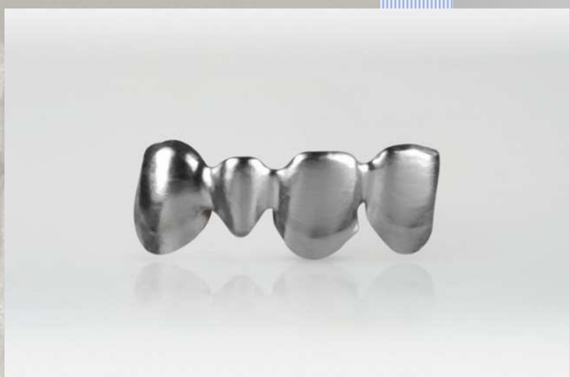
2014

Additive Manufacturing:
SASAM Standardisation Roadmap



SASAM Standardisation Roadmap

RM PLATFORM

SASAM Standardisation Roadmap

EXECUTIVE SUMMARY

This document describes the roadmap for standardisation activities for Additive Manufacturing as drafted from the SASAM project.

It is based on the on-going developments within this sector, it contains the needs and visions from the industry and other principal stakeholders and also reflects development trends within the manufacturing industry and society in general. The SASAM partners have compiled and evaluated documents with respect to their relevance. In all, 25 documents have been selected and the most relevant points from each document have been extracted and highlighted in an evaluation template. Documents and evaluation templates have been made available through the SASAM website (and have been reported in deliverable D2.1.)

The interest and attention for the development of AM standards have gained momentum. A group of over 100 industrially driven stakeholders from all over the world (with a centre of gravity in Europe) is currently active in AM. These stakeholders indicated the need and type of standards to be developed, they must be focussed on customers and market and support industrial implementation of AM. A number of standards categories were distinguished such as design, specific industrial needs, quality of manufactured parts, safety (regulations) and education.

A listing of already existing standards for AM has been drafted. Where relevant, liaisons have first been established with standardisation bodies and an assessment will be made whether further cooperation with Technical Committees will be desirable for AM topics as well. It must be noted that there is no CEN/TC on Additive Manufacturing at the moment. As part of the SASAM project it will be assessed whether the initiation of a CEN/TC on Additive Manufacturing should be requested for in Spring 2014.

Input from AM standardization stakeholders showed that AM technology is expected to release an economical push towards the reliability of the processes, machines and their products. Important topics identified are: terminology, design, test methods, materials and processes, data processing. Among the European participants there is a clear preference for an international standard like ISO compared to the ASTM or any other (VDI, CEN) standard. The remarks also show again the necessary qualification of specific industrial standards.

This dedicated standardisation activity is expected to increase the existing AM business and will help to obtain acceptance on new markets and by new industries. This will be a big opportunity for innovation and economic growth in the European industry, which should enhance competiveness and so be instrumental in creating jobs in Europe. This assessment is also underlined by the European “Industrial Landscape Vision”.

AM standardization documents were analysed and a proposal for the structure of standards has been presented. The following key agreements on the guiding principles to be followed and adopted by all organizations, were drafted:

- One set of AM standards – to be used globally
- Work on a common roadmap and organizational structure for AM standard
- Use and elaborate upon existing standards, modified for AM purposes when necessary to increase efficiency and effectiveness
- ISO TC261 and ASTM F42 should begin the work together and in the same direction with an emphasis on joint standards development.

The benefits which can be achieved by AM indicate that the total sale of AM products will reach USD 3.7 billion by 2015. Standards help to reach such benefit by enabling the necessary certification and approval for e.g. medical and aviation applications. The plastics market is leading whereas there is a very strong growth in AM using metallic base materials (double digit percentage increased growth in sales over the next five years). The exploitation of AM technology as an alternative manufacturing tool will encourage innovation and enhance the competitiveness of labour in Europe.

24 relevant projects have been contacted and asked for a listing of relevant aspects with respect to standardisation within the respective projects. All of them were invited to present their progress on the AM-platform meetings (open discussion forum for AM stakeholders) which are held minimal twice per year. Also, liaisons with relevant TCs have been established and coordinated by STAIR-AM (a CEN/CENELEC pilot to promote standardisation).

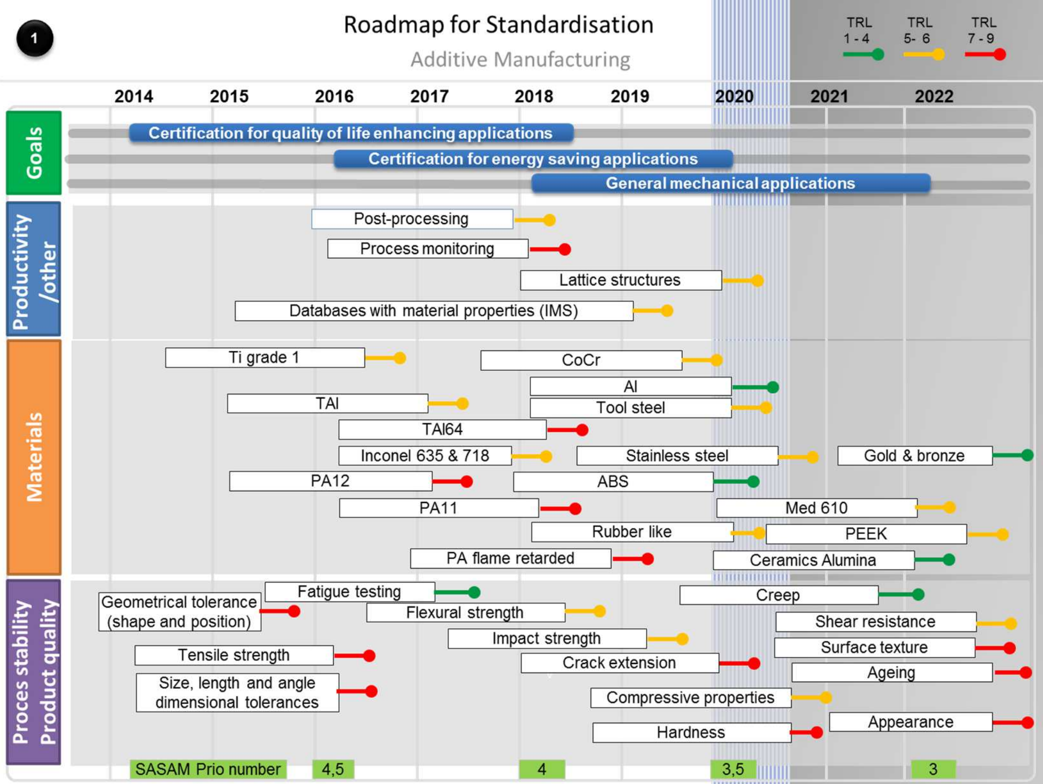
A SWOT analysis of AM from a standards point of view revealed quite some potential and opportunities for European industry. Amongst them are AM related focus points such as products which are optimized for a single location manufacturing, no stock, production on demand, sustainable production. In particular, knowledge intensive processes / potential for high quality jobs in Europe will result from AM implementation. Technologically speaking, the hybrid processes (AM and conventional combined to get best of both) and integration of AM in existing production lines are high priority and have a high potential. This also supports the need for relevant standards development.

Red brick walls and principle challenges indicate quite some recommendations which can be categorised in Technical and General areas for development. Technical Areas include: productivity, process stability, materials, process and product quality, product data and costs.

General areas include: training and education, standards and certification, environment, industry definition, liability and other.

A roadmap indicating timing and topics for AM standardisation was drafted on the basis of the remarks from interviewed stakeholders. The topics that mentioned most were process stability and product quality, materials and productivity. Key priority items for AM standardisation are: databases with material properties, for the materials Titanium grade 1 (i.e. unalloyed Titanium) and geometrical tolerances.

The roadmap is given below:



The SASAM consortium very much recommends that Europe supports a common development of AM standards via ISO-ASTM with an appropriate involvement of European experts. The Vienna Agreement between ISO and CEN enables the approval at the same time of European Standards and International Standards, based on a single draft standard.

SASAM recommends a very strong world-wide cooperation which supports the ideas of the “Industrial Landscape Vision” [1] which recognizes the world-wide approach and significance of Additive Manufacturing.

International Cooperation

During the progress of the SASAM project, a collaboration with a corresponding task group was formed within ISO/TC261 as well as with the ASTM F42 (sub-committee F42.94 Strategic Planning) with the objective of producing a common roadmap. This collaboration has included sharing of background information resulting in an exchange of relevant documents between both organizations.

Moreover, during the on-going development of AM standards through the ISO/TC261 as well as the ASTM F42, and the scoping of stakeholder's requirements within SASAM WP1, it has been made clear that there is shared wish for global (ISO) standards for AM from all parties concerned. The basic reason for this collaboration comes from the rising awareness that the full advantages of AM technologies in the context of the whole manufacturing and supply chain can only be reached if the technical content in any AM standard documents are the same world-wide.

The discussions during Spring and Summer of 2013 have led to the development of a joint plan for AM standards development and a principle on how this collaboration should proceed. The joint ASTM-ISO AM standards development plan is aimed to be a working document that will be modified according to the needs and requirements that evolve during the development of the AM industry. It is therefore open for feedback and suggestions from all involved parties as long as the joint development of AM standards continues. However, since both organizations strive to work on consensus based decisions, any changes need to find a wide support to be accepted.

A consensus regarding the structure for developing AM standards has been reached on the grounds that it meets the requirements and needs from both ISO/TC261 and ASTM F42. The common structure defines multiple levels and a hierarchy of AM standards, based on three levels:

- General standards: specify general concepts and common requirements
- Category standards: specify requirements that are specific to process-, or material categories
- Specialized standards: specify requirements to a specific material, process or application

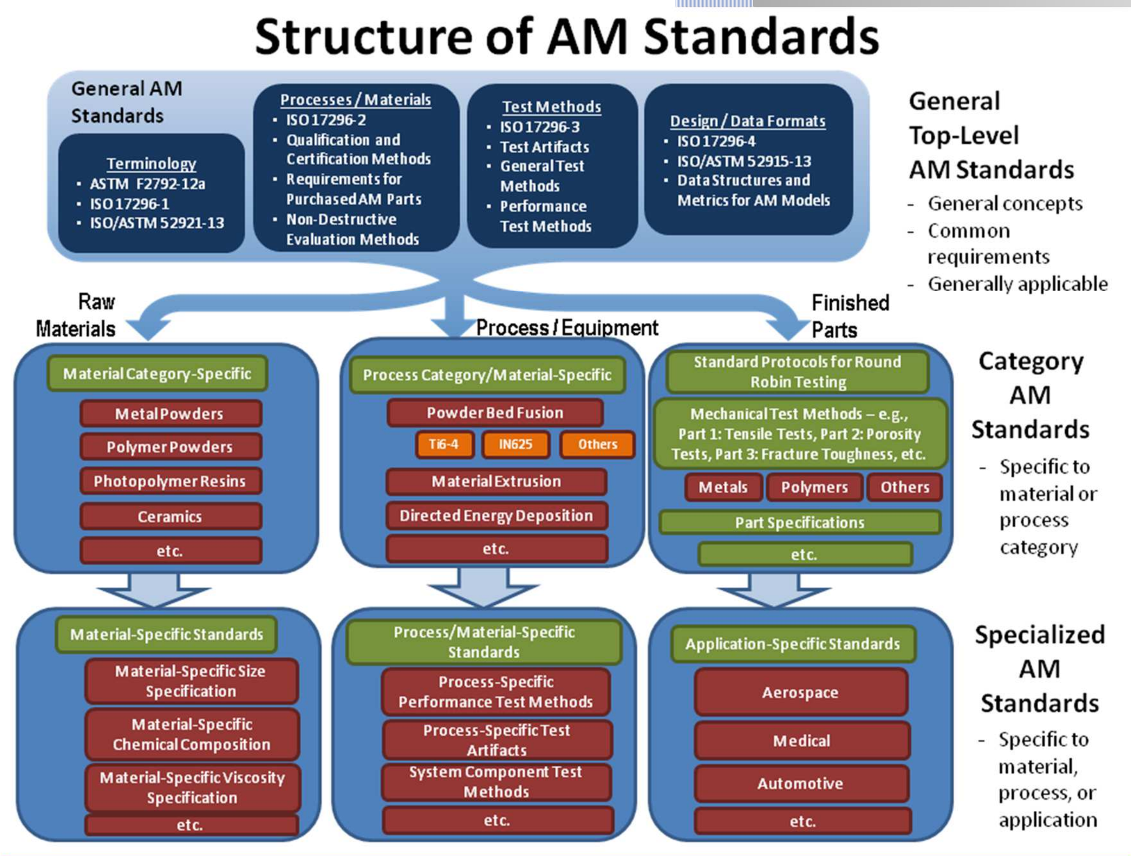


Figure 1: *The agreed structure for AM standard development.*

There is a parent-child relationship between the levels, where characteristics form the parent standards are passed on the child level upon reference. The intention of this structure is to facilitate the development of modularized standards and to reduce the risk for duplication of work as well as the risk of contradiction between standards.

