Containing thermal runaways: a fool's paradise?

Super-hot electric arc discharges and LENRs

Trigger nightmarish thermal runaways in Lithium-based batteries

Some claim their schemes can contain thermal runaways: will they work?

Peak temperatures in worst-case events can reach thousands of degrees Centigrade

Portable electronics

Apple iPod Nano
exploding in Japan (2010)

Examples and discussion

Lewis Larsen

President and CEO
Lattice Energy LLC

August 6, 2013

Severely fire-damaged aft 787
GS-Yuasa Li-ion battery (NTSB)

Runaway

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Mobile platforms

Boeing 787 Dreamliner
Logan Li-ion battery fire (2013)

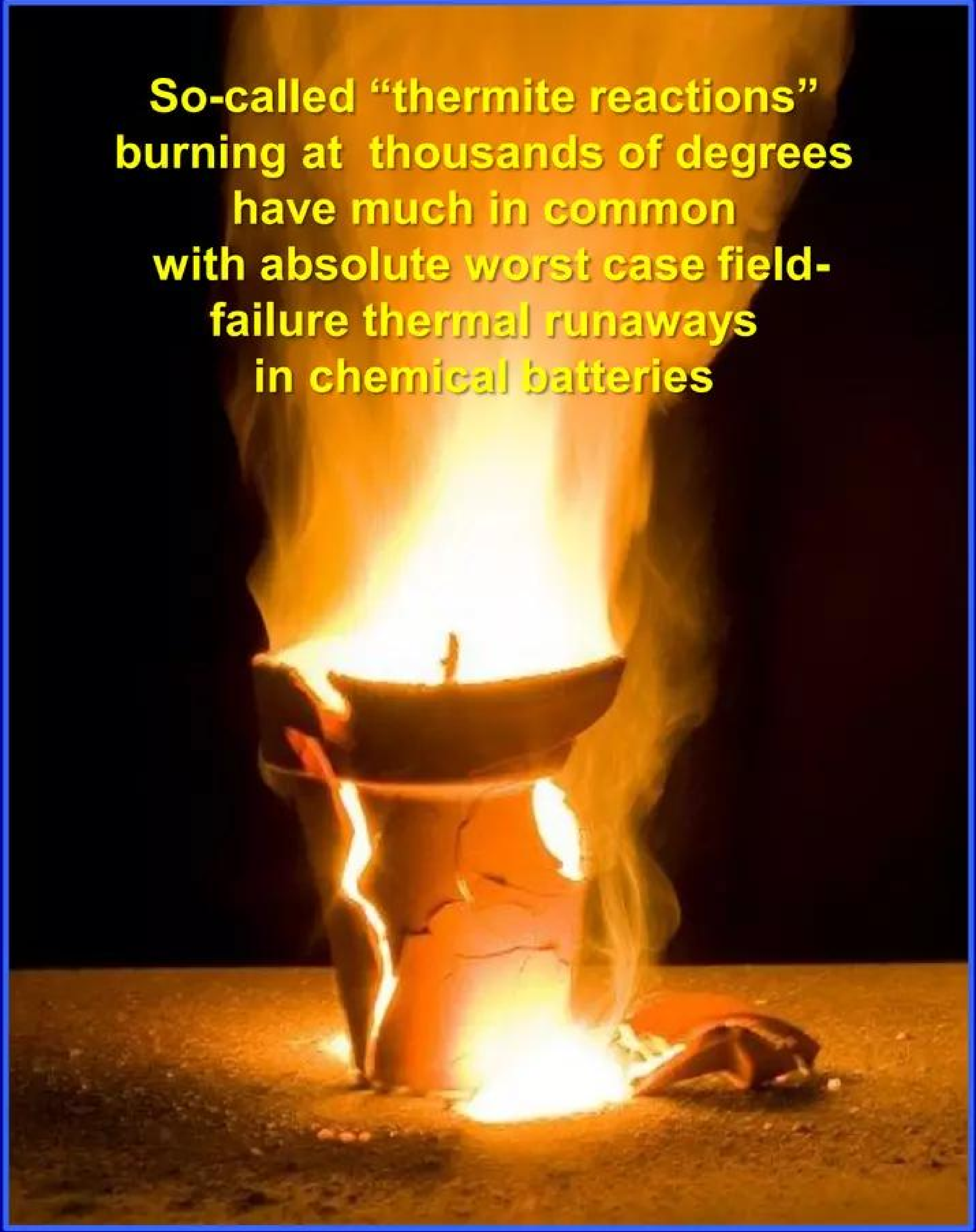
Containing thermal runaways: a fool's paradise?

Topical overview

Focus: thermal runaways in primary and secondary lithium-based batteries

- High-level historical overview: battery chemistries and increased energy density
- Peak temperatures that can possibly be reached during thermal runaway events
- Scaling-up electrical storage capacities can cause increases in safety-related risks
- Different causes of thermal runaways
- Examples of runaways involving portable devices and various mobile platforms
- Runaways in advanced Boeing 787 aircraft
- Incident examples: worst-of-the-worst
- Analysis and commentary on Boeing 787 Dreamliner's battery containment system

Certain chemical reactions release enough heat to actually melt metals



Source: http://www.popsci.com/node/30347

Containing thermal runaways: a fool's paradise?

Contents

Containing thermal runaways: a fool's paradise?

Lithium-based

chemical batteries

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A battery is an electrochemical device that actively stores input electrical energy in chemical bonds (charging); on-command, that stored energy can later be converted back into output electrical energy in the form of a current of electrons (discharging) that can pass through external conductive circuit wiring at some operating voltage and used to do energy-dependent work, e.g. operate power-hungry microprocessors, illuminate lights, run electric motors, etc.

Lead-acid

1859: French inventor, Gaston Plante developed first practical storage lead-acid battery that could be recharged (secondary battery); commonly used as starter batteries on cars today in 2013 – well-known example is the DieHard brand

Nickel metal hydride (NiMH)

1989: first consumer-grade nickel metal hydride batteries became commercially available; resulted from almost 20 years of R&D at the Battelle-Geneva Research Center – work was sponsored by Daimler-Benz and Volkswagen AG (Germany)

Nickel Cadmium (NiCad) and alkalines

1899: Waldmar Jungner invented first nickel-cadmium rechargeable battery and alkaline (non-acidic electrolyte) primary battery; Thomas Edison claimed to have independently invented alkaline in 1901

Lithium ion (Li-ion) and Lithium iron phosphate

1991: Sony and Asahi Kasei (Japan) released first commercial lithium-ion batteries; lithium batteries first proposed in 1970s by Whittingham while at Exxon; Goodenough proposed $LiFePO_4$ in 1996

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Small portable electronic devices have become a ubiquitous, indispensable part of daily life in modern societies

Vast majority of all such products use chemical batteries for power sources

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Lithium-based batteries come in many different shapes and sizes

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Secondary

Primary

Primary batteries CANNOT be recharged safely (fully discharged only once); secondary batteries are designed to be rechargeable

Secondary

Primary

Primary

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$LiCoO_2$ $LiFeS_2$ $LiPbCuS$ $Li/AlMnO_2$ $LiFeS$ $LiFePO_4$

$LiFeS_2$ $LiCu_4O(PO_4)_2$ $LiCuO$ $LiSO_2Cl_2$ $Li\text{-}Cu_4O(PO_4)_2$

Lithium-based batteries come in many different chemistries

$LiAg_2CrO_4$ $Li(CF)_x$ LiI_2 $LiCuCl_2$ $Li_{22}Si_4$

$LiSOCl_2$ $Li_4Ti_5O_{12}$ Li-air $LiBi_2O_3$ $LiAg_2V_4O_{11}$

$LiMnO_2$ $LiBi_2Pb_2O_5$ $LiPbCuS$ $LiAg_2CrO_4$

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Lead-acid chemistry would not work for smartphones

Generally speaking, in portable electronics markets, the batteries with the highest energy densities and duration of electrical power output will usually win the competitive game

+ = No

Using a 30 pound lead-acid battery to power a 4-ounce Apple iPhone is impractical and a non-starter for customers

Going to advanced chemistries beyond lead-acid allows more electrical charge to be stored inside a battery casing that is much smaller in volume and weighs vastly less; i.e., higher volumetric energy density

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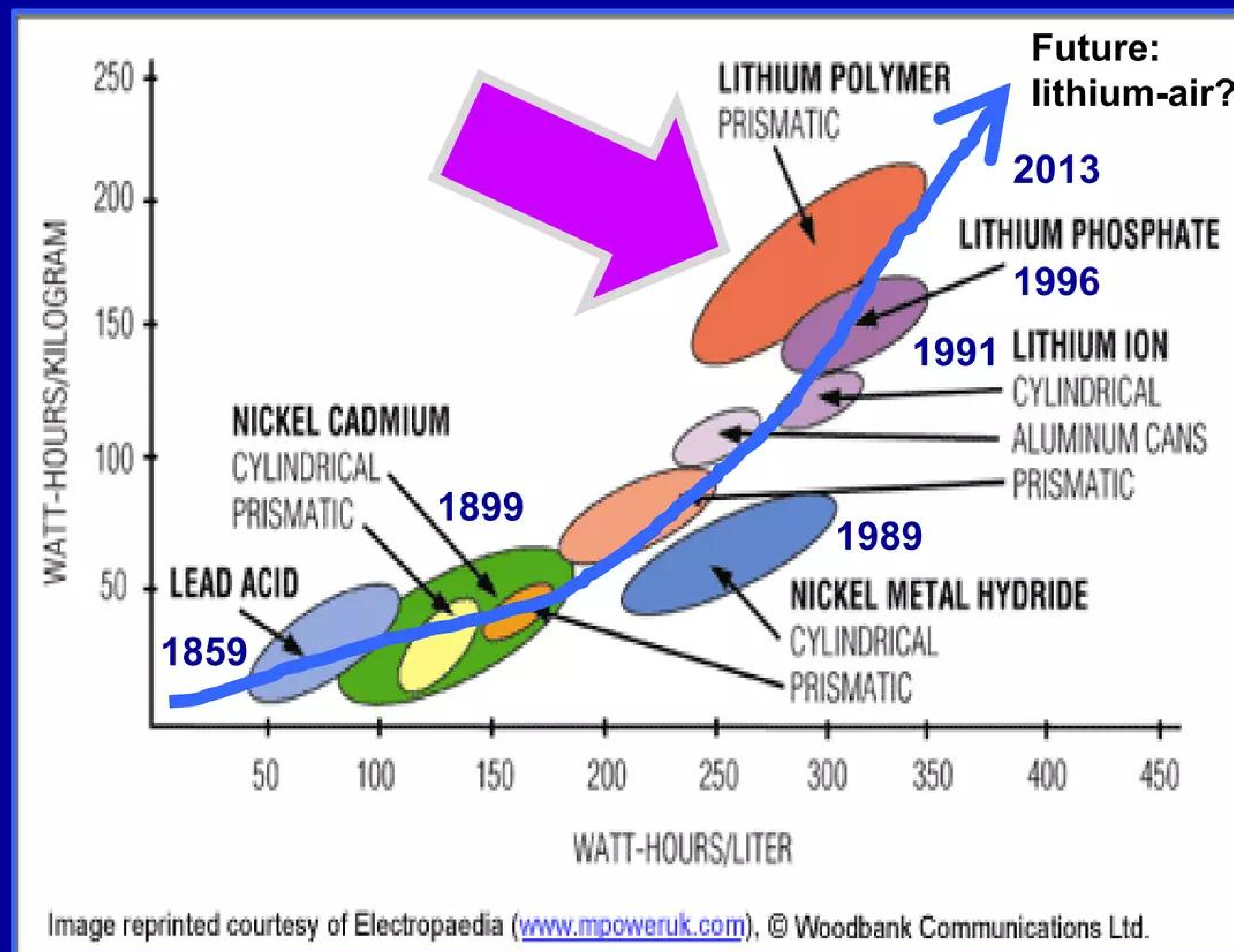
Battery energy densities increased from 1859 to 2013

Large uptick in last 25 years - limited experience with such densities

Lithium-based batteries became extremely dominant in portable electronics because they have much higher energy densities than other battery chemistries



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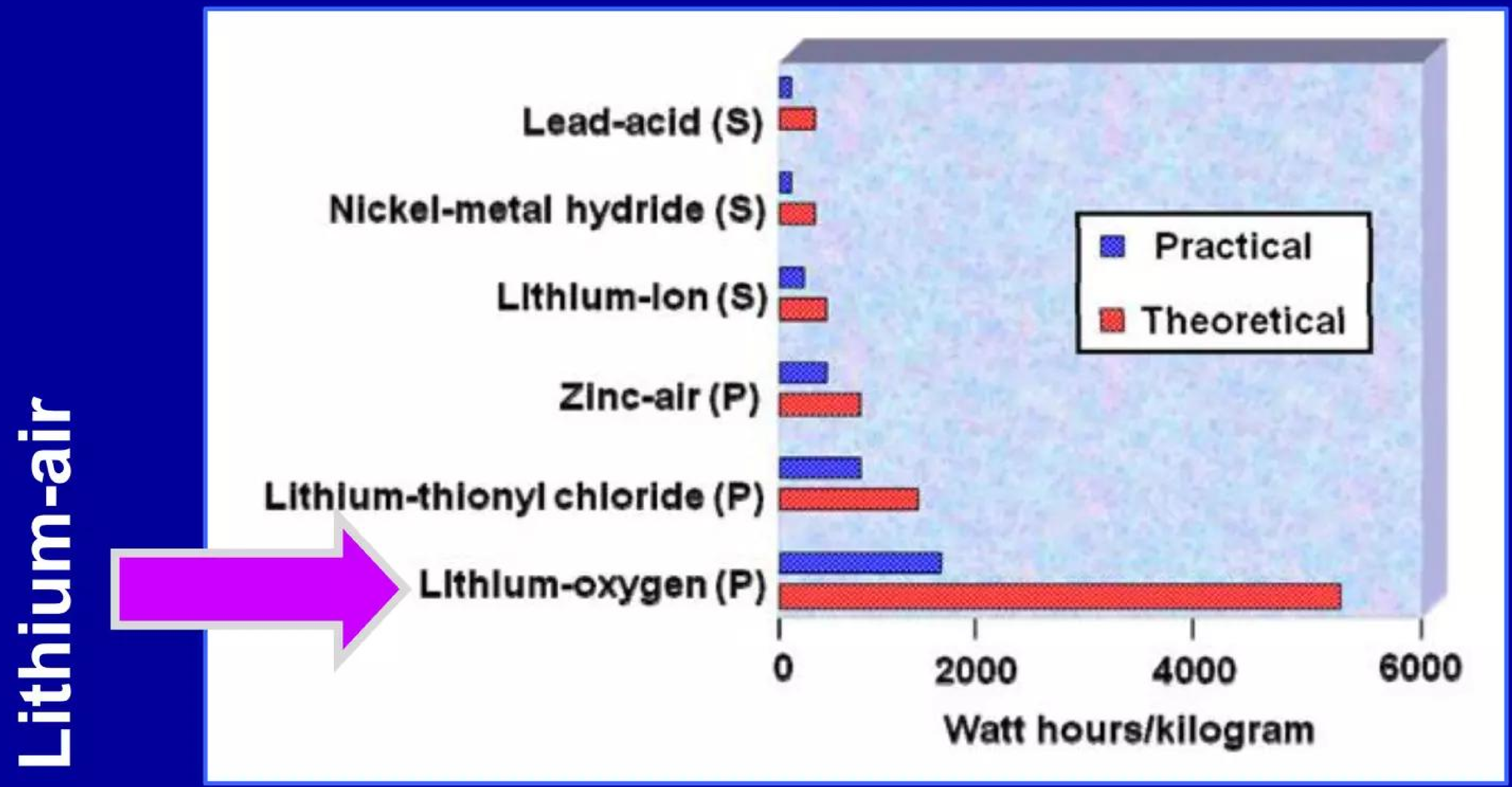
Some battery chemists believe Li-air could rival gasoline

Huge increase in energy density above lithium-ion technology

Great … but will it be sufficiently safe???



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Energy-dense batteries

should be respected

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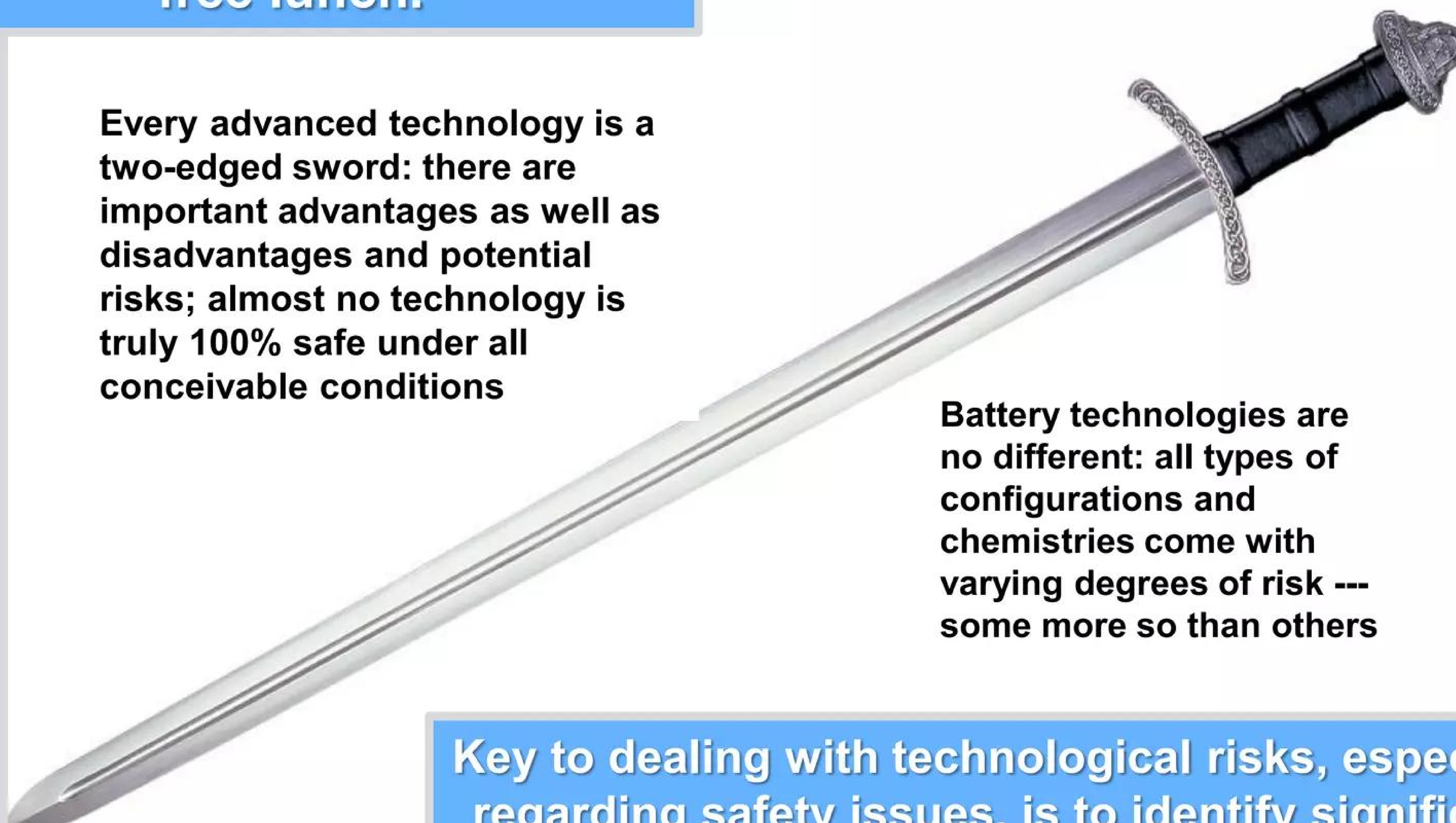
Economist Prof. Milton Friedman famously quipped, "There's no such thing as a free lunch."

