Romancing the Thread: the Story of Dyneema®

As world's strongest, lightest fiber – 15 times stronger than steel, yet floats on water – Dyneema® works to stop bullets, moor oil rigs and repair human joints. Now this revolutionary product is entering the world of apparel. It's been a long and epic road to get this far…

In 1968, chemist Dr Albert Pennings managed to pull some wispy threads from the stirring rods in his beaker. He found it impossible to pull the strands apart. Excited, he rushed to tell his director at DSM, a Dutch company then focused on coalmining and fertilizers. His boss's response: "Fiber?!? Fiber!?! If I wanted a fiber I would pick up the phone and order some! Stop with this nonsense!"

“It’s funny to think it all just started with some stirring in a pot.”

This outburst set the tone for a decades-long ride to bring Dyneema® to the market. The journey would involve multiple co-inventors, dismissive managers, happy accidents, quantum technological leaps, commercial innovations and a few experiments that under current regulations would be considered safety violations. Without the passionate drive by those who believed in the power of this fiber, it would have never gotten this far. Fast-forward to 2015, Dyneema® is a market leader in offering solutions for high-performance ropes/lines, body armor, safety gloves and medical applications.

The use of Dyneema® has produced many iconic images: upturning the stranded cruise ship Costa Concordia in Italy, placing the crown on the Freedom Tower in NYC, and the tethering of satellites in outer space. With its use in bulletresistant vests and other body armor, Dyneema® has become the material of choice for law enforcement and the military.

While renowned in the industry, Dyneema® does not yet have the name recognition of the other three synthetic fibers developed during the 20th century that would impact our world: Nylon, Kevlar and Lycra. But now Dyneema® is entering our daily lives on a broader scale as it inspires more and more developers – believers – to come up with increasingly diverse and ambitious applications.

“You can wake me up in the middle of the night and I’ll happily talk about Dyneema®,” says Yvonne Engelen, VP of Marketing & Sales at DSM Dyneema. Until recently, she was the company’s VP of Innovation – essentially the same job held by Penning’s temperamental boss.

“Call me any time! No problem at all!”

CALL TO ADVENTURE

Almost a half-century after getting yelled at by his boss, Dr Albert Pennings (1932) is alive, well, and still passionate about polyethylene fibers. “My days are now quickly filled with playing bridge,” he admits with a twinkle in his eye. “But if you found me a few bright students to help me, I wouldn’t mind doing a few more experiments.”

In 1957, Pennings followed his professor JJ Hermans – a famous chemist and a writer of children's stories – from the University of Leiden to do his PhD at the University of Syracuse. "It was the time of the Cold War: The Russians were coming! In the Netherlands they were already building bomb shelters. So Hermans wanted to get away to America and he took me with him."

"I learned so much that I wouldn't have in the Netherlands. It was so open. All these Noble Prize winners were dropping by and sharing their latest findings. People like Francis Crick of the DNA molecule! Fantastic!"

Upon his return to the Netherlands ("my wife wanted to go back"), Pennings got a job at DSM where Hermans worked as a consultant – "Hermans just called them and I was in."

At the time, DSM was looking for a new direction. The state company had established itself by transforming coal into fertilizer, and now wanted to explore the booming world of polymer chemistry. As a famous movie quotation described those heady times: "Just one word: Plastics. There's a great future in plastics. Think about it."

