[ˌpriːnə(ʊ)ˈveɪʃ(ə)n]

noun | the act of tracing innovation back to its upstream origins in research

definite form, singular | [*the prenovation*] | radical transparency in the mapping of knowledge, people, and ideas — *the invisible college made visible*

verb | **to prenovate** [ˈpriːnəveɪt] : to surface hidden connections, to render research landscapes legible

antonym | invention (*inventions* are to prenovations what fruit is to root)

There are an enormous number of people out there with invaluable information to share with you, and all you have to do is pick up the phone. They love it when you do, just as you love it when people ask if they can pick your brain about something you happen to know a great deal about—or, in my case, have a number of impassioned opinions on.

Say you happen to know a lot about knots, or penguins, or cheeses, and the right person asks you to tell him or her everything you know. What a wonderful and rare experience. Usually what happens in real life is that people ask you questions you can't remember the answer to, like what you came into the kitchen to get, or what happened on the Fourth of July in 1776 …

When you do actually know a bit about something, it is such a pleasure to be asked a lot of questions about it.

Anne Lamott, *Bird by Bird : Some Instructions on Writing and Life*

THE PRENOVATION PLAYBOOK

From Outreach to Impact

Med stöd från

VINNOVA
Sveriges innovationsmyndighet

Energimyndigheten

FORMAS

Strategiska innovations-program

Content

Foreword from the SIO Grafen Programme Office

From Research to Real-World Change

Many of the innovations we develop today will likely shape the future. The ones we choose to invest in will define it.

Sweden's spirit of innovation has historically led to remarkable advances—nationally and globally. The challenges have been many, but today we face one that may be entirely new. It's not a lack of knowledge, competence, or solutions. Quite the opposite. We are dealing with an abundance of all three—and a system that struggles to turn them into impact.

The gap between academic frontier research and commercial application is vast. Breakthroughs made at our universities often lack a concrete path forward. As a result, brilliant ideas and potentially game-changing solutions are shelved before they ever leave the lab. That's something we want to change.

Graphene and other 2D materials are among the most promising technologies we know today. With the right support, they can contribute to a more sustainable, electrified, and connected world. As a Strategic Innovation Programme, SIO Grafen's mission is not only to support technological development—but also to shape the structures that make real innovation possible. And as always, innovation demands fresh thinking.

Through a proactive methodology developed in collaboration between KTH, Uppsala University, and Linköping University, this project explores how we can reach researchers earlier—and provide the right kind of support to help their ideas create real impact. In the short term, the focus is on graphene. In the long term, our aim is to help strengthen Sweden's deeptech capacity as a whole.

Grounded in our collective experience, interviews with researchers, and field studies, this playbook outlines one possible path toward a more innovation-driven, sustainable, and future-ready research ecosystem. By investing in deeper collaboration within science today, we can help build a brighter tomorrow.

We invite you to take the first step with us.

Author’s note

As Prenovation draws to a close, one thing stands out: it has been a joint effort, carried forward by a diverse and ever-growing team.

You can sense this in the pages ahead. Some sections – like the belief updates and data visualisations – are the product of countless conversations within the project. Others, such as Marie’s reportage or my own postcard from the Graphene 2025 conference, were created more independently.

The first part of this publication, the playbook, sits somewhere in between. I wrote it in my role as project coordinator and business coach at KTH Innovation, but always in dialogue with the Prenovation collective – now counting more than a hundred researchers alongside the core project group.

That is why the playbook is voiced in the first person plural: it reflects the conversations and debates that shaped the work, while remaining a field report written from my desk.

Hannes Eder, Stockholm, September 24th 2025

1

Setting the Scene

A Lab Diary in Disguise

March 2025. The project we call *Prenovation* is just about to begin, and the coming six months are likely to bring both insight and surprise. This text was conceived as a kind of lab diary—a place to document assumptions, lessons, and emerging methods as they unfold. But first, some background.

From Quantum to 2D

The seeds for this initiative were planted during KTH Innovation's involvement in the Quantum Sweden Innovation Platform (QSIP), where I — Hannes — took a leading role in exploring new ways of connecting with research environments.

Our quantum outreach gave us a chance to lift our gaze and try a different way of working. Instead of standing by for ideas to surface, we went into the labs to uncover the innovations that were "waiting to happen."

The approach was messy, but not random. Having worked as a researcher and as part of several editorial teams, I brought with me a kind of journalistic toolkit — one that helped make sense of the emerging landscape.

In hindsight, that work served as a kind of proof of concept: a one-person experiment in method and domain. It didn't scale — but it pointed toward something worth scaling.

Enter Prenovation

The next chapter began when Jon Wingborg — active in both QSIP and SIO Grafen — suggested building on this work in a more deliberate way. Together with the innovation offices at Linköping and Uppsala, we launched *Prenovation*: an ad hoc project with a dual purpose. First, to explore and evolve new outreach methods. Second, to map the landscape of 2D materials research in Sweden.

From the start, it was clear that this wasn't the kind of project that begins with a hypothesis and ends with clean conclusions. It didn't move in a straight line, and it didn't speak with a single voice. The team itself was multidisciplinary, but the diversity ran deeper than that. The signals we tracked were mixed and fragmented. What emerged wasn't a single picture, but a set of overlapping impressions: sketches, patterns, intuitions. Some things were said outright. Others were only hinted at. Often, we found ourselves circling an issue before it revealed its shape. Much of what's included here came from conversations held off the record, in the quiet space between the official line and what people actually feel.

Retooling Outreach

What We're Already Good At, and Why That's Not Enough

Innovation offices are good at what they were built to do. We help researchers and students develop ideas — when those ideas arrive at our doorstep. The model is clear, structured, and service-oriented. IP strategies, pitch coaching, startup support: once a project has momentum, the system knows how to keep it moving.

The current model is excellent at supporting ideas that already have traction. That's what it was designed for — and it does that part of the job well. But it's also reactive by design: it depends on someone already recognising that what they're working on *might* be something. If that moment never comes — if the idea never crosses the threshold — there's not much the system can do.

That's not a failure. It's a structural limitation — one that this project set out to explore from a different angle.

We wanted to look upstream: to the invisible phase. The near-ideas. The research results that haven't yet been seen through an innovation lens — not because they lack potential, but because no one has thought to look.

That's where we began.

Our question was simple: what happens if we knock first? Could we catch something before it crystallised — a hunch, a flicker, a signal that something might be there, even if no one's quite sure what it is?

This kind of work doesn't start with a form to fill. It starts with a question, a bit of trust, and an open-ended conversation.

Retooling Means Relearning

The language of tooling is everywhere in innovation. We have tools for idea evaluation, tools for patent strategy, tools for startup scaling. But when it comes to early-stage outreach—the moment *before* something is a project—we're often reaching for the wrong wrench.

Retooling, in this context, means asking different questions. Slowing down. Learning to see the epistemic contours of a field—not just what counts as a result, but what gets missed, dismissed, or left unexplored.

That shift also requires new instruments and approaches:

- **A new kind of interview**: less like due diligence, more like documentary fieldwork.
- **New modes of data mining**: using bibliometric signals to surface under-the-radar work.

- **New ways of visualising insight**: making patterns visible across projects, people, and institutions.
- **New team structures**: stretching across university boundaries and extending into the freelance world.

The point isn't to throw away the existing toolkit—but to build a complementary one. One that can operate upstream, and that makes space for ambiguity, not just acceleration.

Beyond Metrics : Letting the Map Emerge

One of the first things we had to confront was how little we actually knew. There was no shared map of the 2D research landscape in Sweden—no common list of names, no obvious place to start. Just scattered hunches, and the sense that "a lot is happening out there."

In most innovation work, the system provides the metrics. Success is tied to invention disclosures, licensing deals, startups. Here, we had none of that. No pipeline to manage. No funnel to fill. Just a question: *Could we learn something useful by speaking with people who hadn't yet stepped forward?*

That meant setting our own targets—not for output, but for effort. We landed on 150 conversations. Not because it was a magic number, but because it was concrete—big enough to reveal patterns, small enough to stay human. (It also happened to be about ten percent of the researchers we'd identified across our universities.)

Working this way took some adjustment. We were used to tracking progress against known indicators. Here, there were none. Just impressions. Inflections. The slow accumulation of half-signals that might, or might not, mean something.

We had to build new habits of attention. To notice not just what was said, but how it was said. What people hesitated around. What kept resurfacing. There were no dashboards to lean on—only the discipline of listening.

At times, it felt like moving through fog. But that didn't mean we were lost. It meant we were somewhere the old maps didn't reach.

What This Is (and Isn't)

What's a Playbook, Anyway?

The term *playbook* has its roots in sports, where it refers to a set of strategies, rehearsed moves, and situational responses a team can draw on in the heat of a game. It doesn't guarantee success. It won't predict every move the opponent makes. But it helps a team respond coherently—without having to invent everything from scratch.

In the world of startups and innovation, the word has taken on a similar meaning: not a manual, but a living set of principles and approaches. A playbook isn't a blueprint. It's not about replication. It's about turning insight into action—sharing what worked in one context so others can adapt it to their own.

This playbook doesn't offer recipes. It traces a paths—partly planned, partly improvised, and still in motion. Our hope is that by laying out the thinking behind our choices—what we tried, what surprised us, what we'd change next time—we might offer something useful not just to those working with 2D materials, but to anyone reimagining outreach in a deeptech context.

Built While Flying

We didn't start this project with a playbook. We were supposed to be writing one.

Like most serious efforts, we began by building structure: drafting interview scripts, debating the sequence of questions, trying to anticipate the answers we might get.

But the scripts quickly fell away—not because they lacked rigour, but because the conversations had a life of their own. Researchers opened up in unexpected ways. Tangents turned out to be gold. The best insights came from the parts we hadn't planned.

In hindsight, that shift—from script to presence—marked a quiet pivot. We stopped chasing clean data and started listening for tone, tension, metaphor, ambiguity. That change in attention reshaped everything: our methods, our framing, our language. It wasn't a failure of method. It was an evolution. We were building the process as we went—writing the playbook while using it.

Field Notes and Belief Updates

If this project has a core output, it isn't this playbook—it's our field notes. Our field notes are messy, uneven, and full of ambiguity. But they're also the most alive part of the work. They try to capture not just what was said, but how: the hesitation in a voice, the offhand remark, the shift in tone. Some point toward leads—others surface doubt. Many live in a liminal space: not quite on the record, not quite off. That ambiguity is part of their value. It's also why we don't publish them directly.

Out of this material, a secondary artefact emerged: what we've come to call *belief updates*. The term comes from Bayesian thinking, where it marks a shift in perspective prompted by new information. For us, it signalled a moment of reframing—when something a researcher said made us see the landscape differently.

Belief updates are stylised and anonymised—not to obscure, but to reflect the relational nature of how they were shared. They're not findings or quotes. They're distillations: part reflection, part signal flare. Sometimes they contradict one another. That's fine. The point wasn't to gather data—it was to train attention. To filter for signal, not just volume.

We set an ambitious target: 150 field notes in six months. Some of the last will be written just days before deadline. This playbook, meanwhile, had to be finished much earlier. So what's included here is a snapshot—a partial sample drawn from a process still unfolding. But even if time weren't a constraint, we wouldn't include everything. More isn't always better. We've chosen just enough to illustrate the method, the tone, and the kind of pattern recognition we've been cultivating.

Partial by Design

This playbook doesn't try to show everything. What you see here represents only a fraction of the terrain we've moved through. Behind it lies a larger body of work: bibliometric data, mined and cleaned; Excel sheets with thousands of rows; network diagrams, publication patterns, institutional clusters. We've been mapping, scanning, following weak signals. That work shaped our direction. It helped us decide where to look more closely. But it's not the kind of material you read cover to cover.

Instead, we've chosen to offer glimpses—select visualisations that point toward the richness of that underlying dataset. They're not dashboards. They're not proofs. They're artefacts of attention: tools that helped us reframe what we thought we knew.

So while the belief updates offer moments of insight drawn from conversation, the visual elements in this playbook reflect a different kind of listening—one tuned to pattern, topology, and signal strength across a field still in motion.

Taken together, they don't map the whole. But they hint at it. And for now, that's enough.

Listening as Method

Before we built tools or mapped the field—before we wrote a single belief update—we started with conversations. Not interviews. Not surveys. Conversations. With people we didn't yet know, about things we didn't yet understand.

That might sound simple. But in a system built around deliverables and measurable outcomes, listening without a clear purpose can feel inefficient—even risky. Especially when there's no guaranteed output. Still, that's where we began: with questions, with time, with the sense that something important might surface—not despite the ambiguity, but because of it.

One of our early field notes captured the discomfort: how little it can feel like you're offering when all you have is curiosity. No pitch. No funding. Just a sincere interest in what someone's working on. Was that enough? Apparently, yes. Researchers made time. They answered. They opened up. Sometimes it felt as if they'd been waiting for someone to ask.

That was our first reminder: people who care deeply about their work want to talk about it. Not to sell it. Not to summarise it. Just to have it heard.

The Inevitable (and Productive) Epistemic Greyzone

Early-stage innovation often happens at the edge of what's currently understood. The boundaries are blurred, and the vocabulary is still forming. In that kind of setting, no one holds all the knowledge. Not the researchers. Not the innovation staff. Everyone, in one way or another, is stepping outside their comfort zone.

This project gave us permission to stay in that uncertain space—a space often rushed through in search of traction or clarity. We gave ourselves license to ask questions that risked sounding naïve, and that very naïvety sometimes revealed angles that might have gone unnoticed by a seasoned domain expert.

The same was true for many of the researchers we spoke with. Used to addressing peers, they had to shift register—reaching for metaphors, naming what was usually implicit. That movement wasn't always comfortable. But it was productive. It allowed something else to come into view.

In these kinds of conversations, the value isn't in knowing more. It's in attending differently.

Seeing the System Differently

What's happening with 2D materials in Sweden? Who's working on what? Where is it heading? These are simple questions, but they're surprisingly hard to answer.

The problem isn't a lack of data. Publications, patents, funding calls, and collaborations all leave traces. But those traces are scattered, siloed, and rarely brought together. Everyone sees a part of the picture. No one sees the whole. White papers focus on trends. Scientific reviews stay within established boundaries. Research articles go deep on single topics.

We wanted something else: a sense of what might be taking shape. Not to predict the future, but to get oriented in the present—to notice patterns while they're still soft.

In that sense, our work resembled strategic intelligence—not in the sense of surveillance, but in the practice of situational awareness. We weren't looking for answers. We were looking for early signals—small shifts, informal groupings, signs of movement. We weren't trying to pick winners. We were trying to follow energy—research directions not yet formalised, connections not yet named, ideas still looking for their audience.

Prenovation gave us space to follow some of these threads. We built maps. Held workshops. Read between the lines. And asked questions that don't usually have a home in innovation systems—the open-ended kind, the ones that help you notice what's missing, not just what's there.

That process led us toward something broader. Not just who's working on what, but how different ways of thinking might be forming—quietly, across disciplines and institutions. Like in art or philosophy, these are not formal schools. They're felt before they're named. They form around shared metaphors, problem framings, ways of paying attention. They leave no citation trail, but they shape the work nonetheless.