The corollary to Friedman's maxim is that everything comes with a price

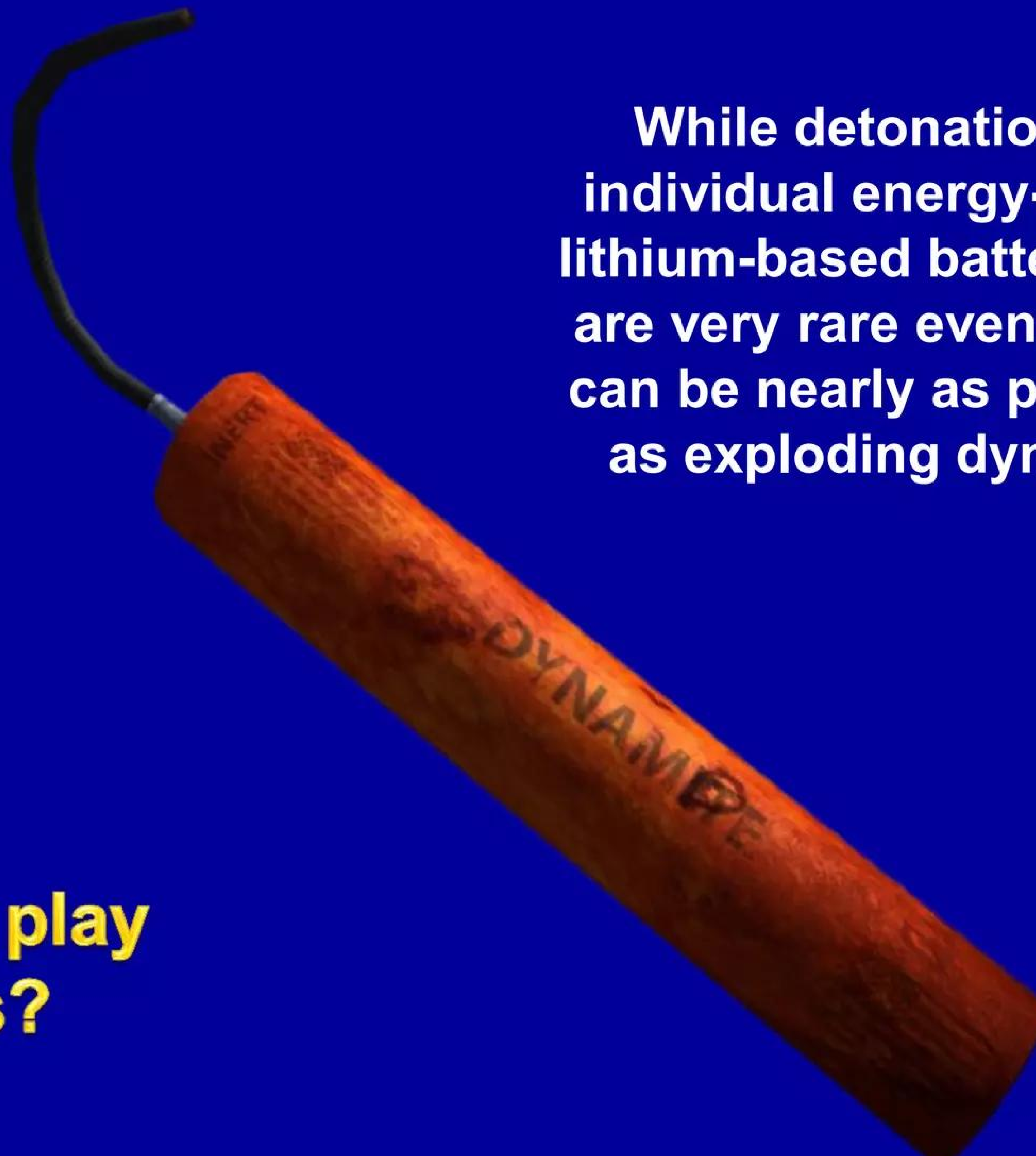


Every advanced technology is a two-edged sword: there are important advantages as well as disadvantages and potential risks; almost no technology is truly 100% safe under all conceivable conditions

Battery technologies are no different: all types of configurations and chemistries come with varying degrees of risk --- some more so than others

Key to dealing with technological risks, especially regarding safety issues, is to identify significant risks, understand them, and prevent or minimize them as much as humanly possible

Containing thermal runaways: a fool's paradise?



While detonations of individual energy-dense, lithium-based battery cells are very rare events, they can be nearly as powerful as exploding dynamite

Would you play with this?

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Would you play with this?

US M67 fragmentation grenade developed post-Vietnam war

While detonations of very large arrays of energy-dense lithium-based batteries, such as multi-cell battery packs used in all-electric vehicles, are very rare events, they can be AS powerful as hand grenades and some IEDs

Or this?


Credit: USMC

Improvised explosive device (IED) Ramadi, Iraq (2006)

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Thermal runaways:

batteries behaving badly

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- Typically well-controlled electrochemical reactions in batteries ordinarily generate a certain amount of process heat which is dissipated harmlessly simply by emitting invisible infra-red radiation from the battery case out into the local environment; contents of battery cells still remain well-within proscribed boundaries of designed range of optimal thermochemical operating temperatures
- On rare occasions, for a variety of different reasons, a battery cell's electrochemical reactions can suddenly start running at greatly elevated rates that create more process heat than normal thermal dissipative mechanisms can easily handle, which then starts raising the temperature of battery cell contents out beyond their ideal safe operating range; threshold for out-of-control danger not yet crossed

At key point --- call it a battery cell's Rubicon --- a dangerous positive feedback loop is created: whereby, increasing cell temperatures further accelerate electrochemical reactions in cells which produces even more heat, boosting local cell temperatures even higher, etc.

Thermal runaways are thus born: only question is how bad they get before destroying enough of a battery to stop accelerating reactions

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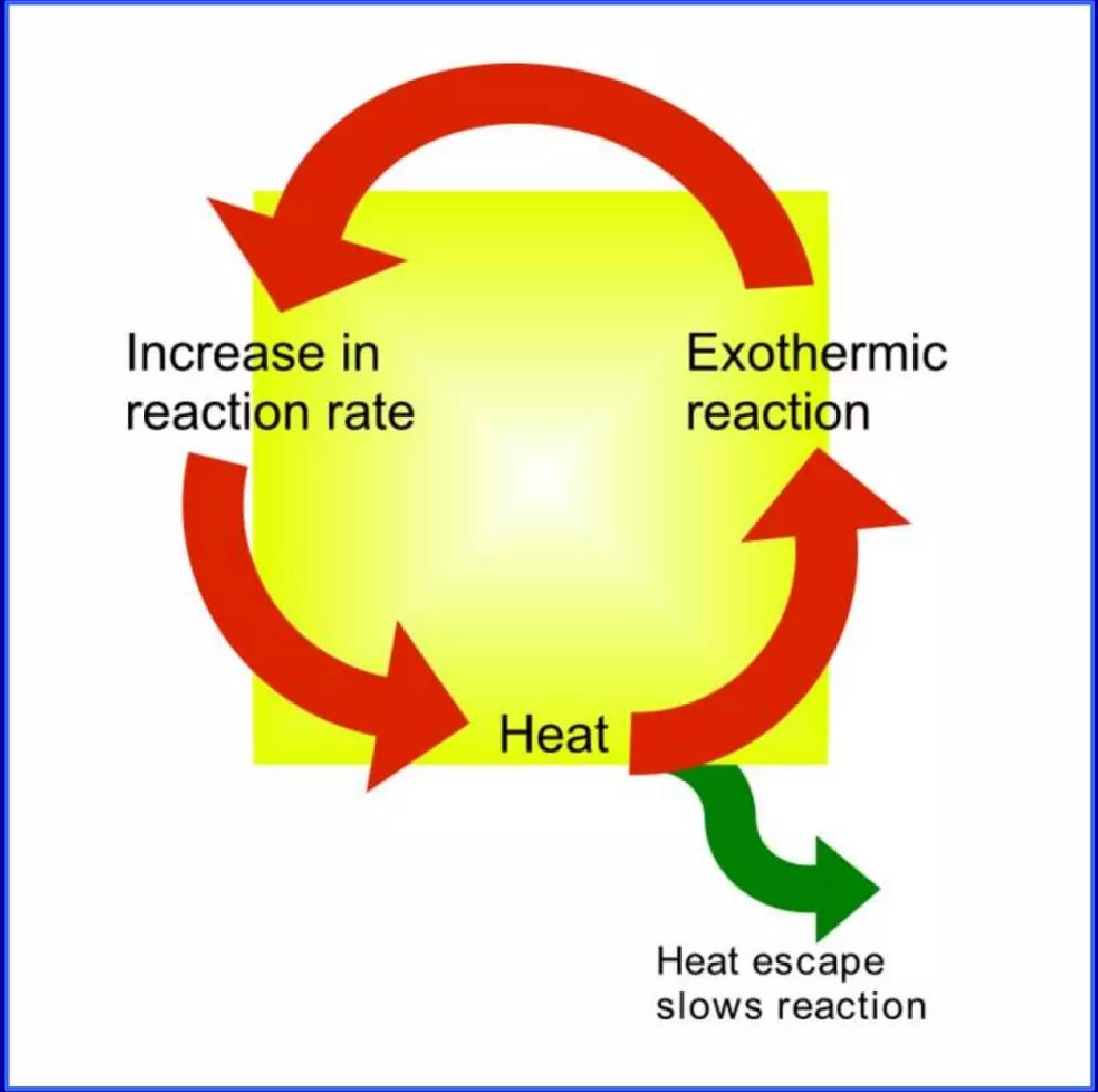
Thermal runaways: positive temperature feedback loop



Source: Wikipedia

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How common are thermal runaway events?

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Good news: thermal runaway events are statistically rare

Bad news: when they do happen, can have catastrophic effects

By any reasonable standard, lithium-based batteries are a pretty safe technology: garden variety thermal runaways only occur at frequencies of one such event per several millions of battery cells

The very worst, least understood type of thermal runaway (which goes under innocuous-sounding sobriquet of "field-failure") occurs at a rate of one such event per ~ 4 - 5 million lithium-based battery cells right off the production line and regardless of their chemistry or primary vs. secondary, according to statistics collected by a major Japanese manufacturer of lithium-ion consumer batteries

There's one more issue: although it's hard to quantitatively specify, probability of thermal runaways seems to increase significantly as batteries age and go thru a great many charge-discharge cycles

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How bad can battery thermal runaways get?

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Battery thermal runaways come in different sizes and degrees of the severity of damage and nature of collateral processes caused by a given runaway event

Garden variety single-cell thermal runaways can be as little as a battery that just heats-up a bit and simply stops functioning … or a battery's case can bulge significantly from internally generated heat without designed venting and releasing of contents from the inside before it stops functioning and then starts cooling down on its own

A slightly worse variant of a garden variety thermal runaway results in just a single cell venting or rupturing, but (in case of flammable electrolytes) there are no hot, flaming battery contents spewed-out that could potentially ignite local combustibles and adjacent cells

In worst-case garden variety runaway, hot flaming electrolyte erupts from a ruptured battery cell, which may ignite nearby materials and cells; in this event variant (that is still not the worst-of-the-worst), internal peak temperatures usually not yet hot-enough to melt metals

Containing thermal runaways: a fool's paradise?

Field-failures are catastrophic events in chemical batteries

Battery industry definition of field-failure thermal runaway:

Safety concerns have been heightened by highly publicized safety incidents and ensuing widespread recalls of lithium-ion batteries used in laptop computers and cell phones [14, 15]. When these rare safety incidents occur, lithium-ion batteries operating under otherwise normal conditions undergo what appear to be spontaneous thermal runaway events, often with violent flaming and extremely high temperatures. Moreover, these failures usually involve cells and cell designs that have passed extensive abuse testing, including the standardized abuse safety tests. *Most such Li-ion safety incidents in the field are not preceded by any obvious external abuse*. We refer to these spontaneous safety incidents as "field-failures".

Source: **"Batteries for Sustainability – Selected Entries from the Encyclopedia of Sustainability in Science and Technology," Ralph J. Brodd, Ed., Chapter 9 by B. Barnett et al., "Lithium-ion Batteries, Safety" Springer ISBN 978-1-4614-5791-6 (2012)**

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Field-failures are catastrophic events in chemical batteries

Simulation: burning electrolyte may raise cell temp up to 1,825° C

- Field-failures much more problematic than garden variety thermal runaways
- If electrolyte is flammable, it will usually be ignited; can then boost temp up to levels that will melt copper and aluminum metals
- Usually breach cases; can ignite all adjacent battery cells via thermal fratricide

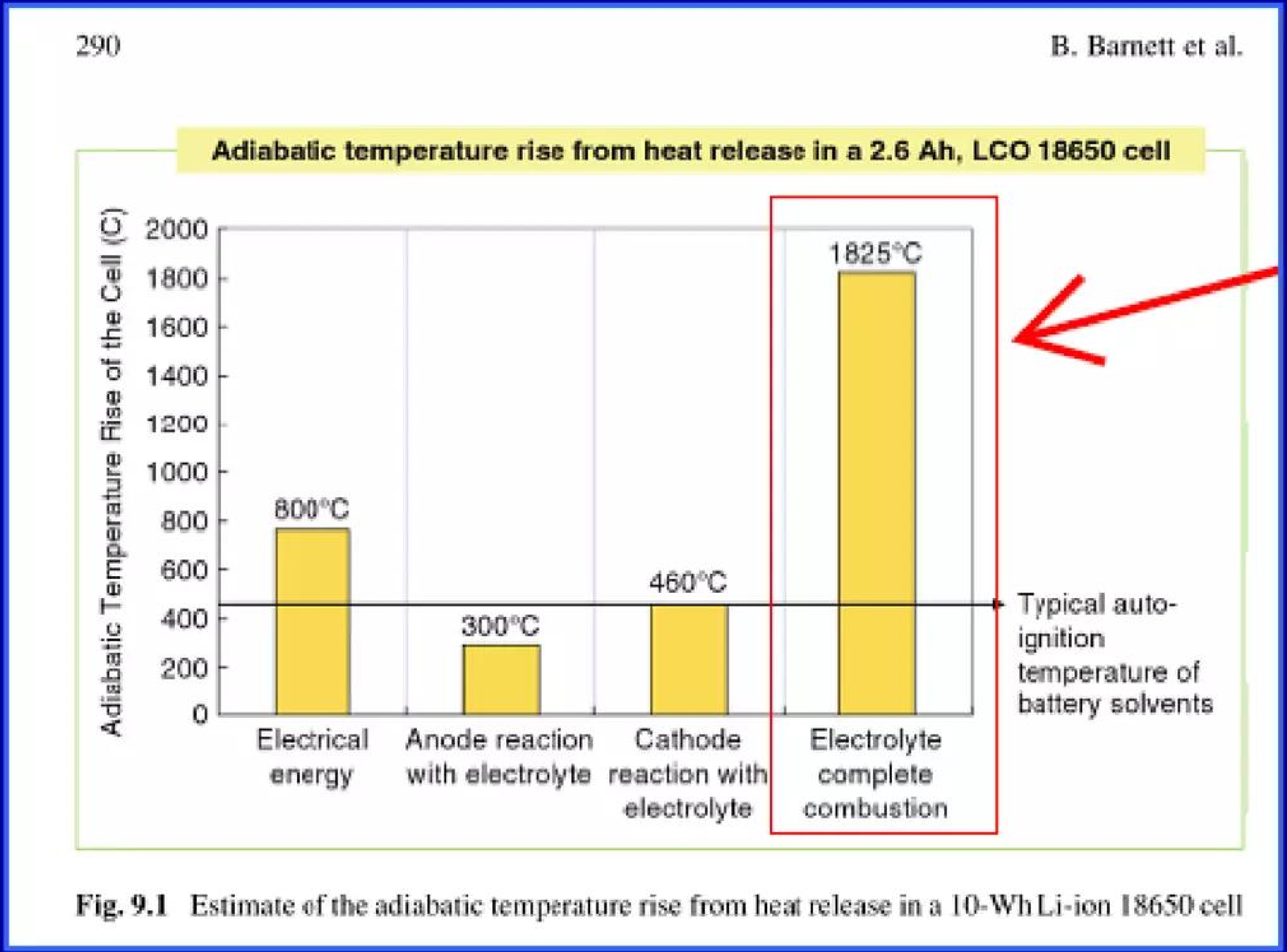

Fig. 9.1 Estimate of the adiabatic temperature rise from heat release in a 10-Wh Li-ion 18650 cell

