CLEAN ENERGY COALITION FOR SANTA FE COUNTY

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batteries

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Article

Assessment of Run-Off Waters Resulting from Lithium-Ion Battery Fire-Fighting Operations

Arnaud Bordes, Arnaud Papin, Guy Marlair, Théo Claude, Ahmad El-Masri, Thierry Durussel, Jean-Pierre Bertrand, Benjamin Truchot and Amandine Lecocq

Special Issue
Thermal Safety of Lithium Ion Batteries
Edited by
Dr. Mingyi Chen

MDPI

https://doi.org/10.3390/batteries10040118 batteries

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Abstract: As the use of Li-ion batteries is spreading, incidents in large energy storage systems (stationary storage containers, etc.) or in large-scale cell and battery storages (warehouses, recyclers, etc.), often leading to fire, are occurring on a regular basis. Water remains one of the most efficient fire extinguishing agents for tackling such battery incidents, and large quantities are usually necessary. Since batteries contain various potentially harmful components (metals and their oxides or salts, solvents, etc.) and thermal-runaway-induced battery incidents are accompanied by complex and potentially multistage fume emissions (containing both gas and particles), the potential impact of fire run-off waters on the environment should be considered and assessed carefully. The tests presented in this paper focus on analyzing the composition of run-off waters used to spray NMC Li-ion modules under thermal runaway. It highlights that waters used for firefighting are susceptible to containing many metals, including Ni, Mn, Co, Li and Al, mixed with other carbonaceous species (soot, tarballs) and sometimes undecomposed solvents used in the electrolyte. Extrapolation of pollutant concentrations compared with PNEC values showed that, for large-scale incidents, run-off water could be potentially hazardous to the environment.

Keywords: Li-ion battery; fire; safety; thermal runaway; toxicity; water; firefighting; pollutants

Citation: Bordes, A.; Papin, A.; Marlair, G.; Claude, T.; El-Masri, A.; Durussel, T.; Bertrand, J.-P.; Truchot, B.; Lecocq, A. Assessment of Run-Off Waters Resulting from Lithium-Ion Battery Fire-Fighting Operations. *Batteries* **2024**, *10*, 118. https://doi.org/10.3390/batteries10040118

Academic Editor: Mingyi Chen

Received: 6 February 2024
Revised: 22 March 2024
Accepted: 25 March 2024
Published: 31 March 2024

1. Introduction

The current development of Li-Ion batteries concerns numerous, application fields, and the thermal runaway hazard about those systems, often leading to fire and sometimes explosion events, remains a resilient issue. In parallel to the wide spread of Li-ion-powered consumer products in complex built environments, the increasing use of applications of LIB for e-mobility or large-scale battery energy storage systems (BESS), in the hundreds of MW power range, requires the urgent development of environmentally friendly strategies to fight lithium-ion battery fires. Considering that water remains one of the most efficient fire extinguishing agents to fight battery fires, and in many cases is the only extinguishing medium available in operational quantities to the fire-brigades, the potential impact of relating fire run-off waters to the environment should be considered and assessed carefully. Lessons of the past have primarily shown that uncontrolled release of toxic fire waters in rivers may lead to a dramatic consequence for water livestock, as primarily shown by major incidents involving large storage of toxic chemicals such as in Basle (Sandoz fire, Switzerland, 1986) [1,2] or in Tianjin (China, 2015) [3]. This is a prerequisite for establishing a clear and science-based firewater management doctrine [4]. In particular, the level of contamination of fire waters in terms of toxicity to aquatic ecosystems is needed to decide on the free release of extinguishing waters into the environment or into rainwater drain systems or on their containment in suitable systems for post-hazardous liquid waste management [5].

During the thermal runaway phenomenon—initiating stage of relating field failures—it is well-known that systems containing Li-ion batteries produce emissions or effluents which can range anywhere within the full spectrum of physical states, e.g., liquids (electrolyte leak or ejection), gases or vapors or solid aerosols [6–10], which adds complexity to both non-flaming and flaming conditions. These emissions may in turn interact with the environment and lead to pollution [11]. One of the contamination modes of both land and aquatic ecosystems is the aerosol sedimentation process arising during smoke plume dispersion, often at a stage where contaminant concentrations in the smoke plume are significantly diluted at a certain distance from the incident. Another possible and easier way of pollution is linked to the extinguishing agents used, typically water used by fire suppression systems or fire brigades, which can carry effluents emanating from the damaged battery. These various modes of contamination have been, unfortunately, largely confirmed in a significant number of fire records, as exemplified by Mc Namee et al. [12]. This shows, in particular, the diversity of influencing factors in terms of burning materials, size, and fire duration, potentially leading to environmental damage. Regarding batteries, the contaminants involved depend on the materials composing the system. These materials vary from one Li-ion battery chemistry/geometry to another and from one system to another, but the phenomena at stake and the resulting effects are close [13]. For small- or medium-isolated batteries (e.g., used for portable applications), the accidental contamination risk should be relatively low, but for more energy- or power-demanding applications leading to larger battery systems (containerized BESS, . . .) or large-scale cell and battery storages (warehouse, recyclers, . . .), the consequences might start to raise concerns in the absence—so far the usual case—of any fire water containment capacity. As a matter of fact, according to EPRI information, 64% of the BESS site owners are considering the implementation of water containment for the firefighting run-off waters [4]. Regarding fire extinguishing waters used to tackle car fires, if detailed studies [14,15] of fire water ecotoxicity had concluded that subsequent fire water run-off had a negligeable impact on the environment, as far as ICE cars are concerned, more caution is likely to be needed with EVs, given the significant differences applied from potential contaminants from the battery and the amount of water requirements.

Emissions during thermal events are directly linked to the materials constituting the battery. However, they will possibly be altered by reactions of thermal decomposition, electrolysis or even combustion that might drastically change the nature and properties of the ejected matter [8]. Carrying those substances by water will vary depending on the chosen extinguishing method. Three options are generally possible: (1) Direct watering of the batteries—when sprinklers or water fire hose are directed to the faulty system with direct contact with the batteries. (2) Fire plume watering for fire and smoke progress abatement—when water is not applied directly to the system but to its surroundings to prevent fire and subsequent damage propagation to adjacent elements and therefore minimize the impact of the root fire. (3) Water immersion—when the battery is immersed in a large volume of water, either after an incident to cool down the sample, or during an incident to try to limit it. In this last option, managing firefighting waters is relatively simple as water is already contained.

Water contamination in the smoke watering scenario (#2 firefighting option) was recently studied by EMPA [16,17] while analysis of immersion water (#3 firefighting option) has been performed both by EMPA and RIVM [18]. However, more globally, published information regarding contamination of fire waters used to tackle li-ion battery fires, regardless of the application, remains quite scarce. Therefore, further investigation is needed to confirm the early trends observed [19] and to address those issues in the entire value chain of LIBs.

In the present paper, the case of direct watering of the batteries is the only scenario studied. Commercially available NMC battery modules composed of two different cell formats (18,650 and prismatic) were chosen for the experimental approach selected in this study.

2. Materials and Methods

2.1. Description of the Samples

Two types of commercial Li-ion modules were used, both composed of NMC/graphite cells.

Module A comprises 16-metal-can prismatic cells (7.5 Ah) and has an electrical energy of 500 Wh. In addition to the electrochemical cells, the module also includes metallic (aluminum plates, cells connectors) and plastic (casing cover, wire insulation etc.) parts.

Module B is an assembly of 2 cell blocks, each one composed of 45-cylindrical 18,650 cells (2.4 Ah), circled with a metallic grid to ensure its mechanical integrity. The total energy of the battery assembly is 900 Wh. In addition to the electrochemical cells, the module also integrates a thin plastic film keeping the cells tightly together and connected.

The week before the abuse tests, the modules were fully charged using a constant current profile at C/5 using a cycling bay from FEV manufacturer.

2.2. Abuse Tests Set Up

Abuse tests on modules were performed in the Ineris 80 m^3 test chamber equipped with a smoke exhaust and treatment system remotely controlled to fully extract, measure, and eventually convey gases through the gas cleaning system of the facility before their rejection to the atmosphere. The room is also connected to a water-draining system to collect all liquid effluents produced by the fire or during the fire suppression process. In the testing room, the air entrance is located on one side, near the ground; extraction is placed in the center of the roof. All tests were performed under air with an extraction flow rate in the test chamber of approximately 2 500 m^3/h.

The sample was positioned in the center of the test chamber for each test, as represented in Figure 1. Modules were positioned on a metal grid, electrically insulated, using a small support made of inert material (calcium silicate).

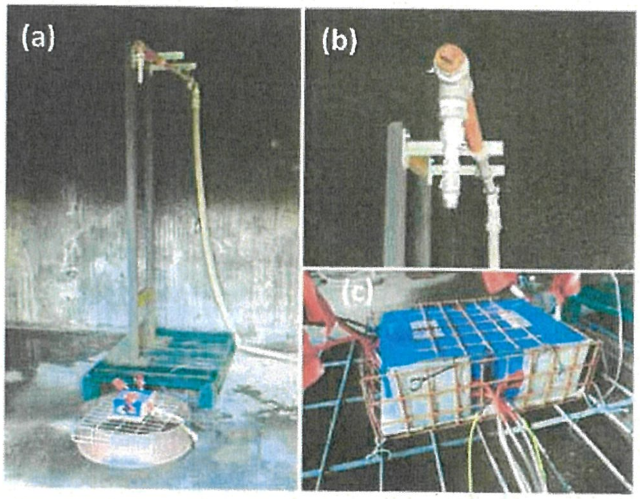

Figure 1. Pictures of the experimental set-up. (a) Overview, (b) sprinkler head, and (c) battery module B. White pads on the front faces of each battery block correspond to the heaters.

For module A, as the thermal pad failed to initiate a thermal runaway, a 20 kW gas burner was selected and positioned 30 cm from the sample and directed to the middle of the module. To prevent any interaction between the propane burner and the water used for firefighting, the burner was switched off as soon as thermal runaway was triggered.

For module B, two thermal pads with individual power of 220 W and a 50 cm^2 surface were put in contact with each cell block.

Since the objective of the tests was to evaluate water contamination in thermal runaway situations, the sprinkler activation was performed manually as soon as the thermal runaway was visually confirmed. As the modules were not equipped with thermocouples, the thermal runaway event was considered occurring when flames were escaping for the first time from the module. The application rate was set at 10 L/m^2/min. The basin surface was 0.25 m^2, and the volume of collected water was estimated by calculation using the water flow, the watering time, and the basin surface.

2.3. *Water Sampling*

After each test, 2 L of water was immediately sampled from the extinguishing water containment basin for chemical composition analysis. It is important to highlight that no filtration was made to keep all of the emissions in the analyzed samples, whatever the chemical or physical processes that were involved in the interactions of emissions from the battery module and extinguishing waters (condensation, dissolution, sedimentation etc.), since the objective of the test was to characterize the global composition of runoff water.

Before the test, the water receptacle was exposed to a direct flame to remove the potential traces of organic solvents. However, deposit remains possible, and a reference was then carried out by watering the same set-up, without any battery, in order to have a baseline of potential species inherently present in the water supply or due to receptacle component extraction during sampling.

2.4. *Water Analysis*

2.4.1. Inductively Couple Plasma Optical Emission Spectroscopy

Inductively Couple Plasma Optical Emission Spectroscopy (ICP-OES, Agilent 5110 equipment, Santa Clara, CA, USA) has been used for the analysis of major elements (Al, Fe, Li, Na, Ni, P).

2.4.2. Inductively Couple Plasma Mass Spectrometry

Inductively Couple Plasma Mass Spectrometry (ICP-MS, Agilent 7900 instrument, Santa Clara, CA, USA) has been used for the analysis of trace elements (Co, Cu, Mn). Instead of the ICP-OES used for major elements by measuring the light emitted from elements, ICP-MS uses a quadrupole to filter the ions according to their mass/charge ratio and counts each mass passed to the detector. The high sensitivity of the ICP-MS detector provides a much lower detection limit than ICP-OES.

2.4.3. Ion Chromatography

Chloride and fluoride species were measured by ion chromatography (Metrohm, 850 Professional IC, Herisau, Switzerland) with conductimetric detection. Ion chromatography is a method for separating ions (Cl^- and F^-) based upon their interactions with resin (stationary phase) and the eluent (mobile phase).

2.4.4. Liquid Chromatography

To extract polycyclic aromatic hydrocarbons (PAHs) from the water sample, a separation of the particle phase was carried out using glass wool. Aqueous phases were extracted using dichloromethane by liquid/liquid extraction and particulate phase was extracted using acetonitrile. Both extracts were evaporated and collected in 0.5 mL of acetonitrile each and recombined in the same vial before analysis.

Analysis of PAHs was performed on a liquid chromatography system, an ultimate 3000 from thermo coupled to a diode array detector (DAD) and fluorescence detector (FLD) detector. Molecules were separated on C18 column (Zorbax eclipse PAH 2.1 × 150 mm 1.8 micron from Agilent). All PAHs were quantified using the FLD detector except for Acenaphthylene that was quantified using the UV-DAD detector.

2.4.5. Gas Chromatography

Carbonates were analyzed using a gas chromatography system from Varian. Samples were diluted in methanol and 1µL was injected in split mode 1:10. Separation was performed on a capillary column from Agilent VF-5 ms 60 m, 0.25 mm internal diameter and 1 µm film thickness. A flame ionization detector was used to quantify the different compounds.

2.5. *Particle Morphology Characterization*

A particle size distribution analysis using the centrifugal disc method (by use of CPS Disc Centrifuge™ instrument, Tokyo, Japan) and further particle morphology study by Transmission Electron Microscopy (TEM, JEOL 1400 Plus instrument, Tokyo, Japan) were carried out on the sampled water. To enable this analysis, all particles larger than 2 µm in size were filtered beforehand.

To perform microscopic analysis of the particles, a droplet of the sample suspension was casted on a copper grid and dried at room temperature to be observed with a TEM (Transmission Electron Microscope, JEOL, 1400 Plus, Tokyo, Japan). A beam of electrons accelerated by a high voltage (120 kV) passes through a very thin sample, in this case a carbonized copper grid on which a microdrop of the sample to be analyzed was deposited. During the electron–matter interaction, the transmitted and diffracted electrons are used to form an image with high resolution in gray levels, and the X-ray photons allow for a micro or even a nano-volume of the sample to be chemically characterized.

3. Results

3.1. *Test Conditions and TR Characteristics*

Table 1 compiles the test conditions and reactions observed during the three successive test runs and Figure 2 gives details on the timeline of the experiments and presents pictures of the markers of significant events.

Table 1. Summary of test conditions and observations.

	Module Type	Module Energy	Heating Method	Reaction	Module State after Test	Sprinkler Flow	Amount of Water Delivered
Test 1	Prismatic cell assembly NMC (module A)	500 Wh	Gas burner	Venting + moderate fire	Upper plastic burnt Mechanical integrity conserved No module casing opening	10 L/m^2/min	7 L
Test 2	Prismatic cell assembly NMC (module A)	500 Wh	Gas burner	Jet fire + explosion	Module casing ejected All cells fully burnt with casing damaged	10 L/m^2/min	7 L
Test 3	Cylindrical cell assembly NMC (module B)	900 Wh	Thermal pad	Jet fire + explosion	All cells burnt Some jelly rolls visible	10 L/m^2/min	9 L

In the first experiment, the thermal runaway of module A was characterized by the emission of a large amount of white smoke followed by the appearance of flames. No jet fire was observed, but a rather moderate combustion process, as visible on the first line of Figure 2 was observed. Water was applied for 2 min 50 s, corresponding to a volume of collected water of 7 L. The flames stopped as soon as water was applied. After the test, no cells presented any side wall rupture, and their mechanical integrity was conserved.

