The Strategic Research Agenda for the Swedish Additive Metal Manufacturing Industry
Additive manufacturing is an industrial tsunami. Swim towards the wave – prepare yourself to the best of your abilities – or run to the mountains and find other things to do. But don’t stand still on the beach, do nothing and pretend that it’s business as usual.

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   About AMEXCI and the SRA.
Cooling plate for high power electronics in an airplane, by Saab Surveillance. An AM solution in aluminum that improved cooling efficiency by 100% and reduced the number of components in the system. The AM design has been patented for removing air pockets and improved distribution of cooling effect.
Additive manufacturing is an industrial tsunami. Swim towards the wave - prepare yourself to the best of your abilities - or run to the mountains and find other things to do. But don’t stand still on the beach, do nothing and pretend that it’s business as usual.

Additive manufacturing could, of course, be regarded as “just another production technology”. It won’t replace casting, milling, turning or welding. But it does open up a new spectrum of design possibilities, and can be used for hitherto unimaginable components with new functionalities, as well as radically reduce leadtimes and total component costs. And it is applicable – with various business models – in almost any industry making metal components. Since AM offers a radically larger design space, the greatest impact will be on how future products are designed, which might seem like a paradox for a new production technology.

Additive manufacturing has passed the peak of the hype curve, and is steadily becoming an established manufacturing methodology, with an expected annual growth of 28% for metal AM*. As with all innovations, though, there are some challenges to overcome before it can be considered mainstream.

Most of the challenges can and will be met by day-to-day industrial and academic activities. Many of them have been listed by other stakeholders, e.g. in the Ramp-Up** report. However, we would like to prioritize three challenges – design competence, quality and productivity, and occupational health issues. These are the areas that in our opinion need focused national collaboration, following an industrial timeline, if a small country like Sweden wants to stay internationally competitive.

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We would therefore like to see three nationwide initiatives:

**One:** A large, nationally coordinated effort to include additive manufacturing design issues in the technical universities, technical secondary schools and other education providers. The Swedish industry will probably need about 1,000 educated AM designers in five years, and some 5,000 in ten years*. On top of that, employees ranging from operators to procurement and HR - and not least on various management level - will need at least conceptual AM competence.

**Two:** A nationally coordinated effort to increase quality and productivity, including development of non-destructive testing procedures and characterization of the most common and useful industrial AM materials, and to make these characterizations public and easily applicable. Improved industrialization of the post-processing must not be forgotten in this context.

**Three:** A national center for the occupational health issues regarding AM, with expertise ranging from AM production to nanomaterial and heavy metal toxicity.

We hope to share our goals, ambitions and priorities with as many influential people as possible. Please feel free to distribute this document to any and all concerned parties.

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**WHAT IS ADDITIVE MANUFACTURING?**

**Additive Manufacturing** – also known as 3D Printing – is a general term for a number of technologies that form a physical object from a three-dimensional digital model, usually a CAD-file. The method relies on a digital data file being transmitted to a machine that then builds the component in a layer-upon-layer fashion to fabricate a 3D object.

**The different technologies** can be classified by the energy source (e.g. laser or electron beam) or the way the material is being joined, for example using a binder, laser, heated nozzle etc. Classification is also possible by the group of materials being processed, such as polymers, metals, sand or ceramics. The feedstock state, with the most common ones being solid (powder, wire or sheet) or liquid, is also used to define the process.

**In manufacturing industry** AM is used both for serial production in specialized areas and for prototyping. AM’s appeal to the industry is based on the unique benefits that AM has, like short or personalized series, unique geometries, minimized material usage, freedom of design and increased functionality. Potential supply chain efficiency – no tooling, minimal equipment, reduced inventory, distributed manufacturing – can be added to the industrial appeal.

