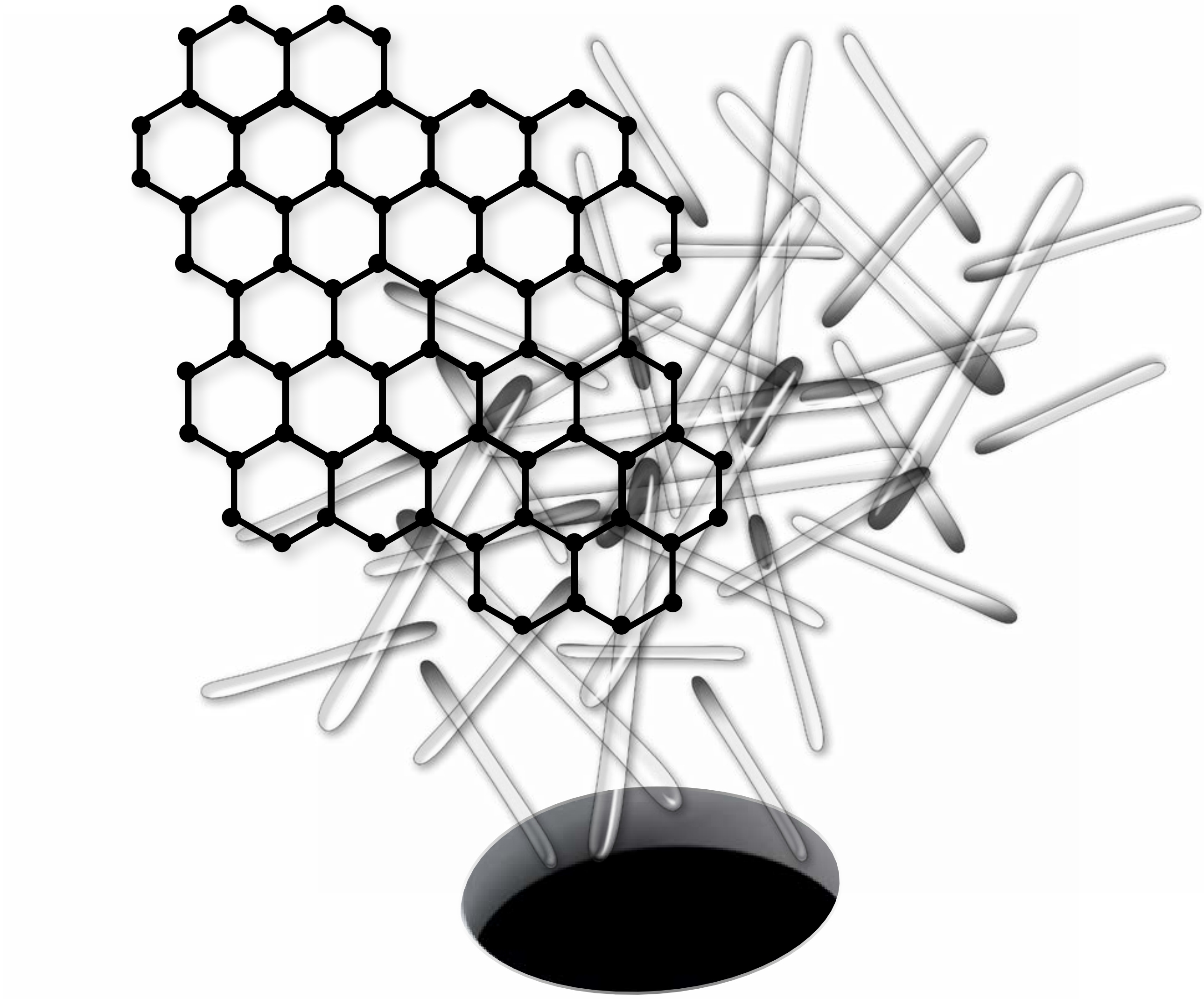
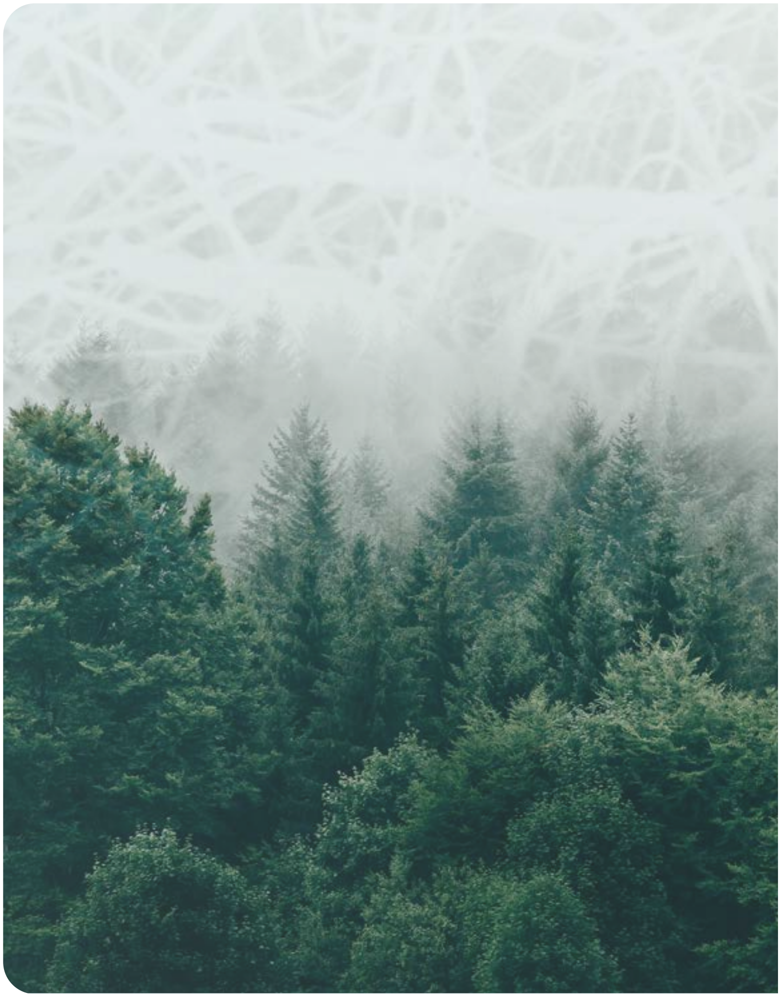
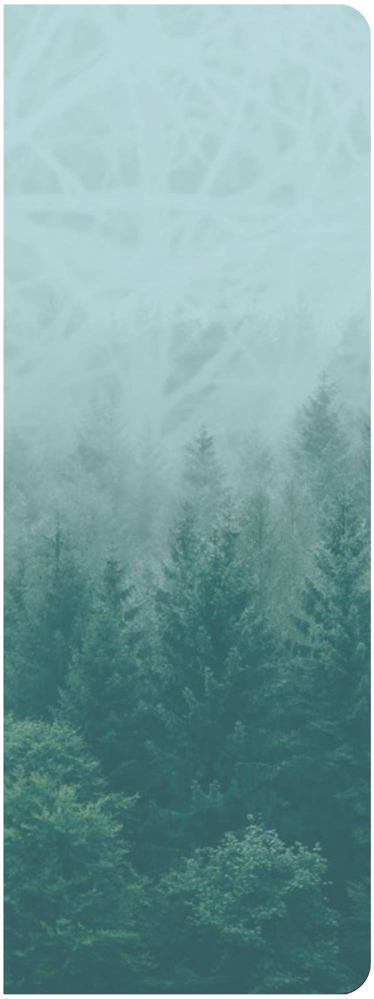


