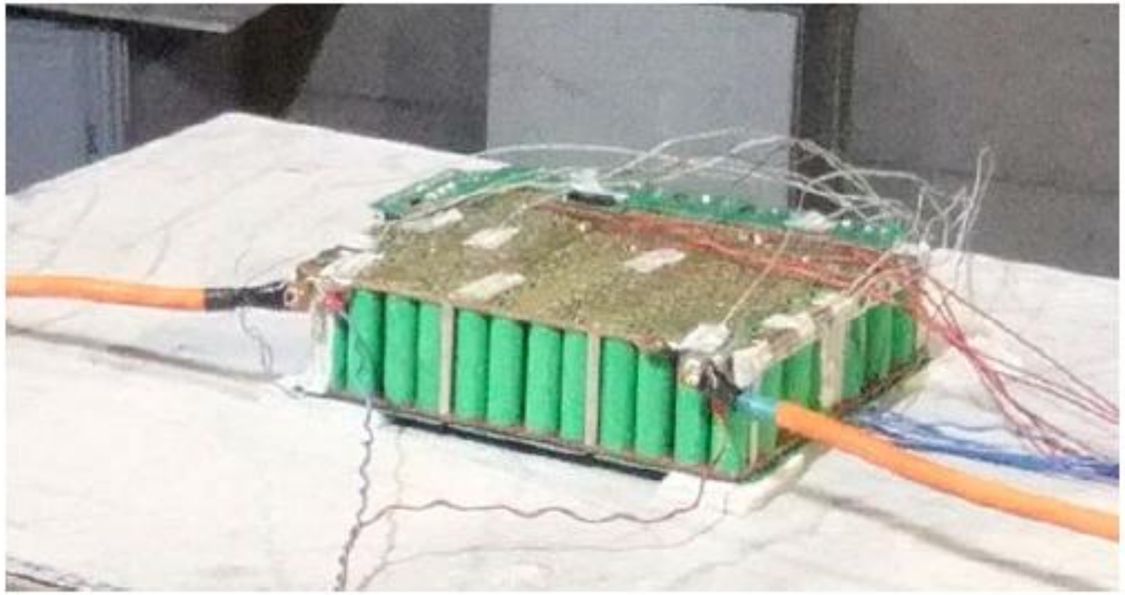
• is critical and cuases module propagation, while module is not designed to isolate TR cell <u>and</u> to remove TR heat



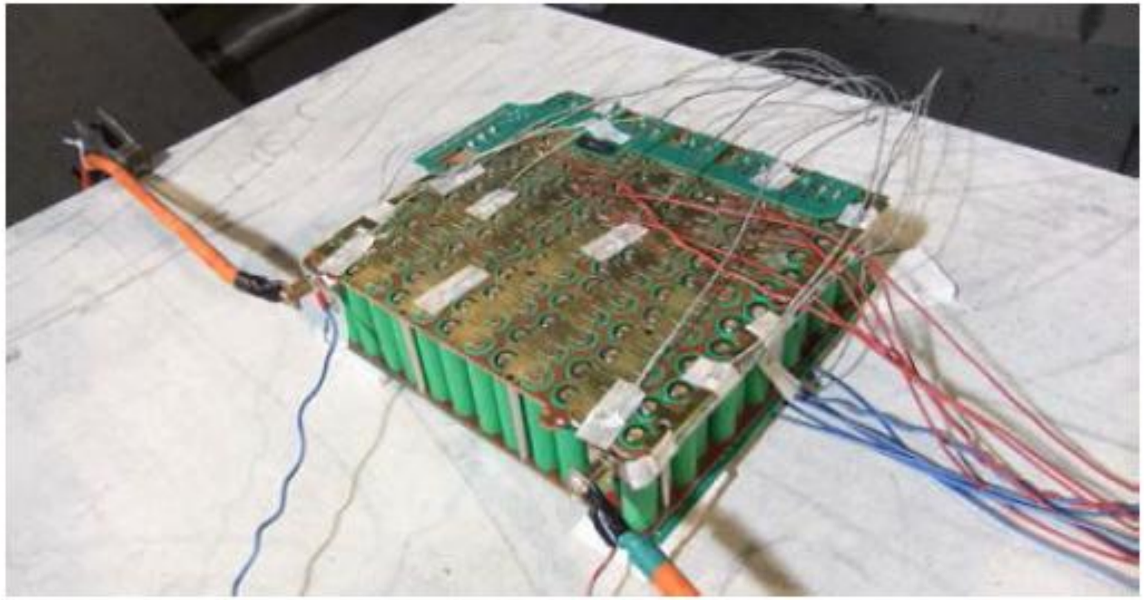
Example from Energy & Environmental Science; DOI: 10.1039/c7ee00385d

Safety – non propagation and single failure containment in case of external short

Safety tests on eFusion prototype battery module



Module at test place just before short circuit



Module at test place after short circuit

Short circuit caused a short peak current, interrupted by a over current protection mechanism in the cell. Temperatures achieved 45 ° C at the bus bar terminals and around 30 ° C at cells

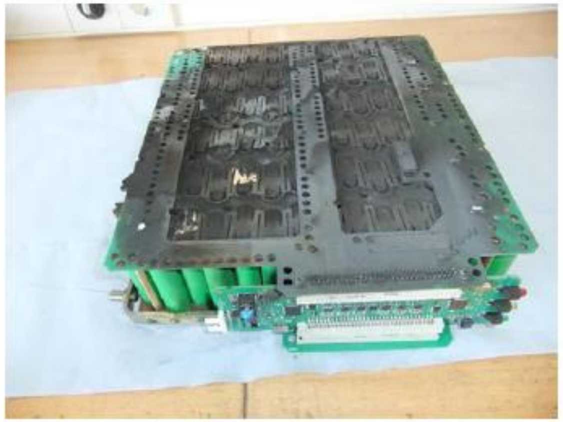
EUCAR Hazard Level 2 (cell fuse blown up, not reparable)

Safety – non propagation and single failure containment in case of internal short

Safety tests on eFusion prototype battery module

Module after 6 nail tests

Top view of the module after 6 nail tests



Bottom view of the module after 6 nail tests

Detailed bottom view of the module after 6 nail tests

Short time sparks, smoke emission, self-extinguished

max temperature of the penetrated cell 364° C,

short time voltage drop for the penetrated cell, penetrated cell disconnected from the parallel connected cells

no propagation for all six nail tests

stil to be improved

EUCAR Hazard Level 5

sparks, smoke emission, no propagation

Conclusion

Main risks need to be addressed

Safety – non propagation and single failure containment

Embedded energy – efficient thermal management system and high performance at cell level

Target for hybrid aircrafts: 600 Wh/kg cell energy density and 1 kW/kg

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