What does it take to successfully scale up a nanomaterial?

INDUSTRY INSIGHT

Sponsored by:

15 YEARS SINCE 2007
cerion nanomaterials
Custom Design & Manufacturing

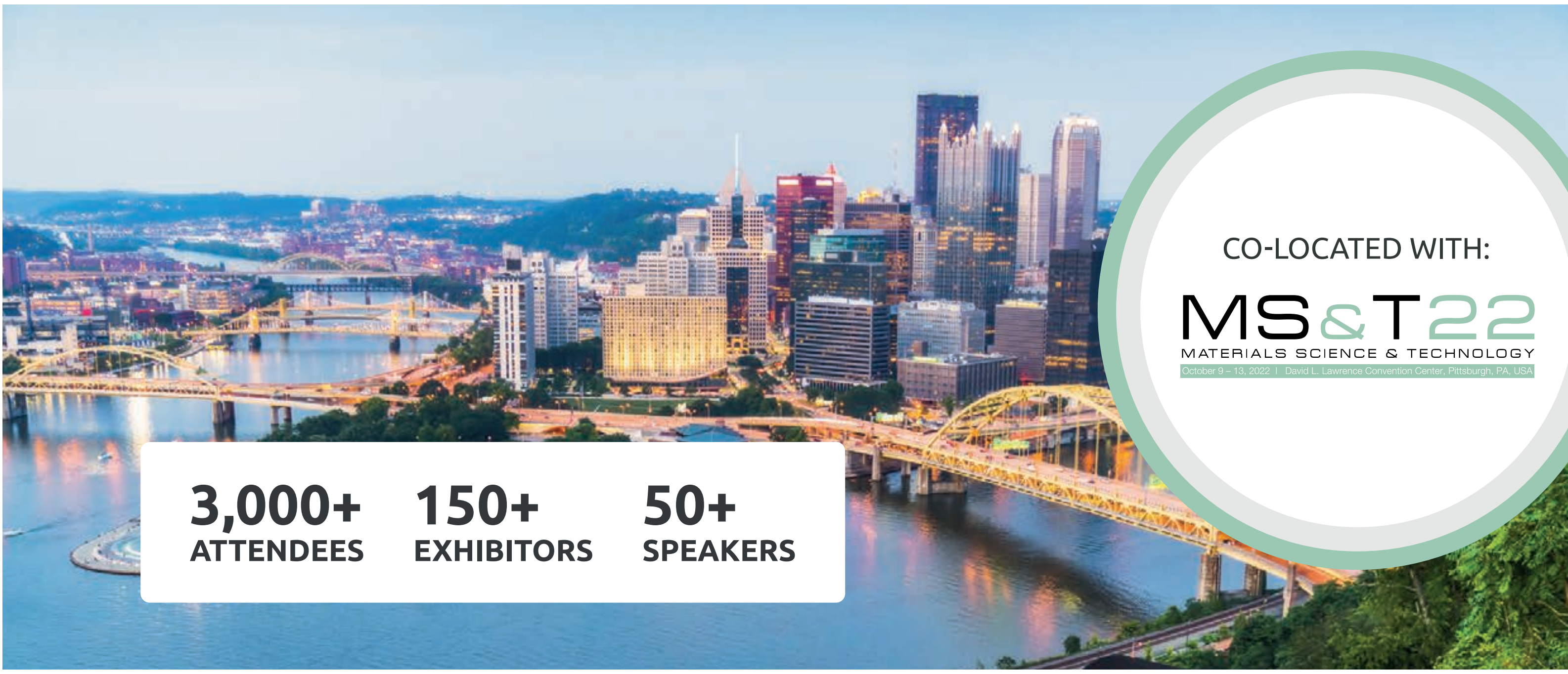
THE Advanced Materials SHOW | USA

THE NANOTECHNOLOGY SHOW

Contents

THE Advanced Materials SHOW | USA

THE NANOTECHNOLOGY SHOW



REGISTRATION IS OPEN

Join us at the world-class conference and exhibition this October in Pittsburgh

October 11 – 12, 2022
David L. Lawrence Convention Center, Pittsburgh, USA

Conference Highlights:

- Transforming Energy Storage with Innovative Materials
- Disruptive Nanoscale Device and Sensor Applications
- Advances in Protective Coatings for Industrial Applications
- The Technical Challenges of Scaling Up Manufacturing and Integration

And many more!

REGISTER FOR FREE

Organizing societies:

The American Ceramic Society

AIST ASSOCIATION FOR IRON & STEEL TECHNOLOGY

TMS The Minerals, Metals & Materials Society

www.advancedmaterialsshowusa.com | www.matscitech.org | www.nanotechnologyshow.com

What does it take to successfully scale up a nanomaterial?

We have spoken to established leaders at every level of the nanomaterials industry to find out their ideas on the challenges facing end users and manufacturers alike when it comes to scaling up a novel nanomaterial. This report introduces the key barriers that remain to widespread nanomaterial uptake and provides suggestions for how to overcome them in order to harness the possibilities of this remarkable technology.

Landon Mertz, CEO, **Cerion Nanomaterials**

Doug Singer, Executive Vice President - Manufacturing, **Cerion Nanomaterials**

Mano Manoharan, Chief Technologist - Materials Industrialization, **GE Aviation**

Chiara Venturini, Director General, **The Nanotechnology Industries Association**

Leroy Magwood, CTO, **XG Sciences**

Terrance Barkan, Executive Director, **The Graphene Council**

Manipulating materials at 1 billionth of a meter…

The minute scale of nanotechnology and nanomaterials can be hard to fathom. 1 nanometer (nm) is 1 billionth of a meter, or 0.00000004 of an inch - a single strand of human hair is between 80,000 and 100,000 nm. The fact that such a scale exists and that useful activity can be done at that level is not a new concept, but it's certainly a mind-blowing one for many of us.

As neatly described by Gabriel Silva in Forbes in 2021: "Nanotechnology is an interdisciplinary area of science and engineering that focuses on technologies and methods capable of manipulating and controlling materials and devices at a molecular scale using physical or chemical methods, or both. Typically, this takes place within a range of about 1–100 nanometers (nm)."

Given these complexities of scale you can rest assured that the smartest brains on the planet are attempting the mastery of nanomaterials. Nevertheless, even those scientists at the cutting edge of this most exciting of technological frontiers would likely be candid about the struggles in one particular area for nanomaterials - scale-up.

Industry-wide, the results of endeavors to scale up nanomaterials have been mixed. Few companies have mastered the art of scale-up when it comes to taking a novel nanomaterial that can be produced at scale - and that is broadly accepted by manufacturers, end users, governments and the wider public as a safe, economical and useful new nanomaterial. Why?