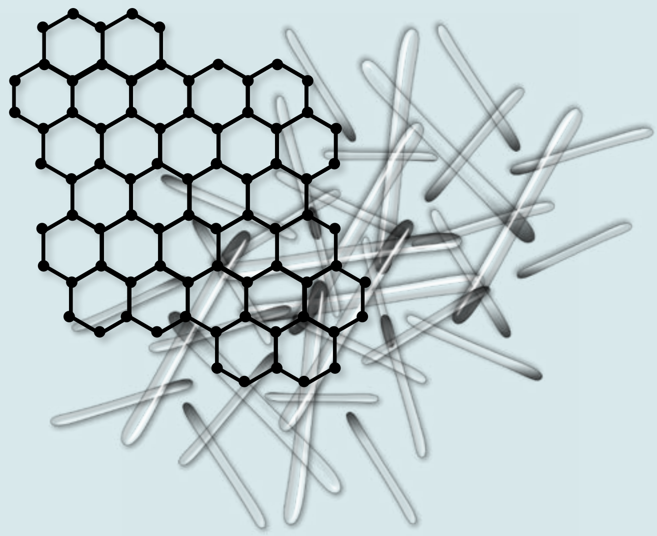
Graphene and nanocellulose – from GAP analysis to increased competitiveness with the aid of standardization, the report

Executive summary

- International standards will be developed. If we do not take part someone else will choose what the standards look like
- The way to influence coming standards is through a strong and active participation of Swedish experts in the SIS and SEK standardization committees
- There is ongoing international standardization work on health, safety, environment, and occupational aspects of nanomaterials. Although these include graphene and nanocellulose, there is no work specifically on these materials.
- We have knowledgeable people in Sweden, and we need to recruit more Swedish experts to the standardization work, especially for health, safety, environment, and occupational aspects
- We need to make sure more industrially applicable methods are included in the standards
- Participating in experimental work, which often results in proposals for new international standards, is crucial for ensuring influence at an early stage
- The SIS standardization committee has started to engage more actively and strategically in the work of the ISO standardization for nanotechnology







Introduction

The industrial landscape is facing a revolution. New functional materials, new manufacturing methods and processes, machine learning and artificial intelligence will solve many of the global sustainability challenges and Sweden is investing heavily in this development in an international perspective. Some good examples of this recognition are the European graphene initiative, Graphene Flagship, which is coordinated from Chalmers, and the European battery initiative Battery 2030+ which is coordinated from Uppsala.

Innovations, which often have their origins in long-term research initiatives, need strategic tools such as intellectual property protection and standardization to achieve full competitiveness. In the case of standardization of nanotechnology (including graphene and nanocellulose), it could be used to a much greater extent among Swedish high-tech companies of all sizes.

Here, Swedish companies have an excellent opportunity to benefit from existing international standards and take the lead in the development of new ones.

The project

This project is a follow-up of the project 2019-01083, Standardization and best practice for new nanomaterials - case studies graphene and nanocellulose with the aim of developing methodologies for implementing standardization in companies' operations.

Stakeholders have been invited to three different workshops, and the discussions at these have served as sources for further work. Participating organizations are found in Appendix 1-2.

The first workshop, held in March 2021, was an introduction to intellectual property rights, accreditation, and standardization as tools for reaching the market.

The second workshop, held in May 2021, focused on the priorities for standardization on the different materials respectively. The national priorities discussed later in this report are based on these discussions.

The third workshop, held in September 2021, had internationalization and Nordic collaboration as themes. It became clear that there is interest for a Nordic collaboration. It was also evident that such collaboration would increase the Nordic influence on the standardization in ISO.

Besides the workshop discussions, the team has held several interviews with stakeholders, especially regarding nanocellulose.

Focus has been on

- Promoting the implementation of standards as a tool in the operations and spreading awareness and understanding of how standardization appeals to and strengthens the various stakeholders in the value chain (R&D → material manufacturers → product / service producer → authority → investors → end customer).
- Discussions on national priorities for standardization regarding the different materials. High priority should be given to stakeholders' active participation in the development of international standards and their use for nanocellulose and graphene, respectively.
- Involving more companies in the standardization process.
- Increasing interoperability through dialogue with other SIS committees and through dissemination of project results in various fora.

Challenges

For advanced materials to reach the market, whether as a stand-alone material or as a property-enhancing additive in other materials, the material must be systematically quality-assured and characterized. For several years, established characterization methods have been in short supply.

Today, international standards exist for defining the vocabulary and structural characterization of graphene and nanocellulose and more standards are under development. However, the industry is looking for established methods that work on an industrial scale.

