Scoping for Smart Materials

MISTRA, Stockholm, 30 November - 1 December 2015

Table of Content

1 Terms of reference

1.1 Background

Mistra have identified the area of *Smart Materials* as a topic of strategic importance for development of core technology with Sweden, as reported in the following extract from the minutes of Mistra Board meeting, 10 December 2014;

"If our society is to develop a greater degree of sustainability, we must learn to manage existing resources as efficiently as possible. This will, of course, make demands on the materials we use – they must be reusable, recyclable and safe for the environment. The new smart materials should be functional when in use and a valuable resource when no longer required. The development of new smart materials should be based on current materials with incremental, innovative improvements well suited for current production systems. A Research programme concerning smart materials should initially include a series of smaller projects with the common objective to develop new materials through research, innovation and collaboration between researchers in universities, institutes and companies."

The original Swedish version of this extract is given in Appendix A.1: Extract from background documents presented at the Mistra Board meeting, 10 December 2014.

1.2 The assignment

The main task for the working group was to analyze whether the research area identified by Mistra could become the basis for a new research initiative funded by Mistra. It was therefore important to take into account the purpose of Mistra (as expressed in the Mistra Statutes), as well as the current Mistra research portfolio and upcoming new initiatives (e.g. 'Sustainable markets' and 'Product design for resource efficiency'). The emphasis of the evaluation was on the long term sustainability of products and processes within Sweden and on the strong link between human society, sustainable development and ecosystems.

In case the working group concluded there was a basis for a new research initiative, it had to:

- Provide an overview of the need to develop smart materials within Sweden based on existing capability and developmental potential;
- Identify the challenges and societal needs in this particular area;

- Propose in detail the orientation of a new research initiative (draft text for a call for funding applications).

The working group comprised three international experts tasked with drawing up a background report with recommendations to the Board of Mistra. A final report was required for submission to Mistra not later than 20 February, 2016.

2 General introduction

A central theme of the 2012 United Nations Conference on Sustainable Development (Rio+20) was the issue of the green economy. Behind this discussion was the notion that sustainable development is dependent highly on the development of materials and processes that drive change, and that this change must be compatible with environmental and financial sustainability.

The concept of smart materials has raised hope in a number of developing and established high tech sectors, including urban infrastructure, energy generation, climate control and manufacturing.

The concept of smart materials is not new *per se*: for many decades, the idea of functional materials that enable better monitoring, control and evaluation of physical and biological systems and processes has been applied consistently to a variety of operational needs. Essentially, smart materials form the interface between at least two physical or biological influences to produce a better integrated solution or approach to a well-defined problem or need. The use of these materials increases the potential for investment, well-being and competitiveness in a high tech market.

3 Working group deliberation

A workshop was held that was attended by 18 members of the Swedish academic, institutional and industrial community. The list of workshop participants is provided in Appendix A.2: List of workshop participants (30. November 2015).

The definition of smart materials was discussed during the workshop and then broadened in subsequent panel discussions. The general definition is given in Appendix A.3: Definition of Smart Materials.

The working group spent several hours discussing the background of smart materials with a view to identifying and prioritizing possibilities for a new Mistra research initiative. To undertake this task, the working group adopted four main criteria:

- The significance of the topic to Sweden and other advanced countries;
- The current state of research;
- The scope of the initiative;
- The possibility of identifying worthwhile and practical research questions.

The working group agreed that the theme of smart materials was both appropriate and topical for a focused research call. This topic provides the main focus for the remainder of this report.

The working group identified the following issues, each of which merits further research. Combined these would constitute a timely and significant research programme relevant to Sweden and other advanced economies:

- What are the direct potential benefits of developing smart materials for the Swedish economy?
- Is there a willingness within Swedish industry to invest in transformative, materials-based technologies?
- Can target areas of sustainability relevant to smart materials be identified for development?

The working group sees an expanded role for materials and process development within Sweden based on a close collaboration between industry, technical institutes and universities in a move towards supporting and promoting a more sustainable environment and economy.

