Addressing the Safety Issues Related to Air Transportation of Lithium-Ion Batteries with Effective Engineered Thermal Management Solutions

33rd Annual International Battery Seminar & Exhibit

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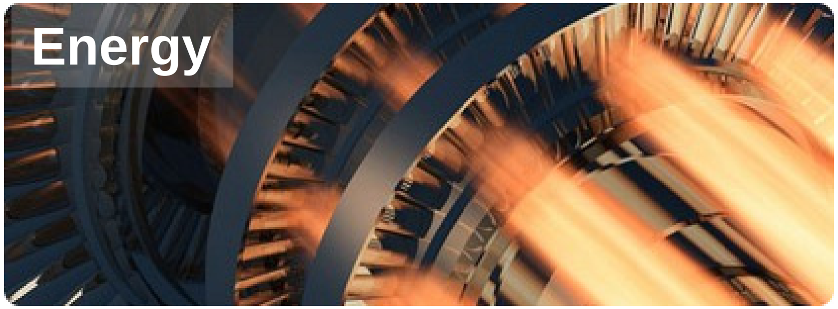
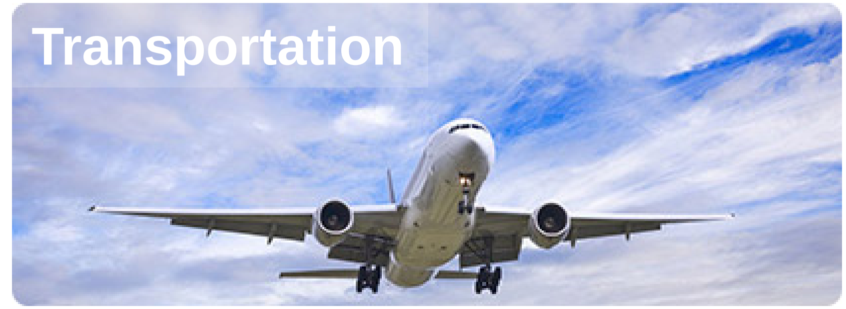
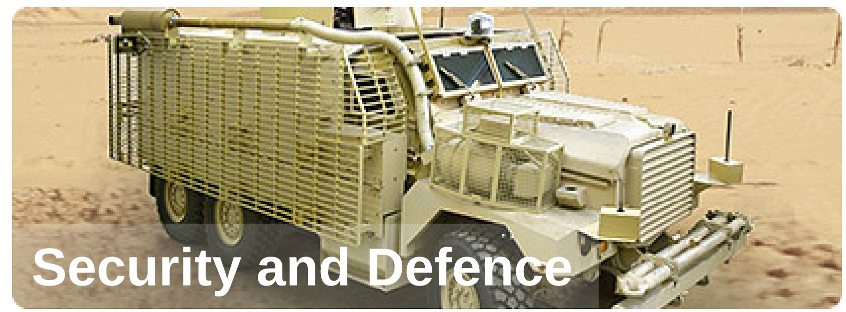
Morgan Advanced Materials

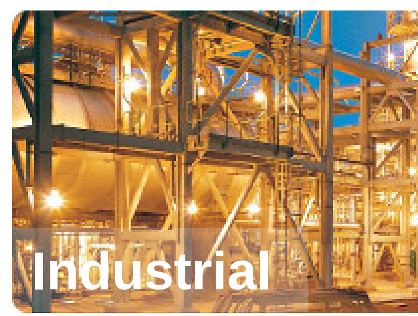
Founded in England in 1856
Stock symbol on LON: MGAM
2015 revenue: GBP912 million (USD1.3 billion)
2 Divisions and 6 Global Business Units
Thermal Ceramics, including Fire Protection: GBP372 million