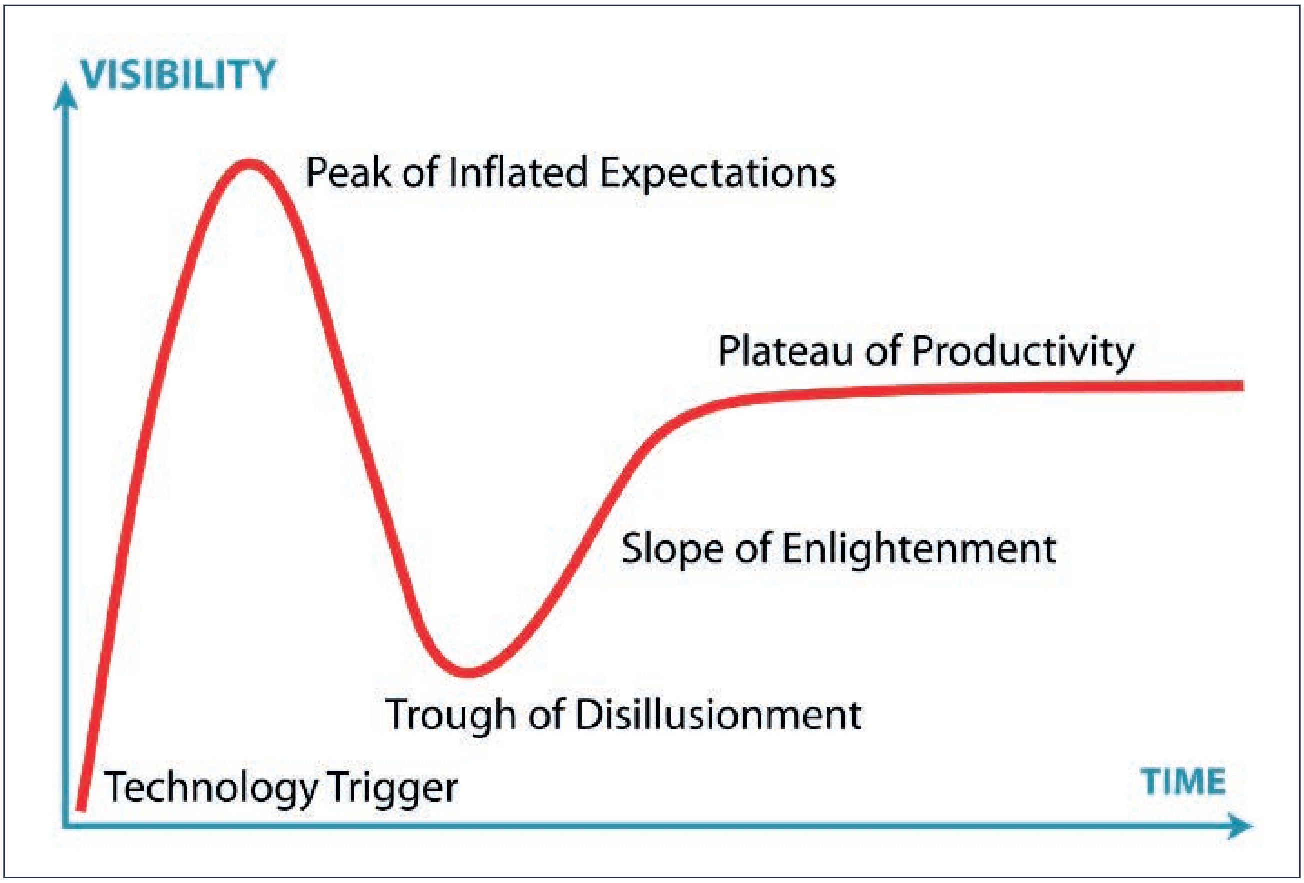
This report seeks to outline first the technical challenges in nanomaterials scale-up, followed by the commercial barriers to growth, before outlining some key considerations that will enable both users and manufacturers of nanomaterials to maximize this exciting technology faster, more economically and with optimal performance results. But first…

Why is scaling up nanomaterials so crucial?

Delivering commercially applicable nanotechnology and nanomaterials could transform multiple bedrocks of our society; teasing the possibility of low-cost clean water, lighter-weight and better performing materials, cleaner energy production, novel biomedical applications, superior pharmaceutical performance, and that's just the tip of the iceberg for the social and environmental benefits.

From a commercial perspective the impact could be equally as transformative, though exactly what the market size will be is somewhat unclear. There are complexities in the classification of nanotechnology that have inspired some wildly varied numbers when looking at growth forecasts. It is safe to say that the outlook appears very positive. With predicted growth ranging between Allied Market Research's predictions of "$1.76 billion in 2020…reaching $33.63 billion by 2030, with a CAGR of 36.4% from 2021 to 2030", and several reports - including one from the EU Commission - that claim a forecast of more than one trillion dollars in the coming decade, whichever side of this fence you sit on, this is an exciting industry to be in.

Nonetheless, despite the promising signs for the technology and its users, this predicted market growth will not be evenly spread unless some fundamental changes are made to business, innovation and market strategies. Many nanomaterials companies currently fail in the 'Valley-of-Death' between concept, scale-up and commercial application. To uncover the reasons behind this we spoke to industry leaders at all levels of the value chain to better understand the challenges, considerations and the opportunities facing those hoping to develop and commercialize nanomaterials.



The ‘Gartner Hype Cycle’ is a commonly used tool that in very simple terms, tracks where novel technologies sit on a common pathway to success - passing through the ‘Peak of Inflated Expectations and the ‘Trough of Disillusionment’ en route to the ‘Slope of Enlightenment’ and finally the ‘Plateau of Productivity’ where a mature industry has widespread commercial uptake and acceptance. The first two milestones will be familiar to many nanomaterials producers and users but there are signs that the sector is on the ‘Slope of Enlightenment’. According to Terrance Barkan, Executive Director at The Graphene Council, “with any new technology there will be an adoption curve and from a producer perspective, there is a need to mitigate their risk by not overly investing in capacity until there’s proven demand”, something of a ‘chicken and egg’ scenario and a challenging one for SME innovators and the wider industry as it pushes for wider uptake.

Arguably for many breakthrough industries, the spark of one stand out success, is what is needed to light the touchpaper. Mano Manoharan, Chief Technologist - Industrialization at GE Aviation agrees that **“Whereas there have been successes on smaller scale projects, you need breakthrough products that make it on a large scale, to enable others to follow their path”.** In fact, long-established nanomaterials are already widely being used in fields such as coatings, antibacterial clothing, cosmetics, food and more. Mano points out that ‘when we currently use nanomaterials, they are often not being advertised’ as there is a level of acceptance. However, for those developing new nanomaterials, the path to commercial application and large-scale uptake is not so clear and the barriers to their use are complex.

Why do nanomaterial-enabled products fail?

