TERA sensor

F

Our solution to increase the yield and quality of Li-ion battery manufacturing

Key figures :

- 42 millions of Electric Vehicles (EVs) in 2023
- 4000 fires due to battery thermal runaway
- clean room requirement for both manufacturing process and worker exposure

By Antoine Dumas, TERA Sensor CTO, May 2024.

www.tera-sensor.com
TERA SENSOR ● 1200 Avenue Olivier Perroy 13790 Rousset ● FRANCE
sales@groupe-tera.com
Version 1.0 _ 05_24

1. Introduction

In recent years, the automotive industry has witnessed a transformative shift towards electric vehicles (EVs). The surge in EV sales is driven by a combination of technological advancements, environmental concerns, and supportive government policies.

In figures, thanks to iae.org, we can see that the sales of EVs has exponentially increased since 2019. In 2023 the quantity of EVs driving around the world was around 42 million whereas it was only 7 million in 2019.

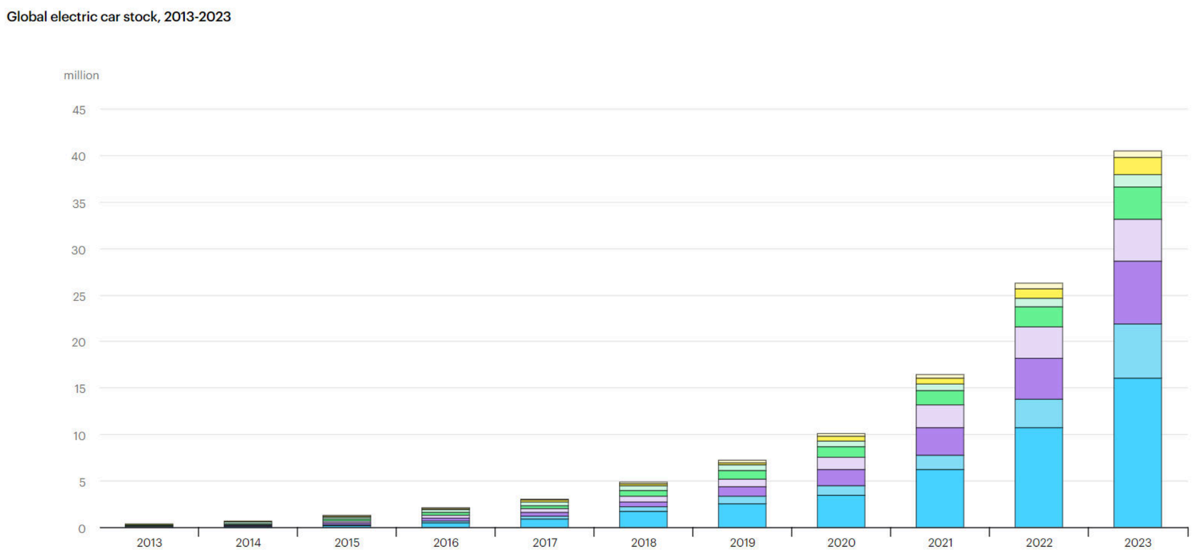


chart 1 : Global electric car stock history.

source : https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars (05/24)

Thanks to the states' policies ongoing, this trend will continue for the coming years.

The territory with the most EVs is China with almost half of the market, followed by Europe.

However, this rapid growth presents a significant challenge: the need to increase the production of battery cells, the heart of electric vehicles. To provide this huge market Europe and US had launched a strategic investment to help battery manufacturers to construct their gigafactories in their territories. It will help to balance and secure the actual production that is utterly led by China.