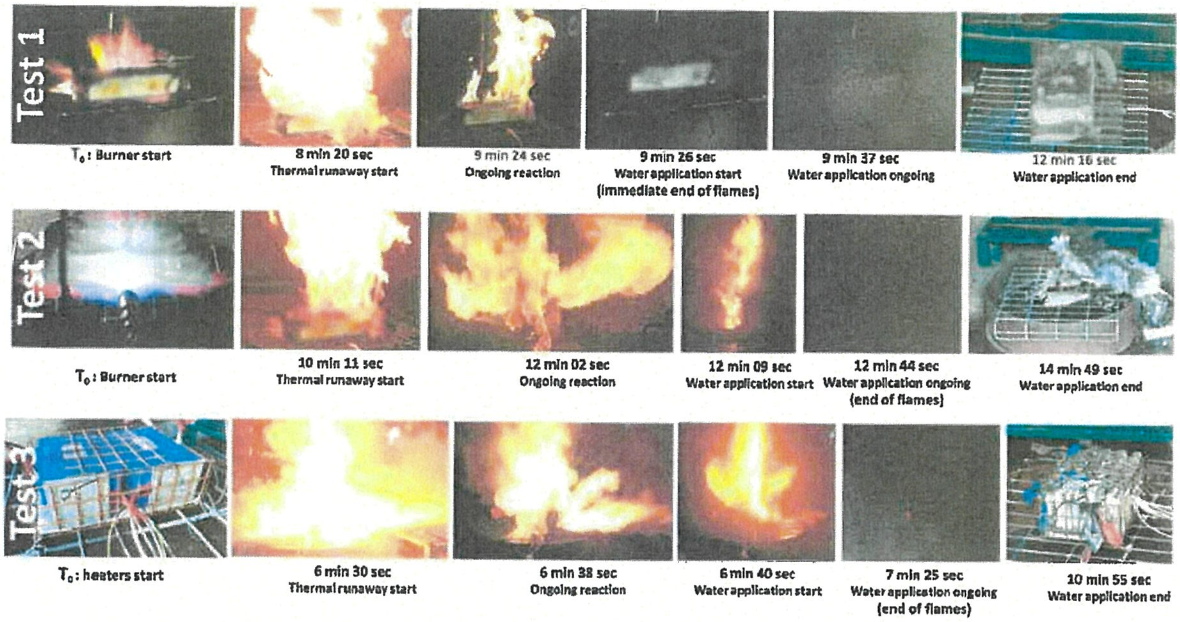

Figure 2. Extracts from the test video and timeline of the three experiments.

Test 2 was performed because module A was only moderately impacted by the first experiment. It was decided that the thermal runaway of module A should be further pushed and to restart the burner. After a few minutes of heating, the module entered again in the thermal runaway process. In this case, the reaction was much more violent since the jet fire was observed, the module casing was ejected, and all cells subsequently seemed damaged, some of them losing their mechanical integrity (casing opening). The second line of Figure 2 shows the reaction's visible effects just before water application (12 min 9 s). Water was applied for 2 min 40 s, leading to an additional volume of collected water of 7 L, i.e., a total of 12 L considering 5 L remains from test 1 (after that 2 L were sampled for analysis). Contamination levels indicated for test 2 are the values corresponding to the mix of the 5 L remaining from test 1 and the 7 L applied during test 2. The flames did not stop immediately upon water application, and an unknown portion of the water vaporized before reaching the receptacle. In the first approximation, this proportion of water vaporized was not considered for further calculation of the contaminant. The flames stopped 35 s after the application of water.

For module B, a single TR/fire water suppression step was carried out when the thermal runaway was reached. The third line of Figure 2 shows that the reaction was rather violent. All of the cells seemed damaged after the test and some of them lost their mechanical integrity (casing opening or jelly roll ejection). Water was applied for 3 min 30 s corresponding to a volume of collected water of 9 L, neglecting once more the vaporizer part. Flames stopped 45 s after water activation.

3.2. *Characterization of Water Contamination*

3.2.1. Halogens and Metals

Table 2 shows the results of the analyses for the presence of the two anions (F^- and Cl^-) as well as a selection of metal compounds. Those species have been chosen to reflect the foreseeable pollutants considering NMC Li-ion batteries composition [20].

As expected, the levels of fluorides and metals are found in large amounts, due to the composition of the cells. In module A, phosphorus and fluoride ions are the dominant species. In contrast, in module B, lithium is the more concentrated pollutant element compared to all other metallic elements and fluorides or chlorides. All these species are found in cell electrolytes or in the electrode for Li. Transition metals contained in the cathode (Ni, Mn, Co) are found mainly when the reaction was violent (tests 2 and 3). Their ratios, across different tests vary but in the three tests, Ni is overrepresented compared with Mn and Co, which is expected as stoichiometry of the current NMC cathode favors Ni. Their presence—in undetermined metal containing chemicals (oxides ? hydroxides ? metal complexes ?) [21]—is consistent, with composition of the selected cells. In order to better understand their respective amount, further studies on their chemical state and their solubility in water are necessary.

Table 2. Analysis of anions (F^- and Cl^-) and a selection of metals in the water before application and in the three samples after extinguishing. QL = quantification limit. Uncertainty values refer to expanded uncertainties (k = 2).

	QL	Uncertainty	Reference	Test 1 (Module A)	Test 2 (Module A)	Test 3 (Module B)
			Ions			
F^- (mg/L)	0.05	8%	0.25	142	91.6	93.7
Cl^- (mg/L)	0.01	3%	24.9	33.4	36.5	203
			Metals			
Al (mg/L)	0.17	15%	0.91	74.2	29.3	73.9
Co (mg/L)	0.03	10%	<LQ	0.42	12.8	7.07
Cu (mg/L)	0.03	10%	0.04	0.30	0.26	4.18
Fe (mg/L)	0.08	9%	0.30	5.92	4.59	0.30
Li (mg/L)	1.67	15%	<LQ	44.5	27.8	360
Mn (mg/L)	0.03	10%	<LQ	1.22	17.0	5.82
Na (mg/L)	1.67	14%	13.0	15.6	16.3	26.2
Ni (mg/L)	0.08	12%	<LQ	3.25	49.0	40.1
P (mg/L)	0.17	17%	<LQ	201	113	5.80

Aluminum, copper, and iron in pristine cells are present in sheets or bulk form and as particulate matter; therefore, they are expected to be less present in particulate emission. Aluminum is, however, found in noteworthy amounts probably because of its low melting point (660 °C). Iron and copper, which have higher melting points are found in relatively low amounts in the three tests.

By comparing the two extinguishing operations on the prismatic cells (test 1 and 2), it can be observed that when the thermal runaway thermal impact is characterized by a fully developed combustion process, the interacting water collected is much more concentrated in Polycyclic Aromatic Hydrocarbon (PAHs) and cathode metals (Ni, Mn, Co). On the other hand, the concentrations of elements essentially coming from the liquid electrolyte (typically Li, P, F) are present in higher quantities (1.6 to 1.8 factor) when the reaction is not fully developed, and where the electrolyte has a chance to be dragged in the water. This observation is coherent with the higher amount of organic carbonates found in test 1 presented in Section 3.2.3.

The comparison of the results between different cell geometries also confirms the importance of this parameter, influencing, in particular, the mechanical strength of the system and, therefore, the confinement of the species.

3.2.2. Poly Aromatic Hydrocarbons (PAHs)

Another important family of water contaminants in fire situations is PAHs. While the common specification for PAHs mentions 16 substances to be analyzed [22], 23 PAHs were analyzed; the results are reported in Table 3.

Table 3. Analysis of 23 PAHs in the water before application and in the three samples after extinguishing. QL = quantification limit. (Expanded: k = 2) Uncertainty of analysis for HAPs is 15% for all species.

PAH (Polycyclic Aromatic Hydrocarbons)					
	QL	**Reference**	**Test 1 (Module A)**	**Test 2 (Module A)**	**Test 3 (Module B)**
Naphtalène (ng/L)	10.0	<LQ	1279.2	2792.2	3114.6
Acénaphtylène (ng/L)	40.0	<LQ	2421.7	2405.1	1193.4
méthyl-1.naphtalène (ng/L)	10.0	<LQ	26.8	459.4	667.1
méthyl-2.naphtalène (ng/L)	10.0	<LQ	203.2	<LQ	2058.4
Acénaphtène (ng/L)	2.0	<LQ	34.1	110.6	275.7
Fluorene (ng/L)	2.0	<LQ	74.1	752.3	1055.0
Phénanthrène (ng/L)	4.0	5.7	360.9	3026.8	2581.6
Anthracène (ng/L)	2.0	<LQ	10.6	330.5	303.3
Fluoranthène (ng/L)	2.0	10.8	57.7	1280.9	349.8
Pyrène (ng/L)	2.0	7.2	45.1	1279.8	20.5
méthyl-2.fluoranthène (ng/L)	4.0	<LQ	7.3	45.1	21.3
B(a)A (ng/L)	2.0	<LQ	24.8	185.7	131.8
Chrysene (ng/L)	2.0	<LQ	32.5	212.3	40.8
Retene (ng/L)	2.0	<LQ	104.9	170.7	19.8
B(e)P (ng/L)	2.0	<LQ	7.5	306.3	50.4
B(j)F (ng/L)	20.0	<LQ	<LQ	106.3	<LQ
B(b)F (ng/L)	2.0	<LQ	34.6	259.6	5.8
B(k)F (ng/L)	2.0	<LQ	8.3	81.0	8.2
B(a)P (ng/L)	2.0	<LQ	13.0	163.9	20.8
D(a.h)A (ng/L)	2.0	<LQ	<LQ	36.7	4.5
benzo(ghi)P (ng/L)	2.0	<LQ	13.3	169.6	4.1
Indèno (ng/L)	4.0	<LQ	35.2	162.1	11.8
Coronene (ng/L)	2.0	<LQ	4.0	54.0	<LQ

It shows the presence of numerous PAHs including naphtalene and phenantrene, the most present, which typically indicates the combustion of hydrocarbon-based products. Specific attention should be paid to B(a)P as it is class 1 on the IARC scale (proven carcinogen). According to the potential ecotoxicological impact of those products, one should pay specific attention to the potential impact of runoff water.

3.2.3. Organic Carbonates

To complete the chemical characterization of the pollutants in the extinguishing waters, a selection of organic carbonates, classically used as electrolyte solvents or critical additives (VC, FEC), was quantified. Results are shown in Table 4.

Table 4. Analysis of 7 common carbonates used as electrolytes in the water before application and in the three samples after extinguishing. QL = quantification limit.

Species	**QL**	**Reference**	**Test 1 (Module A)**	**Test 2 (Module A)**	**Test 3 (Module B)**
DMC (µg/mL)	8.8	n/a	n/a	n/a	n/a
EMC (µg/mL)	8.3	n/a	138	59	n/a
VC (µg/mL)	9.4	n/a	n/a	n/a	n/a
DEC (µg/mL)	8.1	n/a	n/a	n/a	n/a
FEC (µg/mL)	10.2	n/a	n/a	n/a	n/a
EC (µg/mL)	7.7	n/a	1082	461	n/a
PC (µg/mL)	10	n/a	n/a	n/a	n/a

The presence of such compounds is found only in tests 1 and 2. This difference between the tests could be explained by the important combustion reaction observed during tests 3; it is most likely that the high temperature reached during this test led to the total evaporation and possible thermal decomposition of those volatile and easily flammable compounds before being dragged into the wastewaters. The boiling point for EC is typically 244 °C and 100 °C for EMC, which is significantly lower than the flame temperature. For the same reason, as the reaction in test 1 was less violent than in test 2, the quantity of carbonates found is higher for test 1 than for test 2. Species identified in the water are EMC and EC which are very commonly used as electrolyte solvents. Also, the boiling point difference might explain the difference between the quantity of EC and EMC found in the liquid phase, as EMC evaporates more easily. This also means that the massive use of water to cool down a whole system as a container could lead to a higher concentration of organic carbonates since part of the cells might, in such a case, be damaged but not burnt. Hydro solubility of those compounds may also play an important role (778 g/L for EC and 46.8 g/L at 20 °C for EMC) and explain the differences in the concentrations found. These compounds must be carefully monitored because they cannot easily be filtered out or left to settle.

3.2.4. Particle Size Analysis

To complete the chemical analysis of the water, particles sizes in the water were evaluated using the CPS method. Using Stokes' law, a hydrodynamic intensity-weighted particle-size distribution of diameters is obtained and transformed into a volume-weighted or number-weighted particle-size distribution, as presented in Figure 3.

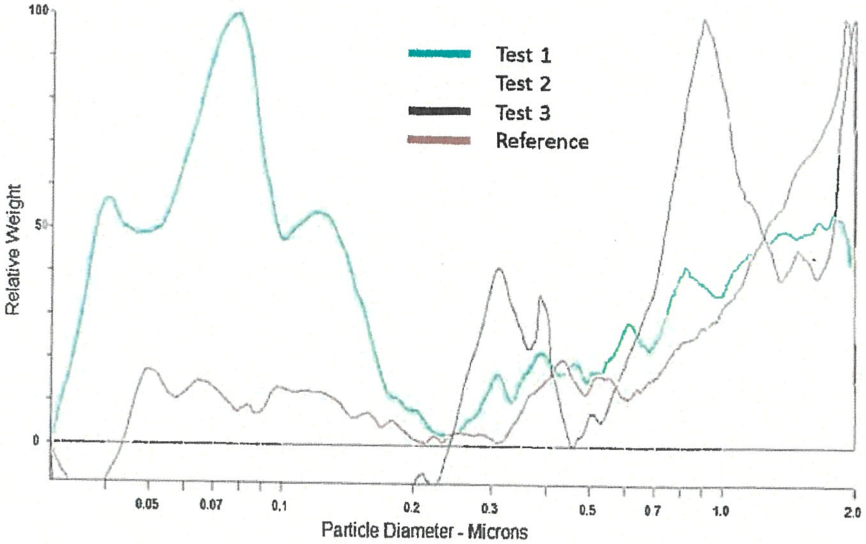

Figure 3. Number-weighted particle-size distribution of the particles presents in the water before application (reference) and in the three samples after extinguishing. Measurement was carried out by CPS.

This analysis leads to the conclusion that only extinguishing water from test 1 has a nanometric fraction, with particles around 70 nm in diameter. Other samples contain a majority of particles between 0.9 and 2 µm. This analysis confirms the possibility, mentioned in the literature [11], that extinguishing water might be loaded with nanoparticles, without being able to quantify them with the method used. Also, because nanoparticles are absent from tests where the reaction was the most developed, it can indicate that those particles might be dragged in the smoke plume before being dragged by water.

To get information on the nature of the nanometric particles in the extinguishing water of test 1, additional analysis by transmission electron microscopy were performed. Images are presented in Figure 4. Figure 4a shows a picture of a representative sample of what was observed over the entire grid. Several populations of particles of highly variable sizes are identified and presented on Figure 4b–d. The majority of particles are the finest and correspond to the smallest black dots in Figure 4a. According to Figure 4b, one can conclude that soot nanoparticles agglomerate and form nanostructured clusters. Spherical particles of intermediate size are then observed (Figure 4c) and are associated with tarballs, having a diameter around 100 nm. Finally, the largest particles (Figure 4d) have a characteristic size around one micron and are mainly metal particles, composed of iron and aluminum.

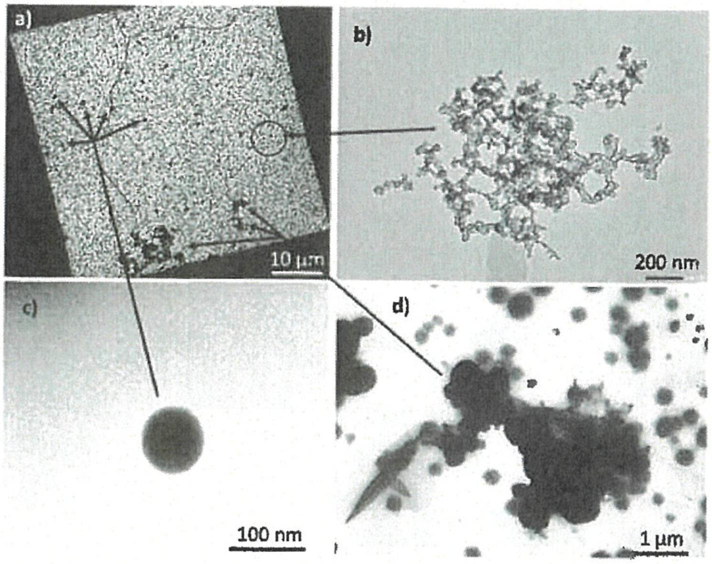

Figure 4. TEM analysis of the particles presents in the extinguished water of test 1. (**a**) Zoom-out of a representative area showing the relatives proportion of the three particles population encountered, (**b**) zoom-in of particles identified as soot agglomerate, (**c**) zoom-in of particles identified as tarballs and (**d**) zoom-in of particles identified as metallic.

Particles bellow 2.5 µm are inhalable and might pose a toxicological risk for humans [23]. In the case of this study, the particles are in water, making eco-toxicity the main risk identified. No size threshold is clearly defined in the literature nor in regulations. Some studies have nonetheless showed that particles with a size lower than 100 nm can enter the root system of higher plants and be translocated to aerial parts which demonstrate the possibility of trophic transfer [24]. In invertebrates (water flee), accumulation of several types of nanomaterials has been shown [25]. The interaction phenomenon between metallic oxide nano materials and freshwater micro-algae was also evidenced by Rivero et al. [26].

3.2.4.1. pH Measurement

Table 5 shows the pH measured in the sampled water immediately after each test.

Table 5. pH of the extinguishing water. (Expanded: k = 2) uncertainty of measurement is 1%.