Landon Mertz is CEO at Cerion Nanomaterials, a company with 15 years of experience in developing custom nanomaterials for mid and large-cap companies. The company focuses on enabling product development and commercialization teams to overcome the ‘Valley-of-Death’ between concept and commercialization. In discussing the root causes of failure Landon points out that the fundamental issue is **“for customers to achieve the subtle balance between nanomaterial design criteria, preserving it during manufacturing scale-up, and successfully integrating the nanomaterial into their product - all the while doing it cost effectively.”**

If these technical and commercial vectors are the biggest challenges facing nanomaterials suppliers across the board, what is the solution? Nanomaterials are highly complex and require careful management to ensure that they are designed, manufactured, integrated and utilized correctly, especially in the move between lab scale to pilot productions and eventually manufacturing scale. After discussion with multiple industry leaders, it appears that there are several technical and market-led drivers that need to be addressed by each prospective nanomaterial developer to ensure their own product success in this hugely promising market.

Overcoming the Technical Challenges in Nanotechnology Scale-Up

“If I build it, will they come?”

One of the most common commercial mistakes made in the development of new products in any industry is to allow the business to be led only by innovation rather than demand. As Chiara Venturini, Director General at the Nanotechnologies Association puts it, “we end up with a solution that doesn’t have a problem”. This is particularly true in a field like nanomaterials where the scope and therefore temptation for further development and innovation is vast, as the famed and overused expression from Richard Feynman goes “There’s plenty of room at the bottom”. It seems like new materials, processes and properties are being discovered in university labs across the globe on an almost weekly basis. However, whilst they may be inarguably exciting at a scientific level, these discoveries may not all have an equally exciting commercial outlook and this is leading to a mismatch in the market.

A parallel and connected contributor to this imbalance in the innovation ecosystem is the low barrier to entry for nanomaterials designers. As Leroy Magwood, CTO at XG Sciences points out, “two people in a lab can make a nanomaterial without any idea how to scale it”. For comparison, for anyone trying to commercialize a battery cell or a semiconductor would require funding well into the billions of dollars - as a result, few people would think to start trying without confirming a commensurate level of demand for the end product. The result is that on the one hand, thousands of very bright minds are applying themselves to developing exciting and potentially game-changing nanomaterials. The downside is that some of these materials are being developed without a defined need in mind.

THE Advanced Materials SHOW | USA
THE NANOTECHNOLOGY SHOW
FREE CONFERENCE
Disruptive Nanoscale Device and Sensor Applications
Register now

Doug Singer, EVP Manufacturing at Cerion Nanomaterials goes a little further in explaining the disconnect: "How do we get a material designer to consider the application? They are often focused on features at any cost - the newest investigation, the newest nanoparticle and the best invention they can make in the lab - but what if they don't have that evaluated by commercial, production and engineering managers. Developers need to invest in production evaluation. Put the same assets and resources into the research, the manufacturability and application evaluation simultaneously". This kind of business-centered approach (understandably) doesn't always come naturally to those who are focused on getting the best out of their product on a scientific level, but it is essential to the product's future success.

As Landon explains, "designing without an application in mind "isn't an intentional business model, but something that often just happens when innovation occurs without understanding commercial needs and requirements from the market, or, simply put 'If I build it they will come'". This thinking is often based on a hope that if a materials designer makes something amazing, that a customer will be found, which is of course entirely possible, but this is unlikely to be the best way to guarantee it will happen.

Some have pointed out that this challenge may have been exacerbated by "today's more complex market landscape"; Mano suggests that, "in the traditional models, you based your product on customer needs, but the new, more complex product landscape means you still have to define the need, but you may not be able to achieve the exact design that the customer has asked for, so you can say - 'we can get this aspect, we can't get that aspect but this is my suggested workaround' - the key to success here is to have product development, design and manufacturing work together with continuous lines of communication". This is the first mention of the importance of communication to the process of commercializing nanomaterials, it will not be the last in this report!

Designing for success - define your value proposition from the start

In order to target the ideal market for a product, producers need to interrogate product ideas from a commercial perspective, before scientific results are considered. For example, If a producer develops a nanomaterial, nothing fails in the R&D phase and it results in an ideal product - who are the customers, what is their need, what are their economic constraints, what is the growth in that sector, are they investing, is this a pain point and above all else - will this product solve a problem for end users in such a transformative way that it will be an easy decision for them to take the risk on partnering with a new supplier and product?

Even if a producer is too late to do this and is already in the process of designing a material without proven demand, Mano has some constructive advice, "Try to think 'what is the purpose of your design?' Then you can come back to your materials and look for specific characteristics. People buy products, not nanomaterials, so what product are you making better with your nanomaterial? You need to define the value proposition". This brings us to the meeting point between commercial and scientific ambitions; to deliver a winning value proposition, developers must have absolute clarity on the pain points that their product is solving, be they performance, economic, security of supply, longevity of product, ESG targets or something else. Mano is clear on this, "you need to define a value proposition first. If I was to sell to the aerospace industry, the standards and the scales are high and you need very high quality materials, but the value proposition is better as the end user can afford the materials in the first place". Conversely, for some easily designed and manufactured materials, high volumes and low margins make sense, for example, in applications like cement or packaging. Mano concludes that 'there is a lot of talk about what the material can do, but you must be able to crisply identify the product you want to fix, what is the value proposition and whether it is disruptive enough for someone to introduce it into the system - then the scale will be less of an issue". Every leader we spoke to reaffirmed that the key is to follow the path from your customer point of view, understanding what their challenges are and addressing them with a product. However, finding out what the end user pain points are can be a barrier in itself, more on that later.

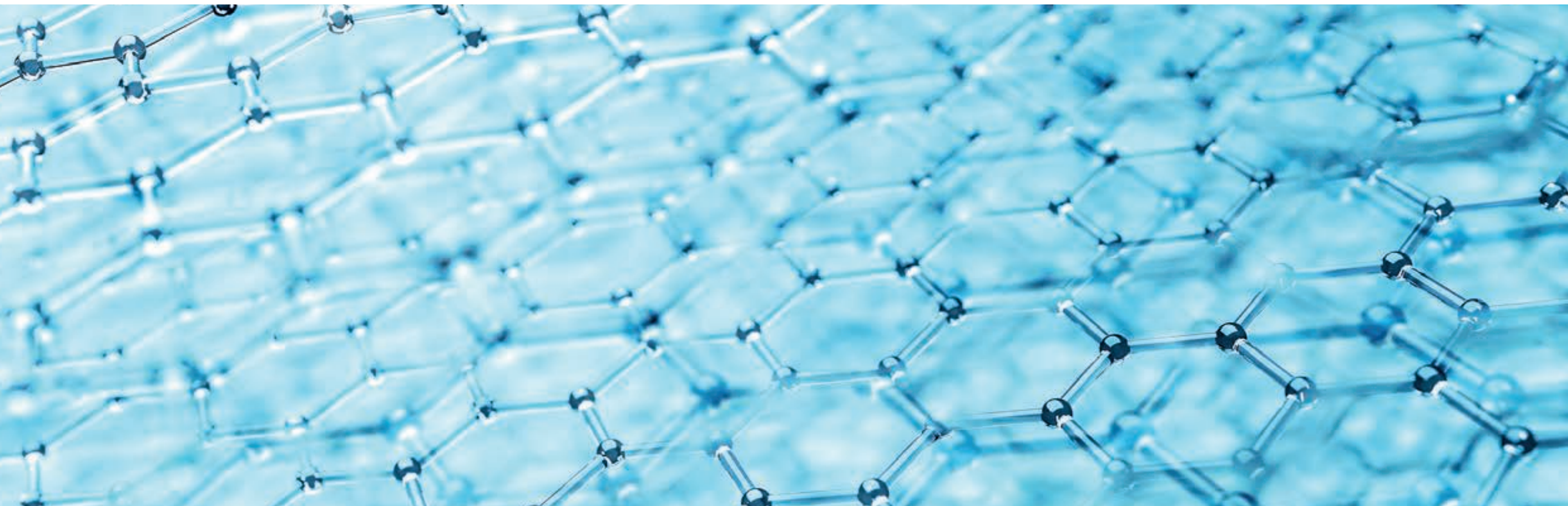
Considerations for manufacturing at scale