There is ongoing international work on several graphene and nanocellulose related standards, mainly related to the vocabulary and to characterisation techniques. The characterisation techniques have so far been focused on methods rather high up in the metrology pyramid, see figure 1. That is, they are typically very accurate, but also require advanced methods that often are expensive and/or difficult to implement in a continuous manufacturing process at industrial scale.

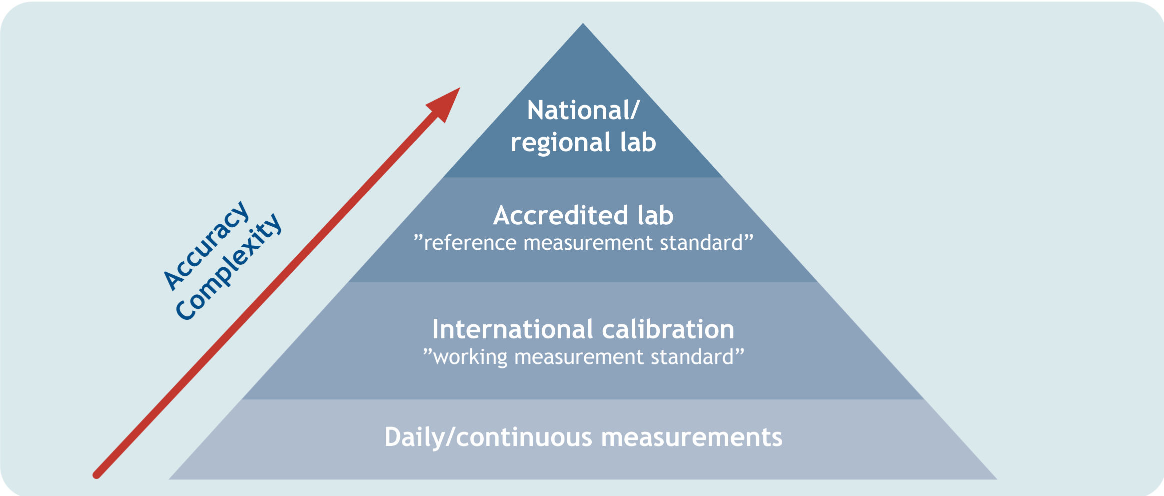


Figure 1. The metrology pyramid. Standards high up in the pyramid yield a more correct result but are also more complex to perform. These are therefore mainly used by national or regional labs. Methods that are used continuously in production are typically less accurate but are on the other hand suitable for faster characterisation.

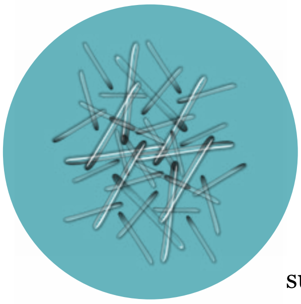
Since there are several standards already being developed, the priority is to make sure that these follow Swedish interests. The two most important aspects to this are:

a) influence the direction towards more industrially applicable standards

b) certify that graphene and nanocellulose produced and used in Sweden is included in coming standards

In the competition with traditional materials, however, it is important that the requirements for the materials are not only linked to the properties and nature of traditional materials. Here, it becomes important that the requirements for products are based on functionality, so that the requirements deal with what is to be achieved and not how it is to be achieved. Such a function-based set of requirements stimulates and encourages new innovative solutions and gives new materials such as graphene and nanocellulose a chance to “get in”.

Academic actors and research institutes can play a role in developing the standards. There are requirements for traceability so that, for example, you can follow a product all the way back to material production via a Gantt-like schedule. Quality assurance and characterization lead to the possibility of ranking suppliers, which could pave the way for a quality stamp of the type “Made in Sweden” which, for example, treats the material’s physical and chemical properties but also that raw materials and manufacturing methods are energy efficient and environmentally and health safe (see more about this below).



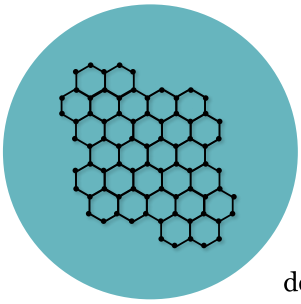
Nanocellulose

The interest in nanocellulose is incredibly large worldwide, and the market has grown a lot in recent years. In 2018, the global market was estimated to be worth approx. 285 MUSD and it is estimated to grow to approximately 660 MUSD by 2023. The largest growth is anticipated to take place in Europe, where Swedish companies will be important and strong players. Companies such as Stora Enso are already making investments and in 2017, Stora Enso announced that they are expanding their investment in nanocellulose, with further investments in Imatra in Finland and Fors mill in Sweden. Holmen has invested in a pilot plant for crystalline nanocellulose together with Processum, More Research and Melodea.

There are more than a hundred different types of nanocellulose (NC). The variations between them are large and there are mainly three factors that determine the difference between the types, namely the source of cellulose, the method of extracting and producing the material, and the surface chemistry.

In Sweden, the majority of nanocellulose is produced from trees. Fibrillar nanocellulose has been around since the early 1980's but commercialization failed due to the energy-intensive process required for to delaminate fibers. The turning point came in the 2010's. With new pre-treatment methods of fiber pulp, the energy consumption was drastically reduced. Sweden, Japan, Finland and Canada are today counted as the countries and regions that is a world leader in the field.

Today, the production capacity of nanocellulose is higher than the demand, hence the market is not able to use the nanocelluloses that are being produced. There is a need to find a "killer application" to justify the production and the higher cost of these nanomaterials, compared to traditionally used raw materials.



Graphene

Graphene is not just one material, but rather a family of materials[1]. This can be compared with polymers or plastics where there are many different materials. The different types of graphene related 2D materials are produced by different manufacturing methods resulting in different lateral sizes, thickness, defects, oxygen levels etc. This situation is also very similar for nanocellulose.

It typically takes a relatively long time to develop a new material before it can make a really significant impact in new products. Graphene is still in a reasonably early stage where many products have been launched, but the potential still is significantly higher. It was estimated in 2019 that the global market demand for graphene material was 15-50 MUSD in 2015 and would increase to 200-2000 MUSD around 2025. Graphene-enabled products were at the same time estimated to have a market value a factor ~100 higher. The performance of any product containing graphene thus depends on what type of graphene is being used. Consequently, most standardisation work regarding graphene is related to the vocabulary and to characterisation methods. This work is furthermore regarded as crucial by both producers and users of graphene.

