

Health- and environmental aspects of additive manufacturing and challenges for a sustainable production (HÄMAT)

Project description

This popular science report presents a short summary of the most important findings and suggestions regarding environment, health and safety (EHS) issues for users of Additive Manufacturing (AM), also known as industrial 3D-printing. The report is based on three different parts of a project (HÄMAT 1-3) that was carried out over the years 2017 - 2024, involving an interdisciplinary network consisting of universities, companies, research institutes as well as non-governmental organizations (HÄMAT websites). The project has been funded by Vinnova and was coordinated by Swerim. The main aim of HÄMAT was to study EHS issues and thereby provide guidance for a well-designed and safe work environment upon establishing this new promising technology.

HÄMAT websites;

<https://www.vinnova.se/p/halso--och-miljopaverkan-orsakad-av-additiv-tillverkning-och-utmaningar-for-en-hallbar-produktion-2--hamat2/>

<https://www.vinnova.se/p/halso--och-miljopaverkan-av-additiv-tillverkning-och-utmaningar-for-en-hallbar-produktion-3---hamat3/>

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1. Metal exposure and health effects

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Background

The most common metal AM techniques are the so-called powder bed fusion techniques, which uses metal in powder form to build the products. The average powder size varies between 30 and 150 μm although very small particles, down to nanosize, occur in the powder and this is a possible health concern. Several different combinations of metals (alloys) can be used in printers, where certain metals are more hazardous to health than others. In the HÄMAT projects, workplace exposure and worker health with a focus on preventive measures have been studied.

Air levels of particles were investigated at 11 companies with metal AM printers and at 3 metal powder production sites. Dust and metal particles have been collected and analyzed using traditional mass-based techniques in combination with real-time particle counting instruments to investigate exposure risks.

In HÄMAT2, worker health was investigated using questionnaires, blood and urine tests, and lung function tests. Body burden of metals was analyzed along with clinical markers for kidney, liver, and cardiovascular status. Results were compared to unexposed office workers called controls (Assenhøj 2023). In the follow up project, HÄMAT3, questionnaires and urine tests were used with the aim to follow up findings in HÄMAT2.

Findings

Workplace exposure

During the projects, the companies improved the work environment through preventive measures and good work routines. Personal protective equipment (PPE) was often used, but not always. Even of the aim was to create a work environment where PPE doesn't have to be used, there are and will be work tasks that require PPE. In general, the overall exposure was lowered and exposure risks during specific work tasks were identified, Figure 1. If the printers are enclosed, they do not emit any dust or particles during printing. However, the workers can be exposed during pre- and post-print activities. The highest levels of dust and metal exposure were seen when the workers handled powder in work tasks such as filling the printer with powder, de-powdering of printed parts, sieving of powder and machine cleaning. The exposure was efficiently mitigated when closed processes and process ventilation were used. The post processes are not specific for AM but must be included in the risk assessment. High levels of small particles were detected during post processing by

milling, grinding, and blasting. The main exposure in powder production was found for sieve operators. In addition, atomization operators in powder production could be at risk for high levels of nanoparticles and metal fumes.

Worker health

In HÄMAT2, no increase in metals in urine could be seen on a group level. However, some individuals had increased metal levels in urine due to high individual exposure. This was still the case in HÄMAT3. This underlines the value of continuously monitoring exposure through urine analyses to be able to confirm that preventive measures and routines are up to date. Most of the lung function tests showed no differences between AM operators and controls, except for fractional exhaled nitric oxide (FeNO) tests which indicated airway inflammation reaction in titanium-exposed workers. Clinical markers for cardiovascular and liver status were approximately the same as in controls. The kidney marker was increased in male operators in HÄMAT2 but not in HÄMAT3, which could be explained by the lowered overall exposure at the participating companies.