	Test 1 (Module A)	Test 2 (Module A)	Test 3 (Module B)
pH	5.2	5.9	11

Depending on the test, the pH of extinguishing water is either acidic or basic. Values obtained in our tests would rate the corresponding water clearly outside recommended freshwater quality standards (6.5 < pH < 9) or limiting pH values for treatment in wastewater sewage systems (see Table 6).

Table 6. pH limit values in different local regulations.

pH Limit Values	Drinkable Water	Industrial Effluent Value for Discharge in Sewage Systems
EPA [27] (USA)	6.5 to 9	
Canada [28,29]	7 to 10.5	6–9
Switzerland [16,17]	6.8 to 8.2	6.5 to 9

Battery field failure incident reports as well as scarce pH values reported in the literature mostly report very basic contaminated water resulting from fire-fighting operations [16–18,30], although this is not always the case [31].

The basicity of the water is sometimes explained by the inner content of the cell that may contain soluble metal hydroxides. By contrast, the resulting acid fire water could be related to the interaction of the water with the acidic gases contained in the fire plume [31]. A difference in concentration in metallic species between the two tests might explain (see Table 2) the difference in pH observed. Depending on the environments in which the water will evolve (acidic or basic soils, etc.), it cannot be ruled out that these pHs are modified [32] before final pouring into aquatic ecosystems (surface of underground water resources).

4. Discussion

These tests were carried out at a small scale compared to what could occur, for example, in the event of an incident with a stationary storage container or storage warehouse. In such an event, the quantities of batteries involved, and the quantity of water used for extinction would be much higher. To estimate the orders of magnitude of water contamination values for a realistic situation (BESS container or storage warehouses), a simplistic extrapolation of the results obtained based on real incident data is proposed. In the Perles and Castelet (Ariège in France) battery stationary storage fire, which is well documented [33], and involving a stationary storage of 1500 kWh, the local authorities estimated that a volume of water of 180 m^3 was used by the firefighters, i.e., 0.12 L/Wh. This volume seems to be a good basis to extrapolate results as other feedback for other large-scale applications give similar values [34].

In the tests presented here, the volume of water used is coherent with other same-level studies [35] and, for test 1 on prismatic cells, 7 L were poured onto the 500 Wh battery (0.014 L/Wh) during test 2, and the total volume of water was 12 L (0.024 L/Wh). For the cylindrical cell, 3.9 L were poured onto the 900 Wh (0.01 L/Wh) battery. The values proposed in Table 7 correspond, for a selection of substances, to an extrapolation using a proportionality rule between the concentrations measured during the tests and the actual conditions reported during the Ariège incident (see Supplemental Material). This calculation also assumes that the normalized water flow rate (per watt-hour) does not significantly influence the mass transfer of pollutants in the run-off water.

In order to evaluate the potential environmental hazard of these wastewaters, the last column presents the "Predicted No-Effect Concentration"(PNEC) of the substance when available on the ECHA website [36]. Those values should be read with caution as they are given for a yearly average and are extracted from several sources, including industrial ones. The concentration in the wastewater was above PNEC values for all the substances studied when the data were available except for naphthalene, showing a potential environmental hazard. Two compounds show a particularly high hazardous potential: Co and EMC with concentrations, respectively, 2500 and 260 times greater than their PNEC. This means that, in a realistic scenario where two fire hoses are used to fight a fire using 1000 L/min, and the waste waters are flowing to a small river with a flow of 3 m^3/s, the concentrations of contaminants in the river are still above the PNEC for those compounds. It is also worth noting that some of the compounds' PNEC could not be found on the ECHA website but might be even more hazardous. For example, a PNEC as low as 0.0017 mg/L can be found for nickel [37] from sources other than ECHA. Another point to consider is the possible interaction between the contaminants. To assess this, the best method would be to test the particle mix directly. Few studies of this kind are available but, Yang et al. has recently shown [8] that particles from the NMC cell thermal runaway could cause inhibition of bacterial activities in the range of 25–200 mg/L and severe acute toxicity at 100 mg/L in 5 h [8] and Quant et al. showed the acute toxicity of the runoff water [19].

Table 7. Extrapolation of the experimental results to a real application and extinguishing. The last column presents the PNEC of the compound when available on ECHA website [36].

Substance	Test 1 (Module A)	Test 2 (Module A)	Test 3 (Module B)	PNEC Freshwater
Al (mg/L)	8.7	5.9	6.2	-
Co (mg/L)	0.05	2.6	0.6	0.00106
Cu (mg/L)	0.04	0.05	0.3	0.0063
Fe (mg/L)		Test 1 (module A)	Test 2 (module A)	Test 3 (module B)
Li (mg/L)	pH	5.2	5.9	11
Mn (mg/L)	0.1	3.4	0.5	0.034
Na (mg/L)	1.8	3.3	2.2	-
Ni (mg/L)	0.4	9.8	3.3	-
P (mg/L)	23.5	22.6	0.5	-
Fluorides (mg/L)	16.6	18.3	7.8	0.89
Chlorides (mg/L)	3.9	7.3	16.9	-
EMC (mg/L)	16.1	11.8	n/a	0.062
EC (mg/L)	126.2	92.2	n/a	5.9
Naphthalene (mg/L)	0.00015	0.00056	0.00026	0.0024

5. Conclusions

In the present work, the two battery modules were triggered in thermal runaway and subsequent degassing and fire. Water was applied to mock-up firefighting operations in order to analyze the composition of the extinguishing water.

The tests presented in this paper highlight that waters used for firefighting on NMC Li-ion batteries are susceptible to containing many metals, including Ni, Mn, Co, Li and Al. Those metals are mixed with other carbonaceous species (soots, tarballs). It is also important to note that particles present in the water can be nanometric or in the form of nanostructured clusters. In addition to the solid contaminants, liquid compounds can be present, especially organic carbonates coming from the electrolyte (EC and EMC in this case) and also gaseous species such as PAH. A comparison with PNEC values showed that this water could be potentially hazardous to the environment, depending on the actual situation encountered in the case of thermal runaway propagation with a Li-ion battery-based system.

These tests also make it possible to identify some trends concerning the reaction scenario. By comparing the two extinguishing operations on the prismatic cells, one can see that when the fire is developed, the water is much more concentrated in PAH and cathode metals (Ni, Mn, Co). On the other hand, the concentrations of elements coming from the liquid electrolyte (typically Li, P, F), more easily accessible, are present in equivalent quantities. Liquid organic carbonates are preferably found in the case of degassing without ignition. These low boiling point liquids are otherwise vaporized and found mainly in the gaseous phase. The comparison of the results between the prismatic cell module and the 18,650-cell module also confirms the importance of the cell and module geometry, influencing, in particular, the mechanical strength of the system and, therefore, the confinement of the inner materials.

As large Li-ion batteries are fast spreading (in so-called Battery Energy Storage Systems, BESS, for example), and only few data on the environmental impact of fires in those systems are available, it is crucial to further develop consolidated knowledge in this field. Several directions could be suggested for future tests like developing higher level (or full scale) testing to increase test representativity. Owing to field operational constraints in terms of emergency response following a fire, considering time between event initiation and water suppressant application as a parameter in futures studies also seems important. Other investigations worth being performed are, for instance, a detailed assessment of air, water and soil local impacts following Li-ion BESS significant incidents or in-depth environmental impact studies of key Li-ion substances like organic carbonate solvents (EC, EMC, etc.).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/batteries10040118/s1.

Author Contributions: A.B. was involved in conceptualization, investigation, formal analysis, in writing of the original manuscript and project administration; A.P. was involved in investigation and formal analysis; G.M. was involved in supervision, validation, review and editing; T.C. was involved in review; A.E.-M. was involved in investigation; T.D. was involved in investigation; J.-P.B. was involved in investigation; B.T. was involved in in conceptualization, investigation and review and A.L. was involved in supervision, validation and review. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the French Ministry for Ecological Transition (Program 181).

Data Availability Statement: The data presented in this study are available in article.

Conflicts of Interest: The authors declare no conflicts of interest.

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CEC Exhibit-2

This article is more than **1 year old**

How solar farms took over the California desert: 'An oasis has become a dead sea'

Residents feel trapped and choked by dust, while experts warn environmental

damage is 'solving one problem by creating others'

By Oliver Wainwright in Desert Center, California

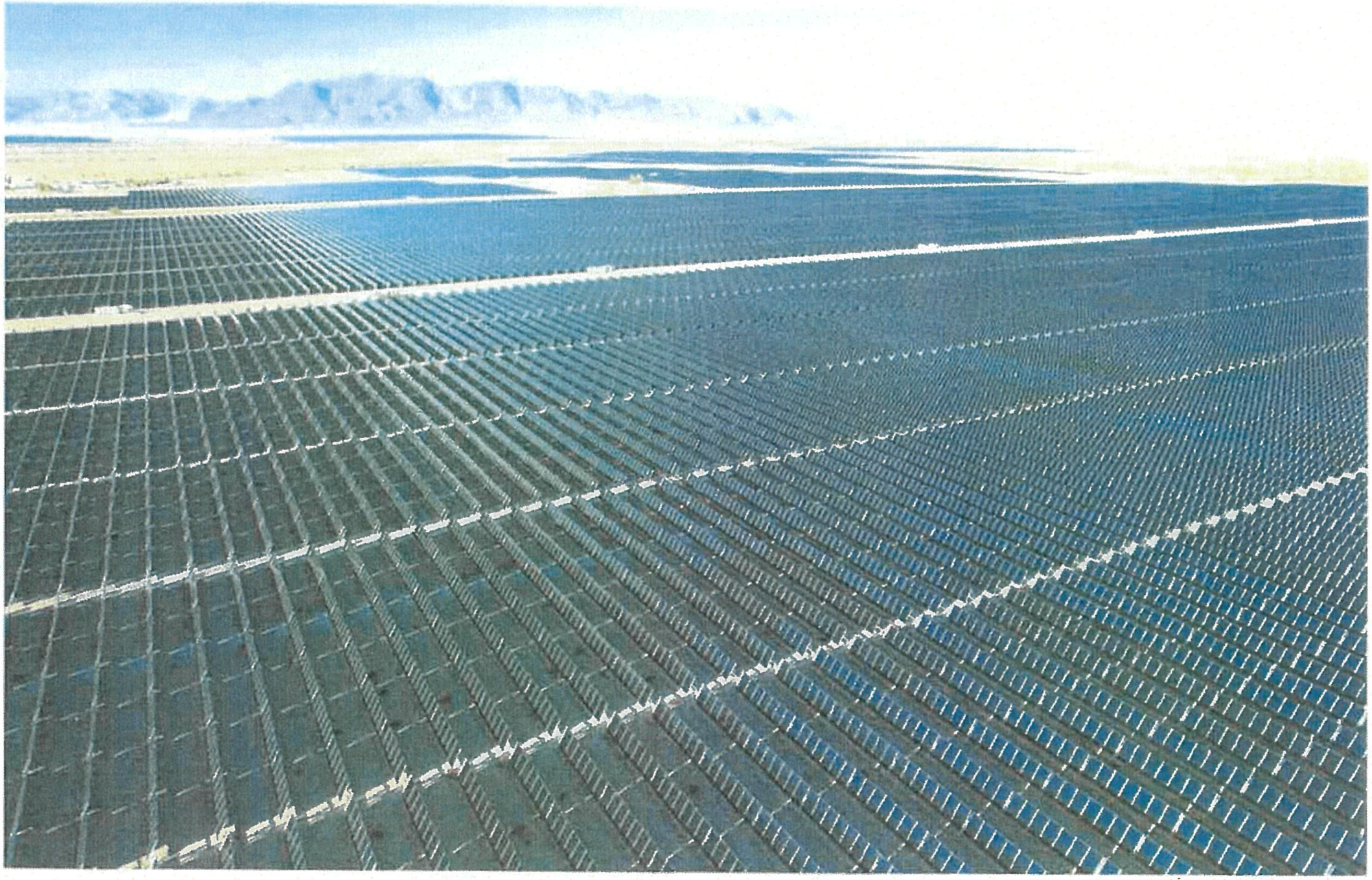
A boiler tower is surrounded by mirrors at the Ivanpah solar electric generating system in the Mojave Desert. Photograph: David McNew/Getty Images

Sun 21 May 2023 06.00 EDT

Deep in the Mojave desert, about halfway between Los Angeles and Phoenix, a sparkling blue sea shimmers on the horizon. Visible from the I-10 highway, amid the parched plains and sun-baked mountains, it is an improbable sight: a deep blue slick stretching for miles across the Chuckwalla Valley, forming an endless glistening mirror.

But something's not quite right. Closer up, the water's edge appears blocky and pixelated, with the look of a low-res computer rendering, while its surface is sculpted in orderly geometric ridges, like frozen waves.

"We had a guy pull in the other day towing a big boat," says Don Sneddon, a local resident. "He asked us how to get to the launch ramp to the lake. I don't think he realised he was looking at a lake of solar panels."



Solar panels in the Mojave desert, near Lake Tamarisk. Photograph: Oliver Wainwright/The Guardian

Over the last few years, this swathe of desert has been steadily carpeted with one of the world's largest concentrations of solar power plants, forming a sprawling photovoltaic sea. On the ground, the scale is almost incomprehensible. The Riverside East Solar Energy Zone - the ground zero of California's solar energy boom - stretches for 150,000 acres, making it 10 times the size of Manhattan.

It is a crucial component of the United States' green energy revolution. Solar makes up about 3% of the US electricity supply, but the Biden administration hopes it will reach 45% by 2050, primarily by building more huge plants like this across the country's flat, empty plains.

But there's one thing that the federal Bureau of Land Management (BLM) - the agency tasked with facilitating these projects on public land - doesn't seem to have fully taken into account: the desert isn't quite as empty as it thought. It might look like a barren wilderness, but this stretch of the Mojave is a rich and fragile habitat for endangered species and home to thousand-year-old carbon-capturing woodlands, ancient Indigenous cultural sites - and hundreds of people's homes.

Residents have watched ruefully for years as solar plants crept over the horizon, bringing noise and pollution that's eroding a way of life in their desert refuge.

"We feel like we've been sacrificed," says Mark Carrington, who, like Sneddon, lives in the Lake Tamarisk resort, a community for over-55s near Desert Center, which is increasingly surrounded by solar farms. "We're a senior community, and half of us now have breathing difficulties because of all the dust churned up by the construction. I moved here for the clean air, but some days I have to go outside wearing goggles. What was an oasis has become a little island in a dead solar sea."

Concerns have intensified following the recent news of a project, called Easley, that would see the panels come just 200 metres from their backyards. Residents claim that excessive water use by solar plants has contributed to the drying up of two local wells, while their property values have been hit hard, with several now struggling to sell their homes.

A large array of solar panels one hour north of Los Angeles in Kern county, near Mojave, California. Photograph: George Rose/Getty Images

"It has been psychologically gruelling," says Teresa Pierce, who moved here six years ago. "From the constant pounding of the metal posts to the endless dust storms. I now have allergies that I'd never had before – my arms burn all day long and my nose is always running. I feel like a prisoner in my own home."

Elizabeth Knowles, director of community engagement for Intersect Power, the company behind the Easley project, said it knew of residents' concerns and was exploring how to move the project further from the community. "Since being made aware of their concerns, we have been in regular contact with residents to listen to their concerns and incorporate their feedback into our planning efforts."

'90% of the story is underground'

The mostly flat expanse south-east of Joshua Tree national park was originally identified as a prime site for industrial-scale solar power under the

Obama administration, which fast-tracked the first project, Desert Sunlight, in 2011. It was the largest solar plant in the world at the time of completion, in 2015, covering an area of almost 4,000 acres, and it opened the floodgates for more. Since then, 15 projects have been completed or are under construction, with momentous mythological names like Athos and Oberon. Ultimately, if built to full capacity, this shimmering patchwork quilt could generate 24 gigawatts, enough energy to power 7m homes.

But as the pace of construction has ramped up, so have voices questioning the cumulative impact of these projects on the desert's populations - both human and non-human.

Kevin Emmerich worked for the National Park Service for over 20 years before setting up Basin & Range Watch in 2008, a non-profit that campaigns to conserve desert life. He says solar plants create myriad environmental problems, including habitat destruction and "lethal death traps" for birds, which dive at the panels, mistaking them for water.

He says one project bulldozed 600 acres of designated critical habitat for the endangered desert tortoise, while populations of Mojave fringe-toed lizards and bighorn sheep have also been afflicted. "We're trying to solve one environmental problem by creating so many others."