[1] Graphene is defined as "a single layer of carbon atoms with each atom bound to three neighbours in a honeycomb structure", but the term is often used to also describe thicker material and material containing varying levels of oxygen. A new term "graphene-related 2D materials" is therefore suggested to also include these materials.

The standardization system

International standards have the potential to remove trade barriers, harmonize research and development activities, and contribute to fulfilling and development of regulations by national and international bodies. One example of an outcome of standards is to provide a framework for naming, describing, and specifying product materials. Another is to specify requirements for measuring, testing, and differentiating materials. A third example is the specifying of standard reference materials that are certified as possessing specified characteristics traceable to a fundamental system of physical units of measurement. A final example is when standards create specifications for commercial products.

A standard is a jointly agreed solution to recurrent problems. The broad aim of standards is to facilitate trade by eliminating technical trade barriers. Some other objectives with standards are to define clear guidelines for consistent function and quality, improve processes, increase transparency, simplify comparison, reduce environmental impact, pave the way for innovation, support sustainable development and address health and safety aspects.

Since there are many different types of standards such as those for terminology, management systems, test methods, fundamental principles and basic requirements for quality, health and safety, organizations can focus on innovation and design to create their competitive edge. This creates overall efficiencies in the value chain.

Being part of something big ...

ISO, the International Organization for Standardization, was founded in 1947 and is governed by an international regulatory framework under the World Trade Organization, WTO, to ensure that the results, the standards, comply with international trade guidelines. Standards contribute to more efficient trade, facilitate the introduction of innovations in new markets. They also contribute to a better understanding and acceptance of new materials and technologies.

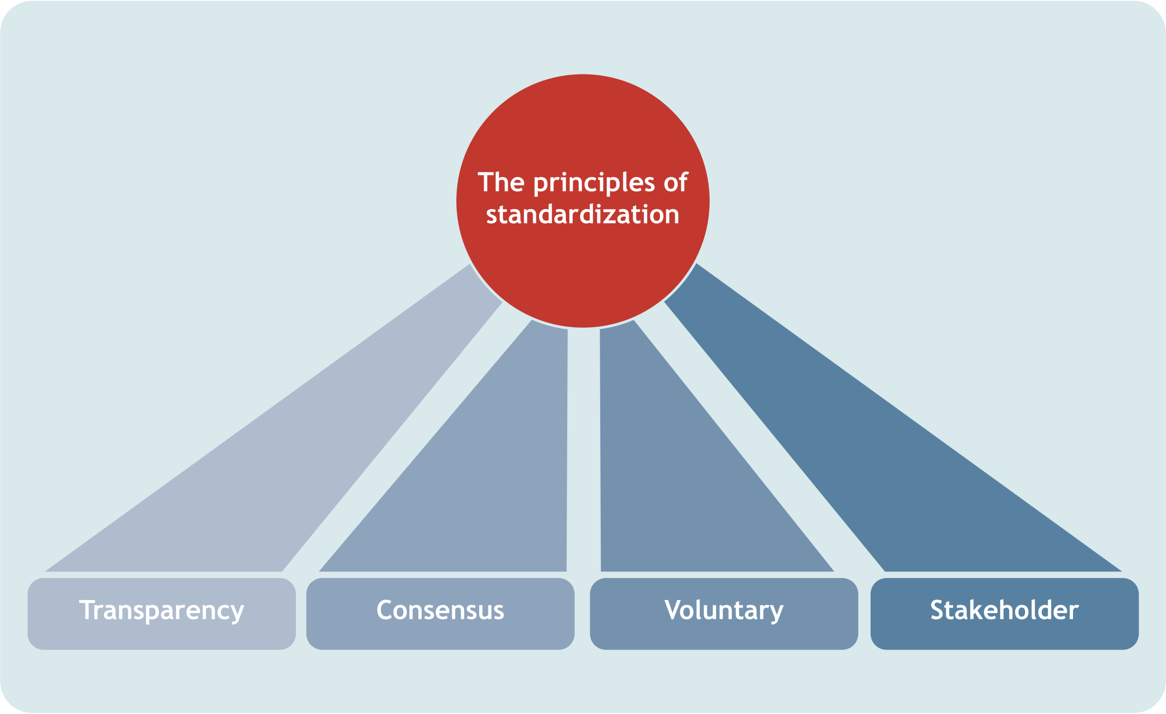


Figure 2. The principle of standardization

One of the key principles of the standardization process is to be stakeholder-driven. This means that the goal and ambition are to consider and involve all affected groups and their needs and views. The possibility for any stakeholder to submit comments, raise objections and propose improvements exist – from the idea stage to the final approval in the standard development process. As such, it is very important to actively participate in the work.

The scope of the standard is discussed, formulated, and agreed on at the outset of the work. It is very hard to change it afterwards. Therefore, it is essential to be active and present in the process at the beginning of any work for a new standard. Another reason for early and active presence is to understand if the work truly is stakeholder-driven and if not, ensure it is.

... starts at home

Sweden nominates members from the SIS and SEK national committees as experts in the relevant working groups within the international ISO, IEC and CEN committees to establish presence in the international standardization process. To be the most effective with establishing a broad and active sphere of influence, it is vital that Sweden attracts a critical mass of stakeholders to its national committees. Additionally, these experts from these stakeholders need to have the appropriate expertise, and also the necessary ambition, time and availability to participate in the work.

At present, the following organizations participate in the standardization work of nanotechnology in the SIS national committee SIS/TK 516 Nanoteknik: 2D fab, Bright Day Graphene, GraphMaTech, If Metall, Konsumentverket, Lunds universitet, Nouryon Pulp and Performance Chemicals, RISE, SIO Grafen, and Stora Enso Pulp and Paper.

The work in the SIS committee is organized into six working groups, five of which mirror the working groups that exist within the ISO committee, ISO/TC 229 Nanotechology. The working groups within SIS/TK 516 are (in Swedish): Terminologi och nomenklatur, Mätteknik och karaktärisering, Miljö, hälsa och säkerhet, Materialspecifikationer, Produkter och applikationer and Grafen. The latter, Grafen, was established in 2020, reflecting the needs of the national graphene community for graphene standards.