Conclusion

Participating AM industries (in Sweden) has shown great interest in worker health and safety. Worker exposure has been lowered during the project due to preventive measures, but some individuals are still highly exposed and may be at risk! The industry is still very young and most of the investigated workers have worked with AM less than five years. We still do not know anything about long term effects.

Key lessons

- Implementation
 - It is possible to manage exposure in AM workshops so that they can be assumed safe to work in
- Air measurements
 - Monitoring of personal exposure and manual tasks is important because this is where exposure occurs.
 - Particle counting instruments are valuable to identify emission sources and prioritize preventions.
- Health
 - Urine samples can be used to detect high exposure to metals.
 - Some individuals were highly exposed and may be at risk.
 - Long term health effects have to be further studied.

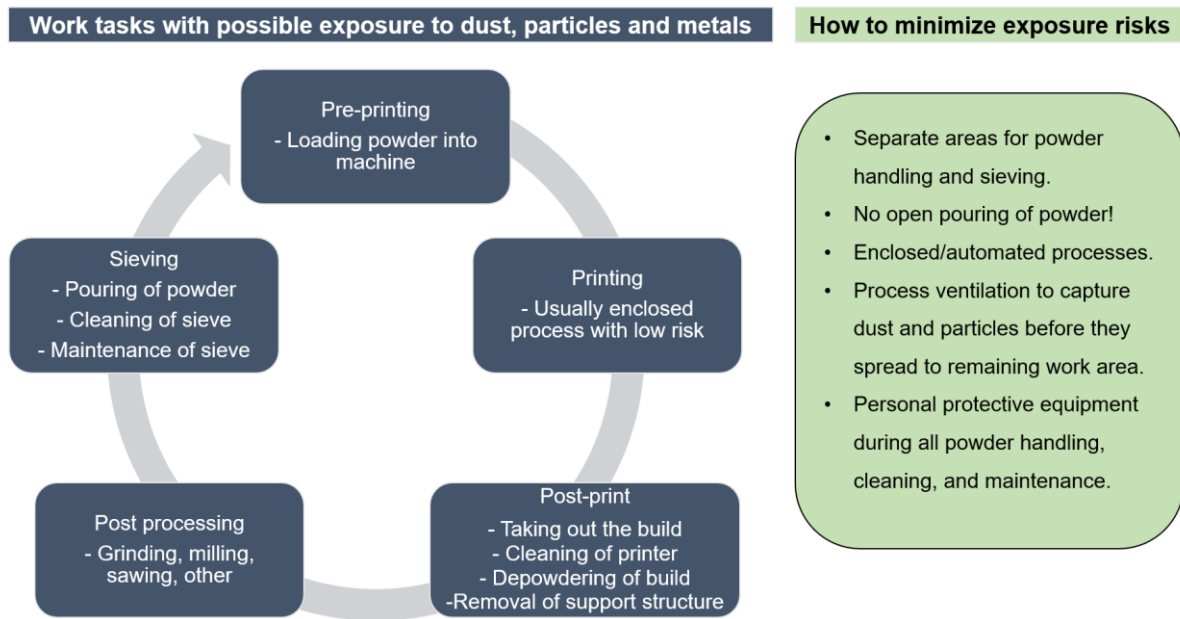


Figure 1. Overview of high risk work tasks and proposals for protective measures

References

Assenhöj M, Almstrand A, Kokelj S, Ljunggren S, Olin A, Karlsson H (2023). Occupational exposure and health surveys at metal additive manufacturing facilities. *Front. Public Health.* volume 11.1292420.

2. Polymer exposure and health effects

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Background

The health of workers at several different companies using polymer printers was examined to investigate if they had more symptoms or were in worse health than unexposed controls. Both standard methods and research methods to test lung function were used. Also, blood samples and particles in exhaled air were collected (Almstrand et al 2022). Workers using AM printers were also examined Monday and Friday in the same week to determine if there were any changes in the tests after a week of exposure.

