

# The Role and Value of Energy Storage in Enhancing Safety

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# Introduction



Lloyd's Register  
Foundation

This research is part of a Lloyd's Register Foundation funded project to develop the content for a Foresight Review on Energy Storage.

“to enhance safety of life and property on land, sea and air”

## ***Talk outline:***

- Seven forms of storage
- Why do we need energy storage?
- How can energy storage **enhance safety**?
- What **hazards** can energy storage introduce?
- How do we **mitigate** these hazards?
- Conclusions



Chemical/biochemical



Gravitational potential



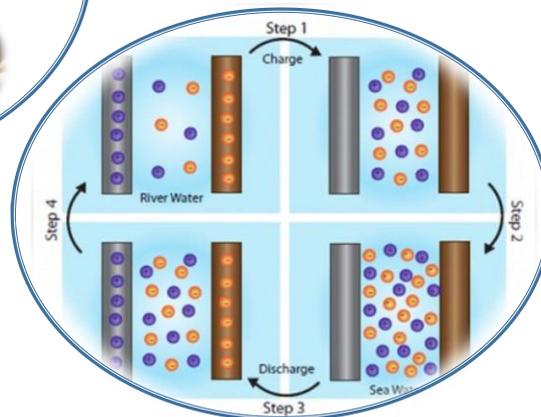
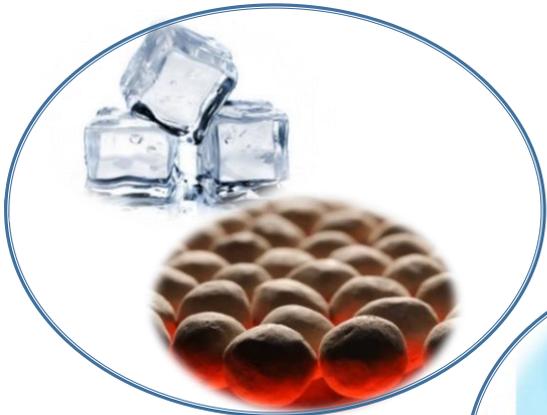
Kinetic/mechanical



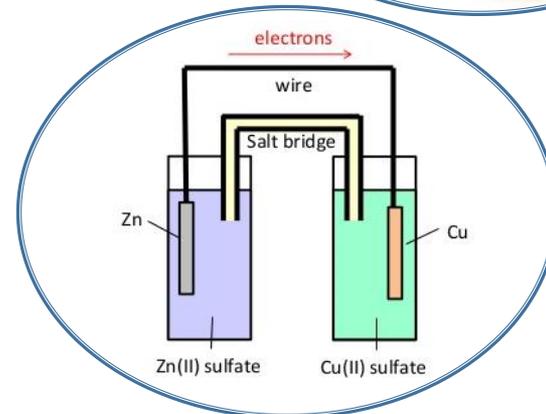
Electromagnetic



# Seven forms of Storage



Osmotic potential



Electrochemical

Thermal



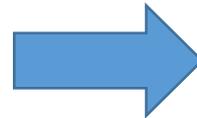
# Why do we need energy storage?

## Current grid

### Sources:

- Coal
- Natural gas
- Syngas
- Hydropower
- Geothermal
- Nuclear

flexible



## Low carbon grid

### Sources:

- Solar
- Wind
- Marine
- Hydropower
- Geothermal
- Nuclear

+ storage

inflexible

Energy storage restores *flexibility* to low carbon systems

# Energy storage: a key enabler

*Modern life and its safety benefits, would be impossible without energy.*

- Energy storage does not stand alone: **part of a system**
- Energy systems are integral to safety:
  - Communications
  - Critical infrastructures
  - Lighting
- Benefits:
  - Facilitates clean, flexible technology
  - Provides multiple services
  - Capable of rapid response
  - Time shifting: decoupling supply from demand
  - Enhances security of supply
  - Reduces dependence on fossil fuels
  - Mobility
  - Empowers consumers