**Additive Manufacturing** is not only used in engineering industry, but also in other areas of society, e.g. medicine, education, architecture, cartography, toys and entertainment. This SRA focuses on metal AM, but other materials are available too, including polymers, metals, ceramics, paper, bio-materials, sand and even food.
Additiv tillverkning, populärt kallat 3D-printning, är en industriell tsunami. Företag kan välja att ”simma mot vågen” och förbereda sig efter bästa förmåga, eller ”fly till bergen” och hitta annan verksamhet. Men att stå stilla på stranden och låtsas att saker och ting är som vanligt kan bli ödesdigert.


Additiv tillverkning är på god väg att bli en etablerad produktionsmetod, med en årlig tillväxt om 28 procent*.

Som med alla innovationer är den dock behämtad med en rad utmaningar. De flesta kommer att löses av industri genom sedvanligt utvecklingsarbete. Men för tre av utmaningarna - designkompetens, kvalitet och produktivitet samt arbetsmiljöfrågan - behövs nationell samling om ett litet land som Sverige ska kunna hävda sig i den internationella konkurrensmarknaden. Vi är väl medvetna om tidigare ansträngningar att kartlägga utmaningarna, exempelvis rapporten Ramp-Up**.

Men vi vill här visa vad industriprioriterar högst, och föreslår därför tre nationella initiativ, att genomföra i den tidslinje industriärna verkar inom:

För det första: En rejäl, nationellt samordnad satsning på att få in additiv tillverkning i en rad utbildningar, från tekniska gymnasier till högskolor, universitet och hos andra utbildningsaktörer.

För det andra: En nationell samling för att öka kvaliteten och produktiviteten, där utveckling av icke-förstörande testprocesser och karaktärisering av material ingår.

För det tredje: Ett nationellt center som fokuserar på arbetsmiljö, för kartläggning och minimering av de hälsorisker som additiv tillverkning i större skala innebär.

Med denna skrift hoppas industriärna står bakom den att få till stånd de förändringar som krävs för att vidmakthålla och stärka vår nationella konkurrenskraft. Vi hoppas få stöd från så många inflytelserika personer som möjligt.

Sprid gärna skriften!

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Conclusions and recommendations

This SRA, Strategic Research Agenda, aims at highlighting the importance of AM for the Swedish metal manufacturing industry, and thereby encourage certain changes and actions in the Swedish AM ecosystem. Utilizing AM to its full potential is crucial for the industrial competitiveness, but the AM discipline needs more critical mass and more structured collaboration between the stakeholders. Such a critical mass requires collaboration efforts on national level, with full backing from industry, academia, research institutes and other stakeholders.
In short, we believe that radical changes in three particular areas are of essence for the Swedish industry to be able to deliver on the AM promises:

**One: Education.** Given that the Swedish industry will need at least 1,000 employees with AM competence in five years, and five times as many in ten years, we urge schools, universities and other education providers to include as much AM in their curricula as possible. Tomorrow’s AM designers need not only design competence – these men and women also need to be familiar with the AM context, including AM production and methodology.

Examples of needs include shorter introductory courses, inclusion of AM in technical secondary school programs and in qualified professional schools (YH-utbildning) and Masters programs with AM focus. There will definitely be an industrial demand, ranging from two-day courses to master programs and Ph.D. projects.

The industry would relish such efforts, and would gladly collaborate by sending staff to courses and offer opportunities for e.g. degree projects and doctoral students. The efforts should also preferrably be nationally coordinated, to increase the student quality while ensuring that industrial needs are met.

**Two: Quality and productivity.** The challenges concerning AM quality and productivity are substantial and multi-faceted. Low number of suitable metal powders, material properties not characterized well enough, machines too small and too slow, manufacturing processes neither robust nor predictable, poorly industrialises post-processing, lack of testing and verification methods, lack of standardized interfaces between design software and machines, as well between machines – those are some of the issues that hamper quality and productivity.

Sweden cannot – and should not – adress all these issues. Some, e.g. the interface issue, will probably be solved best by the large design software vendors in collaboration with machine manufacturers. Other require international standardization efforts, where Swedish industry and academia should be represented.