Exposure and emission measurements were made at the same time as the health examinations to determine what the working environment is like for those who work with AM. Different printing methods were investigated and included: material extrusion, powder bed fusion, vat photo- polymerization, material jetting and multi jet fusion.

Exposure during printing and emissions from printers were measured using different particle and vapor instruments (details in references). Particle counters were used to measure nanoparticle emissions and exposure. Optical particle counters were used to measure exposure to larger particles in the range 0.1-10 μm . Structured exposure diaries were used to correlate the emission and exposure data to 3D-printing tasks. Vapors, determined as Volatile Organic Compounds (VOCs), were also measured. Personal VOC samples were collected during different printing tasks to assess worker exposure. Additionally, VOCs were measured using a real-time sensor. The sensor was placed in printer rooms to observe how VOC levels changed with ventilation, printing, and post-processing over 4 to 5 workdays. Particle emissions inside and outside the printer hoods were also measured to see how well enclosures reduced emissions

Findings

No difference in lung function was found between controls and workers in workshops equipped with polymer printers nor in AM workers Monday to Friday. All workers had normal lung function based on spirometry. AM workers also did not report more upper or lower respiratory symptoms such as nose problems, coughing, or wheezing compared to the control group (Almstrand et al 2023). Analysis of exhaled lung particles showed differences in the composition of the lung surfactant lining the small airways in AM workers compared to controls. Interpreting the health examination data was challenging due to the small number of AM workers. Additionally, there were significant variations in terms of their printing techniques, materials, workload, and the layout of their printing facilities, including ventilation solutions.

Exposure and emission measurements performed, generally showed low personal exposures to dust and VOC compared with many other processing industries but there were large variations (Runström et al 2022). Powder printing processes led to exposure of inhalable dust. Printing that operates at temperatures high enough to produce thermal degradation such as fused deposition modelling (FDM), powder bed fusion (PBF) or multi jet fusion(MJF) emit nanoparticles which could reach high concentrations, similar to a welding environment, if not controlled at the source. VOCs were produced during thermal degradation but also emitted during printing using stereolithography (SLA) or material jetting (MJ) at room temperature, but concentrations of individual vapor components were generally low in comparison to occupational exposure limits (Runström et al 2022, Stefaniak et al 2021).

Some polymer materials that are used in 3D-printing have additional legal demands. Resin-based printers use liquid feedstock (e.g. SLA or MJ) that often are acrylate-based and

classified as skin sensitizing. Workers who are exposed to chemical products that are classified as skin sensitizing H317 or airway sensitizing H334 have to perform medical controls according to AFS 2023:15, "Medicinska kontroller i arbetslivet", unless the risk assessment has shown the exposure to be negligible. It is the employer's responsibility to arrange these health checkups and to perform the risk assessment.

Filament and powder printers can use thermoplastic polyurethane (TPU) as a feedstock. Thermal degradation of polyurethane in other industries have shown the release of diisocyanates, which can cause airway sensibilisation. Workers who are exposed to these type of emissions must perform "medicinska kontroller med tjänstbarhetsbedömning" in AFS 2023:15. For AM, isolated measurements on TPU have not shown any emissions of diisocyanates (Runström et al 2022) but it cannot be ruled out as a possibility if temperatures become high enough.

Key lessons

- Printing emissions can contain substances that may cause respiratory irritation and nanoparticle exposure have been identified as a possible health concern.
- Lung function tests did not show adverse effects in AM workers compared to controls. Small changes in surfactant lipid profile were found in exhaled particles. It's currently unclear whether this change represents a natural biological defense mechanism or early signs of harmful effects. Further investigation into exhaled particles and their connection to occupational exposure is needed in future research.
- When plastic is heated to high temperatures, thermal breakdown occurs, leading to the emission of vapors and potentially high concentrations of nanoparticles.
- Other major exposures found for polymer printers were:
 - Powder exposure during pre- and post-processing tasks in printers using powder as a feedstock.
 - Skin exposure to sensitizing materials during handling of liquid feedstock during printing (e.g. SLA or MJ). Some resin feedstock also contained a substance that is suspected of having reprotoxic effects.
 - Washing printed products with solvents, which could reach high concentrations for short time periods if not done in well-ventilated areas.
- A major challenge regarding exposure and risk assessment in AM environments is the wide range of different techniques and materials used (Runström et al 2022). Risk assessments therefore need to consider emissions and exposure from the process but also evaluate each new material as it is introduced.
- The easiest solution is to control the emissions at the source and our recommendations are to keep 3D-printing exposures as low as possible as a precautionary measure.

