containers. One can imagine the storage systems as an XXL power bank.

Despite the high requirements on safety and reliability of battery cells, which the manufacturers ensure with intensive tests and by implementing extensive protective measures, accidents have taken place in various power storage systems in recent years.

Detailed assessment of the potential risk and possible safety concepts

The residual risk of the thermal runaway scenario – e.g. due to damaged cells – brings with it a high risk of fire and explosion. The chemical chain reactions that lead to these high temperatures can ignite the electrodes (lithium compounds, graphite) and lead to dangerous metal fires.

The electrolyte liquid between the electrodes consists of organic solvents, which vaporise at temperatures above 80°C . **DGUV – Hinweise zum betrieblichen Brandschutz bei der Lagerung und Verwendung von Lithium-Ionen-Akkus – 2020. Brandschutz-Forschung, KIT, Forschungsbericht 175, Jürgen Kunkelmann --2016.**

This volume expansion by a factor of 1000, which occurs with a phase transition from a liquid to a gaseous aggregate condition, leads to high pressures within the cells. In order to prevent the battery cells from bursting during thermal runaway, explosion vents or, where applicable, safety valves are present, which "release" the gas into the environment and protect the cells from bursting.

Figure 3 illustrates thermal runaway using the example of a battery module with 24 conventional 18650 battery cells (3.7 volt, 3000 mAh). In a scenario such as this, the fire load is transferred to

Fig. 1 + 2: Damage to a battery energy storage system after an explosion, Arizona Public Service, 2020 (https://spectrum.ieee.org/dispute-erupts-over-what-sparked-an-explosive-liion-energy-storage-accident, 11.11.2021)

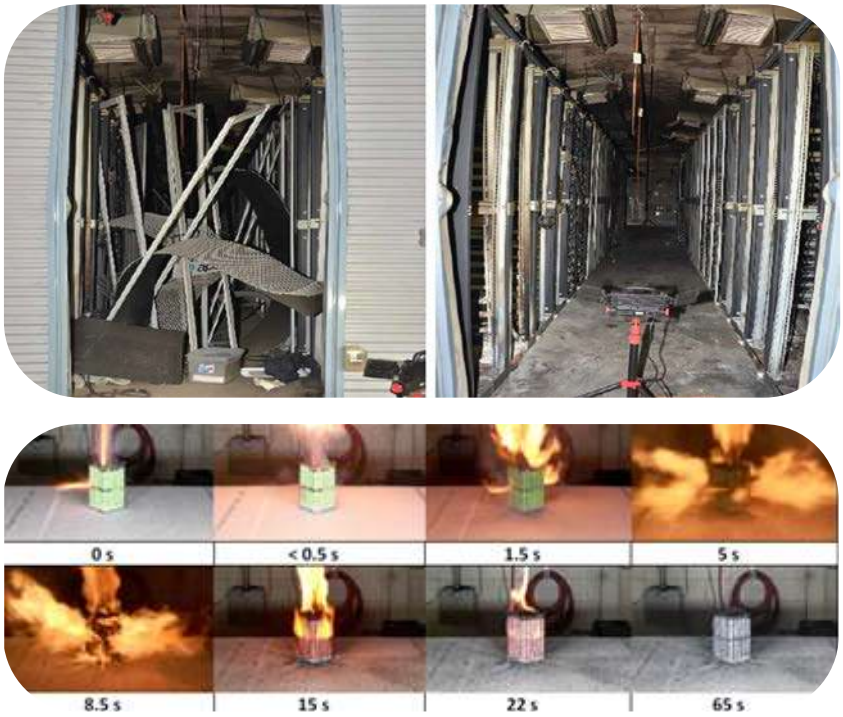

Fig. 3: Spreading of thermal runaway to neighbouring cells

neighbouring cells within seconds. A chain reaction occurs, which is accompanied by cyclical explosive flames from the cells. The explosive flames occur due to the discharge of evaporating, combustible electrolytes. There is also a risk that glowing metal parts and other burning parts of the battery will be expelled . **DGUV – Hinweise zur Brandbekämpfung von Lithium-Ionen-Akkus bei Fahrzeugbränden – 2020**

Particularly batteries with high power densities, such as those used in vehicles and battery energy storage systems, can release several thousand litres of gas into the environment within seconds – depending, among other things, on the cell type, storage capacity and state of charge. **Exponent Inc. – Thermal Runaway and Safety of Large Lithium-Ion Battery Systems – 2015** .

These gas mixtures contain flammable components such as hydrogen, hydrocarbon and carbon monoxide, as