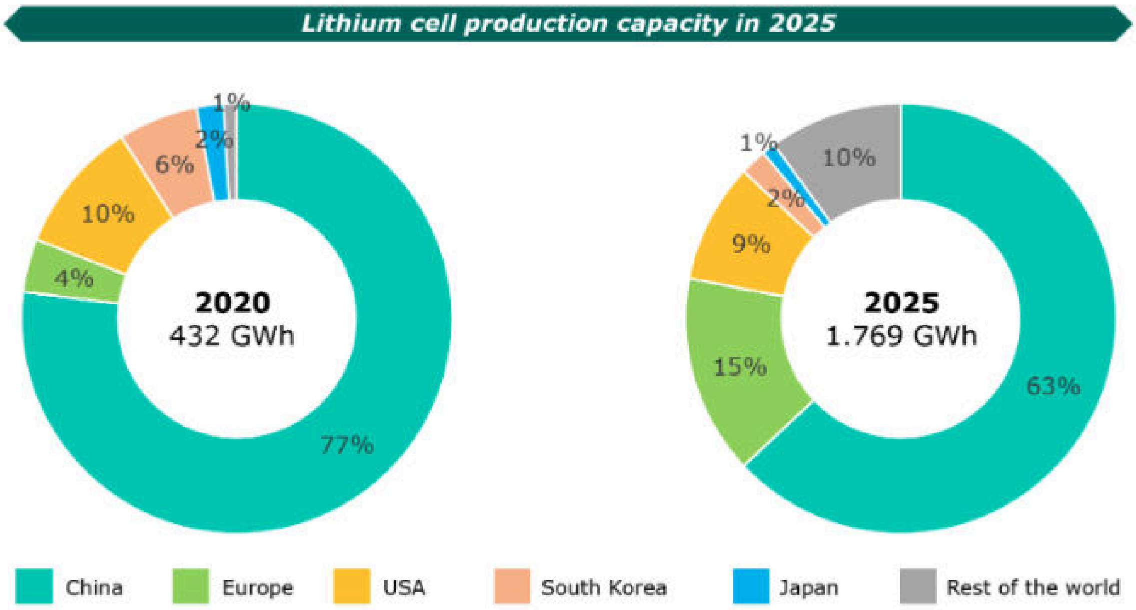


Chart 2 : Li cell quantity production by territory.

source : BloombergNEF (05/24)

As an example, almost 30 gigafactories projects will rise or are rising in Europe from now to 2025 and 15 in the USA.

Nonetheless, this technology is not riskless. The production is using material that reacts with oxygen, moisture by generating explosive gasses like H_2 and dangerous ones, like HF. It also uses toxic metals, especially Cobalt, in powder form. In the end, this industry is only at its beginning and needs to prevent and understand the risk in order to keep the demand growing.

2. Facts in figures : 4 000 EVs fire a year

Lithium-ion batteries in electric vehicles (EVs) present significant fire and explosion hazards primarily due to a phenomenon known as thermal runaway. Thermal runaway occurs when a battery cell overheats, leading to a chain reaction that can cause the battery to catch fire or explode. This can be triggered by physical damage, manufacturing defects, overcharging, or exposure to extreme temperatures.

According to data from the Fire Safety Research Institute (FSRI), thousands of EVs catch fire each year due to lithium-ion battery incidents. The National Transportation Safety Board (NTSB) reported that over 4,000 electric vehicles experience fires annually caused by thermal runaway. These incidents can result in various hazards, including the release of flammable gases, flaming, vented deflagrations, and explosions (FSRI). According to Honeywell's sources, the quantity could be even higher with 25 thermal runaway events for 10 000 EVs sold.

