SFI-skisse nr: (Fylles ut av Forskningsrådet)

1. Tittel og kontaktinformasjon.

SFI arbeidstittel	Additive Manufacturing Enabled Supply Chains
Vertsinstitusjon	SINTEF AS
Kontaktperson	Tor Dokken, tlf 930 58 710, tor.dokken@sintef.no
Partnere	

2. Kort sammendrag.

Additive manufacturing (AM) is, by definition, a family of processes that builds parts as specified by a digital model, by the successive addition of material. The basic principle of successive adding material has brought a new degree of geometrical freedom, and thus a potential for innovation, that is not possible by any other manufacturing technology.

AM is a highly cross-disciplinary field of technology. Besides identification of a suitable product with a sustainable business case, successful application of AM for industrial production relies on mastering the combination of new design methodology and digital modelling (parts and process), with several aspects of materials science. This includes feedstock material as well as the physics of the materials' behaviour during the additive process, and in all operations required for the part produced to fulfil the requirements of the product. To date, AM has proven to bring a highly disruptive capability to several application areas, most commonly found in the fields of aerospace and medicine. However, during recent years, leading companies from energy, oil & gas, shipping and process industries in Norway have also identified AM's ready potential to greatly improve and shorten the supply chain for spare parts, including on-demand and distributed manufacturing. In a longer perspective, the industries' exploitation of AM is expected to enable development of new products with new designs using new, high performance materials.
It is the objective of this SFI to bring together expertise in all necessary disciplines, and conduct world class research, needed to bridge the inter-disciplinary gaps between established state-of-the-art and fulfilling the requirements to enable full scale industrial application of AM technology in Norway.

3. Potensial for innovasjon, næringsutvikling og bærekraftig verdiskaping.

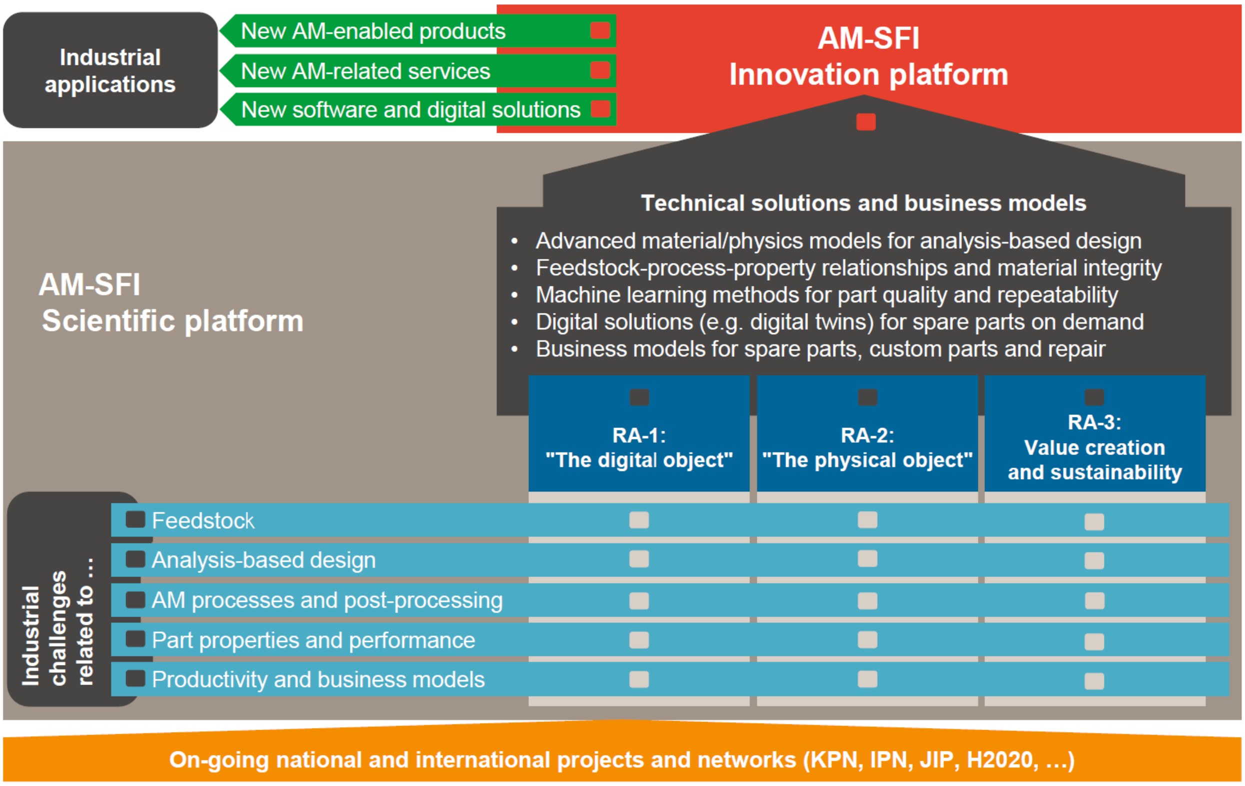
In addition to enabling innovative applications in a growing array of sectors of industry and society, AM has also been identified as an enabling technology for the re-industrialization of high-cost countries such as Norway. For example, in the case of spare parts production for the industries mentioned above, the loss of production due to idle equipment is often far more critical than the cost of the spare parts, and therefore local on-demand production of spare parts from a digital warehouse can be far more advantageous than collecting and distribution from a physical warehouse. However, key industrial challenges to make this possible, and further enable the use of innovative designs and new materials, are:

I. Reliability and performance of parts for critical applications and in demanding environments.
II. Lead time and costs.
III. Analysis-based design to reduce uncertainties and exploit the full potential of AM in industrial applications.

