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Consequences of catastrophic failure of battery energy storage systems

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Consequences of catastrophic failure of battery energy storage systems

Presenter: Aníbal Morones Ruelas, PhD

- Blast effects and testing consultant
- Expertise in explosions and catastrophic failure of equipment and pressure vessels
- Background in turbulent combustion research, biofuels, power quality, and power generation
- Certified Energy Manager since 2006

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BakerRisk

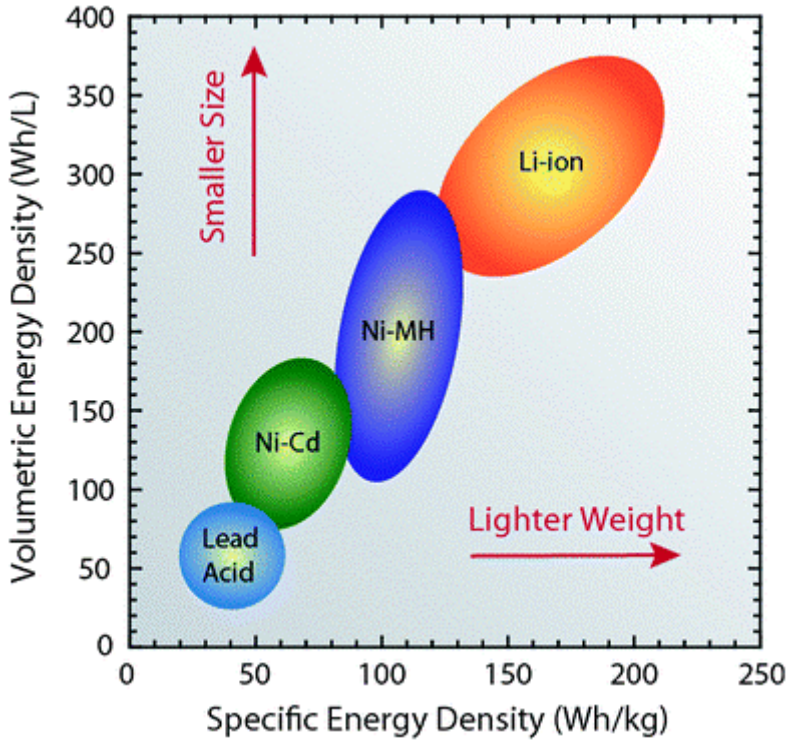
- BakerRisk is one of the world's leading explosion analysis, structural design, and risk management companies
- BakerRisk provides services to government agencies and private companies who are involved with hazardous operations or materials:
  - Comprehensive consulting in process safety and risk management
  - Engineering
  - Laboratory and full-scale facility forensic testing
  - Turnkey blast and fire resistant shelters

Covered in this talk

- Li-ion batteries in utility scale energy storage
- Hazards of Lithium ion batteries
- Past incidents with Li-ion batteries
- Vented deflagrations in BESS

Lithium ion batteries

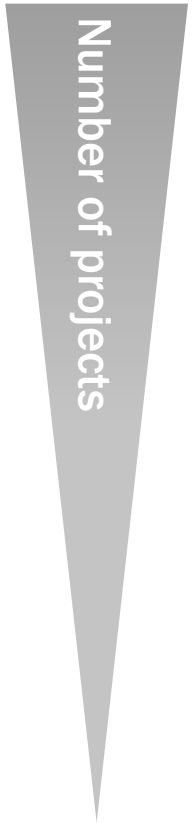
- Since their commercial introduction in 1991, Lithium-ion (Li-ion) batteries have become the dominant technology for consumer electronics devices
- In the near future, the demand for electric vehicles (EV) batteries will outpace other applications
- Stationary energy storage facilities are expected to give a second life to terawatt-hours of batteries that will no longer meet required specifications for usage in an EV