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Field-failures are catastrophic events in chemical batteries

Absolute worst-case Armageddon scenarios involve burning metals

Field-failure category of thermal runaways can reach extremely high peak temperatures of thousands of degrees Centigrade along with big electric arcs

Such temperatures are hot-enough to melt metallic structures inside batteries and combust almost anything and everything located within a battery case

If initiating spark is hot-enough, battery materials containing chemically bound oxygen will release it as O_2; by creating its own oxygen supply, combustion process becomes self-sustaining, self-propagating flame front that consumes all burnable battery materials; progressive thermal fratricide between cells can reduce batteries to unrecognizable debris; such fires could burn in a vacuum

In absolutely worst-case events, even METALS can start burning in very fast, thermite-like reactions that can boost temps up to ~ 4,000° C; this is nightmare scenario where even deadly detonations (explosions) can potentially occur

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Electric arcs

can destroy batteries

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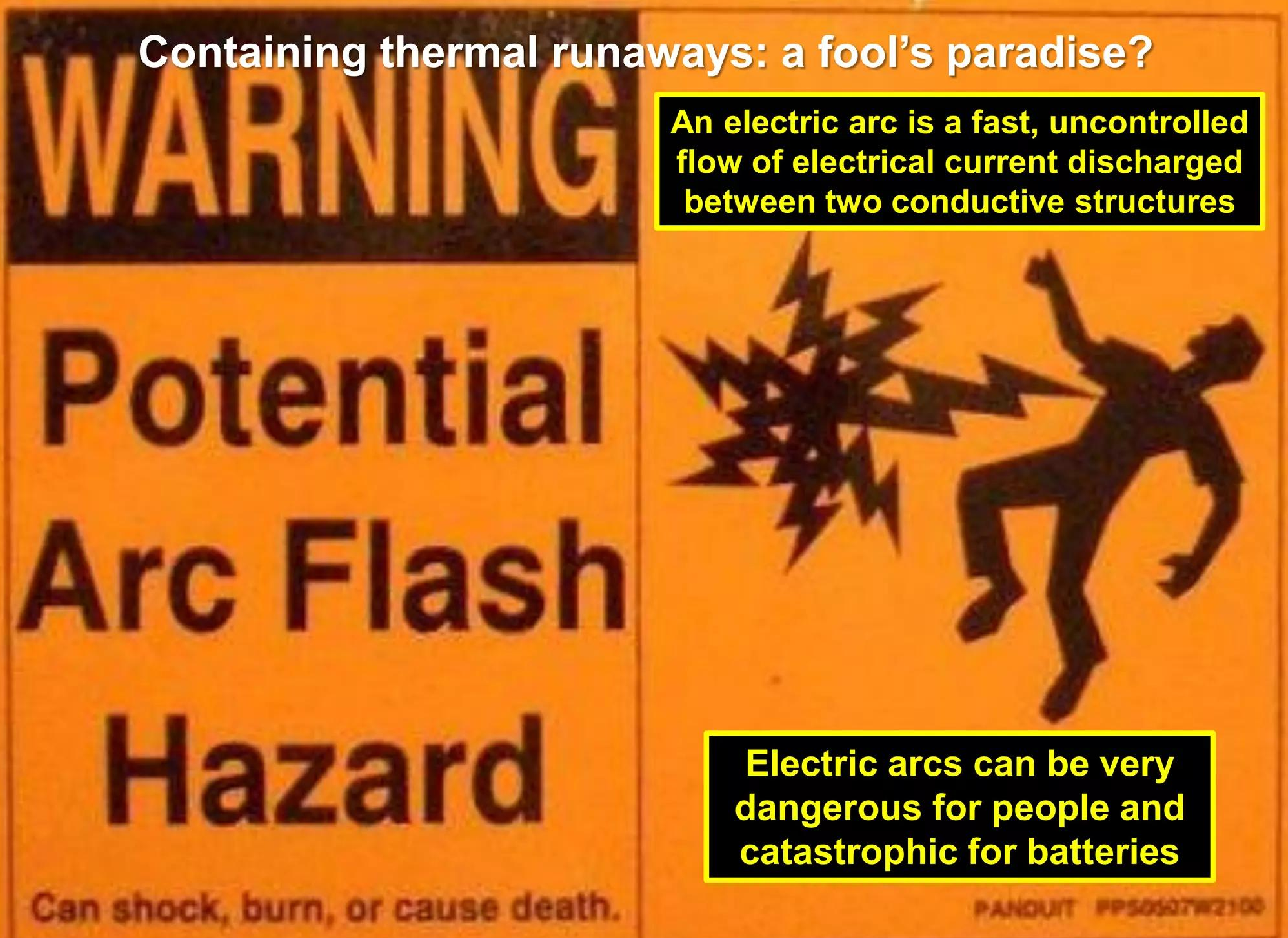

An electric arc is a fast, uncontrolled flow of electrical current discharged between two conductive structures

Electric arcs can be very dangerous for people and catastrophic for batteries

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Violent electric arc discharges in batteries dying from thermal runaways are like lightning - only on smaller scale

Get extremely hot, very fast --- damage nearby structures

Arc discharges (shorts) can start-off being microscopic in size; reach progressively larger physical dimensions as batteries are destroyed by super-hot runaway processes

Internal micro-arc discharges (whatever their proximate cause) can actually trigger major thermal runaway events

> Early in runaway events, arc shorts tend to occur between conductive structures located inside fast-failing batteries
>
> Later, arcs may even breach battery cases and connect to conductive structures outside in vicinity of dying batteries

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Image credit: Automation World

Inner cores of high-current electric arcs can get unbelievably hot in just milliseconds

Various causes of thermal runaways

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Causes of garden variety vs. field failures aren't identical

"Garden variety" thermal runaways:

- Reasonably well understood
- Triggered by substantial over-charging or excessively deep discharges
- Triggered by external mechanical damage to battery cells, e.g., crushing, punctures; internal dendrites can penetrate separators

Field-failure thermal runaways:

- Much rarer and comparatively poorly understood
- Many believe triggered by electrical arc discharges (internal shorts); but what causes initial micro-arcs?
- Much higher peak temps vs. garden variety events
- Lattice suggests: low energy nuclear reactions (LENRs) could well be triggers for some % of them

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LENRs:

green nuclear energy

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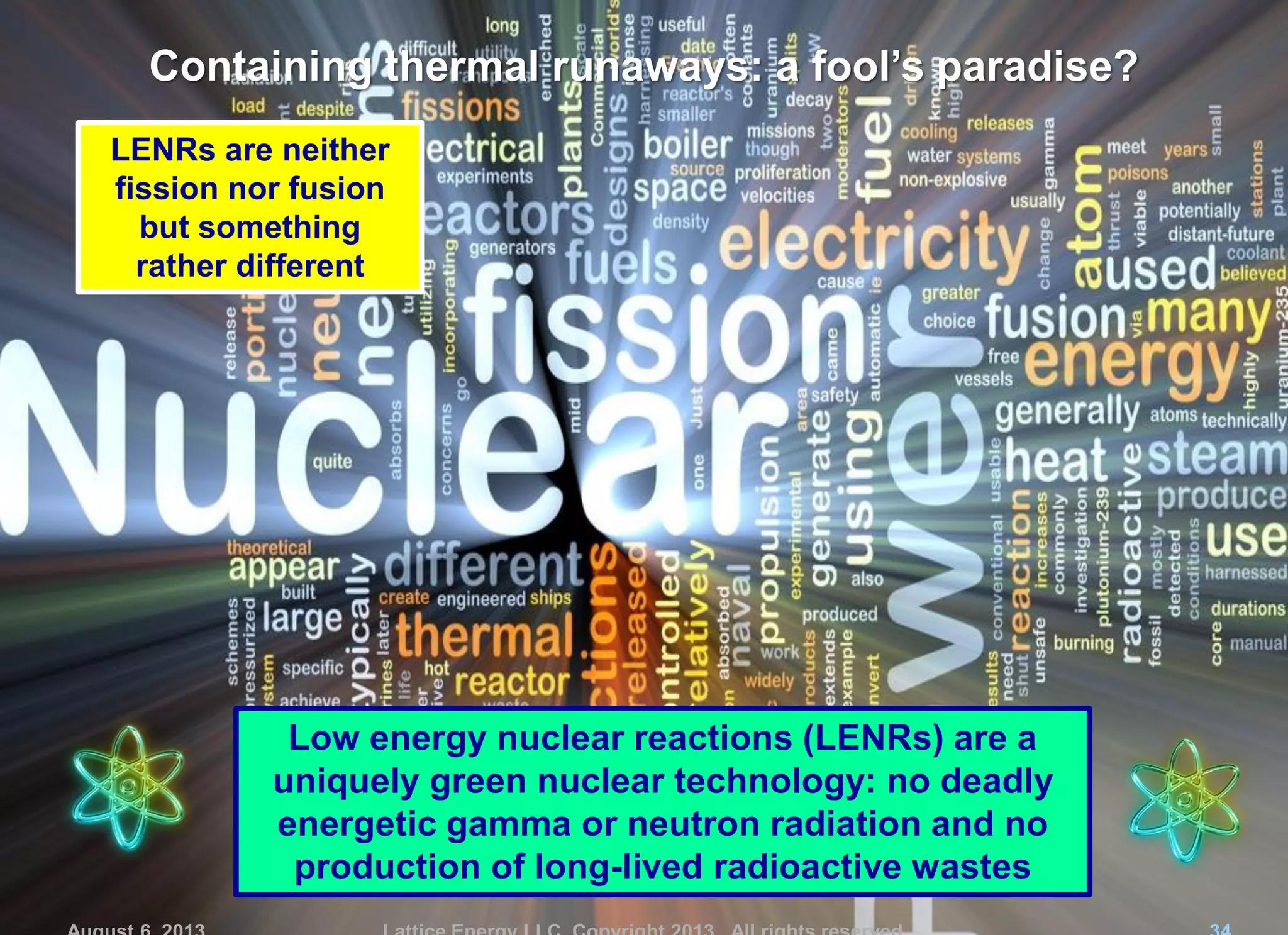

LENRs are neither fission nor fusion but something rather different

Low energy nuclear reactions (LENRs) are a uniquely green nuclear technology: no deadly energetic gamma or neutron radiation and no production of long-lived radioactive wastes

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LENRs: no deadly neutron or gamma radiation or radwaste

Hidden in plain sight for 100 years because radiation signatures absent

From older problematic energy sources | **To a greener less expensive tomorrow**

Evolution of nuclear technology

Fossil fuels + fission + fusion → LENRs + renewables

Containing thermal runaways: a fool's paradise?

Is battery industry unwittingly encountering LENRs?

Microscopic LENR-active hotspots inside batteries hit 4,000 - 6,000^{o} C

- Conditions conducive to initiation of LENRs occur in microscopic, micron-scale regions in random scattered locations on dendrites and other types of growing nanostructures located inside lithium-based batteries
- Although radiation-free, LENRs involving neutron captures on lithium are extremely energetic nuclear processes – can release up to 27 MILLION times more heat than even the most exothermic types of electrochemical reactions
- Microscopic 100 micron LENR hotspot can release 5^{+} Watts of heat in less than 300 nanoseconds; local nuclear reactions raise hotspot temps to 4,000 - 6,000^{o} C
- Micron-scale LENR-active sites that happen to be located close to a plastic battery anode/cathode separator (with or without a ceramic layer) will vaporize and flash-ionize a local region of separator which can in turn trigger an internal electrical short discharge at that particular location ; similarly, an LENR patch occurring on surface of a Lithium cobalt oxide cathode or carbon anode can potentially directly trigger irreversible combustion of an affected electrode

In rare events, LENRs can either induce internal electric arcs and/or directly trigger catastrophic thermal runaways in advanced batteries of varied chemistries

Containing thermal runaways: a fool's paradise?

Is battery industry unwittingly encountering LENRs?

Mechanism for triggering microscopic LENR-active hotspots

Dr. Andre Anders of Lawrence Berkeley National Lab has model:

Steps 1 – 4 below describe his "arc spot ignition" model as follows:

High local electric field, enhanced by:

- Protrusion (e.g. roughness, previous arcing) [dendrites]
- Charged dielectrics (e.g. dust particles, flakes) [nanoparticles]

1. Higher field leads to locally greater e-emission
2. Joule heating enhances temperature of emission site
3. Higher temperature amplifies e-emission non-linearly
4. Runaway electric arc discharge

Positive feedback loop +

To which Lattice would add, based on Widom-Larsen theory:

5. LENRs --- if other necessary preconditions are also fulfilled, as we have outlined in other documents

Timeline

LENR hotspot crater being created

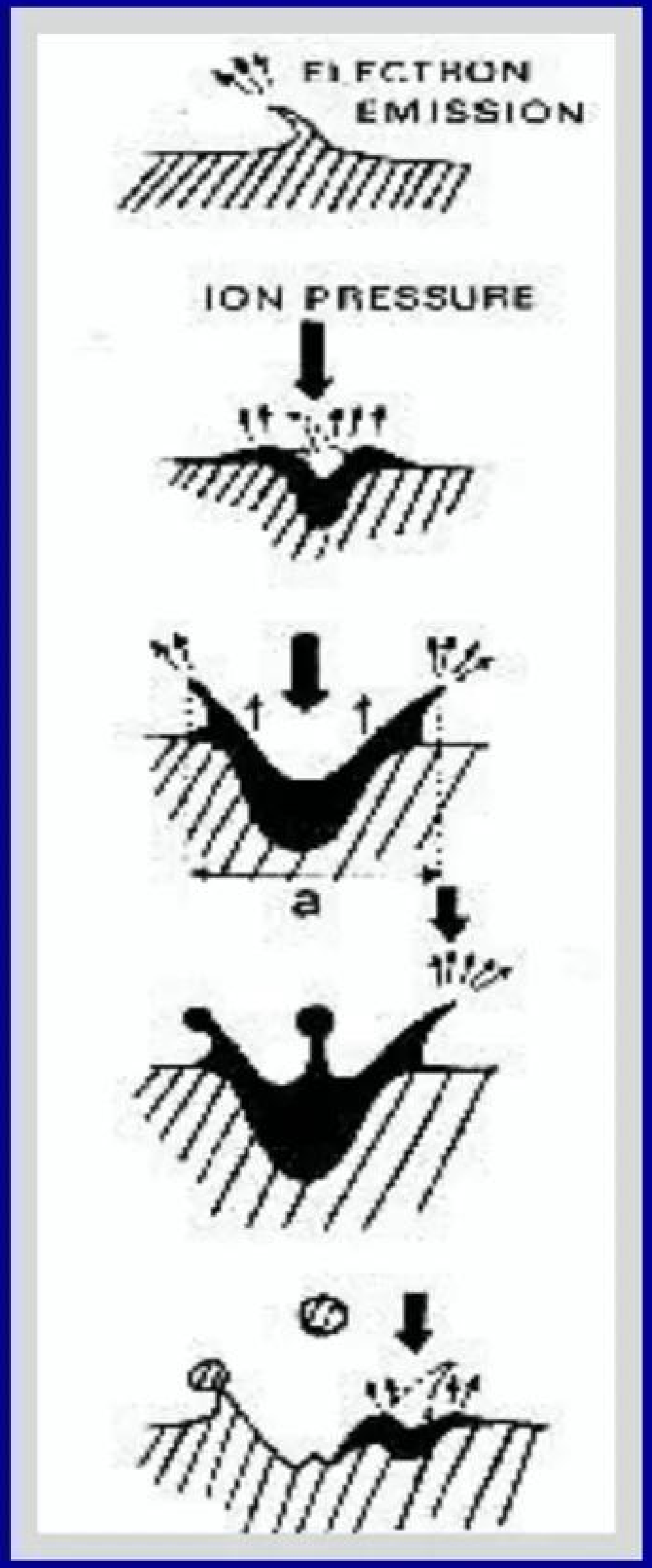

Figure credit: B. Jüttner, Berlin

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Electric arc discharges and LENRs can trigger runaways

Detailed description of LENR processes in batteries

Please note that as little as a single blazing hot LENR-active site measuring only 30 microns in diameter --- if it happens to occur in vulnerable physical location deep inside a battery cell and adjacent to the surface of a plastic separator only 25 microns thick --- can effectively vaporize a tiny local region of the separator, almost instantly turning it into a dense, micron-sized ball of highly conductive plasma. This would in turn create an electrical short between anode and cathode at that location, triggering a large inrush of electrical arc current through the breach in the separator dam. Intense local Joule heating would ensue from the arc current, further enlarging the breach and spatially expanding the superheated region inside a given battery cell. Depending on many complex, event-specific details, such a conflagration may or may not grow to engulf an entire cell; thus rare LENR events do not inevitably cause catastrophic heat runaways.

Under just the right conditions, a single *microscopic* LENR site can trigger a chain of energetic electrical (Joule heating) and chemical (exothermic reactions) processes that together create spatially autocatalytic, very macroscopic thermal runaway events that destroy battery cells billions of times larger than volumes of LENR site(s). In course of such runaways, 99.9^{+}% of total energy released is non-nuclear; hot spark LENRs are just an effective triggering mechanism. Also note that internal electrical shorts - whatever their cause - can also trigger runaways.

Containing thermal runaways: a fool's paradise?

Electric arc discharges and LENRs can trigger runaways

Detailed description of LENR processes in batteries

Within as little as milliseconds after the creation of an electric arc or LENR-active site, nm- to cm-scale local regions of a battery cell at or near such locations can become a super-hot, fiendishly complicated chemical "witches' brew" consisting of many different types of old and newly created compounds, expected thermal decomposition products, various ionized species, and many mutually competing chemical reaction pathways

Positive thermal (heat) feedback loop: the hotter a given region gets, the faster local chemical reactions accelerate therein and the more widely the conflagration spreads into previously unaffected regions of a given battery cell --- this is causative root of thermal runaway effect and "thermal fratricide" that can occur between many cells

Evolution of such complex chemical systems is very rapid and incompletely understood - quite unpredictable with respect to final results: outcomes can range from minor thermal damage to single cell; to combustion of flammable electrolytes and charring of materials inside case and outside via venting; and at worst, to complete combustion of all materials located inside of and including cell casings --- even all contents of surrounding multi-cell enclosures; worst-case Armageddon scenarios involve thermite-like, violent super-fast-reacting pyrotechnic processes

Containing thermal runaways: a fool's paradise?