Early lessons

Earlier studies have shown that there is a clear gap between the wanted situation and the present situation regarding the appreciation, understanding and engagement regarding standards and standardization, table 1. To bridge this gap, further actions are needed to reach a long-term commitment and enhance the impact leading to higher competitiveness.

Challenges with standardization within graphene and nanocellulose	Identified solutions
Low understanding of standardization among stakeholders	Education, better communication
Low stakeholder engagement	Establish national strategy and priorities
Currently, Sweden has low impact on international standard	Strengthen the participation in the international standardization work and contact with ISO, CEN, IEC regarding nanotechnology
Standards including graphene and nanocellulose are handled in a variety of standardization committees without formal coordination	Increase coordination and cross learning between national standardization committees in SIS
Existing nanocellulose standards are mostly appropriate for crystalline nanocellulose	Stronger engagement in the ISO standardization for fibrillous nanocellulose
Many graphene standards are handled by IEC and thus nationally by SEK, not by ISO and SIS/TK516	Strengthen the contact and coordination between the national standardization bodies SIS and SEK regarding nanotechnology
Difficult to engage start-up companies, they do not have the resources to engage	Use the graphene pilot group as a model for future focussed discussions

Table 1. GAP-analysis of standardization regarding nanocellulose and graphene (source: report from previous project)

A clear example of how low or no engagement in standardization can end up favour the competition is the few standards that have been developed for nanocellulose. They primarily apply to crystalline nanocellulose. Swedish companies work mainly with fibrillar nanocellulose, which means that the standards cannot be applied to these materials. The implication is that Swedish innovations based on nanocellulose risk being outcompeted. Therefore, it is extremely important that the Swedish stakeholders engage in standardization of fibrillar nanocellulose.

National concern

New functional nanomaterials, such as graphene and other 2D material as well as nanocelluloses, are emerging as sustainable replacements of traditional petroleum-based materials due to their unique properties and performance. The use of these nanomaterials will promote the circular economy and will allow to advance towards a sustainable society. However, to promote the use of these materials and increase their presence in the market, standards are needed.

Standards will help to define the properties that are highly depending on their origin and processing and get a well-known material that will be used in advanced materials and products. In addition, we need to join efforts to ensure the safety of these new nanocellulose-based materials during their use, their processing and disposal/re-use/recycling.

International impact of national work

In Sweden, SIS (Swedish Institute for Standards) is responsible for facilitating Sweden's national and international standardization. SIS is a non-profit member organization and Sweden's representative in the international standardization organization ISO and the European equivalent CEN, figure 3. SEK, Svensk Elstandard, represents Sweden in the electro-technical standardization within IEC and Cenelec. In some cases, SIS and SEK cooperate closely. In Sweden, there are national committees for Nanotechnology at both SIS and at SEK. SIS works for increased Swedish influence in CEN and ISO and for best practice to be spread and applied in Sweden, and SEK does likewise for Cenelec and IEC.

Figure 3. The standardization map

Within SIS there are some 300 technical committees that work to develop standards in everything from screw sleeves, social responsibility, machine safety, the Internet of Things, to environmental impact and packaging. The SIS committee for Nanotechnology, SIS/TK 516, participates in the work of future standards, both globally and nationally. Nanomaterials provide the opportunity for improved material properties and new application areas. The purpose of standards for nanotechnology is, among other things, to facilitate introduction of nanomaterials in industry and to provide security and credibility so that nanotechnology does not cause new alarms of environmental risks or dangerous workplaces.

SIS/TK 516 is a participating member (P-member) in ISO/TC 229 which means that the committee actively votes and comments on standard proposals and participates in international meetings. This is facilitated by a SIS Project management team.

Work in progress

The standardization regarding nanotechnologies has so far resulted in standards for a long list of materials, not only for graphene and nanocellulose. As mentioned, the work is performed in different international bodies. The table in Annex 1 provides an overview of the most relevant published standards and ongoing work.

Experimental studies before standardization

The first stage of developing a new standard within ISO is that a new work item proposal is submitted to the committee for approval and comments. The committee then votes on the proposal, confirming that a new standard is needed and that the scope is relevant and correct.

However, experimental work has often been performed before the proposal is circulated for approval. In the case of high technology products this can be done within “The Versailles Project on Advanced Materials and Standards (VAMAS)”. It is therefore important to be involved already in this early experimental work to influence the content of coming standards.

Why bother?

Swedish stakeholders need to understand the value and benefits of working with standards. They need to realise that standards:

i) directly support the open, safe and responsible development and introduction of their productsand materials into commerce and consumer products

ii) help to describe and use the developed products by promoting a responsible and ethical product commercialization in the global marketplace

iii) serve to support market development, providing a basis for procurement materials’ specifications and repeatability, and for appropriate regulation

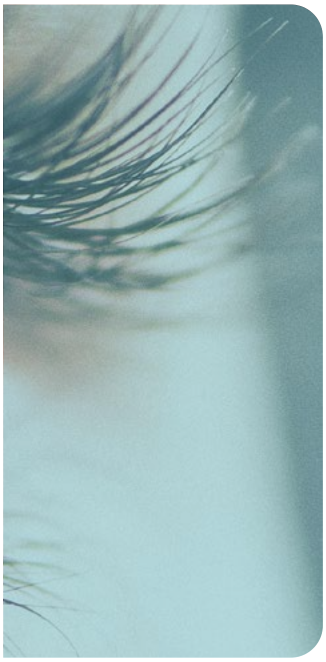
iv) allow sharing and better use of information for other reasons including consistency, interoperability, risk assessment, risk management, health and environmental safety and cost savings.

We can do better

In general, there is an interest from industry to get involved in standardization, but clear goals are needed. Due to lack of resources or time, small companies that produce nanocellulose do not consider themselves able to participate in the Swedish standardization work.

