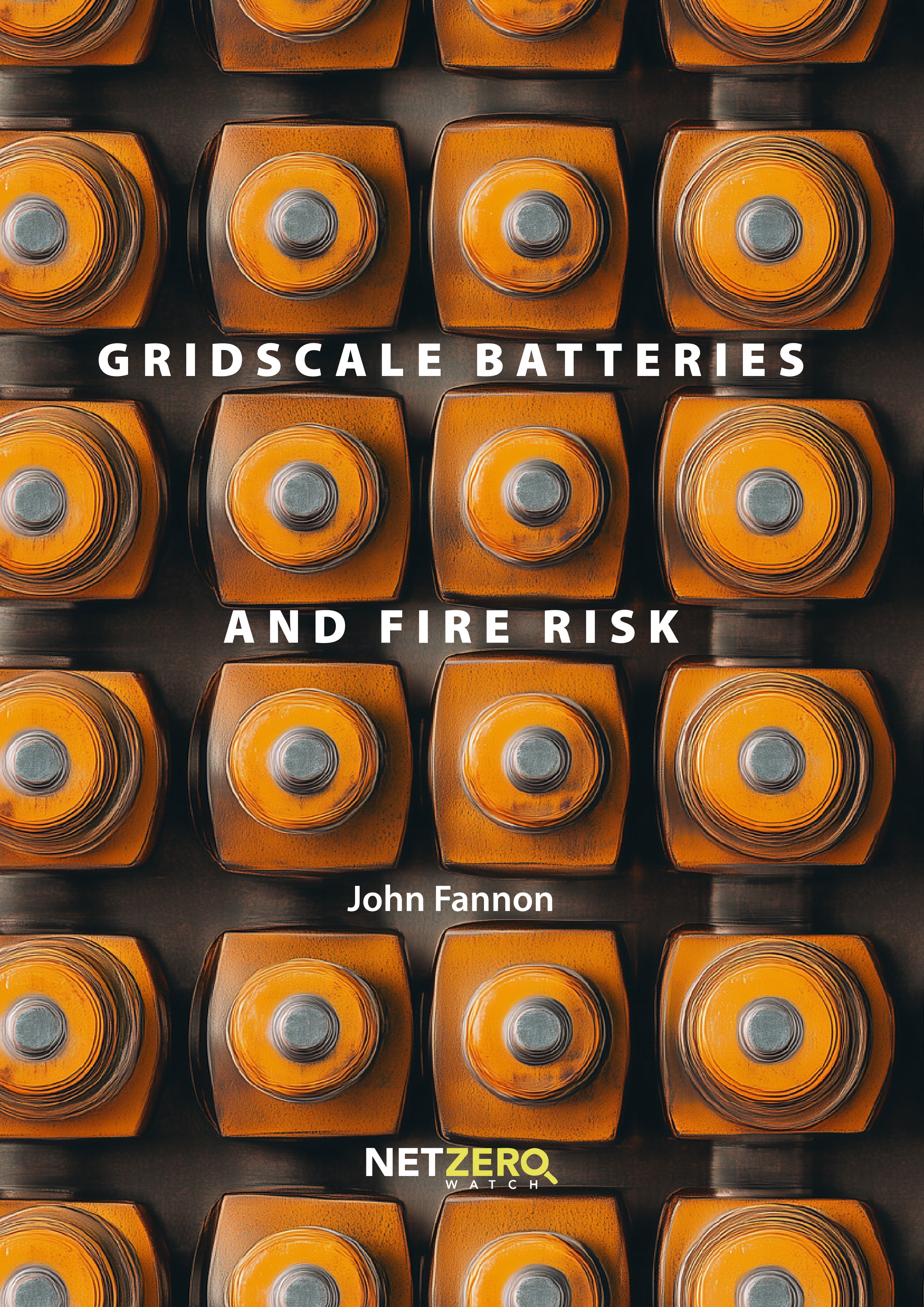

GRIDSCALE BATTERIES AND FIRE RISK

John Fannon

NETZERO WATCH

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Contents

About the author

John Fannon was awarded a BSc honours in physics at Kings College, University of London in 1962. In 1962–63 he studied at the University of Manitoba, Canada, and was awarded an MSc in Nuclear Physics. Returning to the UK, in 1966 he obtained his doctorate in nuclear physics at Kings College. After three years at Daresbury High Energy Laboratory, he joined the Scientific Civil Service at Farnborough. He developed an interest in project management, and subsequently procured projects for the RAF, the Army and the Royal Navy, latterly at Portsmouth and Portland. His final post was as Director of Large Warships at Abbey Wood, Bristol. After retirement, he formed a small company jointly with three colleagues. He undertook logistics studies for industry and for the EU, collaborating with scientists and engineers from many nations. He has more recently devoted time and energy to his positions as Treasurer and Trustee to the Thomas Fowell Buxton Society in Weymouth.