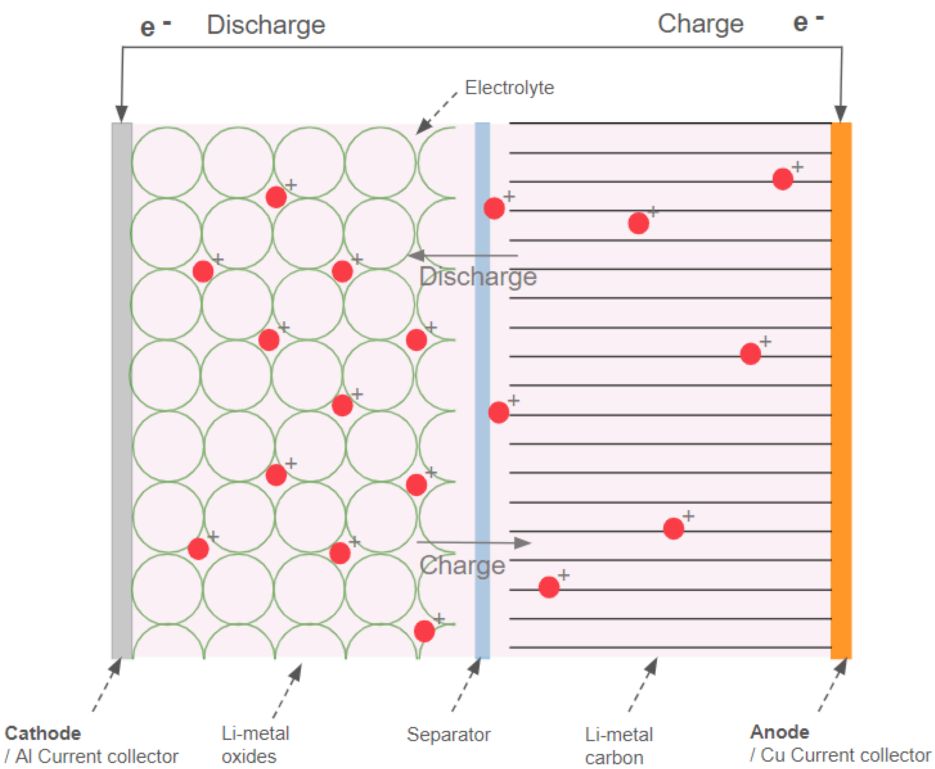
Efforts are being made to enhance the safety of lithium-ion batteries. Researchers are focusing on improving battery design, better thermal management systems, and more effective fire suppression technologies. The development of safer battery chemistries and the implementation of more stringent safety standards are also crucial steps toward mitigating these risks.

The vehicle's constructor had put a high demand on battery manufacturers to increase their quality and reach zero accidents. They focused on the manufacturers since they have known that the majority of the historical issues were coming from a known phenomena which is named the “dendrite” formation.

In conclusion, this thermal runaway issue has to be solved. It will be either by increasing the quality of the production processes or/and by improving the batteries technology.

3. The Li-ion technology & known issue

The dendrite formation is one of the main issues to be solved by the battery manufacturer. To understand it, we need to dig a little deeper into the technology.
The power that is coming from a battery is due to the movement of electrons (e^-) between two electrodes with a potential difference. To balance the exchange of electrons, the ion Li+ moves through the electrolyte inside the cell.