Based on the working group's assessment of the current state of research (see Section 4 below), the working group feels that smart materials comprises a research programme that meets the four criteria set out above and would make an important contribution to the technical and environmental capability in Sweden and similar countries.

4 State of the Art and Research Challenges

4.1 The international research frontier

Smart materials have always received extensive research attention. The advent of the latest 'industrial revolution' (i.e. digitisation of manufacturing, mass-customisation and personalisation, combined with an increasing need of social and environmental responsibility and sustainability), however, has elevated significantly the role of smart materials as essential building blocks of increasingly small and intricate devices and processes. Smart materials represent enabling scientific breakthroughs for numerous innovative solutions to global societal challenges, ranging from smart materials applications for pediatric cardiovascular devices,[1] to cellulosed-based biodegradable flexible electronics[2] and thermochromic windows.[3]

For several years, both the MIT and the WHO annual lists of Top 10 Emerging Technologies have included innovations that are dependent on smart materials (e.g. green concrete (MIT 2010), microscale 3D printing (MIT 2014), recyclable, thermoset plastics (WHO 2015).[4] Moreover, the European Union's list of Key Enabling Technologies (KETs) also includes several large families of smart materials (e.g. photonics, micro- and nanoelectronic, advanced materials).[5]

4.2 Related MISTRA Programmes

The following list describes related projects funded by Mistra:[6]

- Plastics in a sustainable society: Programme to be decided.
- MISTRA NanoSafety:[7] Mistra Environmental Nanosafety aims to develop an interdisciplinary research environment to obtain knowledge that enables

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[1] Daniel S Levi, Nick Kusnezov & Gregory P Carman, Smart Materials Applications for Pediatric Cardiovascular Devices, *Pediatric Research* 63 (2008) 552.

[2] Yei Hwan Jung et al. , High-performance green flexible electronics based on biodegradable cellulose nanofibril paper, *Nature Communications* 6 (2015) 7170.

[3] Linshuang Long & Hong Ye, How to be smart and energy efficient: A general discussion on thermochromic windows, *Scientific Reports* 4 (2014) 6427.

[4] (a) MIT Top 10 Emerging Technologies 2010 (http://opensourcebuzz.technetra.com/2010/05/28/mit-top-10-etech-2010/), (b) http://www.technologyreview.com/lists/technologies/2014/, (c) https://agenda.weforum.org/2015/03/top-10-emerging-technologies-of-2015-2/

[5] Horizon 2020: Key Enabling Technologies (KETs), Boster for European Leadership in the Manufacturing Sector, http://www.europarl.europa.eu/RegData/etudes/STUD/2014/536282/IPOL_STU(2014)536282_EN.pdf

[6] For more information, visit the Mistra website: http://www.mistra.org/

nanotechnology to be used safely in a sustainable society. The programme is focused on the environmental risks of nanomaterials, the properties of nanomaterials that entail risks, and how the consortium could protect the environment against unacceptable emissions. Through collaboration among researchers in many subject areas, from nanoscience and medicine to social sciences, a common platform is expected to be generated for a wide-ranging dialogue with industry, the public and legislators alike.

- Closing the loop:[8] This research was intended to develop methods for identifying resources better and restoring them to industry. Ways of doing this would include developing measuring and processing techniques that enable industrial waste to be upcycled as raw and other materials without spreading pollutants. There was a particularly marked need to make recycling of complex products, such as electronics, computers and cars, more efficient.

  A key aspect of the programme was to facilitate collaboration among different industrial sectors. The programme comprised seven individual research projects (see the list below), involving various industries, with continuous exchange of thoughts and ideas among them throughout the programme period. Resource and waste flows in different sectors would be surveyed. Research on control instruments for encouraging material recycling and analysis of markets and business models for products made from recovered materials would also be carried out. A second phase of this programme is expected to commence in the first half of 2016.
- Future fashion:[9] With a consortium representing a broad range of expertise in Swedish fashion, the research programme has all the potential to reach its goal: a systemic change within the Swedish fashion industry that leads to a more sustainable development within the fashion industry and society. This in turn would strengthen the competitive advantage of the fashion industry.