*Energy storage has captured the public imagination:  
a unique opportunity for engagement!*



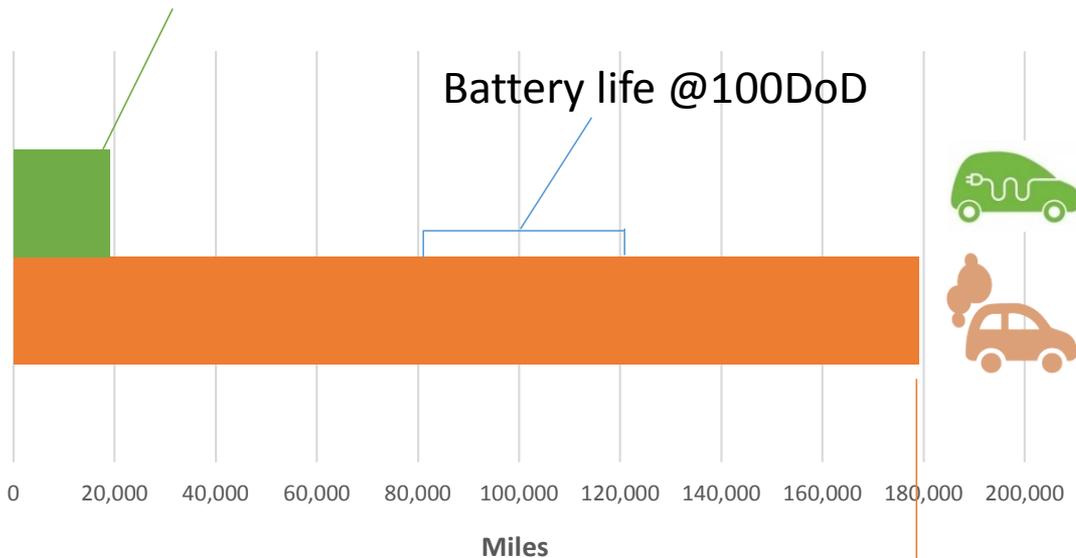
# Facilitating a cleaner world

- Energy storage facilitates decarbonisation
- Reduced dependence on fossil fuels
  - Oil spills
- Replaces diesel generators
  - Improves air quality
  - Reduces noise pollution
- Enables clean transportation



# Cleaning up Transport

Payback emissions point ~19,000 mi



Average life of petrol car

The Nissan Leaf and BMW i3 can now be charged for less than half the CO<sub>2</sub> of even the cleanest non-plug-in EV, the Toyota Prius Hybrid.



# Safer Transport

World Health Organisation: In 2015, 1.25 million people died from road traffic accidents globally. Up to 50 million people non-fatal injuries annually.