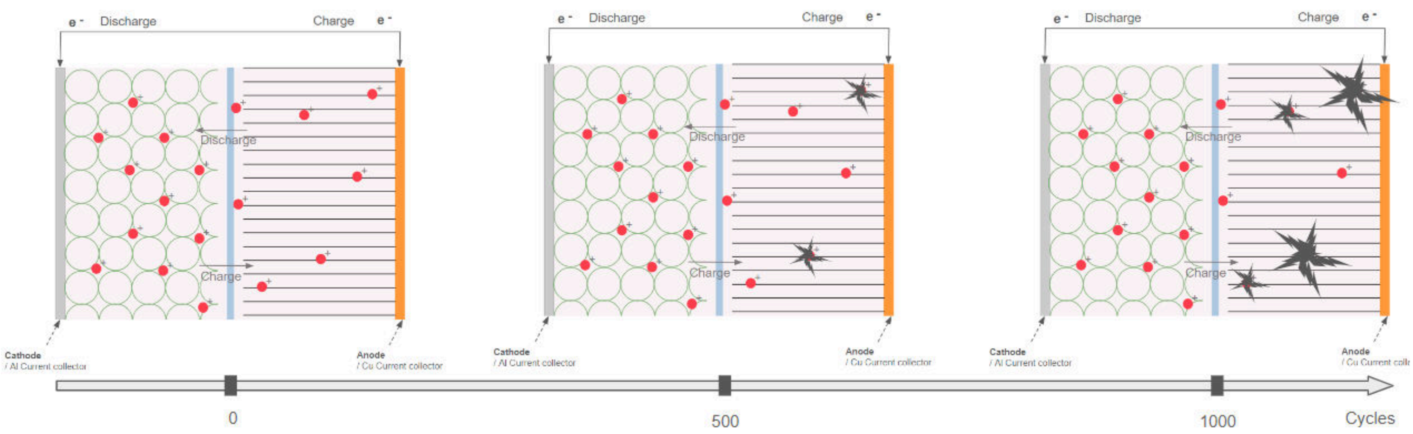


Schematic 1 : inside a Li-ion battery cell

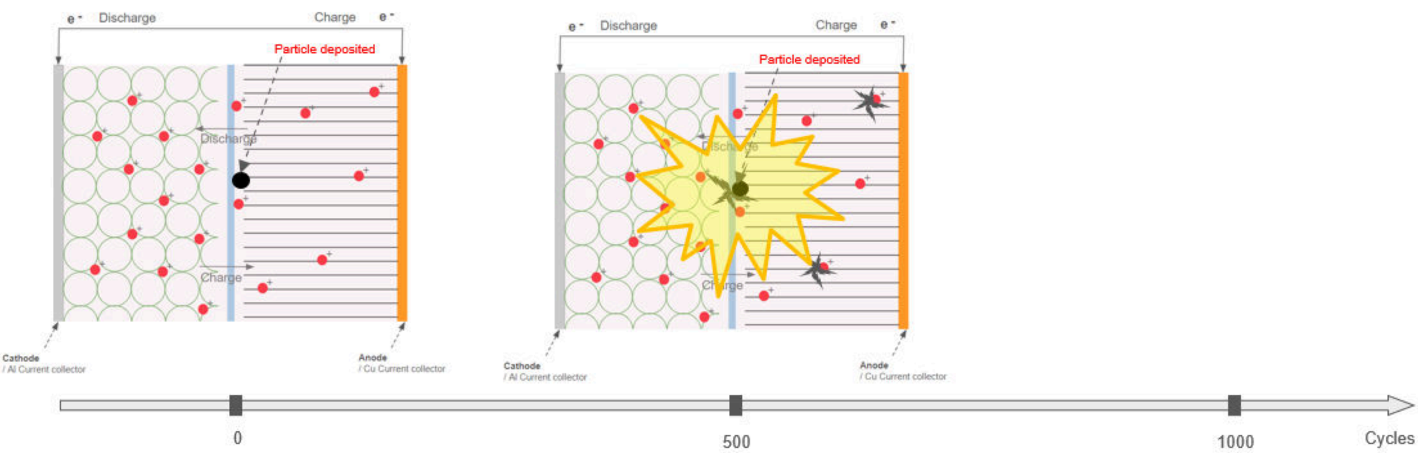
The separator blocks the transfer of electrons in the cell. Electrons can only move through the external circuit.

Usually, the dendrite is formed during the charging and discharging step on the anode. Over cycles, it grows in the direction of the cathode and can create a short circuit when it reaches it. It also decreases the capacity of the cells over time. In normal conditions, the growth is low but when the temperature is over 45°C, the phenomenon is accelerated.

Moreover, when particles are deposited on the separator during the production step it can generate a specific area where the dendrites will form instead of the anode. Due to the fact that the particle is closer to the cathode, it becomes a quick and fast issue to generate the devastating thermal runaway of the battery.



Schematic 2 : normal dendrites formation over time



Schematic 3 : dendrites formation in case of metal particle contamination

As described, the particles trapped at the surface of the separator during the production, can become a cluster for dendrite formation over time. Due to the fact that the particle is closer to the cathode than the anode, it decreases the time needed before the dendrite generates a short circuit by creating a bridge for electrons between anode and cathode.

The best way to greatly reduce this issue is to produce the batteries in clean room environments as described in the ISO 14644.

4. Why producing in clean room environments

We have seen that there is a critical safety issue created by the particle pollution during the assembly state of the anode, cathode and separator. Nonetheless, it's not the only issue. A particle pollution in the electrolyte can also reduce the battery capacity and thus the consistency of the production.

We can find on the subject that regarding the process step of the production, you have to adapt the cleanliness of the room. Usually ISO 5 or 6 is required for the cell manufacturing whereas ISO 7 or 8 might be sufficient for module and pack assembly.