https://www.cei.washington.edu/wp-content/uploads/2015/11/li-energy-density.gif

Battery Energy Storage Systems

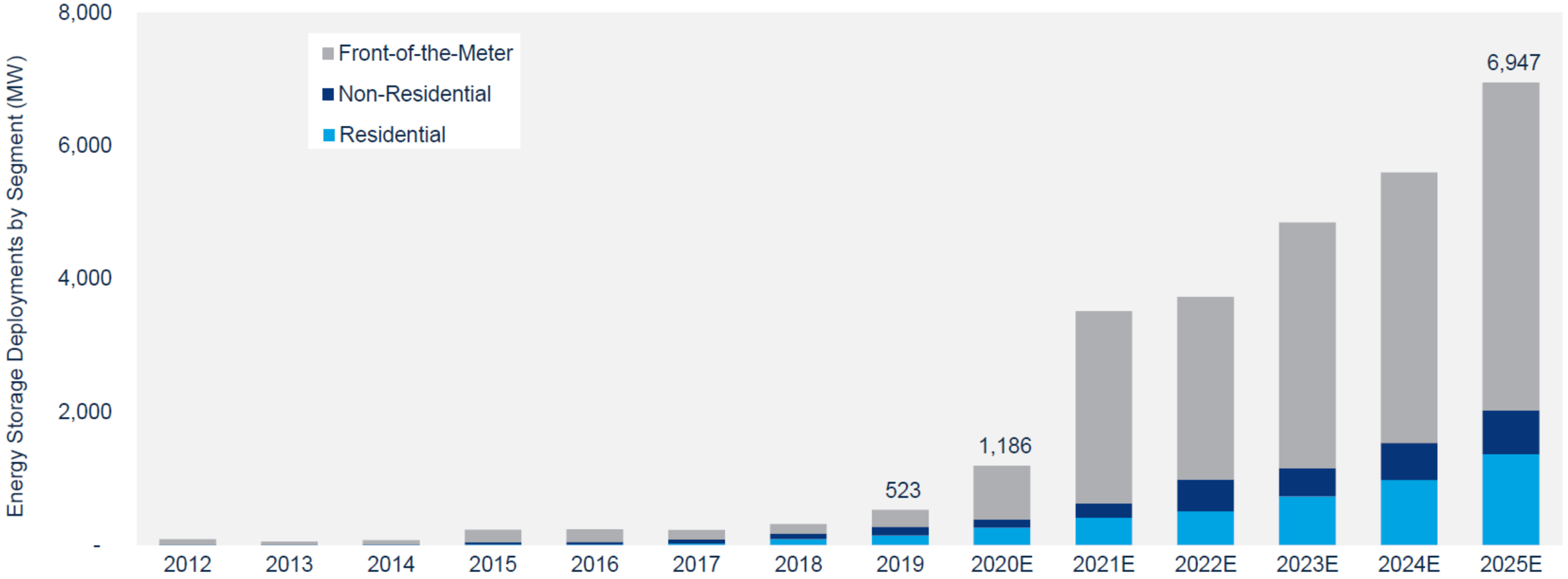
- **Common uses**
  - Electric energy time shift
  - Renewables capacity firming
  - Electric bill management
  - Frequency regulation
  - Onsite renewable generation shifting
  - Microgrid capability
  - On-site power
  - Resiliency
  - Load following (tertiary balancing)