Introduction

Large numbers of battery energy storage systems (BESSs) are being installed around the world, and particularly in the UK, often alongside solar farms or at the landfalls of offshore windfarm export cables, but sometimes as standalone facilities. These are rapidly increasing in scale (Table 1).

Although BESSs are extremely expensive, their operators still expect to make money, buying cheap when electricity is in oversupply and market prices fall, and selling it back when prices soar at times of high demand. The round trip of charging and discharging involves an energy loss of between 10 and 20 percent but still turns a handsome profit.

BESSs are being installed in high numbers, usually on agricultural land, and, particularly in England, close to concentrations of housing. However, batteries are large and unstable concentrations of energy and thus their presence near human habitation brings major risks, particularly from fire.

This paper examines some of impacts of batteries on communities, using as an example, Statera Energy's proposed 400-MW BESS at Chickerell, South Dorset, recently approved by the local council over the objections of the majority of residents. In particular, it examines the potential impact of BESS fires, considering how similar conflagrations overseas might affect people in the relatively densely populated countryside of southern England.

Table 1: The largest BESS facilities.

Name	Comments	Power (MW)	Capacity (MWh)
Vistra Energy Corporation	Moss Landing, California, USA	750	3,000
Manatee Energy Storage Center	Florida, USA	409	900
Victorian Big Battery	Geelong, Australia	350	450
McCoy Solar Energy Project	Mohave Desert, California, USA	230	920
Elkhorn Battery	Elkhorn, California, USA	183	730

Source: Saurenergy.com,[13] Energy Storage News[14]

Battery science

A note on power and energy

Electricity systems are often quoted in terms of their power – the amount of energy delivered per second, measured in megawatts or kilowatts. However, a 400-MW gas-fired power station is very different to a 400-MW BESS. So long as there is fuel available, the gas turbine can deliver 400-MW almost continuously, apart from occasional downtime to allow for maintenance.

This is not the case for a BESS, which can only deliver its rated power for a short time, and so the total amount of energy it can supply – its *capacity*, measured in megawatt hours (MWh) – is a more relevant measure.[1]

A typical 400-MW BESS might run for only 4 hours before being exhausted, so its capacity would be 1600 MWh.

Battery energy storage cells

We are all familiar with the battery in our car, which uses lead and sulphuric acid to generate electricity. It is made up of six cells, arranged in series. A typical car battery might have a capacity of around 0.5 kWh.

Batteries used in EVs and BESS facilities use lithium-ion technology and are much larger. A Tesla Model S battery has a capacity of 85 kWh, made up of a series of 5-kWh modules, each made up of 444 cylindrical cells, storing 12 Wh.

BESS facilities use even larger prismatic cells. A typical prismatic cell offered by EVE en-

Figure 1: Cell sizes

(a) Cylindrical cell, as used in EV battery (b) Prismatic cell, as used in BESS.

ergy Ltd has a capacity of 900 Wh. The relative sizes of cylindrical and prismatic cells are shown in Figure 1. Over 100 cylindrical cells could fit in the volume of a single prismatic cell.

BYD Guangdong (formerly Canton) have recently introduced a 'blade cell', which is rectangular in cross-section, like a prismatic cell, but is long and narrow. These blade cells, which are expected to be used in the Statera proposal, have dimensions of 961 × 122 × 27 mm. The individual cell capacity is 1120 Wh.

The energy in a BESS

A large capacity BESS needs to be handled carefully – so much energy in a confined space is, in effect, an unexploded bomb. A recent working paper by Fordham et al. – a group of eminent physicists – observes that a fully charged 1-MWh BESS has an explosive potential equivalent to 0.86 metric tons of TNT.[2] A 1600-MWh BESS is thus equivalent to nearly 1400 tonnes of TNT, with potential for huge explosions, fires and clouds of toxic gas.

The BESS proposed by Statera would comprise 600 containers, each one housing 4160 cells. Although Statera have quoted a total capacity of 2400 MWh, a calculation based on the data provided suggest a higher capacity, and an explosive potential equivalent to over 3000 tonnes of TNT.[3]

The spread of BESS systems over the past 10 years has been accompanied by a rise in the frequency of spontaneous fires. Up to July 2024 there have been 89 BESS fires recorded worldwide.