Thanks to the time and openness of researchers across the country, we gained insight—not just into the strengths of the system, but also into the everyday realities that shape how science meets society.

This kind of sensing doesn't fit neatly into the usual roles of research or policy. It's not part of anyone's job description—but maybe it should be. Because the better your awareness, the better your bets. And right now, there's no clear system supporting that kind of work. Just a few promising threads.

From Outreach to Resonance

If you'll forgive us, we'd like to close with a broader reflection—one that surprised us as much as anything else we found. It starts with a word we'd never thought to question: *outreach*.

It's an odd term, when you pause to consider it. Borrowed from the language of sales and conversion. You reach out, hoping to draw someone in. In an innovation office context, it makes some sense: you have something to offer—funding, coaching, strategic advice—and the people you approach stand to gain.

But in this project, we had very little to offer. And yet, researchers responded with unexpected warmth. Where our usual outreach efforts can sometimes feel like knocking on closed doors, this time felt different. People weren't just receptive—they were open. As if they'd been waiting for someone to take an interest. As if the reaching out was mutual.

Why?

One answer emerged gradually. From the outside, the 2D materials field might look cohesive. But from the inside, it often feels fragmented. It was rare to meet even two researchers who identified with the same subdomain. The same diversity was visible at Graphene 2025, an international conference attended by one of our team members: countless specialisations, but few common threads.

Scientifically, this isn't a problem. Specialisation is what drives research forward. But socially, it can be isolating. Every niche becomes a kind of lonely node in a global network—technically connected, but often without a local sense of belonging.

That may be part of why people welcomed the contact. Not because we offered solutions, but because the act of reaching out—without agenda, without transaction—touched something else. A desire for connection and context. For resonance.

In the course of this work, we spoke with professors who've led their fields for decades, and with early-stage researchers still finding their footing. What stood out wasn't a hunger for innovation support in the traditional sense. It was something more ambient. A readiness to be seen. A sense of relief, perhaps, that someone was paying attention—not to evaluate or extract, but simply to notice what was happening.

It reminded us—oddly—of Niels Bohr. Famously enigmatic, often hard to follow, Bohr nonetheless created one of the most influential environments in the history of science. His institute in Copenhagen didn't succeed because he had all the answers. It thrived because it made room for questions. It fostered not just excellence, but companionship. A field where thought could unfold in relation to others.

We're not claiming to have built anything like that. But the dynamic felt familiar. What we encountered wasn't a response to our offering—it was a response to presence. To someone stepping into the space without agenda. Just to listen. Just to notice.

Which raises a question. What would happen if this kind of presence weren't the exception?

That brings us to a second term: Φ (phi). In integrated information theory, Φ refers to how much a system is more than the sum of its parts. It doesn't measure how much there is—it measures how connected it is.

A healthy human brain has high Φ because of how richly its parts relate. What if a research field could be nurtured in the same way? Not through centralisation, but through small acts of attentiveness. Not by building new structures, but by sensing and amplifying what's already trying to emerge.

That's not outreach as we've known it.

But maybe it's what outreach could become.

Looking Ahead

This project could never have happened if it wasn't for the goodwill and strategic foresight of the three people in charge of the involved innovation offices. In alphabetical order: Lisa Ericsson, Malin Graffner Nordberg and Ingela Lindahl. As Prenovation is drawing to a close, we gathered them for a short conversation about learnings and what could come next.

What makes this different from the outreach you normally do?

Malin: Outreach is part of our daily practice. What distinguished this project was the method. I often think of outreach as a perishable good — even a kind of contact sport. It only works if you reach researchers at precisely the right moment, when their attention is aligned with yours. What this project offered was a more deliberate and effective way of creating those moments.

Ingela: Precisely. What struck me as novel was that our antennae were directed so deliberately toward a single vertical. That clarity of focus gave us a depth of insight we almost never reach under ordinary circumstances. In many ways, we went in knowing that there were things we didn't know — a kind of 'known unknown' — and by concentrating our attention, those gaps in our understanding began to take shape.

So it wasn't really about graphene?

Lisa: No. The real value of this project was never about graphene as a material — it was about the methodology. There is an intrinsic worth in this kind of detective work: establishing relationships, piecing together what's cooking in a field, and using that knowledge to prepare the ground for a more active role. The bigger the societal challenges we face, the more important it becomes for innovation offices not just to harvest the fruits of research, but to help set the agenda and actively create value. Seen that way, this new kind of outreach is really the prelude to venture creation — and that's something we're now beginning to experiment with in earnest.

What did the bibliometrics reveal that you wouldn't have seen otherwise?

Ingela: They helped us aim, but more importantly they revealed vulnerabilities we hadn't been fully aware of. You could see, starkly, how the departure of a single researcher could unsettle an entire field — or how large sums of funding didn't necessarily translate into a proportional research output. Those are patterns you don't easily notice without this kind of lens.

Malin: For me, that's exactly why data-driven awareness matters. It sharpens our conversations with university leadership, because you're no longer relying on anecdotes but on evidence. And it forces us to face realities that aren't always flattering — but that are essential to acknowledge if we want to be credible.

And what comes next?

Malin: The challenge now is scale. The pilot has been resource-intensive, so the real test is how to make this way of working part of our everyday operations — without losing the presence that made it valuable.

Ingela: Already, it has changed the conversations we're having. They've become more interesting, more informed, because we now have a sharper sense of where the energy in the field lies. That short-term value is real, even as the long-term effects will take time to unfold.

Lisa: The seeds we've sown here will take time to grow, but the momentum is real. What this project shows is a pathway for innovation offices to move from a reactive stance to a proactive one — to be present early, to awaken interest, and to shape opportunities before they're fully visible. That is how this work can travel: not just to other research fields, but to the very future of how we think about our role as innovation offices.

2

A brief note before you dive in

What follows isn't a summary. It's not a list of findings or a catalogue of problems to solve.

These belief updates are fragments. Distilled from real conversations, they've been anonymised, stylised, and sharpened — not to obscure, but to preserve tone, friction, and ambiguity. Each one marks a small shift in how we saw the system.

They're not definitive. They don't add up to a single story. But they trace the contours of one: the shape of a research landscape in motion, and the quiet signals that surfaced when we listened with curiosity and without agenda.

They're not meant to be read all at once. Skim. Pause. Come back later. Let them pull you in where they want to.

That said, some patterns do emerge. As the fragments accumulated, they began to cluster — not by institution or discipline, but by friction. By feel. Some were about language. Others about lag. What follows is organised not thematically, but thematically adjacent — grouped by resonance more than taxonomy.

Roughly speaking, you'll find:

- **The Two (or More) Graphenes** – how the field splinters depending on use case, layer count, or just semantics.
- **Systemic Bottlenecks** – when the problem isn't the material, but the system wrapped around it.
- **Hidden Talent, Dormant Energy** – researchers who aren't inactive, just invisible — and what it takes to bring them in.
- **From Discovery to Translation** – what it really means to carry an idea from lab to life.
- **Infrastructure and Fabrication Gaps** – why scale and reproducibility matter, and why we're not there yet.
- **Outreach, Activation, and the Human Element** – the original hunch of this project: that presence changes things.

Think of these as six windows. Peer through whichever feels most alive to you. The edges between them are porous — and that's part of the point.

The Two (or More) Graphenes

When Graphene Isn't Graphene

Source: Associate professor focused on printed electronics and coatings (KTH)

Before
We assumed that raw material quality in graphene supply chains was stable enough for researchers to build on. That printed electronics and coatings were promising near-term applications. That Sweden's public funding system, once activated, would ensure continuity through to commercialization.

What We Heard
Even with strong public funding and a long track record, one lab's efforts to build use cases in thermal conduction, ceramic and antibiotic coatings are repeatedly slowed by erratic upstream inputs. "We often don't get what we paid for" — materials ordered as graphene arrive closer to graphite, with unpredictable properties and batch variation. This makes it hard to develop reliable processes, even when industry interest exists. In one case, a PoC for ceramic coatings sparked interest from a major industrial player but stalled due to inconsistency in fabrication. For medical coatings, the interest is there too — but access to test infrastructure and clinical validation pathways remains out of reach. Without standards and repeatable inputs, the work can't move forward.

After
We stopped thinking of the graphene supply chain as ready-to-use. Even promising use cases fall apart without trustable inputs — and trust requires both standards and shared accountability. Strong public funding helps get ideas off the ground, but that's not enough. Without supply chain reliability and pathways for testing, promising projects keep stalling just short of impact.

Graphene Was Just the Gateway

Source: Theoretical physicist focused on magnetism and quantum materials (KTH)

Before
Graphene was still treated as the flagship of 2D materials. Even if newer materials were gaining ground, graphene anchored the discourse — scientifically and strategically. We assumed that innovation in 2D materials would radiate outward from this familiar center.

What We Heard
Graphene may have opened the door, but it's no longer where the action is. From a theoretical perspective, it behaves too much like carbon fiber to be especially rich in new effects. Its properties are well known but limited in application scope. The real promise now lies in 2D antiferromagnetic materials — unstable, complex, but potentially revolutionary for fields like neuromorphic computing. Yet this kind of work requires long timelines and deep patience. Simulations are shared openly; companies sometimes form around software, not materials. But for truly novel materials research to thrive, the funding logic must shift from short-term sprints, to long arcs.

After
We adjusted our map. Graphene may have been the gateway drug — but the most interesting physics, and possibly the most disruptive applications, now lie elsewhere. That shift requires a parallel one in mindset: away from application-readiness, and toward risk-tolerant, long-horizon support. Some revolutions need room to meander.

Size or Quality — Not Both

Source: Assistant professor working with ARPES and exfoliated 2D materials (Netherlands)

Before
We assumed that research on 2D materials progressed gradually toward industrial scale — that experimentalists were iteratively solving for larger, cleaner samples. We imagined quality and size as co-optimisable. We also assumed shared infrastructure helped unify disconnected fields.

What We Heard
Angle-resolved photoemission spectroscopy needs millimetre-scale samples. But the highest quality flakes only come from exfoliating bulk crystals, yielding small, fragile samples. This makes high-resolution measurement difficult, and progress slow. One lab developed a method for exfoliating slightly larger samples, but it wasn't patentable and is still far from producing device-sized material. Meanwhile, researchers operate within a fragmented ecosystem: materials scientists and device physicists barely overlap. Shared labs and platforms exist, but facility development is hindered by structural limits such as rent models that discourage infrastructure upgrades. Small grants help, especially for young researchers, but only go so far. The main message: we're still just trying to understand these materials. The value lies in "bringing new knowledge," not in rushing to product.

After
We dropped the assumption that scale is on the horizon. For some questions, it may never arrive — or matter. And we tuned into a quieter truth: infrastructure doesn't just support research — it determines what gets done. When rent models and career timelines dominate, even world-class insight can shrink to fit the system.

Split Market, Missing Piece

Source: CEO of a graphene-based materials company working at the interface of R&D and scaled production

Before
We assumed the biggest challenge for industrial use of graphene was technological: cost, consistency, or quality. We imagined companies mainly struggled to scale due to manufacturing limits.

What We Heard
Technology is only part of it. The real split is structural — between two separate graphene worlds. One focuses on atomically thin, epitaxial layers for electronics; the other on bulk materials and composites for infrastructure, packaging, and sustainability. These worlds barely talk. In one, hybrid materials are "just graphite"; in the other, they're market-ready. This company is scaling up fast — preparing to deliver hundreds of tons. Their composites replace copper wiring and block hydrogen leakage, and their customers don't care about layer count. But to test new materials, they rely on ad hoc contacts. There's no easy way to run mechanical or conductivity tests through academic labs. And no Swedish player is producing graphene at scale — companies like LayerOne (Norway) or Levidian (UK) fill that role abroad. That's a gap. A missing link in the supply chain. And a missed opportunity for Sweden.

After
We stopped assuming that industrial scale follows scientific progress. Different applications require different infrastructures — and different cultures. What connects them isn't more papers. It's testbeds, translation, and trust. If Sweden wants to lead in applied graphene, it needs to build the bridges and the factory.

Ten Years From Impact (Again)

Source: Independent innovation consultant, background in material science and business development (formerly University of Cambridge)

Before
We believed that the European Graphene Flagship — and the ecosystem it helped catalyse — had shortened the path to commercialisation. We thought the ten-year horizon was a stretch goal, but one the field might catch up to with enough coordination.

What We Heard
That ten-year timeline keeps resetting. In 2013, the promise was that graphene would be market-ready by 2023. It still feels ten years away. The Flagship was valuable — "incredibly important" — but remained too academic. Meanwhile, what counts as "graphene" has been diluted. Strictly speaking, it's a single atomic layer. But most of what's sold as graphene today is thicker and lacks the properties that made the material famous. That's okay — as long as we're honest about it. For semiconductors, "real" graphene is required. For composites, "graphene-ish" materials might still be useful. But the field is split — into bottom-up (epitaxial, substrate-grown) and top-down (powder, exfoliated) camps. They serve different purposes and speak different languages. Conflating them hurts credibility. The hype may be fading, but that might be a good thing — if it lets clarity take its place.

After
We stopped assuming that "graphene" means the same thing to everyone. It doesn't. And that's fine — as long as we're clear about what's being built, for whom, and with what expectations. The question isn't "is it graphene?" It's "is it good enough for what you need?"

Two Graphenes, Many Silos

Source: CEO of epitaxial graphene manufacturer with strong academic roots and cross-country operations

Before
We assumed Sweden had a reasonably cohesive national ecosystem for graphene — distributed across regions, sure, but connected. We thought scale-up challenges were technical, not structural.

What We Heard
The ecosystem is deeply fragmented — not just between academia and industry, but within industry itself. Graphene splits into two sectors: electronics (e.g. epitaxial graphene, CVD-grown) and solutions (e.g. flake-based composites). The former is high-tech, low-TRL, and concentrated in places like Linköping and Gothenburg. The latter has more immediate commercial traction. But even within electronics, divisions persist: CVD is cheaper and scalable, but not viable for semiconductors; epitaxy is cleaner, but expensive. As for Sweden's academic players, Chalmers leads, LiU is strong, but others — including KTH and Uppsala — have faded. Key researchers have left. Programs are rumoured to be shutting down. Recruitment pipelines are weakening. And despite high-level initiatives like the Graphene Flagship, Sweden lacks a coordinated strategy. Even scaling up test production requires renting space abroad.

After
We dropped the idea of a unified "graphene Sweden." There isn't one — not yet. What exists is a set of regional silos, tech subcultures, and disconnected actors. The potential is there, but the structure is brittle. Until someone builds a common map — and funds the bridges — the country may keep inventing alone and competing abroad.

Systemic Bottlenecks

You Can’t Spin Out a PowerPoint

Source: Senior researcher and academic entrepreneur with leadership experience (KTH)

Before
We assumed that if promising materials research was well-funded and protected with IP, the path to commercialisation would unfold naturally. That innovation bottlenecks lay downstream — in business models, marketing, or funding rounds.