Electric arc discharges and LENRs can trigger runaways

Electric arc discharges can hit even higher temps than LENR hotspots

Causative agent that can trigger thermal runaways	Regime or requirements	Physical dimensions	Key details	Temperature range in ° C	Comments
Electric discharges: that is, **arcs or sparks;** alternative names for internal electrical short circuits that can occur inside battery cells	Outer edges of tubular arc plasma sheath	Arc lengths can range in length from 2 *nm* between metallic nanoparticles all the way up to as long as several centimeters (*cm*) between larger structures	Chemical and nuclear reactions can occur within; dep. on current	~2,727 up to ~4,727	Heat radiation is mainly created via Joule heating by electrons and ions found in arc discharge plasma; very damaging to materials; can even breach battery cell case
	Innermost core of arc plasma's tubular sheath-like structure			~9,726 up to ~19,726	
LENR-active hotspots: can occur on metallic surfaces or at oxide-metal interfaces anywhere inside battery where be: e^-, p^+ and metals	Require local presence of hydrogen (protons), metals, and surface plasmon or π electrons	2 nanometers (*nm*) to as large as ~100⁺ microns (μ) in diameter; roughly circular in shape	MeV-energy nuclear reactions occur within	~3,700 up to ~5,700	Directly radiate infrared heat photon energy; ionizes nearby molecules, materials, destroys μ-scale nanostructures

Extremely high temperatures can drive very complex, rapidly evolving chemical reaction networks

Scale-up of the internal energy densities, electrical capacity, and sheer physical size of battery systems can lead to much larger thermal runaway events

Zotye M300 EV taxi - Hangzhou, China (2011)

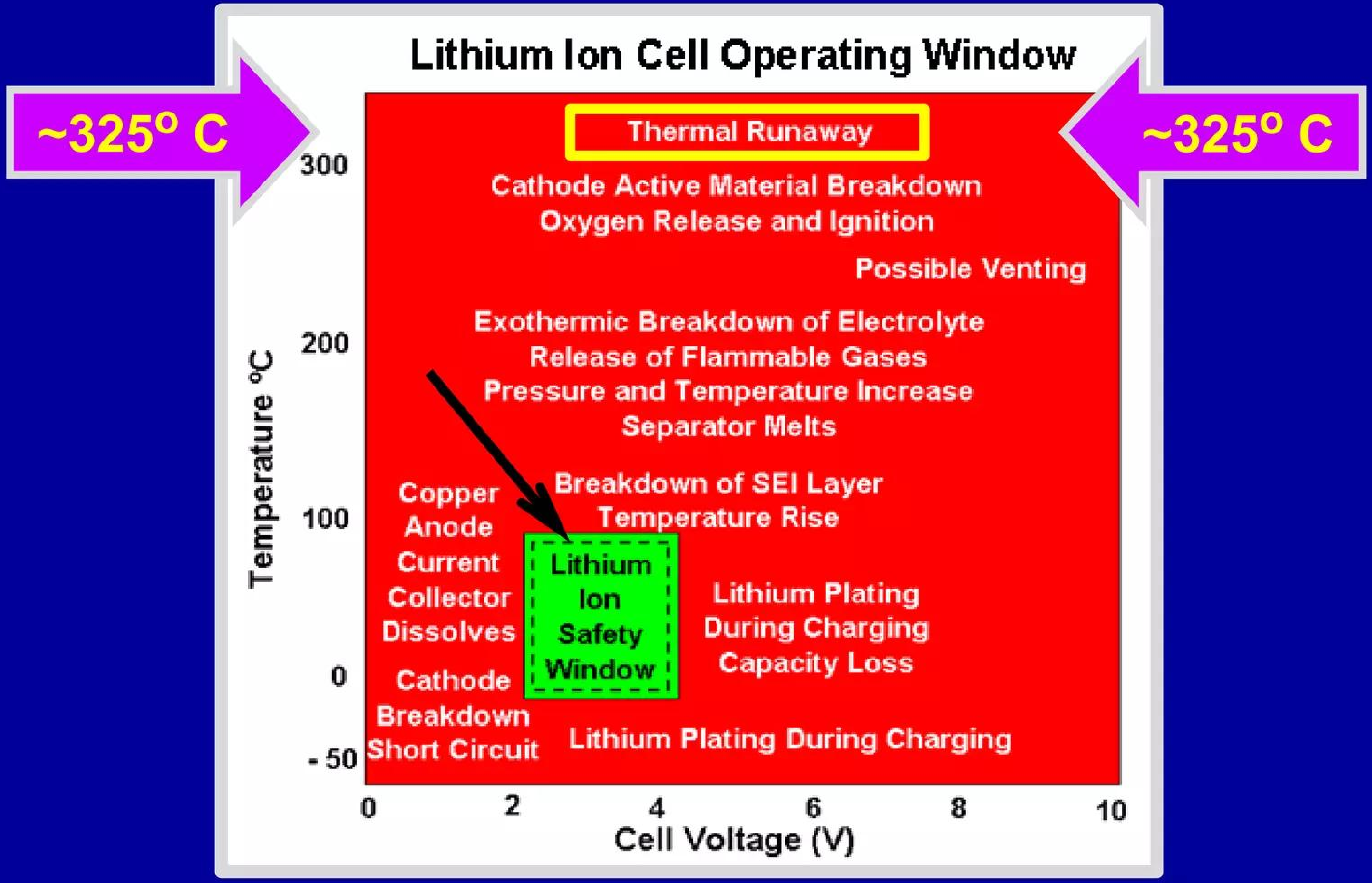
Boeing 787 Dreamliner - Logan Airport, Boston (2013)


Renault F1 car: $LiFePO_4$ battery in KERS system (2011)

Containing thermal runaways: a fool's paradise?

Lithium-ion battery cells have small safe operating window

Local temperatures in electric arcs and LENRs greatly exceed safety window



Containing thermal runaways: a fool's paradise?

Thermal runaways in portable electronics

Containing thermal runaways: a fool's paradise?

Thermal runaways in portable electronics since 1990s






Containing thermal runaways: a fool's paradise?

Battery capacity scale-up can increase safety risks

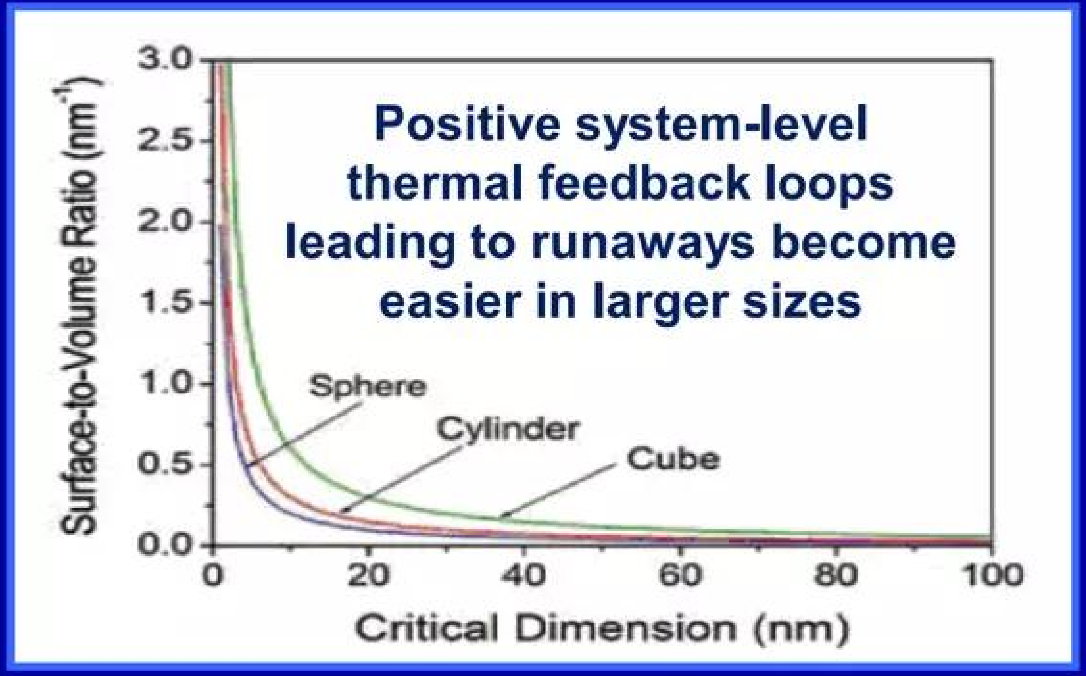
Containing thermal runaways: a fool's paradise?

Battery capacity scale-up can increase safety risks

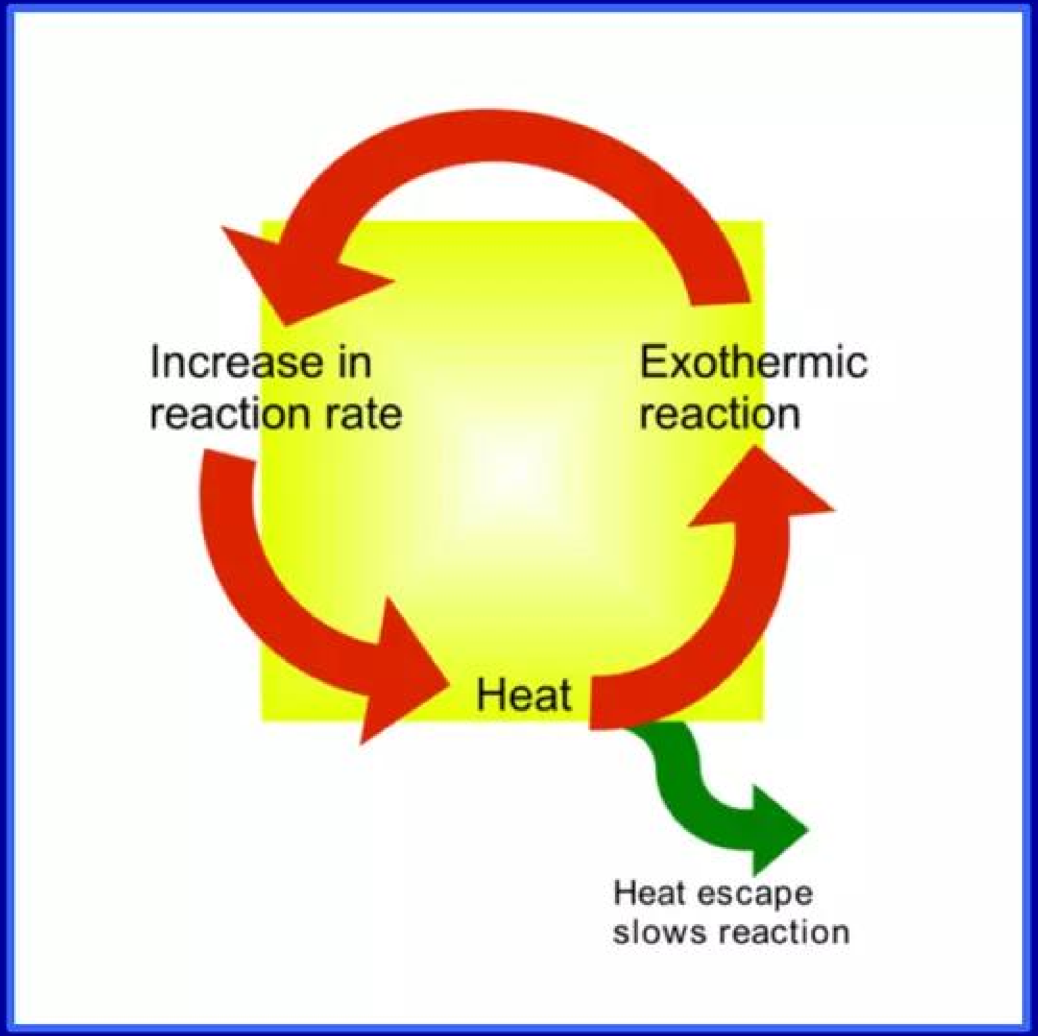
Thermal runaways become more likely if heat dissipation is impaired

For exothermic electrochemical reactions that normally occur inside operating battery cells, total cell heat production scales with the cube of the size of the battery cell ($V \propto r^3$), but a cell's heat transfer capability scales with square of the size ($A \propto r^2$), so that rate of heat production-to-area ratio scales with the size ($V/A \propto r$)

End-result of this immutable scaling relationship between volumetric generation of heat within a given mass of reactants in a cell versus its area-related ability to dissipate produced heat is that chemistries that may well operate very safely in small cells are potentially dangerous and quite thermally unstable in considerably larger ones



Surface area vs. volume decreases with increased size



Consequence: scale-up of the internal energy densities, electrical capacity, and sheer physical size of battery systems can lead to much larger, vastly more dangerous thermal runaway events

Containing thermal runaways: a fool's paradise?

Battery capacity scale-up can increase safety risks

Since 1991: improved battery energy densities enabled by Lithium-ion chemistry mutually reinforced and supported meteoric increases in global unit sales of portable electronic devices including laptop computers and cellphones and more recently, tablets and smartphones [see following charts illustrating explosive market growth]

Using various different chemistries, next logical step for battery technologists was to scale-up arrays of batteries so that their total electrical storage capacity was enough for effective use in hybrid/all-electric vehicles and even larger-scale big applications

Persistently high gasoline prices encouraged CY 2000 global launch of first mass-produced, highly successful gasoline-electric hybrid car, the Toyota Prius. Market success of Prius along with continuing high gas prices and improvements in Li-ion technology encouraged development and sale of all-electric, plug-in vehicles by several new start-ups, notably Tesla (Roadster, 2008) and Fisker (Karma, 2012). Large established auto manufacturers now rising to meet upstarts' competitive challenge

Also driven by high jet fuel prices, parallel developments also occurred in aircraft technology which encouraged adoption of much lighter-weight airframes (carbon-fiber composite vs. older tried-and-true aluminum) and more weight-efficient all-electric (vs. older hydraulic) critical aircraft systems; this led to a need for high-energy-density battery arrays for onboard backup power. These new technological thrusts were embodied in Boeing's 787 Dreamliner (2012) and Cessna Citation (2013)

Containing thermal runaways: a fool's paradise?

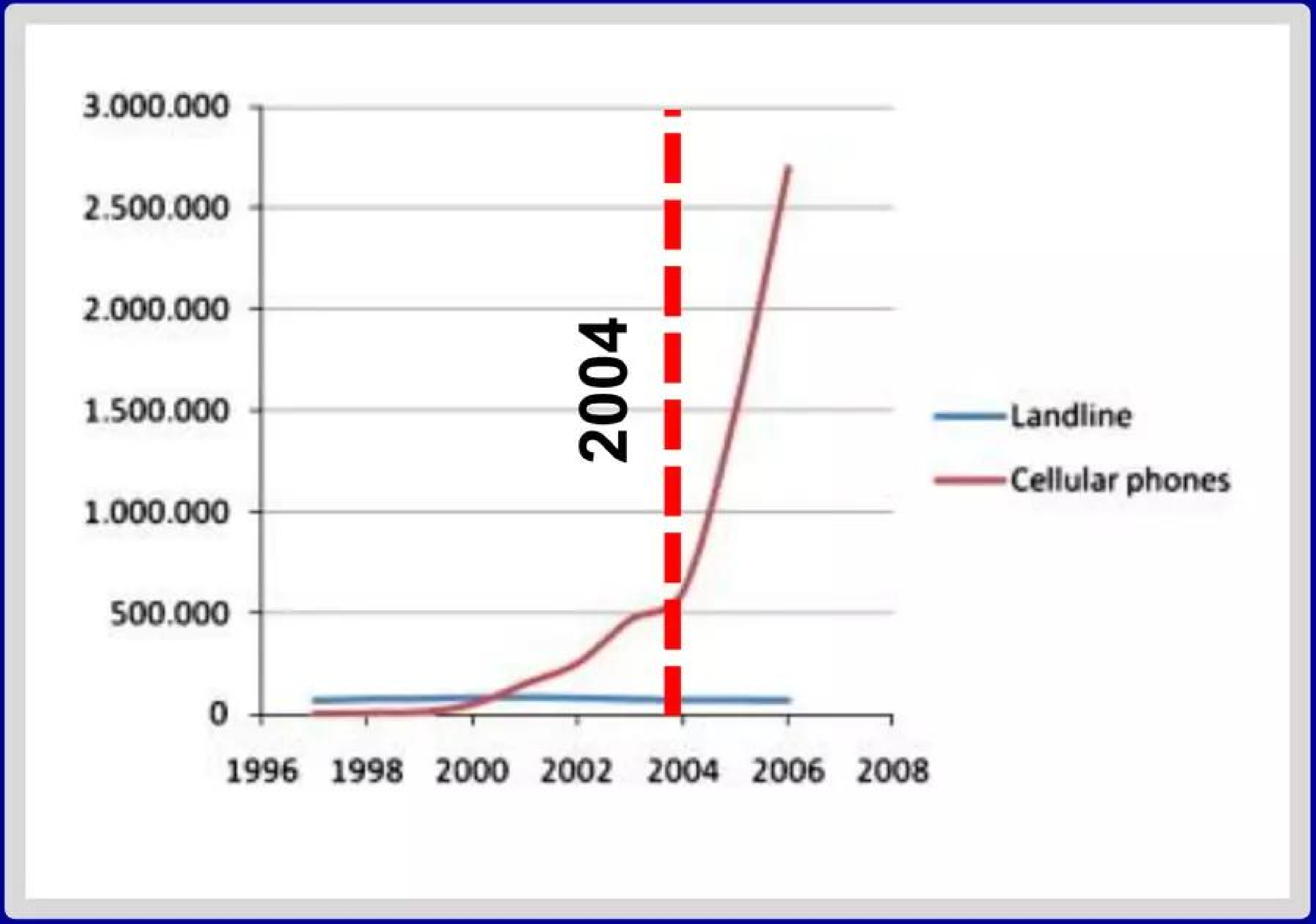
Battery capacity scale-up can increase safety risks