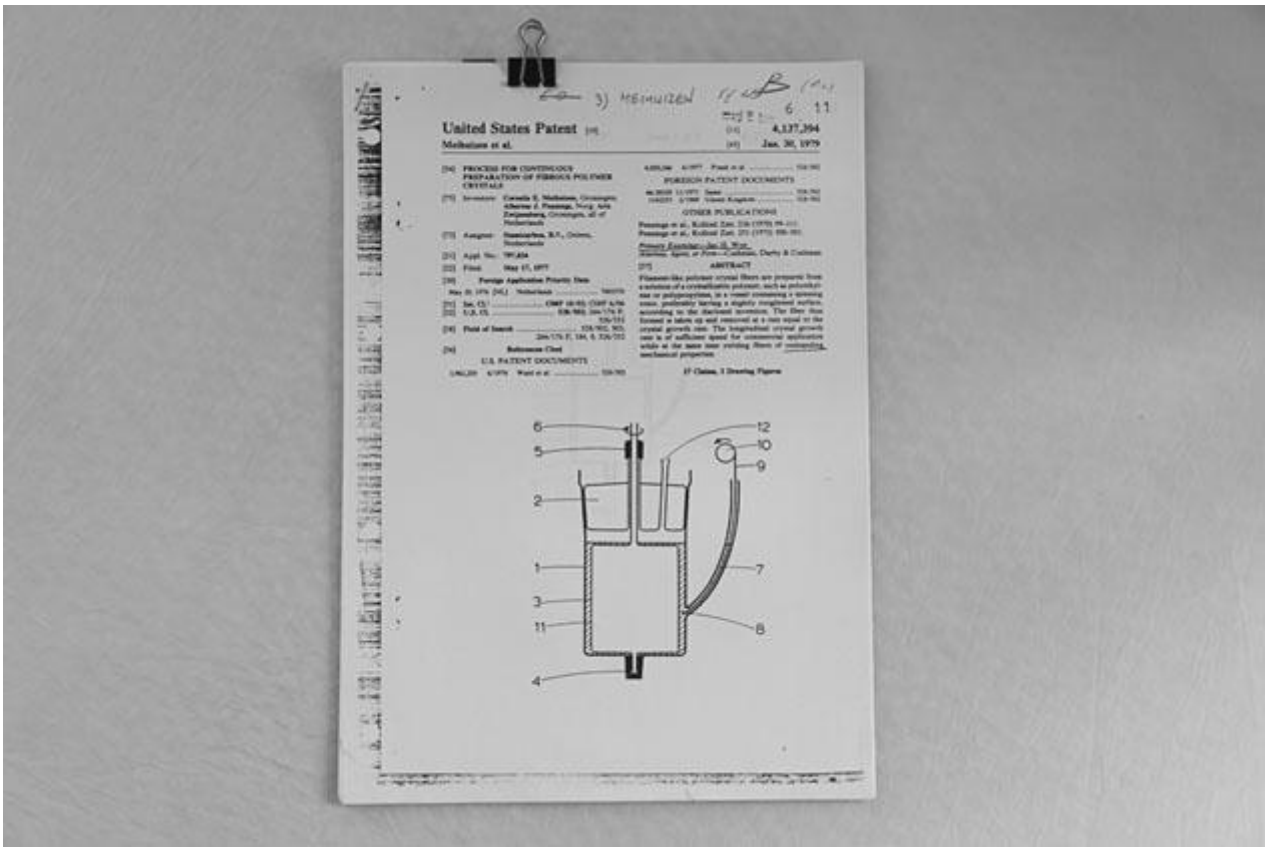
Companies and universities worldwide, often in collaboration, were then focusing on ethylene, which had been discovered by accident a half-century earlier. Made only of carbon and hydrogen, ethylene is the simplest of molecules – but a very interesting one. For example, plants release it as a gas to speed the ripening of fruits. It can also form long polymer chains of varying lengths – polyethylene – and the longer these polymers were, the stronger they'd

be. It was thought that the shorter chains could be applied to make flexible things (think: plastic bags), while the longer, stiffer chains could be applied to transport (think: beer crates).

So DSM established a Fundamental Polymer Research department to explore and develop such holy grails. “I got a room, a desk and a basic lab and was told to get busy. Once a year I’d go to see the boss to get a raise. He’d say, ‘We are very happy with you but what exactly have you been doing?” laughs Pennings. “It was a very free time.”