Focus on technically demanding, growth markets

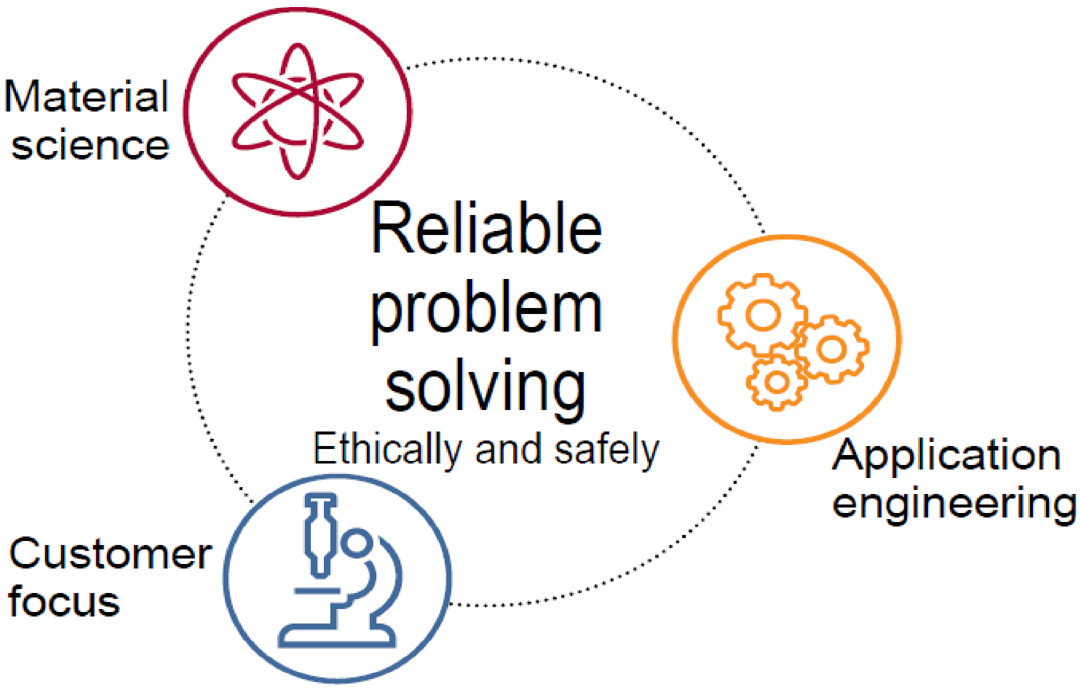








Morgan Advanced Materials



Global Business Units	
Thermal Ceramics	✓
Molten Metal Systems	
Electrical Carbon	✓
Seals and Bearings	
Technical Ceramics	✓
Composites and Defense Systems	✓

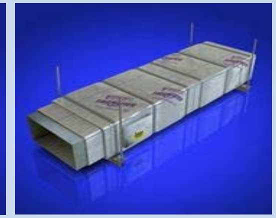
✓ indicates GBU with one or more LIB industry solutions