What We Heard
The real gap is upstream: no robust, reproducible process tech means no real startup traction. Many research efforts race to publish or patent a novel material but never get past the lab bench. Instead of building scalable processes, the focus stays on academic novelty. Without process engineers and cross-disciplinary cleanroom support, promising ideas remain PowerPoint-deep. One proposal: add lab-readiness checkpoints for early-stage projects — a kind of technical due diligence to separate scalable processes from speculative claims.

After
We shifted focus from what’s missing in the business plan to what’s missing in the fab. Commercialisation doesn’t begin with IP — it begins with repeatability. And until Sweden strengthens its shared fabrication infrastructure and embeds process thinking into research incentives, even good ideas will fail to stick.

Can't Scale What Isn't Rewarded

Source: Senior materials scientist, innovation advocate, and leader in research infrastructure and policy (LiU / SSF)

Before
We assumed that innovation support was largely a matter of funding, and that once researchers had a patent or a prototype, the system would help move it forward. We also assumed most barriers were technical — solvable with better engineering or more capital.

What We Heard
Academic culture still treats innovation as a side hustle. Publishing gets you promoted; patents and startups don't. Department heads discourage market-oriented work. Researchers lack money and support to file patents — and often file too early, weakening their position. Without structured incentives, even good ideas stagnate. Meanwhile, the scale-up phase — the real test — is physically hard, underfunded, and rarely institutionally supported. Universities need internal capital for prototyping, shared IP schemes, and clear pathways for researchers to stay involved without exiting into full-time entrepreneurship. Intermediaries help, but they must be empowered. EU grants are dauntingly bureaucratic; writing them requires specialists, not just scientists with spare evenings. Without reform, Sweden's best ideas will keep leaving — for Boston or Shenzhen.

After
We no longer see innovation friction as a funding issue alone. It's cultural, procedural, and cumulative. Systems reward what they track, and right now, they're tracking the wrong things. Until innovation counts on the same scoreboard as citation counts, the best materials may stay in the lab — or leave the country.

Rethink the System

Source: Associate professor and startup CTO working at the research–industry interface (LiU)

Before
We assumed that once a prototype existed, its utility would speak for itself — that promising sensor research would naturally find its way into industrial settings. We also assumed young researchers would drive that transition, given the tools and ambition.

What We Heard
The real bottleneck isn't the prototype — it's the system. Lab-grade sensors often outperform their commercial counterparts but are too risky to adopt without support. Researchers know how to build, but not how to translate. Industry doesn't always know what to ask for, and researchers don't know how to answer in their language. This mutual opacity blocks uptake. One response: start earlier. A national graduate network now links young researchers in 2D materials across Sweden. But entrepreneurial mindset is still rare, and Vinnova is not reaching early-career innovators. Meanwhile, disruptive work is underway — like reverse modelling, where instead of designing materials and seeing what they can do, researchers start with a target (like a molecule or condition) and simulate the optimal material to match. It's AI meets sensing meets purpose-built design. That's the future — but only if structures are in place to carry it through. National excellence centres, cross-sector platforms, and coordinated support for deep tech innovation could help.

After
We stopped assuming that good science finds a market on its own. The distance between insight and impact is longer than it looks — and the bridge has to be built from both sides. To go from molecule to market, it may not be the material that needs redesigning — it's the system around it.

The Microscope Is Not Enough

Source: Senior microscopist and infrastructure lead working on 2D material surfaces and catalysis (LiU, Ångström House)

Before
We assumed that deep structural insight into 2D materials — especially through microscopy — was inherently valuable to both academia and industry and that infrastructure equalled advantage. We underestimated the extent to which even cutting-edge environments struggle to move the needle when structural gaps persist.

What We Heard
LiU is home to some of the most advanced microscopy capabilities in Europe. And yet, translating discovery into application remains hard. Even promising work — like structural stabilization of 2D surfaces — gets stuck when novelty thresholds block patenting or when industry is too risk-averse to adapt. Large companies shy away from fundamental research. Infrastructure changes are costly. Cultural mismatch and low perceived urgency keep university breakthroughs from being adopted. Meanwhile, efforts to encourage interdisciplinarity or impact sometimes backfire — becoming tick-box exercises rather than productive collaborations. Instead,build real forums, not just calls. Train scientists to talk across boundaries. Help them plan for application from the start. And crucially: treat advanced materials as a national strategic asset — on par with AI.

After
We stopped thinking that capability alone drives impact. Even world-class instruments can't compensate for weak incentives, shallow partnerships, or missing cultural alignment. To make advanced materials matter, you need more than atoms in focus — you need systems in sync.

Goldene Is Real

Source: Assistant professor working across 2D material synthesis, catalysis, biomedical sensing, and industrial translation (LiU)

Before
We thought of materials breakthroughs — like a monolayer of gold — as future bets: long horizon, uncertain payoff, mostly hype for now. We also assumed the real hurdle would be making the material, not figuring out what to do with it.

What We Heard
Goldene isn't stuck in the lab, it's already being produced at scale. Wafer-sized sheets are real. Triple layers are more stable. The chemistry is transferable to other metals. And use cases abound: PFAS degradation in water, hydrogen evolution, printed electronics, biosensors, even UV-triggered cancer treatments. The collaborations are in place — with IVI, TU Wien, RISE, Nvidia, Tanaka Precious Metals. Market research has been done. A spinout is forming. So why isn't it everywhere? Because the real work starts after discovery: validating the effect, scaling the process, navigating regulation, protecting IP. And all of that requires time, engineering capacity, and serious funding — far beyond what research grants can cover. Sweden has the talent, but the support system is piecemeal. What's needed is sustained, interdisciplinary effort: bridging clean tech, med tech, and microelectronics. And rethinking what "early-stage" really means.

After
We updated our sense of how innovation happens — not as a breakthrough, but as a braid. The material is ready. The science is sound. What's missing isn't gold — it's glue: validation capacity, engineering muscle, and strategic capital to hold it all together. If Sweden wants to lead, it needs to stop waiting for "impact" and start investing in the long arc of translation.

Hidden Talent, Dormant Energy

Not All Carbon Is Graphene

Source: Senior polymer scientist focused on sustainable materials and carbon-based additives (KTH)

Before
We tended to conflate carbon-based nanomaterials under a shared umbrella. Graphene, carbon dots, carbon flakes — all part of the same family, we thought, just at different resolutions. We assumed that adjacent research was tethered to the 2D narrative, or at least aiming in that direction.

What We Heard
Some research doesn't want to be pulled into the 2D tent. A long-running exploration of carbon additives in bio-based polymers made clear: "this is not graphene — not even 2D." The focus was on 0D and 1D structures: carbon dots, flakes, oxidized particles too small or too disordered to count as layered. These were added to polymers to give them antibacterial, fluorescent, or cell-scaffold properties. The work was adjacent but not overlapping. Funding came from other streams. Commercialisation was never a core priority, but may become one now, depending on where the next generation of researchers takes it.

After
We corrected our habit of seeing all carbon-based nanostructures as tributaries to the graphene mainstream. Not everything black and nano wants to be layered. Adjacent work on carbon dots may not feed directly into the 2D ecosystem — but it still expands the conceptual field. And some paths only bend toward impact when the right person arrives to explore them.

Nobody Cares if It’s 2D

Source: Professor in inorganic chemistry and thin-film coatings for energy and industrial applications (Uppsala University)

Before
We assumed that researchers in 2D materials saw “2D” itself as an identity — a unifying feature worth signalling to collaborators, companies, or funding bodies. We also assumed that 2D materials were primarily associated with physics or electronic devices.

What We Heard
In many real-world contexts, the 2D label is irrelevant. One startup based on ultra-hard coatings — harder than Gorilla Glass — emerged from this researcher’s lab, but the material isn’t pitched as “2D.” It’s thin, yes, but what matters to customers is performance, not classification. Reinforcement and wear resistance are the main draws. Similarly, ongoing academic work focuses more on ceramics than on graphene. Industry partners don’t care about layer count — they care about resilience, adhesion, and scalability. Networking still matters, especially locally, but buzzwords don’t. What would help? More connective tissue between university groups and nearby companies, especially in places like Uppsala where local industry ties are weaker than in Linköping.

After
We dropped the idea that “2D” is a selling point. It’s often a research category, not a commercial one. Outside the lab, it’s what the material does that matters. Thin isn’t a pitch — performance is. And to bridge research and application, proximity and practicality may count more than nomenclature.

Still Listening

Source: Senior theoretical physicist focused on atomistic modelling in nanobiotech and amorphous solids (Uppsala University)

Before
We assumed that once researchers drifted away from 2D materials, they were unlikely to return — that attention moves with funding, and expertise follows.

What We Heard
For a while, graphene was the future of biosensing — especially in DNA sequencing via nanopores. Once deeply engaged with modelling the behaviour of nanomaterials and exploring new sensing architectures. But that line of work peaked around 2010–2012, and focus gradually shifted. Today, they are more involved in protein sensing and amorphous materials. Still, the interest hasn’t gone away — it’s just dormant. they’ve kept up with the literature. Collaborations with solid-state groups continue. They use the local MyFab facilities. And crucially, they are open: to reactivating past research lines, to new collaborations, and to stepping back in. What’s missing isn’t will — it’s a trigger.

After
We revised our view of the expert landscape. Not everyone active in 2D is visibly so. Some of the most valuable experience sits at the edge, quietly available, waiting for the right reason to re-engage. Dormant doesn’t mean disinterested. Sometimes, all it takes is an invitation.

Quiet Willingness

Source: Senior lecturer and computational physicist working on 2D materials, magnetism, and electron dynamics (Uppsala University, Materials Theory)

Before
We imagined that computational researchers were either fully integrated into application pipelines or too far removed to care. We assumed the main issue was lack of interest or relevance.

What We Heard
There's interest but not a lot of infrastructure to support it. His work spans heterostructures, defect engineering, and magnetic 2D materials. He has been part of EU projects and collaborates closely with Chalmers. But links to innovation offices are minimal, and he's not connected to SIO Graphene. That's not from resistance — just inertia. He's enthusiastic about new connections, eager to hear about upcoming events, and has several concrete suggestions for who else to talk to. But he's cautious about overpromising — collaborations need to make real sense, and contributions are clearest when theory meets a defined experimental or application question. What's missing isn't will — it's matchmaking.

After
We recalibrated our view of the "outer circle." Some of the most willing contributors to innovation are just beyond the usual loop — visible, capable, but unengaged for structural rather than personal reasons. The opportunity? Build better on-ramps. And don't mistake quiet for closed.

Ready When You Are

Source: Researcher in structural chemistry working on nanomaterials for energy applications (Uppsala University)

Before
We assumed that researchers working with 2D materials — even occasionally — had at least some connection to existing innovation platforms or national networks. We thought that interest and involvement went hand in hand.

What We Heard
Some researchers are eager to connect — but haven't yet been invited. She works with nanomaterials for energy storage and conversion, including 2D materials as one among several options. She's never interacted with SIO Graphene or any innovation support office and isn't part of any national 2D network. But she's clearly open: to collaboration, to events, to thinking about translation. She mentions a gap — Uppsala isn't well connected to the Graphene Flagship or similar initiatives. And she offers leads — other divisions on campus working closer to devices. The interest is there. The infrastructure isn't.

After
We updated our view of who's "in the field." Many researchers are adjacent to 2D work — not branded by it, but open to it. With no platforms to engage through, their energy stays local. But it doesn't have to. What's needed is an easy door to walk through. And a reason to say yes when it opens.

From Discovery to Translation

The Wafer-Scale Window

Source: Senior microfabrication researcher and academic entrepreneur (KTH)

Before
Wafer-scale integration was understood as a long-term ambition for 2D materials — something out of reach for most academic labs. The boundary between materials research and microfabrication was assumed to be slow to cross.

What We Heard
One group working in micro- and nanofabrication has already extended wafer bonding techniques to 2D materials, using substrates procured externally. Their focus isn't material synthesis but integration — building process chains that work at scale. That makes them an outlier: while many labs are confined to small flakes or chips, this one can operate at the wafer level, thanks to specialised cleanroom tools available locally. Translational efforts have already begun through a startup focused on sensing applications — one of the few spaces where industrial entry feels viable. Broader industry engagement remains elusive, especially among Sweden's larger corporates. But some niches are opening.

After
We sharpened our sense of where real-world readiness might emerge first. The bottleneck isn't just material quality — it's processing infrastructure. Groups that can handle full wafers, even with imperfect material, are positioned to move faster. Sensing may be the first viable entry point, long before mainstream semiconductors open up. And when the ecosystem can't align around shared needs, it's not for lack of research — it's a gap in incentives and language.

The Second Life of Graphite

Source: Senior researcher in polymer nanocomposites and sustainable materials (KTH)

Before
We assumed that the world had moved on from the early hype cycles of graphene, and that practical applications would require material formats more robust than a single atomic layer. We also assumed that if major companies were making real bets on graphene, we'd hear about it.

What We Heard
There's still reason to think of graphene as being in its infancy. The problem isn't that it failed, it's that it's still too delicate. Many of its best properties disappear with stacking or scale, as breaks ruin conductivity. Rather than being a failure case, this is reminiscent of carbon nanotubes (CNT): a slow burn, with commercial relevance arriving only after deep, often invisible, industrial investment. Some large companies may already be investing. One industrial facility visited abroad was researching CNTs at full scale before having a defined use case. In parallel, raw graphite is under pressure from battery demand and flagged by the EU as critical. Recycling it into graphene could be a way forward. One quiet, promising application: using graphene-based lubricants to reduce mechanical friction across a range of systems, enabling energy savings with global scale.

After
We updated our sense of timeline. If graphene is still in its early days, it's not just because science is slow. It's because some industrial investments are quiet by design. Meanwhile, upstream constraints like graphite scarcity may shape the field more than downstream demand. Sometimes, usefulness comes not from what the material can do on paper, but from where it can be recovered, and how quietly it can save energy.

Don't Start the Company Too Soon

Source: Senior materials scientist and group leader working across predictive modelling, synthesis, and application-driven 2D research (LiU)

Before
We believed that once a novel material was discovered, the race toward application naturally followed. We assumed that funding systems, while imperfect, generally moved ideas from lab to market. And we saw spinouts as a useful proxy for success.

What We Heard
Not so fast. Some discoveries, like 2D gold, are barely past the point of synthesis. Even if the spectroscopic data is promising, no one's ready to talk catalysis. And that's fine. Rushing to form companies before a real use case is understood often leads to dead ends. What's needed is early, open collaboration with industry — long before prototypes or IP. But funding structures make that hard. National calls are too narrow and unpredictable. European calls are promising but too demanding. Meanwhile, the pressure to spin out for its own sake creates a kind of theatre of translation. What would help instead? Support during proposal writing. Recognition for researchers doing translational work. And the freedom to let ideas emerge from the ground up, not just from top-down policy priorities.

After
We adjusted our expectations. The gap between discovery and deployment is not just technical — it's procedural, cultural, and psychological. Scaling a material is hard. Coordinating a multi-partner EU grant is harder. Talking about commercialization in a way that's honest, precise, and inspiring? That's a rare skill. So maybe the question isn't "why haven't they started a company yet?" It's "why would they? And what would it solve?"