In addition to this ASTM F42 and ISO/TC261 have agreed upon a list of high priority items to pursue as pilot AM standards for joint development:

- Harmonization of existing ISO 17296-1 and ASTM 52912 terminology standards (to be convened by ISO)
- Standard test artefacts (to be convened by ASTM)
- Requirements for purchased AM parts (to be convened by ISO)
- Design guidelines (to be convened by ASTM)

The work within these topics has been initiated after the Summer 2013, and will be continued with high priority during 2014.

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CONTENTS

Introduction to AM standardisation

The Additive Manufacturing (AM) concept is based on additive freeform fabrication technologies for the automated production of complex products. Additive Manufacturing processes are defined as:

"a processes of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing fabrication methodologies."

[ISO 17296-1 and ASTM 2792-12]

AM is expected to grow considerably because it offers several advantages: developers can produce functional complex hollow structures in small batches, and the structures can be precisely modified to e.g. changing stress requirements. The components can be customized with specific internal geometry, porosities or surfaces, and extreme lightweight structures can be manufactured. These additional and enhanced capabilities compared to the conventional manufacturing technologies are highly related to costs and the part design. A popular term to describe the new possibilities enabled by AM is "complexity for free".

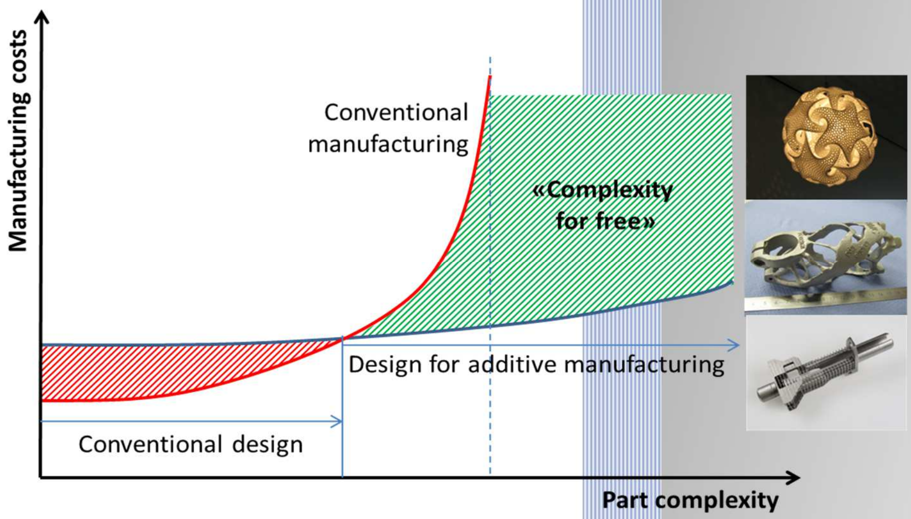

Figure 2: *Complexity for free (source: Inspire* [2]*).*

Two distinct markets are the pioneers of AM: the aeronautical industry and the medical industry (orthopaedic and dental implants) are sectors where AM is flourishing. However, for many applications the use of AM technology is regarded as an exception due to the lack of standards, certification and best practices. There is therefore an urgent need to develop these standards, particularly with regards to critical applications, such as medical implants (for health, healing and quality of life), load carrying structural parts and engine components for aircrafts (for energy savings and improved performance).

The overall objective of SASAM is to create a roadmap for standardization of AM technology, based on the long term vision as well as the more immediate needs of the industry and other major stakeholders. The roadmap includes an outline for the steps needed to transform the visions and needs into an industrial standard that not only provides a solid ground for practical, industrial application of AM technology, but also enables and stimulates further innovation and development within this area. For this the integration and coordination of standardization activities within the European AM community and other stakeholders needed to be organised. This was realized primarily in coordination with ISO/TC261, but also through collaboration with ASTM F42 and the recently initiated CEN/Cenelec STAIR initiative for additive manufacturing.

The roadmap report has been built from the following three principal tasks:

1. Gather and evaluate information from other relevant roadmaps and most important developments within this sector.
2. Transform the outcome and conclusions from this information gathering and match this with the AM stakeholders and requirements survey.
3. Gather feedback, finalize and publish the roadmap for standardization serving the additive manufacturing technology.

During the course of the SASAM project, collaboration with the corresponding activities of ISO/TC261 and ASTM F42 has been initiated, with the objective of developing a common roadmap which will facilitate the development of a truly international standard for additive manufacturing across the different standardization organizations.

During the on-going development of AM standards through both the ISO/TC261 and the ASTM F42, and the scoping of stakeholder's requirements within SASAM WP1, it has been made clear that there is a shared wish for global and international standards for AM by all parties. Even if the majority of European stakeholders which are part of SASAM, tend to favour ISO standards there are also significant groups that prefer ASTM and CEN standards. In respect for this, an agreement between ISO/TC261 and ASTM F42 has been made to collaborate on the development of joint standards for AM. The discussions during Spring and Summer of 2013 have led to the development of a joint plan for AM standards development, and a principle on how this collaboration should proceed. While the SASAM project consortium, which represents the European AM stakeholders, has contributed to this development, it has been very clear from the beginning that the outcome of the collaboration agreement would determine the direction of development of AM standards.

The joint ASTM-ISO AM standards development plan is to set up a working document that will be modified according to the needs and requirements during the development of the AM industry. It is therefore open for feedback and suggestions from all involved parties as long as the joint development of AM standards continues. However, since both organizations strive to work on consensus based decisions, any changes need to find a wide support to be accepted. Because of these developments it would not make any sense to develop an independent SASAM roadmap alongside the ASTM and ISO plan and collaboration. Therefore it is the intention of this delivery report, D2.3, to present this joint plan in relationship with present relevant standards, the input from AM stakeholders, projects and documents relevant to AM standardization, SWOT analysis, and a time frame with priorities for AM standardisation. It needs to be emphasized that the main input and priorities as given in this report are mainly the views of the European stakeholders as investigated and collected by SASAM.

The SASAM consortium very much recommends that Europe supports a common development of AM standards via ISO-ASTM with an appropriate involvement of European experts. The Vienna Agreement between ISO and CEN enables the approval at the same time of European Standards and International Standards, based on a single draft standard.

SASAM recommends a very strong world-wide cooperation which supports the ideas of the "Industrial Landscape Vision" [1], which recognizes the world-wide approach and significance of Additive Manufacturing.

Standards to support industrial implementation of AM

In the past, development, modification and industrial use of AM production processes have been quite dispersed, uncoordinated and to a large extent aimed towards prototyping purposes. Even if the mechanical and material properties of today's AM products are on an adequate level for commercial use, the lack of availability of an International and European Standard is hampering real industrial implementation of AM technology.

Due to the nature of AM, where the basic principle to build products is by successive addition of material, products produced by AM-technologies will show different values of the material properties depending on the parameter set-up used during manufacturing. This makes the evaluation and quality management of the products complicated and maybe even unpredictable, which is unacceptable for, for example the aeronautical and medical industries.

The development of corresponding standards is an important step to improve the current situation and makes the benefits of additive manufacturing accessible and useful for manufacturing purposes to numerous sectors of industry.

In order to have an idea of the scope of the industry, one should be aware that there are already about 30 laser sintered components produced with AM-processes installed in the Boeing 787 (Ref Scott Martin, Boeing, IAG member) and the numbers are likely to raise dramatically in the future. According to estimations from Airbus Industries, an aircraft produced entirely by additive manufacturing would be 30 % lighter and 60 % more cost effective than by current machines [3]. Resources and energy efficiency combined with economical production are the central challenges for commercial aircraft construction in the future. Additive Manufacturing is one of the key technologies to address these challenges. Additive Manufacturing technologies support and enable

- Advanced European industrial production on a cost- and resource-efficient (sustainable) footprint.
- The exploitation of AM technology as another manufacturing tool will encourage innovation and enhance the competitiveness of labour in Europe.
- A globalised economy.
- The production of personalised goods and services.
- The development and implementation of Advanced, ICT-Enabled Manufacturing Systems.

The Strategic Research Agenda SRA 2013, drafted by the AM-Platform (the European Platform for AM, [4]), refers to standardisation as an important tool to facilitate innovation and bring new products to the market. This is fully in line with the recommendations of the European "Industrial Landscape Vision" [1]. The gap between the knowledge and technology capability obtained through research and the current requirements for actual market introduction of a new product or technology needs to be supported/bridged by standardization. Therefore international and European standards regarding AM are urgently required to promote and help implement a widespread use of the AM process and to regulate evaluation of existing products.

Existing standards for AM

From various sources, an overview of current standards relevant to AM and their status was drafted. This is briefly presented in the Table 4.1 where the active standardisation bodies as well as the top level standards currently being elaborated are indicated, including their status. An extensive overview is provided in Table 4.2.

	VDI	UNM 920	UNE (AEN/CTN 116)	TC ISO /261	TC ISO/61	ASTM F42
WG1 : Termi-nology	3 terminology / 1 coordinate system					
	2 terminology / 1 coordinate system + 2 working group (ASTM)					
WG2 : Methods-Processes-Materials	1 powder specification / 1 TA6V powder bed fusion					
	1 polymer testing / 1 guideline metal testing / 1 general guideline testing + 11 working group (ASTM)					
WG3 : Test Methods	2 methods polymers test					
	1 : Guideline to receipt parts / 1 : Drawing – representation for AM					
WG4 : Data processing	1 AM File					
	1 Data processing					

Voted : Ongoing work :

Table 4.1 Progress and planning of required AM standardization, numbers indicate # of standards concerned

SASAM also made an inventory of the needs of its international stakeholders (102 in total) and came up with some additional needs for standards. These needs include:
"Design": the design process for additive manufacturing (AM) is different from traditional design processes and has to be taken into account, respectively needs to be standardized.
"Specific industrial needs": specific standards and restrictions apply to different sectors of the AM market such as the medical- and aerospace industries.
"Part quality": the requirements for part quality are very much product- and sector specific
"Safety (regulations)": safety regulations for processing as well as handling the materials are not yet developed for AM technology and processes
"**Education"**: appears to be an important issue that can be influenced by standards (may not be subject to standardization itself.