Thermal management solutions are wide ranging

FIBER

Bulk
Blanket
Modules
Converted
Paper





IFB & FIREBRICK

JM, K & TJM Grades

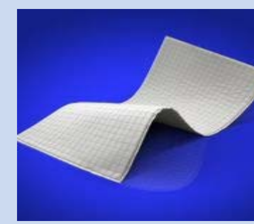
MONOLITHICS

Dense Monolithics
LW Monolithics
Special Shapes

SPECIALTIES

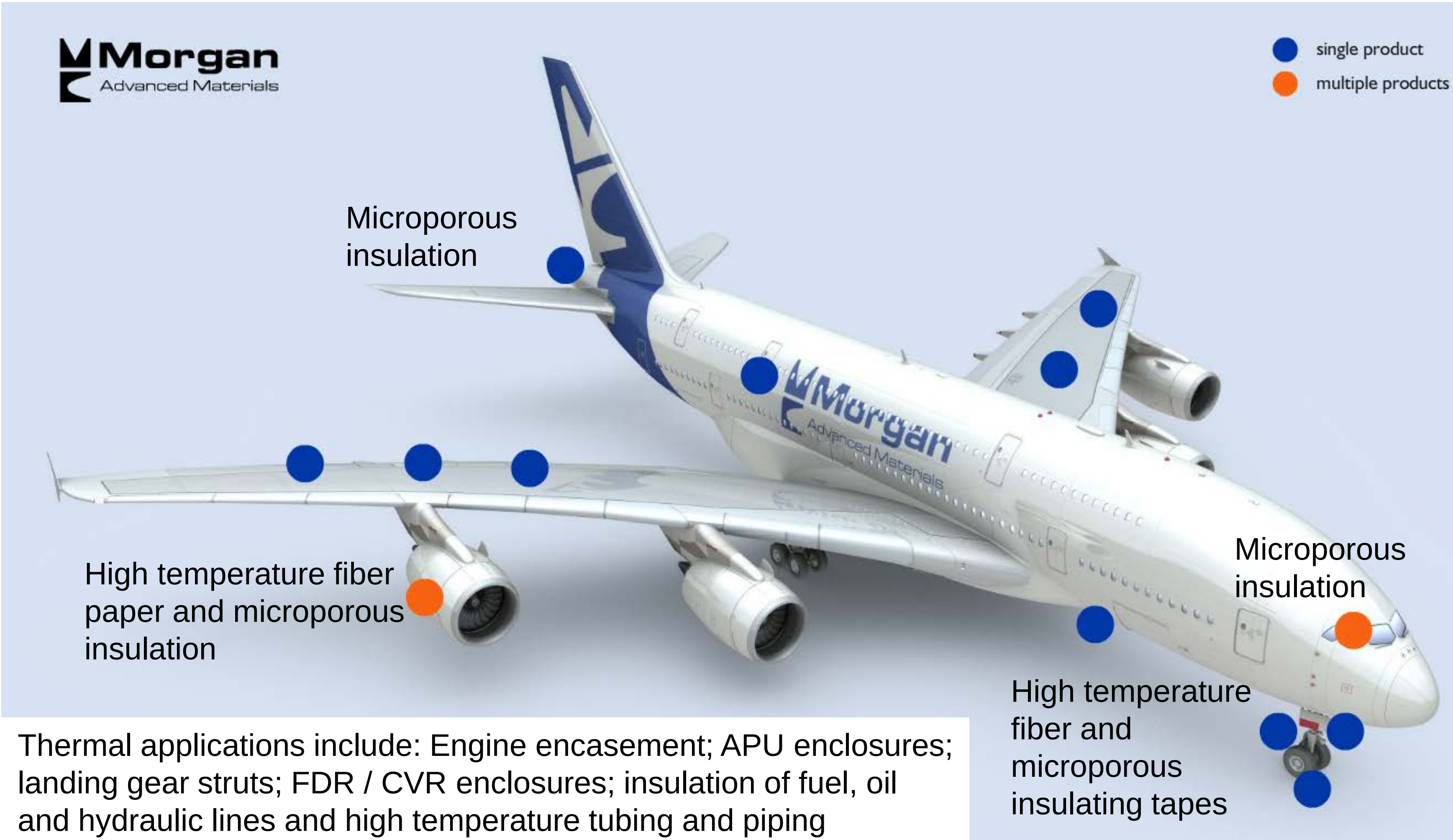
Heat Shields
Graphite Insulation
Engineered Insulation
Microporous Insulation





Morgan engineers and installs high performance insulation in operating environments from -70°C to 3000°C

Morgan’s products on an aircraft



Thermal applications include: Engine encasement; APU enclosures; landing gear struts; FDR / CVR enclosures; insulation of fuel, oil and hydraulic lines and high temperature tubing and piping

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Batteries on an aircraft

Morgan Advanced Materials

Permanently installed batteries:

FDR/CVR;
Emergency Locator Transmitter;
Automated External Defibrillator;
Flashlights;
A/C systems

Batteries in the cabin:

Notebook computers; Tablets; MP3 players; Mobile phones; Cordless devices; Cameras; Spare Batteries