In the end, working on cleanliness production can increase the yield from 50% to 85% and so reduce the cost of production and become more competitive.

One last topic is about the use of hazardous chemicals in the composition of Li-ion batteries. The main toxic compounds are the Cobalt (Co) and the Manganese (Mn). Regarding the toxicology datasheets of the INRS in France, the professional exposure limit for Co in Europe and USA is 0,02 mg/m^3, this means that the factory needs to reach a very low level of Co particulate matter in the air. This very low concentration can be reached thanks to a cleanroom installation with continuous monitoring, especially during process steps.

Material	LCO % Weight	LFP % Weight	LMO % Weight	NMC % Weight
Aluminum	5.20	6.50	21.70	22.72
Cobalt	17.30	-	-	8.45
Copper	7.30	8.20	13.50	16.60
Iron/Steel	16.50	43.20	0.10	8.79
Lithium	2.00	1.20	1.40	1.28
Manganese	-	-	10.70	5.86
Nickel	1.20	-	-	14.84
Binder	2.40	0.90	3.70	1.39
Electrolyte	14.00	14.90	11.80	11.66
Plastic	4.80	4.40	4.50	3.29

Table 1 : example of Li-ion battery composition [1]

Showing such a quality management system will generate confidence with the EVs constructor, reduce safety issues and keep confidence in the final user in order to keep the market growing quickly.

5. Existing solution to monitor cleanroom environment in real time

For real-time monitoring of particles in clean rooms, an efficient system must be implemented to continuously track and manage particulate contamination. An explanation of the survey plan for particle contamination is available in the standard ISO 14644-2.

The aim of a continuous monitoring towards a classification campaign is to ensure that the production is always compliant with the cleanliness needed. As known, the quantity of pollution inside a cleanroom is dependent on the activity, thus the particles concentration will be compliant with different ISO classification, as defined is ISO 14644-1, at different daily times.

Another advantage of a real time monitoring system is that, in case of continuous quality improvement, it helps to find the different sources of particles generation inside the factory. Either a process step that has to be improved or an issue on some parts of the decontamination system.

Moreover, these solutions are usually more affordable than the reference instruments used for the classification and easy to use.

One of the best solutions found on the market is the Safyr OPC from the Belgium Safyr company.

Image of two different solutions for real time monitoring, Lighthouse on the left and Safyr on the right

The Safyr OPC is the most complete solution, it can be used either with a battery pack power supply integrated on the design, to reach up to one week autonomy for diagnostic and particle pollution source searching, or plugged to an external power supply for long term monitoring of an area.

The data are sent wirelessly to a gateway and can be retrieved thanks to the Lyra interface or with a wired Modbus protocol.