DOE OE Global Energy Storage Database

https://new.siemens.com

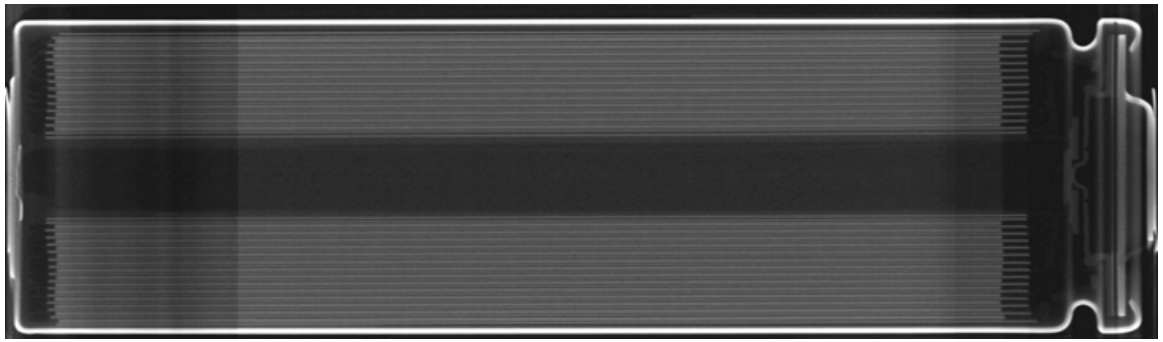
US energy storage annual deployment forecast



Wood Mackenzie / ESA | US energy storage monitor Q2 2020

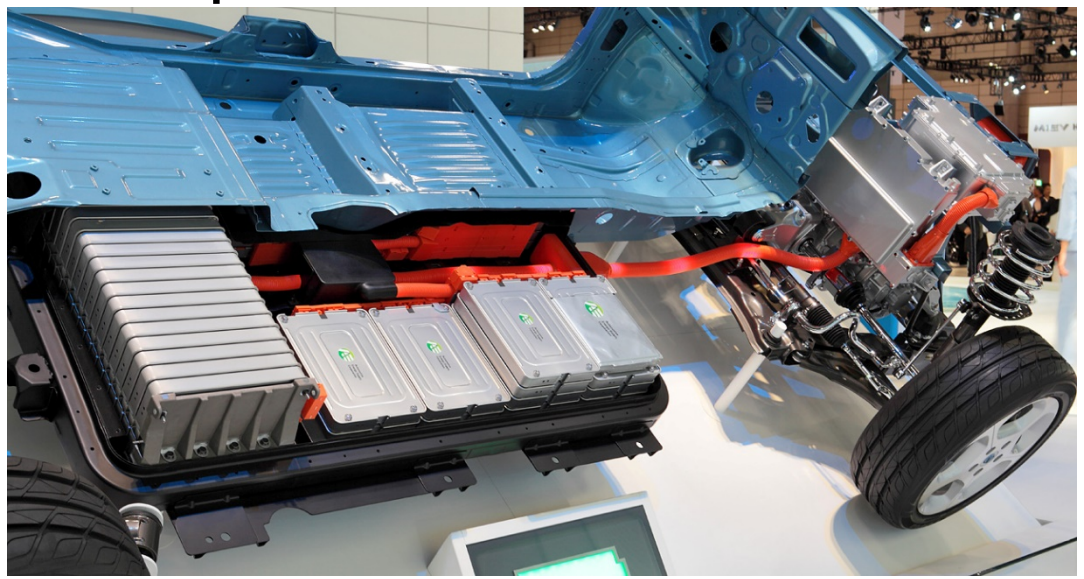
Hazards of Li-ion cells

- Hazards (fire and blast)
  - Flammable organic electrolyte
  - Runaway potential
  - Outgassing potential
  - Stored energy!



(Mikolajczak, Kahn et al. 2011)

- Aggravating factors
  - High energy density
  - Large capacity
  - Bulky formats and closed packing complicate heat removal



Nissan Leaf's lithium-ion battery pack. Picture by Tennen-Gas

Hazards of Li-ion cells

- The major part of existing cells have electrolytes composed of a lithium salt in an organic solvent. The solvent is a flammable liquid.
- A cell in runaway, i.e., rapid exothermic degradation, will consume itself. The heat generated may drive other cells into runaway. Cells may rupture and/or vent decomposition gases.
- Decomposition gases are usually a mixture of H_2, CO, CO_2 and short chain hydrocarbons.
- Even if there is no fire, a distressed Li-ion battery still poses a threat.