The process-based challenges in scaling up the manufacture of a nanomaterial are myriad but perhaps the most common challenge is that just because you can make one tiny batch of the perfect nanoproduct, doesn't mean you can automatically make 100,000 identical batches or indeed that you can scale the process to make one batch that is 100,000 times greater in volume.

LAB TO PILOT TO PRODUCTION LINE AND DESIGNING FOR MANUFACTURE

To understand the point here you need to be thinking about what changes between a tiny lab scale production, to a pilot scale, to full commercial scale production line. As Mano highlights, "Anyone can make anything in the lab, so if you can make 1lb of something you can probably make 10lbs, but you may not be able to make 100lbs or 1000lbs. Leroy uses the example of making a drink at a party, "if you are making someone a drink, no problem - then someone asks you to make a gallon of that same drink, you probably just get a bucket, but ask me for 1000 or 10,000 gallons and the strategy has to change". Mano expands on this metaphor, "think of particle size distribution, 50 gallons made in individual batches will have a different make up in each one versus one large batch of 50 gallons. What you are testing from one batch is not going to represent what you are actually making." This type of thinking is crucial when scaling up from lab scale to full volumes of commercial production.

Part of the solution to this issue is to focus carefully on designing a material for manufacturing from the beginning. "Some processes work very well at the lab scale stage" Landon says, "but are either impractical, cost prohibitive or impossible to achieve at larger scales. We see this all too often from customers who are looking to scale-up a nanomaterial made in-house. The issues are numerous and include feedstocks that are in low supply or uneconomical, processing steps that can't be replicated with industrial equipment or require new invention and finally expectations on cost that are inconsistent with the reality of the synthetic pathway they chose to make the nanomaterial. Commercializing requires a whole of company approach that needs to start from the beginning of a program and has to encompass scientific, engineering and business functions to be successful. On-going planning, evaluation and clear-eyed risk prevention measures can avoid years of frustrated efforts and the loss of a significant investment. But you need experienced people who do this regularly to avoid the common pitfalls, and most companies working with nanomaterials don't have this in-house."



MANAGING YOUR EQUIPMENT NEEDS

If a product requires new manufacturing production lines for a client, they will have to think very carefully about how much this product will be worth to them in order to make the investment and risk worth it. “You also have to get new equipment, so you have to ask the question, how much of the existing equipment can you use?” says Mano, ”for example, if you are just replacing an early stage part of the equipment you are more likely to find success. If you need to build a whole new value stream, the task and the cost become limiting factors”. Complexities of scale like this need to be established to understand the feasibility of production at every stage as every material that you make will need a pilot plant, and the funding to make a pilot plant, followed by the same for full scale production.

"One also has to consider all of the cost and risks associated with going it alone," says Mertz. "Most companies are experts in their industry, their products and their customers. If nanomaterials are not core to their business, but are an important component of their new product, they should carefully consider whether developing that nanomaterial competency in-house fits within their product development roadmap and budget. Often it does not, and yet many companies do at least attempt initially to go down this road. This is where specialists with commercial nanomaterial manufacturing experience shine best - delivering faster and at a lower total cost of investment and with substantially less risk than the in-house alternatives".

CONTINUOUS OR BATCH PRODUCTION - A CHALLENGE THAT HAS DIVIDED EXPERTS

A consistent discussion within the nanomaterials community is focused on the viability of continuous versus discrete batch production in producing consistent, high performing materials at scale. Chiara acknowledges, there isn’t complete consensus within the sector: “Members in the association are divided, some want to go with continuous and some want to do batch - for some materials it might be easier to replicate to get to continuous than for others, there isn’t a unified position on this. Also, in practical terms, nanomaterials are very small, you normally only need to produce small quantities as the customer is only going to request a certain amount”. So do we really need continuous production when the quantities are at such a tiny scale? The impact of this conversation on scale-up comes through the ability to make consistent products that are replicable and that will perform identically when divided into batches, another risk for product failure.

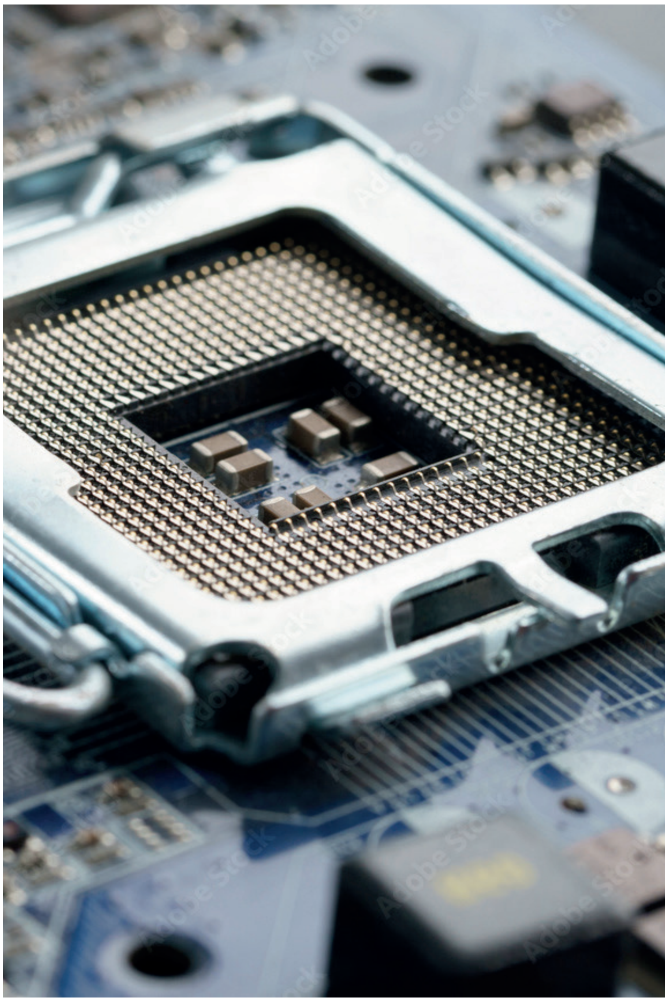
Landon adds, “The majority of the nanomaterials market runs on batch processes. When done correctly, it is very cost efficient. Fundamentally our customers require high degrees of material customization and have different production volume requirements. This is what batch processes were made for. Continuous on the other hand is best suited to manufacturing a single material in high volume, reliably. This approach is simply incongruent with the current and future needs of the market. A close analog to nanomaterials manufacturing would be pharmaceuticals. This industry primarily uses batch manufacturing, where demand and customization are similar to our industry. Continuous has been touted for decades as having the potential of delivering cost savings, and yet today, only four out of over 19,000 drugs on the market leverage these processes."