Lithium-ion cells and thermal runaway

Lithium cell abuse

The cells in a lithium-ion battery work well if maintained properly, but if abused, the results can be catastrophic. The types of abuse can be summarised as follows:[4]

- *Mechanical abuse* occurs if the cell is penetrated by an object such as a nail or a bullet. A short circuit occurs, the temperature rises, and thermal runaway can follow.
- *Electrical abuse* can occur if the cell is overcharged or discharged to too low a value continuously. This abuse can result in what are called 'dendrites', which are whiskers of lithium growing onto the electrodes. If these dendrites become long enough, they can pierce the separator, and cause a short circuit and thermal runaway.
- *Thermal abuse* arises if a cell overheats. Each cell has an internal resistance and, during the charge or discharge, this will generate heat. The amount of heat generated per cell is small, but within each container there can be thousands of cells. If the temperature within the container were to rise, the plastic separator might collapse, a short circuit would follow, and thermal runaway would ensue.

Thermal runaway

Fordham et al. describe how lithium battery cells, in certain circumstances, can become overheated. If they reach a certain temperature, they will catch fire and emit noxious gases. If a single cell bursts into flames, it will heat up adjacent cells, which will also burst into flames. If the cells are not immediately cooled down, a chain reaction will set in and there will be what is called 'thermal runaway':

- a single cell failing could cascade into neighbouring cells in a module
- modules could then cascade into neighbouring modules followed by…
- the consumption of the entire stack and then the container.

With noxious gases, fires and explosions a possibility, thermal runaway must be avoided at all costs.

A recent paper by Marlair et al. sets out key lessons learned from recent lithium-ion battery incidents.[5] The authors conclude that 'No chemistry, not even less reactive LFP lithium-ion chemistry, is exempt from thermal runaway'. They criticise reliance on the use of safer materials in the hope of negating the thermal runaway hazard, and instead recommend a fail-safe approach (if that can be achieved), with multi-layer protection barriers.

Any design claiming to incorporate such a fail-safe approach needs to be exhaustively analysed and tested, and safety conclusively demonstrated before any decision is made whether or not to give the go ahead.

Preventing thermal runaway

Battery management systems

BESSs with high capacity require a large number of cells. For example the giant 2400 MWh facility planned by Statera is to be housed in 600 containers, each holding 4160 blade cells, each cell having a capacity of 1120 Wh. Simple arithmetic indicates that over 2 million lithium-ion blade cells are required.

Each cell must operate within strict limits, neither being over charged nor over discharged. While manufacturers enforce strict quality control over their production, there will always be variations in performance between individual cells. This strict quality control means that these variations are very small. However the large numbers of cells being charged and discharged regularly means that small differences can be magnified, particularly as the cells age.

All batteries therefore require a battery management system, capable of coping with every conceivable eventuality. The state of charge and the state of health of each cell needs to be monitored, as do their temperature of operation, charge control, and cell balancing.

Balancing the cells means taking account of the individual characteristics of each cell. When charging for example, some cells reach their maximum charge limit before others and must be isolated out of the charging process by electronic switches while the remainder continue to be charged. A similar system needs to be used to monitor and avoid over-discharging.

Computer-based battery management systems have been developed to carry out these vital tasks, but the process is complex. As BESS facilities become ever larger, it is vital that a battery management system is equal to the demands of managing the batteries. The penalty for a misdiagnosed problem can be devastating.

Thermal management systems

Each cell within a BESS generates a small amount of heat. As the capacity of cells increases, the total amount of heat generated in each container increases, and this must be removed. Each rack within a container will have its own cooling system, which expels the hot air from the container.

The design of the thermal management system needs to maintain the temperature in any container within the crucial values. Failure to do so would lead to changes in the internal resistance of the cells, which could lead to overheating, with all the consequent implications on safety.

The thermal management system is therefore critical to safe operation of the facility, and its effectiveness must be verified using a high-fidelity thermal analysis of the environment within containers when loaded under various charging conditions.[6]

Standards and Regulations

It is important to distinguish between standards and regulations. An industrial standard is a norm agreed by experts in the profession as a goal towards which all practitioners can work, so that the customers can be assured of quality and safety. Standards are not legally enforceable. Regulations, on the other hand, are Statutory Instruments and have the force of law.

Remarkably, there are no safety standards or regulations governing the development, installation and maintenance of BESS facilities in the UK. By necessity, US standards are used. These have been developed by the National Fire Protection Agency (NFPA) and UL Solutions (formerly Underwriters Laboratories), a global safety science company. Both organisations have provided such services for over 100 years. The NFPA produces a standard for Energy Storage Systems, NFPA 855, and revises it every two years; the most recent version was produced in 2023. NFPA have started developing NFPA 800, which seeks to produce standards for the whole lifecycle of a lithium-ion battery.

UL Solutions have developed standard tests for lithium-ion cells of various types (e.g. cylindrical or prismatic), and tests of cells arranged in groups or modules. UL 1973 concerns the construction requirements for battery cell safety, including electrical and mechanical tests. UL 9540A specifies the testing of the capabilities of the fire resistance mechanisms designed to mitigate the effects of thermal runaway. The tests are carried out with cells arranged in the modules and racks that form part of a BESS. A single cell is heated up to induce thermal runaway and the effects are recorded and analysed.