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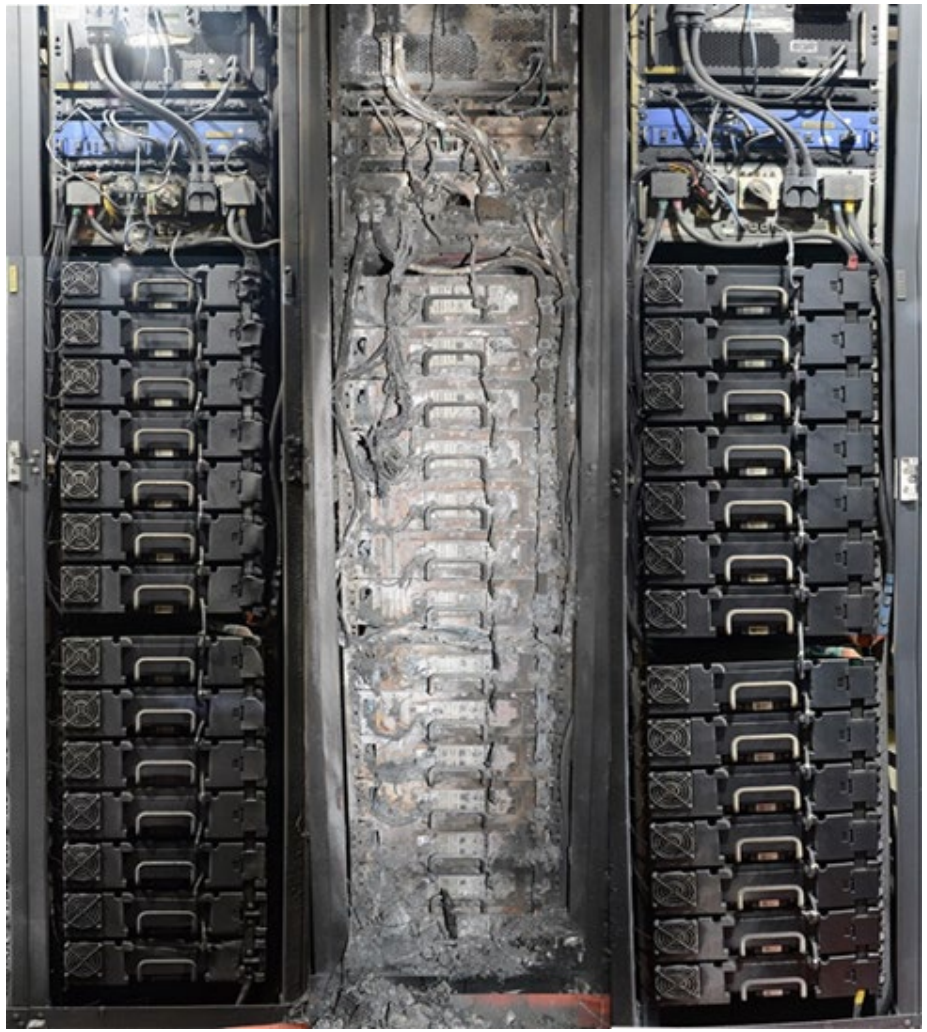
Past incidents

Past incidents with Li-ion batteries

Year	Incident	Cause
2006-2007	Dell Laptops caught fire	Internal cell defect
2011	GM Volt caught fire	Crash test damage, short
2012	Smoke in hybrid tugboat	Overcharge
2013	Smoke and off-gas in Tesla S	Road debris damage
2013	Heat and smoke in Boeing 787	Internal cell defect
2017	Runaway in Galaxy Note 7	Physical damage / defects
2017-2018	BESS fires in South Korea	Poor engineering / defects
2019	BESS explosion in Arizona	Short circuit

Apr 19, 2019: BESS explosion in Arizona



Key events:

- At least one battery cell enters in runaway. Anomaly detected in electrical parameters.
- Within the next two minutes, electrical protections triggered and clean agent fire suppression system operated (runaway still cascaded throughout the affected rack)
- 3 hours later, the container door was opened. Within minutes of opening, an explosion occurred, injuring several firefighters

(DNV GL Energy Insights USA 2020)

Apr 19, 2019: BESS explosion in Arizona

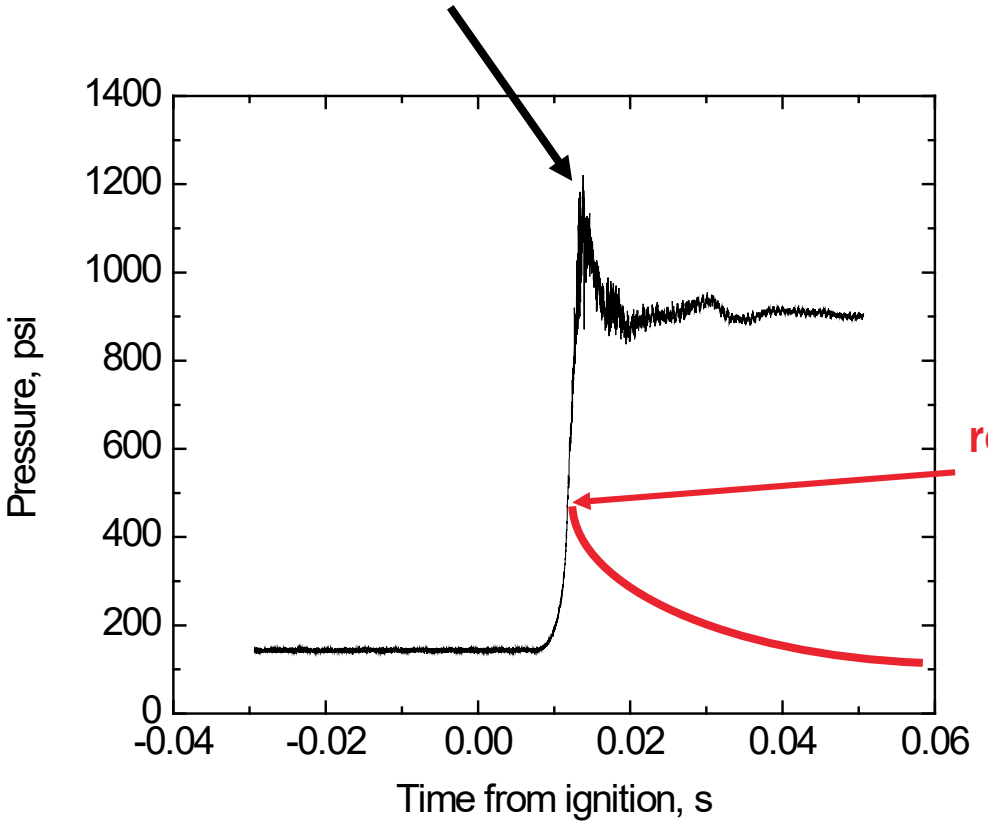
Contributing factors:

- The fire suppression system was incapable of stopping thermal runaway
- Lack of thermal barriers between cells to prevent cascading thermal runaway
- Flammable off-gases concentrated without a means to ventilate
- Emergency response plan did not have an extinguishing, ventilation, and entry procedure