There are many challenges that face a company in the physical endeavor of scaling up their materials manufacturing, but arguably, these issues are all surmountable and more importantly, they are almost all uniquely within the developer’s power to overcome. The same cannot be said of the next, and most prominent cause of product failures and nanomaterial reputational losses. Integration.

Integration, Integration, Integration!

If there is one factor that might rise above all others under discussion when it comes to defining the fortunes of a commercially viable product or a confusing failure, it is how the nanomaterial is integrated into a product. This is more often than not where product challenges can occur and inhibit the performance benefits provided by the nanomaterial. However, it isn't always that the nanomaterial is faulty or doesn't 'work'. Landon at Cerion Nanomaterials suggests that "50% of our work is designing the material required by the customer, the other 50% is helping customers get the material into their system while preserving its performance attributes. We always tell our customers that the more transparent you can be about what you're doing with this material, we can design around potential pitfalls. For example, if the material is going into a coating that will be heat treated at 500°C - nanoparticles will aggregate and grow to larger sizes, impacting their performance. So, what can we do? Depending on the customer's needs, we might add a growth inhibitor or use a surface treatment that doesn't burn off until high temperatures – thus preventing or lessening particle growth. These issues can be solved but only if the potential for an issue is known, communicated and then accommodated."

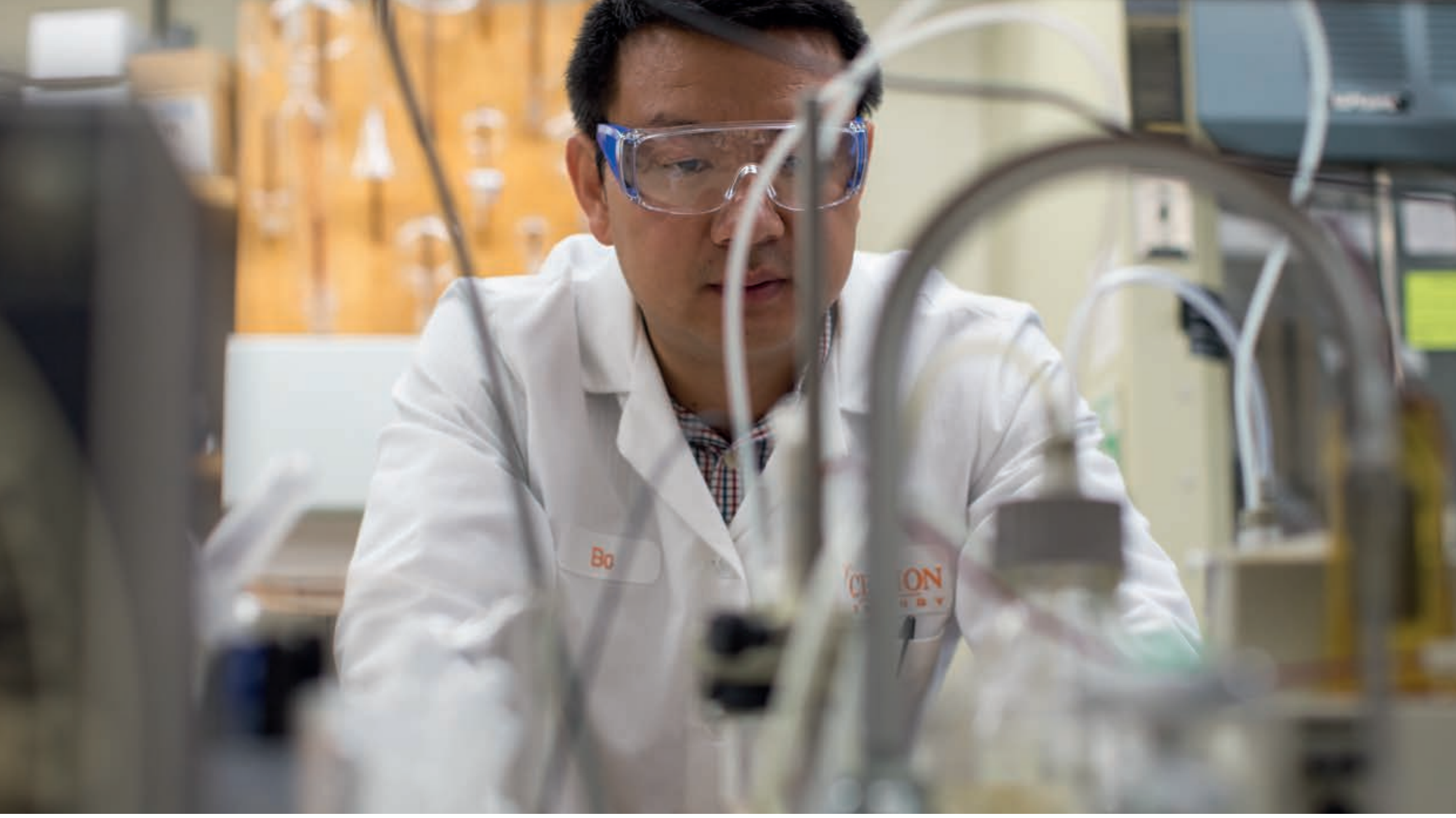
On the other side of the fence, if a nanomaterial developer isn't explicit about the optimal conditions for delivering the promised material performance, and the processes required to achieve this, then the material is often doomed to fail for the same reasons - good and transparent communication is crucial in both directions. In multiple cases over the past few decades, large-scale first movers have attempted to use a new nanomaterial, invested millions of dollars to get to 'tiny batches' and then after that experience, don't want to go through the process again. Landon backs this view: "We find that larger companies who are successful in their industry understand that nano is not their area of expertise, so do not see the value in taking the risk of investing in an in-house solution. They'll go out of house. Conversely, smaller to medium sized companies can be so set on capturing every cent in their market that they miss chances to collaborate with vertically integrated partners that could allow them to get to market faster and at lower cost".



Moreover, according to Leroy, "A lot of nanomaterials companies work on the concept of multiplicity, they work with lots of small samples, then batch them together and send to a client, the customer is happy but then the customer wants to get that larger scale in one go and the process goes wrong. Your final product is so small that the tiniest defects wouldn't matter with multiplicity, but when you try and scale up in one batch things go wrong."