Proof of Concept, End of Road

Source: Senior applied researcher in nanotechnology, hydrogen production, and biosensing (LiU)

Before
We assumed that applied research with visible prototypes — especially in clean energy and sensing — had a clear path to follow: build, test, partner, scale. We believed the real challenge was getting the science to work, not getting it funded once it did.

What We Heard
Prototypes abound: graphene biosensors, sun-powered hydrogen catalysts, self-powered zinc oxide sensors for cars, doors, and water security. The science works. The costs are low. But nothing moves. Why? Because once the proof-of-concept is built, support drops off. Sweden's innovation system heavily underfunds Technology Readiness Levels 5–7 — the messy, expensive middle stretch between lab and market. International PhD students used to help bridge the gap, arriving with external scholarships. That pipeline is now closed by regulation. Grant agencies reject proposals even with industrial support. A startup mimicking sunlight with 98% accuracy folded for lack of backing. Meanwhile, the academic system rewards publications, not perseverance. Researchers cobble together low-cost solutions from bulk chemicals while watching promising tech stall for lack of a few hundred thousand kronor.

After
We stopped mistaking prototype for progress. Having a device on the bench isn't the halfway point — it's barely step two. Without institutional mechanisms to carry applied research past proof, good ideas will keep piling up just shy of impact. The innovation system isn't just missing capital — it's missing continuity.

From Question to Patent

Source: Entrepreneur and co-founder of a bio-based graphene company focused on sustainability and clean production

Before
We assumed most deeptech startups were spun out of research — that there had to be a lab, a paper, or at least a PI in the origin story. We also thought material development always started with fundamental science, not with a hunch.

What We Heard
This startup didn't start in a lab — it started with a question: why does graphene production have to be so dirty? From that conversation between an economist and a fuel cell researcher came a bet: that it should be possible to extract graphene from lignin, a forestry by-product. No prior research. No institution backing. Just time, lab access, and the confidence to try. One year later, they filed a patent. Their product is reduced graphene oxide (rGO), aimed at batteries and fuel cells. They found allies at KTH and were supported early by SIO Grafen, which helped them plug into academic infrastructure like the Electrum lab and connect with researchers. That proximity mattered. But their path wasn't about publishing. It was about proving, pivoting, and staying close enough to science to build something new — without starting from it.

After
We rewired our sense of how deeptech can begin. Some materials don't come out of research — they come out of frustration, curiosity, and a blank slate. And with the right support, even an outsider question can lead to insider impact.

Infrastructure and Fabrication Gaps

Layer Count Doesn't Matter

Source: Materials scientist with startup experience and international perspective (KTH)

Before
Single-layer precision was treated as essential to 2D material studies. Startup potential was assumed to follow from technical promise. Sweden's advanced infrastructure was thought to be matched by an integrated innovation ecosystem.

What We Heard
The functional boundary of a 2D material isn't always its physical thickness. If electronic behaviour remains confined to a plane, layer count becomes secondary. One research effort focusing on magnetic 2D materials targets drastic improvements in logic and memory device efficiency—orders of magnitude in power and footprint. But despite strong fabrication capacity, the surrounding ecosystem struggles to align. The groups making new materials aren't well linked to those engineering devices. Meanwhile, innovation support tends to wait for demonstrators that haven't yet emerged. In a more integrated setting, things might have moved faster.

After
We relaxed the idea that "true" 2D materials must be single-layer. And we re-evaluated what an ecosystem needs to translate research into action: not just funding and facilities, but shared focus and fluent conversation between fields. When these are missing, potential stays latent.

Composites Are a Team Sport

Source: Simulation and materials modelling expert working on polymers and nanocomposites (KTH)

Before

We viewed the graphene ecosystem as a fragmented but naturally self-organizing system — loosely coordinated through funding calls but driven by diverse applications. We assumed composites were a downstream domain, waiting for better base materials to unlock their potential.

What We Heard

The future of graphene in real-world systems may lie not in pure materials but in what they can be added to. One line of work integrates graphene into industrial cable joints — not a headline-grabbing application, but a place where small gains in conductivity matter at scale. Similar thinking now extends to wearables: flexible sensors, better mechanical compliance. But all of it hinges on material quality. High-performance graphene suitable for composites remains scarce, and the issue isn't just local — it's global. Add to this a national scene where research groups compete over the same calls, often duplicating effort instead of coordinating it, and progress slows. Opportunities exist, but the system isn't wired to make the most of them.

After

We updated our sense of where impact might land first. Not in spectacular new devices, but in infrastructure — power, sensing, insulation. Composites are an ensemble effort: they require not just material performance, but coordination across labs, suppliers, and use cases. Without quality inputs and structural alignment, even well-placed bets will underperform.

The Sample Is the Bottleneck

Source: Early-career physicist studying electronic structure of 2D materials (KTH)

Before

We assumed that understanding 2D materials at the electronic level was a matter of having the right instruments — beamlines, lasers, algorithms. We didn't think as much about how much those insights depend on getting a good enough sample in the first place.

What We Heard

The measurement tools are advanced — ultrafast lasers, synchrotron radiation, sub-picosecond time resolution. But the limiting factor is still material preparation. For experiments to work, exfoliated samples need to be clean, stable, and large enough to scan — which means building or modifying equipment to make them in-house. In this case, that means a custom vacuum exfoliation chamber. Only then do the downstream optics matter. There's interest in societal impact — and awareness that computing paradigms might change — but for now, the focus stays on enabling better measurement. Commercialisation is a potential future, but a vague one.

After

We recalibrated our sense of what "infrastructure" means in fundamental research. It's not just the detectors or the software — it's the upstream sample quality that enables everything else. And if societal impact is to follow, it begins not with a pitch deck, but with a flake clean enough to measure.

Let the Scientists Science

Source: Associate professor and founder in energy materials and biomedical sensing (LiU)

Before

We assumed that academic spinouts were meant to be led by their founders and that the same person who makes the breakthrough should shepherd it to market. We also assumed the main barrier to commercialisation was funding or IP, not leadership bandwidth.

What We Heard

His lab works across two fronts: biomedical sensing and sustainable energy materials. Their graphene projects, from aircraft coatings to chromatography sensors, show early promise but stall at scale or funding. The underlying issue? Too few researchers are trained to think like entrepreneurs, and too few companies are run by people who understand markets. LINXOLE, builds hole-transport materials for perovskite solar cells. It's backed by LEAD and Wallenberg, but progress is limited because the market isn't ready yet. Still, it's better run by someone with business experience. Researchers should focus on what they're best at. The bigger lesson: even with Sweden's generous early-stage support, translation stalls if the materials aren't mature or if leadership isn't aligned. Local networks matter too — and foreign researchers often struggle to access them.

After

We updated our view of what early-stage commercialisation really takes. Not just money. Not just patents. But the right person in the right role at the right time. A scientist doesn't have to be a CEO. In fact, maybe they shouldn't be. And that clarity can make or break a company.

Organic Solar Cells, Real-World Gaps

Source: Experienced researcher in organic photovoltaic cells.

Before

We assumed innovation in solar energy was mainly about efficiency — that better performance led to adoption and that organic solar cells, though flexible and sustainable, seemed like a niche beside silicon and perovskites.

What We Heard

Organic photovoltaics (OPVs) aren't out of the race — they're running on a different track. These transparent, flexible solar cells aren't made for rooftops, but for window panes, greenhouses and portable devices. Unlike rigid silicon panels, they're uniquely suited for applicatinos in agriculture and mobile charging — tapping into markets potentially as large as those served by traditional solar, yet with far less funding support.
However, early exposure to business and commercialization training is critical if researchers are to bring their ideas beyond the lab. On top of individual motivation, what's often missing is structured support — for funding, networking, and building relationships with partners and potential customers. These gaps make it harder for promising research to take the leap toward real-world impact.

After

We stopped equating solar innovation with lab efficiency. Real-world impact depends on fit, flexibility, and follow-through. For OPVs to scale, Sweden needs more than better materials — it needs testbeds, opportunities, and talent pipelines. This will come also funding for less-hyped technologies, promoting interdisciplinary collaboration, and commercialization training embedded early in research careers.

Outreach, Activation, and the Human Element

Substrates Are Optional

Source: experienced materials chemist (KTH)

Before
We assumed 2D material development was, by definition, tied to substrates. That exfoliation vs. epitaxy was the major axis of difference. That fabrication happened either in cleanroom environments or not at all.

What We Heard
One group was synthesising 2D and quasi-2D materials in solution — skipping the substrate entirely. Their colloidal approach let them explore new architectures, improve transport properties, and even build working applications (sensors, thermoelectric fluids, cutting lubricants). It also meant their experimental scope wasn't limited by what the cleanroom allowed. For a while, they even spun out a startup. But when a major industrial partner backed out, citing discomfort with "the word nanoparticles," the venture collapsed. The researcher was left convinced that Sweden's lab infrastructure and investor conservatism make commercialisation deeply uphill.

After
We updated our mental model of who gets to play with 2D materials. It's not just a physicist's game. Chemistry labs working in solution-phase synthesis might have fewer constraints — and a broader experimental playground — than their device-building counterparts. Substrate-free doesn't mean fringe. But we also heard a cautionary note: even promising prototypes may go nowhere if industry finds the language scary and the ecosystem brittle.

Good Enough for a Paper

Source: Early-stage PhD student with hands-on experience in exfoliated 2D materials (SU, formerly KTH)

Before
We assumed that meaningful experimental work on 2D materials required advanced infrastructure—cleanrooms, gloveboxes, wafer-scale samples, and single-layer precision.

What We Heard
A master's student, working with imperfect exfoliated crystals and no access to a vacuum glovebox, was still able to extract publishable insights about surface properties in complex 2D systems. Her "home-made" samples weren't single-layer, but they were good enough to show something real. The work will become a paper. Still, when choosing where to do her PhD, she didn't stay in the same lab. She went where the funding was secure and the basics were in place.

After
We updated our view of the minimal viable setup for learning something new. Perfect isn't required—but infrastructure gaps still shape career paths. Some of the brightest minds are making do with limited tools, and when they leave, it's not for prestige—it's for stability. The ecosystem pays for its patchiness in talent drain.

Pick Your Battles Together

Source: Theoretical physicist with expertise in quantum materials and international R&D systems (Nordita/UConn)

Before
We saw graphene as both platform and poster child — a material whose applications would either scale or stall, depending on quality and use case. We assumed national strategies could still shape deeptech outcomes, even in small countries.

What We Heard
The landscape splits: in some domains, graphene has already delivered — in glues, coatings, composites. But in others, like semiconductors, optics and magnetism, it's still a platform for basic science. Most of the newer 2D materials remain unexplored. Their promise lies less in specific products than in their potential to unlock the physics behind next-generation technologies — quantum computing, neuromorphic systems, and more. That future won't be unlocked alone. Small countries trying to do it solo risk irrelevance. International giants pick the best talent from everywhere. The Nordic region must do the same. Meanwhile, attempts to commercialize fundamental research often hit a wall: researchers want to stay researchers, but can't find the support or flexible structures that would let them test an idea without career penalty. "Sliding doors" are missing — exits and re-entries between academia and entrepreneurship.

After
We zoomed out. The bottleneck isn't just technical — it's systemic. Support for foundational 2D research must be paired with institutional agility and international alignment. Without that, the best ideas — and the people behind them — will get stuck on the wrong side of the door.

Hydrophobic, Hydrophilic, Helpful

Source: Recently graduated PhD in materials science and energy harvesting (KTH)

Before
We thought of 2D materials primarily in terms of their electronic or optical performance — bandgap, mobility, conductivity. We didn't think as much about how basic chemical properties like hydrophobicity might determine their use in fabrication. We assumed 2D research and device prototyping happened in the same lab — or at least on the same floor.

What We Heard
Some materials just don't want to be printed. Graphene, for instance, is too hydrophobic for certain ink-based techniques. Mxene, by contrast, is hydrophilic — much easier to mix, print, and prototype with. That makes it better suited to 3D-printed supercapacitors on paper, tape, or film. But it also comes with its own limitations — Mxene is unstable in air, prone to oxidation. Every material is a trade-off. Meanwhile, a broader insight emerged: engineers and materials scientists often work side by side but not together. Their cultures, timelines, and incentives differ. For early-stage researchers, that division can mean working in silos — alone, unsure when or how to engage with commercialisation.

After
We updated our view of what counts as a "limiting factor" in materials work. Sometimes, it's not performance but chemistry — not how a material behaves once embedded, but whether it can be handled in the first place. And we took note of a quieter design flaw: invisible walls between departments can be just as limiting as material properties.

Someone Had to Say 'Yes'

Source: Co-founder of a photonics-focused graphene spinout from KTH

Before
We assumed most startups emerged out of a combination of research maturity and entrepreneurial initiative — that the science led the way, and support came later.

What We Heard
Sometimes, it's the support that makes the science into a startup. This KTH spinout is built on more than a decade of research in MEMS and 2D material integration for sensing and photonics. The technical foundation was solid. But it wasn't until SIO Grafen backed them — twice — that the team dared to take the leap. This co-founder sees the field split in two: materials-centric and semiconductor-centric, with limited cross-talk between them. That matters, because potential spinouts get stuck when they don't see where they fit. He thinks KTH could have many more commercial pathways — especially in the semiconductor end of 2D — if there were more targeted structures in place. Compared to quantum, graphene's TRLs are higher, and its interdisciplinarity lower. But the bottleneck is similar: risk appetite and bridge-building.

After
We updated our sense of what gets startups started. It's not just maturity. It's permission. Someone had to say yes, early, for the idea to move. And the more split the field, the more these early yeses need to be loud, specific, and repeated.

From Lab to Launch.

Source: Professor in material science working at both academic research and tech. commercialization

Before
We assumed strong lab performance would naturally lead to the market—that scientific progress could drive innovation, and researchers would become the champions of their own technologies.

What We Heard
Most technologies remain stuck in the lab: only a few manage to stand out. Conductive adhesives, where 2D materials like MXenes are blended with polymers to match soldering performance, and flexible thermally conductive substrates, critical for heat dissipation in next-gen electronics — both are startup-ready. But getting there takes more than science. It takes strategic focus. Funding should be directed toward technologies with commercial potential, not just academic merit. The biggest bottleneck is entrepreneurship. Scientists rarely lead the charge. Commercialization depends on finding the right champion — often someone with a business background, who still understands the tech and dares to take the leap. Even with the right people in place, the environment matters. A persistent pre-seed funding gap holds back early progress — and collaboration, while essential, is not always easy. Large companies tend to be secretive and risk-averse, and in academia, partnerships work best when they're complementary, not competitive.

After
Science does not sell itself. The real path to impact lies in focus, translation, and team — not just data. To get promising results into the world, we need structured support, strategic funding, entrepreneurial matchmaking and pre-seed capital that backs risk.

3

A peripheral experiment

When we set out on this project, our idea was only loosely defined: we wanted to look for stories. For inspiration, we turned to Marie Granmar – a science journalist with an engineering background who for many years has written for, among others, Forskning & Framsteg. We were curious to hear what she might find if she talked to the same people we had – but from another angle. We saw the collaboration as a deliberate experiment at the project's periphery. And we were delighted by what she brought back.