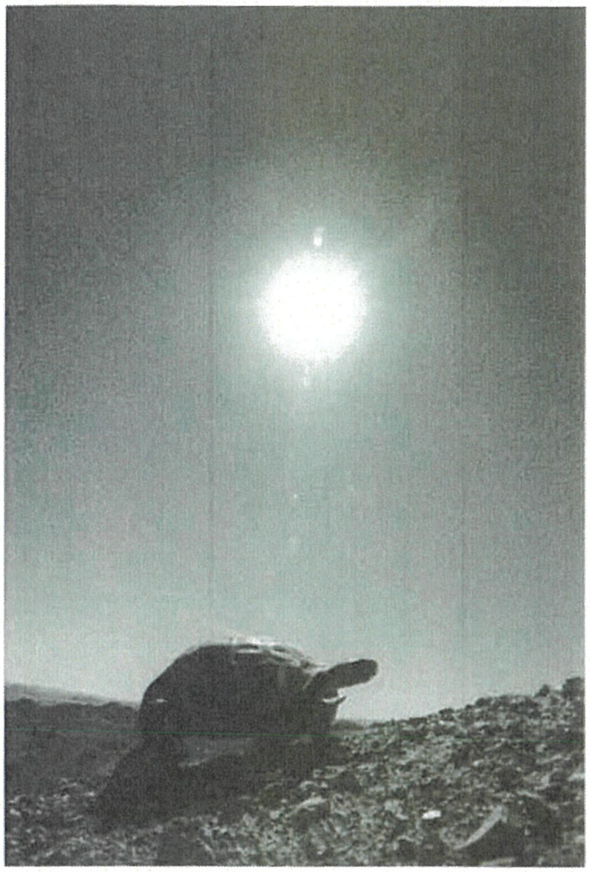
Heliostats at the Ivanpah solar thermal power plant in the Mojave desert. Photograph: Ashley Cooper/Alamy

As the pace of construction has ramped up, so have voices questioning the cumulative impact of these projects on the desert's populations. Photograph: Oliver Wainwright/The Guardian

Such adverse impacts are supposed to be prevented by the desert renewable energy conservation plan (DRECP), which was approved in 2016 after years of consultation and covers almost 11m acres of California. But Emmerich and others think the process is flawed, allowing streamlined environmental reviews and continual amendments that they say trample conservationists' concerns.

"The plan talks about the importance of making sure there's enough room between the solar projects to preserve wildlife routes," says Chris Clarke of the National Parks Conservation Association. "But the individual assessments for each project do not take into account the cumulative impact. The solar plants are blocking endangered species' natural transport corridors across the desert."

Much of the critical habitat in question is dry wash woodland, made up of "microphyll" shrubs and trees like palo verde, ironwood, catclaw and honey mesquite, which grow in a network of green veins across the desert. But, compared with old-growth forests of giant redwoods, or expanses of venerable Joshua trees, the significance of these small desert shrubs can be hard for the untrained eye to appreciate.



A Mojave desert tortoise under the desert sun. Photograph: Scott Trageser/Alamy

"When people look across the desert, they just see scrubby little plants that look dead half the time," says Robin Kobaly, a botanist who worked at the BLM for over 20 years as a wildlife biologist before founding the Summertree Institute, an environmental education non-profit. "But they are missing 90% of the story - which is underground."

Her book, The Desert Underground, features illustrated cross-sections that reveal the hidden universe of roots extended up to 150ft below the surface, supported by branching networks of fungal mycelium. "This is how we need to look at the desert," she says, turning a diagram from her book upside-down. "It's an underground forest - just as majestic and important as a giant redwood forest, but we can't see it."

The reason this root network is so valuable, she argues, because it operates as an enormous "carbon sink" where plants breathe in carbon dioxide at the surface and out underground, forming layers of sedimentary rock known as caliche. "If left undisturbed, the carbon can remain stored for thousands of years,'" she says.

Desert plants are some of the oldest carbon-capturers around: Mojave yuccas can be up to 2,500 years old, while the humble creosote bush can live for over 10,000 years. These plants also sequester carbon in the form of glomalin, a protein secreted around the fungal threads connected to the plants' roots, thought to store a third of the world's soil carbon. "By digging these plants up," says Kobaly, "we are removing the most efficient carbon sequestration units on the planet - and releasing millennia of stored carbon back into the atmosphere. Meanwhile, the solar panels we are replacing them with have a lifespan of around 25 years."

Mirrors sprawl across the desert at the Ivanpah solar electric generating system near Nipton, California. Photograph: David McNew/Getty Images

For Alfredo Acosta Figueroa, the unstoppable march of desert solar represents an existential threat of a different kind. As a descendant of the Chemehuevi and Yaqui nations, he has watched as what he says are numerous sacred Indigenous sites have been bulldozed.

"The history of the world is told by these sites," he says, "by geoglyphs, petroglyphs, and pictographs. Yet the government has chosen to ignore and push aside the creation story in the name of progress."

His organisation, La Cuna de Aztlan, acts as custodian of over 300 such sites in the Lower Colorado River Basin, many of which, he says, have already been damaged beyond repair. He claims that a 200ft-long geoglyph of Kokopelli, a flute-playing god, was destroyed by a new road to one of the solar plants, while an image of Cicimitl, an Aztec spirit said to guide souls to the afterlife, is also threatened. "The solar projects cannot destroy just one sacred site without destroying the sacredness of the entire area," he adds. "They are all connected."

He cites a 2010 report by the California Energy Commission, which includes testimony from the heritage experts Dr Elizabeth Bagwell and Beverly E Bastian stating that "more than 800 sites within the I-10 Corridor and 17,000 sites within the Southern California Desert Region will potentially be destroyed", and that "mitigation can reduce the impact of the destruction, but not to a less-than-significant level".

The Bureau of Land Management declined a request for an interview. In an emailed statement, its public affairs officer, Michelle Van Der Linden, did not directly address questions about solar plants' water use, health issues, or ecological and archeological impacts, but said the agency operated within the applicable laws and acts. "The DRECP effort was a multiple-year collaborative discussion resulting in an agreement reached between the BLM, numerous environmental groups, partners and stakeholders, in regards to the application and decision process related to renewable energy projects. Project issues were and continue to be identified and addressed through the National Environmental Policy Act process, which includes the opportunity for public engagement and input and also addresses many of the cumulative impacts and additional environmental, social and economic concerns mentioned."

'So many other places we should put solar'

Wild burros near the Ivanpah solar electric generating system. Photograph: David McNew/Getty Images

But a more fundamental question remains: why build in the desert, when thousands of acres of rooftops in urban areas lie empty across California?

"There are so many other places we should be putting solar," says Clarke, of the National Parks Conservation Association, from homes to warehouses to parking lots and industrial zones. He describes the current model of large-scale, centralised power generation, hundreds of miles from where the power is actually needed, as "a 20th-century business plan for a 21st-century problem".

"The conversion of intact wildlife habitat should be the absolute last resort, but it's become our first resort - just because it's the easy fix."

Vincent Battaglia, founder of Renova Energy, a rooftop solar company based in Palm Desert, agrees. "We've been led to believe that all solar is good solar," he says. "But it's not when it molests pristine land, requires hundreds of millions of dollars to transmit to city centres, and loses so much power along the way. It is simply preserving the monopoly of the big energy companies."

California recently reduced the incentive for homeowners to install rooftop solar panels after it slashed the amount that they can earn from feeding power back into the grid by about 75%. Forecasters suggest that, after doubling in size from 2020 to 2022, the market for residential solar installations is expected to decrease by nearly 40% by 2024 as a result.

Battaglia is optimistic that home energy storage is the answer. "Batteries are the future," he says. "With solar panels on rooftops and batteries in homes, we'll finally be able to cut the cord from the big utility companies. Soon, those fields of desert solar farms will be defunct - left as rusting relics of another age."

Back in Lake Tamarisk, the residents are preparing for the long battle ahead. "They picked on a little town and thought they could wipe us out," says Sneddon. "But they can't just mow us over like they did the desert tortoises.

"They thought we were a bunch of uneducated redneck hicks living out here in the desert," says Pierce. "We're going to show them they were wrong."

CEC Exhibit-3

Solar Power in Your Community

A guide for local governments on how to increase access to and deployment of solar PV.

U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Types of Solar

There are four main types of photovoltaic solar deployment which local governments may consider in their planning. The types of solar are differentiated by their size and scale. Understanding the differences between the types of solar deployment can help local governments identify the scale of solar deployment that can best meet community needs. Although each category does not have a standard size, these definitions include the typical size range for each type.

- Residential solar: Also referred to as "rooftop solar", residential solar is a form of distributed energy with solar panels mounted on individual rooftops. Residential solar deployments can range in size from 3 kW–11 kW (Feldman et al. 2021).
- Commercial solar: Commercial solar is a larger form of distributed solar energy that encompasses rooftop and ground-mounted deployment. Commercial solar deployments can range in size from 100 kW–2 MW (Feldman et al. 2021).
- Community solar: Also referred to as "solar gardens" or "shared solar", community solar is another form of distributed energy where customers can buy or lease a portion of an off-site shared solar project. Community solar sites are typically <5 MW in size. See more information on community solar in Section 6.2.
- Utility-scale solar: Utility-scale solar deployments are ground-mounted systems that feed the generated electricity directly into the electric grid. Utility-scale solar deployments can range in size from 5–100 MW (Feldman et al. 2021).

The size estimates included here are not strict boundaries, and state or local laws may define solar deployment sizes differently. This guidebook focuses primarily on residential and community solar. Innovative applications of solar energy, like agrivoltaics or floatovoltaics, fall within these categories depending on the scale at which they are deployed. See Section 6.4 for more information on innovative solar deployment.

Low- and Moderate-Income Targets

Solar targets specific to LMI communities can help ensure more equitable solar deployment at the local level, but will require a clear definition of LMI in order to set goals. LMI-specific targets may also exist at the state level. For example, some states, such as Colorado and Oregon, have an LMI carve-out in their community solar policies that dedicates a certain percentage of community solar subscriptions to LMI households. Section 2.4 describes LMI-targeted financing options.

TIP

The following obstacles to LMI solar deployment should be considered when setting LMI-specific targets:

- Upfront installation costs and community solar subscription costs can be prohibitive for LMI households.

CEC Exhibit-4

NFPA RESEARCH FOUNDATION
RESEARCH FOR THE NFPA MISSION

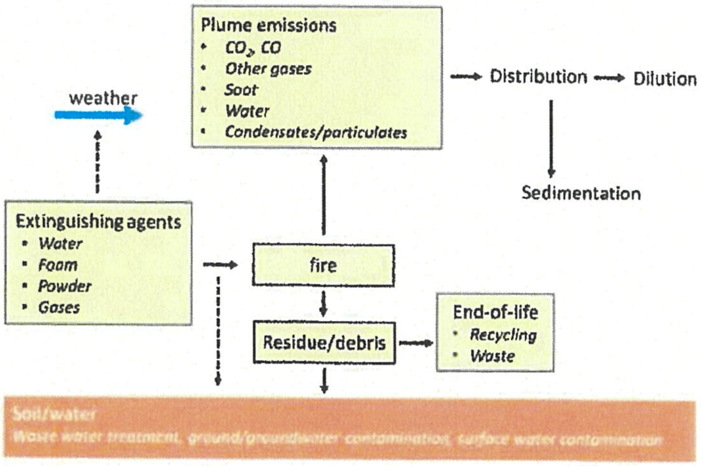
Project Summary

Environmental Impact of Li-ion BESS Incidents compared to other types of fires

Background

Most fires occurring in the built environment contribute to air contamination from the fire plume (whose deposition is likely to subsequently include land and water contamination), contamination from suppression water runoff containing toxic products, and other environmental discharges or releases from burned materials.

Incidents involving lithium-ion batteries are mostly focused on fires and the release of potentially toxic gases, which may pose toxicity concerns for first responders or the public. In addition to the exposure risk to first responders and spectators at, for example, a road traffic accident, there is also the broader spectrum of the environmental impact of such fires. In addition to heat, with fire or a toxic and potentially explosive vapor cloud, there is also a possibility of air transportation of substances and with time, their deposition in other, distant places.



The close surroundings are also affected by the fire debris, transportation of pollutants by fire extinguishing agents and release of remaining contamination from fire debris of burnt batteries. Following fire suppression activities, the run off into the water or soil may present concerns in terms of environmental impact. As the use and application of lithium-ion batteries continues to grow, questions remain as to how the environmental impact to air, soil and water from lithium ion battery fires compares to other common fires.

Research Goal

The overarching goal of this research program is to evaluate the environmental impact (to air, water, and soil) of a lithium-ion ESS fire (including runoff from suppression activities) compared to other common types of fires.

Research sponsored by

This project is generously sponsored by the members of the FPRF Energy Storage Research Consortium (ESRC), including: Energy Safety Response Group (ESRG), Fire & Risk Alliance, LLC, FM Global, General Motors (GM), Pacific Northwest National Laboratory (PNNL), Southern Company, Tesla, UL Research Institutes, and Wartsila Energy.

Environmental Impact of Li-ion BESS Incidents compared to other types of fires

Project Tasks

This research project, with technical oversight from the project technical panel, will involve the following tasks:

Task 1: Literature review

Task 1.1: Collect and analyze the relevant literature on the topic. The analysis should consider types of environmental impact, facility/fuel types, fire impacts, etc.

a) Generally characterize ESS systems. Where information is available, identify and characterize the material composition of the components of a BESS, including the batteries, coolants, insulation, electrical components, encasement materials, etc. that may contribute to the airborne emissions or ground contamination following fire suppression activities during a fire event.

b) Scenario identification: Identify a representative number of lithium-ion battery fire scenarios to characterize and evaluate the toxic gas emissions, pathways and environmental impact.
   i. Identify a representative number of lithium-ion battery fire scenarios to characterize and evaluate the toxic gas emissions, exposure pathways and environmental impact. Also identify relevant datasets or other data sources that consider emissions and particulates from li-ion battery cells with different chemistries, state of charge, different failure modes, etc.
   ii. Identify a representative number of other common fire scenarios (e.g., other products/fuels) to characterize and evaluate the toxic gas emissions, exposure pathways and environmental impact. Also identify relevant datasets or other data sources of emissions and particulates from other common fire scenarios fires

c) Identify, review and summarize available international literature and compile available test data on toxic gas products, concentrations, emissions and particulates to the ***Air*** (airborne contamination) and exposure pathways resulting from:
   i. Li-ion battery ESS fire scenarios selected in Task 1.1.C.(i)
   ii. Other types of fire scenarios selected in Task 1.1.C(ii)

d) Identify, review and summarize available international literature and compile available test data on toxic gas products, concentrations, emissions and particulates to **Soil and Water** (e.g., contamination from water-runoff) and exposure pathways resulting from:
   i. Suppressed Li-ion battery ESS fire scenarios selected in Task 1.1.C(i)
   ii. Other types of suppressed fire scenarios selected in Task 1.1.C(ii)

e) Summarize a list of toxic products and exposure pathways resulting from fire scenarios defined in Task 1.1(c) and clarify the similarities and differences between Li-ion ESS fires and other standard fire scenarios.

Task 1.2: Summarize all information gathered in Tasks 1.1 in an interim draft report. This summary report should address all the findings from Tasks 1.1, including the impact of different li-ion battery chemistries, battery capacities, and varying states of charge and states of health.

Task 2: Update Emissions Factors Database.
Using the data found in Task 1 and building on the database of emissions factors of building materials from the past FPRF "Environmental Impact of Fire in the Built Environment: Emissions Factors" project, add data on emissions from li-ion battery ESS fires to this existing database.

Environmental Impact of Li-ion BESS Incidents compared to other types of fires

Task 3: Gap Analysis and Research Plan

- Conduct an assessment of key gaps in information reviewed in Task 1, in consideration of an overall environmental impact assessment of li-ion battery ESS fires compared to other common fires. Specifically, identify key gaps in literature, data, and emission factors, at a minimum.
- Based on the identified gaps, develop a research plan to fill the knowledge gaps, including preliminary details for needed experimental testing.