Growth in lithium-ion battery market paralleled cellphones

Sony and Asahi Kasei (Japan) released first commercial lithium-ion batteries in 1991

Generally speaking, smartphones require significantly more electrical power to operate for extended periods than limited-function, plain vanilla cellphones

Meteoric growth in unit sales of cellphones

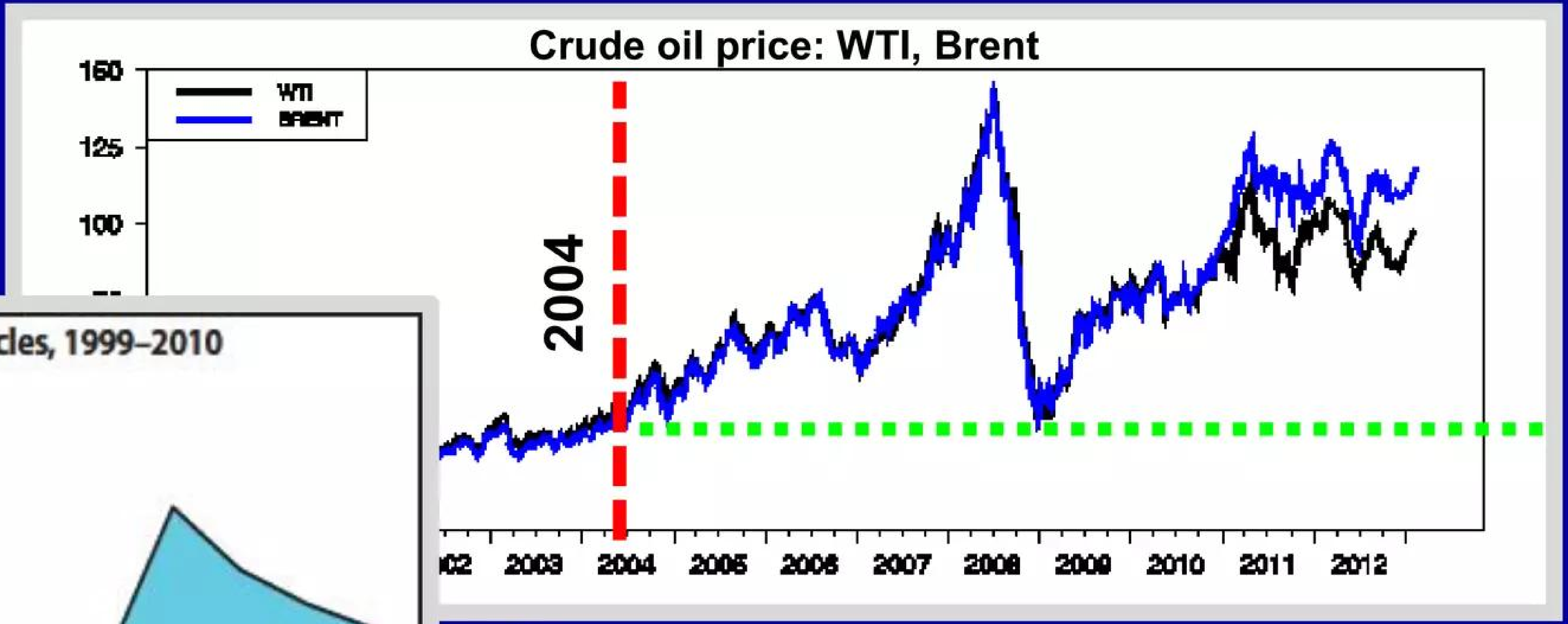


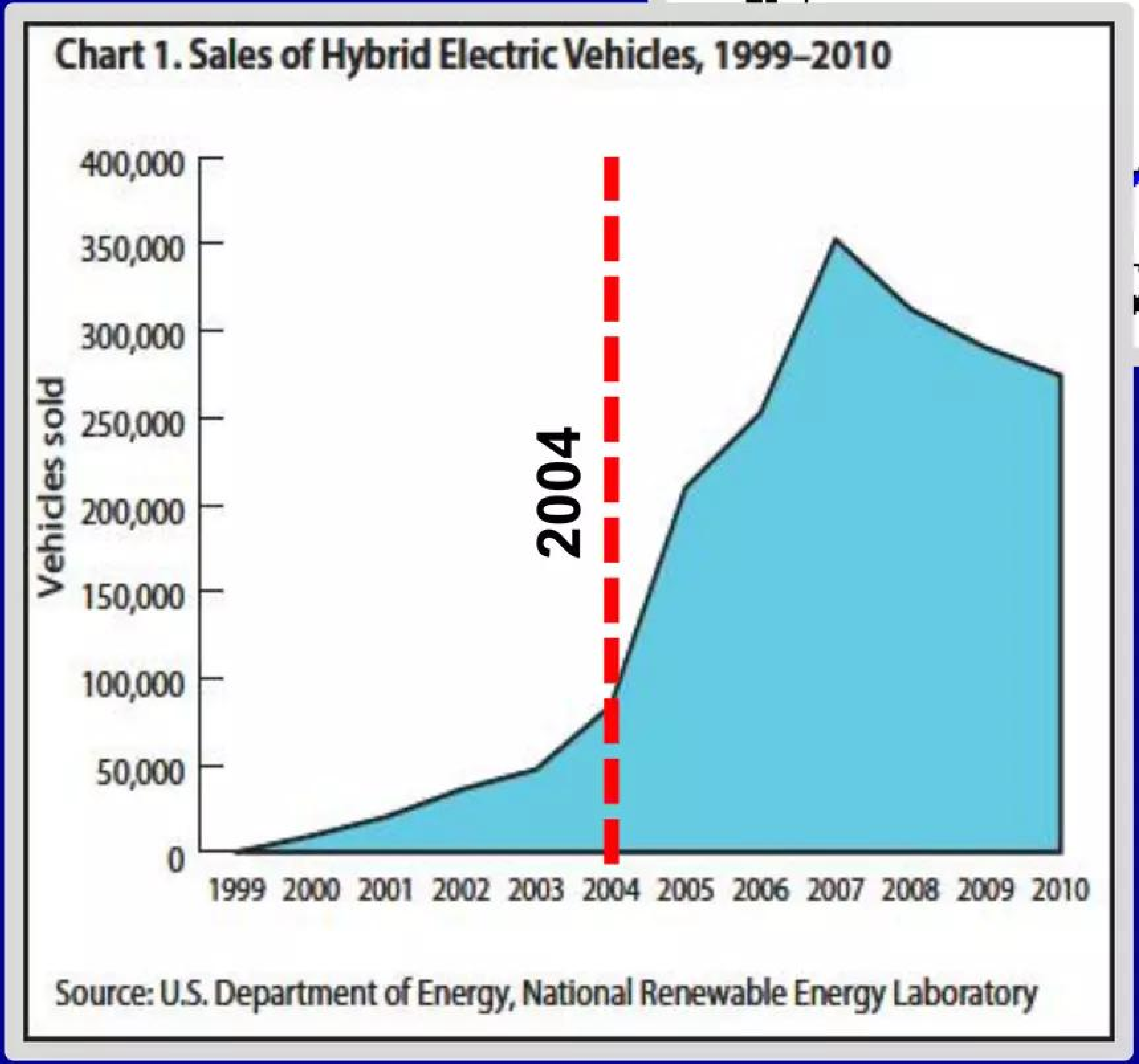
Unit sales of smartphones are accelerating

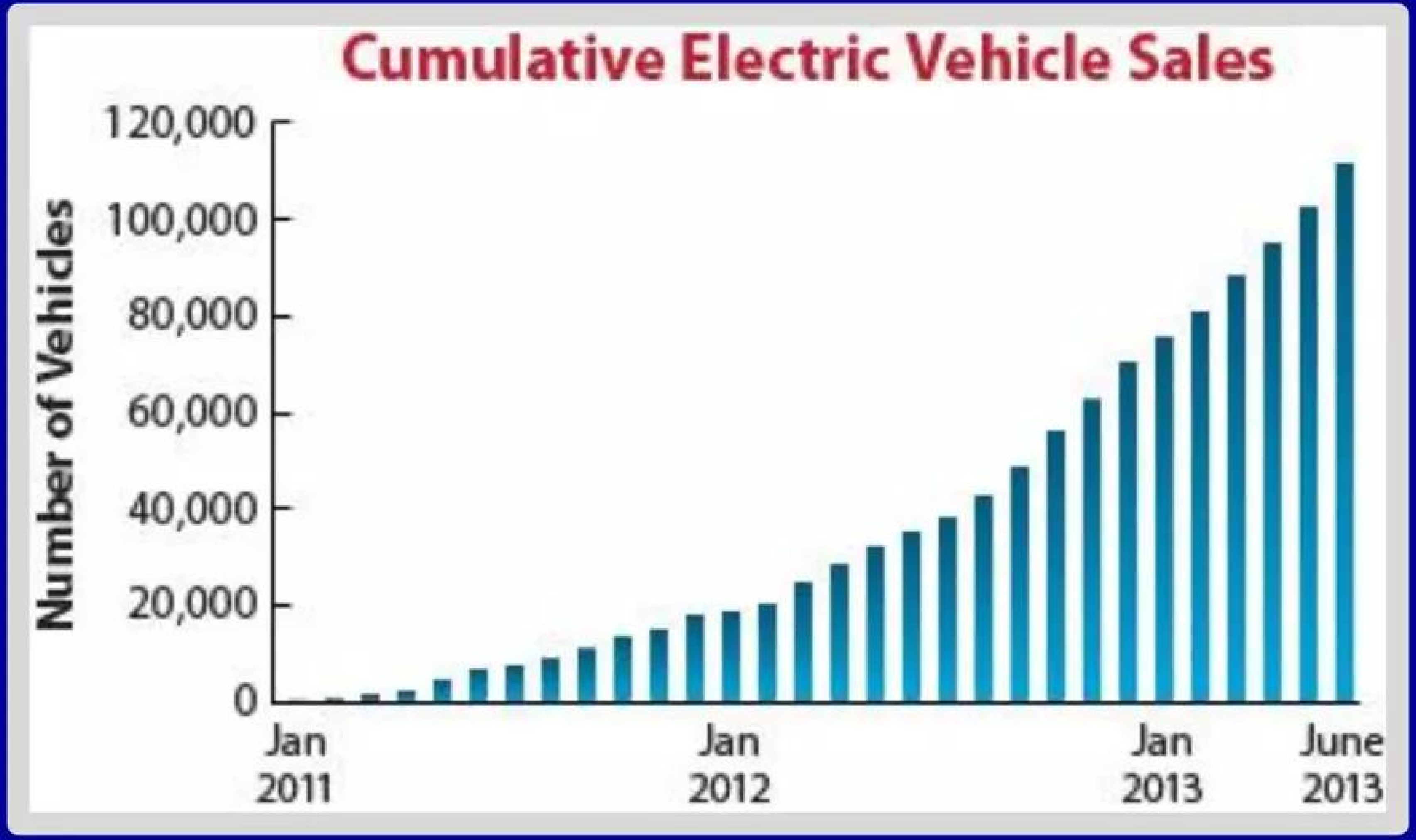
Containing thermal runaways: a fool's paradise?

Scale-up of batteries creates additional safety risks

Persistently high gasoline prices since 2004 boosted demand for EVs







Containing thermal runaways: a fool's paradise?

Battery capacity scale-up can increase safety risks

Risks can increase with scale-up

Thermal runaway event inside single-cell, lithium-based "button" battery might ruin a small electronic device, but it probably won't set anything else on fire or hurt any nearby person or persons seriously

Runaway inside smartphone's multi-cell battery might start a woman's handbag smoking or burn a hole through a man's pants pocket, or make someone drop it, but it generally wouldn't cause serious skin burns or ignite a large portion of someone's clothing

Catastrophic runaways inside significantly larger, multi-cell laptop computer batteries have inflicted serious burns on people's legs and in several documented cases, have even burned-down entire homes

Runaways involving large to extremely large many-cell secondary batteries on stationary (onsite back-up power) and mobile platforms such as hybrid or all-electric vehicles and passenger or cargo aircraft are very serious matters; can cause multiple fatalities and up to many millions of $ in physical damage to equipment and/or local facilities

Containing thermal runaways: a fool's paradise?

Thermal runaways

on mobile platforms

Containing thermal runaways: a fool’s paradise?

Thermal runaways on mobile platforms

New applications for lithium-based batteries in autos and aircraft

Fires and other dramatic incidents have received much attention in media

Bigger is better, right?

Not necessarily

“There are known knowns; there are things we know that we know. There are known unknowns; that is to say, there are things that we now know we don't know. But there are also unknown unknowns – there are things we do not know we don't know.”

Donald Rumsfeld

U.S. Secretary of Defense
Press conference (2002)

Containing thermal runaways: a fool's paradise?

Thermal runaways on mobile platforms

New applications for lithium-based batteries in autos and aircraft

Fires and other dramatic incidents have received much attention in media

> Scale-up of any technology involves a certain level of inescapable intrinsic risks, some of which are known, and some which are not, e.g. Rumsfeld's "unknown unknowns"

Battery industry has had less than 25 years of experience with high-energy density lithium-based batteries; most of that was in consumer portable electronics applications where power demand/storage was measured in Watt-hours, not kilowatt-hours

By contrast, lead-acid batteries have been used in the US for 150 years, nickel-cadmium for 67 years, consumer alkaline for 54 years; those chemistries are tried-and-true and known to be relatively safe

Unfortunately, lead-acid batteries are impractical for all-electric vehicles and aircraft --- their energy densities are simply too low

Containing thermal runaways: a fool's paradise?

Thermal runaways on mobile platforms

New applications for lithium-based batteries in autos and aircraft

Fires and other dramatic incidents have received much attention in media

Within the past several years, there have been battery-caused:

- **Incinerations of hybrid and all-electric consumer vehicles**
- **Houses burned to the ground (EVs, laptop computers)**
- **Cargo aircraft destroyed in flight with crew fatalities**
- **Thermal runaways on passenger aircraft (Boeing 787)**
- **Bizarre explosion of lithium-ion battery recycling plant**
- **Unexplained destruction of US Navy all-electric minisub**
- **And a myriad of other mishaps that have been reported**

Containing thermal runaways: a fool's paradise?

Albeit expensive, Tesla Motors makes beautifully styled, well performing all-electric vehicles

Tesla Motors S

Have they been incredibly smart in how they engineered and manage their huge Lithium-based battery packs?

Or have they just been very lucky …. so far? Time will tell.

Containing thermal runaways: a fool's paradise?

Obama-backed Fisker Automotive laying off most rank-and-file employees, exploring bankruptcy

POSTED AT 2:01 PM ON APRIL 5, 2013 BY ERIKA JOHNSEN

Like 235 Tweet 96 +1 5

The Solyndra-fication of the Department of Energy loan-guaranteed Fisker Automotive, whose many merits as a hybrid sports car maker were once hailed throughout the land, is almost complete. The supposedly green-tech company announced that they intend to lay off nearly all of their regular employees on Friday, and that they will maintain about 53 senior managers and executives — mostly to pursue buyers for the company's assets. The WSJ reports:

While also a beautiful car this brand new Fisker wasn't quite so lucky

Totally destroyed by a fire

Containing thermal runaways: a fool's paradise?

<u>During 2011</u>: several suspicious, rather frightening fires occurred in Renault F1 race cars equipped with Li-ion batteries in the cars' KERS (kinetic energy recovery system); the Saft Li-ion batteries used in the 2011 season's Renault Formula 1 (F1) KERS appear to have had a lithium iron phosphate chemistry

James Allen on F1
"A new take on Heidfeld's Renault explosion"
Posted August 1, 2011
http://www.jamesallenonf1.com/2011/08/a-new-take-on-heidfelds-renault-explosion/

http://www.liveleak.com/view?i=9e5_1312126530

http://www.youtube.com/watch?v=TzPv9ptIXNI

http://www.youtube.com/watch?v=9Nk2lR9HYbE

Containing thermal runaways: a fool's paradise?

An Audi R8 supercar self-incinerated in Mumbai, India back in January 2013; for amazing videos of this Mumbai incident, see below:

There is strong likelihood that Audi R8 fire's causative factor could have been an owner- or dealership-installed aftermarket lithium iron phosphate battery that replaced a lead-acid battery which was originally installed during assembly at the Audi factory in Germany. This particular R8 model included an optional factory-installed 465 Watt Bang & Olufsen multi-speaker auto stereo system, which may have prompted car's owner to install an aftermarket lithium-based replacement battery with much greater electrical storage capacity than a factory installed lead-acid of comparable physical size (so he could operate the powerful stereo like a mega-boom-box when the car's engine was not running). Audi later publicly chastised vehicle's owner for making unspecified "unauthorized modifications" to car

"Audi R8 up in Flames in Mumbai at Parx Supercar Rally 2013"

https://www.youtube.com/watch?v=pu2Gxxh4a-E

https://www.youtube.com/watch?v=9YuCJrSLuuA

http://www.youtube.com/watch?v=ZcurEOijIX0

Containing thermal runaways: a fool's paradise?

<u>June 2011</u>: a catastrophic lithium-manganese battery fire with a just-parked German-made MÜNCH GmbH Model TTE - 1.2 all-electric motorbike occurred during the TTXGP Silverstone race. According to the stories of eyewitnesses to the spectacular blaze, 16 fire extinguishers were unable to stop the conflagration. While this bike's battery pack was not terribly large as Lithium-based batteries go, it nonetheless produced an almost impossible-to-extinguish fire. Luckily, a rider was not sitting on the motorbike when the incident occurred.