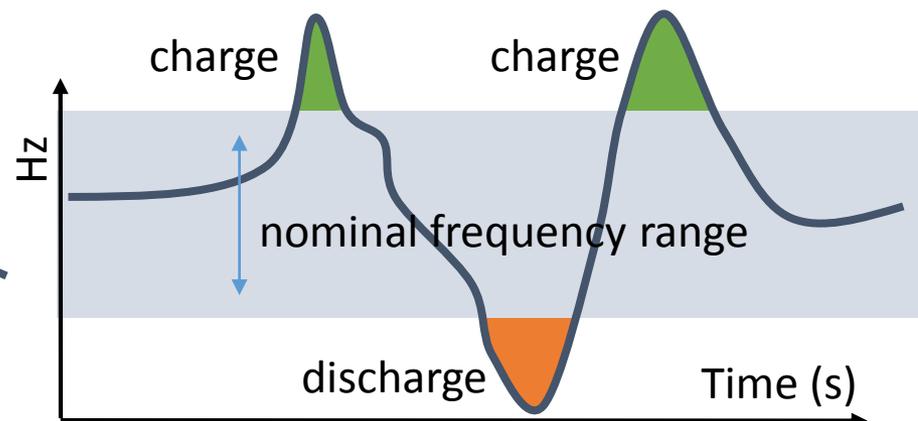
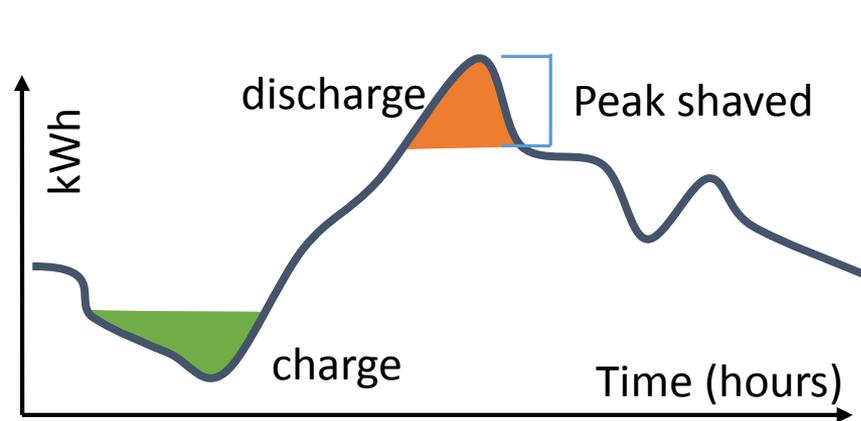
- New energy storage enables safer technologies:
  - Human error -> autonomous vehicles.
  - Dangers of onboard petrol tank.
- Electric cars:
  - Lower centre of gravity: less likely to roll.
  - Much longer crumple zone.
- Tesla Model S:
  - Lowest likelihood of injury to occupants, even in high speed collisions.
  - Li-ion battery did not ignite at any time. In fact, no incidents in Model S or Roadster yet.
  - 5-star safety rating: overall and in *every* subcategory (rare achievement).
  - Independent testing by the National Highway Traffic Safety Administration (NHTSA).

<https://cleantechnica.com/2013/08/20/tesla-releases-more-info-on-tesla-model-s-5-star-safety-rating-new-safety-records/>



# More Reliable Grids

- Makes renewables smooth and dispatchable
- Rapid response (milliseconds) to events enhances security of supply
- Load shifting:
  - Peak shaving – energy store supplies power during peak demand
  - Load levelling – charges up when supply too high
  - Decouples demand from supply
- Voltage control: improves power **quality** (variability  $V \rightarrow$  damage)
- Enhanced frequency regulation: grid **resilience** when changes occur
- Black-start support



# Multiple Safety Benefits

- Supports critical infrastructure/services during natural disasters
- Off-grid access to power
- Mobility
  - Portable devices (connectivity)
  - Transport
- Heat/cold storage – efficient & matches energy required
  - Air conditioning in a warming world
  - Warmth in winter
  - Safer food and medicine delivery – less waste
- Reduced dependence on fossil fuels
  - Oil wealth concentrated in few countries
  - Renewables available to everyone
  - Expensive, scarce, risk of fuel theft



# Risks & Hazards

## Technology level:

- Large energy reservoirs (electricity, heat/cold, water, etc.)
- Chemicals may be: flammable, corrosive, toxic, explosive...
- Environmental damage over full lifecycle
- Difficult to transport batteries safely