"Graphene has been an eye-opener"

Better water purification, more energy-efficient electronics, and new two-dimensional supermaterials. The Nobel Prize–winning discovery of graphene is still important, even if development is now moving in new directions. Here, three researchers share their views on the future of the much-hyped material.

Expectations have been high ever since the research breakthrough more than 20 years ago that led to the 2010 Nobel Prize in Physics. Not everything has turned out as initially imagined, but research on graphene has opened many new doors. So say three researchers in Linköping, Stockholm, and Uppsala.

"The ultrathin sheets of carbon, just a single atom thick, that André Geim and Konstantin Novoselov first isolated were a material with properties unlike anything else. That triggered a boom in new research," says Biplab Sanyal, associate professor of physics at Uppsala University.

By Marie Granmar

He is among the Swedish researchers who have published the most graphene-related papers between 2015 and 2024. During that time, the challenges have shifted. Many chemically produced graphene variants have been developed, including larger flakes for industrial use.

In the early days, there were great hopes that graphene would replace silicon and revolutionise electronics. We are not quite there yet, notes Sanyal, adding that it is common for new applications to take time — anywhere between five and fifty years.

"At the same time, the graphene breakthrough has been vital for the development of theoretical materials physics. We've learned a great deal about this class of materials," he says.

One area boosted by graphene research, according to Sanyal, is superconducting materials — which conduct electricity with zero losses and are in demand for quantum computers, energy storage technologies, and medical equipment such as MRI scanners. Superconducting behaviour has been observed in graphene when two layers are stacked and twisted at a small angle.

Overall, understanding of material physics has deepened, for example the discovery of more quantum states than previously thought.

"It's opened up a whole new world of nanoscale Lego building," says Sanyal.

He came to Uppsala University in 2000 after a post-doc in Canada, just as the Ångström Laboratory was being built. "It was good timing," he recalls, feeling he could contribute his expertise from alloy research.

"There was a vibrant atmosphere here and a large group of researchers who shared my interests. That's still true today, and that's why I enjoy it so much," he says.

At present, much of his work focuses on two-dimensional magnetic materials — ultrathin, stable in single layers. A goal is to develop materials that make mobile phones more energy-efficient, important as ever more data is handled by portable devices.

Among others, Sanyal is studying iron-, germanium- and tellurium-based materials with strong magnetic properties, relevant for so-called spintronics. Spintronics uses not just the charge of electrons but also their spin state to store or transmit information, which is especially valuable for new types of memory devices.

"Graphene can help here too, in combination with other materials," he says.

A useful feature of the 2D magnetic materials he studies is that they function at room temperature.

"You can't exactly carry a fridge around with you everywhere," Sanyal jokes.

Much is in motion, but many challenges remain — achieving high-quality materials, scaling to industrial production, and more.

Per Persson, professor of physics at Linköping University, emphasises that graphene's impact goes beyond thin, strong carbon sheets.

"Graphene has been an eye-opener, including for what my group works on — materials called MXenes," he says.

MXenes share similarities with graphene: atom-thin layers that conduct electricity and heat like metals. They also dissolve well in water, which enables many applications, and they can be tailored in countless ways.

"Graphene is fairly limited, being only carbon. MXenes can be made from thousands of element combinations. The more you can build a material from the ground up, the more uses you can find," Persson explains.

Although he has also published on graphene, today Persson works mainly on other 2D materials. For instance, he has demonstrated methods for dissolving MXenes into single flakes.

"The holy grail is to create materials that are durable, yet have large surface area and low weight," says Persson, listing applications ranging from energy storage — such as capacitors that recover braking energy from trams, lifts, and cranes — to moulded computer casings that shield electromagnetic fields more efficiently than today's metal housings.

Over 30 years of electron microscopy, Persson has seen countless fascinating structures.

"Hardly a day goes by without a wow-moment, diving into samples magnified a million times," he says.

Two-dimensional materials, he finds, are more beautiful than others because there is less background "noise" and the effects are clearer.

"The most beautiful is probably when we heat samples, the atoms arrange themselves, and the structure matches theory," he says.

Persson's shift toward materials beyond graphene is not only about scientific interest. Research directions are shaped by funding.

"Research on graphene should continue, but to do research you need funding. Grants strongly affect what we focus on," he notes.

And for research to translate into products, he argues, companies willing to take risks and look beyond the immediate horizon are needed — something he feels is lacking in Sweden.

"Many are too cautious, and risk missing the next big thing," he says.

He highlights positive momentum in green energy and sustainability. Promising results have come in water purification, for instance with one-dimensional carbon materials such as graphene oxide. These efforts are influenced by the UN's Sustainable Development Goals, which aim to avoid the use of conflict minerals while promoting renewable energy and clean water access.

One researcher studying graphene oxide for water purification is Minna Hakkarainen, professor of polymer technology at KTH in Stockholm. She has helped develop a method for filtering heavy metals from water, similar to an award-winning membrane material now commercialised in Australia.

Hakkarainen now works mainly with polymers. Originally a chemist from the University of Helsinki, she came to Stockholm in 1992 on a Nordic exchange scholarship.

"Then I stayed on in Sweden, but I've always had collaborations with colleagues in Finland," she says.

She agrees that the initial hype around graphene has faded, but still sees lasting importance.

"There is great potential for different applications, especially in polymer composites. Even tiny amounts of graphene oxide can improve mechanical properties, enable otherwise incompatible polymers to mix, or introduce entirely new characteristics. For example, antibacterial effects are interesting for biomedical uses," she says.

The Swedish research institute RISE likewise judges graphene and graphene oxide to be significant going forward. A trend analysis on their blog (October 2024) highlighted strong market growth. According to the *Graphene Global Market Report 2024*, the market grew from USD 1.08 to 1.32 billion between 2023 and 2024, and is expected to reach USD 2.98 billion by 2028 — driven by lower production costs thanks to new techniques.

One of the few Swedish companies manufacturing and selling graphene-based products is Graphmatech in Uppsala, which last year launched several new products — including a composite that reduces hydrogen leakage from tanks, supported with SEK 10 million from the Swedish Energy Agency. The composite, made of polyamide and graphene, is used as a liner in pressure vessels for storage and transport, preventing climate-damaging hydrogen leaks.

Graphmatech has also developed a graphene-based filament for 3D printing, combining graphene with a polymer for components needed in electronics.

"What makes carbon materials so fascinating is the many ways carbon atoms can stack. Beyond thin graphene, there are nanotubes and spherical fullerenes. That opens many possibilities — and we've probably not yet seen the best of them," says Sanyal.

Minna Hakkarainen

Per Persson

Biplab Sanyal

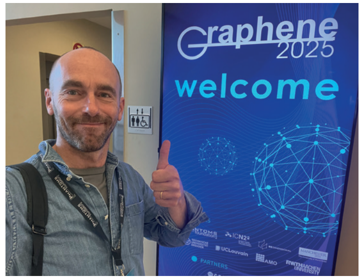
4

Driving innovation

... is less about being an expert than about seeing the bigger picture and how new technologies can be turned into value. Still, it's hard not to get pulled into the details once curiosity takes over. That's what happened in San Sebastián, where we caught a glimpse of Graphene2025 – a conference with 250 speakers from across the globe. We only managed to scratch the surface, but even that was more than enough to spark our interest.

Postcard from San Sebastián – a Field Trip to Graphene2025

By Hannes Eder



The first thing that struck us was how the conference name itself seems to have been outpaced by the field. While graphene may have kick-started the 2D revolution, nearly twenty years after Geim and Novoselov's pioneering work, the list of atomically thin materials is now all but unmanageable. The ever-growing family tree can—at least schematically—be divided into three main categories: elemental materials, compounds, and heterostructures.

The elemental group includes graphene (an excellent conductor), phosphorene (a semiconductor), and hexagonal boron nitride (hBN), which is electrically insulating but thermally conductive. In addition to these three, there are a range of other monolayers, such as silicene, germanene, and antimonene—often more experimental in nature.

The second group, compounds, is dominated by the so-called Transition Metal Dichalcogenides (TMDs)—chemical compounds of the form MX_2, where M is a transition metal (such as molybdenum or tungsten) and X is a chalcogen (sulfur, selenium, or tellurium). Examples include MoS_2, WS_2, $MoSe_2$, and WSe_2. Unlike graphene, TMDs are inherently semiconducting, making them particularly interesting for applications in electronics, photonics, and sensing.

The third—and perhaps most talked-about—category is heterostructures: materials constructed by stacking different 2D layers on top of each other. Since these layers are held together by weak van der Waals forces rather than covalent bonds, they can be combined without being structurally damaged. This "LEGO-like" approach enables tailor-made material properties, and it's not uncommon to combine, for example, a conductive graphene layer with a semiconducting MoS_2 layer and an insulating boron nitride layer in the same structure.

The second thing that quickly becomes apparent is how dramatically the application areas for 2D materials have expanded. For those mainly familiar with the flagship name *graphene*, it's common to associate it with two main use cases. When the material was at the height of its hype following its discovery, two properties in particular were emphasized: its exceptionally high electrical conductivity, which was expected to enable the next generation of miniaturized electronics; and its extreme mechanical strength—graphene is about 200 times stronger than steel by weight—which was expected to improve traditional composite materials like rubber, concrete, and plastic.

To some extent, both properties have found real-world applications. Graphene is now used in commercial composites to improve electrical and thermal conductivity, and can be found in heat-conductive films, anti-corrosion coatings, and certain types of sports equipment. In electronics, however, the initial promises have proven harder to fulfill. The lack of a bandgap has limited graphene's usefulness in logic components, where other 2D materials like TMDs have shown greater potential.

At the same time, it's clear that some hopes have yet to materialize. Several speakers at Graphene2025 pointed out that the current supply of graphene powder far exceeds industrial demand. Production has scaled up faster than the market, reflecting a classic pattern in new materials development: the potential is clear, but the path to widespread commercialization is often longer and more winding than expected.

Still, that's not the whole story. In one of the more industry-focused presentations, Sainathan Nagarathanam from Tata Steel emphasized that the biggest bottleneck in reaching TRL 9 in their development projects wasn't a lack of application ideas or technological barriers—it was access to graphene of sufficient quality. According to him, it's still difficult to find suppliers that can provide graphene powder in large quantities with consistent and reliable material specifications. This contradictory situation—where some actors face surplus while others face shortage—suggests that the market isn't mature yet, and that standardization, certification, and supply chains remain bottlenecks for many players.

So the problem isn't a shortage of graphene per se, but a shortage of standardized, quality-assured graphene in industrially relevant volumes. Meanwhile, several presentations pointed to alternative directions where sustainability, rather than performance, was the primary focus. Hjalmar Granberg from RISE AB presented a project in which lignocellulose—biomass from wood and plants—is transformed via laser into a conductive, graphene-like material. The method stands out for its low environmental impact, circular thinking, and potential for local production. Whether it solves a real problem remains to be seen, but it's a reminder that 2D materials don't always have to be high-tech or look sleek—they can also connect to bioeconomy and sustainable manufacturing.

If graphene was originally introduced as a *universal material*, the conference program suggested a clear shift toward more application-driven and material-specific research. Several presentations started not from the intrinsic properties of the materials, but from specific application areas, and it was clear that 2D materials are now viewed more as a toolbox than a singular technological breakthrough.

One area that received significant attention was optoelectronics, where TMDs like MoS_2 and WSe_2 stood out as light-sensitive semiconductors with major potential in photodetection, infrared sensing, and modular photonic circuits.

A particularly eye-catching presentation came from Valentyn S. Volkov, co-founder of the Dubai-based company XPANCEO, which is developing multifunctional smart contact lenses based on 2D materials. Volkov is an established researcher with over 10,000 citations, and the company has already published results in *Nature Communications* (2023), signaling strong scientific grounding. Among the members of XPANCEO's scientific advisory board and board of directors is Nobel laureate Konstantin Novoselov, one of the discoverers of graphene.

Founded in 2019, XPANCEO has raised around $40 million in venture capital and was able to showcase prototypes of its lenses during the conference—combining multiple futuristic features in a wearable format:

- biosensing, such as intraocular pressure and biomarker measurement
- color blindness correction
- ability to see in the infrared spectrum
- user interface control via eye movement
- and—perhaps most visionary—optical zoom integrated into the lens surface

Several of these features were demonstrated in rudimentary form during the conference, but as Volkov himself emphasized in a private conversation afterward, the technology remains at a low TRL. The first commercial product is scheduled for late 2026, but much of the more spectacular functionality is, according to him, still far in the future. In that light, the feeling of science fiction may not have been far off.

Perhaps the most striking detail isn't the individual functions themselves, but the fact that even today's prototypes reportedly combine over fifty different 2D materials—a number that, according to Volkov, continues to grow as new functional layers are added. This signals a paradigm shift in photonics and materials integration, where the modularity of 2D materials enables the tailoring of optical, electrical, and chemical properties on the micron scale.

Extending from the growing family of 2D materials suited for photonics are applications with names as peculiar as *valleytronics* and *twistronics*.

The former is a research field where information is encoded in so-called *valleys*—local energy minima in a material's band structure—which can be manipulated using circularly polarized light or electric fields. Monolayer TMDs such as MoS_2 and WSe_2 have proven particularly promising for this purpose, as their band structures allow for selective exciton excitation in specific band structure valleys. This opens the door to a new kind of optoelectronic information encoding beyond charge and spin.

Twistronics, on the other hand, is based on a seemingly simple but powerful concept: rotating two atomic layers relative to each other by a small angle—often less than two degrees. This *magic angle* rotation can give rise to entirely new electronic phenomena, such as superconductivity or Mott insulation, by creating a moiré superstructure in the resulting material. While twistronics was initially associated primarily with graphene–graphene combinations, researchers are now actively exploring how other 2D materials—including TMDs and hBN—can be used in twisted heterostructures to realize quantum states with specific optical or electronic properties.

Both of these fields remain largely at the level of fundamental research, but several speakers at the conference emphasized their long-term potential—not least within quantum information, photonics, and advanced sensor systems.

A more down-to-earth application that seems likely to appear in upcoming generations of electric vehicles and mobile phones is the so-called supercapacitor. Unlike conventional batteries, which store and release energy through controlled chemical reactions, supercapacitors store energy electrostatically—that is, as a charge distribution between two electrodes. This allows them to charge and discharge in fractions of a second, last significantly longer (up to hundreds of thousands of cycles), and function better in extreme cold. In theory, supercapacitors could therefore replace or complement today's batteries in applications where fast charging, high power, and long durability matter more than maximum energy density—for example, in wearables, start-stop systems in cars, or next-generation smartphones.

The technology has long been a subject of intense research and has already found a few industrial applications, but has struggled to reach widespread commercial adoption—partly due to limited energy density, and partly because the manufacturing processes have proven difficult to scale. This is where 2D materials—with their extremely high surface-to-volume ratios and excellent conductivity—enter the picture as a potential game-changer.