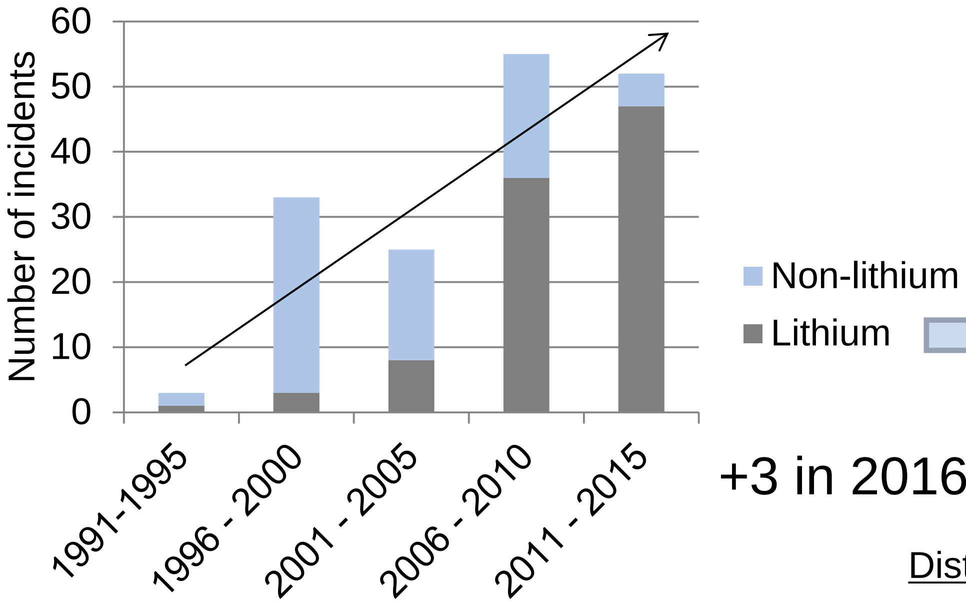
Batteries in the hold (restricted to cargo planes):

Installed in portable devices;
Installed in larger devices;
Packed separately

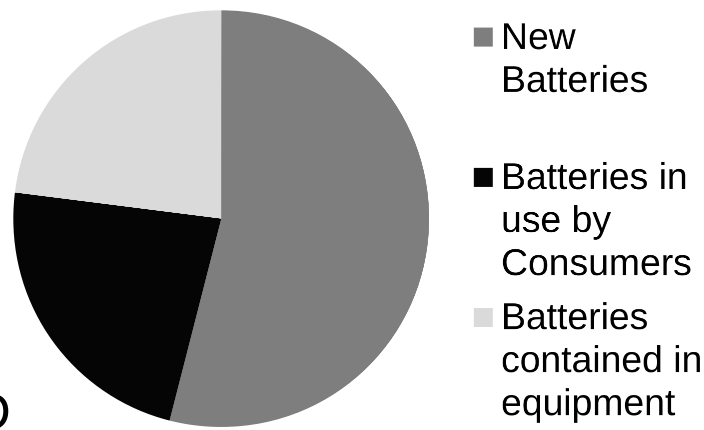
Derived from "Risks related to Lithium Batteries," C. Bezard, 18th Flight Safety Conference, March 2012

Growing number of incidents

Between March 20, 1991 and January 15, 2016, 171 air/airport incidents involving batteries carried as cargo or baggage have been recorded by FAA



+3 in 2016 YTD



Distribution of Lithium battery incidents in air transport

Data source: http://www.faa.gov/about/office_org/headquarters_offices/ash/ash_programs/hazmat/aircarrier_info/media/battery_incident_chart.pdf

Derived from presentation “Navigating the Regulatory Jungle”: Hwang and Leary ,USDOT, Baltimore, 2015

Catastrophic events attributed to lithium-ion batteries

- Fire erupted in a cargo plane (UPS – DC8) that landed in Philadelphia on February 7, 2006 – airplane destroyed

- A cargo plane (UPS – B747) with 81,000 lithium batteries caught fire and crashed after it left Dubai on September 3, 2010 – airplane destroyed, 2 crew members killed

- A cargo jet (Asiana – B747) crashed into the East China Sea on July 28, 2011, after the crew reported a fire on board – airplane destroyed, 2 crew members killed