Addressing these challenges, and to ensure predictable and repeatable physical properties in the parts, the SFI will combine practical experiments with machine learning and simulations to describe and model the behaviour of relevant materials in the selected AM processes.

The SFI will implement a digital backbone that will serve as a model of how the value chains and digital twins for AM can be organized. This is expected to enable major innovations for the industrial organization of digital warehousing. For example, *Equinor* has tens of billions worth of NOK in spare parts stored in physical warehouses. Replacing even a fraction of this stock by digital warehousing would have a large economic impact. Further savings can be gained by efficient use of AM, only the parts needed are made, using less material, and with minimized waste in the process. Dependent on the reasons for the need of replacement, repair of a worn or broken part by rebuilding the missing material is another possibility for reducing waste. A digital model never goes out of stock, therefore the need to replace whole modules due to a few lacking spare parts can be avoided. Local production also requires less transport. These are all aspects of AM enabled innovation that reduce waste, costs and possible environmental impact. Innovations based on exploiting the freedom of design for better performance and lighter products by AM and developing new materials will improve competitiveness, and open new markets for the involved companies.

4. Forskningsoppgaver.
The R&D topics will be selected based on the industrial challenges summarized in Sect. 3, and existing strong fields of expertise in the research groups involved, which again are mostly based on earlier national and international industry-focused R&D projects. The structure of the activities in the SFI is as follows:



A schematic illustration of the SFI. The starting point is the industrial challenges (bottom left) and the competence from earlier projects (bottom arrow). The research areas (RA-1 to RA-3) will deal with digital and physical aspects of materials/parts, AM processes and value chains, as well as analyses of value creation and sustainability. Output from the research areas will be utilized in an innovation platform (upper right).

Feedstock (in the form of powder, wire etc.) for the AM processes: The main materials in the SFI will be commercial metal alloys and polymer-based materials and composites. The SFI will build competence on optimal feedstocks and how critical parameters of the feedstock can be measured and controlled in an industrial setting. The SFI will also include development/modification of feedstock for AM, with Si-based and Al-based materials. Demonstrators will be manufactured with such new feedstocks. There is a large potential to design and develop innovative alloys tailored for AM components. In order to meet the special requirements of AM production technologies, the chemistry of the metal as well as process parameters for metal production must be optimized to get desirable microstructures.

Analysis-based part design for AM and AM process simulations. In order to utilize the geometrical freedom and fast turnaround offered by AM, virtual product development in the form of numerical simulations is an important tool. Commercial software packages for AM have been introduced in later years, claiming to address and simulate everything from A to Z. However, there is a clear potential for improvements. One area of improvement is to introduce novel mathematical approaches, such as isogeometric analysis. We will also improve the material/physics models and associated material data, in order to improve the reliability of AM process simulations (e.g., to simulate the warpage and possible defects of the final part, built in a certain way) and analysis-based part design (e.g., to reduce part weight with a given mechanical loading). We also plan to address multiphysics-based design for AM, e.g., for chemical engineering applications, for which there are no commercial software packages.

AM processes and post-processing: The SFI will use the AM facilities of the research partners and industry partners, and the three national catapults with AM infrastructure, as well as AM labs of international collaborators. R&D tasks directed towards the AM processes may include aspects of process monitoring and in-situ control. New commercial processes or process steps, claiming higher productivity, better part quality or better repeatability, will be benchmarked, also with research tools. Moreover, the SFI will perform research on post-processing and heat treatments to improve part properties.

Part properties and performance: The SFI will do research on material-process-microstructure-property relationships. Fundamental relationships will be studied experimentally and numerically in order to establish a firm basis for using AM parts in demanding and novel applications. Robust and repeatable AM processes, and predictable mechanical performance, are essential factors for the industrial use of AM. The research will include studies of fatigue, fracture mechanics and corrosion. Non-destructive methods will also be studied, since such methods are important for quality control of critical parts in production lines.

Digitalization: The "digital thread" is central for the AM value chain, from the product development phase to the approval and supply of products. One research activity will deal with new numerical geometry representations. This will give benefits in the simulation of complex geometries, such as non-uniform lattice structures, and it will also lead to solutions for more effective usage and sharing of geometry models in the various phases (design/FEA, production, quality control). Finally, the SFI will include research on digital twins and use of product lifecycle management to develop more effective AM value chains.