References

Almstrand A-C, Bredberg A, Runström Eden G, Karlsson H, Assenhöj M, Koca H, Olin A-C, Tinnerberg H (2023). An explorative study on respiratory health among operators working in polymer additive manufacturing. *Front Public Health*. 11:1148974.

Particles: P-trak 8525, CPC 3700, Partector 2, DataRAM
VOC sensor: Aerasgard KLQ

Runström Eden G, Tinnerberg H, Rosell L, Möller R, Almstrand A-C, Bredberg A (2022). Exploring Methods for Surveillance of Occupational Exposure from Additive Manufacturing in Four Different Industrial Facilities, *Annals of Work Exposures and Health*, Volume 66. Issue 2.163–177.

Stefaniak AB, Du Preez S, Du Plessis JL (2021). Additive Manufacturing for Occupational Hygiene: A Comprehensive Review of Processes, Emissions, & Exposures. *J Toxicol Environ Health B Crit Rev*.1-50.

3. Polymer Characterization

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Background

In the first two parts of the project, HÄMAT1 and HÄMAT2, we identified particle and gaseous emissions in the workplace from four polymer AM techniques (photo-polymerization, powder bed fusion, material jetting and material extrusion). Emissions from one of the techniques; material extrusion, showed high concentrations of nanoparticles which in some cases reached maximum levels of the particle counting instrument (500 000 particles/ml). In HÄMAT3, the focus was to learn more about the emitted particles, with two specific aims 1) to develop a method for enabling chemical and morphological characterization of particles and 2) collect enough material by established methods for toxicological testing of the particles.

Findings

Particles emitted during the process were small and of low mass. For more reliable characterization we were able to increase the particle number concentration through optimization of printer settings such as speed, temperature, size of nozzle and thread, settings of cooling fan, and design of printed object. For toxicological testing we managed to

program printer settings for continuous high particle production over three consecutive weeks.

The developed method for collection of particles enabled simultaneous sampling on various substrates. Visual inspection clearly showed particles deposited on the different substrates, which was later confirmed using advanced analytical techniques. The different substrates were optimized for different subsequent analytical techniques, such as coating with gold or silver nanostructures, and the samples needed no further sample preparation.

In this project we collected and analyzed particles emitted from three different polymer materials and three different printer makers. From all tests we were able to collect and analyze particle amount, chemical composition, and morphology using fluorescence and SEM.

Conclusion

We have in this project developed a method for collection and subsequent analysis of particles emitted during material extrusion with different polymer material. As the sample is collected simultaneously on optimized substrates no further sample preparation was needed enabling characterization of the same sample with various advanced analytical techniques. This presents a more complete understanding of the particle's morphology and chemical composition. Covered by this project were the analytical techniques SEM, fluorescence, and Raman, however this method has also proven to be useful for analysis with TEM and TOF-SIMS. The method can be used for all print methods with polymer and metal printers as well as airborne particles from other processes.

Key lessons

- Airborne respirable particles formed during printing in polymer materials can be collected and morphologically and chemically characterized.
- Enough total mass of airborne respirable particles needed for toxicological testing was difficult to sample.

4. Fires and explosions

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Background

When introducing new technologies, it is highly important to be aware of potential exposure-related risks for the workers. In addition to risks related to inhalation, skin contact and ingestion of dust and particles, depending on the material in question, there is also a risk of fire and explosion.