Collaboration with other countries is a prerequisite for an internationally viable system for characterizing advanced materials. In parallel with quality assurance and characterization, standards need to be developed to ensure reproducibility in manufacturing and comparisons between different suppliers and materials. Sweden needs to take an active part in this standardization work to be able to influence the development. For Sweden to have a strong position in international competition, there needs to be a well-functioning communication of standards within the national network. For maintaining the high ambitions of being one of the leading countries in the use of advanced materials, we need to establish national priorities for standardization, and characterization. With this project, the road is paved for a deeper engagement in standardization.

Highlight the work!



It was early in the project recognized that regarding nanocellulose, a stronger commitment is needed from Swedish and Nordic experts, as the existing standards still apply mostly to cellulose nanocrystals and not to cellulose nanofibrils that are the most produced in Nordic countries.

By joining the efforts developed in the different SIS committees, we need to be aware of what is going on in all the sectors where the materials are used. We need to get knowledge about the existing standards committees for nanocelluloses and their related work (international, regional, national and other standards developing organizations).

Standards are required for comparing different graphene materials and also to be able to have two different suppliers of the same material, which often is necessary. Since some of these standards already are under development, it is crucial that the Swedish perspective is included.

Generating awareness within industry, academia, government authorities and other sectors on the activities in standards development for nanocellulose materials is important. Priority should be addressed towards increasing the information of the need of using standards in universities. Students need to be aware of the importance of regulations and standards from the very beginning of their professional life. Universities are often the place where high tech startups are created, and early awareness of the value of standards should be emphasized in in the education.

Influencing the international standards development for nanocellulose and graphene is very important, to facilitate the commercial Swedish transactions. Therefore, the work of SIS should be more visible nationally and within the Nordic countries. This would increase the presence of experts in the SIS committees. It could also help to increase the awareness about standards within the market. Promoting international collaboration for developing sets of widely used and broadly supported international standards is key.

High tech startups often lack resources for this kind of work. Economic support could encourage engagement from SMEs in standards development.

Focused discussions

We started a working group focused on graphene within the technical committee for nanotechnology at SIS within the previous project. During this project we have continued to add more participants to the group and also started to work more closely.

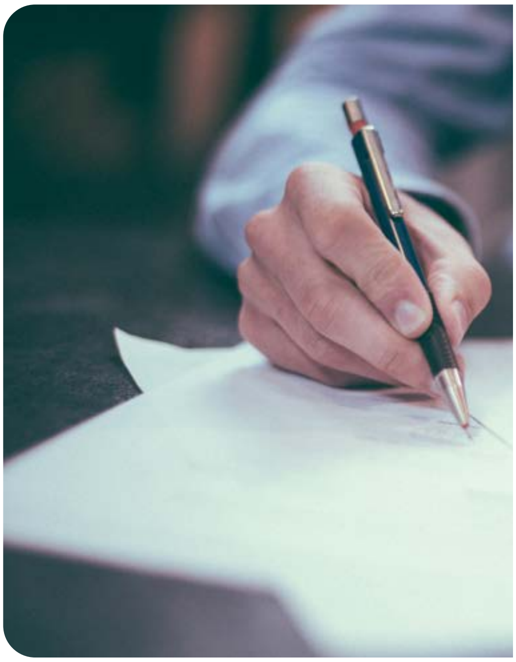
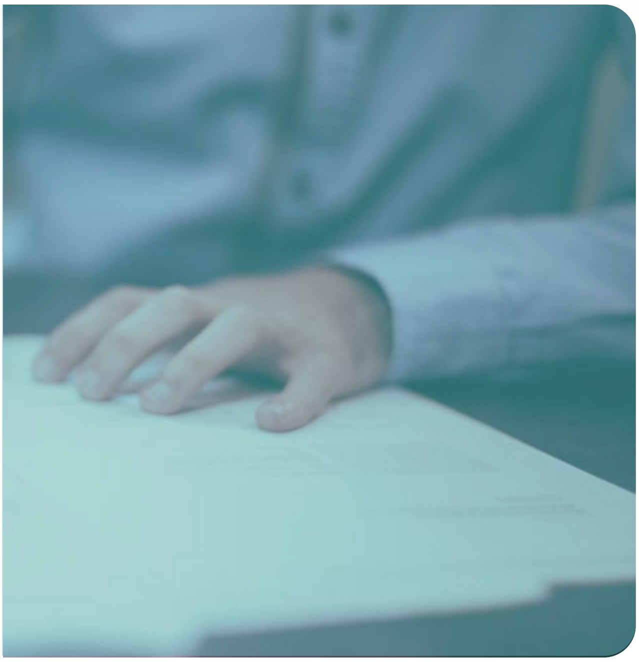
Before voting on the last few drafts, we have organised meetings where we discuss and formulate the Swedish standpoint. We have also discussed the priority and what we should focus on getting across at international working group meetings at ISO level.

We believe this is a good way of influencing coming standards.

As standardisation is built on international collaboration, it is also important to connect with groups and people in other countries. At least two Swedish organisations have therefore joined the Graphene Flagship standardisation committee during the project.

International impact

The workshop “From a Nordic point of view - Standardization of nanocellulose and graphene” showed a mutual interest in Nordic collaboration. However, there is still no collaboration with SEK, which would be important to set up as other important graphene-related standards are produced within IEC.

Recommendations

Swedish standardization work on nanotechnology has been going on for a couple of years, but there are still very few actors who actively participate in the work. To be able to influence the development, Sweden needs to take a more active part in international standardization work. Acting on standard proposals and developing own proposals for standardization documents should be of high priority. Moreover, it is important to create conditions for quality-assured production of graphene and nanocellulose in Sweden and the Nordic countries, thereby strengthening competitiveness on the international market. There is a need to create commitment and knowledge among the stakeholders, from academia to market.

A further ambition would be to facilitate for the users to find the right quality for a specific application. We therefore recommend strengthening the future work in the following aspects:

- Further increase the commitment to standardization in the entire value chain
- Substantially increase the contribution to, and involvement in, the international work by commenting on standardization proposals and creating standard proposals based on the national priorities
- Increase Sweden's impact on international standardization in ISO through increased collaboration with international bodies and within the Nordic region.
- Graphene, nanocellulose and other nanomaterials can be used as an additive in many other products. It is therefore important to set up collaborations with committees working on relevant standards where nanomaterials (including graphene) are used.
- Participating in the experimental work is crucial when it comes to influencing international standardization. Allocating funding for experimental activities regarding standardization should therefore be a priority for Swedish funding agencies.
- Nordic collaboration will multiply the impact when it comes to voting. We advise the standardization committees in the Nordic countries to establish common meetings for discussions on ISO proposals.