It is important to note that UL 1973 and UL 9540A involve the steady heating of a single cell to induce out gassing and thermal runaway. This is a test of the response of the system to thermal abuse. There are no tests yet available that assess the response to an internal short circuit. Yet a short circuit produces a very high current and extreme heating over a small area of the cells – analogous to a bolt of lightning. Internal short circuits have been the cause of many destructive BESS fires.

In approving an application for a BESS, a local council gives the applicant *carte blanche*, relying on that applicant's professional integrity to carry out the work safely. There are no regulations to work to. Even if there were, councils do not have the technical expertise to inspect the work in progress. The applicant and their subcontractors will use the standards that are extant during the procurement process.

UK regulations governing the building of BESS facilities are long overdue. Dame Maria Miller, until recently the MP for Basingstoke, did her best to get the Government to look at the issue, but her efforts have of course been swept away by the election. A moratorium on all BESS projects until such regulations are agreed would be the sensible way ahead. Any measure proposed to reduce carbon dioxide emissions and decarbonise the electricity grid must not override public safety.

BESS fires

Despite the deployment of the systems outlined in the last section, BESS fires do happen. The development of BESS facilities over the past 10 years has been accompanied by a rise in the frequency of spontaneous fires. In Korea there have been 30 BESS fires since 2017 – so many that the Korean authorities imposed a moratorium on building BESS until the causes were investigated. It was found that some BESS fires occurred in coastal areas with higher humidity, which may be a point to raise regarding the siting at Coldharbour.

In this section, two significant BESS fires are described. The Fordham et al. paper has details of many others.

Moorabool

The Victoria Big Battery 300 MW/450 MWh project was commissioned at Moorabool, near Geelong, Australia in late 2021. The State of Victoria had extolled the facility on their website,[7] and a question was asked of its safety. Their reply was:

While grid scale batteries are relatively new, lithium battery technology is proven and has an excellent safety record. The battery will be located away from residential areas and will be required to comply with strict fire and electrical safety regulations.

Construction started in early 2021, but in July, during initial testing, one of the 212 Tesla Megapack containers caught fire,[8] after a leak in the cooling system caused a short circuit.

The conflagration was so fierce that the adjacent container was destroyed and a further one scorched. 150 fire fighters attended, with crews wearing breathing apparatus. Fire and Rescue Victoria deployed a specialist drones unit, as well as a HAZMAT appliance, which conducted atmospheric monitoring, with a Scientific Officer in support.

Eventually it was decided to let the fire burn out and concentrate on protecting other modules. This approach avoids the real possibility of death or serious injury to the firefighters as a result of toxic fumes or explosions. However, it meant that the fire burned for over three days.

The fire released a considerable amount of toxic smoke. The prevailing wind, from the north west, directed it towards the nearby port city of Geelong, with a population of a quarter of a million. Emergency services issued a warning that toxic smoke could be encountered over an area covering over 30 km^2 (Figure 2). Emergency services issued a warning for toxic smoke in areas up to 9 km away, including Batesford, Bell Post Hill, Lovely Banks and Moorabool. Residents were warned to move indoors, close windows, vents and fireplace flues and to bring their pets inside.

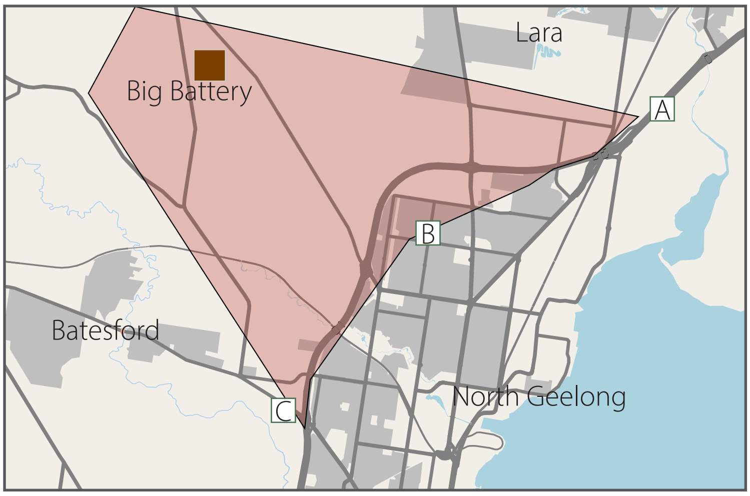


Figure 2: The smoke plume from the Victoria Big Battery fire.

Distances from the fire: Point A, 9.1 km; B, 5.5 km, C, 6.9 km.