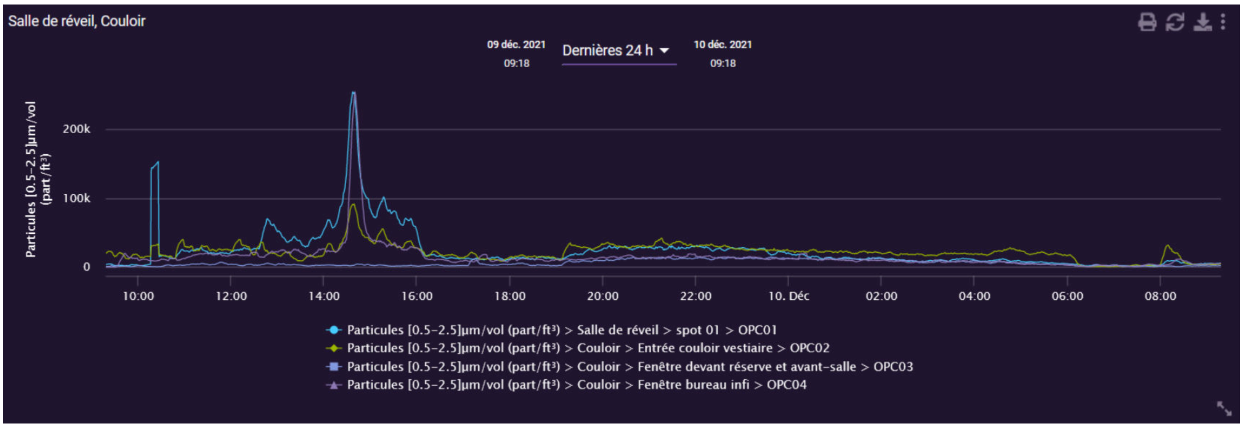
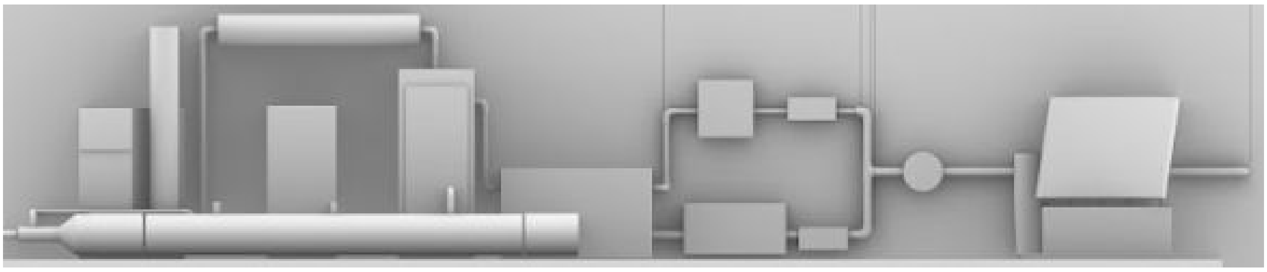


Image of the Safyr OPC measurement on Lyra

To be compliant with the specifications needed for a continuous monitoring sensor regarding the standard ISO 14644-2, the sensing technology must be qualified as described in the ISO 21501-4 standard.

In order to meet the requirements, Safyr has made a partnership with TERA Sensor to develop its own OPC (optical particle counter) technology for the real time monitoring. This collaboration has given birth to the Safyr OPC sensor. A technology affordable and reliable in order to deploy several tenths of units in the same factory.

It's important to understand that affordable doesn't mean low performance. Each sensor is calibrated and delivered with its calibration certificate. The calibration is made by the HeX Group company in a R&R tested specific bench for this technology.



Schematic 4 : HeX bench architecture

Designation	Values	Units
GENERAL		
Technology	*Optical*	-
Targeted pollutants	Particulate Matter	-
Outputs	Channel 1 : pcs >0.3 µm Channel 2 : pcs >0.5 µm Channel 3 : pcs >1.0 µm Channel 4 : pcs >2.5 µm Channel 5 : pcs >5.0 µm Temperature Relative Humidity	*pcs / m³* °C %
Airflow	*2.83* *0.1*	*L/min* *cfm*
Size	*Annex 1*	*mm / Inches*
Lifetime *Calibration recommended every year*	*1*	*year*
PERFORMANCE		
Particle Size detection range	*0.3 - 10*	*µm diameter*
Detection efficiency for PolyStyrene Latex 0.3 µm diameter particles (NIST certified)	*35 ± 15*	*%*
Detection efficiency for PolyStyrene Latex 0.5 µm diameter particles (NIST certified)	*100 ± 20*	*%*
False Count	*< 3 False counts over 15 minutes*	*raw particles number*
Maximum particle number concentration	*up to 3.3 E9* *up to 9.3 E7*	*Particles per m³* *Particles per ft³*
Detection Limit	*350* *10*	*pcs/m³* *pcs/ft³*
Refresh rate	*1 / 10 / 60*	*sec.*
Warm-up time	*10*	*sec.*

Table 2 : abstract of the Safyr OPC sensor datasheet (2024)

6. Complementary solutions for more detailed informations

In fact, the real time monitoring of the factory is one of the best way to understand and improve the process. Nonetheless, the informations provided are limited. In the case of the particles pollution especially, it gives the quantity and an information on the size. By combining this information to the localization where the monitoring device is implemented, you can guess what is the chemical nature of the particle although you can't be sure.

However, you will often need to have the information of the chemical composition of the particles detected because it could generate a specific reaction on the process or have more or less important sanitary impact on workers.