UNDERSTANDING WHEN AND WHERE THE FAILURE IN INTEGRATION TAKES PLACE:

A less understood issue with nanomaterials integration is whether nanomaterials are being used in the right applications for their specific properties. Leroy argues that "integration needs a technology change - integration now is taking materials with a high failure rate, and placing a nanomaterial into a product that has a high failure rate, like a plastic bottle. The system you are placing the nanomaterial into is old and the defects are there already, we need to integrate the nanomaterials at an earlier stage of the process. Just putting graphene in when the bottle that is already defect ridden doesn't improve the overall system and it is up to the customer to determine if a marginal improvement warrants the cost. The dispersion of graphene needs to start at a position in the value chain where its implementation can yield a solution to the problems of a conventional material or system". This is just the highlights of what can cause product failure for a nanomaterial. However, even if you get the product right, and arguably many nanomaterials producers have matured and can deliver a valuable product at reasonable volumes, there is another large barrier preventing their use even when they do work, and that is a lack of trust from end users.



Hurdling the Commercial and Market-Led Barriers

Considerations for manufacturing at scale

One of the least understood elements of nanomaterials is their environmental impacts and health concerns - real or perceived. Whether it's in their fabrication, handling or in the end use application, and particularly when it is destined for a consumer product, the levels of nervousness are high, but is this warranted? For manufacturers and regulators alike the challenges are complex. As Leroy puts it, "Regulatory hurdles are the elephant in the room" - on top of trying to successfully deliver a material that performs as expected, "how can you then navigate the regulation space with so many jurisdictions, it becomes even muddier as to what you can actually achieve". It seems there isn't a linear path towards a system of guidance for such a wide-ranging technology that could combine with almost any industry, sector, product or system - each with their own regulatory frameworks.

According to Chiara "part of this is a teething problem, some of these materials are very new, their chemical and physical properties are new, especially in jurisdictions like the EU which tend to take a precautionary principle approach, you can't simply roll them out to the market. We need to be sure that they are safely made, used and disposed of". Moreover, how these materials are made, what they are made from, and how they are used can present such varied complexities as to make the potential variables almost infinite and any cohesive strategy for regulating them challenging in the extreme.

One of the key concerns is defining what the material is that you are trying to regulate, should a mined and milled graphene be considered in the same way as one that has been chemically produced? Do graphene platelets fall into the same category as graphene oxide? Some have argued that existing chemical regulations could be extended to incorporate much of the nanomaterial space but when you consider, for example, that nanogold is 100x more conductive than normal gold this also doesn't quite fit.

Despite these challenges, there is willingness on all sides to find a route forward and outlining a road map towards a stable regulatory landscape that encourages safe innovation is crucial. According to Chiara, "The industry needs a predictable regulatory environment because the time and investment required to get, for example, a semiconductor from lab to market can be 10-15 years, so working with regulations that have been around for some time makes this a lot easier. Industry operators do want to comply, they just want to understand their requirements". Landon suggests that the issue has been potentially overemphasized anyway, "The fear at times is greater than reality. From a handling perspective, dispersions are generally very safe to work with, and while powders run an inhalation risk, one must remember that nanoparticles in powder form agglomerate

In essence, for all products, at the nanoscale or otherwise, there is an equation that is needed to balance the risk and reward for each product. As Leroy suggests "it might mean that reaching the tipping point where a nanomaterial becomes essential before people will accept the risk of nano over the positives of the absolute need for energy. In much the same way as these equations are done today on the use of oil and gas, or bleach in your home". There are known risks, but the rewards outweigh these to enable the product to hurdle the potential regulatory barriers.

Reaching market acceptance

One of the key barriers to the long-term success of a new product is the amount of time it takes to reach commercially sustaining volumes of demand from a large scale, flagship customer. Terrance feels that bluechip companies are by nature cautious and that "from the demand side of the equation, especially with large scale customers, there is an adoption and trial period. Large companies, which are often very risk averse, require new materials to go through a trial and testing period to validate the efficacy of the material before they would introduce it on any large scale into any of their product lines". This means testing, and lots of it, trial runs, and data analysis; especially for those industries focused on safety such as food production, aerospace or pharmaceuticals. During this lull period, smaller businesses can flounder between product design success and actually getting it into an application.

One factor that is rarely spoken about is the idea of 'planned obsolescence'. This phrase is something of a dirty term and often left unspoken but it is very much a present phenomenon in the modern world; nanomaterials have the capacity to double the lifecycle of a road tire for example, and that can significantly reduce the market for road tires. In the end the sheer performance levels of nanomaterials could be argued to be too good for industry needs for profitability. It should be noted that the EU for example, has been looking at this topic and exploring ways of tackling planned obsolescence so the impact of this factor might be reduced by policy or regulatory action in the coming years.

A further potential barrier to market acceptance is the hegemony that typically characterizes established industries like the materials sector. The global players who currently dominate materials manufacturing are making incremental improvements all the time but can be resistant to order of magnitude change for fear of cannibalizing their own market. Those who want to become new market leaders must lean forward and deliver a paradigm change that benefits society. Terrance Barkan points to the obvious example of "Tesla wasn't a traditional car company. They all tried EVs, but it took an innovator to come from the outside and turn the market upside down. And that's typically the case in many new markets. We think with new materials, it's going to be those companies that really want to take a leadership position or a disruptor position because the improvements are so significant." So we may just be waiting for Elon Musk to buy a graphene company, stranger things have happened!

Building trust through evaluation and characterization

When evaluating a nanomaterial producer as an end user it can be hard to discern between those with an exciting but ultimately untested product or process, and those who can deliver. As partners to both materials users and makers, Cerion Nanomaterials are well placed to comment on this and their EVP of Manufacturing, Doug Singer had a few pointers as to what to look for in a potential partner:

- How many years have they been around?
- Are they profitable?
- What's the biggest batch size they are making?
- Do they have experienced teams solely dedicated to scale-up and manufacturing?
- Do they have the necessary dedicated teams and infrastructure for core commercialization functions? These include research, development, engineering, quality assurance, quality control, characterization, manufacturing, shipping & logistics, regulatory as well as financial planning & analysis.

Another tool that helps to instill trust and confidence in the manufactured nanomaterial is quality systems. Establishing quality assurance parameters for raw materials, automating and tightly controlling manufacturing processes, confirming those processes with in-line measurements and having well-grounded release specifications are absolutely critical to successful nanomaterial commercialization.

Landon expands on this idea: "A lot of nanomaterial companies go out-of-house for characterization expertise, which presents time, cost and quality challenges. We've seen first-hand how both technicians and equipment brands can generate variability in the data. While not the most exciting area of our business, we have invested millions to bring characterization in-house. This lets us iterate faster and cheaper during the design of the nanomaterial, and provide customers surety that the nanomaterial we made in the lab is exactly the same when it rolls off the manufacturing floor."

Assessing the interactions and behavior of a material's foundations provides key information that end users require to ascertain whether the material meets requirements. The challenge here can be that laboratory-centered characterization techniques are myriad and depend on the type of material, the end application, the properties and characteristics required, and the need for a destructive or non-destructive method, so consistency of approach by both the end user and the producer is the only way that they will achieve the same results. Using different laboratories, methods, or analysis could provide confusing and conflicting insights. Moreover, testing in this manner requires very expensive and hard to access equipment which is not always possible to get as regularly as might be needed. But getting this process right can be the difference between a successful and timely product delivery or being left with timing, performance or cost issues.