In 1963, Pennings was just having a regular day fractionating out different polyethylene lengths from a solution so they could be studied for their properties. When he decided to stir the solution to see what happened, he noticed a strange thing: wisps of what he knew to be the longest polyethylene crystals were forming around the stirring rods. This set him thinking: *If they were the longest, they must also be the strongest…*

“It’s funny to think it all just started with some stirring in a pot,” laughs Pennings. By 1968, he was able to pull these wisps out in the form of a thread-like material. “In a sense it was simple: we’d have this string of swollen stuff and we’d hold it over a hot plate and stretch it out with our hands. The solvent would evaporate out, and we were left with a tiny string – a really strong polyethylene fiber.”



OLD PATENT FROM ALBERT J PENNINGS' ARCHIVE

While the discovery initially brought Pennings the wrath of his boss, his publications gave him global fame. He was soon named professor at the University of Groningen where he continued his work – producing several more generations of polyethylene fiber obsessives. He also remained a consultant for DSM who he would call whenever a promising PhD student needed support on polyethylene research. DSM would pick up the tab in return for the patent.

FROM GRAMS TO TONS

So how do you transform grams of wispy stuff into tons of product ready for a multitude of uses? Especially when DSM was not a fiber company and Kevlar was already established on the market as a strong and light "magic fiber".

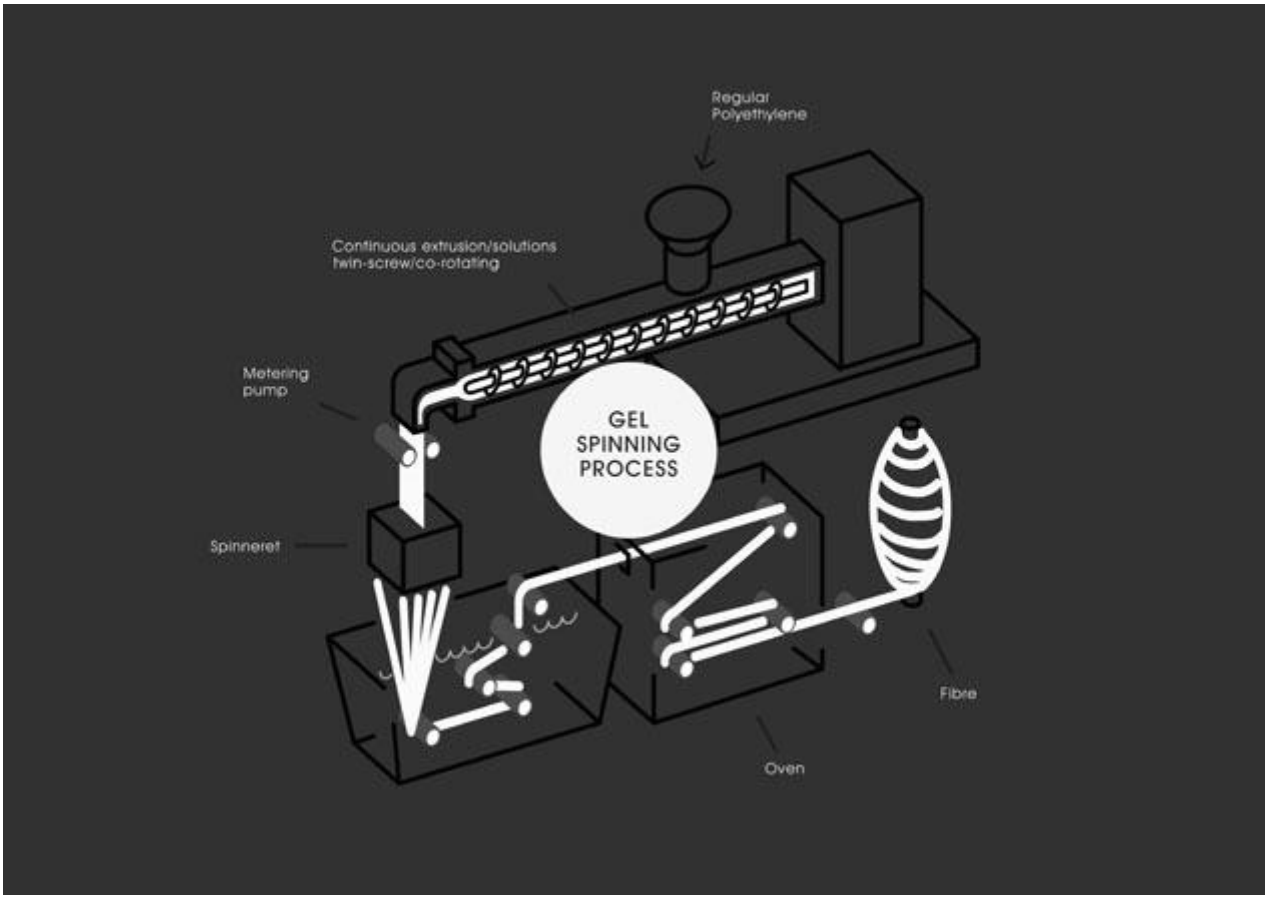
It was only in 1978, that DSM asked employee Paul Smith, a former PhD student of Pennings, to look into scaling up Pennings' process. Later, another DSM employee, Piet Lemstra, who also earned his PhD at University of Groningen just across the hall from Pennings, joined him.