Information and pictures from: DOT/FAA/TC-13/2; https://aviation-safety.net/airlinesafety; "Fire Hazards of Lithium-Ion Batteries" R. E. Lyon et al., International Aircraft Systems Fire Protection Working Group Meeting, October 21 to 22, 2015; "Fire Suppression in a Class E Cargo Compartment" Dhaval Dadia, ICAO Meeting, October 30-31, 2013

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Legislation history – Primary Lithium (UN 3090)

- April 28, 1999 Fire at LAX -120,000 lithium primary cells led to issue of FAA DGAB-00-02 on September 7, 2000
- Subsequent studies showed that lithium metal primary cell fires cannot be suppressed by halon
- Banned on passenger aircraft by FAA in 2005 – details in DOT PHMSA HM-224C (April 2, 2002) and HM-224E (December 15, 2004)
- Banned on passenger aircraft by ICAO starting January 1, 2015 – details in ICAO Technical Instruction for the Safe Transport of Dangerous Goods by Air and the 56th Edition of the IATA Dangerous Goods Regulations (DGR)

http://phmsa.dot.gov/hazmat/regs/rulemaking/archive/hm-new

https://www.iata.org/whatwedo/cargo/dgr/Documents/lithium-battery-guidance-document-2015-en.pdf

Legislation history – Lithium-Ion (UN 3480)

- Lithium batteries (both UN 3090 and UN 3480) are currently classified as Class 9 hazardous materials in Title 49 CFR, Hazardous Materials Regulations (HMR) and the ICAO Technical Instructions

- FAA (SAFO 16001) supports recommendations that before operators engage in the transport of lithium ion batteries as cargo on passenger aircraft, or lithium ion or lithium metal batteries on cargo aircraft, they should be aware that ICAO and major airframe manufacturers (Boeing and Airbus) have recommended that operators perform safety risk assessments in order to establish whether, or how, they can manage the risk associated with the transport of these batteries

- Transportation by air of lithium-ion batteries is not currently banned in either cargo or passenger aircraft. However, this is about to change.

http://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/safo/all_safos/media/2016/SAFO16001.pdf

New legislation with effect from April 1, 2016

- On February 22, 2016, the ICAO Council passed a prohibition on lithium ion batteries (UN 3480) on passenger aircraft as cargo that goes into effect on April 1, 2016.

- ICAO "Technical Instructions for the Safe Transport of Dangerous Goods by Air" 2015-2016 (Doc 9284) incorporating corrigenda and addenda up to and including addendum number 4 (February 23, 2016) include the above and other new requirements which include:
  - Lithium ion cells and batteries must be offered for transport at a state of charge (SoC) not exceeding 30% of their rated design capacity
  - Details related to acceptable packing and labeling

http://www.icao.int/Newsroom/Pages/ICAO-Council-Prohibits-Lithium-Ion-Cargo-Shipments-on-Passenger-Aircraft.aspx

Contents

Types of High Temperature Insulation Fibers

- High Temperature Insulation
  - Amorphous
    - Alkaline Earth Silicate (AES)
      - Melt-spun
      - CaO, MgO, SiO_2, ZrO_2
      - Superwool® Plus, Superwool® HT
    - Aluminosilicate (ASW / RCF)
      - Melt-spun / blown
      - Al_2O_3, SiO_2, (ZrO_2)
      - Kaowool®
  - Crystalline
    - Polycrystalline (PCW)
      - Sol-gel
      - Al_2O_3
      - Alphawool®

ASW/RCF invented 1942
PCW invented 1969
AES invented 1986
(Microporous invented 1958)

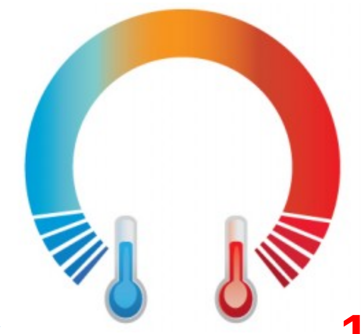


Key Advantages of Superwool® over RCF:

- Low bio-persistence
- Low shrinkage up to classification temperature
- Low thermal conductivity

What is microporous insulation?