Is there really 'no such thing as bad publicity'?

Everyone we spoke to agreed on the challenge of communications , at all levels. There is a general hesitation by the consumer, partially driven by early scientific studies and regulators who are keen to get out in front of health, safety and environment risks – whether real or perceived. This can be coupled with early adopters, users who didn't have success using nanomaterials or makers touting benefits that did not match reality.

"A big issue is that communicating the functionality of the product doesn't always go smoothly" Chiara agrees. "A couple of decades ago, nanomaterials were coming from universities - academic backgrounds - and they haven't necessarily taken the business angle when looking at a material and a specific application". This fits in with the 'Trough of Disillusionment' status that was mentioned at the start of this report, but these events are a decade or two old and there are signs that the industry itself is getting closer to maturity.

Terrance Barkan feels that "the technical aspect for graphene at least, has been largely addressed. That doesn't mean it's static but the first R & D threshold of 'does graphene work and does it make a marked improvement of performance' has been answered. We know across all these industries, we have enough data. We have enough proof of concept. We have enough demo products that we know that it works." However, he is not so confident that this step change has yet taken root amongst end users. "It's past the phase where we know that it works. The next stage is adoption - and this is where I would say one of the biggest obstacles is companies that tried graphene in the past. They think it doesn't work, you can't get enough of it or it's too expensive, and this is outdated and no longer true". So how can companies overcome this perception from end users and get their products in front of the right people and taken seriously?

Our next and final section will outline industry-wide movements that would underline and support companies in establishing themselves as serious suppliers and thereby buttressing the reputation of nanomaterials generally in the market.

Paving the Way for Future Scale-Up Success

Inspiring productive investment ecosystems

Establishing a healthy and successful investment ecosystem would allow companies to access the funding they need to take proven pilots to the next level. Both Leroy in the US and Chiara in Europe pointed to the lack of middle stage investment to help those who are ready to scale but can't fund themselves at that level. As Chiara says, "There is a general scale-up challenge in Europe in terms of bringing successful technology to market. The ecosystem is not always supportive of start-ups. There is funding and access to research infrastructure, but accessing the infrastructure can be very difficult from a bureaucratic point of view". Mano agrees, "Government support here is key, how do you set up policy that will help the middle scale innovation? There's a lot of funding for early stage development, but how do you put in policy incentives that help the manufacturability and the middle stage of the R&D process"

Landon adds, "The challenge in the United States is that government nanomaterial investment happens at the basic and applied research level. Policymakers assume the capital markets have a profit incentive to take the risk on commercialization. However, all industries compete for capital from the private markets. With internet utilities, IoT devices, SaaS and Artificial Intelligence - the lower risk, reasonable returns and short time horizons are attractive. It takes smart money to recognize that materials innovation provides sticky revenues, impressive year-over-year growth, outsized margins and very attractive internal rates of return – but over a longer time horizon."

Unlike its western counterparts, countries such as China and Russia have recognized this gap in the capital markets and have intervened in their domestic industrial base to bridge the gap. Tens of billions of expenditures have flowed from national and provincial governments directly into nanomaterial companies for the express purpose of enabling commercialization. This government intervention in to the free market has created a competitive disadvantage for western nanomaterial users and makers, and only a change in government policy can counterbalance these risks. Western policymakers must ask themselves, as Landon states, "What if the US or EU does not dominate and have first mover advantage in a general purpose technology such as nanomaterials? What will be the first, second and third order impacts to their economies, defense posture and foreign policy? To answer this question, simply imagine if existing enabling technologies like computing originated in the Soviet Union, or that future advancements in artificial intelligence or quantum computing are dominated by nations who are near-peer adversaries. Policymakers won't like the risks they see when using this simple thought experiment around the criticality of nanomaterials."

Standardization - a misleading distraction or nanomaterial kingmaker?

As producers of one of the more commercially advanced novel nanomaterials, the graphene industry has taken several steps to cement its growth and reputation in recent years - one of which has been the effort to standardize the material. The Graphene Council has been busy putting together a graphene classification framework which is being translated into an ISO standard, this means that materials can be tested against this framework and datasheets built enabling direct comparison between the standards to the material.

As Terrance puts it, “It doesn't matter if you have graphene quantum dots, graphene oxide, or graphene nano platelets. It also doesn't matter how the material was produced or what the raw material is, you can classify it and then you can compare apples with apples”

This approach and push for standardizations is welcomed by many, but doesn’t come with universal approval, or certainly not without caveats. Leroy at XG Sciences points out that standards can help you define one specific type of graphene, made from a specific raw material or through a specific process, but that doesn’t inform you as to whether it is the best one for your application. As Leroy explains, “The ISO standard helps if you are a true producer of graphene, but there are also people who have things that are loosely graphene, get to a certain percentage of graphinization, not the same as someone who starts with graphite and gets all the way through to graphene but this kind of standardization could cause complexity because some products that are genuinely useful are no longer seen as valuable as end users don’t see graphene if it doesn’t meet the ISO standard”. Leroy does agree that he sees the need for customers to be able to identify what a good material is and to use standards to give you a scope on this. However he cautions users against relying on them too much in case you end up, for example, with a much higher quality graphene, and therefore more expensive product, than you actually need for your application. So standardization may prove useful in defining what a material is but not necessarily whether it is right for a product.

Industry-wide coordination

As highlighted throughout this report, collaboration is going to be key for nanomaterials in the coming years. Vertically, horizontally, between industry and regulators and even with consumers where possible. It will only be through widespread conversations and co-ordination that many of the above barriers can be overcome. Again, the landscape here is uncertain, nanomaterials have as many differences as they do similarities and as Leroy points out, "The conversations are being had by many different special interest groups that lobby for graphene but also nanomaterials in general." However Leroy feels that a consolidated knowledge center in the US, comparable to Graphene @ Manchester in the UK would bear fruit with regards to driving improved coordination in the States. Terrance also suggests that improved collaboration between competitors at this still early stage of the industry would benefit most parties. "If for example graphene suppliers worked together on a client proposal, they are de-risking the supply for the client and as few producers have the capacity to scale to the requisite amounts there is more than enough business for joint ventures in these cases". In the 21st century this kind of thinking would hugely benefit the bottom line, the economy and the environment to pool both human and material resources.

Vertical integration is the key for Mano, and as a vastly experienced industry leader, currently at an end user, he has a good view of what is working: "One key reason that GE has been successful in CMCs and has found a way to scale these pathbreaking innovations is our investment in vertical integration, from both an equipment and expertise point of view, from fibers to component manufacture. Nanotechnology needs a similar approach for vertical integration from material to product, get people who are ultimate users of the technology in the joint venture from the start". Mano sees three aspects to scale up:

"The materials, the manufacturing and the product design - the more integrated these functions are, the easier it is to scale".