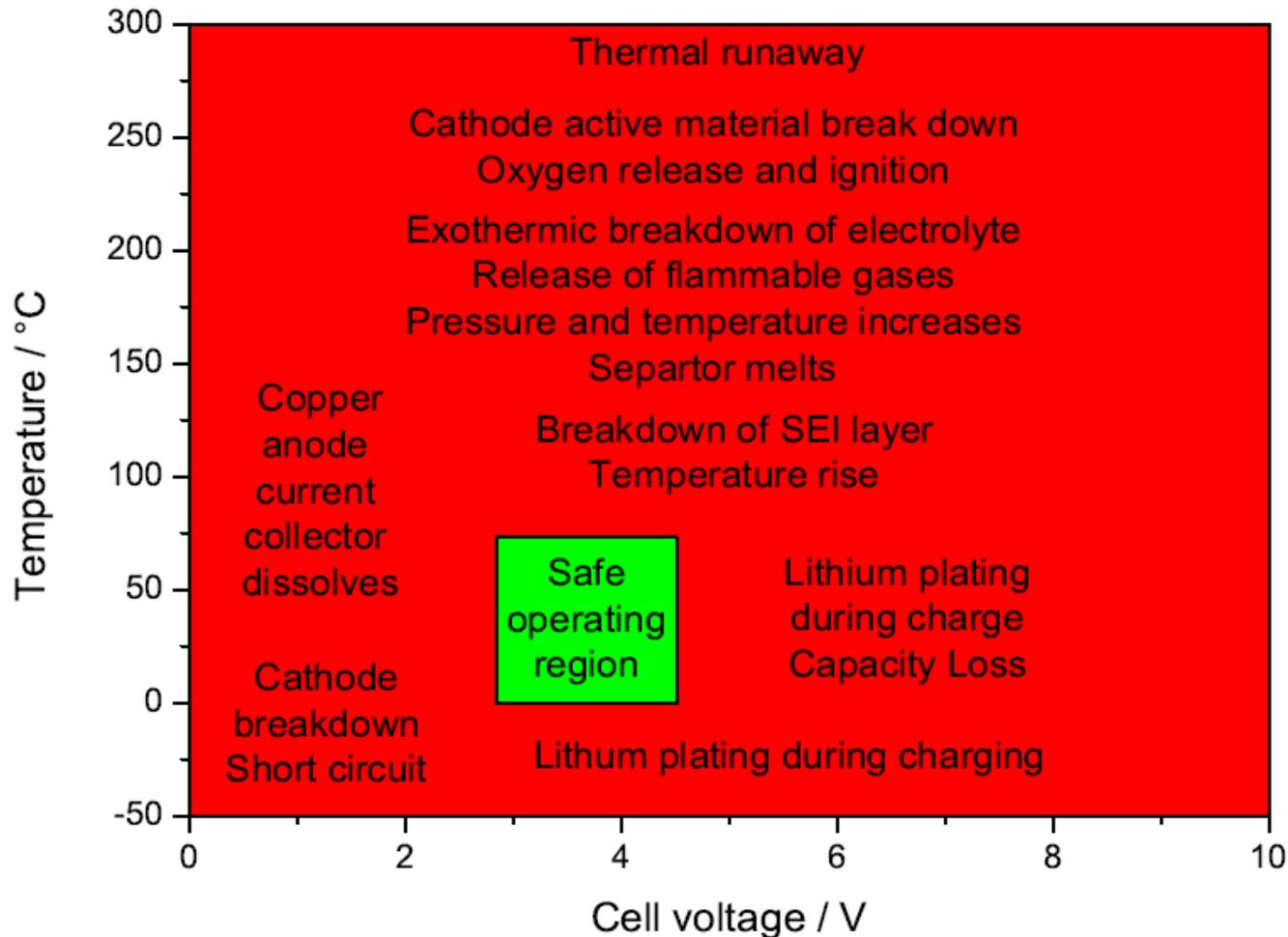
## System Level:

- Increased system complexity - hybridisation
- First and second responders
- Supply chain integrity: scarce resources
- Second life usage



# Battery Safety

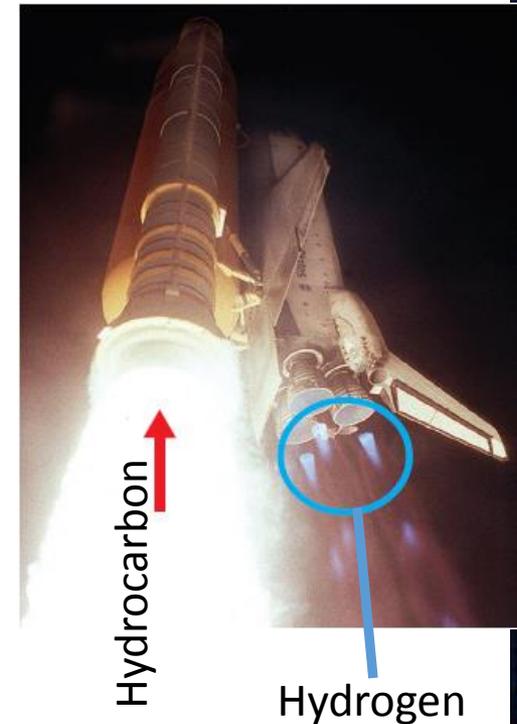
Li-ion has many, poorly understood failure mechanisms.