Huge stirring rods were built. Experiments were undertaken. But nothing worked – Smith and Lemstra were unable to scale up production.

"Paul and I were quite good friends," recalls Lemstra (1946). "We were frustrated by the lack of progress and we were sitting having a beer. We started to wonder whether it was possible to use a gel state first as a precursor to making a fiber. So we started experimenting on a Wednesday and by Friday we had something we could easily stretch out. We left it lying on the table over the weekend and on Monday it was still stretchable even though the solvent had totally disappeared. It had stayed in its disentangled state! This was the beginning of making Dyneema® on an industrial level."

"It's actually very simple. The more you dissolve the long chain molecules in a solvent, the more they become separated. Then you cool it down to a gel state and the molecules are more or less disentangled, so it is easy to stretch them. You can then remove the solvent, or later, during the stretching/drawing process – either way you end up with nearly perfectly aligned molecules," says Lemstra.

Put more simply using a common metaphor: the long molecules had turned from a mass of chaotic cooked spaghetti into an elegantly aligned pack of uncooked spaghetti.



More experiments followed – and not all of them following the safety regulations now entrenched in the DSM of today. Lemstra: “At that time, we were using this solvent in very high concentrations. So we could only work with it during the weekend because of the smell. One Saturday I remember asking someone to go get us some coffees but he couldn’t walk because the rubber of his shoes had partially dissolved and he was glued to the floor.”

The resulting 1979 patent for gel spinning earned the two chemists much academic acclaim and awards. In 2010, it was even part of a series of stamps that celebrated the 10 most important patents in Dutch history – which included LED-lighting and solar cars.

But with his name not on the patent, Pennings felt bypassed. A dispute followed and his working relationship with DSM ended. Meanwhile, Smith moved to Dupont and the project was left with Lemstra. Unfortunately, DSM management still did not believe in the product. Their negativity only increased after they consulted with a fiber-producing company in the Netherlands.

“This company said the fiber was just candlewax unable to resist high temperatures and it lacked any good properties. They saw no future in it,” says Lemstra. “And the management at DSM believed them.”

So, the management killed the project in 1982. But afterhours, the maverick science continued…

ALLIED FORCES

Chemical engineer Rob Kirschbaum (1952), at that time a manager of a DSM pilot plant, became a believer in polyethylene fibers while driving home with his neighbor and colleague Paul Smith on the night after the gel-spinning discovery.