- A low density powder comprised of heat resistant particles and high temperature fibers compressed to form a microporous structure
- The most efficient insulation commercially available for a wide temperature range, engineered to control all three modes of heat transfer – convection, conduction and radiation
- Inorganic material, recyclable and safe from an H&S perspective



-70ºC

1100ºC

Material optimization / application engineering

Best

Insulating Value

Key Selection Criteria

•Application temperature
•Chemical Resistance
•Environmental Factors
•Installed weight and thickness
•Installation requirements
•Initial and total cost of ownership

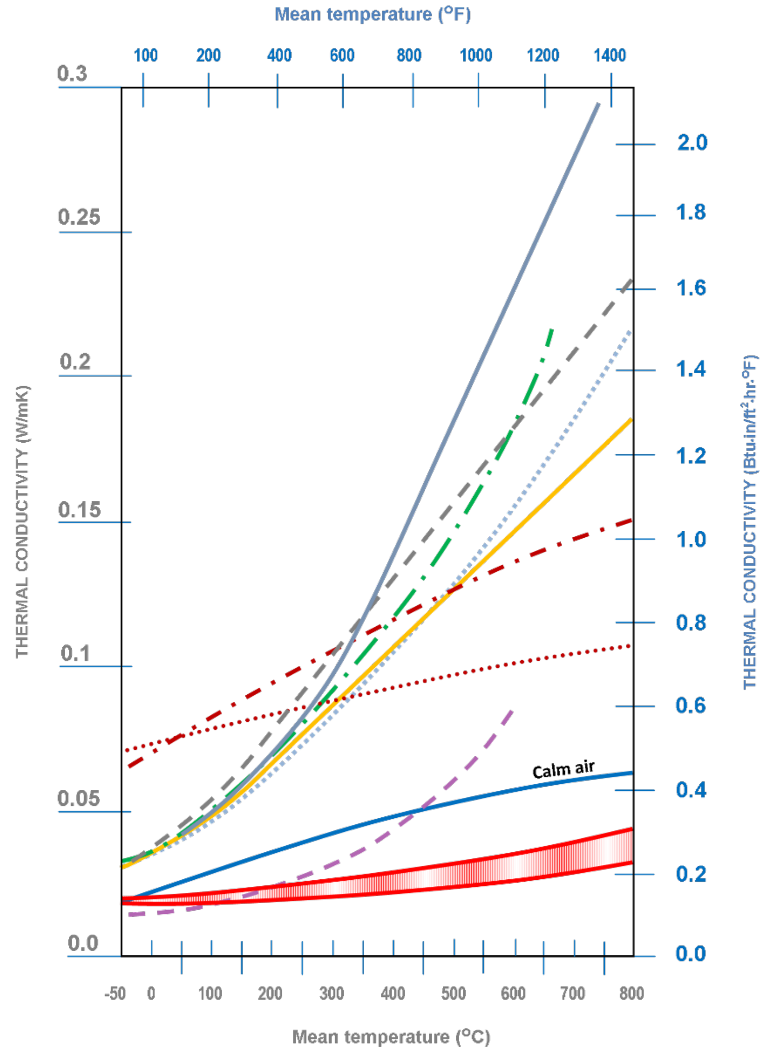
Structural Aspects

Strongest

Thermal conductivity comparison

Thermal conductivity comparison of WDS microporous insulation products vs. other types of insulating products

- Perlite (granular)
- Mineral Wool (100 Kg/m³)
- RCF blanket (130 Kg/m³)
- Low shot AES blanket (130 Kg/m³)
- LD Calcium Silicate
- AES fiber board (300 Kg/m³)
- Opacified LD Calcium Silicate
- Aerogel blanket
- WDS® insulation



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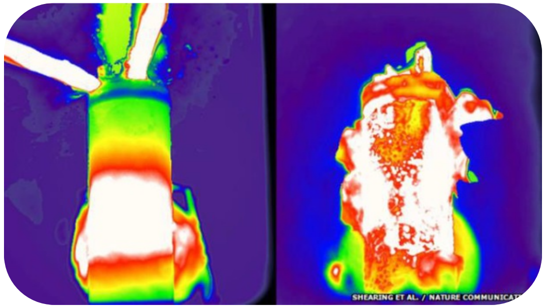
Aviation industry safety challenges with Lithium Ion