Value creation and sustainability via new business models and product innovations: In the SFI, the research partners will collaborate with user partners from industry and public enterprises – both in the research activities and via case studies. The case studies will deal with product innovations and business models, especially for spare parts on demand and mobile AM solutions. New business models and products will be analyzed regarding their sustainability, and their contributions towards a circular economy.

5. Organisering.

The multi-disciplinary skills needed for the proposed SFI are not available in one university or research institute – the competences needed are spread across several research groups in different locations. The research partners are selected based on complementary skills, relations to industrial partners, and academic reputation. The roles of the research partners are as follows:

Research partner	**Role and contribution of knowledge and competences**
SINTEF (Oslo, Raufoss, Trondheim, Porsgrunn)	SINTEF will lead the SFI and contribute with competences within digital, material science, manufacturing and numerical simulation. Several SINTEF institutes/groups will be involved.
NTNU (Trondheim, Gjøvik)	Additive manufacturing technology, materials science, metallurgy, solid state mechanics.
UiA (Grimstad)	Additive manufacturing technology, materials science.
IFE (Kjeller)	Modelling, numerical methods

The SFI will be led by a management team. The steering committee will have representatives from user partners and research partners, and the committee will be led by a representative from the industry. Finally, the SFI will have a scientific advisory board.

A digital cooperation infrastructure will be used to facilitate cooperation and reduce travelling. Research partners and user partners can participate remotely in meetings and lectures. The cooperation complements the digital backbone for the digital twin to be set up as part of the research activities.

The SFI will have an innovation platform to foster innovation based on results from the SFI, as well as possibilities offered by (existing and new) AM technologies in general. Furthermore, the SFI will generate an ecosystem for AM-related R&D in Norway, and thereby initiate a portfolio of AM projects, e.g., national IPN projects and projects funded by the European Union.

6. Internasjonalt samarbeid.

The research partners all have a large international network, both academic institutions and various networks and organizations. Some important international partnerships are listed below:

- Isogeometric analysis for AM: ICES Univ. of Texas (US), University of Pavia (IT), Singapore University of Design and Technology (SG), Technion (IL)
- AM process simulation: CIMNE (ES) and TU Munich (DE)
- AM technology and materials science: KU Leuven (BE), Mid Sweden University (SE), Inspire (CH)
- As a small AM research centre at the international level, we also plan to form a strategic alliance with one of the major European AM research centres in Germany or UK.
- A Nordic industrial cooperation based on the newly established Nordic AM Group.

7. Forskerutdanning og kjønnsbalanse.

AM is a relatively new field, and AM technologies and materials are still in rapid development. Hence, the industry needs knowledge and competence at different levels. The research of the SFI will enable the industry to develop new materials, and to use AM for their existing and new products, in a robust, predictable and effective way. The centre will educate candidates at the master and PhD level. The students will also do research in connection to industrial user cases. Research partners, students and user partners will participate in joint "master class" workshops, which will also feature industrial cases and practical sessions. Specific courses that addresses competence gaps in the industry will be developed by the academic partners.

The centre management will be gender balanced. We plan to the extent possible to put female scientist in positions where they can act as role models and be visible as part of the community. Special emphasis will be put on attracting female students. We plan to have cooperation with organizations such as the Norwegian branch of Women in Data Science to attract women to the positions announced.

8. Foreløpig budsjett og kostnader.

Organization	**Average cost per year RTD partners in MNOK**						**Sum over 8 years**
	Staff hours	PhD/ Post doc.	Software/ Equipment	Travel/ meetings	Sum		
Centre management	1.6		0.2	0.2	2.0		16.0
Research institutes	3.0	2.0	0.5	0.5	6.0		48.0
Universities		6.0	0.5	0.5	7.0		56.0
Sum	**4.6**	**8.0**	**1.2**	**1.2**	**15.0**		**120.0**

	Average financing per year in MNOK	**Over 8 years in MNOK**
Research council	12	96
Industry cash	3	24
Sum	**15**	**120**
Industry in-kind	3	24
Grand sum	**18**	**144**

9. Forholdet til etablerte sentre og andre større satsinger.

The SFI-AM will be complementary to some running SFIs. An SFI-AM will be situated downstream in relation to SFI Metal Production. SFI Manufacturing has some activities on AM, but these do not overlap with the scope and focus areas of the proposed SFI-AM summarised above. SFI CASA develops material models for mechanical responses but has not focused on parts made by AM.

The proposed SFI-AM will take advantage of national infrastructures, in particular Manulab which hosts AM machines and advanced characterization equipment (CT, Gleeble). SFI-AM will also collaborate with the three Norwegian Catapult centres that have declared that AM shall be a key technology in their service offerings and training portfolios (Manufacturing Technology, Future Materials and Ocean Innovation).

SFI-AM will cooperate with the cluster Subsea Valley (including NCE Energy Technology) in network building and creation of new projects.