Most of the time, the clean room manager will ask for precise laboratory analysis. For example, to discriminate the different metals you have in the air, you can use the standard CEN EN 14902 (Pb, Cd, As, Ni) … Some laboratories are specialized in this field, such as TERA Environnement in France, and can support the clean room manager by choosing the right sampling and the right analysis regarding its different problems.

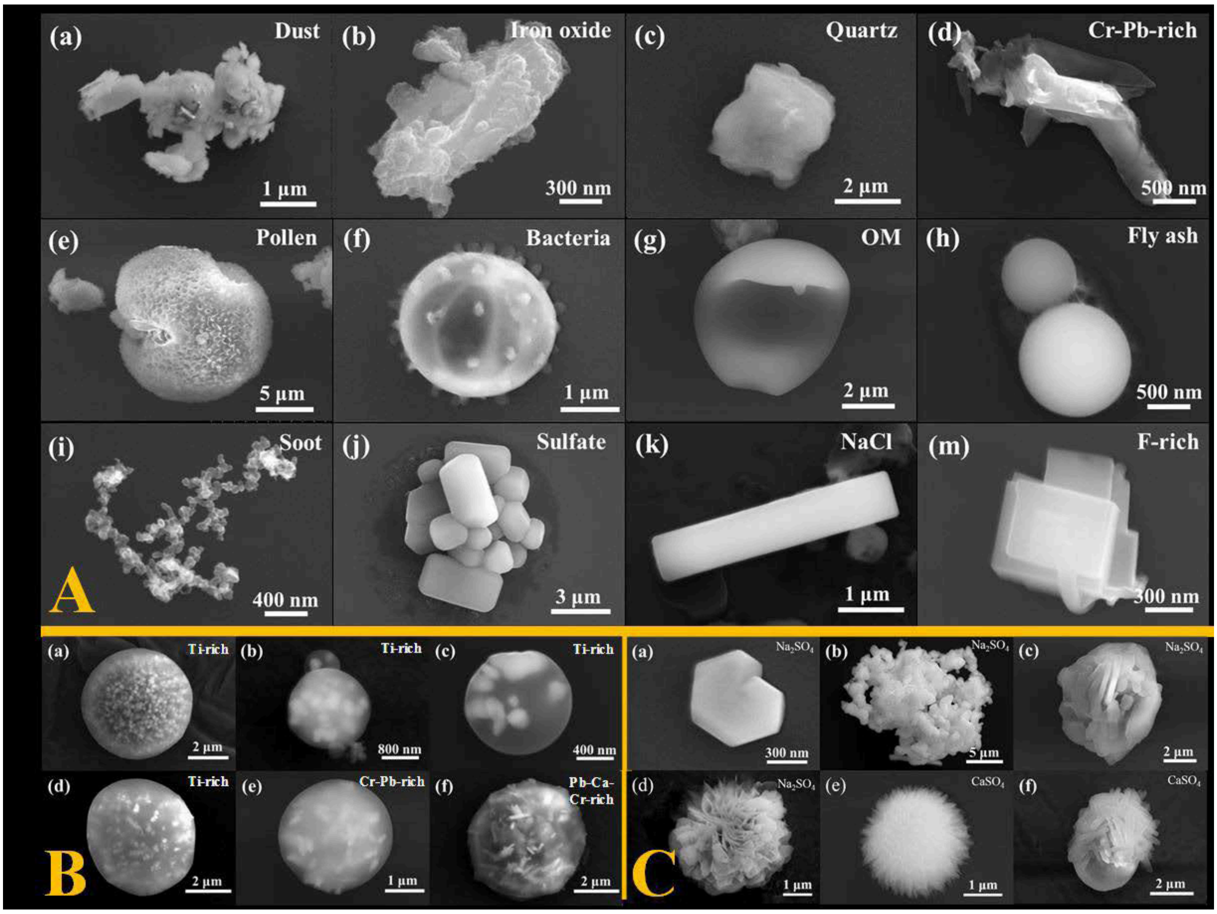


Figure 1. example of different particles detectable by a monitoring system and discriminatable by laboratory means.[2]

These additional analysis are strongly recommended during the first time of operation of the clean room in order to understand and validate the performances. After this period, during each abnormal event like an increase of the particle concentration or a rise of particle concentration whereas the process is turned off, it should be important to combine the real time data and the laboratory precise data to investigate easily on the source of the problem and its real consequences.