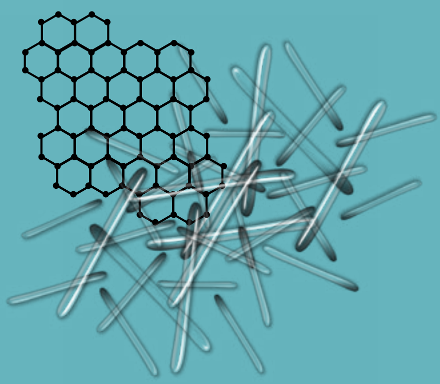
From now on

The work within SIS/TK 516 has been intensified during the last year. One reason might be that the entire business is coming of age, and to reach a higher level of maturity, there is an urge to go from lab scale to production, and hence to use scalable methods for quality assurance.

The project has brought positive effects that we did not envision in the beginning. The committee SIS/TK516 has grown, and new experts have joined the work. Added to that, SIS has opened solid discussions with other experts regarding joining the committee. During the project, a good relationship with the management of ISO/TC 229 has been created. Moreover, the positive response from experts for the potential strength in and benefits of standardization

The graphene and nanocellulose communities are committed to continue the work for a stronger impact on international standards. The need of joined efforts towards the development of cellulose nanofibrils standards to promote their use in the market. A first step will be a closer collaboration among experts of the different SIS committees to define priorities and define a common strategy to work together more effectively.

The work regarding graphene and related 2 D materials will continue through a new project. Building on the existing ISO work, we will explore the appropriate/applicable measurands for Swedish industry and academic partners working actively on graphene-based materials (producers, integrators, and end-users). The project will act as a catalyst for a long-term national commitment to standardization of graphene and other advanced materials. It has the potential to ensure the quality of Swedish-made graphene through increased use of standardized characterization methods, which is relevant for both manufacturers and customers. As Swedish graphene companies aim for an international market, it is important that Swedish expertise contributes to the development of international standardization so that national interests are not bypassed.



”International standards have the potential to remove trade barriers and also to harmonize research and development activities.”

- Åsalie Hartmanis, Project leader, Chalmers Industriteknik

Projektet är finansierat av Vinnova

Design and illustration: Astrid Hedenström
Photo: Filip Zrnzevic, Hans Reniers, Noah Buscher, Thomas Lefebvre/Unsplash, Nasa, Pexel, +Matton

Appendix 1

Standard documents ISO, CEN and IEC on nanucellulose and graphene. The links to the documents.

ISO/TC 229 – Nanotechnologies	
Published documents	
ISO/TR 19716:2016	Nanotechnologies — Characterization of cellulose nanocrystals
ISO/TS 20477:2017	Nanotechnologies — Standard terms and their definition for cellulose nanomaterial
ISO/TS 20477:2017	Nanotechnologies — Standard terms and their definition for cellulose nanomaterial
ISO/TS 21346:2021	Nanotechnologies — Characterization of individualized cellulose nanofibril samples
ISO/TS 23151:2021	Nanotechnologies — Particle size distribution for cellulose nanocrystals
ISO/TR 19733:2019	Nanotechnologies — Matrix of properties and measurement techniques for graphene and related two-dimensional (2D) materials
ISO/TS 21356-1:2021	Nanotechnologies — Structural characterization of graphene — Part 1: Graphene from powders and dispersions
ISO/TS 80004-13:2017	Nanotechnologies — Vocabulary — Part 13: Graphene and related two-dimensional (2D) materials

ISO/TC 229 – Nanotechnologies	
Documents in progress	
ISO/WD TS 23361	Nanotechnologies — Crystallinity of cellulose nanomaterials by powder X-ray diffraction (Ruland-Rietveld analysis)
ISO/AWI TS 21356-2	Nanotechnologies — Structural characterization of graphene — Part 2: Chemical vapour deposition (CVD) grown graphene
ISO/AWI TS 23359	Nanotechnologies — Chemical characterization of graphene in in powders and suspensions
IEC/CD 62565-3-1	Nanomanufacturing — Material specifications — Part 3-1: Graphene — Blank detail specification
ISO/AWI TS 80004-13	Nanotechnologies — Vocabulary — Part 13: Graphene and related two-dimensional (2D) materials

IEC/TC 113 Nanotechnology for electrotechnical products and systems	
Published documents	
IEC TS 62607-6-1:2020	Nanomanufacturing - Key control characteristics - Part 6-1: Graphene-based material - Volume resistivity: four probe method
IEC TS 62607-6-3:2020	Nanomanufacturing - Key control characteristics - Part 6-3: Graphene-based material - Domain size: substrate oxidation
IEC TS 62607-6-4:2016	Nanomanufacturing - Key control characteristics - Part 6-4: Graphene - Surface conductance measurement using resonant cavity
IEC TS 62607-6-6:2021	Nanomanufacturing - Key control characteristics - Part 6-6: Graphene - Strain uniformity: Raman spectroscopy
IEC TS 62607-6-10:2021	Nanomanufacturing - Key control characteristics - Part 6-10: Graphene-based material - Sheet resistance: Terahertz time-domain spectroscopy
IEC TS 62607-6-13:2020	Nanomanufacturing - Key control characteristics - Part 6-13: Graphene powder - Oxygen functional group content: Boehm titration method
IEC TS 62607-6-13:2020/ COR1:2020	Corrigendum 1 - Nanomanufacturing - Key control characteristics - Part 6-13: Graphene powder - Oxygen functional group content: Boehm titration method
IEC TS 62607-6-14:2020	Nanomanufacturing - Key control characteristics - Part 6-14: Graphene-based material - Defect level: Raman spectroscopy
IEC TS 62607-6-19:2021	Nanomanufacturing - Key control characteristics - Part 6-19: Graphene-based material - Elemental composition: CS analyser, ONH analyser
ISO TS 80004-13:2017	Nanotechnologies - Vocabulary - Part 13: Graphene and related two-dimensional (2D) materials