		VDI (National guideline)	UNM 920	TC ISO /261	TC ISO/61	ASTM F42	UNE (AEN/CTN 116)
WG1 : Terminology	Voted	VDI 3404: Generative Fertigungsverfahren - Rapid Technologien. Grundlagen, Begriffe, Qualitätskenngrössen, Liefervereinbarungen Additive fabrication- Rapid technologies (rapid prototyping) Fundamentals, terms and definitions, quality parameters, supply agreements	NF E 67-001 - Terminology			F2792-12a Standard Terminology for Additive Manufacturing Technologies F2921-11e2 Standard Terminology for Additive Manufacturing—Coordinate Systems and Test Methodologies	
	Ongoing work			ISO/ASTM 52921Coordinate Systems and Test Methodologies ISO/NP 17296-1 : Terminology		WK26433 New Terminology for Directed Energy Deposition Additive Manufacturing Technologies WK26367 New Terminology for Lattice Structures	
WG2 : Methods-Processes-Materials	Voted	VDI 3404: Generative Fertigungsverfahren - Rapid Technologien. Grundlagen, Begriffe, Qualitätskenngrössen, Liefervereinbarungen Additive fabrication- Rapid technologies (rapid prototyping) Fundamentals, terms and definitions, quality parameters, supply agreements	XP E 67-010 - Powder - Technical specification			ASTM F2924 - 12 Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion	
	Ongoing work	VDI 3405-Blatt 1: Additive Fertigungsverfahren, Rapid Manufacturing: Laser Sintern von Kunststoffbauteilen, Güteüberwachung Additive manufacturing processes, rapid manufacturing - Laser sintering of polymer parts - Quality control VDI 3405-B: Generative Fertigung (Additive Manufacturing) metallischer Bauteile durch Strahlschmelzen – Qualifizierung, Qualitätssicherung und Nachbearbeitung Additive manufacturing processes, Rapid Manufacturing - Beam melting of metallic parts; Qualification, quality assurance and post processing		ISO/WD 17296-2 : Methods, process&materials		WK28741 Electron Beam Melting (EBM) Titanium 6Al-4 V ELIWK26106 New Specification for Material Qualification for Additive Processes WK26105 Material Traceability for Additive Processes WK26102 Metrics for Initial Conditioning of Machines &/or Performance Metrics for Metal Deposition WK25296 Electron Beam Melting (EBM) Titanium 6Al-4V WK25479 Conditioning of machines and performance metrics of metal laser sintering systems. WK27752 Laser Sintered Polyamides WK30557 Standard Specification for Laser Sintering Moderately Conductive High Melt Temperature Polymers for Non-Structural AerospaceComponents WK33776 Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion WK33833 Additive Manufacturing Cobalt-28 Chromium-6 Molybdenum with Powder Bed Fusion WK37654 New Practice for Machine Operation for Directed Energy Deposition of Metals WK37658 New Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion WK37683 Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Extra Low Interstitials with Powder Bed Fusion	
WG3 : Test Methods /design	Voted				ISO 27547-1:2010 Plastics -- Preparation of test specimens of thermoplastic materials using mouldless technologies -- Part 1: General principles, and laser sintering of test specimens		UNE-116005 .Layer by layer manufacturing in plastic materials.Additive manufacturing.Preparation of testing specimens
	Ongoing work		XP E 67-030 - Spécifications guideline in order to receipt parts produced by additive manufacturing	ISO/CD 17296-3: Performance criteria and quality characteristics		WK30107 New Practice for Reporting Results of Testing of Specimens Prepared by Additive Manufacturing WK37892 New Guide for General Design using Additive Manufacturing WK38342 New Guide for Design for additive manufacturing	ASERM 1-001-009.Technical drawings. Representation for additive manufacturing
WG4 : Data processing	Voted					F2915-12 Standard Specification for Additive Manufacturing File Format (AMF) Version 1.1	
	Ongoing work			ISO/ASTM 52915 Standard Specification for Additive Manufacturing File Format (AMF) ISO/CD 17296-4: Data processing			

Table 4.2 overview of current standards and their status (December 2013)

Existing standards from other sectors relevant to AM

Additive Manufacturing technologies are interdisciplinary and many materials, test methods and defined properties, some process steps and data preparation are similar to other industrial processes. Hence it needs to be assessed how to liaise the AM standardization activities with or within other ISO/TCs and CEN/TCs. A short inventory resulted in the following list of TCs:

- ISO/TC 61 "**Plastics**": first contacts and exchange have been initiated.
- ISO/TC 106 "**Dentistry**": the TC is at present formed by 9 subcommittees, as following:
    - TC 106/SC 1 Filling and restorative materials
    - TC 106/SC 2 Prosthodontic materials
    - TC 106/SC 3 Terminology
    - TC 106/SC 4 Dental instruments
    - TC 106/SC 6 Dental equipment
    - TC 106/SC 7 Oral care products
    - TC 106/SC 8 Dental implants
    - TC 106/SC 9 Dental CAD/CAM systems
- ISO/TC 119 "**Powder Metallurgy**": particularly AM metal powders processing from various materials would involve this TC. First contacting has been initiated and needs to be continued
- ISO/TC 172/SC 9 "**Electro-optical systems**": Laser-technologies in general and laser sintering in particular are currently being standardised in this TC. First contacting has been initiated and needs to be continued
- ISO/TC 184/SC 4 "**Industrial Data**": data exchange of CAD/CAM systems which have similarities with the AM data preparation and flow would involve this TC. First contacting has been initiated and needs to be continued. The working groups of ISO/TC 184/SC 4 are the following:
    - ISO/TC 184/SC 04/AG 00 "Change management advisory group"
    - ISO/TC 184/SC 04/PPC "Policy and planning committee"
    - ISO/TC 184/SC 04/WG 02 "Product characteristics and libraries"
    - ISO/TC 184/SC 04/WG 03 "Oil, Gas, Process and Power"
    - ISO/TC 184/SC 04/WG 08 "Joint SC 4 - SC 5 WG ; Manufacturing process and
    - management information"
    - ISO/TC 184/SC 04/WG 11 " Implementation methods and conformance methods"
    - ISO/TC 184/SC 04/WG 12 "STEP product modelling and resources"
    - ISO/TC 184/SC 04/WG 13 "Industrial Data Quality"
    - ISO/TC 184/SC 04/WG 21 "SMRL Validation Team"
    - ISO/TC 184/SC 04/WG 22 "Reference data validation team"
    - ISO/TC 184/SC 04/WG 23 "Vocabulary validation team"
- CEN/TC 121: The subject “**Additive manufacturing**” is partly included in the scope of CEN/TC 121. Projects which affect welding, especially laser and electron beam welding, can be handled under CEN/TC 121.
- CEN/TC 138: **Non destructive testing** : first contacts and exchange has been initiated.

First liaisons have been established and it will be assessed if cooperation with the above TCs and additional ones (e.g. on welding) will be preferred for AM topics as well.
Please note that there is no CEN/TC on Additive Manufacturing at the moment. As part of the SASAM project it will be assessed whether a CEN/TC on Additive Manufacturing should be initiated in Spring 2014.

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Input from AM standardization stakeholders

As part of the SASAM project, a questionnaire was prepared to investigate the requirements, wishes and priorities of the European AM standardisation stakeholders from industry, research and government bodies. The answers from 102 respondents with an industrial share of 56 % were analysed.

The analysis showed that 90% of the persons who responded to the questionnaire are using standards therefore implying that they are familiar with the background of standardisation and the topic in general. Also the quality standardisation and customer requirements are in the focus of all participants.

The industry respondents indicate a benefit for the product development to fulfil special industrial requirements e.g. from the medical sector. The need for standards for the development in general (also R&D related) was underlined by all groups.

Quality or qualification (system qualification, part quality, quality control) turned out to be the dominant topics of the given remarks from the interviewed AM standardisation stakeholders.

The view on the market and new business opportunities e.g. a “world-wide” level playing field for users, manufacturers, suppliers, etc. was also mentioned.

AM technology is expected to release an economical push towards the reliability of the processes and their machines and manufactured products

Important topics identified were: terminology, design, test methods, materials and processes, data processing.

There is a clear preference for an international standard and European participants definitely focus more on the ISO than to the ASTM or any other (VDI, CEN) standard. The remarks also show again the necessary qualification of specific industrial standards.

The inventory on needs for standards for Additive Manufacturing can be summarised as follow:

1. Standards are in use by a majority of the participants
2. There is an urgent **need** for AM standards
3. It is of great importance that the AM standards will be **globally and internationally** accepted
4. The needs resp. the **requirements of the customer (end user of AM parts) are main drivers** for using standards; also for upcoming AM standards
5. The prioritized topics for AM standardisation are **materials; processes/methods and test methods**
6. The **reliability of machines and processes** are expected to improve as a result of the development and application of standards
7. The most common argument for the need of standards are **quality or qualification** (system qualification; material quality, part quality, quality control)
8. **Market opportunities** are directly related to future standards

These answers and the comments from the participants show that there is a huge interest for the development of standards and it is reflecting also the enormous hope and expectations of the community regarding the new technology.

The standardisation activity is expected to enlarge the existing AM business and will help to get acceptance in existing markets (medical and aerospace) and in new markets by new industries. This will be a big opportunity for innovation and economic growth in the European industry, which should enhance competiveness and so be instrumental to creating jobs in Europe, which is also underlined by the European "Industrial Landscape Vision".

AM standardization documents analysis and proposed structure of standards

The SASAM consortium has evaluated 25 recent documents listed in Table 7.1 with relevance for standardization of AM. From these documents, the most important findings were collected and combined with the scoping of the stakeholders requirements for standardization of AM technology. This provided a very useful source of reference, reported below. This list can be complemented by the European Foresight Study “Industrial Landscape Vision” [1], which addresses AM as one of the significant tools to reach the goals of this vision.

Table 7.1: List of evaluated documents, nominated as relevant for AM standardization

Doc. Nr.	**Publisher:** Institute behind the document	Name of document
1.	Air Force Research Laboratory (US)	Additive Manufacturing of Aerospace Alloys for Aircraft Structures
2.	Science and Technology Policy Institute (US)	Additive Manufacturing: Status and Opportunities
3.	Additive Manufacturing Platform (EU)	Additive manufacturing: Strategic research agenda 2011, A future vision for AM
4.	European Commission (EU)	Factories of the future PPP, Strategic multi-annual roadmap
5.	Joint Research Centre (JRC), European Commission (EU)	Industrial landscape vision EU – Draft
6.	Additive Manufacturing Platform (EU)	Platform on Rapid Manufacturing (RM), vision on 2020 for RM
7.	Naval Air Warfare Center, Weapons Division (US)	RARE Parts through RM&R, Additive Manufacturing: State of the art 2010
8.	The University of Texas at Austin, (US)	Roadmap for Additive Manufacturing, Identifying the future of Freeform processing
9.	NIST ASTM F42	A strategic approach to organize ASTM F42 standards
10.	NIST Workshop ASTM F42	Additive manufacturing: Standards and other international trends
11.	EU Joint Research Centre (JRC)	How will standards facilitate the context of EU innovation and competitiveness in 2015? Foresight study 17-18 December 2012
12.	DMRC, University of Paderborn	Expert survey on current and future requirements on direct manufacturing technologies 2012-03-23
13.	DMRC, University of Paderborn	Expert survey on current and future requirements on direct manufacturing technologies, second part, Oct. 2012.
14.	NIST Workshop	Workshop scope and objectives

15.	NIST Workshop	Manufacturing the road to success
16.	NIST Workshop	Report of the break-out group for Quality and Certification
17.	NIST Workshop	Report of the break-out group for Modelling and Simulation
18.	NIST Workshop	Report of the break-out group for AM Materials
19.	NIST Workshop	Report of the break-out group for Process Equipment
20.	NIST Workshop	NIST White papers: Measurement Science for metal based AM
21.	NIST Workshop	NAMII: Priority Applied Research Needs
22.	UK AM Special Interest Group	Shaping our competency in additive manufacturing
23.	UK Big Innovation Centre	Three Dimensional Printing Policy: Why Britain neds a framework for 3D printing
24.	ISO	European (international) standards for fusion welding
25.	ASTM	Standard specification for Additive Manufacturing File Format (AMF)

Following the recommendations from a) the list of evaluated documents, b) SASAM stakeholders requirements, c) the joint plan and work agreement between ISO/TC261 and ASTM F42, the following key agreements on the guiding principles to be followed and pursued by all organizations, were drafted:

- One set of AM standards – to be used all over the world
- Common roadmap and organizational structure for AM standards
- Use and elaboration upon existing standards, modified for AM when necessary
- For efficiency and effectiveness, ISO TC261 and ASTM F42 should begin the work together and in the same direction

Emphasis on joint standards development

Since one of the most urgent, expressed needs for the AM standards is that it should be international and globally accepted, it would be counter-productive to have different roadmaps for the different standardisation organisations working on this topic. Therefore, as mentioned in the introduction, the present roadmap has been developed in cooperation between ASTM F42, ISO/TC261 and SASAM. Common needs and interests for the standardization of AM were identified and coupled to the working system and on-going work of each organization. Based on this, a common roadmap structure was proposed and a shared list of high priority candidates for joint AM standards development was made.