Several research groups around the world are now investigating how these materials can be used to build the next generation of supercapacitors, though in many cases, the work remains at the laboratory stage. One exception is the international project RiC2D, presented by Professor Hassan Arafat from Khalifa University in the United Arab Emirates. The project stands out for having taken concrete steps toward industrial application and illustrates just how far the field has come in a short time.

At RiC2D, researchers are developing a technique to manufacture microsupercapacitors using Electrohydrodynamic (EHD) printing—a method where inks based on 2D materials such as graphene, MXenes, and carbon nanotubes (cylindrical carbon structures just a few nanometers in diameter with exceptional strength, conductivity, and flexibility) are printed with micron-level precision to build up porous electrode structures layer by layer. The great advantage of this technique is that it enables the creation of very thin, yet extremely surface-rich electrodes—critical for storing as much charge as possible in a small area.

In earlier studies, the project reported an areal capacitance of up to 1,450 mF/cm², one to two orders of magnitude higher than what's typical for today's commercial microsupercapacitors. In practice, this means more energy per square millimeter—something that opens the door to applications where every millimeter counts, such as in wearable electronics or embedded sensor systems.

Although no specific TRL level was stated during the presentation, the impression was that this is likely one of the projects closer to actual implementation. The technology had been demonstrated in relevant environments, and the researchers outlined a clear path toward industrial production. It's still too early to speak of broad commercial rollout, but RiC2D illustrates how far 2D materials research has advanced—from lab scale to real-world applications—especially in the field of energy storage, where the demand for fast, durable, and small-scale solutions continues to grow.

The list of futuristic application areas goes on—from water purification and environmental sensing to quantum photonic circuits and atomically thin battery components—and the most profound impact might come from how 2D materials, more than anything else, may reshape the human condition. I'm thinking of the emerging field of bioelectronics, and in particular, neural interfaces.

If you know anything about this, you're probably thinking of Elon Musk's company Neuralink, which has received plenty of media attention for its ambitions to connect the human brain with computers via implanted threads and chips. But Neuralink is far from alone in this space—and at Graphene2025, an alternative was presented that appeared more grounded, both scientifically and technologically: the Spanish company INBRAIN Neuroelectronics.

INBRAIN is a spin-off from the European Graphene Flagship program, developing graphene-based electrodes for brain implants—extremely thin, flexible, and conductive films that can be placed directly onto brain tissue with minimal disruption. Unlike many conventional implant materials, which rely on metals or polymers, INBRAIN leverages graphene's combination of mechanical compliance, electrical conductivity, and biocompatibility. The company has already completed a first clinical implantation study and is now planning further applications in the treatment of neurological disorders such as Parkinson's, epilepsy, and dementia.

Using graphene in the human body naturally raises questions about toxicity and biodegradability, but research in this area has made clear progress. Among others, Bengt Fadeel and his team at Karolinska Institutet have shown that graphene oxide—depending on its structure and functionalisation—can be broken down by the immune system, and that the material, in several forms, is less cytotoxic than, for example, carbon nanotubes. Altogether, this suggests that properly designed graphene may indeed become a long-term sustainable material in medical contexts.

Some of the most insightful reflections didn't come from the stage, but over coffee. Andrew Strudwick from GEIC — the Graphene Engineering Innovation Centre in Manchester — mentioned that their facility has excellent roll-to-roll capacity for CVD production, but that they don't work with epitaxy. Ironically, epitaxy was the very topic of Strudwick's own PhD — and according to him, Sweden is at the global forefront of the field.

This points to a more nuanced map than the usual dichotomy between powder-based composites and electronics. In the context of electronics, the tension between CVD and epitaxy suggests that several technological pathways are available, each with different requirements regarding crystal structure, substrate integration, and material specifications. And it is in this zone of tension that the long arcs of material history begin to reveal themselves.

Epitaxy is not a new technique — and the same goes for many of the materials now included in the 2D family. Transition metal dichalcogenide like MoS_2 were used in bulk form long before they became monolayer sensations. Even MXenes have their roots in MAX phases, which were first studied back in the 1990s. So the new wave isn't just about discovering something new — it's about scaling down, restructuring, and sometimes rediscovering what was already there. Perhaps it's precisely this blend of continuity and shift that makes the evolution of 2D materials so difficult to pin down.

To end on a different note: there was a palpable shift in tone and representation. The gender balance among speakers appeared noticeably better than at many comparable conferences in physics and materials science — an impression shared by French physicist Annick Loiseau, one of the pioneers behind the Graphene Flagship and a central figure in the field's development. In a conversation off stage, she speculated that the EU's longstanding focus on gender equality in research funding might finally be starting to show results — at least in the form of a somewhat more mixed cohort among younger researchers.

A closer look at the programme showed that about 20% of speakers were women — still far from parity, but above average for many of the disciplines underpinning 2D materials research. In particular, PhD presentations stood out for their more balanced distribution, suggesting a gradual shift. Among keynote speakers, however, women remained significantly underrepresented.

Numbers, of course, only tell part of the story. But the impression remained: the conversations felt unusually generous, reflective, and restrained. Perhaps a more diverse room contributed to that. For organisers, funders, and research leaders, this is not just a responsibility — it's also an opportunity: to shape the culture of a research field that is still in the process of finding its form.

By the Numbers

a brief look at the data that guided our interviews

While this playbook focuses mainly on the outreach methods developed and applied during *Prenovation*, the project also offered an opportunity to map the landscape of 2D materials research in Sweden. This work was made possible thanks to input from the KTH Library, which provided a list of the most frequently publishing authors in the field—spanning both academia and industry. The dataset proved invaluable in guiding our outreach efforts and in revealing similarities and differences across research domains.

The following pages provide a short description of the data collection process and a selection from the dataset that formed the foundation of the project. The figures shown here represent only a subset of the broader data analysis carried out within *Prenovation*. They are *not* intended as measures of publication quality or impact; indicators such as citation counts or journal impact factors were deliberately excluded. Our goal was instead to highlight trends in research topics and to trace connections among authors and institutions.

Behind these pie charts and histograms are the people who kindly agreed to be interviewed, sharing their knowledge and perspectives. We gratefully acknowledge their openness, which made this project possible from start to finish.

About the data collection

The data on publications and projects has been compiled by KTH Library. For publications, Web of Science was searched via the library's SQL database Bibmet.

The relevant body of publications was defined through an iterative keyword process. We began by searching for *graphene* in titles, abstracts, and keywords. From these results, we extracted additional search terms that frequently appeared alongside *graphene*. This process was repeated until no further relevant terms were found.

The final keyword list was: 'graphene', '2d material', '2-dimensional material', 'Mxene', 'nanosheet'.

The corpus consisted of research articles and review papers published between 2004 and 2024, each with at least one author affiliated with a Swedish institution.

A publication list was created with information on:

- Authors' names and affiliation
- Year of publication
- Number of authors
- Subject category according to Web of Science journal classifications
- Citation indicators

This information was compiled into a consolidated list of individuals, their institutional affiliations, publication counts, and average bibliometric indicators.

The resulting dataset served as the initial basis for identifying potential interviewees and continued to expand as participants suggested additional researchers—often early-career scientists with fewer publications but valuable perspectives.

Projects

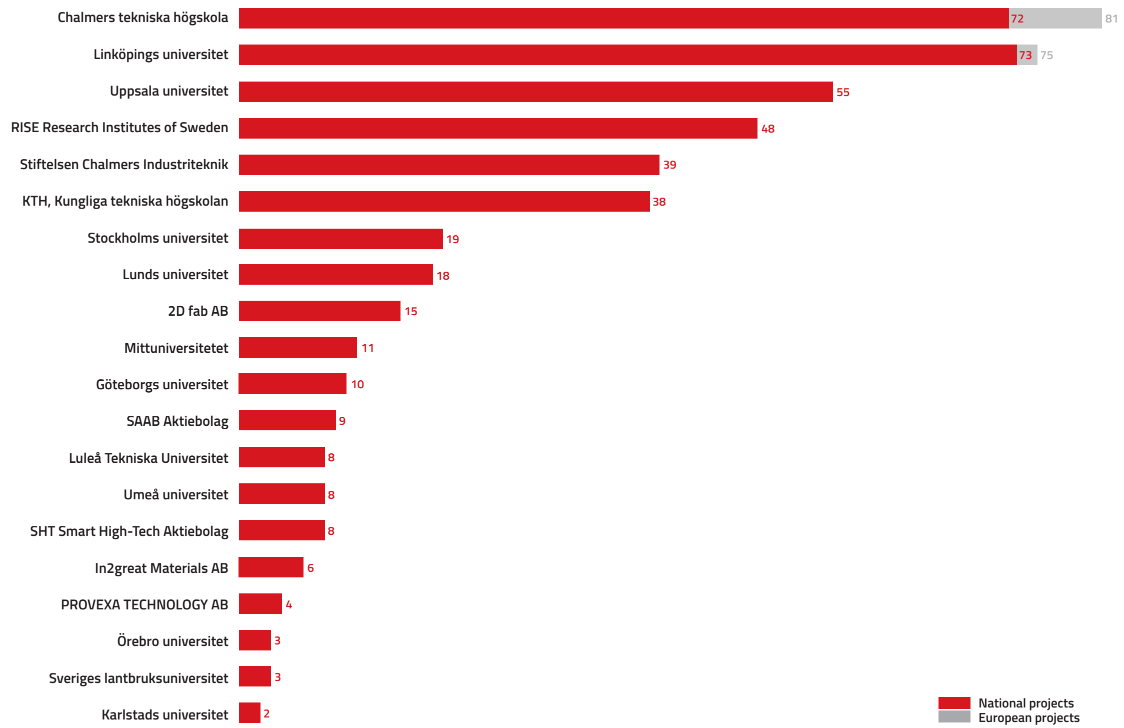
For projects, searches were conducted in Swecris and CORDIS using *ad hoc* R packages developed by the KTH Library.

Swecris contains data on projects funded by major Swedish agencies such as the Swedish Research Council, Riksbankens Jubileumsfond, and Vinnova, while CORDIS covers EU-funded projects.

The visualisations include only the coordinating organisations, and the datasets are limited to projects awarded between 2004 and 2024.

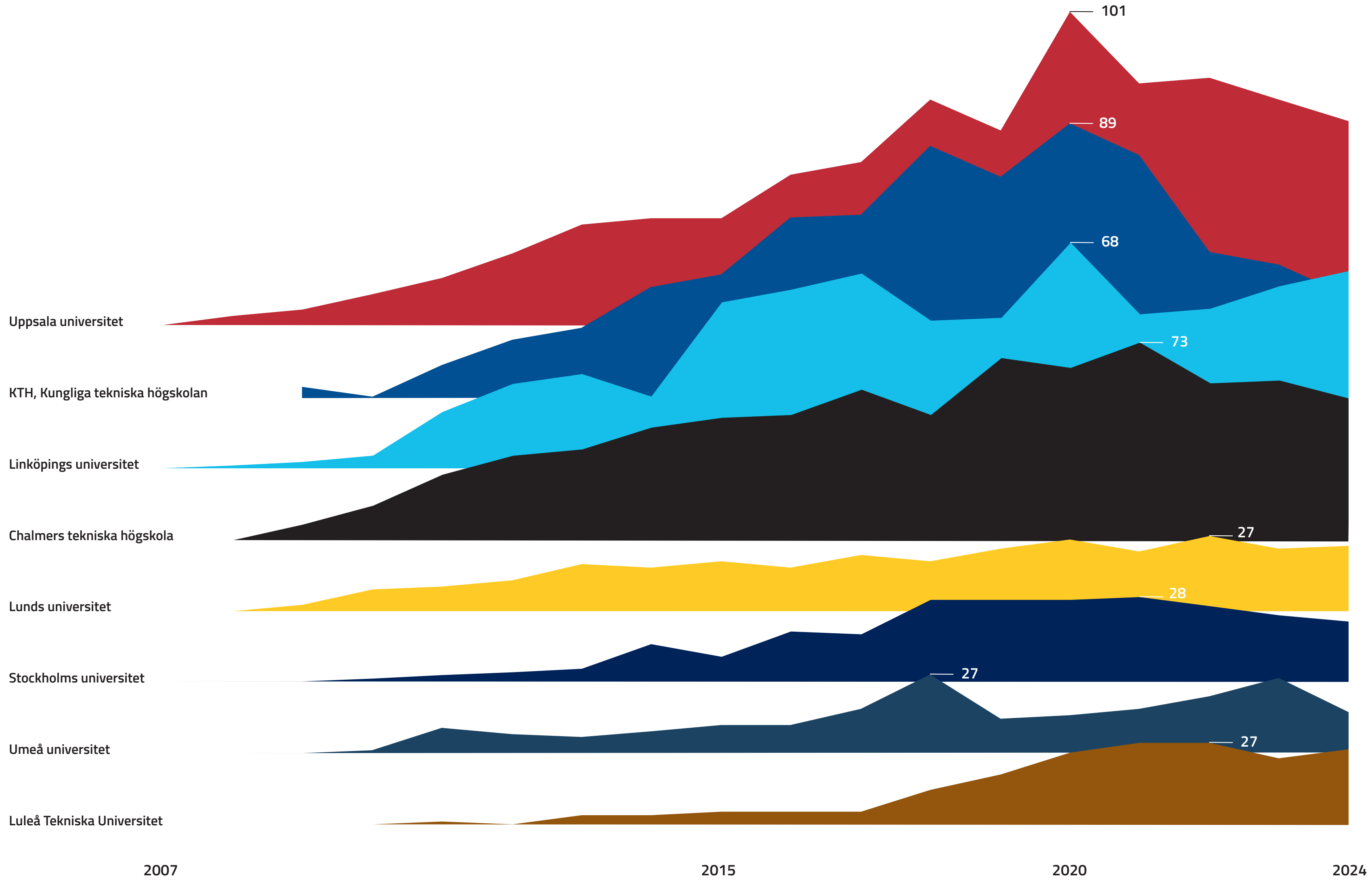
Swedish universities, research institutes, and companies that coordinated **the largest number of projects in the areas of graphene and 2D materials**. The image displays the number of coordinated projects for both national projects (in red) and European projects (in grey).

Svenska universitet, forskningsinstitut och företag som har koordinerat **det största antalet projekt inom områdena grafen och 2D-material**. Bilden visar antalet koordinerade projekt för både nationella projekt (i rött) och europeiska projekt (i grått).