“I picked him up and he said, ‘I made a crazy invention. I will not be able to sleep tonight because the fiber we made is about ten times stronger than steel – and this single filament is nothing, you can barely see it. And this is a process that can be scaled up!’” recalls Kirschbaum.

“I was sold. This was a real breakthrough! So I became the cheerleader of the gang.” Kirschbaum’s evangelical skills proved formidable – skills he perhaps picked up from his father, a leader of the Mormon Church in the Netherlands.

But DSM management still lacked the zeal. “I needed 400 000 guilders to build this pilot line,” recalls Kirschbaum. “And to that they said: Are you out of your mind? We have no spinning knowledge. We have no fiber market knowledge. First, find yourself a licensee or a partner – preferably both.”

As the project was put on hold, the science continued undercover. “I was part of a team which you would call a skunk team. Mavericks. We did experiments on weekends and holidays because then we’d have the place to ourselves. We’d jump over the gate to get into the lab and our wives would come by and slide us pizzas through the bars.”

But such subterfuge would later prove essential. “We were working on what would become the twin screw extruder, an invention of Han Meijer. It multiplied the solution concentration and expanded the financial feasibility by a factor of four or five. Without that, Dyneema® would have never have become a commercial product!”

“Excuse me, could you please tell me what the value is of a cooked soldier?”

Around that time, Allied Signal (now Honeywell) in the US got a patent that was remarkably similar to that of DSM’s – but Allied’s fiber had a melting point 20 or 30 degrees above the original melting point of the polymer. “When we saw this, we couldn’t believe our eyes,” says Kirschbaum.

And indeed, after some investigations and experiments of their own, the DSM team could prove that the fiber was actually the same as their original patent. In turn, Allied was convinced that they needed a license for this original Dyneema® patent.

With the resulting license fee and running royalty enough to keep DSM’s research and development funded for several years, management began seeing a future for Dyneema®.

Meanwhile, Allied used the license to produce their own polyethylene fiber, Spectra, as a direct threat to the dominance Dupont’s Kevlar held in the ballistics market. Nervous, Dupont

started a campaign showing how Spectra, as a polyethylene fiber with a low melting point, would become less effective in stopping bullets at around 80 degrees Celsius.

“When I saw this being presented at a scientific conference, I just laughed and put up my hand to ask a question,” recalls Kirschbaum. “Excuse me, could you please tell me what the value is of a cooked soldier?”

JAPANESE SUN

Then with Japan’s Toyobo, DSM found the partner they needed to go commercial themselves. Toyobo had over a 100 years of spinning experience and 1001 ideas on how to apply the fiber – from fishing nets to stringing together pearl necklaces that would be impossible to rip off one’s neck to steal. “I must say they were quite creative with their ideas,” recalls Kirschbaum.

A joint venture was formed and together they started to build a pilot plant. But first, a few cultural walls had to be hurdled.

“We already wanted to brand the product Dynema – with just one ‘e’. We thought it was a great name, combining the Greek words for strength and fiber. But the Japanese said: with ‘dy’ we think of daikon, a large radish, which we use to describe short and ugly legs. And ‘ne’ sounds like our number for two – and we want to be Number One!” laughs Kirschbaum. “And, I think ‘ma’ had something to do with their mothers-in-law.”

“So we said how about if we add an ‘e’ and make it say Dyneema®. They finally agreed and Nippon Dyneema was born. This story is a nice example of how DSM and Toyobo cooperated: showing you’re flexible while still pushing through what you wanted…”

“We really managed to set up a coherent and cooperating team with them. I loved it. I still remain good friends with my Japanese counterpart. There was little negotiation at that time, since we were all chasing the same target. We wanted this pilot plant up and running. We also needed each other – we couldn’t have done it separately.”

Backed by a partner already sending through samples and a lucrative license deal with Allied, DSM could now afford to scale up their own production lines.

ENTERING THE ARENA

“My job was to turn the Dyneema® project into a business,” says Jos Schneiders (1951) who became the director of the Dyneema® project in 1989. “It was a totally new product based on totally new technology – we had to build a plant here in the Netherlands and bring it to market. Moreover, DSM was absolutely not a fiber company.”