IEC/TC 113 Nanotechnology for electrotechnical products and systems	
Published documents	
PWI 113-93 ED1	IEC TS 62565-3-3: Nanomanufacturing - Material specifications - Part 3-3: Graphene-based material - Sectional blank detail specification: Monolayer graphene
PWI 113-95 ED1	IEC TS 62607-6-15: Nanomanufacturing – Key control characteristics – Part 6-15: Sample preparation for the reliability test of sheet resistance and contact resistance for graphene and two-dimensional materials
PWI 113-118	IEC TS 62607-6-23: Nanomanufacturing - Key control characteristics - Part 6-23: Graphene film - Sheet resistance, Carrier density, Carrier mobility: Hall bar
PWI 113-119	IEC TS 62607-6-24 Nanomanufacturing - Key control characteristics - Part 6-24: Graphene film - Number of layers: Optical contrast
PWI 113-131	IEC TS 62607-6-28 Nanomanufacturing - Key control characteristics - Part 6-28: Graphene-based material - Number of layers: Raman spectroscopy
PWI 113-133	IEC TS 62565-3-6 Nanomanufacturing – Material specification - Part 3-6 Graphene-based material - Blank detail specification: Graphene oxide

PNW TS 113-580 ED1	Nanomanufacturing - Key control characteristics - Part 6-29: Graphene-based materials - Defectiveness: Raman spectroscopy
PNW 113-598 ED1	IEC TS 62607-6-17: Nanomanufacturing - Key control characteristics - Part 6-17: Graphene-based materials and common carbon material - Order parameter: XRD and TE
IEC 62565-3-1 ED1	Nanomanufacturing - Material specifications - Part 3-1: Graphene - Blank detail specification
IEC TS 62565-3-2 ED1	Nanomanufacturing – Material specifications - Part 3-2: Graphene-based material - Sectional blank detail specification: graphene-based ink
IEC TS 62565-3-5 ED1	IEC TS 62565-3-5: Nanomanufacturing - Material specifications - Part 3-5: Graphene-based material - Sectional blank detail specification: Graphene powder and dispersion
IEC TS 62607-6-2 ED1	Nanomanufacturing - Key control characteristics - Part 6-2: Graphene-based material - Number of layers: atomic force microscopy, optical transmission, Raman spectroscopy
IEC TS 62607-6-4 ED2	Nanomanufacturing - Key control characteristics - Part 6-4: Graphene-based materials - Sheet resistance: Microwave resonant cavity
IEC TS 62607-6-5 ED1	Nanomanufacturing - Key control characteristics - Part 6-5: Graphene materials - Contact and sheet resistance: Transfer length method
IEC TS 62607-6-7 ED1	Nanomanufacturing – Key control characteristics – Part 6-7: Graphene based material – Sheet resistance: van der Pauw method
IEC TS 62607-6-8 ED1	Nanomanufacturing – Key control characteristics – Part 6-8: Graphene based material – Sheet resistance: In-line four-point probe
IEC TS 62607-6-9 ED1	Nanomanufacturing - Key control Characteristics - Part 6-9: Graphene-based material – Sheet resistance: Eddy current method
IEC TS 62607-6-11 ED1	Nanomanufacturing - Key control characteristics - Part 6-11: Graphene - Defect density: Raman spectroscopy
IEC TS 62607-6-12 ED1	Nanomanufacturing – Key Control Characteristics – Part 6-12: Graphene-based material – Number of layers: Raman spectroscopy, optical reflection</p>
IEC TS 62607-6-18 ED1	IEC TS 62607-6-18: Nanomanufacturing - Key control characteristics - Part 6-18: Graphene-based material - Functional groups: TGA-FTIR
IEC TS 62607-6-20 ED1	Nanomanufacturing - Key control characteristics - Part 6-20: Graphene-based material - Metallic impurity content: ICP-MS
IEC TS 62607-6-21 ED1	IEC TS 62607-6-21: Nanomanufacturing - Key control characteristics - Part 6-21: Graphene-based material - Elemental composition, C/O ratio: XPS
IEC TS 62607-6-22 ED1	IEC TS 62607-6-22: Nanomanufacturing - Key control characteristics - Part 6-22: Graphene-based materials - Ash content: Incineration
IEC TS 62876-3-1 ED1	Nanomanufacturing - Reliability assessment - Part 3.1: Graphene-based materials - Stability: Temperature and humidity test
IEC TS 62876-3-2 ED1	Nanomanufacturing – Reliability and durability assessment – Part 3-2: Graphene - Ellipsometry measurement of Graphene

CEN/TC 352 Nanotechnologies	
Published documents	
CEN ISO/TS 80004-13:2020	Nanotechnologies - Vocabulary - Part 13: Graphene and related two-dimensional (2D) materials (ISO/TS 80004-13:2017)

CEN/TC 352 Documents in progress	
FprCEN ISO/TS 21356-1(WI=00352056)	Nanotechnologies - Structural characterization of graphene - Part 1: Graphene from powders and dispersions (ISO/TS 21356-1:2021)
prCEN ISO/TS 80004-13 rev(WI=00352052)	Nanotechnologies - Vocabulary - Part 13: Graphene and related two-dimensional (2D) materials

Appendix 2

The following organizations/companies have participated in the workshops arranged in March, May and September 2021.

2D fab AB	Lunds Tekniska Högskola
Abalonyx	METSTA (Finnish Standards)
Applied Nano Surfaces	Mittuniversitetet
Bright Day Graphene AB	MoRe Research / RISE
Chalmers Industriteknik	Norsk Standard
Chalmers University of Technology	PIK Solutions
Finecell	Projekt tillväxt
FOI	RISE
Fonden West Pensionsstiftelse	SIO Grafen
Graphmatech	SIS
Göteborgs universitet	SSA AB
Hälsinglands utbildningsförbund	Stora Enso
ISO TC 229	SweNanoSafe
KTH	TestBed Nano u.b.
Karlsruher Institut für Technologie: KIT	Tetra Pak Packaging Solutions AB
LKAB	Vinnova
LTU