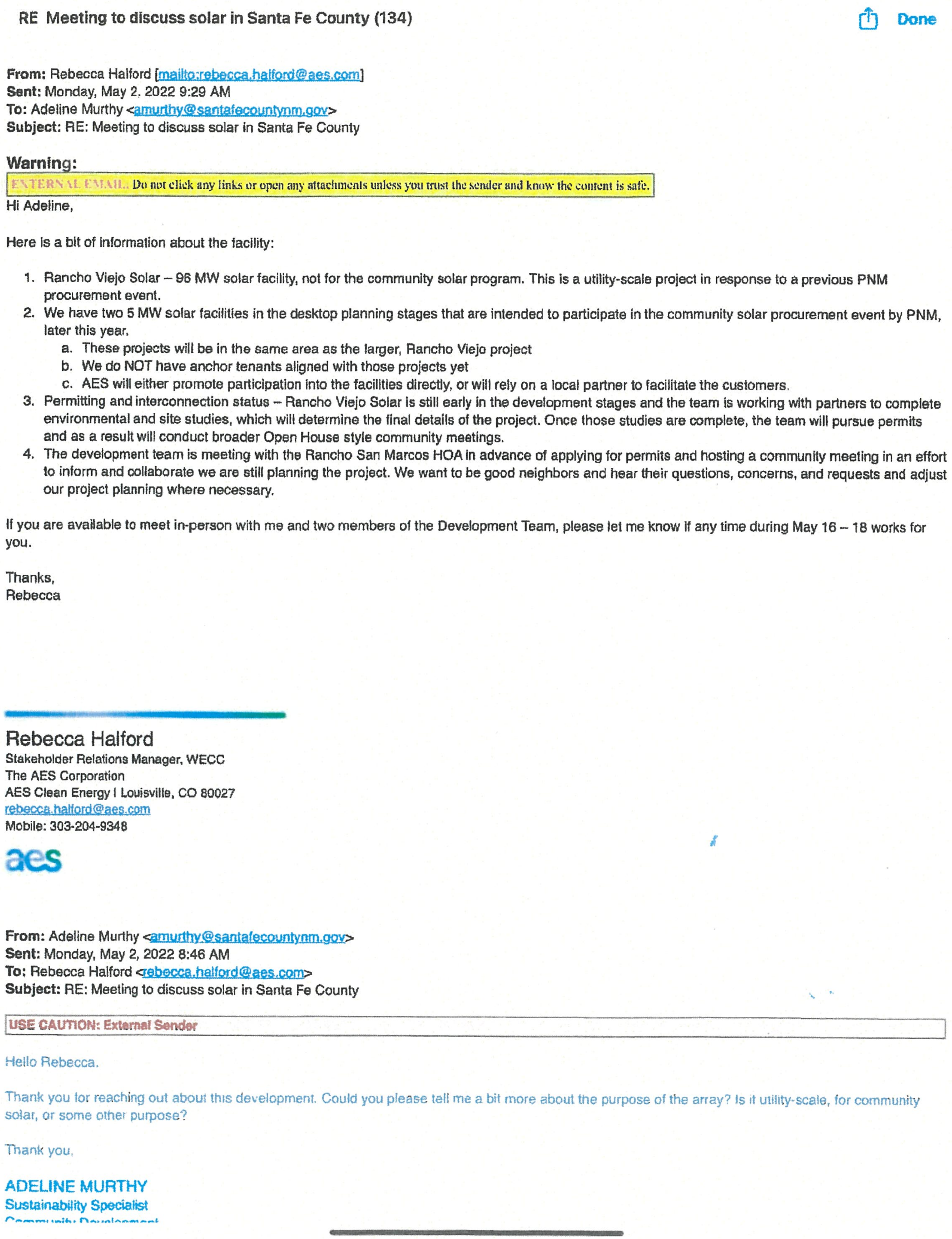
Task 4: Develop a Final Report

Develop a draft final report, summarizing the findings from Tasks 1 – 3, and review with the technical panel. After incorporating panel feedback, submit a final report for publication.

Schedule and Implementation

This project is expected to be completed within 6-months of project initiation. This research project is led by the Fire Protection Research Foundation and will be conducted in accordance with the "Research Foundation Policies for the Conduct of Research Projects". The project will be guided by a Project Technical Panel who will provide input to the project, recommend contractor selection, review periodic reports of progress and research results.

CEC Exhibit-5



RE Meeting to discuss solar in Santa Fe County (134)

From: Rebecca Halford [mailto:rebecca.halford@aes.com]
Sent: Monday, May 2, 2022 9:29 AM
To: Adeline Murthy <amurthy@santafecountynm.gov>
Subject: RE: Meeting to discuss solar in Santa Fe County

Warning:
EXTERNAL EMAIL. Do not click any links or open any attachments unless you trust the sender and know the content is safe.

Hi Adeline,

Here is a bit of information about the facility:

1. Rancho Viejo Solar – 96 MW solar facility, not for the community solar program. This is a utility-scale project in response to a previous PNM procurement event.
2. We have two 5 MW solar facilities in the desktop planning stages that are intended to participate in the community solar procurement event by PNM, later this year.
   a. These projects will be in the same area as the larger, Rancho Viejo project
   b. We do NOT have anchor tenants aligned with those projects yet
   c. AES will either promote participation into the facilities directly, or will rely on a local partner to facilitate the customers.
3. Permitting and interconnection status – Rancho Viejo Solar is still early in the development stages and the team is working with partners to complete environmental and site studies, which will determine the final details of the project. Once those studies are complete, the team will pursue permits and as a result will conduct broader Open House style community meetings.
4. The development team is meeting with the Rancho San Marcos HOA in advance of applying for permits and hosting a community meeting in an effort to inform and collaborate we are still planning the project. We want to be good neighbors and hear their questions, concerns, and requests and adjust our project planning where necessary.

If you are available to meet in-person with me and two members of the Development Team, please let me know if any time during May 16 – 18 works for you.

Thanks,
Rebecca

Rebecca Halford
Stakeholder Relations Manager, WECC
The AES Corporation
AES Clean Energy | Louisville, CO 80027
rebecca.halford@aes.com
Mobile: 303-204-9348

From: Adeline Murthy <amurthy@santafecountynm.gov>
Sent: Monday, May 2, 2022 8:46 AM
To: Rebecca Halford <rebecca.halford@aes.com>
Subject: RE: Meeting to discuss solar in Santa Fe County

USE CAUTION: External Sender

Hello Rebecca,

Thank you for reaching out about this development. Could you please tell me a bit more about the purpose of the array? Is it utility-scale, for community solar, or some other purpose?

Thank you,

ADELINE MURTHY
Sustainability Specialist
Community Development

RE Meeting to discuss solar in Santa Fe County (134) Done

Stakeholder Relations Manager, WECC
The AES Corporation
AES Clean Energy | Louisville, CO 80027
rebecca.halford@aes.com
Mobile: 303-204-9348

aes

From: Adeline Murthy <amurthy@santafecountynm.gov>
Sent: Monday, May 2, 2022 8:46 AM
To: Rebecca Halford <rebecca.halford@aes.com>
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Hello Rebecca,

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Thank you,

ADELINE MURTHY
Sustainability Specialist
Community Development
505-992-9862

SANTA FE COUNTY

From: Rebecca Halford [mailto:rebecca.halford@aes.com]
Sent: Friday, April 29, 2022 5:27 PM
To: Adeline Murthy <amurthy@santafecountynm.gov>
Subject: Meeting to discuss solar in Santa Fe County

Warning:
EXTERNAL EMAIL: Do not click any links or open any attachments unless you trust the sender and know the content is safe.

Hello Adeline,
My name is Rebecca Halford and I'm reaching out to you in hopes of scheduling a meeting to discuss a solar facility that our team has in early development stages. The Project would be located in south Santa Fe County off of Hwy 14, a preliminary map is attached. A few of us from the project development team will be in Santa Fe during the week of May 16 to meet with the Rancho San Marcos HOA Board. While in town I was hoping to meet with you and any others on your team to discuss the project and to hear from you about your thoughts on solar development in the area and what the opinions and questions from the community might be. Would you be available to meet sometime May 16, 17 or 18?

Thank you,
Rebecca Halford

Rebecca Halford
Stakeholder Relations Manager, WECC
The AES Corporation
AES Clean Energy | Louisville, CO 80027
rebecca.halford@aes.com
Mobile: 303-204-9348

CEC Exhibit-6

PowerTech
ADVANCED ENERGY STORAGE SYSTEMS

Safety of Lithium-Ion batteries

Lithium-Ion refers to a family of Lithium-based battery technology. This family includes several sub-families or technologies, such as:

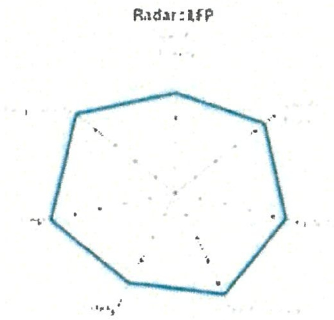
- LCO: Lithium Cobalt Oxide
- NCA: Nickel Cobalt Aluminium
- NMC: Nickel Manganese Cobalt
- LiFePO4 or LFP: Lithium Iron Phosphate
- LTO: Lithium Titanate Oxide, etc...

Often, we can hear that a product is equipped with **"Lithium-Ion" batteries**, this does not really have any meaning on the technology used. However, out of habit, the technology referred to as Lithium_Ion is usually **LCO, NCA or NMC**

Each of these technologies has **very different characteristics**, particularly in terms of **safety**, which can be found in the table below.

TECHNOLOGY	PROS / CONS	APPLICATION FIELD

Lithium Iron Phosphate (LFP-LiFePO4)

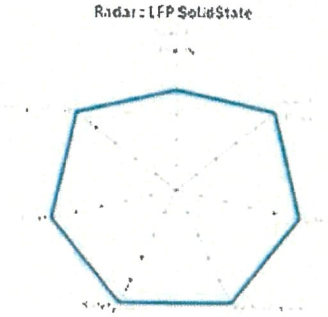


LFP Radar

- Excellent lifespan
- High level of safety
- Specific power
- Abundant material : Iron + Phosphate
- Good recyclability
- Slightly lower specific energy than LCO, NMC and NCA

- Vehicle traction (EV)
- high power applications
- Renewable energy storage
- Stationary batteries
- UPS, back-up, etc.

Lithium Iron Phosphate Solid State

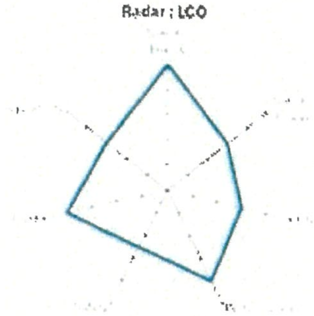


LFP SolidState Radar

- Excellent lifespan
- Very low cell temperature rise during use
- Extremely high level of safety
- Full charge in 30 minutes
- Very high power levels
- Cost
- Abundant material : Iron + Phosphate
- Good recyclability
- Slightly lower specific energy than LCO, NMC and NCA

- Vehicle traction (EV) et heavy duty traction
- Marine propulsion
- Robotics and AGV
- High power applications
- Renewable energy storage
- UPS, back-up, etc.

Lithium-Cobalt-Oxyde (LCO)



LCO Radar

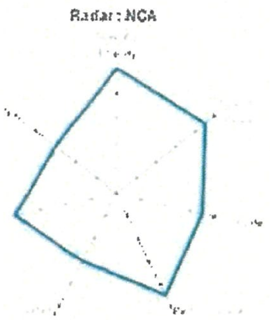
- Specific energy
- Limited Lifespan
- Dangerous chemistry if poorly controlled
- Rare material : Cobalt
- recyclability

- Low power application
- Power tools

Lithium Nickel Cobalt Aluminium (NCA)

- Specific energy
- Specific power
- Cost
- Dangerous chemistry if poorly controlled

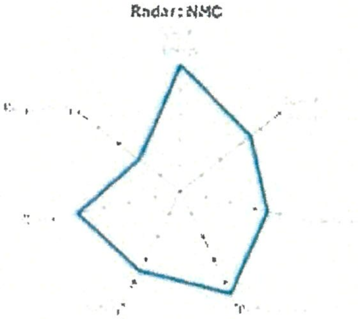
- Embedded applications
- EV
- Power tools, etc.



NCA Radar

- Rare material : Cobalt / Nickel
- recyclability

Lithium Nickel Manganese Cobalt (NMC)



NMC Radar

- Specific energy
- Limited Lifespan
- Safety
- Rare material : Cobalt + Manganese + Nickel
- recyclability

- Embedded applications
- EV
- Power tools, etc.
- Powerwall (TESLA)

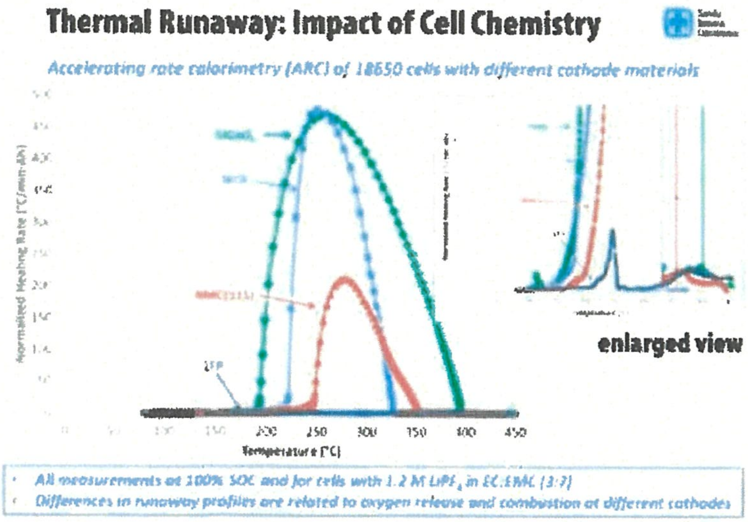
Thermal Runaway

One of the main causes of danger for lithium-ion cells is related to the phenomenon of thermal runaway. This is a heating reaction of the battery in use, caused by the nature of the materials used in the chemistry of the battery.

Thermal runaway is mainly caused by the solicitation of batteries under specific conditions, such as overload under adverse climatic conditions. The result of a thermal runaway of a cell depends on its level of charge and can lead in the worst case to an inflammation or even an explosion of the Lithium-Ion cell.

However, not all types of Lithium-Ion technology, due to their chemical composition, have the same sensitivity to this phenomenon.

The figure below shows the energy produced during an artificially induced thermal runaway



Thermal Runaway: Impact of Cell Chemistry

Accelerating rate calorimetry (ARC) of 18650 cells with different cathode materials

- All measurements at 100% SOC and for cells with 1.2 M $LiPF_6$ in EC:EMC (3:7)
- Differences in runaway profiles are related to oxygen release and combustion at different cathodes

Thermal Runaway Lithium-Ion – Impact of cell chemistry

It can be seen that among the Lithium Ion technologies mentioned above, **LCO and NCA are the most dangerous chemicals** from a thermal runaway point of view with a temperature rise of about **470°C per minute.** The **NMC chemistry** emits about half the energy, with an increase of 200°C per minute, but this level of energy causes **in all cases the internal combustion of materials and the ignition of the cell.**

In addition, it can be seen that **LiFePO4 – LFP technology** is **slightly subject to thermal runaway** phenomena, with a temperature rise of barely **1.5°C per minute.**

With this very low level of energy released, the **thermal runaway** of the Lithium Iron Phosphate technology is **an inherently improbable event** in normal operation, and even very difficult to artificially trigger.

More recently, with the arrival of **LFP Solid-State technology**, the level of safety now exceeds all safety standards, with a **thermal runaway that is intrinsically impossible to trigger** in normal operation.

Combined with a BMS, Lithium Iron Phosphate (LifePO4 – LFP) is currently the most secure Lithium-Ion technology on the market.

Mecanical Safety of Lithium-Ion Cells

Like thermal runaway, Lithium-ion cells have a different level of safety depending on the shocks or mechanical treatments they may undergo during their lifetime.

The nail penetration test is the most revealing way to qualify level of safety of Lithium-Ion batteries.

The test presented below is performed by perforating a Lithium Ion NMC cell and a Lithium Ion LiFePO4 cell.

We find here the same extremely stable behavior of Lithium Iron Phosphate cells while the NMC cell ignites almost immediately.