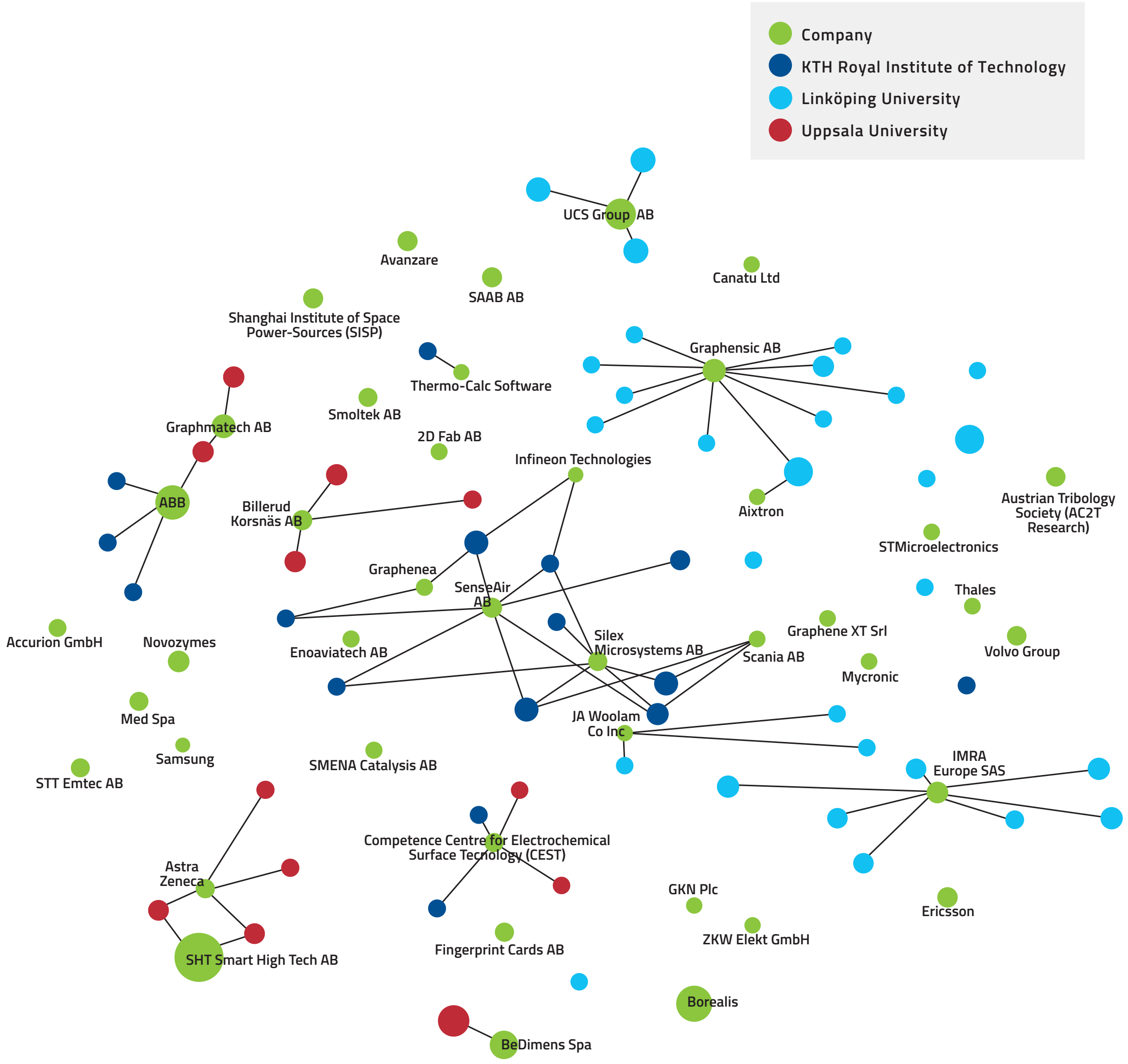
This image shows the **number of publications over time** in the fields of graphene and 2D materials for Swedish universities that published at least 10 papers in any given year.

Den här bilden visar **antalet publikationer över tid** inom områdena grafen och tvådimensionella material för svenska universitet som publicerat minst 10 artiklar under minst ett år.

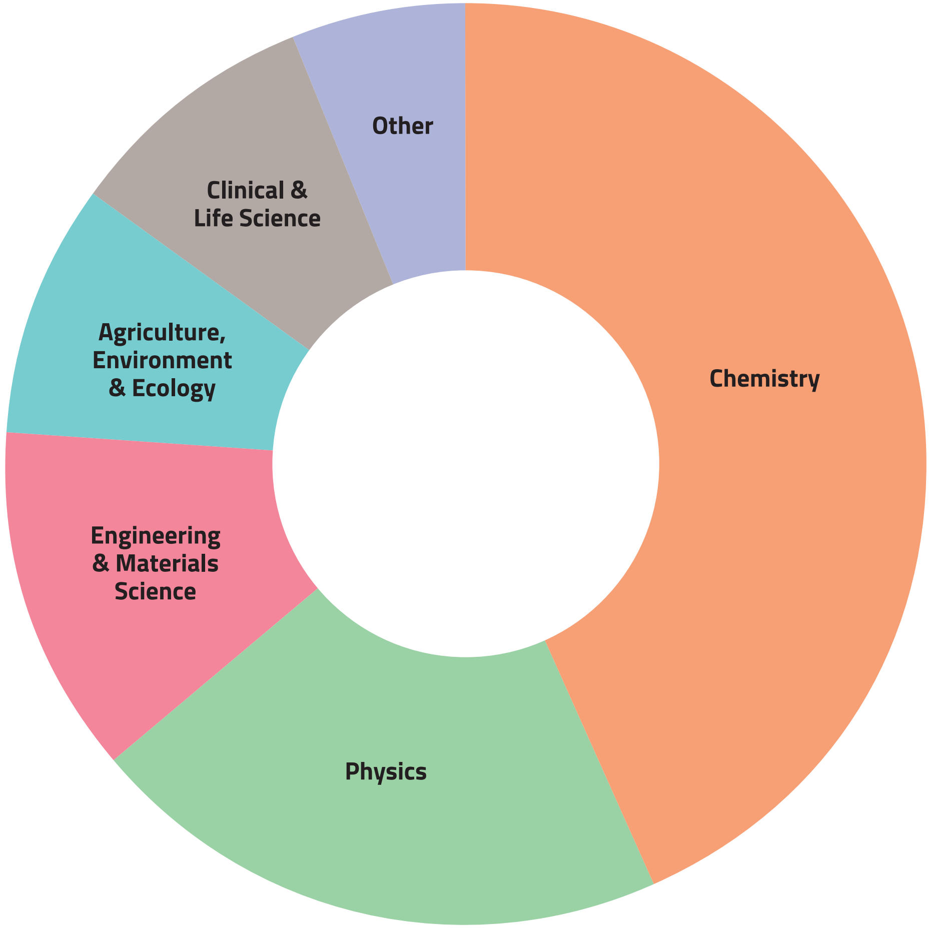


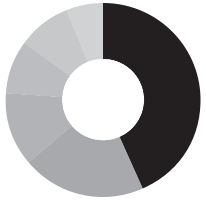
The diagram illustrates the **publications by Swedish authors affiliated with companies or the private sector**. When a paper includes Swedish co-authors from the industry as well as co-authors from Uppsala University (UU), KTH Royal Institute of Technology, or Linköping University (LiU)—universities participating in Prenovation—we highlight that connection.

Diagrammet visar **publikationer av svenska författare knutna till företag eller den privata sektorn**. När en artikel har svenska medförfattare från industrin samt medförfattare från Uppsala universitet (UU), KTH Kungliga Tekniska Högskolan eller Linköpings universitet (LiU) – universitet som deltar i Prinnovation – lyfter vi fram den kopplingen.



Swedish publications on 2D materials sorted by topic

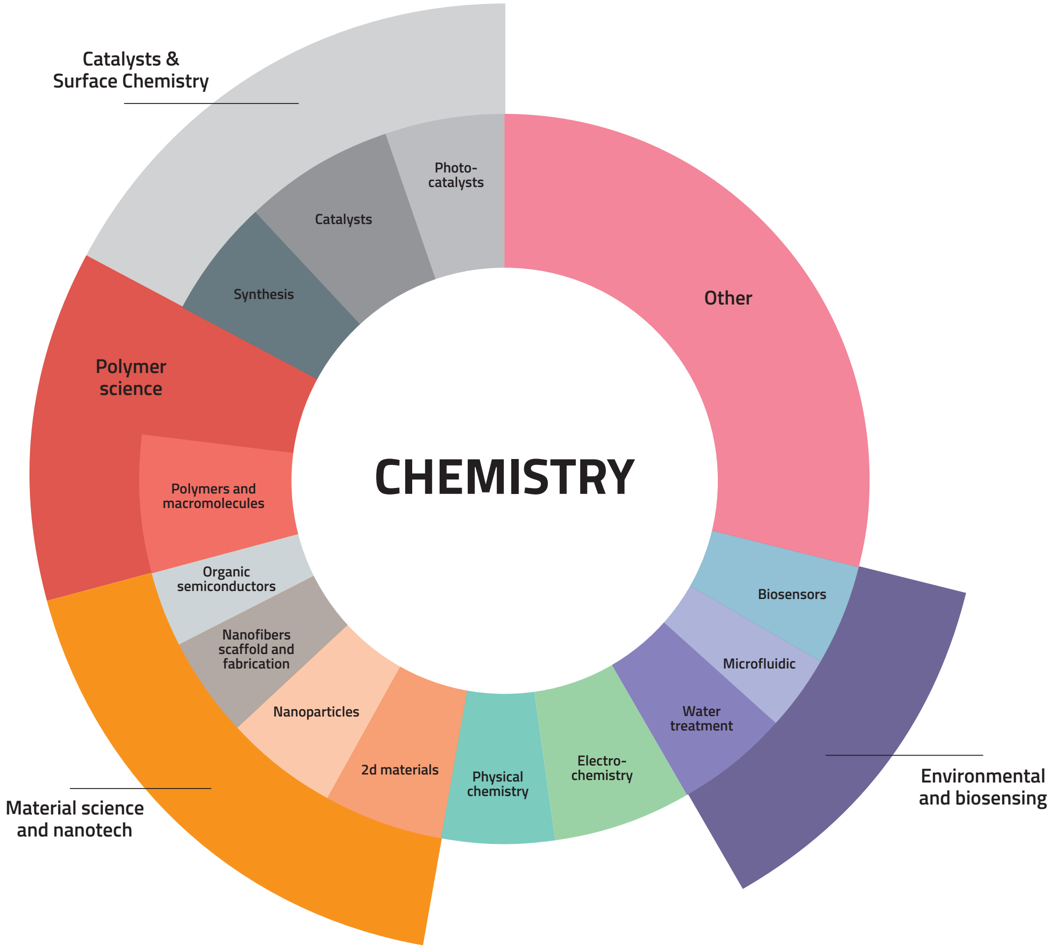


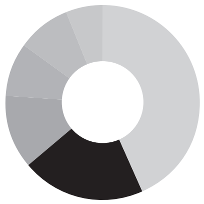


Swedish publications on 2D materials in **chemistry**

Within chemistry publications, there is significant fragmentation across various topics, with contributions in nanotechnology, catalysis and polymer science leading and covering, in total, about 50%.

Inom kemipublikationer finns en stor fragmentering över olika ämnesområden, där bidrag inom nanoteknik, katalys och polymervetenskap är de största med, totalt, cirka 50 % vardera.

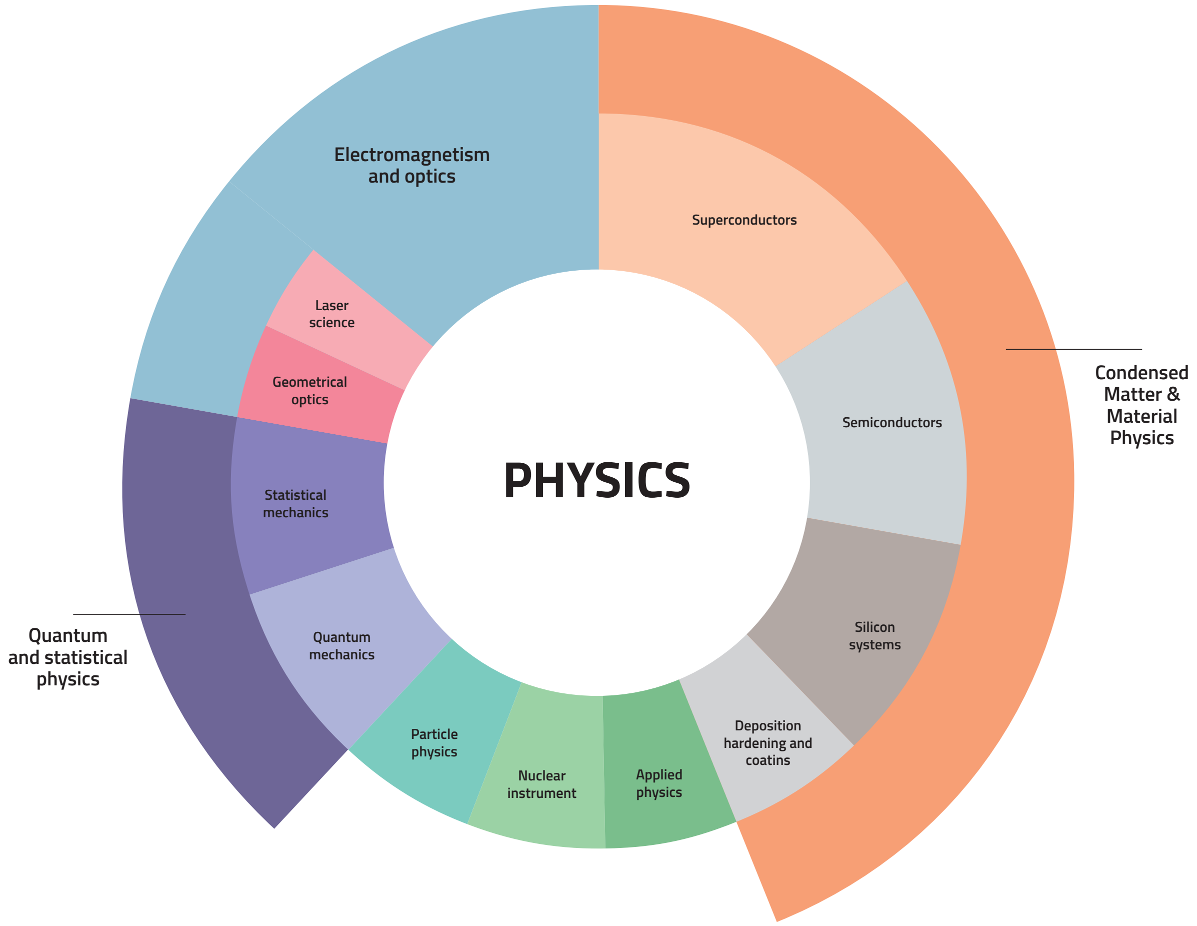


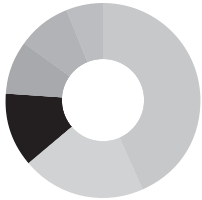


Swedish publications on 2D materials in **physics**

In physics, condensed matter and materials science represent the dominant sub-category, accounting for approximately 45% of all publications. Across all sub-categories, we observed a balanced distribution between theoretical and experimental contributions.

Inom fysik utgör kondenserad materia och materialvetenskap den dominerande underkategorin och står för cirka 45 % av alla publikationer. Inom samtliga underkategorier observerades en jämn fördelning mellan teoretiska och experimentella bidrag.