<u>Munch TTE motorcycle specifications</u>:

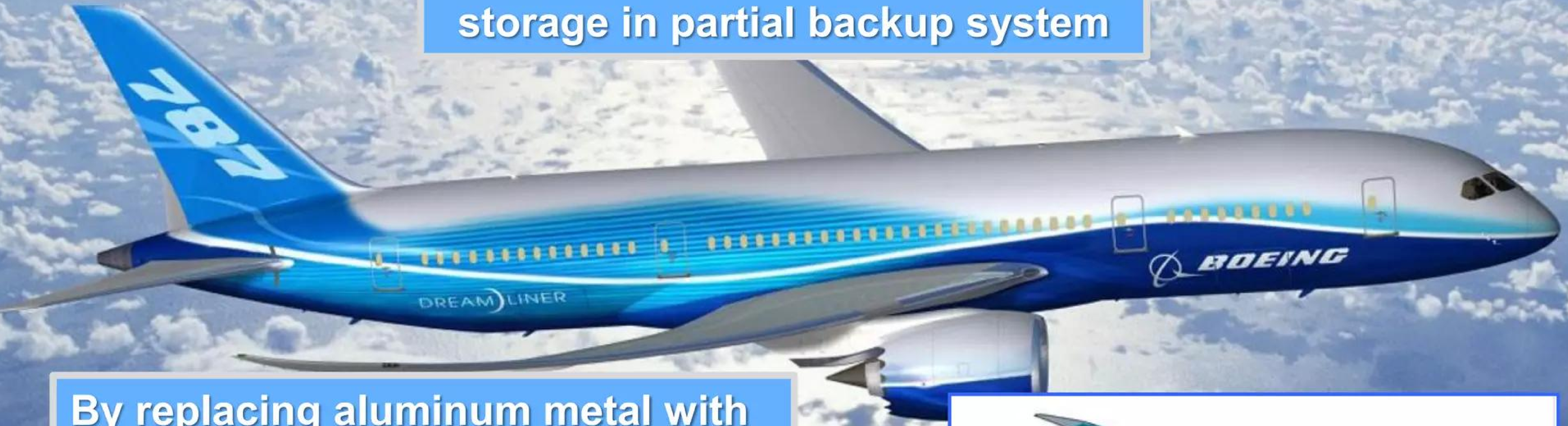
Engine:	Synchronous permanent magnet 3-phase motor
Output:	Max. 90 kW at 350 V/260 A
Maximum speed:	12000 RPM
Torque:	90 Nm at 8,500 RPM
Traction battery:	Lithium manganese Nominal 350 V DC circuit Charging time: 4 hours, number of cells: 1680 Output: Max. 400 V/400 A
Vehicle weight:	TTE 1.1: 220 kg – TTE 1.2: 204 kg
Seat height:	770 mm
Speed:	Over 240 km/h depending on configuration
Range:	Up to approximately 200 km depending on configuration (14 kWh)

As of 2013, most recent versions of MÜNCH all-electric motorbikes apparently switched to lithium-polymer battery chemistry from previous lithium-manganese

Containing thermal runaways: a fool's paradise?

Thermal runaways on advanced passenger aircraft

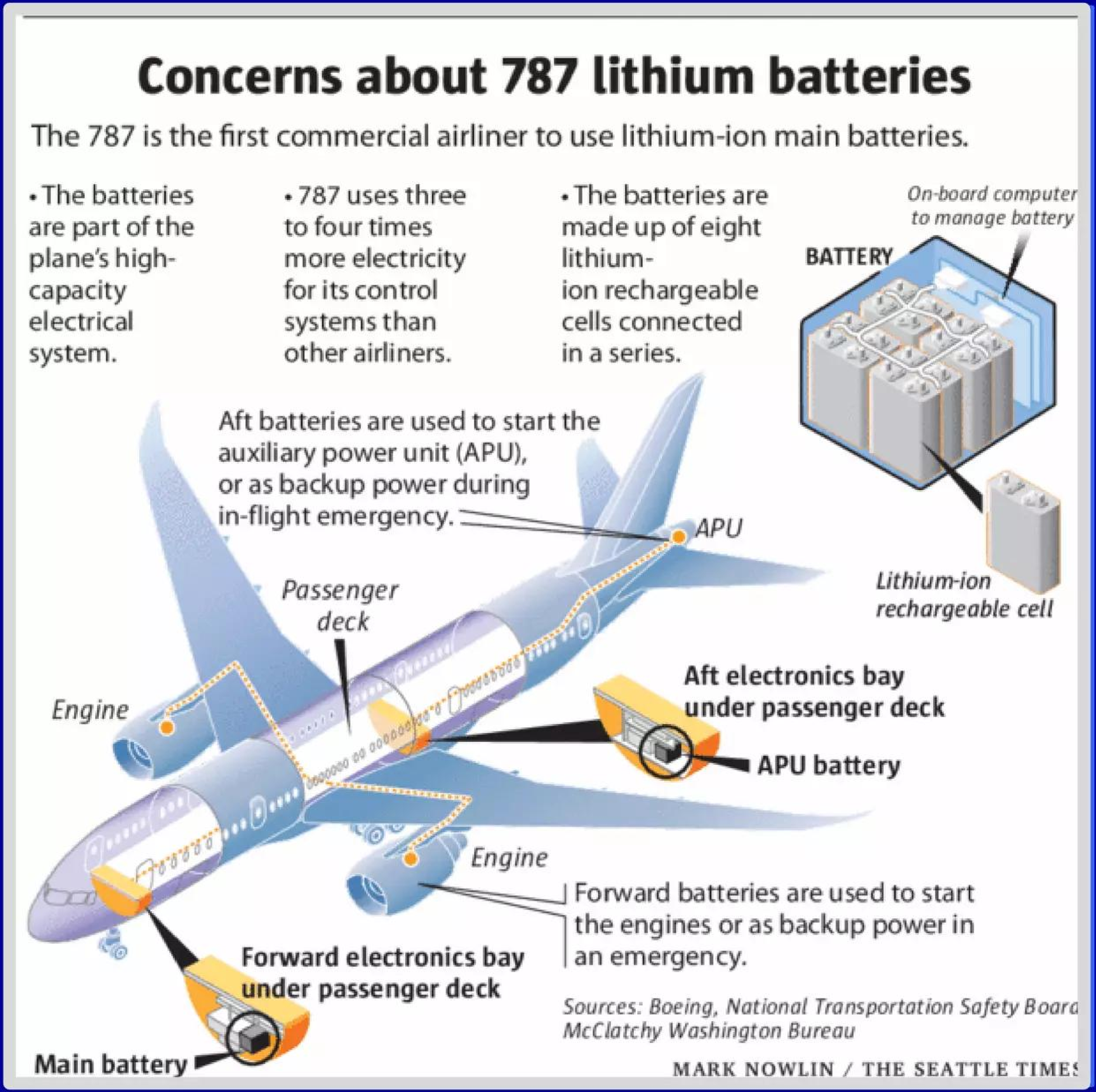
Dreamliner's total electrical power network is ~1.5 megawatts; chose lithium-ion batteries for onboard storage in partial backup system



By replacing aluminum metal with carbon-based composite materials, Boeing achieved a very significant reduction in aircraft's total weight

By replacing hydraulics and other systems with electric-powered equivalents, Boeing further reduced plane's weight

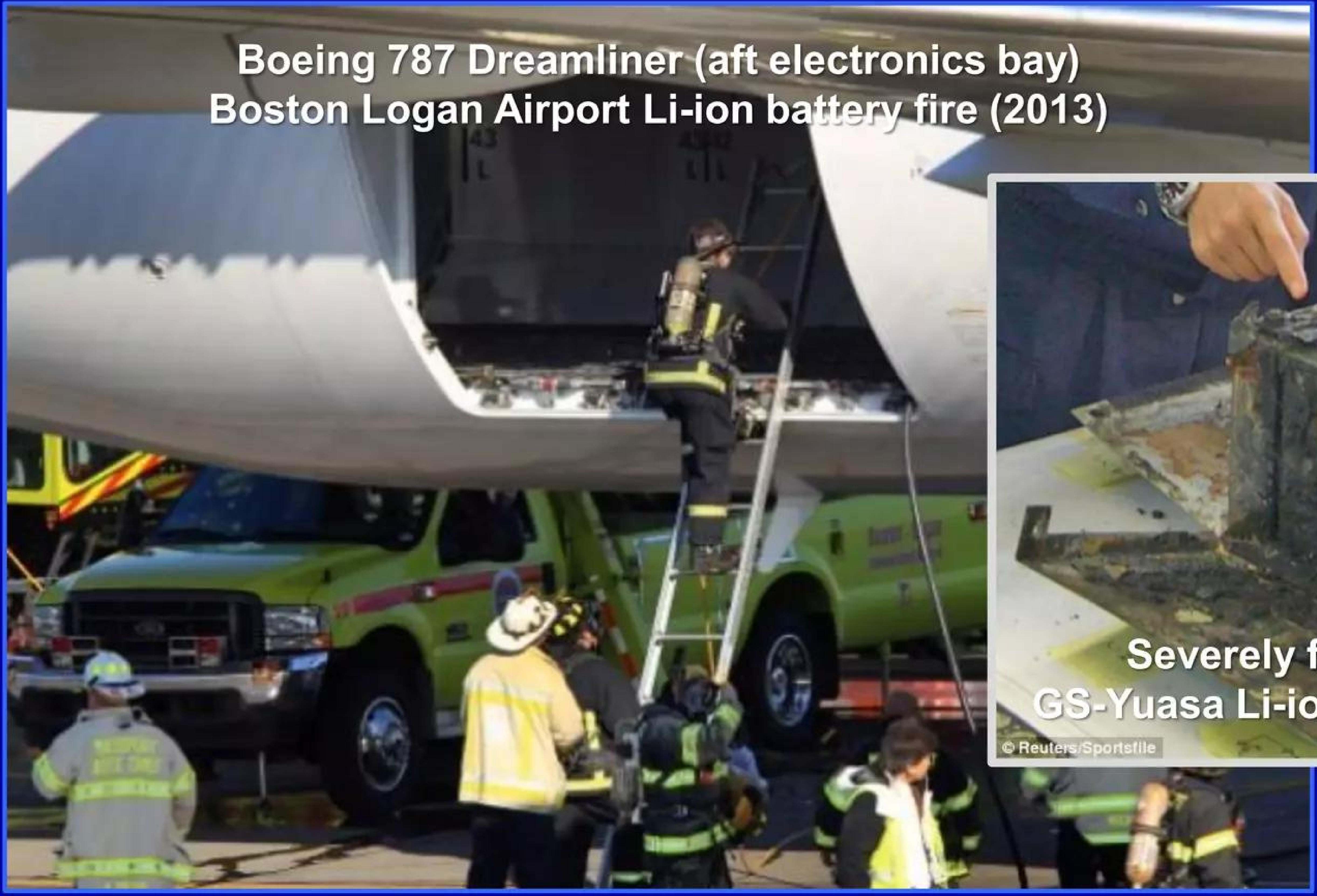
Containing thermal runaways: a fool's paradise?



Containing thermal runaways: a fool's paradise?

Thermal runaways on advanced passenger aircraft

Since it began flying passengers on Oct. 26, 2011, brand-new Boeing 787 Dreamliners have experienced two thermal runaway incidents involving GS-Yuasa lithium-ion system backup batteries: first with JAL while on the ground in Boston and second with ANA on a domestic flight in Japan



Containing thermal runaways: a fool's paradise?

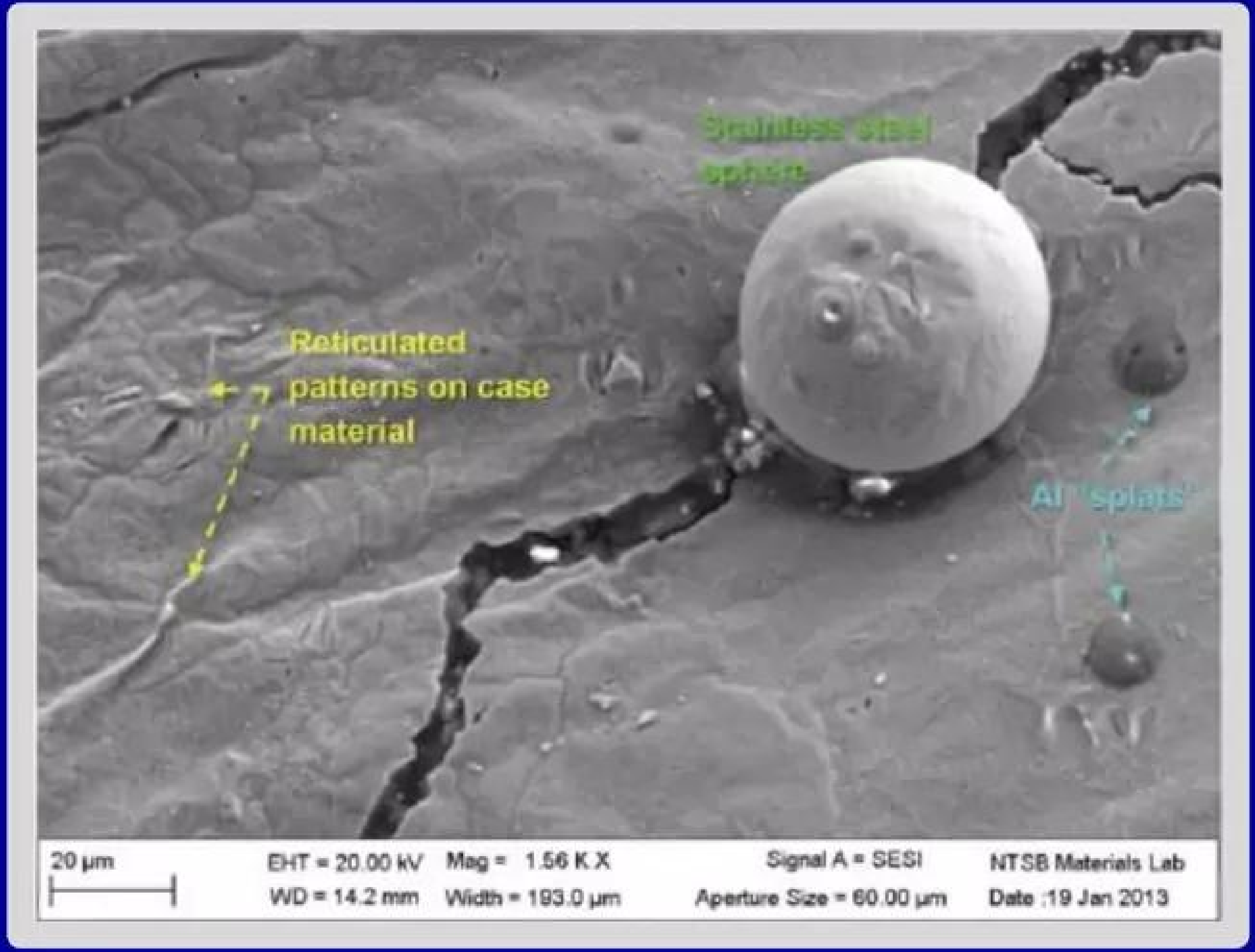
Thermal runaways on advanced passenger aircraft

NTSB investigated Dreamliner GS-Yuasa battery runaway at Logan

NTSB report indicated very high local temperatures

Data suggests that temperatures above 3,000° Centigrade likely occurred at local hotspots created by electric arc shorts that erupted inside certain GS Yuasa battery cells during Boeing Dreamliner thermal runaway incident at Boston Logan airport

NTSB Report No. 13-013



Lattice contends that the presence of perfect stainless steel microspheres in battery debris implies that local temperatures were > 3,000° C

NTSB Report No. 13-013

Such stainless steel microspheres are created by condensation of droplets from a vapor phase; similarities to laser ablation

Containing thermal runaways: a fool's paradise?

Thermal runaways on advanced passenger aircraft

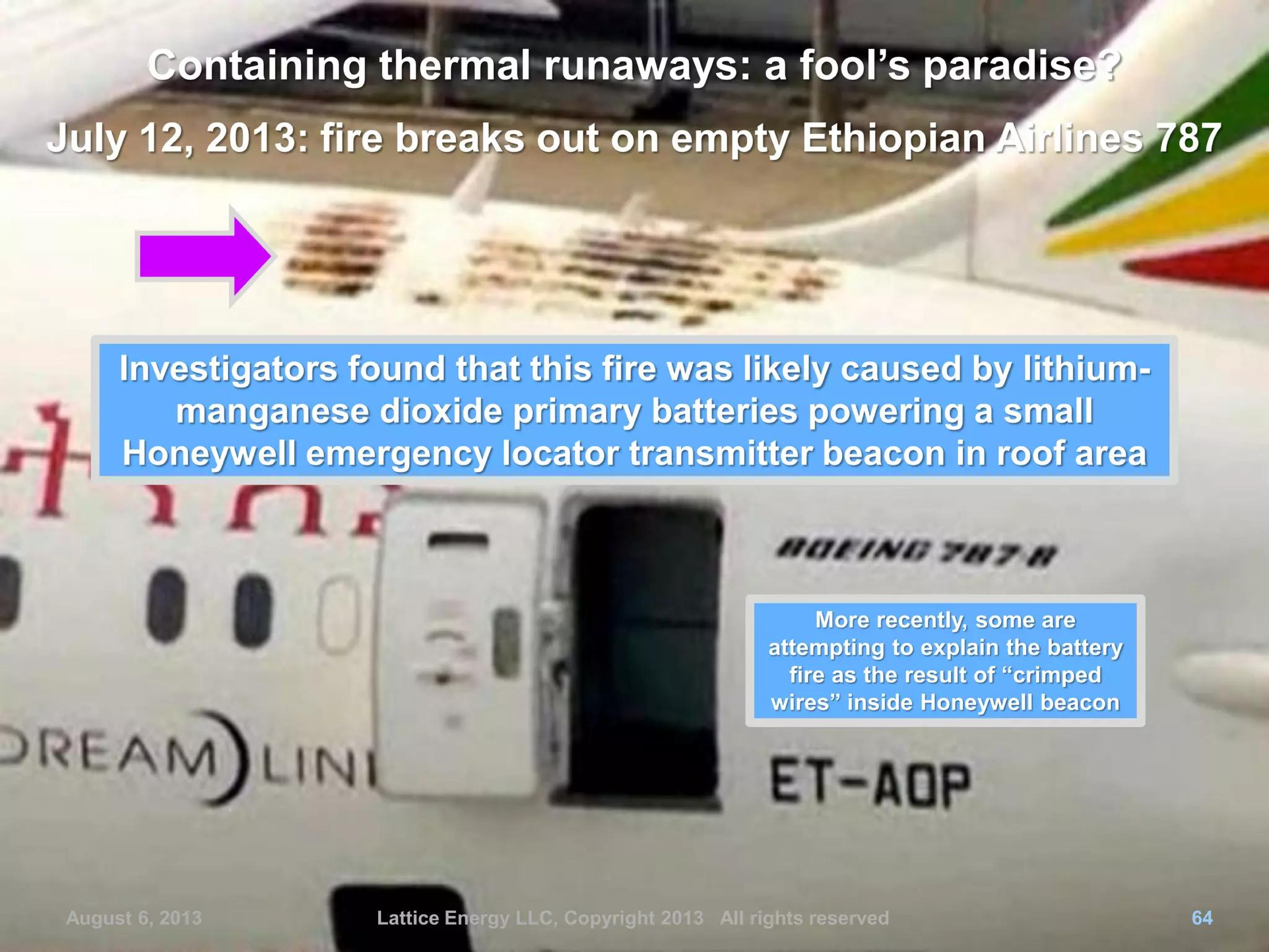
NTSB investigated Dreamliner GS-Yuasa battery runaway at Logan

- When NTSB scientists investigated charred debris found inside the ruined Logan GS Yuasa battery cells with a scanning electron microscope (SEM), near locations where electric arcs (internal short circuits) had obviously occurred they discovered notable numbers of perfect (microscopic) stainless steel microspheres lying amongst the disorganized rubble of various burned battery materials
- What Lattice realized that many other scientists following NTSB's investigation did not notice was that these beautiful little metallic microspheres are smoking gun evidence for vaporization and condensation of stainless steel comprising the battery cell casing in local hotspots created by high-current, low voltage electric arcs, i.e., one or more internal shorts likely occurred inside GS Yuasa battery cell #5

This experimental data implies that the local temperature of the battery casing's Type 304 stainless steel hotspots directly exposed to the internal short's arc plasma didn't just get to the melting point of such steel (~1,482 degrees C) --- instead these local areas got all the way up to the boiling point of stainless (> 3,000 degrees Centigrade), were turned into a gaseous vapor (expanding in volume by >50,000 x in the process of vaporizing); solid steel then recondensed from hot metallic vapor in the form of perfect nanoscale steel spheres as portions of the super-hot metallic Fe-alloy vapor quench-cooled into nanoparticles seen in SEM images shown on the previous slide

Containing thermal runaways: a fool's paradise?