# The Trouble with Hydrogen

GOOD	BAD
Non-toxic	Colourless, odourless, tasteless
Non-corrosive	Can embrittle some metals
Lighter than air - disperses	Prone to leak

- 40+ years of experience using hydrogen in industry
- 19<sup>th</sup> century – “coal gas” contained 50 % H<sub>2</sub>
- Engineered safety:
  - Good ventilation
  - Detection sensors



PROPERTY	HYDROGEN	NATURAL GAS	PETROL VAPOUR
Auto-ignition temperature	585 °C	540 °C	232 °C
Flammability range in air	4-75 %	5-15 %	1.4-7.6 %
Explosion range in air	18-59 %	5.7-14 %	1.1-3.3 %
Minimum ignition energy	0.02 mJ (29%)	0.29 mJ	0.24 mJ
Radiant heat	low	high	high



# Mitigation: preventative

- Upfront safety & recyclability design
  - Research & choose safer chemistries
  - Incorporate green chemistry principles
  - Design for recycling
- Safety engineering
  - Sensors & control mechanisms
  - Power electronics
  - Robust packaging
  - Better diagnostics needed (state of health and state of charge)
  - Independent manufacturing quality assessment
- Choosing the right location
- Consequences of failure: public may reject technology



# Mitigation: curative

- Regulations to control second life and end of life
  - Leasing systems, making the manufacturer responsible
  - Full disclosure of state of health
- Crisis planning
  - Training for first and second responders
  - Set priorities for attention
- Operational safety
  - Training for installers, maintainers, inspectors
  - Standards, codes and best practise
  - Regular inspections



# Conclusions

- Energy Storage can both enhance safety and add new hazards.
- Good design and operational standards can mitigate these.
- Research and implement mitigations, before the industry grows:
  - Choose safer technologies from the start.
  - Green chemistry principles.
  - Upfront safety design.
  - Apply effective safety engineering.
  - Develop and enforce standards and codes of practice.



# Thank you!



Prof. Nigel Brandon  
Prof. Goran Strbac



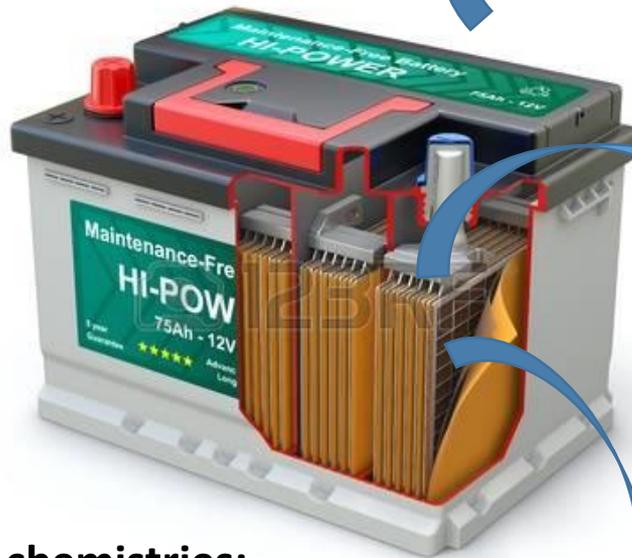
# Safer design

## Better packaging:

- Self-sealing to keep oxygen out
- Prevent structural damage
- Easy to dismantle for recycling
- Safety vents to avoid pressure build up