Also the European Foresight study on the significance of standards for Europe [5] mentions: *"The importance of standardisation in stimulating and enabling innovation and competitiveness in Europe is at the heart of European policy."*

Therefore, five priority areas for standardisation are defined:

1. Standards for integration;
2. Standards for environmental sustainability;
3. Standards for quality and performance;
4. Service standards;
5. 'De-risking' standards;

Structure of AM standards

The agreed common structure of AM standards defines multiple levels and a hierarchy based on three levels (see Figure 3):

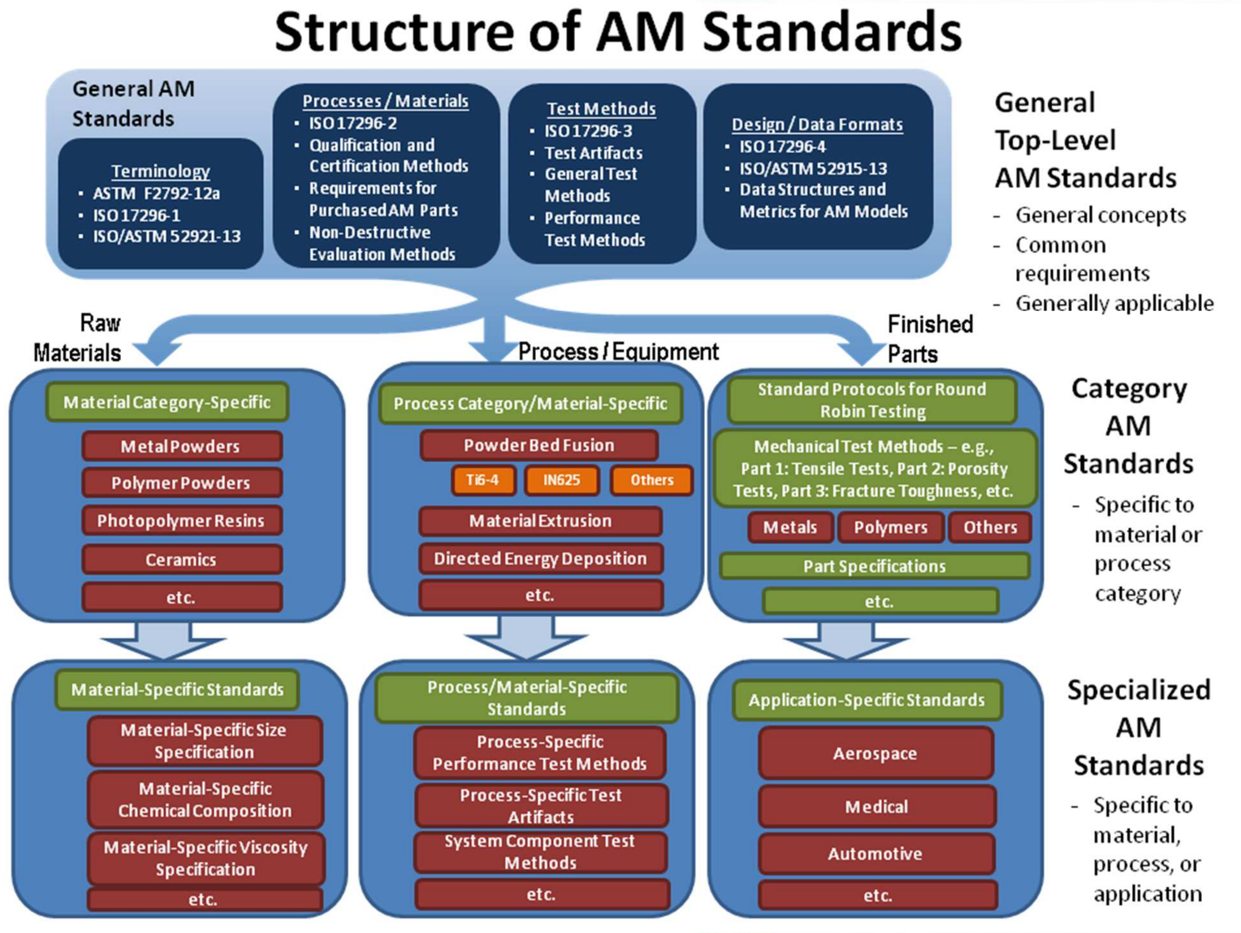

***Figure 3**: The agreed structure for AM standard development:*

General standards: specify general concepts and common requirements;

Category standards: specify requirements that are specific to process- or material categories

Specialized standards: specify requirements to a specific material, process or application

Several usage guidelines have been established as follows to facilitate the use of the common structure of AM standards:

- The structure diagram is intended as a high-level guide only. Some exceptions or specific circumstances may exist that do not match this structure.
- Specific bullet points and words in the blue/green/red/orange “boxes” are examples and indications only to demonstrate the types of standards that may be necessary for that portion of the hierarchy. The specific standards and groupings are yet to be determined.
- Modularized standards are intended.
- A hierarchy of standards exists to reduce duplication within AM standards. Specifically:
  - parent/child relations exist between levels (from top to bottom)
  - characteristics pass from parent level to child level (upon reference)
  - child level standards can modify/augment the characteristics as needed for specific use
- The key question relevant to the three possible paths vertically through the hierarchy is:
  - What will the developed standard specify or evaluate? (Raw Materials, Process/Equipment or Finished Parts)

Proposed pilot AM standards for joint development

SASAM, ISO TC261 and ASTM F42 identified a consensus list of high-priority candidates for potential (joint) AM standards development as follows:

- Qualification and certification methods
- Design guidelines
- Test methods for characteristics of raw materials
- Test methods for mechanical properties of finished AM parts (such as non destructive testing)
- Material recycling (re-use) guidelines
- Standard protocols for round robin testing
- Standard test artefact, enabling a comparison of AM processes, materials and machines on a part level
- Requirements for purchased AM parts
- Harmonization of existing ISO/ASTM terminology standards

Though all of these topics are high-priority, the following are chosen by ISO/TC261 and ASTM F42 (supported by SASAM stakeholder requirements) to pursue as pilot AM standards for joint development:

1. Harmonization of existing ISO 17296-1 and ASTM 52912 terminology standards (to be convened by ISO)
2. Standard test artefacts (to be convened by ASTM)
3. Requirements for purchased AM parts (to be convened by ISO)
4. Design guidelines (to be convened by ASTM)

For readability reasons, only a subset of the above-mentioned topics is currently being mapped into the roadmap given in chapter 12.

Cooperation and collaboration procedures

Besides the scope of SASAM, ISO/TC261 and ASTM F42 have agreed on several specific procedures on how the cooperation will be carried out in practice. But since this is based on the specific practices and tools of each organization it will not be addressed under the SASAM project.

Benefits for AM that can be achieved by using standards

The benefits which can be achieved by AM indicate that the total sale of AM products will reach USD 3.7 billion by 2015 Wohlers, 2012 [6]. Standardization is essential for the use of AM in critical applications like in energy saving applications in air craft engines or for medical applications healing injured people with medical implants manufactured by AM.

Standards will support the possibilities for certification and approval for medical applications (e.g. FDA) and aviation applications (e.g. AIA). Without standards such certifications and approvals are very complicated if not impossible. The business case for all stakeholders is evident as standardization will boost the application of this technology in critical sectors. The time consuming standardization process is limiting energy saving applications and improved quality of life for injured and disabled people.

Generally speaking, the aims of standardization are:

a) to promote the quality of products, processes and services by defining those features and characteristics that govern their ability to satisfy given needs i.e. their fitness for purpose;

b) to promote improvements in the quality of life, safety, health and protection of the environment;

c) to promote the economic use of materials, energy, and human resources in the production and exchange of goods;

d) to promote clear and unambiguous communication between all interested parties, in a form suitable for reference or quotation in legally binding documents;

e) to promote international trade by the removal of barriers caused by differences in national practices;

f) to promote industrial efficiency through variety control.

The SASAM consortium consists of partners with long experience and extended networks within and around the area of AM. All partners have therefore been asked to gather and estimate market relevance for standardization of AM. Their shared view is that the AM industry is expected to have continued strong growth in the medium to long term. It was estimated [6] that the total sale of AM products and services being at USD 1.7 billion for 2011, will reach USD 3.7 billion by 2015. The plastics market is leading with currently around 30,000 machines in the field, whereas there is a very strong growth in AM using metallic powders (over 500 machines sold to date (Wohlers, 2012) [6], which is expected to show double digit percentage increased growth in sales over the next five years. The exploitation of AM technology as another manufacturing tool will encourage innovation and enhance the competitiveness of labour in Europe.

When industry specifics are considered, the general view is that AM continues to flourish in the last few years in particular areas. One is the industrial/production market, which includes medical, (orthopaedic implants), dental, aerospace, automotive, power generation, tooling and many others. The other one is the consumer market where most recently the 3D home printer of less than 2000 EUR has unlocked a large worldwide web based AM community (Fablabs). These mainly include decorative home accessories, fashion, art and entertainment. Within both sectors, AM will be a key technology in future product development. Figure 4 shows the size of the AM market for specific materials with a simplified prediction for significant future growth.