Findings

Regarding flammable dust and powders, accumulation on surfaces may entail a considerable risk, depending on amount, size and element. Polymer dust could potentially be a risk, but historically it appears that metal dust is more prone to cause accidents or incidents. Dust layers, if sufficiently thick, are dangerous since they can stir-up and form a mixture with air in an explosive range (Ekhoff 2019).

Without being stirred-up, a dust layer is typically too densely packed to explode. Although for some powders, a layer can ignite and if not disturbed, will slowly burn. If water or something else stirs-up the burning powder, an explosion can occur. Nickel- and stainless-steel based powders are hardly ignitable unlike Al- or Ti-based powders which are considered high risk materials.

Volatile organic compounds (VOCs) released during printing are also flammable, but a sufficiently high content cannot accumulate for an explosion or fire to occur. On the other hand, flammable solvents are a notable risk. Some polymer techniques require washing and quantities are handled, fireproof (or ATEX classified) work areas are good solutions to prevent unwanted incidents.

Key lessons

- If handling flammable dust and powders, it is important to prevent the build-up of dust layers by cleaning regularly.
- Read the safety data sheet for new products before start-up.
- Always carry out risk assessments before new work steps.

References

Eckhoff RK (2019). Chapter Two - Dust explosions: Fundamentals. *Methods in Chemical Process Safety*. Volume 3. 7-32.

5. Characterization, toxicity, and immune responses in cell systems

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Background

In this project, we have investigated feedstock metallic particles that are used to produce different surfaces and products with different AM techniques. We have compared new feedstock particles with those that are reused in the process. We have also collected particles that are formed in various AM printers during the actual printing process. Using a number of different methods, we have investigated the reactivity of the particles, for example how the chemical composition of particles changes depending on particle size, whether they emit metal ions in various body-relevant solutions or whether they can form reactive molecules (Wang et al 2021, Alijagic et al 2024). We have exposed cultured human lung cells and immune cells to the particles and studied the cells' survival, whether the particles cause damage to the cells' genetic material (DNA), and whether they give rise to an inflammatory response in the cultured cells. The effects have been compared with other particles for which harmful effects are already known. We also tested chemical extracts from plastic waste from electronic and electrical equipment, which is reused for AM techniques, to study whether chemicals found in plastics can mimic human hormones, change cell shapes, or cause inflammation.

Findings

The particles we examined showed different chemical composition depending on their size, but no or little ability to form reactive molecules. There was also no major impact on the survival of the cells under the conditions tested (Karlsson et al 2023). Several of the particles caused a slight increase in strand breaks in the lung cells' DNA, but no chromosomal damage (a more severe form of damage) was noted (Vallabani et al 2022). The particles tested in HÄMAT projects showed a relatively small, or no, inflammatory response (Vallabani et al 2022, Alijagic et al 2024). In contrast, chemicals extracted from plastic waste had pronounced effects - they triggered inflammation, activated hormonal receptors, and changed morphology of different structures within the cells as an early warning sign of toxicity (Alijagic et al 2025).

Conclusions

When the powders and particles tested in the study were compared with particles that we have previously found to have a clear acute effect on cultured cells, the tested particles were found to be less reactive. However, the comparative particles were often nanoparticles, while the tested particles were generally larger. Therefore, the study cannot draw clear conclusions about the toxicity of nanoparticles from AM. The design of the study focused on relatively acute effects; thus, it is difficult to draw any conclusions about possible effects following more chronic long-term exposure. On the other hand, the chemicals from plastic waste showed clear potential to cause toxicity in human cells, already by short-term exposures.

Key Lessons

The samples of particles to be tested were difficult to retrieve and thus only a few parameters of toxicity were tested. Future studies should have a clear focus on the smaller particles (nanoparticles) and also include longer exposure times.