July 12, 2013: fire breaks out on empty Ethiopian Airlines 787



Investigators found that this fire was likely caused by lithium-manganese dioxide primary batteries powering a small Honeywell emergency locator transmitter beacon in roof area

More recently, some are attempting to explain the battery fire as the result of "crimped wires" inside Honeywell beacon

Containing thermal runaways: a fool’s paradise?

Thermal runaways in battery shipments on cargo aircraft

Final report was issued concerning Dubai accident in 2010

BRIAN MURPHY July 24, 2013
DUBAI, United Arab Emirates (AP) — A fast-moving fire that began in cargo containing lithium batteries turned the inside of a United Parcel Service plane into a "catastrophic" chain reaction of flames and smoke before a crash three years ago in the desert outside Dubai, according to a report released Wednesday. The 322-page investigation into the crash, which killed both pilots, backed up preliminary probes pointing to the lithium batteries as the possible cause of the blaze and drew further attention to the potential risks of the batteries in aviation”

Quoting from safety recommendation 4.33 SR 57/2013 listed in this report: "Given the active failure modes of lithium batteries, the battery risk factors concerning possible susceptibility to various extraneous forms of mechanical energy, for example vibration, possibly in a harmonic form, could be an initiating action risk."


GCAA

AAIS Case Reference: 13/2010

AIR ACCIDENT INVESTIGATION SECTOR

FINAL

AIR ACCIDENT INVESTIGATION REPORT

Uncontained Cargo Fire Leading to Loss of Control Inflight and Uncontrolled Descent Into Terrain

Boeing 747-44AF
N571UP
Dubai
United Arab Emirates
03 September 2010

General Civil Aviation Authority
of the
United Arab Emirates

Containing thermal runaways: a fool's paradise?

Anomalous electrical issues on passenger aircraft

July 22, 2013 - Qatar Airways confirms grounding of a 787 due to unspecified " … problems with an electrical panel"

Since then – as of this writing, little or no detailed technical information has been publicly released by Boeing or Qatar Airways, other than to state that the "replacement parts" arrived, were successfully installed and tested, and that the "minor technical problem" has been solved

Exactly what happened here? Today, no one seems eager to inform

Credit: AFP/FILE)

Containing thermal runaways: a fool's paradise?

Thermal runaways:

worst-of-the-worst

Containing thermal runaways: a fool's paradise?

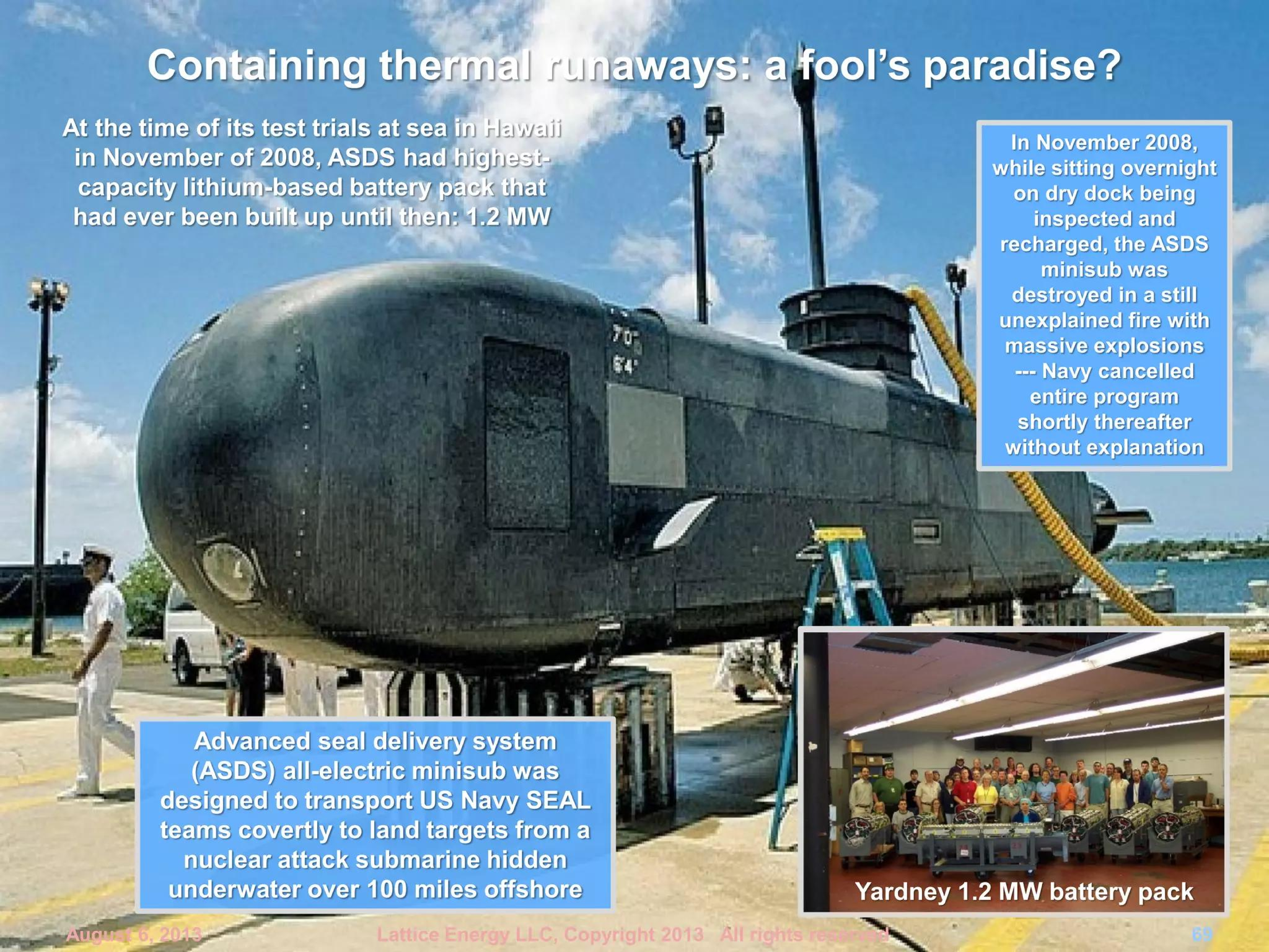
Battery capacity scale-up can increase safety risks

Incidents involved scale-up of battery array capacities to megawatts

The bigger they are
the harder they fall

Take-aways: amazingly, even advanced lead-acid battery chemistries are not completely immune to thermal runaways; and considering the very limited numbers of installations, extremely large battery scale-ups appear to have a very poor safety record

Containing thermal runaways: a fool's paradise?



At the time of its test trials at sea in Hawaii in November of 2008, ASDS had highest-capacity lithium-based battery pack that had ever been built up until then: 1.2 MW

In November 2008, while sitting overnight on dry dock being inspected and recharged, the ASDS minisub was destroyed in a still unexplained fire with massive explosions --- Navy cancelled entire program shortly thereafter without explanation

Advanced seal delivery system (ASDS) all-electric minisub was designed to transport US Navy SEAL teams covertly to land targets from a nuclear attack submarine hidden underwater over 100 miles offshore

Yardney 1.2 MW battery pack

Containing thermal runaways: a fool's paradise?

Plant's smoldering ruins the next day

Pile of used lithium-ion batteries

November 2009: largest North American lithium-ion battery recycling plant, operated by Toxco Waste Management and located near Vancouver, BC, Canada, had a still-unexplained series of large explosions and fire in an underground area of the plant where hundreds of thousands of used Li-ion batteries waiting-to-be-recycled were stored. In the end, the conflagration apparently destroyed roughly half the plant; no formal incident investigation report has ever been released by anyone.

http://www.youtube.com/watch?feature=player_embedded&v=dfQwYKqmfk4

http://green.autoblog.com/2009/11/09/lithium-battery-recycling-facility-suffers-explosions-fire/

Containing thermal runaways: a fool's paradise?

Toxco lithium-ion battery recycling plant incident

Storage of spent batteries at extremely low temperatures didn't help

Summary:

In Toxco's Canadian plant, spent discarded batteries awaiting recycling were stored in isolated underground bunkers at roughly 324 degrees below zero (below liquid nitrogen temperatures) in the hope of avoiding potential problems with latent electrochemical activity known to be present in old spent batteries. Nonetheless, ultra-cold storage temperatures did not prevent the incident: many pallets stacked high with used Li-ion batteries somehow spontaneously caught fire and exploded anyway. Unfortunately, while *chemical activity* may be negligible at such temperatures, *electromagnetic activity* is mostly unaffected

Speculation: the fatal flaw in Toxco's risk management logic was an implicit assumption that cold temperatures *per se* would assuredly help substantially reduce the likelihood of serious battery failures and fires inside their densely packed underground storage facility. They apparently blithely assumed that they were only dealing with temperature-dependent, purely chemical risk factors in Li-ion batteries. Unfortunately, given the possibility of internal, spontaneous, vibration-spark-triggered LENRs (of which they were totally unaware) such an assumption can be very problematic

Containing thermal runaways: a fool's paradise?

Toxco lithium-ion battery recycling plant incident

Storage of spent batteries at extremely low temperatures didn't help

Discussion:

When hundreds of thousands of Li-ion cells are densely packaged and stored on pallets in close physical proximity to each other, even if the incidence of field-failure events is only 1 per 5,000,000 cells (the best available estimate so far), the odds of an incident occurring are likely to be worse than one might initially imagine. This problem of heightened risk becomes apparent when one realizes that the probability of failure due to LENRs and/or internal field-failure electrical shorts is probably substantially higher in old used spent batteries. This is the case because internal dendrites and other types of troublesome nanostructures have been gradually growing inside all scrapped batteries as they passed through many charge/discharge cycles and gradually aged over their useful lifetimes prior to being discarded

Thus, even so-called spent lithium batteries can still be quite hazardous: (1) used batteries awaiting recycling still hold a significant levels of electric charge on some nanostructures located inside scrap batteries; (2) no matter how cold it may be, a random stray vibration of one sort or another can potentially wiggle or move a minuscule metallic lithium nano-dendrite or surface nanoparticle through just enough distance to where it can short-out and arc to another nearby battery microstructure. If the location of such an internal micro-electric arc short is unlucky, that is, if it just happens to be in a location within a battery cell where metals, oxides, and protons (hydrogen atoms) are in close contact with each other and a plastic separator, the possibility of triggering a local, micron-scale LENR-active fireball of plasma at 4,000 - 6,000 degrees Kelvin and arc short field-failure is created

Containing thermal runaways: a fool's paradise?

Kahuku wind farm in Hawaii had ~12,000 *X*treme Power "advanced lead-acid" batteries that stored 15 MW of excess generated electricity for later sale

Roof is burning-through just above many of the facility's 20-foot high towering battery racks

July 31, 2012: its huge towering battery banks were completely destroyed in a still-unexplained, fiery conflagration shown to left

2013: this battery storage facility has still not been rebuilt. *X*treme Power suddenly decided to cease battery manufacturing and instead focus on developing and selling software for battery management

Interior of facility showing battery banks

Close-up: batteries in racks

Containing thermal runaways: a fool's paradise?

Mitigating runaway risks:

is containment possible?

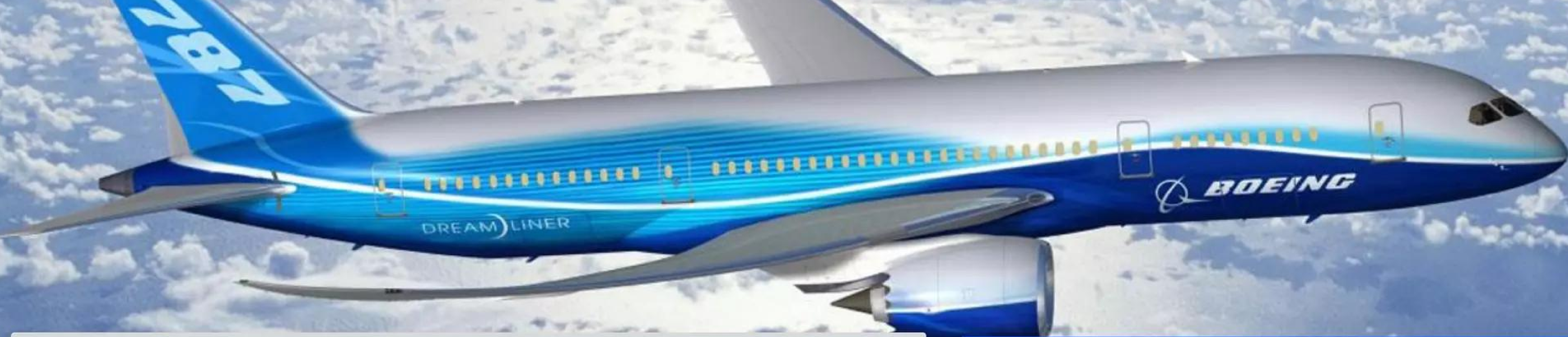
Containing thermal runaways: a fool's paradise?

New aircraft materials have different physical properties

Aluminum metal's melting point: 660^{o} C

Structural carbon composite's matrix auto-ignition point: 595^{o} C

Unlike carbon composites, under normal circumstances --- and even with extreme heating --- it is very difficult to get bulk aluminum metal to actually burn



July 12, 2013: Ethiopian Airlines Dreamliner incident at Heathrow Airport illustrated the level of severe damage that even a relatively small battery thermal runaway can inflict on composite aircraft structures

"Auto-ignition" point means the temperature at which a material will spontaneously catch fire, i.e., combust, when exposed to air

Containing thermal runaways: a fool's paradise?