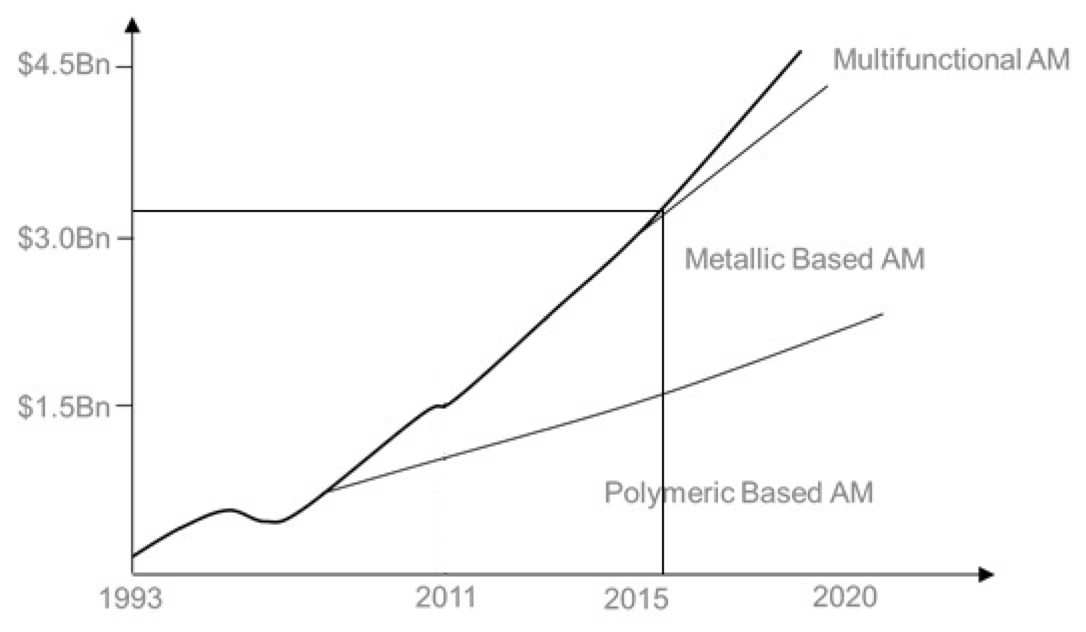

Figure 4 *Simplified actual and predicted AM market including material usage (Courtesy of TWI)*

Relevant projects & initiatives

The inventory of stakeholders which are candidate for liaison within the AM standardisation effort revealed the following European FP7 Framework funding programme:

- **3D-HiPMAS** - 2012-2015: Pilot Factory for 3D High Precision MID Assembly. Integration of new functions on smart plastic products, demonstrates pilot line fabrication of advanced MID based micro assemblies for the branches communication, transportation, life sciences and energy.

- **ADM-ERA** – 2011-2013: Reinforcing AM research cooperation between the Central Metallurgical Research and Development Institute and the European Research Area. The overall aim of the ADM-ERA project is to integrate the CMRDI into the ERA, by developing cooperation with European research and innovation organisations in AM of Ti and CoCr alloys based prostheses, and biocompatible ceramic materials: HA, PEEK and TCP.

- **AEROBEAM** 2012-2013: Direct Manufacturing of stator vanes through electron beam melting. Aerobeam is aimed at increasing the TRL of EBM through investigation of recyclability of EBM powder and the mechanical properties of aeronautical Ti6Al4V stator vanes elaborated by EBM, an AM Technique.

- **A-Footprint** 2008-2012: develop (AM based) novel ankle/foot and foot ortheses for common disabling conditions which are cost effective, high-speed to market (<48h), and personalised for form and function.

- **AMAZE** – 2013-2017: AM aiming towards zero Waste and efficient production of high-tech metal products. The overarching goal of AMAZE is to rapidly produce large defect-free additively-manufacture metallic components up to 2 metres in size, ideally with close to zero waste. A further aim is to achieve 50% cost reduction for finished parts, compared to traditional processing.

- **AMCOR** – 2012-2015: AM for wear and corrosion applications. The Project will develop and demonstrate Laser Metal Deposition (LMD) industrial manufacturing systems for the deposition of functional graded coatings (FGM) and 3D features onto metallic components supplied by industry that are subjected to in-service wear and corrosion.

- **Cassa Mobile** – 2013-2016: Mini-factories in a 20' ISO-container for customised products using local flexible production. A mobile, flexible, modular, small-footprint manufacturing system that can be easily configured for different products and processes (a.o. additive manufacturing module)

- **CompoLight** – 2008-2011: The project proposed to solve identified shortcomings of AM by addressing five areas, all of which were related to design and production of lightweight metal parts.

- **DIGHIRO** – 2010-2014: Digital Generation of High Resolution Objects. The project will develop a micro scale AM system. The plan is to study many applications of micro scale AM technology, including micro fluid diagnostics (lab-on-the-chip) and medical applications.

-

- **DirectSpare** – 2009-2012: The project investigated the strengthening of industries competitive position by the development of a logistical and technological system for spare parts that is based on on-demand production.

- **HiPr** – 2012-2015: HiPr is to develop and integrate all necessary base technologies which create the basis to control and monitor the condition of micro-tooling for complex high-precision 3D parts (a.o. in-depth process and material knowledge, in-line measurements, real-time predictive maintenance)

- **HIRESEBM** – 2011-2013: High resolution electron beam melting with the aim of developing an electron beam melting (EBM) AM process to enable the fabrication of high resolution medical implants with optimised porous structures directly from metal powder.

- **HYPROLINE** – 2012-2015: High performance production line for small series metal parts. The objective of Hyproline is to strengthen the competitiveness of the European industry by introducing manufacturing methods, which will allow companies to reduce time-to-market and number of rejects; make more customised and innovative products; and make products >20% more accurate with considerable savings (>30%) in consumption of waste metal, fluids and services, with an equivalent reduction of CO2 emission.

- **IMPALA** – 2008-2012: The development work within IMPALA focussed on demonstrating significant advantage over conventional manufacture and ensuring further uptake of LAMP processes for the manufacture of medical implants, aero-engine components and other small-size applications in the dental, electronic, (micro-) tooling and precision-mechanics field.

- **KARMA** – 2010-2013: Knowledge based process planning and design for AM. The objective of this project is to design, develop and test an Expert Process Planning tool, implemented into a knowledge-based engineering system (KBE) that can suggest the optimal technological scenario, the optimal build orientation and estimate functional properties of AM parts automatically and in a short time.

- **M&M'S+** – 2013-2014: 3D Printer for silicon MEMS & NEMS. The project will explore ways to develop and commercially exploit a new type of 3D printing tool for manufacturing of silicon nanostructures. These 3D printers will make it possible to design and implement silicon micro- and nano-electromechanical system (MEMS&NEMS) sensors and photonic components.

- **Mansys** 2013 – 2016: Manufacturing decision & e-supply chain management System for Additive Manufacturing. Combine multiple build platforms (Laser and Electron-Beam technologies), modelling, post-processing (Machining, Finishing and Heat-Treatment) and 3D scanning techniques, customisation, automation, self-management, reduced material usage and waste.

- **Megafit** 2008-2013: realise zero-defect manufacturing of complex high-precision metal parts by applying adaptive process control, multi-stage micro-forming and additive manufacturing of customized parts (in-line measurement and real-time adaptive process control).

- **MERLIN** – 2011-2014: Development of Aero Engine Component Manufacture using Laser AM. The concept of the MERLIN project is to reduce the environmental impact of air transport using AM techniques in the manufacture of civil aero engines.
- **NANOMASTER** – 2011-2015: Graphene based thermoplastic master batches for conventional and AM processes. The aims of the project are to reduce the amount of plastic used to make a component.
- **OXIGEN** – 2013-2017: Oxide dispersion strengthened materials for the AM of high temperature components in power generation. OXIGEN will develop different (Oxide Dispersion Strengthened (ODS)) alloys individually designed to address specific high temperature materials performance challenges currently limiting power generation component capabilities.
- **PHOCAM** – 2010-2013: Photopolymer based customised AM technologies. This project aims at developing integrated lithography-based AM systems which will, for the first time, facilitate the processing of photopolymer-based materials for the factory of the future.
- **SASAM** – 2012-2014: Support action for standardisation in AM. SASAM's mission is to drive the growth of AM to efficient and sustainable industrial processes by integrating and coordinating Standardisation activities for Europe by creating and supporting a Standardisation organisation in the field of AM.
- **Step-up** – 2009-2012: Step-up in polymer based RM processes. An innovative mechano-chemical approach (based on high energy ball milling) will be used for the development of innovative nanopolymers to be used in AM based on Selective Laser Sintering (SLS).

The information for these projects where taken from the European Union CORDIS website: http://cordis.europa.eu/ (CORDIS Search Service - European Union, 2013)

All the above projects have been contacted and asked for a listing of relevant aspects with respect to standardisation within the project. All of them are invited to present their progress on the AM-platform meetings which are held minimal twice per year. Also, liaisons with relevant TCs as described in chapter 5 are maintained and coordinated by STAIR-AM [9].

SWOT analysis of AM from a standards point of view

Consumer 3D Printing is currently at the top of the Garners hype cycle (Figure 5), which implies that there are definitely some items and challenges which need to be resolved for successful industrial uptake of the technology. In contrast, "Enterprise 3D Printing" (a.k.a. and more technically correct: Additive Manufacturing) is on the so called "Slope of Enlightment", a long-term growing line, implying that the involved technologies have already reached a certain maturity, enabling real industrial manufacturing.

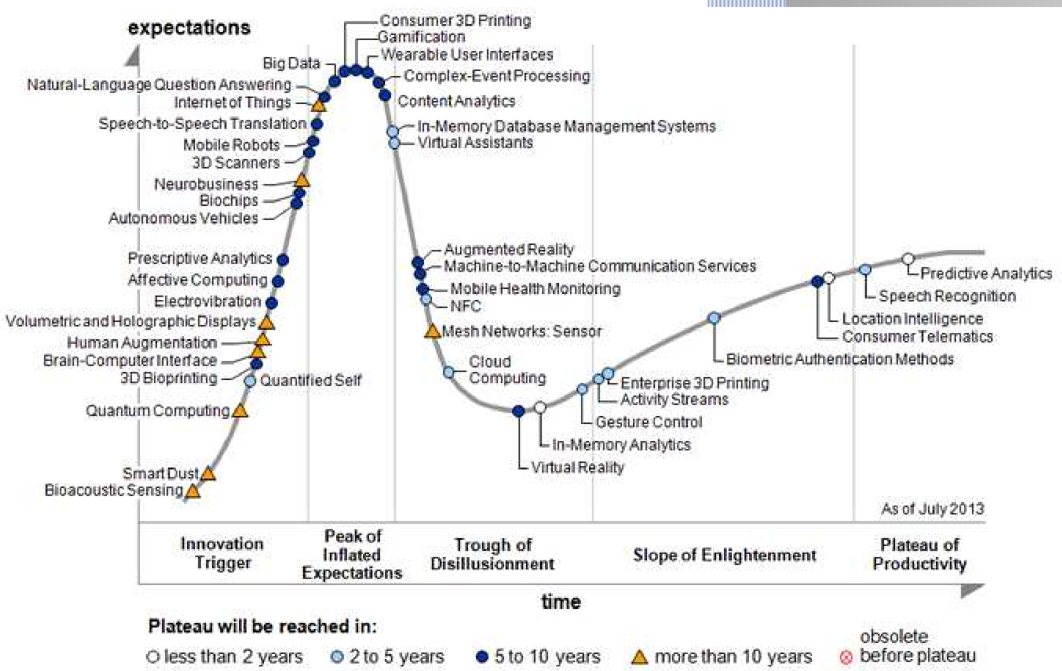

***Figure 5** Garners hype cycle 2013[10]*

The topics concerned are presented in the SWOT Figure 6 below, indicating strengths, weaknesses, opportunities and threats. In the Figure 5 besides general AM topics, the focus is on standardisation related topics. The “S” indicates that standardisation activities are ongoing for this topic.