Moss Landing

On 4 September 2021, Vistra's BESS at Moss Landing, California underwent an emergency shutdown, when some of its battery packs overheated and threatened to burst into flames.[9] In the event, the overheated batteries didn't catch fire, but did fill the building with smoke. Officials with Monterey County said that the facility's fire suppression systems worked perfectly, and there was no threat to the public. A further report suggested that a dry bearing in one of the pumps produced smoke, which triggered the smoke detectors. These in turn initiated water sprinklers, which short circuited the electronics, causing them to overheat. This melted plastics and wiring, but the lithium-ion batteries (fortunately) did not catch fire.

However, a year later, in the early morning of 20 September 2022, some of the Moss Landing battery packs overheated and caught fire.[10]

The police cordoned off an area of about 3 km radius around the site while the situation was brought under control. As at Moorabool, people were advised to stay indoors and close windows, and to bring pets indoors. In Figure 3, the position of the BESS, on the site of a disused power station, is marked. The blue boundary

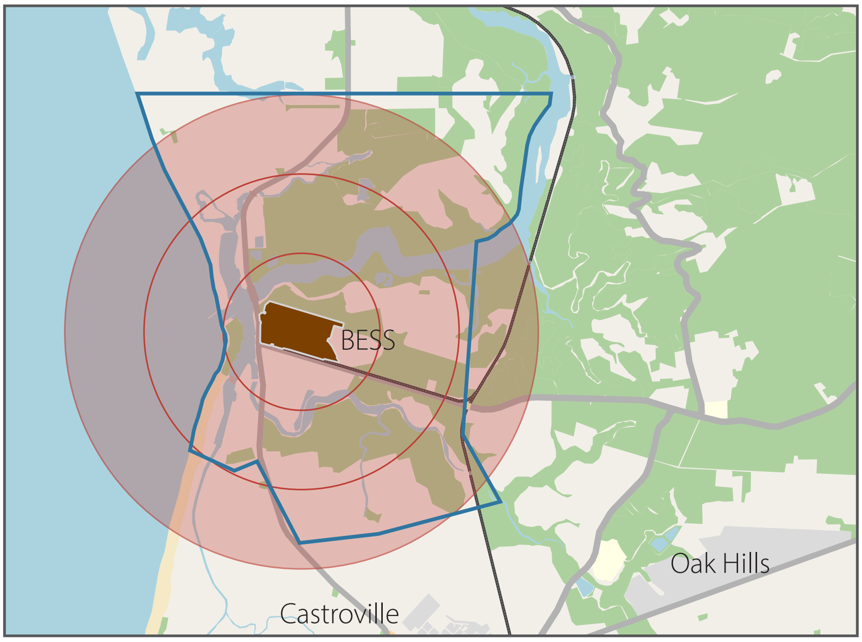


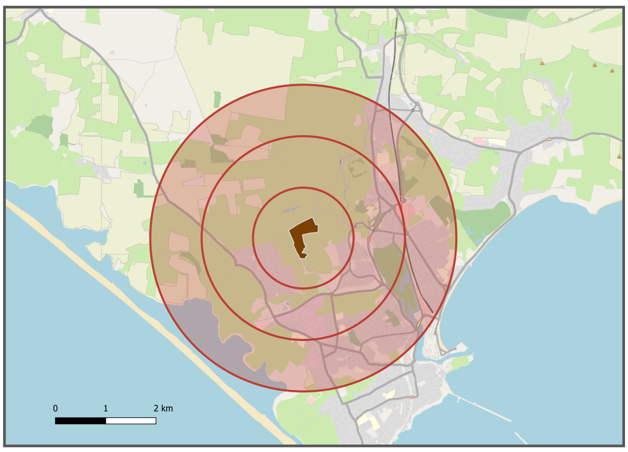
Figure 3: The Moss Landing emergency area
Emergency 'area of concern' marked in blue. The area around the BESS is semi-rural in nature.

represents the area of concern imposed when the emergency was recognised, and the red circles are spaced at 1 km, 2 km and 3 km from the centre of the BESS. The California Highway Patrol closed Highway 1 at 6:59 a.m. Officials estimated that the highway closure in the area would last into the afternoon, but the CBS news was still showing the area 'Shelter in place area' at 8 pm that evening.

The effect of a fire at the Statera Chickerell site

If an emergency similar to the second Moss Landing incident were to occur at the Statera site in Chickerell, it is likely that there would be major disruption in Weymouth, which has a population of around 60,000. Figure 4a is a map of the area, while Figure 4b shows the effect of a Moss Landing size fire on the area. Circles of 1, 2 and 3 km radius, centred on the BESS in Chickerell, are overlaid. The 3-km radius encompasses all of Chickerell, a large part of Weymouth, and surrounding farmland to the north and north-west

(a) Site map



(b) Effect of Moss Landing size fire

Figure 4: The Chickerell site
Figure 5: (a) Site map (b) Effect of a Moss Landing size fire.