Additional analyses, particles, exposure times, etc., need to be tested in order to draw conclusions. It is therefore important that all exposure in the work environment is as low as possible. Caution is advised when using plastic waste from electronic equipment in AM environments, as it contains hazardous chemicals.

References

- Wang X, Vallabani NS, Giboin A, Lundqvist J, Färnlund K, Karlsson HL and Odnevall, I (2021). Bioaccessibility and reactivity of alloy powders used in powder bed fusion additive manufacturing. *Materialia*, 19, 101196.
- Vallabani NVS, Alijagic A, Persson A, Odnevall I, Särndahl E, Karlsson HL (2022) Toxicity evaluation of particles formed during 3D-printing: Cytotoxic, genotoxic, and inflammatory response in lung and macrophage models. *Toxicology*. Feb 15;467:153100.
- Karlsson HL, Vallabani NVS, Wang X, Assenhöj M, Ljunggren S, Karlsson H, Odnevall I (2023) Health hazards of particles in additive manufacturing: a cross-disciplinary study on reactivity, toxicity and occupational exposure to two nickel-based alloys. *Sci Rep*. 13(1):20846.
- Alijagic A, Wang X, Vallabani NVS, Melin P, Karlsson HL Särndahl E, Odnevall I (2024) Characteristics and health risks of the inhalable fraction of metal additive manufacturing powders. *NanoSelect*. 10.1002/nano.202300188
- Alijagic A, Seilitz FS, Bredberg A, Hakonen A, Larsson M, Selin E, Sjöberg V, Kotlyar O, Scherbak N, Repsilber D, Kärrman A (2025) Deciphering the phenotypic, inflammatory, and endocrine disrupting impacts of e-waste plastic-associated chemicals. *Environmental Research*. Environ Res. 269:120929.

6. Implementation

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Background

Since the short- and long-term risks associated with the nanoparticles and gases created by AM are unknown, the basic principles (in order) are to:

1. reduce created emissions as low as reasonable attainable (ALARA)
2. contain and reduce leaks to the workplace as much as reasonable possible
3. reduce any remaining particle and gas levels using ventilation both close to the source and by general ventilation

In cases where there are known health hazards associated with the materials used or created during the process it is also feasible to add:

1. monitor particle emissions in the workplace
2. personnel check-ups to monitor blood and expiration levels
3. use of personal protection equipment during sensitive tasks

When introducing new technologies, it is highly important to be aware of potential exposure-related risks for the workers. In addition to risks related to inhalation, skin contact and ingestion of dust and particles, depending on the material in question, there may also be a risk of fire and explosion.

Findings for polymer AM

The polymer materials used for FDM and SLS are typically not hazardous per se, but the extrusion process used by FDM creates nanoparticles and gases that are released into the air. These are so small, so if inhaled there is a high risk of them staying in the body, with unknown long-time consequences.

The polymer materials for SLA/resin printers often contain material that can be skin sensitising, so study the material datasheets before use, and use adequate personal protective equipment when handling.

Here are some key findings for the nanoparticle emissions created during polymer extrusion (FDM):

- Extrusion of most commonly used polymers in FDM creates very high nanoparticle emissions. Some polymers also release gases detectable by the

human nose. There is typically no correlation between the smell during extrusion of the material and its nanoparticle emissions.

For example: ABS has a distinct odour when printing, but PLA has basically no smell at all. Both materials however, create nano-particle emissions during extrusion.

- When measuring nanoparticles, the sensitivity-range of the measurement instrument must be wide. This since all the particles created by extrusion are very small (nanoparticle range and a typical instrument used for air-quality (type PM2.5) detects nothing for this kind of particles.
- For these emissions it seems that the smaller particles the detector can measure, the higher result you get. We saw a ten-fold increase in levels when using an instrument with a range starting at 6 nm compared to one that starts at 20 nm.
- These kind of very light particles stay air-borne for very long times. If used in low-ventilated areas the increased levels can be detected 10-15 hours later.
- Using higher extrusion temperatures create more particles. Lower the extrusion temperatures if possible.