6 billion Lithium Ion cells were manufactured in 2015 – 30% were transported by air

Situation	Immediate consequence	Ultimate consequence
Thermal runaway in packed Lithium Ion cell	Transmission to large number of adjacent cells	Fire / explosion / pressure wave
Thermal runaway in Lithium Ion cell in use	(Transmission to adjacent cells)	Fire / explosion / pressure wave
Fire external to package	Elevated cell temperatures start thermal runaway	Fire / explosion / pressure wave



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Thermal Runaway
- Auto-accelerating heat generation
- Rapid temperature increase
- Expulsion of flammable gases and liquids

"Fire Hazards of Lithium-Ion Batteries" R. E. Lyon et al., International Aircraft Systems Fire Protection Working Group Meeting October 21 to 22, 2015

Many causes of thermal runaway – electrical, mechanical, thermal

Additional challenges in all applications

- Ideally would employ chemistries and cell structures to prevent thermal runaway from starting, but increasing energy densities make this increasingly difficult, especially in applications where space is critical

- Once thermal runaway in one cell has started then the challenge is to prevent propagation from cell-to-cell, from module-to-module and from pack to surroundings – this applies in electronics, electric vehicle, energy storage and other applications

- In the case of aviation, the key is to extend the time needed for remediation measures to be employed where possible and to land the plane safely

Images from: “Fire Hazards of Lithium-Ion Batteries” R. E. Lyon et al., International Aircraft Systems Fire Protection Working Group Meeting October 21 to 22, 2015 and “Fire Suppression in a Class E Cargo Compartment” Dhaval Dadia, ICAO Meeting, October 30-31, 2013

Morgan Advanced Materials expertise

- Morgan's understanding of the materials science required to prevent the spread of thermal energy is demonstrated in our supply of the material surrounding FDR and CVR products which is designed to survive arduous mechanical and thermal conditions
- We are also the trusted supplier of materials for surrounding living quarters in offshore oil rigs, specifically designed to protect the structure to allow additional time for operators to escape from a fire

Living Quarter Module for Gudrun Offshore Platform

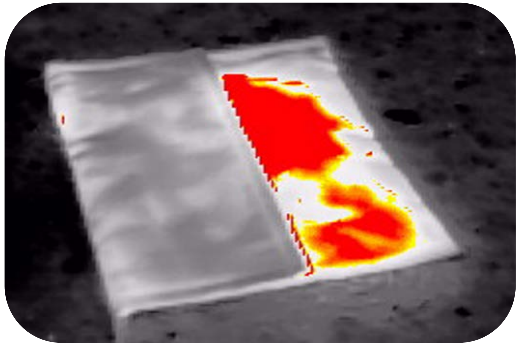
10,000 m² FireMaster Marine Plus Blanket installed in 2011 for one hour fire protection of external and internal structure

New product recently deployed by one major airline

A composite product incorporating FireMaster® Marine Plus Blanket

FireMaster® Battery Bag

- PED containment bag for emergency storage of defective personal electronic devices to avoid expansion of fire in case of thermal runaway of Li Ion batteries.