There are, though, some fruits hanging lower than others for Sweden. Characterization of metal powders is one, verification methods is another. We would therefore suggest a national effort to characterize the most common and useful AM materials, and make these characterizations public in formats that are useful for the industry – research reports are not enough.

These characterizations should be expanded to include proper, non-destructive testing and verification procedures. Assuming results are met, such an effort would vastly increase the quality and productivity of AM, and lower the threshold for new AM entrants. In essence, industrially viable AM needs a well defined design window, where quality is predictable and repeatable.

**Three: Occupational health.** The occupational hazards of AM metal manufacturing are to a great extend unknown. Heavy metal content in nano-scale powders certainly give cause for concern, and measures to mitigate the risks are taken by the industry. However, this is a field where more research is necessary in order to understand exactly what measures are needed, and at what cost. We would therefore welcome a national center for the occupational health issues regarding AM, with expertise ranging from occupational medicine and biomedicine to AM production, nanomaterial and heavy metal toxicity.
Where we want to be, soon.

Goals and wanted position

In five years the companies behind this SRA expect to have AM activities worth at least one billion SEK. Another five years later that number could be fivefold or even tenfold, hence the focus on industrial additive metal manufacturing in this SRA. Other AM application areas, e.g. medical, dentistry, fashion or food, may or may not use similar materials, and may have other challenges and different priorities – this SRA focuses on research based on industry needs.

For the long term, the industrial ambition cannot be any other than that Swedish industries will use AM as easily and as naturally as any other manufacturing technology, e.g. casting, milling, turning or welding. AM should then be

<table>
<thead>
<tr>
<th>Strategic need</th>
<th>Short term, 2018-2020</th>
<th>Mid term, 2020-2023</th>
<th>Long term, 2023-2028</th>
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</thead>
<tbody>
<tr>
<td>Design competence</td>
<td>AM design in M.Sc programs in Swedish universities. AM design in secondary school.</td>
<td>1,000+ people with AM design competence, in Sweden.</td>
<td>5,000 people with AM design competence, in Sweden.</td>
</tr>
<tr>
<td>Materials and production</td>
<td>Non-destructive verification methods and improved post-processing for AM components.</td>
<td>Defects in serially produced AM components on par with components manufactured with traditional methods.</td>
<td>Full control of defects and verification methods. AM is a natural part of production development. Post-processing fully industrialized</td>
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<td></td>
<td>Collaboration creating a virtual national testbed for AM machines. A culture of mutual learning.</td>
<td>Procurement know-how of AM machines on par with traditional manufacturing machinery.</td>
<td>Smart AM-centric production. AM design space drives and improves other production methods.</td>
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<td></td>
<td>3-4 materials properly characterised, in public domain. Proper methods for fast material characterisation.</td>
<td>At least one qualified AM material for each major industrial application. Faster and more efficient qualification methods for new materials.</td>
<td>Materials designed bottom up from industrial needs. Integration of different materials. Ability to handle conducting and non-conducting structures.</td>
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</tbody>
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The table illustrates some of the strategic research needs, with a possible time line.
Many forms of education are needed for raising AM awareness.

used for any components, systems and products where the technology is appropriate and advantageous. That goal should be reached in about 10 years, for Swedish industries to stay competitive. It’s worth reemphasizing that AM is a globally disruptive manufacturing technology that will give huge advantages to those who master it, whether in Sweden or elsewhere.

The goal is ambitious but realistic if the journey starts immediately. Several milestones need to be passed before reaching it. One of the most crucial activities is to increase the number of AM proficient people in the industry. Many forms of education are needed - short 2 day courses for raising AM awareness, AM elements in secondary school, AM elements and AM courses at universities, and probably even AM-focused Master programs. It is highly likely that the Swedish industry will need at least 1,000 AM-savvy people in engineering, procurement, management and for operating the machines five years from now, and that number will probably grow to some 5,000 in ten years. The Swedish industry hereby urges all relevant education providers to include AM in their curricula, and to expand the AM programs already in place. Many large Swedish corporations would gladly partner with schools and universities to ensure that the educational content is in line with industrial needs, and thus easily lead to good jobs for the students. One example is the Swedish Arena for Additive Manufacturing and its plans to focus on education issues in collaboration with several universities.