At the end, there is also a risk to worker safety in the event of an incident at the factory. As with the production process, regarding the chemical composition of the pollution, the risk is not the same. If after the real time detection of a peak of particle pollution, the sampling for further analysis in the laboratory showed, for example, that it was a Cobalt main composition, then a biological sampling of the workers present can be asked by a skilled person. Thanks to the real time monitoring, the tests can only be done on selected exposed individuals and not all the factory's workers.

In France, public institutes such as INRS and ANSES study the sanitary impact of the concentration of pollutants in biological fluid and how to prevent workers from being exposed. For Cobalt, the recommended values are expressed in µg/g of creatinine (a waste created by the muscles and present in the urine) and are very low. What is also important is when someone has to sample biological fluid. Usually, the sampling is done at the end of the week and of the working day. Nonetheless, in case of an incident, it's better to be advised by a professional. In France, we found that Toxilabo is known as an expert in this domain.

7. Conclusion

We have seen that the exponential growth of the EVs market is endangered due to the known issue of the dendrite formation inside the battery cell (see in chapter 3). Nonetheless, this threat should be handled quickly by the manufacturers thanks to the availability of real time air monitoring solutions and air cleaner systems. The investment seems low compared to the return in terms of confidence of the market and production yield.

Annexes

Sources :

[1]Sobianowska-Turek, A.; Urba´ nska,W.; Janicka, A.; Zawi´slak, M.; Matla, J. The Necessity of Recycling ofWaste Li-Ion Batteries Used in Electric Vehicles as Objects Posing a Threat to Human Health and the Environment. Recycling 2021, 6, 35. https://doi.org/10.3390/recycling6020035

https://www.swirvisionsystems.com/battery-inspection/

https://www.batterypoweronline.com/news/a-look-inside-your-battery-watching-the-dendrites-grow/

https://sps.honeywell.com/us/en/support/blog/siot/what-is-thermal-runaway

https://www.cleanroomsusa.com/ev-battery-autocleanroom

https://www.achengineering.com/the-role-of-cleanrooms-in-ev-battery-manufacturing/#:~:text=Cell%20Manufacturing%3A%20The%20cell%20manufacturing,or%20ISO%20class%206%20classification.

https://www.optical-particle-counter.com/en/2023/04/07/prix-de-linnovation-2023-pour-safyr-opc/

https://cleanair.camfil.us/2024/04/18/the-crucial-role-of-air-quality-control-in-ev-battery-production-plants/

Örüm Aydin, A.; Zajonz, F.; Günther, T.; Dermenci, K.B.; Berecibar, M.; Urrutia, L. Lithium-Ion Battery Manufacturing: Industrial View on Processing Challenges, Possible Solutions and Recent Advances. Batteries 2023, 9, 555. https://doi.org/10.3390/batteries9110555

Dossier Le stockage de l'énergie électrochimique en technologie lithium-ion - article 4
Ivan Lucas et Antonin Gajan, CultureSciences-Chimie, 2021

Cobalt et composés minéraux (*)
Fiche toxicologique synthétique n° 128 - Edition Août 2022
INRS

[2]Li, C.Y., Ding, M.S., Yang, Y., Zhang, P.C., Li, Y., Wang, Y.C., Huang, L.C., Yang, P.J., Wang, M., Sha, X., Xu, Y.M., Guo, C.W. and Shan, Z.W. (2016) Portrait and Classification of Individual Haze Particulates. Journal of Environmental Protection, 7, 1355-1379.
http://dx.doi.org/10.4236/jep.2016.710118

https://tera-environnement.com/

TERA sensor

https://www.inrs.fr/publications/bdd/biotox/dosage.html?refINRS=Dosage_25

https://toxilabo.fr/prestations/

https://www.achengineering.com/the-role-of-cleanrooms-in-ev-battery-manufacturing/

https://camfilapc.com/blog/battery-manufacturing/