For information, the LCO, NCA, or Lithium Polymer cells have a similar behavior to the NMC in a perforation test (immediate inflammation)

Stress Tests of Lithium Chemistries Lithium Polymer (LiPo) vs Lithium Titanate (LTO) vs Lithium Iron Phosphate (LFP) :

LEAD ACID BATTERY DOWNSIDES

LITHIUM-ION BATTERY ADVANTAGES

LITHIUM-ION VS LEAD-ACID BATTERY

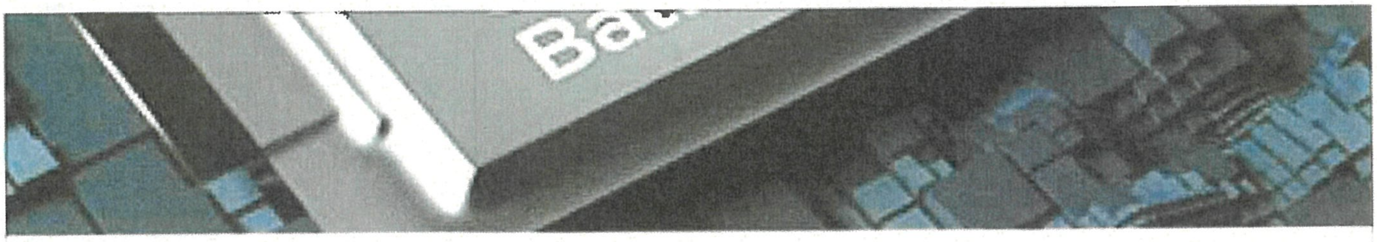
LITHIUM-ION VS LEAD-ACID COST ANALYSIS

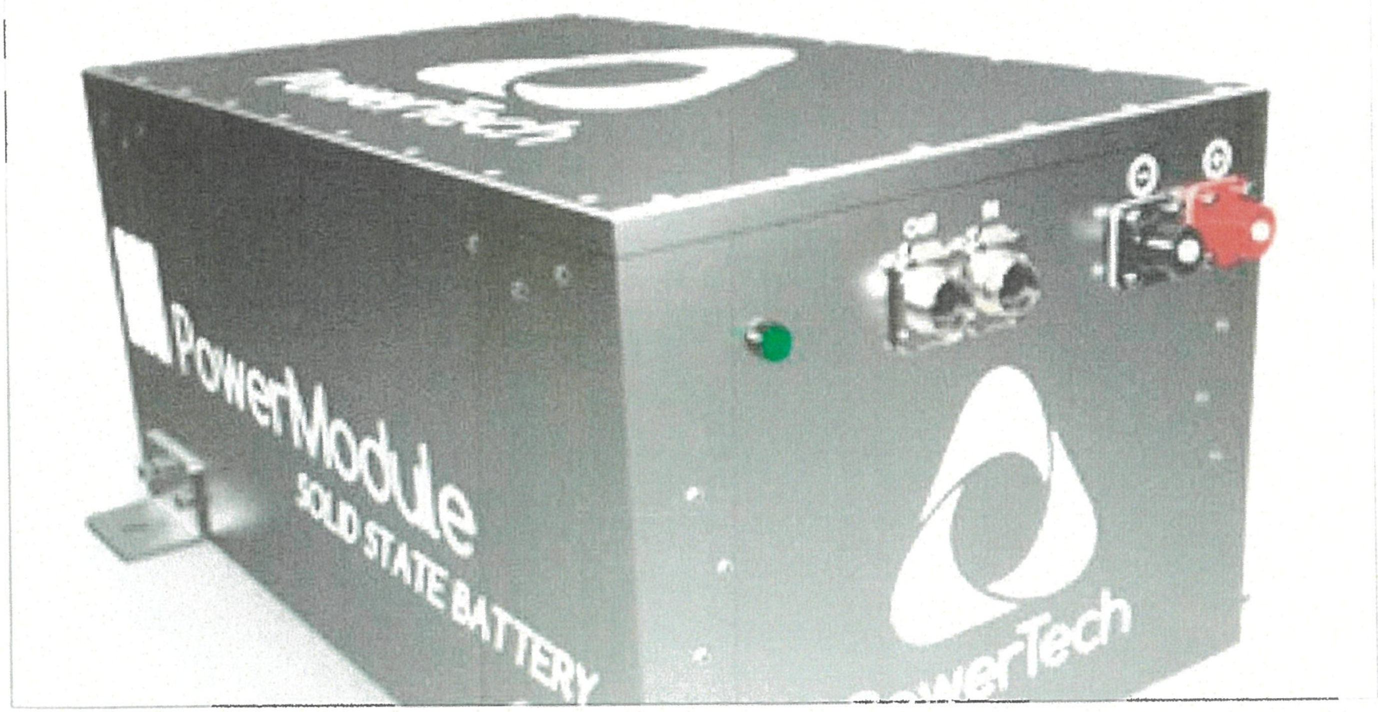
[illegible]

LITHIUM IRON PHOSPHATE (LIFEPO4 - LFP)

THE SOLID-STATE LITHIUM BATTERY REVOLUTION

LITHIUM-ION STATE OF CHARGE (SOC) MEASUREMENT

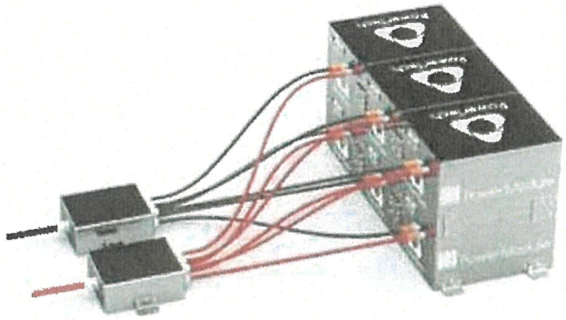




PowerBrick

PowerBrick

PowerModule



MADE IN
FRANCE

TAG CLOUD

100% electric (11) Ducasse sur Seine (2) Electric Marine (8) Exhibition (4) Fleet Management & Telemetry (3) Innovation (20) LiFePO4 (13) Lithium batteries for Robotics (3) Lithium Ion batteries system (11) Market and Key facts (5) PowerBrick (9) PowerModule (12) PowerRack (8) PowerTech Systems Company (5) Self-Consumption (3) SmartEnergies Fair (2) Speed week Bonneville (3) Technology - Engineering (21) utility grid (4)

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CEC Exhibit-7

Novec 1230 (FK 5-1-12) clean agent **01/20/2025**

The AES Story of why the Thermal Runaway System works and is safe:

Definition of Clean Agent - that it has no ozone depletion potential and evaporates quickly and doesn't mess up equipment. ***(Pretty limited scope of clean?)***

Novec 1230 does not burn; it is a fire extinguishing agent designed to suppress flames by removing heat from a fire, meaning it is specifically formulated to not combust itself. [1]

Key points about Novec 1230:

- Function: It works by rapidly vaporizing when released, effectively cooling the fire and extinguishing it.
- Clean agent: Considered a "clean agent" because it leaves no residue after extinguishing a fire, making it suitable for sensitive equipment.
- Environmental impact: Has a low global warming potential compared to older fire suppression agents.

AES stops the story here.

The rest of the story:

NOVEC 1230 decomposes at temperatures more than 500°C (932°F) and it is therefore important to avoid applications involving hazards where continuously hot surfaces are involved. Upon exposure to the flame, NOVEC 1230 will decompose to halogen acids.[2]

Key points about Novec 1230 decomposition:

- High temperature trigger: Decomposition primarily occurs at very high temperatures, exceeding 500°C.
- Fire exposure: When discharged onto a flame, Novec 1230 can decompose due to the intense heat.
- Decomposition products: The main concern is the creation of halogen acids as byproducts of decomposition.
- Rapid discharge importance: To minimize decomposition products, Novec 1230 should be discharged quickly to extinguish a fire rapidly.

Examples of halogen acids

- Hydrofluoric acid (HF): A weak acid that dissolves easily in water
- Hydrochloric acid (HCl): A halogen acid formed when halogen acid gases react with hydrogen
- Hydrobromic acid (HBr): A halogen acid formed when halogen acid gases react with hydrogen
- Hydroiodic acid (HI): The strongest halogen acid because iodine is the least electronegative halogen

This is possibly what happened at the latest Moss Landing Fire. It appeared the fire was being controlled by the Fire Suppression System. Reignition occurred with already hot surfaces, any subsequent Novec 1230 would then have decomposed as opposed to vaporize.

Hydrofluoric acid (HF) toxicity can cause severe burns, tissue damage, and organ failure, and can be fatal. The severity of the effects depends on the concentration of the acid, the duration and size of exposure, and the area of the body affected. [3]

HF (hydrogen fluoride) is not flammable; it is considered a non-flammable gas, meaning it will not burn under typical fire conditions. [4]

Key points about HF:

- Non-combustible: HF does not ignite easily and is classified as non-combustible.
- Corrosive hazard: While not flammable, HF is highly corrosive and can cause severe burns upon contact with skin.
- Potential for hazardous reactions: When exposed to certain metals, HF can generate flammable hydrogen gas.

One often used scenario suggesting limited ability to pollute is that any toxic components would be consumed in a fire. However, HF is not flammable.

Here is how HF combines with the external cooling spray and enters the environment as ground water pollution. HF condenses out of the flame plume when cooling water reduces the temperature of the plume to the point that the HF becomes a liquid.

HF (Hydrogen Fluoride) can be a liquid, specifically a colorless, fuming liquid at lower temperatures, while at higher temperatures it exists as a gas; it is considered a corrosive and highly hazardous substance. [5]

Key points about HF as a liquid:

- Hydrogen bonding: The ability of HF to form strong hydrogen bonds allows it to exist as a liquid at room temperature, unlike other hydrogen halides like HCl which are gases.
- Appearance: Liquid HF is clear and colorless with a strong, irritating odor.
- Temperature dependence: Below its boiling point, HF is a liquid, but above that point it becomes a gas.

Hydrogen Fluoride (HF) is lighter than air. While the gas itself is lighter than air, under certain conditions, a cloud of vapor or aerosol from HF can appear heavier than air due to its potential to form a heavier mist when released. [6]

Key points about HF and air density:

- Density comparison: HF has a lower density than air, meaning it will rise when released.
- Vapor formation: Although the gas is lighter, the vapors produced from HF can sometimes be heavier than air, creating a potentially hazardous situation.
- Important consideration: When handling HF, always take proper safety precautions due to its corrosive nature, even though it is lighter than air.

HF is combined with the water and water vapor of the cooling spray and becomes heavier than air and settles to the ground with the water or settles into lower regions of the area as combined with water vapor.

Sources:

[1] https://blog.koorsen.com/what-is-novec-1230#

[2] https://www.suppression.com/catalog/suppression/clean-agent-suppression/novec-1230/kidde-novec-fk-5-1-12#

[3] https://www.ncbi.nlm.nih.gov/books/NBK441829/#

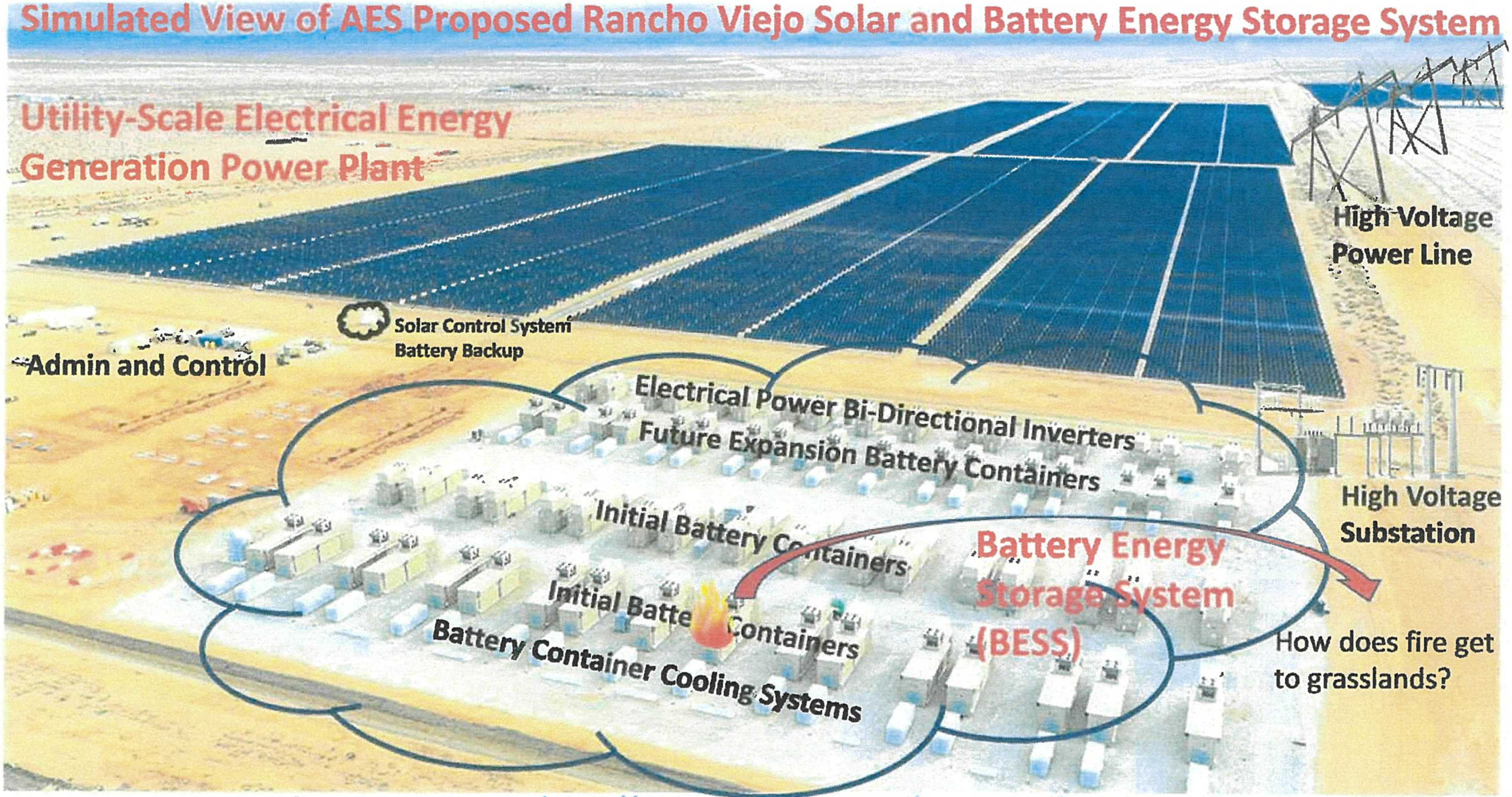
[4] https://cameochemicals.noaa.gov/chemical/2013#

[5] https://www.cdc.gov/chemical-emergencies/chemical-fact-sheets/hydrogen-fluoride.html

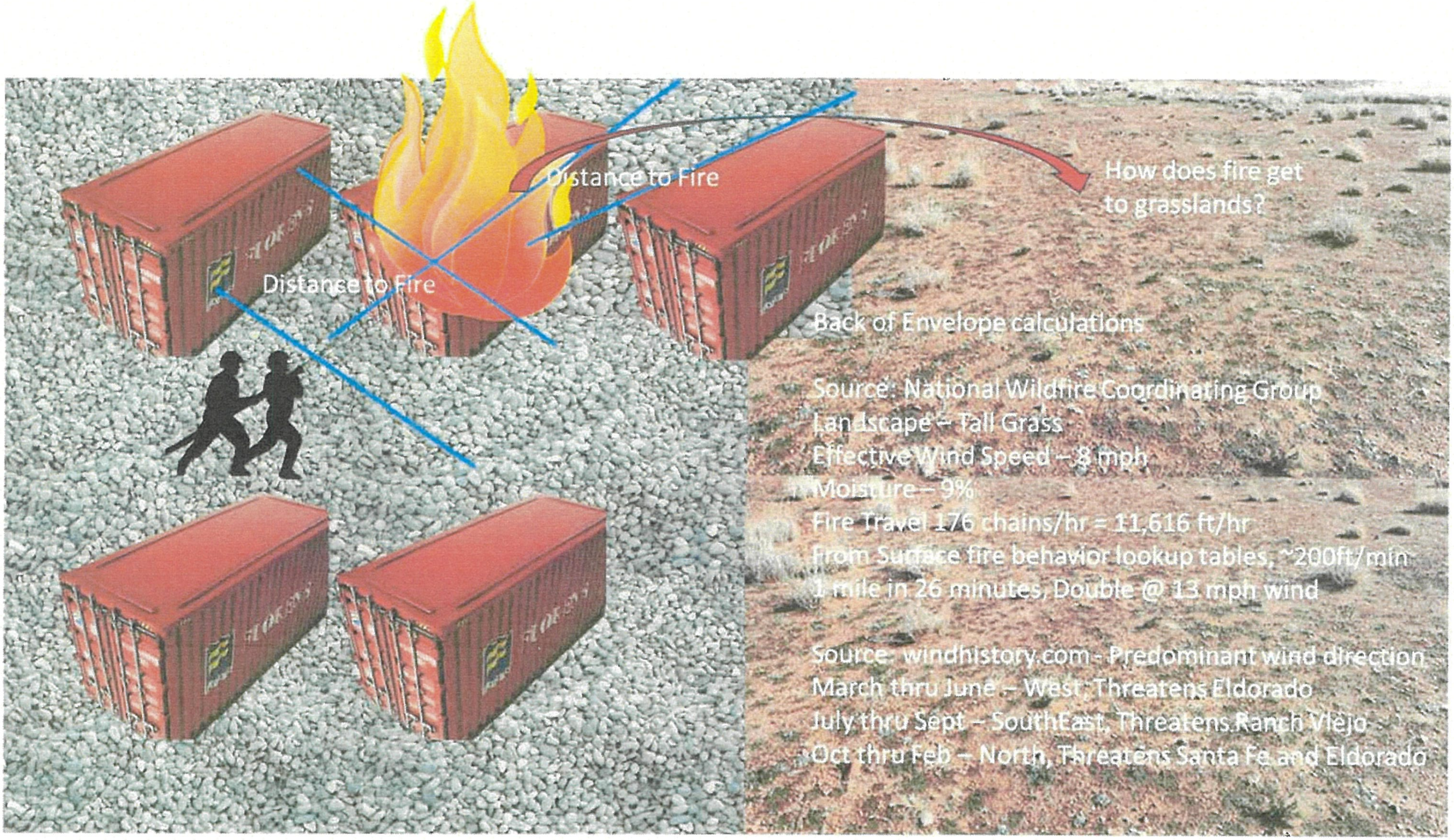
[6] https://www.ivhhn.org/information/information-different-volcanic-gases/hydrogen-fluoride#