How quickly could farmers get their animals indoors? The many tourists[11] and people going about their business in outdoor work would be suddenly vulnerable. Shoppers in Weymouth and Chickerell would be confined in shops and supermarkets, children in schools would have to shelter in place. It would be a lockdown all over again but without preparation or warning.

As noted above, at Moorabool it was decided to let the fire burn out. As a result, the area affected was larger than at Moss Landing. The shape of the Moorabool plume was roughly a 45° segment of a circle of radius 9 km, with its apex stepped back from the source of the fire.

The 'wind rose' shown at Figure 5 is a representation of the direction of the prevailing winds at a particular location. It shows that the wind in the Weymouth-Chickerell area comes predominantly from the south west.

As a result, the smoke would most likely be blown initially over populated suburbs of Weymouth, but then over countryside (Figure 6a). However, wind from a slightly more southerly direction (Figure 6b) would tend to blow the smoke towards Dorchester (population 20,000), and the plume would only need to be marginally bigger to take in the whole of that town. The hills north of Weymouth (Bayard Hill and Bincombe Hill) would force the plume to rise, and adiabatic cooling would ensue with the possibility of rain. That rain could contain hydrofluoric acid – as Bob Dylan once sang 'A hard rain is gonna fall!'

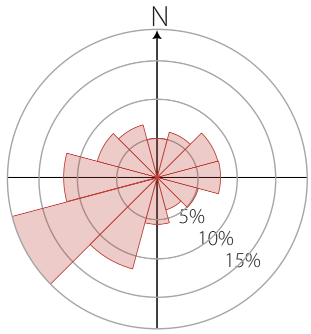
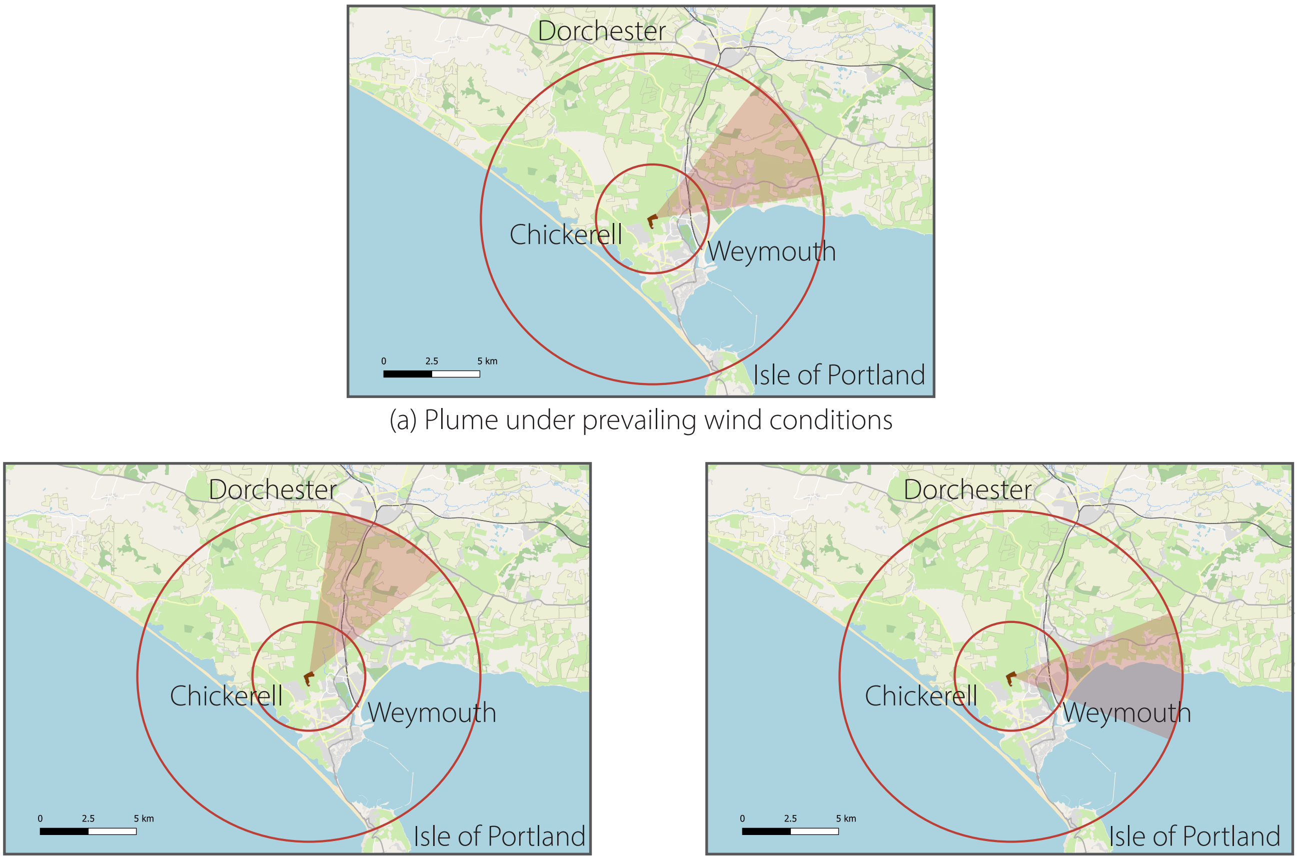