The first real component printed at Saab; the breech of the grenade rifle Carl Gustaf. Printed in Titanium using EBM. Tested in live firing tests and it performed perfectly. The breech was scanned with Computer Tomography before and after the live firing test, but no cracks could be identified. The firing tests subjected the breech to extreme mechanical and thermal loads and this showcase illustrated that AM materials are possible to use even for highly stressed components.
Where we are today.

Current situation and challenges

There is a strong sense of urgency in the metal manufacturing industry. Many major Swedish companies have established AM task forces, and some have started AM prototyping. The forerunners have even begun serial production of commercial components and are sending dozens or even hundreds of employees to AM courses.

The Swedish AM ecosystem supporting the industry features several proactive universities, a number of advanced research institute initiatives, several machine suppliers and subcontractors, and not least a disproportionally large number of world class manufacturers of metal powder. There is also an understanding of the industrial urgency among government agencies supporting innovation, illustrated by numerous reports and substantial tax money allocated to AM research projects. It is worth noting that the EU has defined “AM skills” as a strategic need for Europe.

Universities with AM research and AM education include Chalmers University of Technology, University West (Högskolan Väst), Royal Institute of Technology (KTH), Linköping University, Örebro University, Lund University and Mid-Sweden University. Among the research institutes, Swerea Kimab (soon in a new institute) and Swerea IVF (soon integrated in RISE) both have high ambitions and strong know-how, with Kimab focusing on materials and IVF on manufacturing issues.

However, the spread is large between forerunners and laggards, in the industry as well as within academia. Several large corporations struggle with their business models for AM, and lack AM critical mass in spite of having dedicated AM teams with top management support. Many small and medium sized companies find the cost of entry prohibitive. Some universities have no AM activities at all, and only a handful of secondary schools have AM on their curricula. And much research and development is done in silos, with far from enough interaction and communication between the stakeholders and the AM ecosystem at large.

Companies who have taken some steps on their AM journey face a number of technical challenges, all hampering the productivity. Process robustness is one – today a component manufactured in one machine will probably not have the same features as another component made in an identical
machine, with identical parameters and from seemingly identical metal powder. Many material properties are simply not well enough known, and the production robustness leaves much to be desired. The variety of metal powders available is not considered satisfactory, and not enough optimized for industrial needs, sometimes due to the fact that the industry has not been able to specify those needs.

**Also, verification methods**, especially for advanced structures, are sorely lacking. Once a component is manufactured, it is more often than not very difficult to test that it has the right shape and an acceptable level of defects, at least not without destroying it. New non-destructive test methods must be developed, preferably standardized. Today it’s possible to design more advanced structures than can be analyzed – thus better analysis methods for e.g. dynamic loads and lattice structures are highly anticipated, as well as methods for fatigue analysis and post-processing. The entire AM value chain – from design to qualified components and systems of components, including post processing – would benefit from a higher degree of automation. Today, post processing can be much more costly than the printing.
As with many new technologies, more standardization is a pressing issue for AM. There are some standards, but more are needed – for powder, for AM machinery, between CAD tools and machines and also between machines, just to name a few areas.

There are also many non-technical challenges. Design culture, or rather lack thereof, is probably the single most important factor hampering the Swedish industry from adopting AM. There are of course examples where AM can make an existing component much lighter, or where AM can reduce lead time for existing component designs, but one-to-one replacements rarely add enough value to justify additive manufacturing.