Strengths	Weaknesses
• E-supply chain, sending data, global distributed production / local supply chain (S) • Unique topological optimized products • Multi material and graded structures are possible (S) • Economies of scale: series of 1 • No stock, production on demand • High material efficiency (high buy-to-fly ratio) • Sustainable production • Knowledge intensive processes / potential for high quality jobs in Europe • Europe has a good knowledge base for AM	• New technology without sufficient standardisation (S) • Process speeds are low resulting in high cost per part • Process stability and reproducibility is low, more real-time process control is required (S) • No material specific standards available (S) • Initial accuracy of parts is low, (local) post processing of surfaces is needed (S) • High material cost (S) • No process specific (NDT) test method available (how to test 1 offs?) (S) • Not sufficient education of users, design engineers etc. (Design for AM)
Opportunities	**Threats**
• Hybrid processes (AM and conventional combined to get best of both) • Integration of AM in existing production line (S) • Customized design by new design tools (S) • Multi material and smart products possible (S) • Re-use of materials (S), Novel materials (ceramics, biopolymers,..) • New business models for on demand on location (S) • High potential in high tech systems industry and its suppliers	• Not many OEMs in Europe • Limited knowledge of AM @ engineers • Growth of Asia (machines and service providers) • Patents will lapse (more competition will arise) (can be + and -) • Developments in US and Asia are fast and have better financial support

Figure 6 *SWOT analysis for AM; “S” indicates: standardisation activities ongoing for this topic*

Red brick walls (principle challenges)

In order to get the AM technology successfully implemented, the topics indicated in the SWOT table need to be elaborated or resolved. The recently finished SRA 2013 (Strategic Research Agenda) drafted by the AM-Platform [4] stakeholders indicates a multitude of recommendations from which the most relevant to standardisation are listed below in Figure 7 . They can be categorised in Technical and General areas for development.

Technical areas include: Productivity, Process stability, Materials, Process and Product quality, product data and costs.

General areas include: Training and education, Standards and certification, Environment, Industry definition, Liability and Other.

The full list, including the prioritization tables, can be found in the SRA 2013 document.

Technical topic	Technical principle challenges
Productivity	• Increase build-speed, possibly through new approaches to scanning or sources of energy. • Support higher volume production, possibly through enabling batch consistency and methodologies for consistent materials supply. • Decrease the time to create each layer, the overall time between layers, and start-up and shut-down time. • Develop methodologies for measurement of AM products.
Process stability	• Increase material process ability, quality and performance. • Increase control of process tolerances. • Improve surface finish of processed parts. • Improve process control and monitoring. • Further develop lasers with improved efficiency and control. • Reduce residual stresses in metal products. • Develop methodologies for 'Right first time' processing. • Develop tools for better temperature management during processing. • Improve geometrical stability. • Analyse energy consumption and development of methodologies for its reduction. • Develop multi-material manufacturing for AM technologies. • Increase software utilisation

Materials	• Develop AM materials performance, static and fatigue, to enable a similar or superior demonstrable performance level of cast and wrought material. • Interchange-ability of process parameters between different AM machines. • Identification of new semi-crystalline and amorphous polymers suited to different AM mechanisms. • Tailored materials for AM. • Develop materials' consistency and repeatability e.g. fixing process parameters. • Analyse material properties of different materials and multi-materials using AM techniques, including their validation. • Analyse and develop of new materials for AM processing e.g. biomaterials, superconductors and new magnetic materials, high performance metal alloys, amorphous metals, ultra-high temperature ceramic composites, metal-organic frameworks, new nano-particulate and nano-fibre materials.
Process and product quality	• Develop in-process monitoring and control methodologies and systems including techniques for reducing the requirements for post-processing activities. • Develop a 'streamlined' workflow for hybrid manufacturing, combining AM processes to meet geometric and surface finish requirements. • Develop material characteristics and the mechanism by which the material is processed to improve surface quality. • Investigate in-situ sensors to provide non-destructive evaluation and allow for early detection of flaws/defects. • Develop design tools and methodologies to empower design engineers to take advantage of AM. • Increase the understanding of power-beam manipulation (laser or electron beam) and material interaction(s) and their associated changes particularly for smaller parts production for increased surface finish.
product data	• Develop databases to allow a catalogue of materials performance information for particular applications, materials and processes. • Develop an 'online' portal of materials information for comparison and sharing.

Costs	• Reduce scrap and improve repeatability. • Faster turnaround addressing material/part/component handling. • Materials processing whereby new powder production sources or new/improved methodologies for supply chain integration are facilitated. • Identification of new supply chain opportunities and establishment of existing supply chains for potential products. • Improve material utilisation.

General topic	Principle challenges
Training and Education	• Develop AM specific training modules encompassing design/ modelling, processes, materials and applications. • Non-technical outreach programmes for management, or other non-technical business personnel, on logistics, lean manufacturing and new business models. • University and technical college courses, education materials, and curricula at basic undergraduate and post-graduate levels. • Events based on specific industrial case studies, technology transfer support and supply chain assistance. • Training programs for industry practitioners certified by professional bodies. More educational resources dedicated to increasing the knowledge of AM technologies, materials and their applications.
Environment	• Improve the heat sources used in AM, for example more electrically efficient lasers. • Improve process productivity to reduce resource usage including in-process losses. • Validation and standardisation of the batch-to-batch recycling of materials, especially for polymeric materials. • Develop strategies for recycling material after the part has finished its natural usage life e.g. melting of used parts, the monitoring and control of material chemistry, and the atomisation of material to create feedstock for AM systems.

Standards and Certification	• Develop processes to increase certification of AM e.g. advanced in-process inspection and quality control techniques. • Further industry engagement in the ISO/TC261, CEN and ASTM F42 working groups on standards development. • Develop methodologies for preventing or correcting product defects. • The following topics have been identified as a priority by ISO and ASTM: Qualification and certification methods, design guidelines, test methods for characteristics of raw materials, material recycling guidelines, standard protocols for round robin testing, standard test artefact, requirements for purchased AM parts, harmonization of existing ISO/ASTM terminology Standards, tests on finished parts.
Industry Definition	• Technology and research requirements need to be categorised as to fit the diverse range of AM technologies, especially for standardisation, liability and intellectual property. • An industry advisory group that focuses on AM supply chains and common areas of capabilities for Europe.
Liability	• Develop new business models stating clear rules and guidelines on the effective supply of AM produced components to ensure product safety, but also accountability in the event of faulty or damaged parts/products.
Other	• Global collaboration in the area of AM would be beneficial particularly between EU and USA. • Identification of applications and work with end-users to understand the business case for using AM over other manufacturing routes. • Mechanisms for taking a product into production e.g. taking proven concepts at TRL 4 and moving them to TRL 7 to 9. • Supply chain development, from material supply, reliable AM systems to post-processing. • More consideration to the value proposition for AM e.g. digital data.

Figure 7 *prioritization tables for AM from the SRA 2013 [4]*

Prioritization (high prio topics) and Roadmap (timeframe)

The SASAM partners have made an inventory about topics and priorities of standardisation to enable a consistent route forward to get AM standardisation in place. The information from 102 respondents (more than 95% were from Europe) with an industrial share of 56 % was used, analysed and prioritized.

An extensive list of topics was drafted based on which a prioritization was given.

The complete list and rating is given in Figures 8 to 12. The data are presented in a standardisation roadmap indicating the timing in Figure 13.

Priorities are categorised into:

- Product quality
- Materials (metals, polymers, ceramics)
- Other Subjects

The raw data with on the vertical axis the priority (on a scale from 0 to 5) are given in Figure 8 below, the roadmap is based upon these priorities.