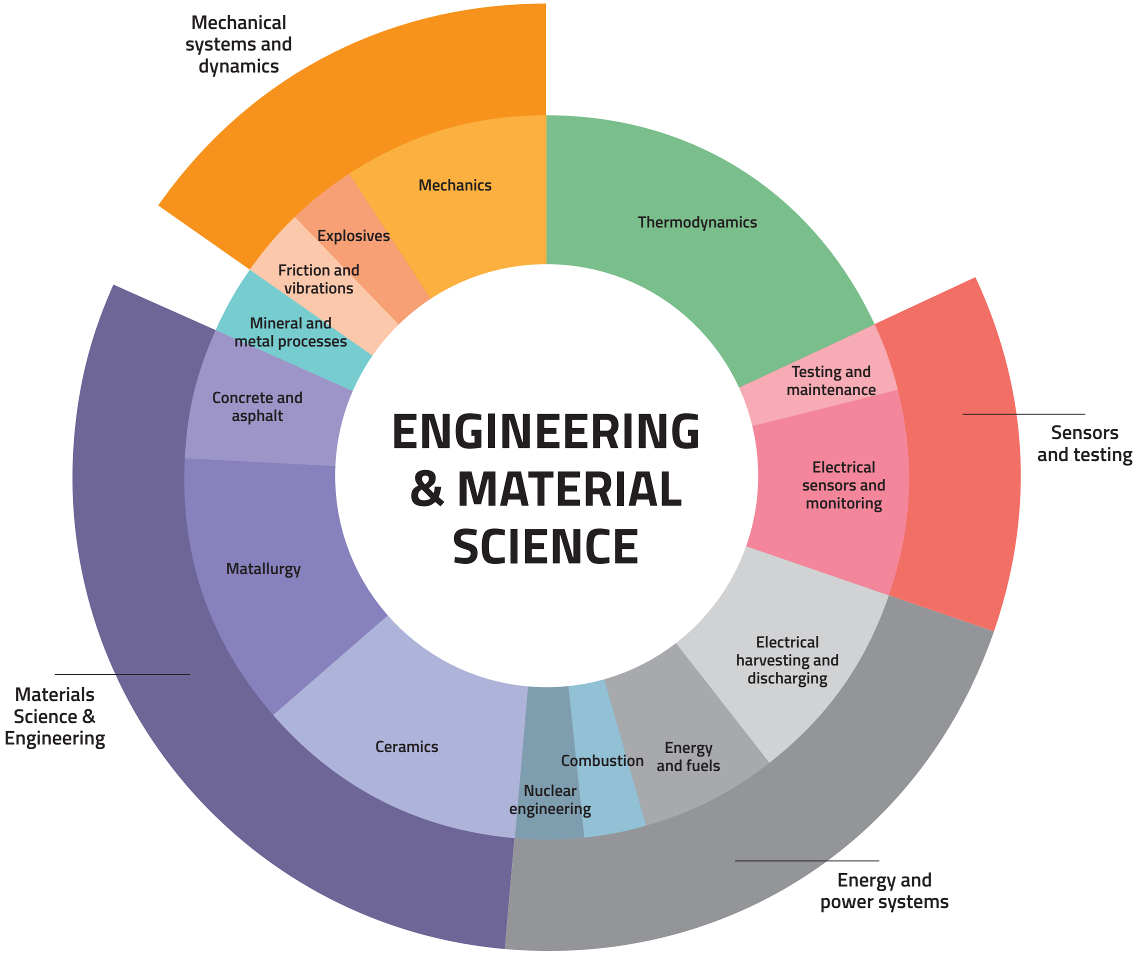


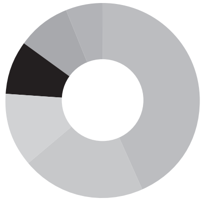


Swedish publications on 2D materials in **engineering and material science**

Within engineering and materials science Thermodynamics, Matallurgy, Ceramics and Mechanics are the main subtopics Electrical harvesting/ discharging and electrical sensors and monitoring following closely.

Inom teknik och materialvetenskap är termodynamik, metallurgi, keramik och mekanik de huvudsakliga underområdena, medan elektrisk energiupptagning/-utladdning samt elektriska sensorer och övervakning följer tätt efter.

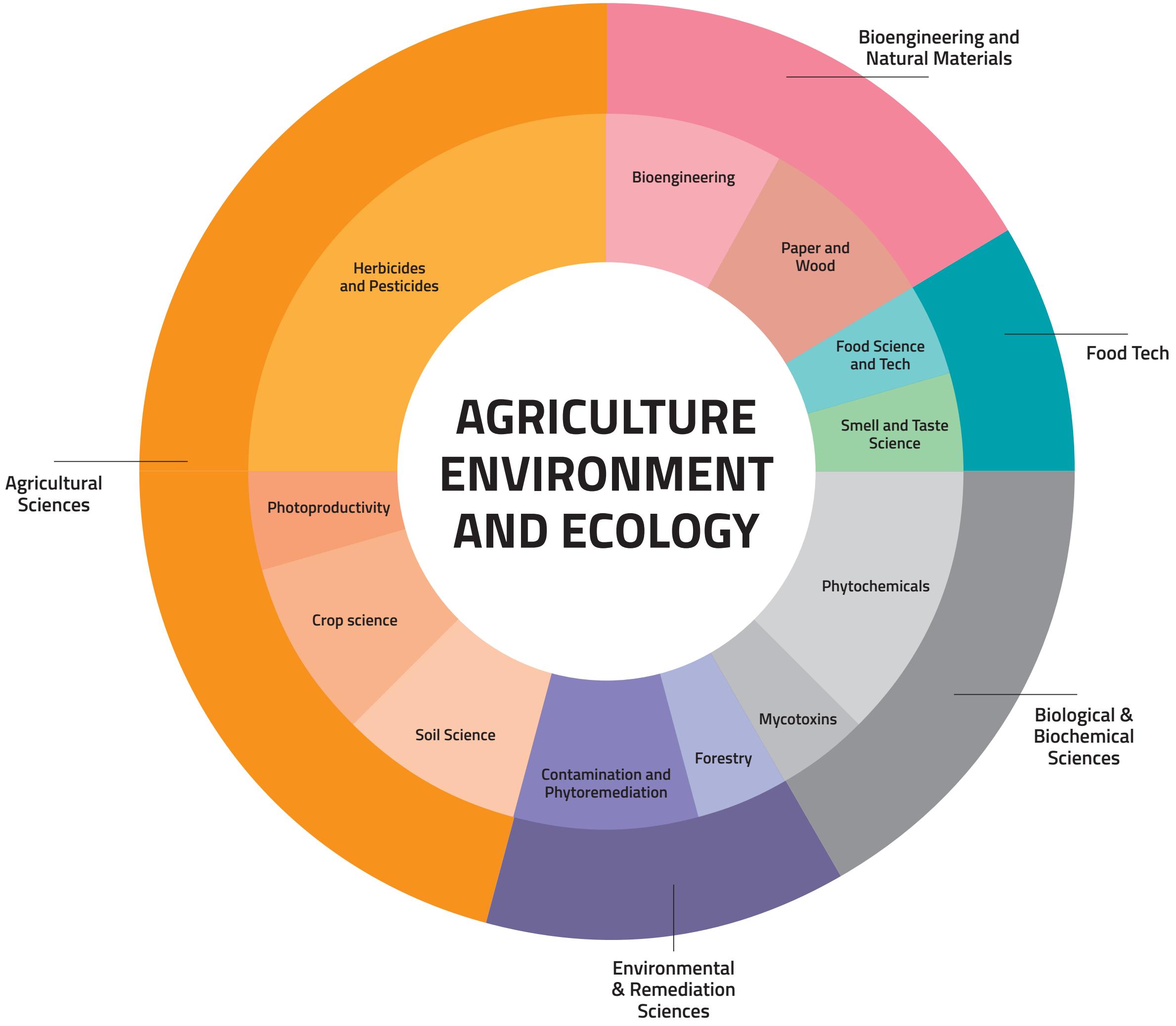


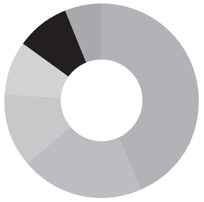


Swedish publications on 2D materials in **Agriculture and Ecology**

Within agriculture and ecology, the most relevant subtopics are herbicides and pesticides, which account for approximately 25% of the total. In contrast, the broader categories of biochemistry, bioengineering, and food technology together represent around 45% of publications.

Inom jordbruk och ekologi är de mest relevanta delområdena herbicider och pesticider, vilka står för cirka 25 % av det totala. De bredare kategorierna biokemi, bioengineering och livsmedelsteknik utgör istället omkring 45 % av det totala.

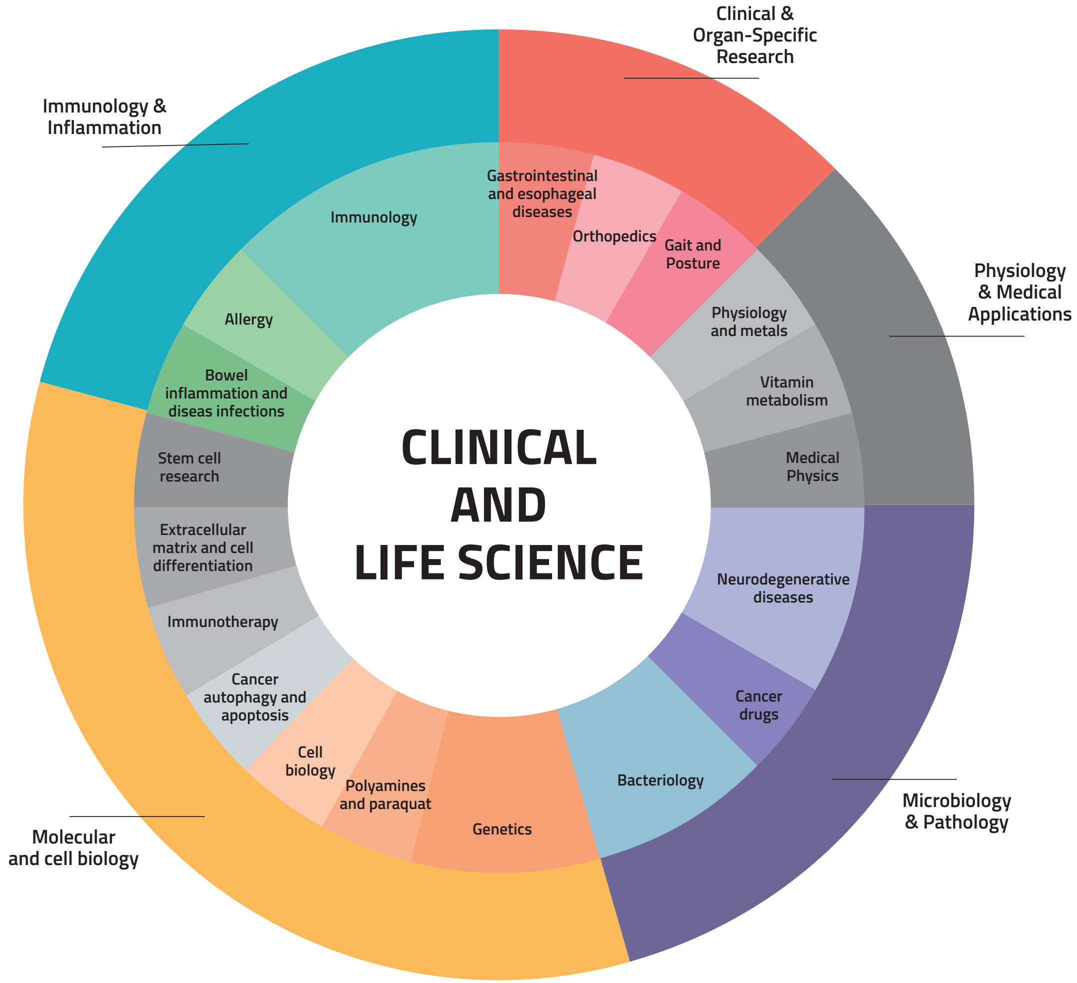




Swedish publications on 2D materials in **Clinical and Life Science**

Within clinical and life sciences, the most relevant macro-category is molecular and cellular biology, including genetics, stem cells, and immunotherapy. This is followed by studies in immunology and inflammation, as well as microbiology.

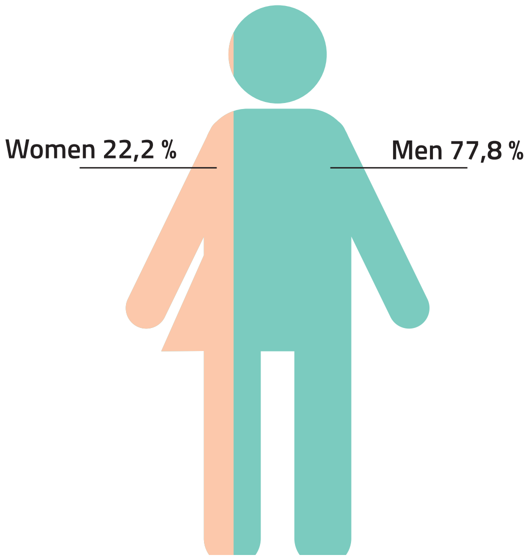
Inom klinisk medicin och livsvetenskaper är den mest relevanta huvudkategorin molekylär- och cellbiologi, inklusive genetik, stamceller och immunterapi. Därefter följer studier inom immunologi och inflammation samt mikrobiologi.



Gender distribution

Only 22% of the top 250 authors from Linköping University, KTH and Uppsala University—defined as researchers who have published at least seven papers *on graphene or 2D materials* over the past 10 years—are women. Approximately 84% of these researchers are still affiliated with a Swedish university, while 8% are now working in another European country. Around 2.8% are currently affiliated with a university in China, and another 2.8% have moved to a university in the United States.

Endast 22 % av de 250 främsta forskarna från Linköping Universitetet, KTH och Uppsala Universitetet – definierade som forskare som har publicerat minst sju artiklar om *grafen (eller en annan 2D material)* under de senaste tio åren – är kvinnor. Ungefär 84 % av dessa forskare är fortfarande verksamma vid ett svenskt universitet, medan 8 % nu arbetar i ett annat europeiskt land. Cirka 2,8 % är numera knutna till ett universitet i Kina, och ytterligare 2,8 % har flyttat till ett universitet i USA.



Where does the talent come from?

Among the top 250 authors from Linköping University, KTH, and Uppsala University—defined as researchers who have published at least seven papers on graphene or another 2D material over the past 10 years—we found that 43% had completed their undergraduate studies or were already employed in Sweden before obtaining their current research position. The remaining 57% were almost evenly split between researchers previously affiliated with a university in another European country and those coming from a non-European university.

Bland de 250 främsta forskarna från Linköpings universitet, KTH och Uppsala universitet – definierade som forskare som har publicerat minst sju artiklar om grafen eller ett annat tvådimensionellt material under de senaste tio åren – fann vi att 43 % hade genomfört sina grundutbildningsstudier eller redan var anställda i Sverige innan de fick sin nuvarande forskartjänst. De återstående 57 % var nästan jämnt fördelade mellan forskare som tidigare var knutna till ett universitet i ett annat europeiskt land och de som kom från ett universitet utanför Europa.