Figure 6: Wind rose for Chickerell.
Data: Global Wind Atlas.

If the wind was more westerly (Figure 6c),



(a) Plume under prevailing wind conditions

(b) Plume under more southerly wind conditions

(c) Plume under more westerly wind conditions

Figure 7: Effect of Moorabool size fire on Chickerell
Smoke plume under (a) prevailing (b) more southerly and (c) more westerly conditions.

the plume could take in the whole of Weymouth, while less frequent northerly winds could threaten parts of Isle of Portland.

Either way, those unfortunate to reside within the area of potential toxicity would have to endure lockdown for many hours, perhaps days. If the fire occurred during a period of high pressure, the toxic smoke would not disperse in a particular direction but spread out over a wide area on Chickerell and Weymouth. (You can observe the effect if you light a garden fire at a time of high pressure area – the smoke just spreads out over neighbours' gardens and the telephone begins to ring.)

The effect of fire at a proposed BESS site near the Thames Estuary

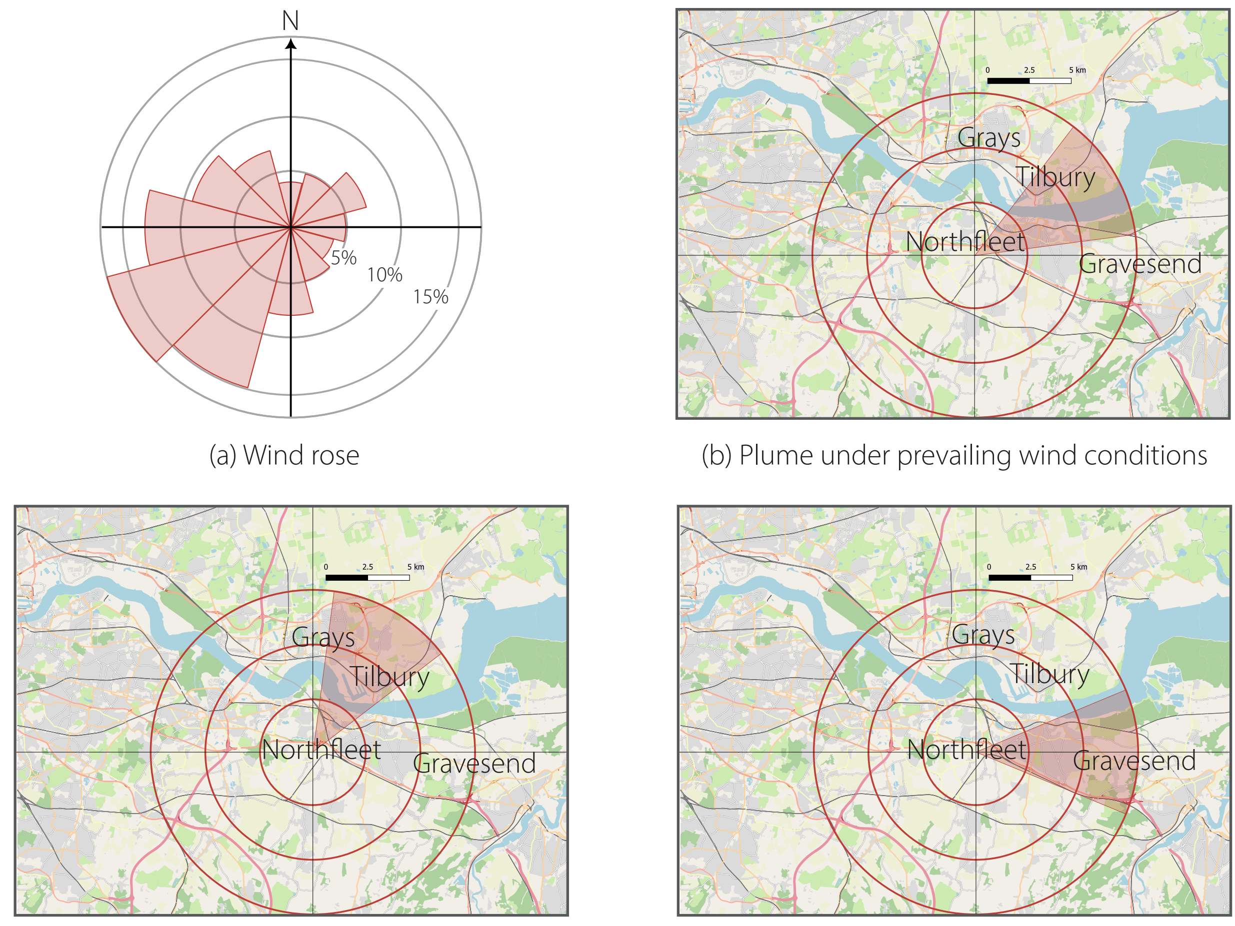
In this section, I consider the effect of a Moorabool sized fire at the BESS proposed for a site at Southfleet, near Gravesend.[12]