1

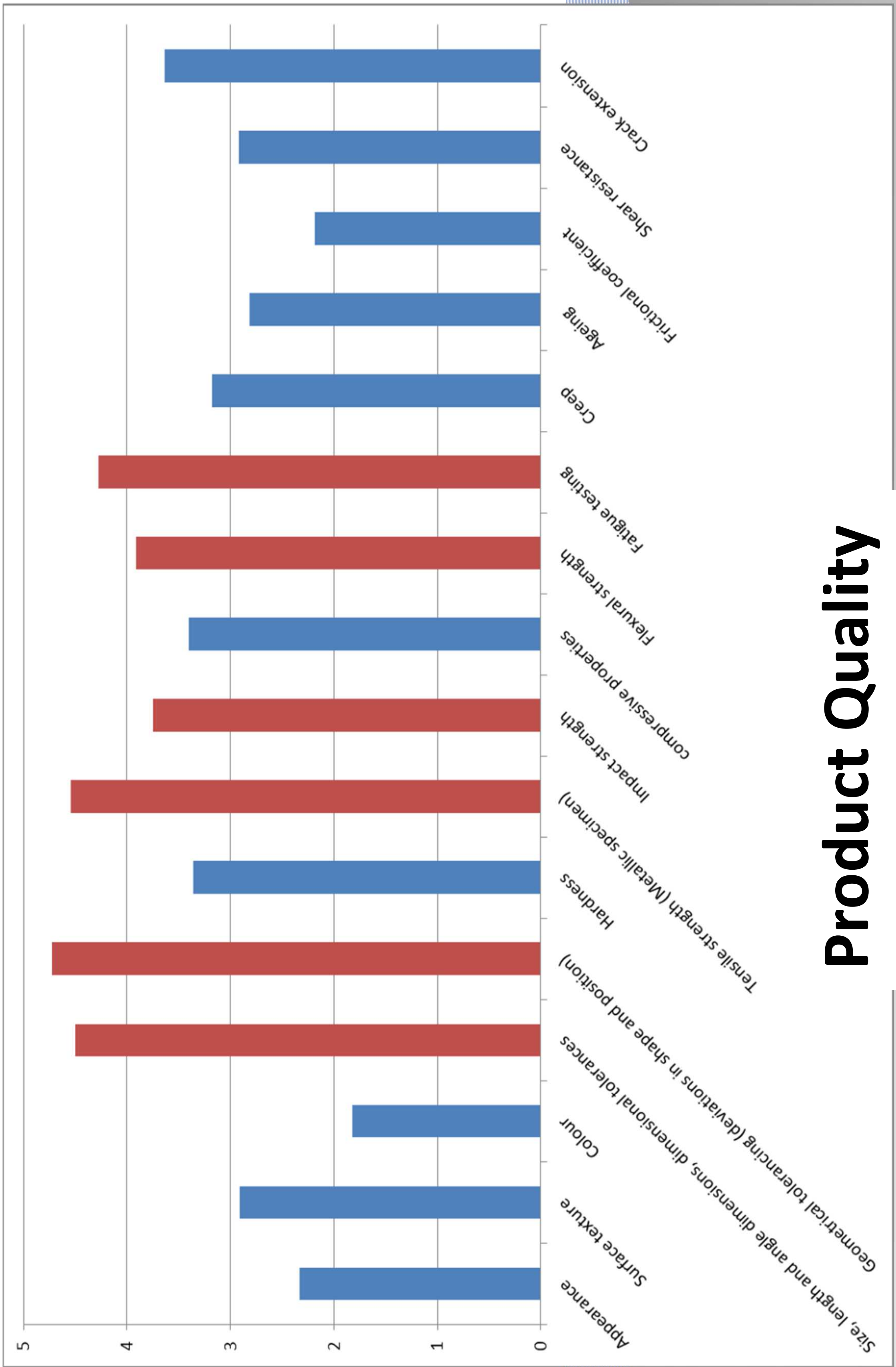

Figure 8 *prioritization table for AM from the 102 AM stakeholders interviews*

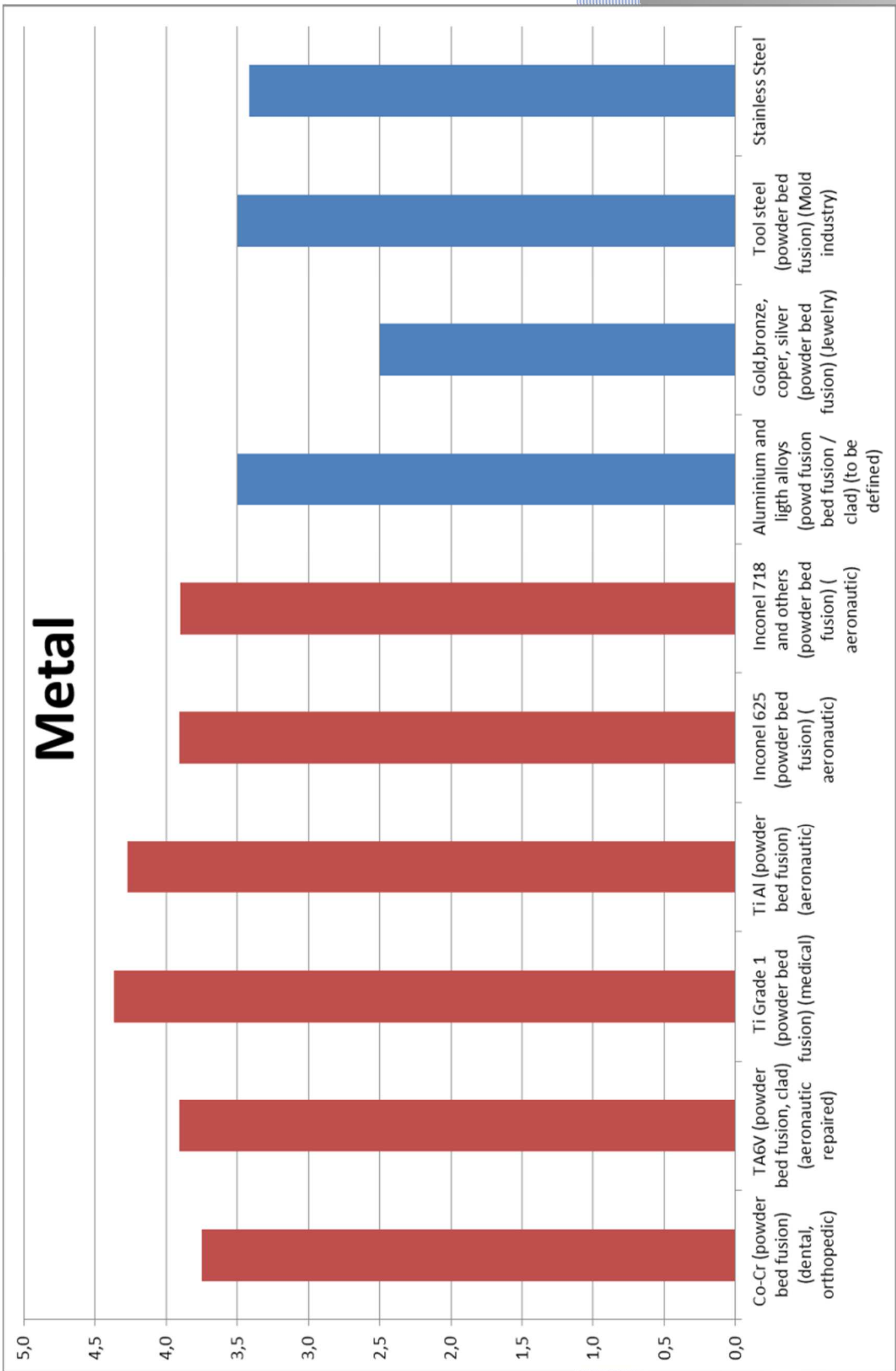

Figure 9 *prioritization table for AM from the 102 AM stakeholders interviews*

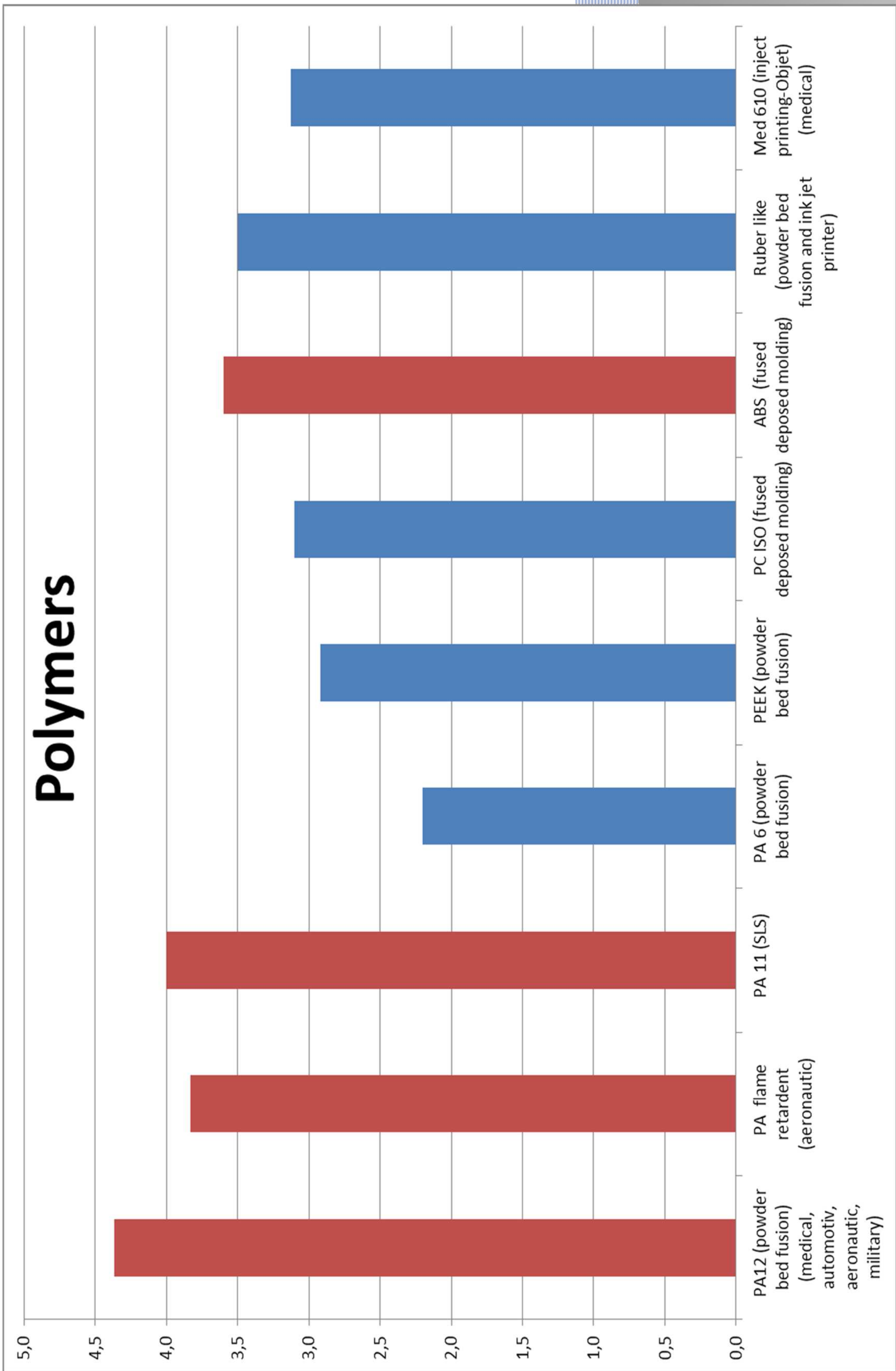

Figure 10 *prioritization table for AM from the 102 AM stakeholders interviews*

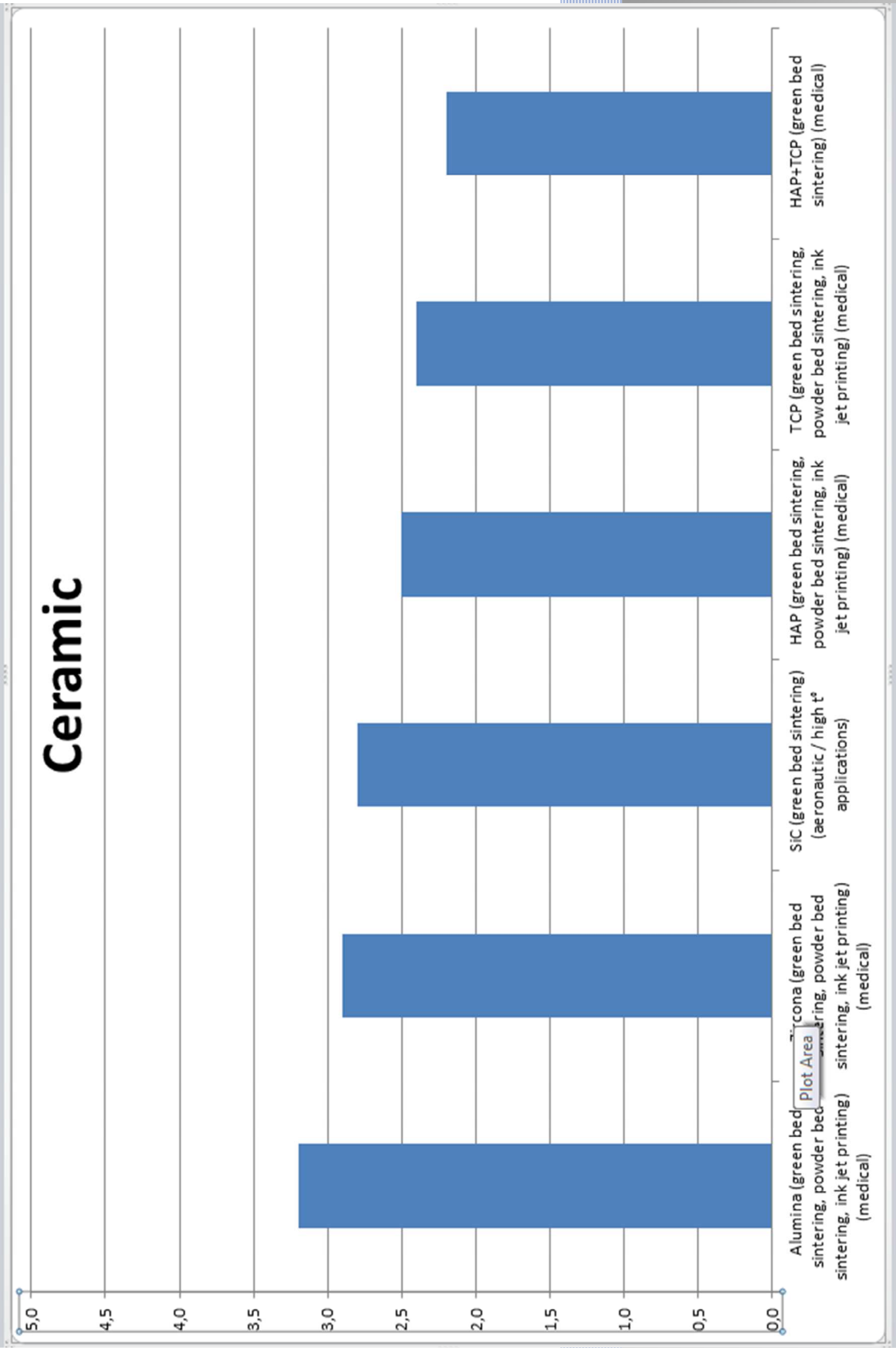

Figure 11 *prioritization table for AM from the 102 AM stakeholders interviews*

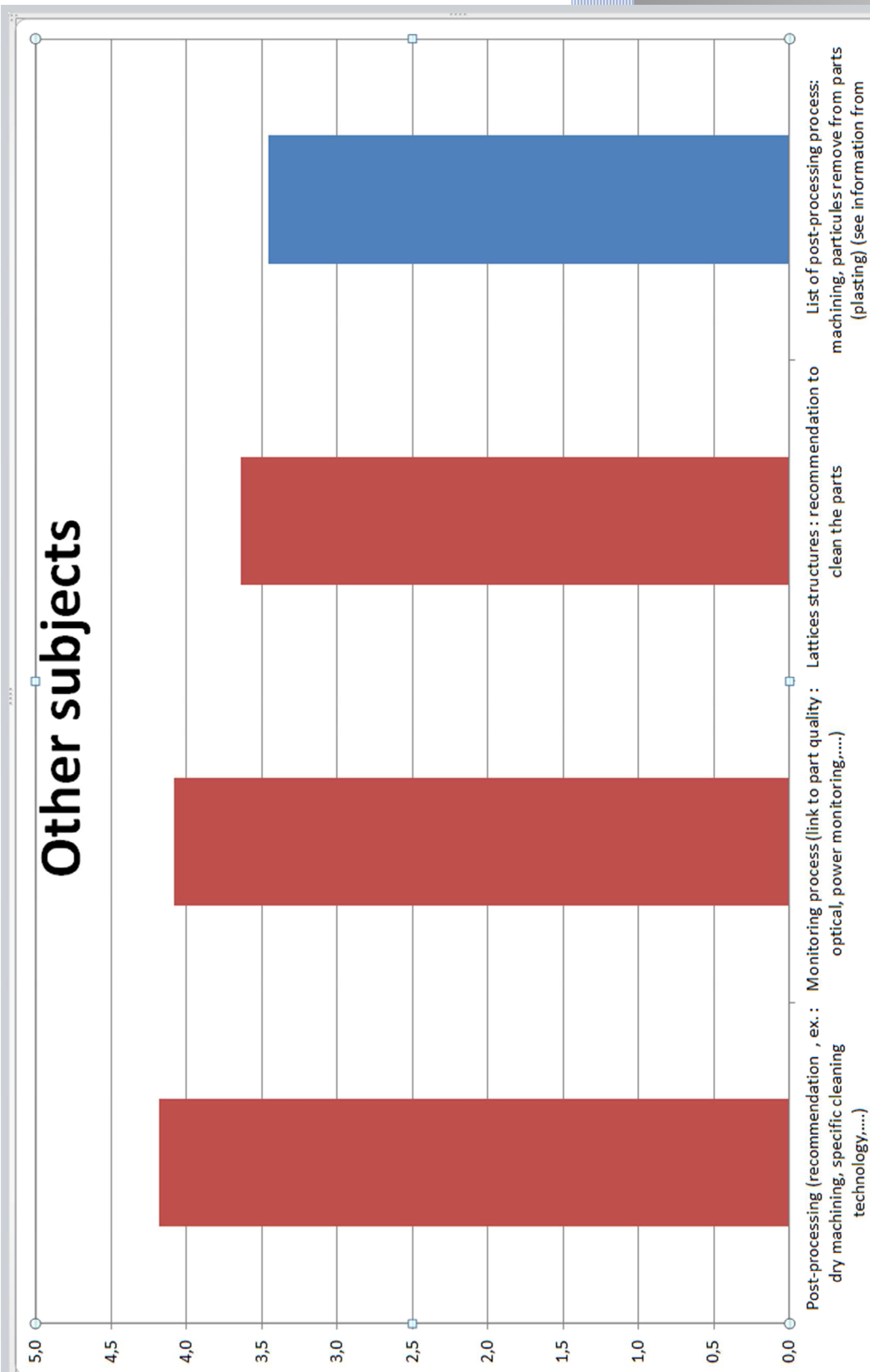

Figure 12 *prioritization table for AM from the 102 AM stakeholders interviews*

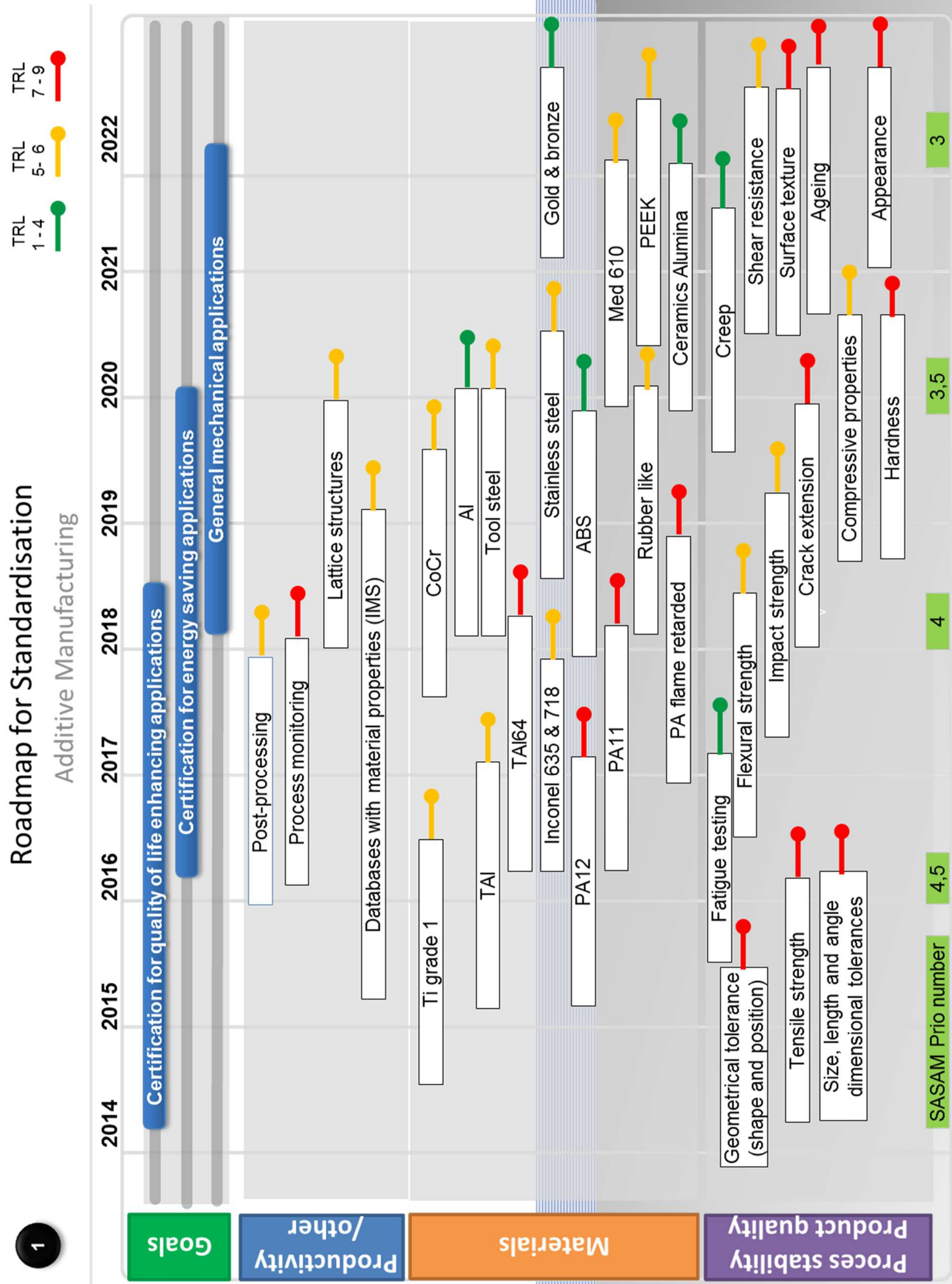

Figure 13 *AM* standardisation roadmap indicating the topics and priority timing.

Conclusions

It can be concluded that the interest and attention for the development of AM standards has gained momentum and that a group of over 100 industrially driven stakeholders from all over the world (with a centre of gravity in Europe) is active.

The needs and type of standards to be developed were all customer and market driven, tstandards must be developed to support the industrial implementation of AM.

A listing of already existing standards for AM has been drafted. First liaisons with standardisation bodies have been established and it will be assessed whether a cooperation with the corresponding TCs will be desirable for AM topics as well.

There is no CEN/TC on Additive Manufacturing at the moment. As part of the SASAM project it will be assessed if a CEN/TC on Additive Manufacturing should be applied for in Spring 2014.

Input from AM standardization stakeholders showed that AM technology is expected to unlock an economical push of the reliability of the processes and their machines and manufactured products. There is a clear preference for an international standard and European participants are definitely more inclined to the ISO than to the ASTM or any other (VDI, CEN) standard. The remarks also show again the necessary qualification of specific industrial standards.

The standardisation activity is expected to boost the existing AM business and will help to get acceptance on new markets and by new industries. This will be a big opportunity for innovation and economic growth in the European industry, which should enhance competiveness and so be instrumental to the creating of jobs in Europe, which is also underlined by the European "Industrial Landscape Vision".

AM standardization documents were analysed and a intentional structure for the standards was proposed. The following key agreements on the guiding principles to be followed and pursued by all organizations, were drafted: One set of AM standards – to be used all over the world; work on a Common roadmap and organizational structure for AM standards, use and elaborate upon existing standards, modified for AM when necessary.

The benefits which can be achieved by AM indicate that the total sale of AM products will reach USD 3.7 billion by 2015. Standards contribute to this by proving the necessary certification and approval for e.g. medical and aviation applications. The exploitation of AM technology as another manufacturing tool will encourage innovation and enhance the competitiveness of labour in Europe.