Carbon-composite aircraft materials are thermally fragile

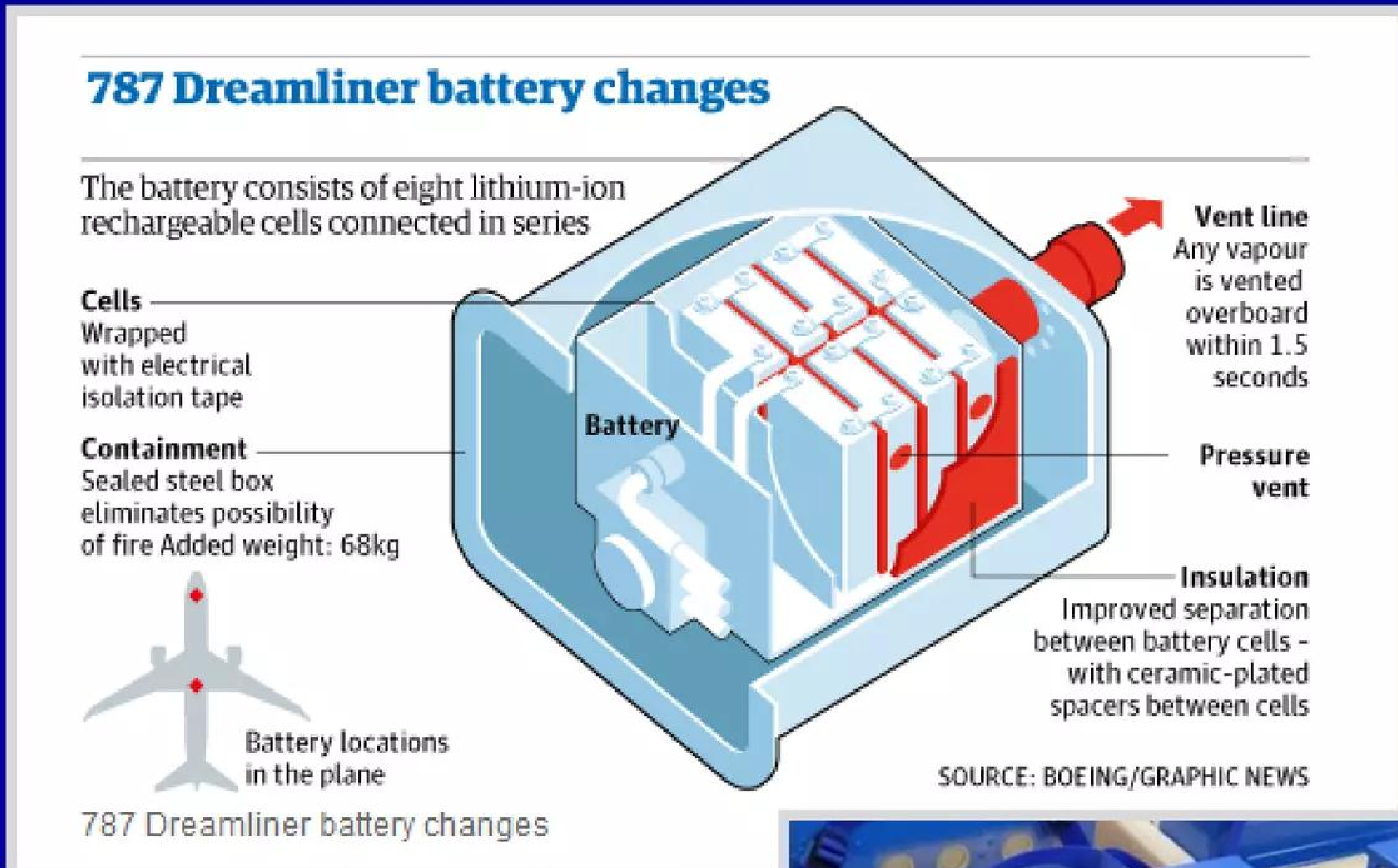
If battery thermal runaway occurs, must protect composites from heat

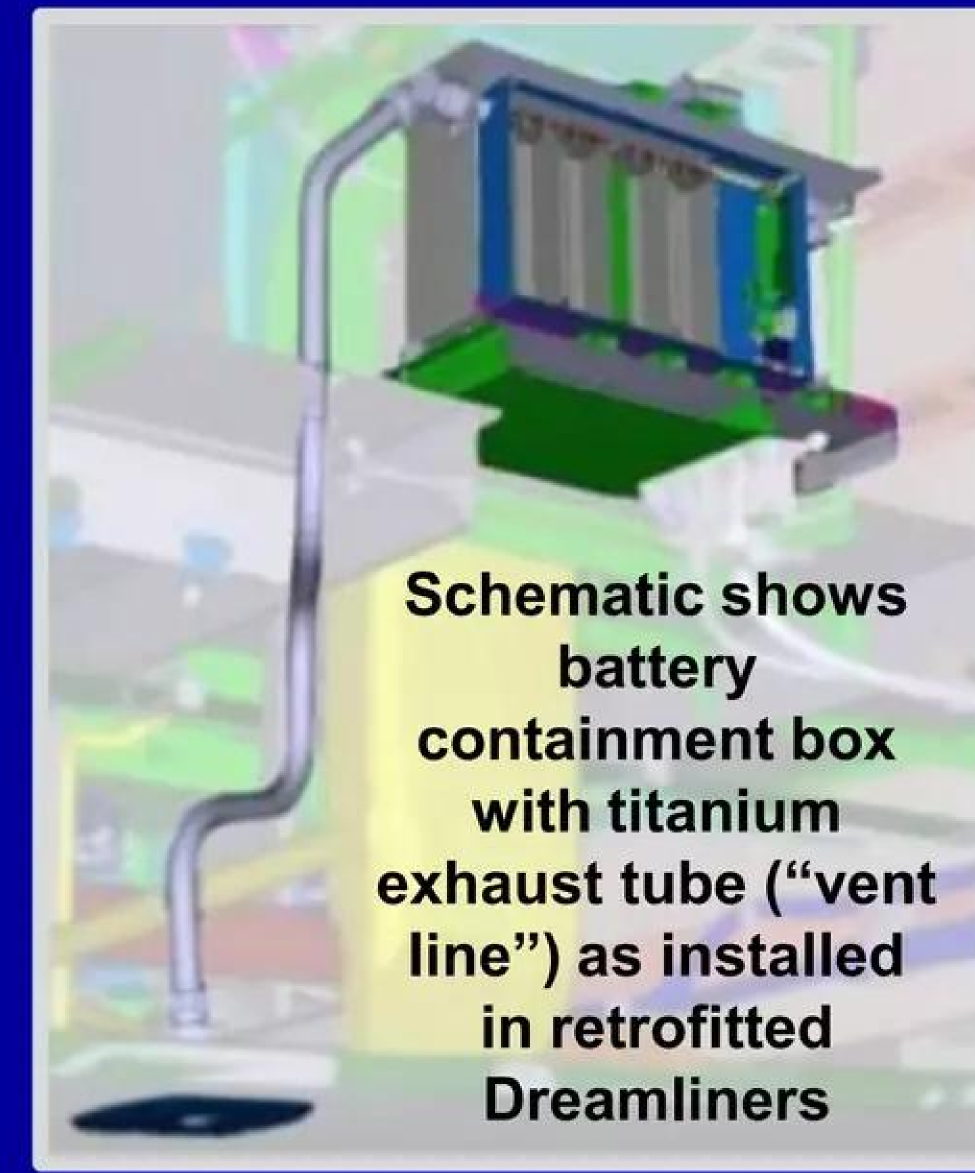
- Given their locations in critical fore and aft electronics bays, JAL and ANA thermal runaways --- had they been even worse than they were --- could potentially have created in-air catastrophes if fires had spread beyond the battery cases and then raged unchecked within those key compartments
- For whatever reasons, Boeing chose not to switch-back to older, less runaway-prone but lower energy-density nickel-cadmium batteries
- To protect thermally fragile aircraft structures and mitigate the risk of open fires and noxious combustion products spreading inside the plane, Boeing chose to design a total containment system for the 787's batteries

In designing the new system, engineers were faced with two key issues: (1) Boeing has stated publicly that it did and still does not know the root cause(s) for either the JAL or ANA runaway fire incidents; and, (2) were those truly worst-case scenarios that had occurred, or is there a possibility that much hotter and even more destructive runaways could occur with 787's GS-Yuasa batteries?

Containing thermal runaways: a fool's paradise?

New battery containment systems by Boeing and Cessna




Schematic shows battery containment box with titanium exhaust tube ("vent line") as installed in retrofitted Dreamliners


New battery case installed inside stainless steel containment box


Redesigned aluminum case for GS-Yuasa battery


Cessna Citation's armored steel battery box

Containing thermal runaways: a fool's paradise?

Discussion of Boeing 787 battery containment system

- How can someone properly design a system-solution to mitigate or fully obviate runaways if: (1) one doesn't understand root cause(s) of Li-ion runaways, and/or (2) it's unclear which worst-case runaway parameters a system must be able to accommodate without compromising safety?
- Answer: one must make reasonable assumptions based on best-practices knowledge and best-possible data that is available about prior incidents
- While Boeing has not publicly enumerated assumptions embodied in its design for 787's battery containment system, they are partly revealed in their choice of materials for that system: airtight, bolted-shut 1/8"- thick stainless steel containment vessel (m.p. = ~1,480° C) and solid titanium metal exhaust tube (m.p. = ~1,650° C) which looks to be ~2" in diameter

Given these particular choices of key materials and decision to create a sealed airtight box that aggressively exhausts hot gases and airborne particulates to the outside world after 1.5 seconds have elapsed into a runaway event, it appears that - and this is admittedly speculation on our part - Boeing engineers presumed that JAL and ANA incidents were representative worst-case runaway scenarios for GS-Yuasa's batteries

Containing thermal runaways: a fool's paradise?

Resistance is futile – it will be combusted

- Previously noted computer simulations of 100% combustion of all flammable electrolytes in Li-ion cell suggested max peak temps of ~1,850° C. Knowing that, if one assumed that worst-case GS-Yuasa runaway scenario was merely cells spewing hot electrolyte burning in air, one would try to deny oxygen to the blaze (airtight containment vessel) and simultaneously rapidly vent hot combustion gases --- where most of the heating and high temps would occur --- to the outside world (via exhaust tube from containment vessel); interestingly, Boeing's mitigation strategy and choice of materials appear to be consistent with just such assumptions
- Fine, but what happens if some of these key assumptions are violated? What if JAL/ANA incidents are not true worst-case runaway scenarios? In that case, Houston … we may have a problem

Interestingly, NTSB's investigation of JAL/Logan incident reported abundant evidence for combustion of significant amounts of electrolyte originally present in battery cells. While sustained temperatures across large regions of battery were clearly below 660° C m.p. of aluminum (otherwise, entire case would have melted), there was unequivocal evidence (perfect stainless steel microspheres) that peak temperatures in some local regions exceeded 3,000° C, especially near areas where electric arcing (internal shorts) had occurred

Containing thermal runaways: a fool's paradise?

Resistance is futile – it will be combusted

- What about Boeing's assumption (Sinnett stated to reporters, "… the box is not simply designed to contain a fire, it prevents one from starting.") that simply denying an external source of oxygen to the interior of a battery containment vessel will absolutely prevent any occurrence of fire during a runaway event? Unfortunately, this key assumption is clearly erroneous --- it is well-known that, under some conditions, worst-case battery runaway events can generate their own oxygen supply as a result of intense local heating of battery materials containing elemental oxygen
- True worst-case battery runaways (far nastier than JAL/ANA events) can potentially reduce large portions of battery contents to unrecognizable slag heaps radiating infrared heat at thousands of degrees. Such lava could potentially melt-though and breach aluminum and even stainless steel containers; only known metal that would be likely to survive a melt-through under such a scenario is pure tungsten m.p. ~3,422° C (presently costs ~$100/lb.)
- Under certain conditions, titanium can ignite at >1,650° C (or even lower at higher oxygen partial pressures); its flames burn at ~3,300° C. A more robust battery runaway mitigation system might utilize tungsten for its containment vessel and exhaust pipe, coupled with an <u>open</u> overhead blast shield/fume hood (as on a stove with an exhaust fan) so that large overpressures resulting from worst-case battery detonations do not easily create shrapnel

<u>Summary</u>: some very extreme types of thermal runaway events could potentially violate Boeing's present design assumptions. Are totally sealed, 100% airtight battery runaway containment systems feasible goals or is it a fool's paradise? Time and events will tell

Containing thermal runaways: a fool's paradise?

Useful knowledge for the

big batteries in one's life

Containing thermal runaways: a fool's paradise?

Be prepared:

forewarned …

is forearmed

Containing thermal runaways: a fool's paradise?

If you're riding in an all-electric car, and you see and/or smell smoke inside or see it trailing the vehicle

Hangzhou Halts All Electric Taxis as a Zotye Langyue (Multipla) EV Catches Fire

April 12th, 2011 | Posted in Electric Car | zotye

A Zotye Langyue/Multipla EV serving as a taxicab burst into flame Monday afternoon in Hangzhou, Zhejiang, prompting the city to halt all electric taxis on safety concerns.

Firefighters rushed to the scene in minutes but couldn't do much as the car quickly turned into a big fireball, and then ashes and an empty, back shell. No one was injured; the driver and two passengers in the vehicle got out in time.

Get to the side of the road and exit the troubled vehicle just as fast as you possibly can

This could prevent serious injury or even save your life

Containing thermal runaways: a fool's paradise?

If you happen to own an all-electric or even a hybrid motor vehicle

And you want to be prepared for a worst-case scenario

Consider fire-proofing your garage or car-port and add fire/smoke alarms that can also alert occupants inside the house

This could help prevent serious damage to your home

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News Home | Arts | Headlines | Pictures | Most read | News Board

Newly-built mansion burns down after owner's two-week old $100,000 electric car catches fire in the garage

By DAILY MAIL REPORTER

PUBLISHED: 11:30 EST, 11 May 2012 | UPDATED: 13:55 EST, 11 May 2012

Share | Tweet | +1 | Share — 15 View comments

A luxury electric car is claimed to be the source of a fire which engulfed the owner's new mansion causing hundreds of thousands dollars' worth of damage.

Jeremy Gutierrez had parked his brand new Fisker Karma car in his garage - on the ground floor of the property - just minutes before it allegedly set alight and caused the ensuing house fire in Sugar Land, Texas

Obama's Chevy Volt: Electric Car Charger Suspected in House Fire

Posted by FactReal on November 13, 2011

FIRE CAUSED $800,000 IN DAMAGE TO A NORTH CAROLINA HOME

Containing thermal runaways: a fool's paradise?

All energy-dense batteries
should be treated with the respect
due any device that contains
a great deal of stored energy.

Containing thermal runaways: a fool's paradise?

Lattice can help assess battery runaway risks

Working with Lattice

We are commercializing LENRs; also consult to advance LENR technology

1-312-861-0115   lewisglarsen@gmail.com

Larsen c.v.: http://www.slideshare.net/lewisglarsen/lewis-g-larsen-cv-june-2013

- **Lattice welcomes inquiries from large, established organizations that have an interest in seriously discussing the possibility of becoming a strategic capital and/or technology development partner in the near- or long-term time frames**
- **To augment working capital and promote further development of LENR technology, Lattice also selectively engages in some fee-based third-party consulting. This work covers various topics in the context of micron-scale, many-body collective quantum effects in condensed matter systems (including photosynthesis), field failures involved in Li-ion battery thermal runaways, nuclear waste remediation, and ultra-high-temperature superconductors, among others. Additional areas of expertise include long-term strategic implications of LENRs on high cap-ex investments in power generation and petroleum-related assets, as well as long-term price outlooks for precious metals and crude oil. We consult on any of these subjects as long as it does not involve disclosing proprietary engineering details applicable to Lattice's planned LENR power generation systems. Consulting is subservient to company's main goal: commercializing LENRs for applications in ultra-high energy density portable, mobile, and stationary power generation systems**

Additional reading for the technically inclined

Containing thermal runaways: a fool's paradise?

Relevant documents

Technical discussions about LENRs and batteries:

"NTSB reports indicate very high temperatures"
Implications of witches' brew cauldrons in superheated regions of cells

L. Larsen, Lattice Energy LLC, May 7, 2013 [51 slides]

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-technical-discussionntsb-logan-dreamliner-runaway-data-suggest-high-local-tempsmay-7-2013

"Steel microspheres in NTSB Dreamliner battery SEM images suggest high local temps"

L. Larsen, Lattice Energy LLC, April 30, 2013 [33 slides]

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-technical-discussionntsb-logan-dreamliner-runaway-data-suggest-high-local-tempsmay-7-2013

July 2010: Lattice began publicly warning that LENRs could trigger Li-ion battery runaways:

"Could LENRs be involved in some Li-ion battery fires? LENRs in advanced batteries"

L. Larsen, Lattice Energy LLC, July 16, 2010 [68 slides]

http://www.slideshare.net/lewisglarsen/cfakepathlattice-energy-llc-len-rs-in-liion-battery-firesjuly-16-2010

Containing thermal runaways: a fool's paradise?

Relevant documents

Peer-reviewed paper - overview of expanse of Widom-Larsen theory of LENRs:

"A primer for electro-weak induced low energy nuclear reactions"

Y.N. Srivastava, A. Widom, and L. Larsen

Pramana - Journal of Physics 75 pp. 617 - 637 October 2010

http://www.ias.ac.in/pramana/v75/p617/fulltext.pdf

Lattice document concerning LENR-based power generation systems vs. fission and fusion:

"Truly green nuclear energy exists – an overview for everybody: no deadly gammas … no energetic neutrons … and no radioactive waste"

L. Larsen, Lattice Energy LLC, updated and revised through June 23, 2013 [108 slides]

http://www.slideshare.net/lewisglarsen/powering-the-world-to-a-green-lenr-future-lattice-energy-llcapril-11-2013

Index to large collection of documents re LENR theory, experimental data, and the technology:

"Index to key concepts and documents" v. #11

L. Larsen, Lattice Energy LLC, May 28, 2013 [82 slides]

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-index-to-documents-re-widomlarsen-theory-of-lenrsmay-28-2013

Containing thermal runaways: a fool's paradise?

Key

take-aways

Containing thermal runaways: a fool's paradise?

Key take-aways

- Excellent functional fit between lithium-ion batteries' higher energy densities and increased power requirements of component-dense portable electronic devices of all kinds has driven enormous unit growth in global Li-ion battery markets that has continued unabated from the early 1990's right up until today
- Fantastic market success of lithium-based batteries and continual improvements in energy density have encouraged battery technologists very familiar with relatively small-scale applications to scale-up into very large arrays of lithium-based cells that can address much larger electrical energy storage requirements of applications involving stationary backup systems and mobile platforms that include hybrid and all-electric plug-in vehicles, as well as advanced aircraft such as the Boeing Dreamliner. Unfortunately, this has lead to unforeseen safety issues that were either simply not readily apparent to anyone or irrelevant in vastly smaller-scale system applications
- It appears that micron-scale LENRs might well be intimately involved with electric arcs, i.e., internal shorts, in helping to trigger some unknown % of battery field-failures and other types of battery-destroying, catastrophic thermal runaway events
- Boeing's 787 Dreamliner battery thermal runaway containment system appears to have some shortcomings in its design with respect to the level of worst-case event that it could comfortably handle; time will tell if Lattice's assessment is accurate

Containing thermal runaways: a fool's paradise?

Key take-aways

- MYTH: there is no such thing as a battery chemistry that is 100% immune to the risk of catastrophic field-failures and thermal runaways; only differ in relative probabilities
- For a variety of reasons involving various aspects of nanotechnology, advanced battery technologies and LENRs are presently converging and overlapping in device parameter space; in batteries, the two work at cross-purposes because *μ*-scale LENR hotspots are an enemy of properly functioning battery chemistries and possibly a causal factor that helps trigger an unknown % of thermal runaways
- For good reasons, many are excited about future prospects for lithium-air battery technology. That said, its development and eventual applications should be approached with proper circumspection from a system safety perspective. Thermal runaways can have drastic consequences and even multiple fatalities when they happen to occur in conjunction with substantially scaled-up system applications of advanced battery technologies on mobile platforms in which people share enclosed spaces with large numbers of batteries, whether part of onboard systems or cargo
- Speculating beyond Li-air, successful commercialization of LENRs could enable development of battery-like portable power sources that are deliberately designed to produce and endure very high thermal fluxes; future LENR-based products would be revolutionary and could have intrinsic energy densities that are at least one million times larger than any possible chemical battery technology