## Built-in protection:

- Flame retardants to prevent fire/explosion
- Waste heat recovery for thermal power



## Power electronics:

- Monitor cell age and temperature
- Cut off current to faulty cells

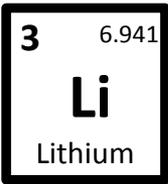
## Safer, less reactive chemistries:

- Sodium batteries
- Li-S batteries safer
- Aqueous batteries

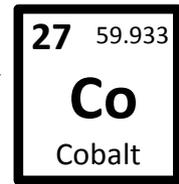
## Safer structure:

- Large numbers of low power cells
- Improved separations to avoid short circuits
- Built-in sensors to detect chemical/gas leaks



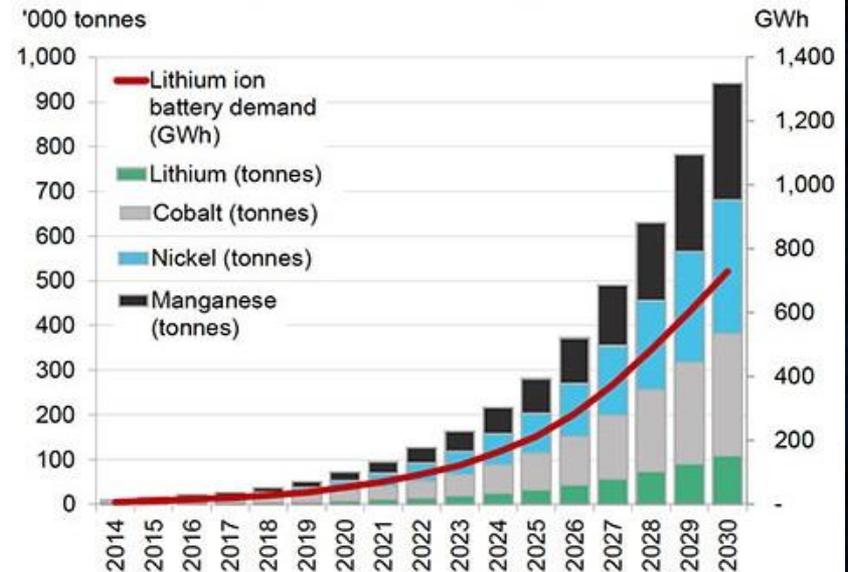


# Sustainability: Resource availability



- Material supply:
  - securely available?
  - environmental impact
  - cost to mine & refine
  - time to develop new mine
- Li: EU study predicts reserves (>30m tons) could be exhausted by 2050.
- Nissan Leaf: ~4 kg Li.
- Cobalt:
  - mining danger and ethics.
  - price increased by 140% in 2017.
  - 55% from Democratic Republic of Congo.

Global lithium-ion and materials demand forecast from EV sales, 2015–2030 (thousands of tonnes, GWh)



Source: Bloomberg New Energy Finance





<http://esrn.co.uk>

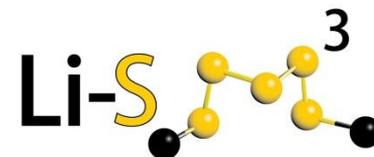
- Networking arm of the Energy Superstore
- **Free** membership, connecting:
  - Students
  - Academic & industry researchers
  - Government
  - Interested laypeople
- Website: news, events, funding and job opportunities
- Social media (LinkedIn and Twitter)
- Email announcements
- Events

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Lithium Sulfur Batteries: Mechanisms, Modelling and Materials



# What do we mean by safety?



- Lloyd's Register Foundation:
  - “safety of life and property on land, sea and air”
- Environmental protection and sustainability
- Energy systems are integral to safety:
  - Data management
  - Communications
  - Critical infrastructures
  - Lighting
- How safe is safe?
- Many incumbent technologies are not “safe”
- Public perception issues
- Humans struggle to fairly assess risk
  - Cognitive dissonance
  - Depends on extreme nature rather than statistics
- New technology: no long term studies or stats