Market opportunities and the impact of Net Zero targets

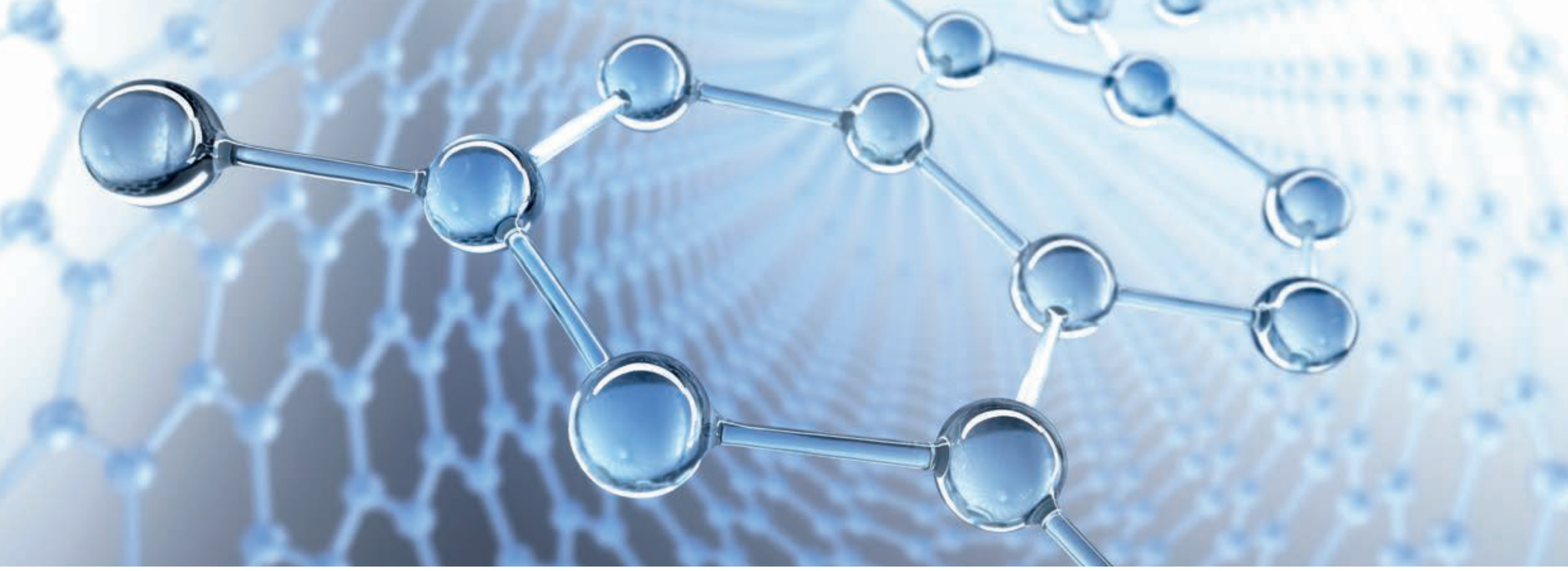
It is impossible to discuss the production of anything in 2022 without an essential conversation around sustainability. With limited global resources and the need to manage these very carefully, both to achieve better results and to reduce the amount of natural resources that we need and their impact on the environment this element is no longer an afterthought for most businesses, and certainly those in the manufacturing space. Nanomaterials stand as a potentially transformative solution if the scale can be achieved. Terrance Barkan feels that: “you can't really talk about anything to do with industry at the moment without bringing in the Net Zero angle, because it is finally taking center stage after having been on the periphery, with a lot of greenwashing for a long time”. Whether it is increasing longevity, reducing the requirement for volume, or providing new solutions to environmental challenges, nanomaterials are a key ingredient to a sustainable future if they can be scaled sustainably.

WHICH INDUSTRIES ARE LEADING THE WAY ON SCALING UP?

One topic that garners diverse responses is the question of which industries are likely to be first mover end users for the new classes of nanomaterials. The most mature nanomaterials markets are for nanoparticles, CNTs and graphene which are already on their way up to, or are comfortably on, the ‘Plateau of Productivity’. Leroy acknowledges that for graphene “the application end of the spectrum is wide open, medical devices, paper products, cement, graphene is just an enabling tool - you can literally use it in every industry - but to have it taken up by batteries and electrification is what everyone wants to see”. This focus on sustainability-focused industries is echoed by Chiara, suggesting that “surfaces and coatings can be huge for nanomaterials, carrying out building refits to meet climate challenges, also in lightweighting, utilizing nanostructures in construction and automotive - making them the same strength but with much lower volumes, another interesting application is enhancing textile functionality”. Chiara also identified the applications recently brought into focus brought up by the pandemic, “uptake for disinfectant purposes and in medical applications in general has been accelerated”. Terrance feels that “Graphene can be seen as a leader for new nanomaterials and we have seen graphene producers who have increased scale”. In terms of sheer volume, it is hard to compete with the cement and construction industry for graphene in particular where buildings and foundations are already being built with graphene as a key part in the materials.

However Terrance points out that the most exciting advances from a technology point of view are in much smaller volumes: “if we look at sensors and medical applications, we see real advances there. Of course the amount of graphene that is being used is so small you could almost count the atoms. It's a really small footprint, it's single layer, atomic graphene that's being used, but the impact is to make sensors that are much more sensitive, and much more responsive”.

This is where the crux of the issue may lie, when we speak of scale-up, what we actually mean is commercialization, as perhaps the solution is not to deliver ever greater amounts of nanomaterials but to deliver those that will have the greatest impact.



Conclusion

One thing that remains clear in the challenge of scaling up nanomaterial, is that nearly all of the issues outlined in this report could be mitigated, if not negated entirely by better communication and collaboration at every single level of development. This means collaboration between the design, production and commercial teams in-house; between innovating SMEs and their end users; and between those end users and regulatory and consumer bodies. If the industry can work to promote this kind of transparency across the value chain and assert the excellent value proposition that nanomaterials can offer in support of Net Zero targets, the future of the nanomaterials sector is surely a bright one.

Written by: Olivia Ryan-Hill, Conference Director, The Nanotechnology Show, with thanks to all the industry experts who contributed.

REFERENCES:

https://ec.europa.eu/growth/sectors/chemicals/reach/nanomaterials_en

https://www.grandviewresearch.com/industry-analysis/nanotechnology-and-nanomaterials-market

https://www.alliedmarketresearch.com/nanotechnology-market

https://www.businesswire.com/news/home/20210514005289/en/Worldwide-Nanomaterials-Industry-to-2029---Emerging-Applications-in-the-Electronics-Industry-are-Driving-Growth---ResearchAndMarkets.com
https://cordis.europa.eu/programme/id/H2020-EU.2.1.2.

https://www.bbc.com/future/article/20160612-heres-the-truth-about-the-planned-obsolescence-of-tech

https://www.edie.net/brussels-targets-greenwashing-planned-obsolescence-in-new-eu-consumer-rules/