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[7] http://www.mistra.org/en/mistra/research/ongoing-research/mistra-environmental-nanosafety.html

[8] http://www.mistra.org/en/mistra/research/ongoing-research/mistra-closing-the-loop.html

[9] http://www.mistra.org/en/mistra/research/ongoing-research/mistra-future-fashion.html

Large companies like H&M and other fibre, textile and fashion-related businesses and organisations are also be involved in the research; this should help boost the impact of the programme.

5 Sweden's interests

A reasonable focus for the development of smart materials could be on Biotechnology, where Sweden has an established track record. The country needs to maintain a competitive edge, which is a main driver for this initiative.

Specific areas of research include smart textiles and wearable electronics, cellulose (from the timber industry), silica, packaging and liquid absorbent materials (such as Upsalite®), biomass and bio-refinery.

Up to 10% of the funds available should be reserved for potentially disruptive, blue skies research. Funding for such high risk research may be included as component of a larger, more applied project, or as a stand-alone smaller project.

A strategic reserve of up to 10% should be retained to potentially cover for specific issues arising during the conduct of the project.

The initiative should both develop and incentivise small companies and strongly encourage Swedish-based industry/institute/university collaboration. Basic and applied research are both important within this context for generating innovation. A sensible funding model should be developed for SMEs and large companies, and a diverse research environment should be promoted. The initiative can support limited international involvement, although the primary focus should be on funding Swedish organisations.

Sweden has a number of established environmental goals and strategic research initiatives, with which this call is entirely consistent.

6 Future priorities

Future priorities within Sweden will be on education, infrastructure, research and raw materials. The challenge is to make smart materials smarter by shifting from materials the nation has to materials the nation needs. A focus on disruptive technologies is particularly desirable as part of this programme.

7 Conclusions and recommendations

The working group is strongly of the opinion that research on and development of smart materials has significant potential for the advancement of sustainably technology within Sweden and is potentially important for the Swedish economy and for the Swedish societal agenda.

The amount of investment needed to undertake potentially transformative research in smart materials for the development of technical, economic and social systems within Sweden is difficult to define. There is a clear need to focus on existing capability for well-defined and established Swedish industry, supported strongly by Swedish institutes and Swedish universities.

We therefore recommend that Mistra initiates a research and development programme on smart materials that addresses the issues outlined in Section 3 above and with the following main characteristics:

- Engagement of Swedish organizations, including industries, institutes and universities;
- Adopting a systems approach and interdisciplinary research where possible;
- Including limited, but relevant, international collaboration;
- Widespread dissemination of new ideas and generic results.
- A long-term programme within initial commitment of four years. The range of individuals and groups that would potentially find the research we are proposing valuable is very broad. It would include all those engaged currently in internationally and nationally in materials research;
- Any output created from the Mistra funded programme as part of the research should be presented in such a way as to make the method and findings as accessible as possible to the wider scientific community and to the general public.

The likely outcomes of this new programme would be:

- Real changes in the technical capability of Swedish industry;
- Creation of international research networks;
- Building up of a training and research capacity in Sweden based on smart materials.

The specific recommendations of the working group are:

1. The initiative should be managed by a two-stage application process that involves an initial invitation to submit an outline of limited length followed by panel evaluation, short-listing and invitations to submit full proposals.
2. The duration of the initial programme should be four years, which is consistent with standard Mistra practice.
3. Up to 10% of the funds available should be reserved for potentially disruptive, blue skies research; funding for high risk research may be included as component of a larger, more applied project, or as a stand-alone smaller project.
4. A strategic reserve of up to 10% should be retained to potentially cover for specific issues arising during the conduct of the project.
5. The initiative should develop and incentivise small companies and strongly encourage Swedish-based industry/institute/university collaboration.
6. Basic and applied research are both important within this context for generating innovation, and this should be acknowledged in the call for proposals.
7. A sensible funding model should be developed for SMEs and large companies, and a diverse research environment should be promoted.
8. The initiative can support limited international involvement, although the primary focus should be on funding Swedish organisations.