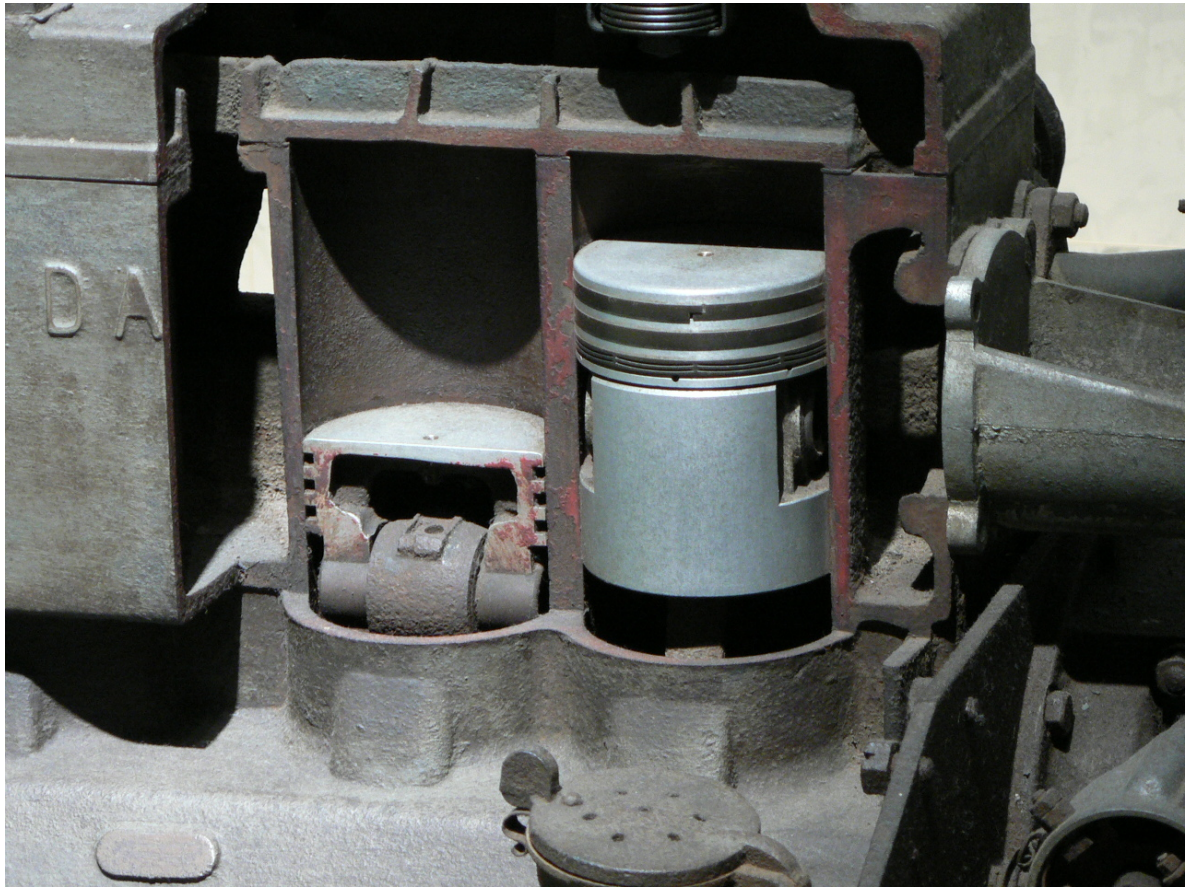
(DNV GL Energy Insights USA 2020)

Vented deflagration

Equilibrium pressure at constant volume



Pressure peak reduced through venting



DAT engine . Picture by 160SX (talk)

Vented deflagration

Recent battery projects

Customers include battery cell manufacturers, vehicle manufacturers, utility companies and EPCs. Examples services rendered to BESS:

- Vented deflagration calculations (blast and fire hazards)
- Evaluation of the combustion properties due to off gassing of the battery
- Evaluation of doors as deflagration vents
- Assessment of the dynamic response of the building housing the batteries to internal explosions
- Assessment of blast and fire damage on third party structures and bystanders in explosion scenarios originating from BESS facilities

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Baker Engineering and Risk Consultants, Inc. is one of the world's leading explosion analysis, structural design, and risk management companies. BakerRisk provides comprehensive consulting, engineering, laboratory, and full-scale facility testing services to government agencies and private companies who are involved with hazardous operations or materials.

35+ years

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