The facility is described as a 300-MW BESS, although no capacity is given. The power rating suggests it is similar to the Moorabol Big Battery. The proposal is very different to the Chickerell, however, because if approved it will be built close to major conurbations.

With the wind in any of the main prevailing directions (Figure 7a), a smoke plume would affect one of the the nearby centres of population (Figures 7b–d). These are (together with their populations):

- Grays (44,000)
- Tilbury (12,500)
- Gravesend (58,000)
- Northfleet (30,000)

The Port of Tilbury might also be affected.



(a) Wind rose

(b) Plume under prevailing wind conditions

(c) Plume under more southerly wind conditions

(d) Plume under more westerly wind conditions

Figure 8: Effect of Moorabool size fire on Thames Estuary

(a) Wind rose and smoke plume under (b) prevailing (c) more southerly and (d) more westerly conditions.

Way ahead

The Fordham et al. paper deplores the continuing reliance on lithium-ion BESS facilities and warns that this is not a safe or fruitful policy for this country. The authors argue that the regulatory regime under which they operate is inadequate. In particular, the Health and Safety Executive have ruled that large-scale BESS facilities are not covered by the Control of Major Accident Hazard Regulations (COMAH), a decision that Fordham et al. argue is scientifically mistaken and incorrect in law. They also observe that even if the decision were to be reversed, the regulations would still need tightening if BESS facility operation were to be put on a sound regulatory footing.

Whether or not COMAH regulations are in force at the time when planning permission is sought, local councils must insist that all BESS proposals should present a formal Safety Case, a structured set of safety documentation, providing evidence that hazards have been fully addressed, and that the residual risks had been reduced to render them As Low As Reasonably Practicable (ALARP). This is similar to what is required of the nuclear industry.

The author has been accused of nimbyism in objecting to the building of a BESS in his neighbourhood. After researching the background for this report, I confess to be a NIABY (not in anyone's back yard). BESS facilities are a blot on the landscape, dangerous and are not at all necessary given the alternative option of safe mini-nuclear power plants with a small footprint.

Notes

1 It is a common mistake is to use the term 'capacity' when referring to the power rating of the battery system.

2 https://www.researchgate.net/publication/352158070_Safety_of_Grid_Scale_Lithium-ion_Battery_Energy_Storage_Systems.

3 Each cell has an energy capacity of 1120 Wh and there are 600 containers, each housing 4160 cells. The total capacity is therefore 1120 × 4160 × 600 = 2,795,520,000 Wh or 2796 MWh, very close to 2800 MWh.

4 https://www.youtube.com/watch?v=VWMfeseybt4.

5 https://www.cetjournal.it/cet/22/90/108.pdf.

6 https://pubs.acs.org/doi/10.1021/acsenergylett.2c01400.

7 https://www.energy.vic.gov.au/renewable-energy/batteries-energy-storage-projects/victorian-big-battery.

8 https://news.cfa.vic.gov.au/news/firefighters-bring-large-battery-fire-near-geelong-under-control.

9 https://esterobaynews.com/news/questions-over-battery-plants-after-moss-landing-incident/.

10 https://www.cbsnews.com/sanfrancisco/news/tesla-moss-landing-power-storage-facility-fire-shuts-down-highway-1-residents-told-shelter-in-place/.

11 Weymouth almost doubles its population in the tourist season with outdoors activities such as equitation, many camp sites, and crowded clean beaches.

12 https://www.kentonline.co.uk/gravesend/news/energy-storage-plant-planned-for-green-belt-305810/.

13 https://www.saurenergy.com/solar-energy-news/the-top-5-largest-battery-energy-storage-systems-worldwide.

14 https://www.energy-storage.news/moss-landing-worlds-biggest-battery-storage-project-is-now-3gwh-capacity/.

For further information about Net Zero Watch, please visit our website at www.netzerowatch.com.