8 Appendix

Appendix A.1: Extract from background documents presented at the Mistra Board meeting, 10 December 2014

“Om samhället ska utvecklas mot en större grad av hållbarhet måste vi hushålla med befintliga resurser så effektivt som möjligt. Det kommer att ställa krav på de material vi använder – de måste vara återanvändbara, återvinningsbara och riskfria för miljön. De nya smarta materialen ska vara funktionella under tiden de används och en värdefull resurs efter slutanvändning. Utvecklingen av nya smarta material bör ske utifrån dagens material med stegvisa, innovativa förbättringar som är välanpassade till dagens produktionssystem. Ett forskningsprogram om smarta material bör initialt bestå av en rad mindre projekt med det gemensamma målet att utveckla nya material genom forskning, innovation och samarbete mellan forskare på universitet, institut och företag.”

Appendix A.2: List of workshop participants (30. November 2015)

David Cardwell	Cambridge University, UK
Steffi Friedrichs	SF SPRL Consultantcy
Alexandra Davydova	Kungliga Tekniska högskolan, Stockholm
Andrea Fornara	SP Sveriges Tekniska Forskningsinstitut, Stockholm
Ann-Christine Albertsson	Kungliga Tekniska högskolan, Stockholm
Birgitha Nyström	Swerea IVF, Stockholm
Christopher Folkeson Welch	Mistra, Stockholm
Ellen Moons	Karlstads universitet, Karlstad
Eva Lindh-Ulmgren	Swerea KIMAB, Kista
Francisco Vilaplana	Kungliga Tekniska högskolan, Stockholm
Gabriella Josefsson	Disruptive materials
Gert Nilson	Jernkontoret, Stockholm
Jonas Enebro	SP Sveriges Tekniska Forskningsinstitut, Stockholm
Lena Smuk	SP Sveriges Tekniska Forskningsinstitut, Stockholm
Lina Wendt Rasch	Chemicals Agency, Stockholm
Maria Strömme	Uppsala universitet, Uppsala
Mikael Syväjärvi	Linköpings universitet, Linköping
Monica Ek	Kungliga Tekniska högskolan, Stockholm
Steven Savage	FOI, Totallförsvarets forskningsinstitut, Stockholm
Sara Isaksson	Kungliga Tekniska högskolan, Stockholm
Susanna Wold	Kungliga Tekniska högskolan, Stockholm
Ulrica Edlund	Kungliga Tekniska högskolan, Stockholm

Appendix A.3: Definition of Smart Materials

Smart materials are biological or non-biological materials that have one or more properties that can be changed significantly in a controlled way under the influence of external stimuli. In addition, they include materials that can achieve, or potentially achieve, a novel or pronounced effect or physical change that is not achievable by existing materials or techniques.

Smart materials may be of particular relevance to a specific application that enables unique operation of a device or a process. They are often composites of some sort, but are not necessarily complex in nature or composition. They don't have to be new, or limited to a specific scale.

Smart materials can contribute to the industrialisation of environmentally friendly applications for the general benefit of society in many ways. For example, they may facilitate the avoidance of harm to humans and the environment by substituting for and reducing the need for harmful chemicals (e.g. enable a move away from plastics or flame-retardant materials). Emerging materials need to be tested carefully for toxicology to avoid problems encountered historically (e.g. PCBs).

Appendix A.4: Horizon 2020 technology readiness levels (TRL)

Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified:

TRL 1 – basic principles observed

TRL 2 – technology concept formulated

TRL 3 – experimental proof of concept

TRL 4 – technology validated in lab

TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 7 – system prototype demonstration in operational environment

TRL 8 – system complete and qualified

TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)