24 relevant projects have been contacted and asked for a listing of relevant actions with respect to standardisation within the project. All of them are invited to present their progress on the AM-platform meetings which are held minimal twice per year. Also, liaisons with relevant TCs as are maintained and coordinated by STAIR-AM

A SWOT analysis of AM from a standards point of view revealed quite some strength and opportunities for European industry. Amongst them were generally AM related such as unique topological optimized products, no stock, production on demand, sustainable production. In particular, knowledge intensive processes / potential for high quality jobs in Europe will result from AM implementation whereas Europe has a good knowledge base for AM. Technologically speaking, the hybrid processes (AM and conventional combined to get best of both) and integration of AM in existing production lines are high priority and high potential. This also urges the need for relevant standards development.

Principle challenges indicate quite some recommendations which can be categorised in Technical and General areas for development.

Technical comprises: Productivity, Process stability, Materials, Process and product quality, product data and costs.

General areas comprise: Training and education, Standards and certification, Environment, Industry definition, Liability and Other.

A roadmap indicating timing and topic for AM standardisation was drafted on the basis of interviewed stakeholders. The topics selected were process stability and product quality, materials and productivity and other. Key priority items for AM standardisation are: databases with material properties, for the materials Titanium grade 1 (unalloyed titanium) and geometrical tolerances.

The SASAM consortium very much recommends that Europe supports a common development of AM standards via ISO-ASTM with an appropriate involvement of European experts. The Vienna Agreement between ISO and CEN enables the approval at the same time of European Standards and International Standards, based on a single draft standard.

SASAM recommends a very strong world-wide cooperation which supports the ideas of the “Industrial Landscape Vision” which recognizes the world-wide approach and significance of Additive Manufacturing.

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ACKNOWLEDGEMENTS

This roadmap was financially supported by the European Commission under contract nr 319167, project acronym SASAM: Support Action for Standardisation in Additive Manufacturing, Call: FP7–NMP–2012-CSA-6, 2012 – 2014. Website: www.SASAM.EU

Consultation

This Roadmap document is open to the AM community for review in order that all relevant stakeholders have the opportunity to express their suggestions for improvement, identify other essential recommendations or provide general comments. This input will be progressed and will result in a next version of the Standardisation Roadmap.

Please direct responses to:

Frits Feenstra (frits.feenstra@tno.nl) (Coordinator SASAM)

Further updates will be provided at www.SASAM.EU and www.AM-Platform.com

The SASAM project consists of the following partners