CEC Exhibit-8

Simulated View of AES Proposed Rancho Viejo Solar and Battery Energy Storage System



Base Image Source: https://www.mortenson.com/newsroom/battery-energy-storage-solutions
Notations by Clean Energy Coalition for Santa Fe County: https://www.cleanenergycoalitionsfc.org



Back of Envelope calculations

Source: National Wildfire Coordinating Group
Landscape – Tall Grass
Effective Wind Speed – 8 mph
Moisture – 9%
Fire Travel 176 chains/hr = 11,616 ft/hr
From Surface fire behavior lookup tables, ~200ft/min
1 mile in 26 minutes, Double @ 13 mph wind

Source: windhistory.com - Predominant wind direction
March thru June – West, Threatens Eldorado
July thru Sept – SouthEast, Threatens Ranch Viejo
Oct thru Feb – North, Threatens Santa Fe and Eldorado

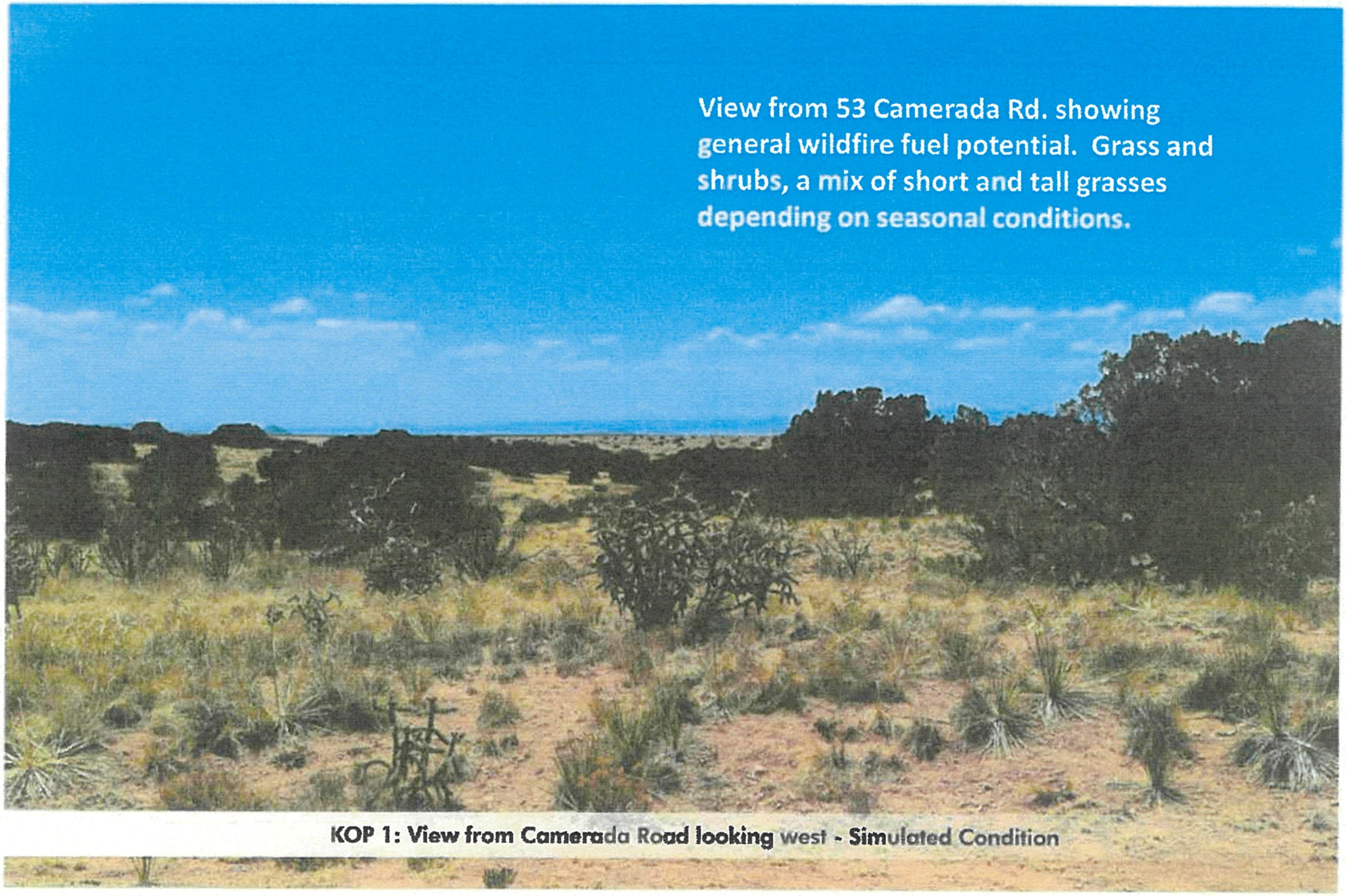
Fuel Model 3 (Tall Grass – 2.5 ft)

Surface Fire Behavior Lookup Tables (NWCG.GOV)

Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. Wind may drive fire into the upper heights of the grass and across standing water. Stands are tall, averaging about 3 feet (1 m), but considerable variation may occur. Approximately 1/3 or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses.

SPREAD Ch/hr		Effective Windspeed(EWS), mph *Use 20ft/FCST wind only if EWS = MFWS and assumes unsheltered wind adjustment (0.4)												
*20ft/FCST		NWNS/O	Back - ½	Flank - 1	5	10	15	20	25	30	35	40	45	50
EWS					2	4	6	8	10	12	14	16	18	20
1-hr Moisture, %	1	8	18	32	68	157	261	377	502	636	776	923	1076	1234
	3	6	14	25	52	121	201	290	387	490	598	712	829	951
	5	5	11	20	42	97	162	234	312	395	482	574	669	767
	7	4	9	17	36	82	137	198	264	335	409	486	566	650
	9	4	8	15	32	73	122	176	234	296	362	430	501	575
	11	3	8	14	29	67	111	161	214	271	331	393	458	526
	13	3	7	13	27	62	103	149	198	251	306	364	425	487
	15	3	6	12	25	57	95	137	182	231	282	335	391	448
	17	3	6	10	22	51	85	122	163	207	252	300	350	401
	19	2	5	9	19	43	71	103	137	174	212	253	294	338
	21	2	4	7	14	32	53	77	103	130	159	189	194	194
	23	1	2	4	8	18	30	43	54	54	54	54	54	54

Low	*Moderate*	High	Very High	Extreme



View from 53 Camerada Rd. showing general wildfire fuel potential. Grass and shrubs, a mix of short and tall grasses depending on seasonal conditions.

KOP 1: View from Camerada Road looking west - Simulated Condition

Browse » Publications » Technical Papers » 2017-01-1354

2017-03-28

Vehicle Fires Resulting from Hot Surface Ignition of Grass and Leaves 2017-01-1354

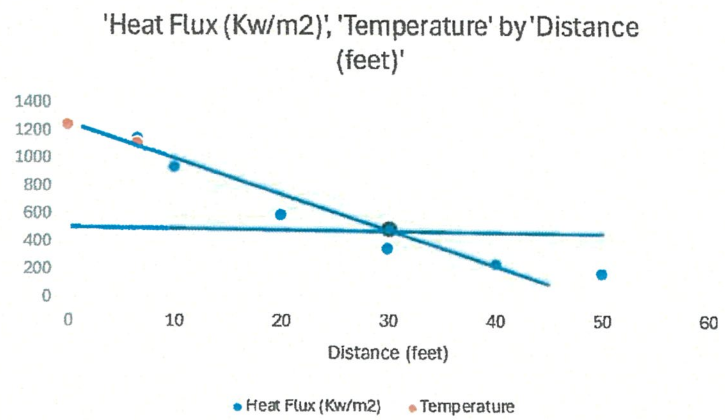
One potential fire ignition source in a motor vehicle is the hot surfaces on the engine exhaust system. These hot surfaces can come into contact with combustible and flammable liquids (such as engine oil, transmission fluid, brake fluid, gasoline, or Diesel fuel) due to a fluid leak, or during a vehicle collision. If the surface temperature is higher than the hot surface ignition temperature of the combustible or flammable liquid in a given geometry, a fire can potentially ignite and propagate. In addition to automotive fluids, another potential fuel in post-collision vehicle fires is grass, leaves, or other vegetation. Studies of hot surface ignition of dried vegetation have found that ignition depends on the type of vegetation, surface temperature, duration of contact, and ambient conditions such as temperature and wind speed. Ignition can occur at surface temperatures as low as 300 °C, if the vegetation is in contact with the surface for 10 minutes or longer. At surface temperatures of 400 °C, ignition can occur in 3 minutes, and at surface temperatures of 500 °C, ignition can occur in a few seconds. We made measurements of the surface temperature at various locations along the exhaust system of a passenger vehicle, including on the catalytic converter, under different transient conditions. The temperatures were measured using thermocouples welded to the exhaust system. The tests show that the maximum external surfaces temperatures occur under transient conditions after the vehicle comes to a sudden stop. Thus, testing that only measures steady-state temperatures or temperatures while the vehicle is moving will not necessarily capture the worst-case temperatures. For the vehicle tested, exhaust system components can reach temperatures of 400 °C and these temperatures can be sustained for minutes after the vehicle stops, and thus are capable of igniting dried vegetation.

Hiller Report, page 4/5 states Theoretical complete fire engagement of enclosure would result in external wall temperature of approximately 1241-degree C. This represents an external distance to grass fuel of 0 feet. With a design basis wind of 9 mph, the surface temperature of a first responder at 6.5 feet would intermittently be 1110-degree C. A reasonable assumption is that the decrease in resulting surface temperature would be proportional to the gradient of the Heat Flux. The Heat Flux gradient can be plotted from the data in the Hiller Report, page 34, Table 2. Once the data is plotted the gradient plot is used to plot a similar linear gradient for temperature over distance. The estimated intermittent temperature at 30 feet from the radiating enclosure is on the order of 500-degree C or less.

Distance (feet)	Heat Flux (Kw/m2)	Temperature
0		1241
6.5	1148	1110
10	939	
20	589	
30	348	500
40	235	
50	170	

Table 2: Theoretical Momentary Heat Flux as a Function of Distance

Distance	Momentary Maximum Theoretical Heat Flux (kW/m²)
10′	939
20′	589
30′	348
40′	235
50′	170
60′	127
70′	98
80′	77
90′	62
100′	51



The estimated intermittent temperature at 30 feet can be combined with the SAE Technical Paper estimations for dry grass ignition. Even if you apply a large confidence interval on the intermittent temperature below 500-degree C. It can be established that at 30 feet, dry grass could ignite from the radiated energy of an enclosure fire engagement in the range of 5 – 8 minutes.

CEC Exhibit-9

SEARCH NEW MEXICO

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Jose Villegas, a National Guard chaplain, was one of the first in La Cieneguilla to find out his well water was contaminated with PFAS. Credit: Nadav Soroker/Searchlight New Mexico

When PFAS hits home: Poisoned wells in La Cieneguilla

Unable to drink their water, residents want action — and answers from the New Mexico National Guard.

by **Ed Williams**
February 15, 2024

During the decades that he's lived in his home southwest of Santa Fe, Jose Villegas was oblivious to the toxic chemicals that were seeping through the aquifer, slowly spreading under his house in the historic village of La Cieneguilla and into the well that supplied his family with drinking water.

His neighbors were also drinking the well water, unaware that the New Mexico National Guard had discovered **more than a year earlier** that the groundwater and soil on its site by the Santa Fe airport were contaminated with PFAS, a class of chemicals linked to cancer and other illnesses — and present in everything from household products to firefighting foams at military sites.

That changed in August 2023, when a groundwater specialist with Santa Fe County knocked on Villegas's door and asked if he would allow his water to be tested. The results came back at 14 parts per trillion (ppt), nearly four times higher than a proposed federal safety standard to protect human health. Blood tests would later confirm that the chemicals were in his body at high levels.

"I thought this water was pure and clean," Villegas said, adding that his family had potentially been drinking contaminated water for years. "Now I got this PFAS, this firefighting foam, in my *sangre,* in my blood. I have a right to be upset, right? I'm 65, I'm supposed to be going on my golden years. And then I have to deal with this shit?

"They need to declare an emergency over here, because nobody can use their wells," he said.

As a chaplain in the National Guard, Villegas is quite familiar with the facility that he and others in the community feel is primarily responsible for the water contamination: the National Guard's Army Aviation Support Facility on the Santa Fe airport property some 2.5 miles to the north, where firefighting foams were stored and potentially used for training until the early 2000s, according to the National Guard.

Jose Villegas, an official with the Texas Band of Yaqui Indians, stands by his garden in La Cieneguilla, where he used to grow vegetables and share them with his neighbors. He can no longer grow food there because of PFAS contamination in his well water. Credit: Nadav Soroker/Searchlight New Mexico

Villegas knew the foams were on-site — but nobody had told him that the chemicals had spread into the groundwater, or that those chemicals could put his family's drinking water at risk and contaminate his neighbors' water as well.

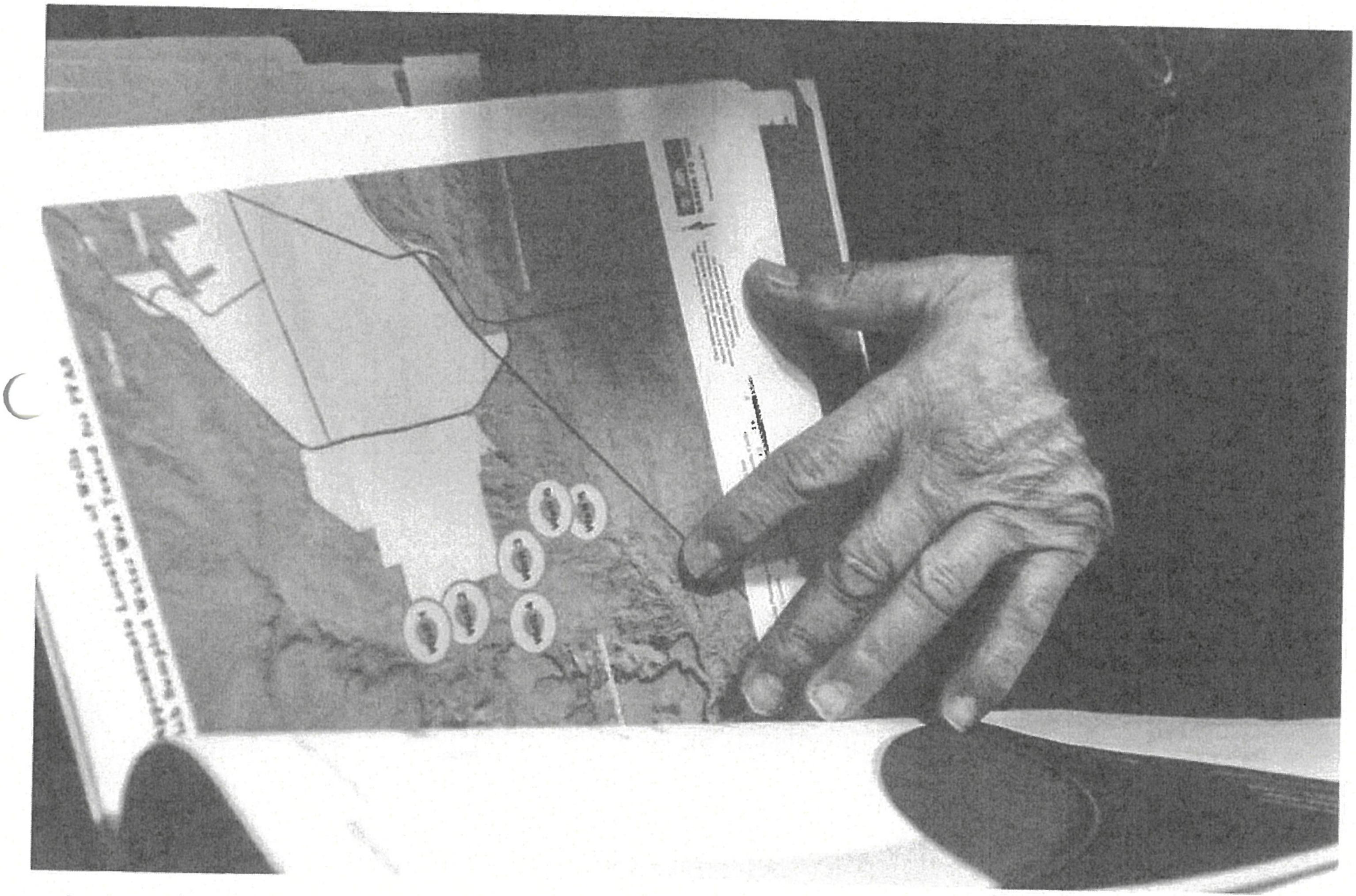
"They know me," Villegas said of the National Guard. "I thought they would have the courtesy to tell me that our water might have a problem. I've heard nada from them — they haven't so much as offered me a glass of clean water to drink."