This value-add more often than not requires new, innovative designs, where the number of components can be reduced, and the new component can be given new features and properties hitherto impossible or unimagined. Only a limited number of Swedish companies have yet mastered such necessary design skills in any volume – it requires AM design thinking not only among engineers and designers but also in procurement, among AM operators and not least on several management levels. It takes commitment to get there, and that commitment needs a critical mass of know-how, supported by a not unsubstantial budget.

The occupational health issues constitute a third challenge for AM, not only in Sweden but all over the world. Most metal powders for AM contain toxic heavy metals, and nanoscale particles constitute a health issue in themselves. Exactly how harmful these substances are to the human body is unknown, so industrial forerunners have taken a cautious effort, supplying operators and other people visiting AM factories with state of the art protective clothing, including e.g. HEPA filters. AM machine operators are also tested regularly for harmful blood and urine levels of nickel, chromium and other toxic substances, so far with only sporadic occurrence of non-prohibitive levels.

Occupational health is a topic that most AM enthusiasts prefer not to talk too much about. The awareness is nevertheless omnipresent, and several AM companies recognize that much more work is needed in this field. There is also a recognition that Sweden, with a tradition of being strong in occupational health as well as manufacturing in general, could take a global leading position here.
What could go wrong?

Threats

AM will significantly change the way the industry designs metal components and objects, regardless of any Swedish initiatives. Multinational industrial corporations in Europe, Asia and the USA, perhaps most notably Siemens, GE, Toyota and Hitachi, several major German automotive brands, are investing heavily in AM technology and know-how, and so do institutes like Fraunhofer and agencies such as NASA. The AM tsunami is bound to happen, thus the greatest threat to Swedish industry would be to do nothing, or to do too little, too late.

A specific threat for a small country like Sweden is a lack of critical mass, made worse by the fact that much development here takes place in rather isolated silos. Absence of interaction and communication imply that the same – or at least very similar – research sometimes is done in more than one place, and that progress made is not always found or recognized by those who need to know about it even though it is technically available. More openness, more explicit incentives by the industry, and an increased perceptiveness to the industrial incentives, would contribute to remedy this particular threat. This SRA attempts to clarify the industrial position in creating such a collaborative climate, not just between corporations but including all Swedish AM stakeholders. The companies supporting it would welcome – and invest their time and money in – new collaborations, assuming satisfactory ambitions.

The threat of an occupational health incident is already mentioned. A single test sample from an operator with high levels of, say, chromium, would be enough to immediately halt all AM production at that site, and potentially put a dent in the entire AM movement. It will probably not be a showstopper, but such an incident would put the general focus on issues not benefitting the industry.
Who should do what?

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Schools, universities and other education providers must shoulder the responsibility of getting AM on their curricula, and to recruit students with various backgrounds and genders. The industry will gladly help with domain expertise, welcome students on field visits and offer degree projects. The industry will also happily assist the design students with the entire AM context, i.e. include process and material issues in the design education.

Universities and institutes performing research in the AM field must step up their activities and be more attentive to industry needs. Smart specialization is of essence - there are enough challenges for everyone, and Sweden is too small to have competing research groups. Researching stakeholders also have a lot to gain by building more trust among their industrial customers, through intensified networking and higher levels of professionalism regarding IPR and other sensitive issues.

Strategic needs and priorities

With so many challenges and such a strong need to ramp up the critical mass, priority must be given to needs considered strategic by the industry. Each company with AM ambitions can and should do many things internally, e.g. invest in education for its staff and elaborate business cases for components considered suitable for AM production. The industry as a whole has good reasons to voice its opinions clearly, preferably speaking with one voice.

The table highlights our vision of who should do what. Note that the long term goal for industrial collaboration is identical to the long term goal of the research providers.
This Strategic Research Agenda attempts to clearly show what the Swedish manufacturing industry needs in order to take full advantage of the global AM movement.

The companies supporting the SRA are committed to do what it takes to reach that goal, in collaboration with other stakeholders in the ecosystem.

The SRA was written and produced by Adam Edström and Sofia Målberg at RISE Acreo. The authors wish to thank everyone who contributed to this work, in large and small.

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