For polymer FDM printers we give the following recommendations:

1. Only use printers with closed design and built-in filters of high capacity and quality, alternatively couple printers to local exhaust ventilation Open printers are not recommended.
2. Add fume hoods for post-processing activities that may emit particles or chemicals.

For polymer powder printers we give the following recommendations:

1. Only use printers with closed design of the powder handling and depowdering as well as built-in filters of high capacity and quality.
2. Place printers in separated enclosures with separate ventilation.
3. Add fume hoods for post-processing activities that may emit particles or chemicals.
4. Consider that explosion risks may be present at certain dust-levels in air, especially during feedstock handling or cleaning. ATEX procedures may be required in some cases.

For SLA printers we give the following recommendations:

1. Only use printers with closed design and built-in filters of high capacity and quality.
2. Place SLA printers and washing/curing stations in a fume cupboard/enclosure with separate ventilation.

3. Add fume hoods for post-processing activities that may emit particles or chemicals.
4. Study safety datasheets for all materials used, and use personal protective equipment (PPE) when handling all feedstock (resins) and other chemicals.

Findings for metal AM

For powder-based metal AM we give the following recommendations:

1. Only use printers with closed design of the powder handling and de-powdering.
2. Add process ventilation close to the printers.
3. Close off area where the printers and post-processing is used and check the general ventilation for that area.
4. Add use of PPE during tasks with high exposure risks.
5. Add general monitors of good quality for particle emissions in the workplace area and outside.
6. Implement personnel check-ups to monitor urine metal levels, especially when using metals with known health risks.
7. Assume that particles < 15 um is present since they may be present in the powder and they may be created during printing/post-processes.
8. Consider that explosion risks may occur at high dust-levels in air, especially during feedstock handling or cleaning. ATEX procedures may be required.

7. Acknowledgement

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The participating project partners in Appendix 1 are acknowledged for generously contributing with their resources.

The participating people, from the different partners, in Appendix 2 are acknowledged for efforts and provided knowledge.

APPENDIX 1. PARTICIPATING PARTNERS

	HÄMAT (2017-2018)	HÄMAT2 (2018-2021)	HÄMAT3 (2022-2024)
1	Swerim AB (formerly Swerea KIMAB AB)	Swerim AB	Swerim AB
2	Volvo Cars AB	Volvo Cars AB	Volvo Cars AB
3	Protech Nordic AB	Protech Nordic AB	Alfa Laval Technologies AB
4	Sandvik AB	Sandvik AB	Sandvik AB
5	Tetra Pak Packaging Solutions AB	Nederman Distribution Sales AB	Befesa Circular Alloys Sweden AB
6	RISE (formerly Swerea Swecast)	Add North 3D AB	Add North 3D AB
7	RISE (formerly SP)	Siemens Energy AB	Siemens Energy AB
8	RISE (formerly Swerea IVF)	RISE AB	RISE AB
9	SVEAT	Absolent AB	Absolent AB
10		AMEXCI AB	AMEXCI AB
11		IKEA of Sweden AB	SSAB EMEA AB
12		Arcam AB	Arcam AB
13		MarkForged Sweden AB	MarkForged Sweden AB
14		Brogren Industries AB	Uddeholms AB
15		Höganäs AB	Freemelt AB
16		3D Center Nordic AB	Albasec AB
17		ZYYX Labs AB	ZYYX Labs AB
18		Perstorp AB	Sensor Visions AB
19		Region Östergötland	Region Östergötland
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21		Karolinska institutet	Karolinska institutet
22		Örebro universitet	Örebro universitet
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Many more contributed to the successful outcome of the project. Crucially, volunteering staff at the project partners made the research involving health checkups possible. Invited speakers at webinars organized within the framework of the projects are also acknowledged. Occupational health care providers offered important advice and will make use of the findings.