Pictures and videos created by and used with permission of Lufthansa/Germanwings

Moving from mitigation to prevention

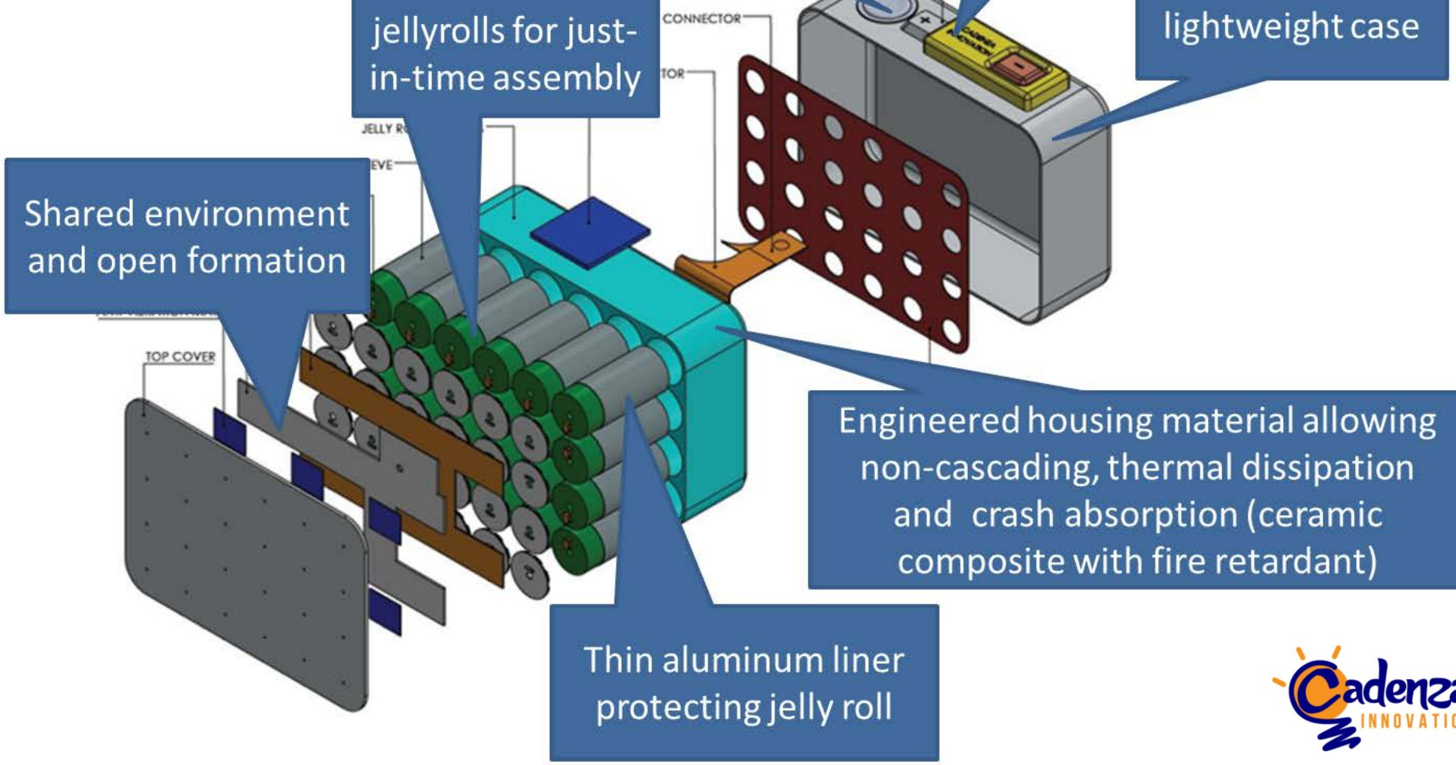
- To address the EV and ESS market opportunities for LIB requires:
  - high energy density
  - low cost
  - uncompromising safety
- > 500 Wh/L
- < $125/kWh including electronics
- Intrinsic safety

- A visionary team led by Christina Lampe-Onnerud has conceived of a way to address these requirements

- Morgan is proud to be partnering with Cadenza Innovation in developing a novel engineered housing solution incorporated within the Cadenza solution

Cadenza INNOVATION

Cadenza Technology Platform: Multi-Jellyroll Architecture



Cadenza INNOVATION

Conclusions

- Current chemistries and cell structures of the vast majority of lithium ion batteries cannot protect against the possibility of thermal runaway in certain conditions
- It continues to be necessary for large quantities of lithium ion batteries to be transported by air
- Although legislation continues to improve the requirements for safe air transport of lithium-ion batteries, there is still a significant and urgent need to provide additional protection for the passengers, crew and aircraft
- As the leading global manufacturer of thermal fire protection systems, Morgan Advanced Materials is working with the air transportation industry to develop solutions to address this need

FIREMASTER
www.morganthermalceramics.com

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Questions?