“Toyobo brought in their yarn technology to Heerlen but there were still problems with the stability of the yarn,” says Schneiders. “Our technology manager, Koos Mencke, disputed the Japanese technology. So I said, here is a half million to research and prove that your way regarding technology is the way to get to a more stable yarn. And within half year he proved himself to be right: the yarn was stronger and more stable than that produced by Nippon Dyneema or Spectra.”

“The start-up phase lasted a year. That was considered quite a long time and our management became nervous. It was a wild and hectic time to keep everyone on-board. But it was also an exciting time, especially for a young man. Fighting our management who didn’t believe we could do it. Fighting the existing market that couldn’t believe that yarn could be so strong. We were constantly fighting against traditional mind-sets.”

While in the past, all the subterfuge around the development of Dyneema® usually involved scientists, Schneiders – as a believer – now had to pull his own guerrilla maneuvers on the business side.

“At one point in 1993, the management wanted to sell Dyneema® to another company. I was told to calculate our value. So of course I made some precise mistakes to make sure the price

was too high. And indeed, the potential buyers also thought it was much too high," recalls Schneiders with a laugh. "Meanwhile we were busy with the second generation plant and the first generation line was hitting the market and doing very well. So, the prospective buyers came back a half-year later to say that they would pay the price. And then we said, sorry, but the price has now doubled."

> "You need the room to go just beyond the borderline of what's allowed – only then can you succeed."

Meanwhile, the market had to be won over. "At the time I took over, we were developing literally 1001 applications – really the strangest ideas covering a huge range. But our team was small so one of my first decisions was to focus on three applications: body armor, yarn lines for sailing and mooring systems for container ships and oilrigs."

To convince the skeptical markets, the 'seeing is believing' approach proved most effective: body armor that could stop bullets from a Kalashnikov, and mooring lines breaking the machines meant to test them.

"With today's rules for safety and control, it would be almost impossible to bring something like Dyneema® to the market. Plus, you need the room to go just beyond the borderline of what's allowed – only then can you succeed. It's there where innovation happens. I was lucky since I had someone on the board of directors who was also a believer. He told me to just try to answer the board's questions as best as I could and he'd have my back. And we managed it: we proved the impossible!" enthuses Schneiders.

"Even now, twenty years later, I still get excited thinking about that period."

SHARING THE SPOILS

By 1990, Dyneema® had taken its throne as the strongest fiber in the world. And as commercialization and scaling-up capacity became the priority, science was forced to take a backseat again.

“Dyneema® had a tough time at the beginning to find the right applications and markets. But once they did, we couldn’t make it fast enough,” says Tim Kidd (1974), one of DSM-Dyneema’s current New Business Development Managers. “By the early 2000s we were more of a plant manufacturing company – continuously adding new production lines. Which is great because we were making lots of money. But it went counter to fundamental research.”

“There was some frustration with the scientists because they didn’t want to produce more of the same. They saw so much more potential – that the bigger picture was being missed in terms of both the product itself and its potential applications.”

In 2008, DSM-Dyneema began opening itself up to a bigger picture: namely, those other 1001 market needs that can be met by developing and producing improved grades of fiber.

“That’s where we are now. We no longer start from the science, but from a problem or opportunity in the market. We then use our science and know-how to bring out another next best fiber. Exploring this with new commercial partners in new industries is a deeply inspiring process!” enthuses Kidd.

“Dyneema® is such an enabling material in so many different ways. It has such amazing properties. If you see it and touch it, you still won’t believe what it can do – it intrigues you… I think it should be seen as a problem solver – as a way to solve real-world problems.”

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The young Brazilian textile engineer Marina Calazans-Behn (1984) was brought in as R&D Project Engineer Life Protection. She was also attracted to the versatility of Dyneema®. “It’s a fiber with so much potential and flexibility. You can do so many things with it: from stopping bullets to having a suture on your body.”