News of the water contamination has rocked La Cieneguilla, a small village sandwiched between the Santa Fe Airport and the neighborhood of La Cienega.

ut it is only the most recent community to find itself at **the frontlines** of a national crisis: Across the country, thousands of private wells near **military sites**, **factories** and **airports** have become contaminated with PFAS at levels higher than what federal regulators and medical experts consider safe for drinking.

While there have been major efforts to address the problem, any real action to clean up PFAS contamination can take years, or even decades.

The situation can be particularly dire for private well owners, who are largely responsible for their own water quality. In New Mexico alone, an estimated **270,000 people** rely on water from a private well. They have little recourse if PFAS or other contaminants are discovered in their water. Lawsuits can be filed and the responsible party might eventually agree to a cleanup. But action is rarely swift.



A **Santa Fe County map** of the wells it tested for PFAS, one of many documents that Villegas has been collecting. Credit: Nadav Soroker/Searchlight New Mexico

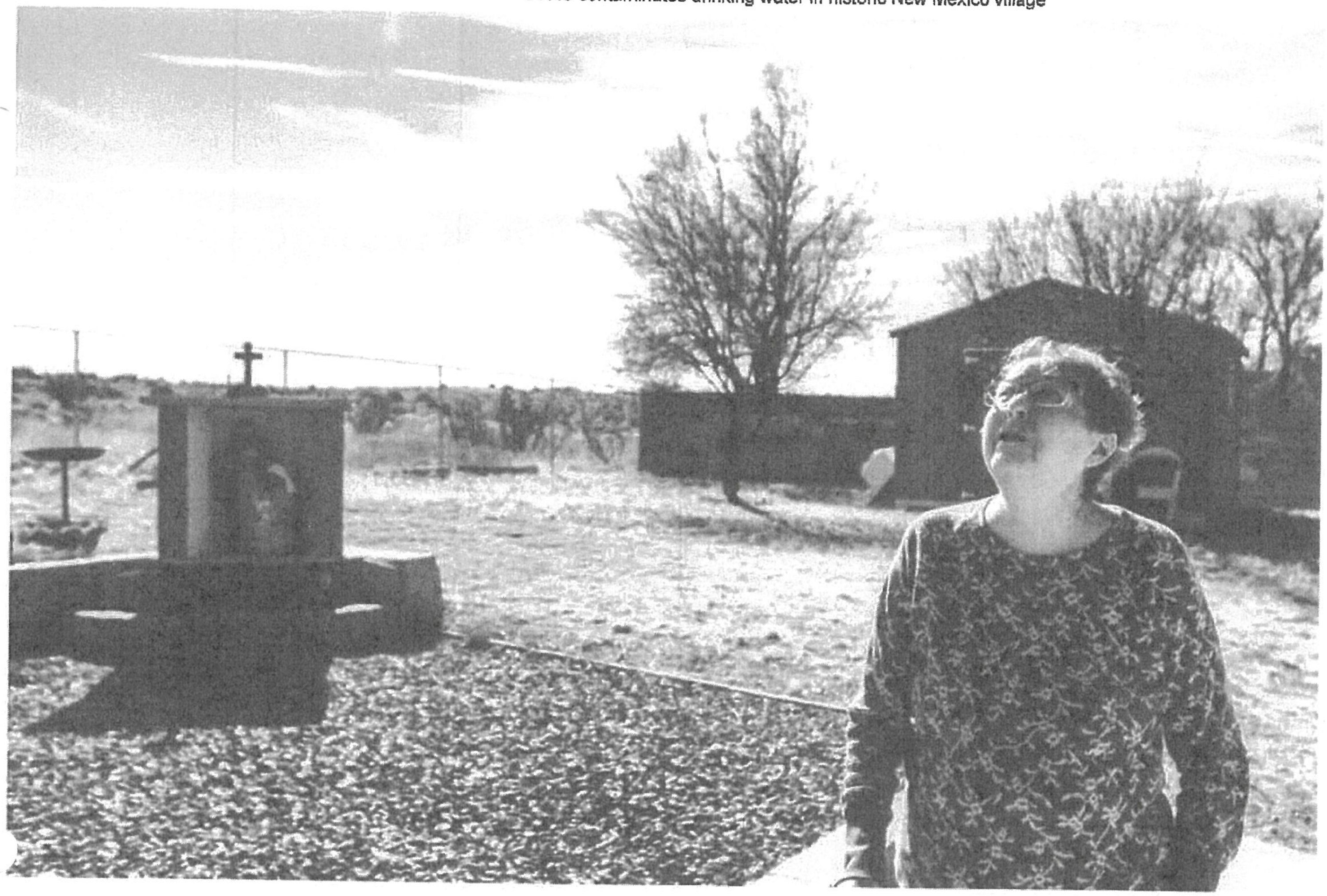
"Something that tends to get lost is just how long these processes take and how many people continue t be exposed in the meantime," said Jared Hayes, senior policy analyst at the Environmental Working Grou , a nonprofit that tracks PFAS issues. "There are still going to be people drinking contaminated water for years to come."

Another blow for a historic community

For La Cieneguilla, the contamination is like salt on old wounds. "The fact is, this is an old traditional community, right next to tribal land, and many of the residents have historic roots," said Camilla Bustamante, the Santa Fe County Commissioner for the district. "There has been a lot of encroachment and lack of consideration on the development and impacts to that village. It's an issue of environmental justice."

The construction of the airport and National Guard facility on La Cieneguilla's northern flank, as well as the installation of the Santa Fe wastewater treatment plant and other upstream projects, have all been completed without input from the community, she said, even though each has the potential to impact residents' health.

The discovery of the PFAS contamination — and a perceived lack of communication by the National Guard and other authorities — has added to the gut punch, residents say.



Vioma Trujillo, at her home in La Cieneguilla, offers a prayer to a deceased friend who was an environmentalist. Trujillo, also an advocate for the environment and water rights, believes the PFAS problem is one more sign of government neglect. Credit: Nadav Soroker/Searchlight New Mexico

"It's an environmental catastrophe," said Vioma Trujillo, who has lived in La Cieneguilla since 1979. She's hoping the county will test her well for PFAS, saving her the hundreds of dollars it would cost out of pocket. In the meantime, she's drinking bottled water. "The government has never respected this land grant," she said, referring to the land rights granted by Spain and Mexico and **acknowledged by the U.S. government** in the 1848 Treaty of Guadalupe Hidalgo.

"We have our water rights. We respect the water, and now this. It's so painful."

Levels eight times too high

After testing Villegas's water, Santa Fe County tested an additional five private wells in the vicinity; in addition, several neighbors forked up the money for private testing. In all, concerning levels of PFAS appeared in at least 10 wells. In one instance, tests revealed the chemicals at 32 ppt — eight times the EPA's recommended drinking water limit of 4 ppt. (PFAS chemicals have also been detected at two wells in the nearby La Cienega neighborhood, but at much lower levels.)

Pablo C de Vaca points to the new well his daughter built at her home in La Cieneguilla. PFAS was discovered in the water shortly afterward. Credit: Nadav Soroker/Searchlight New Mexico

"There are kids who are drinking this water, and elderly people," said Pablo C de Vaca. His daughter, he said, recently bought a house in La Cieneguilla and paid $20,000 to install a new well, only to hear the news that the water was contaminated. "She doesn't think she could sell the house now if she wanted to," he said.

"There's been no communication" about the contamination from authorities — "we don't know what's going on," C de Vaca added.

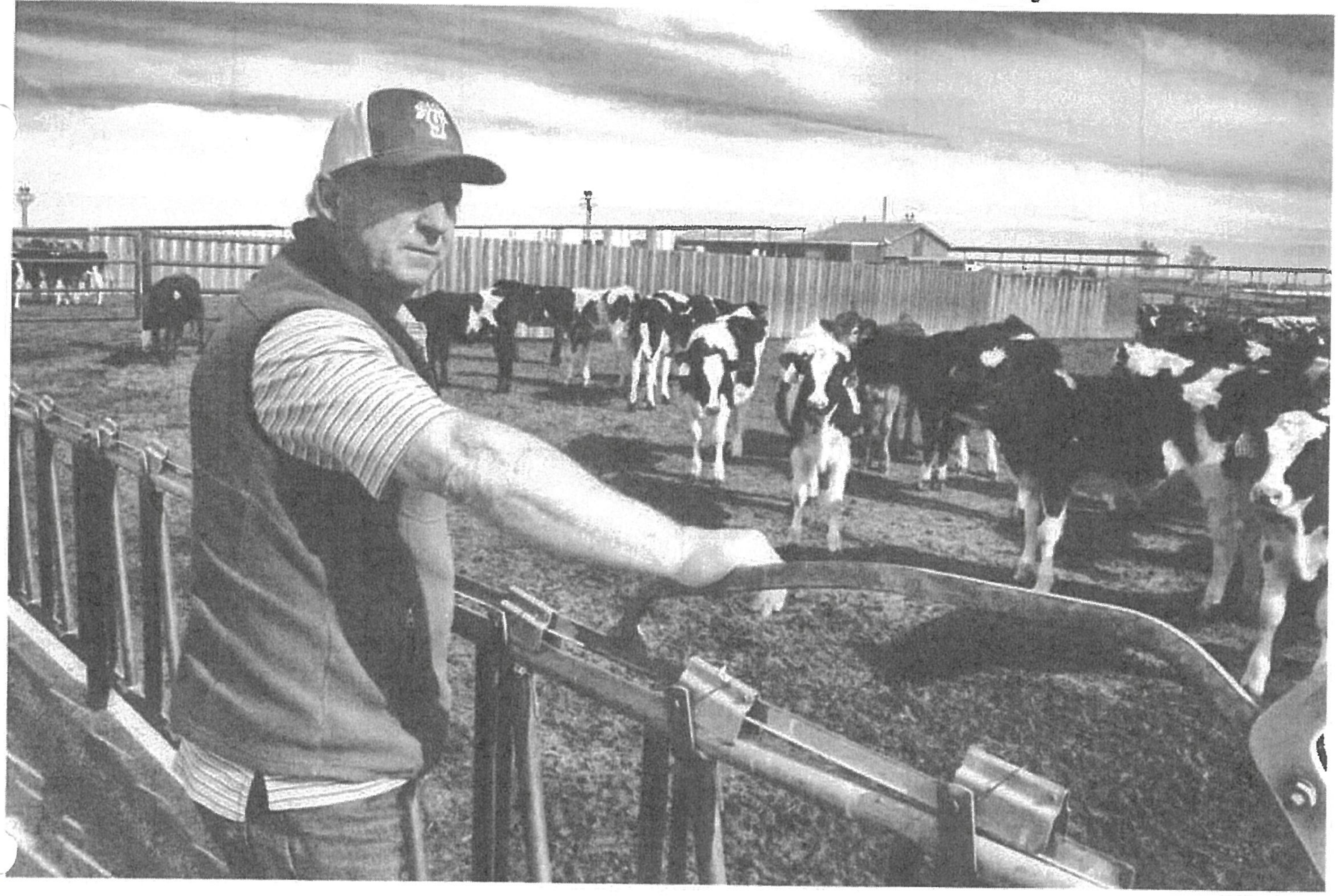
C de Vaca's daughter hired a company to install a well-water filter system, which costs upwards of $2,000. Other neighbors have done the same, sometimes using their social security checks to cover the costs. Many residents are drinking bottled water, another expense. Some, like Jose Villegas and his wife, have stopped using their taps entirely, fearful of even bathing in the contaminated water. Villegas called one military remediation contractor to ask what it would cost to completely clean up his property. The answer: $700,000.

'Forever chemicals' everywhere

Since their invention in the late 1930's, PFAS has become ubiquitous in the environment. Often called "forever chemicals" because they don't break down in water, soil, animals or the human body, PFAS (per- and polyfluorinated alkyl substances) are present in myriad products, from nonstick cookware and stain-resistant carpeting to furniture, food packaging, outdoor gear, and **dental floss**. Most notably, the chemicals have been used at military installations in the form of Aqueous Film Forming Foams, or AFFFs, a highly effective firefighting product.

The foams were used for decades to extinguish jet fuel fires or for training exercises and were stored at military bases throughout the country — including at the National Guard facility near La Cieneguilla.

PFAS-laden foams have also seeped into the groundwater at more than **700 other military sites** around the country, according to the Environmental Working Group. That includes Cannon Air Force Base in Clovis, where dairy farmer Art Schaap had to **euthanize his entire herd** of more than 3,000 cows because they drank the water. Farmers in the area have been forced to spend hundreds of thousands of dollars on water filtration systems. Kirtland Air Force Base in Albuquerque has also detected the chemicals, as has Holloman Air Force Base near Alamogordo, where a nearby lake was found to have PFAS measuring more than **84,000 times higher** than health advisory levels.



Art Schaap looking over some of his Holstein cows at the Highland Dairy in Clovis. "This has poisoned everything I've worked for and everything I care about," he said. Credit: Don J. Usner/Searchlight New Mexico

As early as **the 1960s**, studies showed that the substances could potentially be harmful to humans. Over the last 40 years, a mountain of research has revealed that PFAS is linked to numerous environmental and human health problems, including **increased risks** of cancers, liver damage, thyroid problems, kidney disease, reproductive harm and other issues.

Nevertheless, it took the EPA until 2023 to announce the first proposed legally enforceable federal standard for certain PFAS chemicals in drinking water, setting the limit — which has not yet been finalized — at 4 ppt. Crucially, the new rule would force industries to meet the limit or risk enforcement action. The EPA's previous health guideline for drinking water set a suggested limit of 70 ppt, a level that has long been considered far too high.

A winning petition from New Mexico

There has been additional progress in the battle against PFAS exposure, especially at the state level. In December 2018, New Mexico added three types of PFAS to its list of toxic pollutants, a move that allows state regulators to require cleanups from polluters who contaminate the groundwater.

Another key regulatory move was a step the U.S. Environmental Protection Agency took this month to classify certain types of PFAS as hazardous waste — an action taken in response to a **petition** Gov. Michelle Lujan Grisham sent to the agency in 2021. This regulation will help states prevent and compel cleanups of future PFAS pollution.

But as it stands today, the process of initiating a cleanup can be excruciatingly slow. That's due in no small part to the ubiquity of PFAS in the environment: The first step in any cleanup is to identify the responsible party, but when it comes to PFAS there can be many contributors.

An entrance to the Army Aviation Support Facility in Santa Fe, where PFAS was discovered. Credit: Nadav Soroker/Searchlight New Mexico

The National Guard highlighted this in its 2023 study of PFAS found on its facility near La Cieneguilla. The report showed that groundwater under the site was flowing toward homes in La Cieneguilla and La Cienega. But the National Guard claimed that the Santa Fe Airport and neighboring municipal wastewater treatment plant potentially contributed to the contamination.

The National Guard said it plans to undertake a "remedial investigation" to define the nature and extent of the contamination and evaluate risks to human health and the environment. That process can take "several years to complete," New Mexico National Guard spokesman Hank Minitrez **stated in an email**.

In the past, in cases that didn't involve PFAS, the New Mexico Environment Department has used its legal authority to go after groundwater polluters without waiting for them to complete their own study. But in this case, the agency is holding off until the National Guard provides more information.

"At the appropriate time, we will take the appropriate action," said John Rhoderick, director of NMED's Water Protection Division. Rhoderick said the state is hoping the responsible parties will clean up the contamination voluntarily — otherwise, the process could get tied up in court, which could drag things out even further.

"I know people don't want to spend the money to pay for a filter on their home and the ongoing costs for something they didn't do," Rhoderick said. "But the reality is this: Even if we had a clear-cut responsible party and we began to move forward on everything, it would be a significant period of time before anything began to happen on those private wells, *if* anything."

The pace has infuriated residents of La Cieneguilla.

There might not be a legal obligation to inform neighbors under current law, Jared Hayes of the Environmental Working Group said of the situation. But there is "an ethical one."

"They really ought to be getting help for those surrounding communities," he said.

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