She’s worked on ballistics and cut-resistant gloves, and is now focused on expanding the potential in using Dyneema® for high-performance apparel – to build on already successful applications in outdoor gear, fencing and bicycling. She sees the fiber’s recent use in the popular Levi’s® 501® Strong denim series as proof that Dyneema® will have a growing influence on the apparel world as people recognize how the fiber can enable longer life and exponential.

She considers her forbears as heroes: “As scientists – and passionate people – we can’t stop thinking if someone says NO. This really happens a lot. I’ve worked on several projects that have been stalled because a company thinks it will take too long, so let’s not do it now. But we still want to understand it and work on it, and spend for example, our Friday afternoons on it…”

And what has she come up with on a ‘Friday afternoon’?

“I cannot say because they are still being patented,” she laughs.

TO THE STARS…

When asked what his fantasy science fiction application for Dyneema® would be, Harm van der Werff (1963) looks embarrassed. He’s Principal Scientist Material Properties of Fibers at Dyneema® and a former PhD student of Pennings.

“I tend to think about the unique properties – and not immediately about how it will be used. I think our system is like having a Ferrari but that we’re still in the bicycle races. We can still go to other levels. We know we have the potential to make it stronger and lighter by at least a factor or two. And with other properties even more so – by a factor of 10 or 20.”

“Other people can dream up the applications. Then I can focus on what I love about working with Dyneema®: making that transition from thinking about tiny invisible molecules to having something tangible in your hands – something you can pull or even shoot! That you think about molecules and then, end up with a bulletresistant vest or moorings for an oil rig...”

“Dyneema® also has the beauty of simplicity. Being simple and effective is the highest degree of something. If you look at a polymer textbook, there’s polyethylene on page one – it’s only carbon and hydrogen. It’s so simple, but it’s so amazingly versatile.”

“And it all started with one surprising experiment by Pennings who said hey look, some fibers are being formed – maybe I’ll just get a wire and try to fish it out… It’s like a magic trick! And that material had nearly the same strength as what we still mix for our normal commercial level!

“I think people call that serendipity.”

Membrane holds back the waters: ‘Tsunami Catcher’

“We now know that a one-centimeter thick membrane made of Dyneema® is enough to stop a 20-meter high tsunami,” says DSM scientist Roel Marissen. After the shocking fatalities caused by the tsunamis in the Indian Ocean in 2004 and off the coast of Japan in 2011, Marissen began to wonder how we can better protect ourselves from these earthquake-caused waves. He and his team came up with a flexible tsunami barrier made out of Dyneema® membrane that floats into place. It might sound like science fiction but it’s already been modeled and tested together with Delft Technical University. Watch the demonstration video here.

Extreme extremes: G-force resistance

The young Swiss company Development Never Stops uses Dyneema® as they develop and prototype innovative designs for highly technical garments – from extreme sportswear to G-resistant suits for military jet pilots. During their constant experiments with new fibers and weaves, “We found the combination of lightness and strength with Dyneema® to be super unique so use it regularly. We use Cuben fibers for super lightweight applications such as emergency jackets for mountaineering or ultra running gear, in the form of reinforced fabrics, sewing threads and reinforcement embroideries,” says Marcel Geser, one of the company’s three partners. “We’re now looking to laminate it with other materials for lightweight waterproof garments, and how to apply it in other high-end functional applications – such as backpacks and footwear.”

On the beat: NYPD to wear lighter, thinner and more effective body armor

Over 20,000 New York City policemen and women will be wearing bullet-resistant vests made from Dyneema®. The Alpha Elite™ body armor is 20% lighter and 30% thinner than the vests currently used – and also has wraparound protection. In surveys, police officers often admitted they rarely wore the previous vests and that often slowed their emergency response as they retrieved their vest from the trunk of their cruiser. Now, officers say their new vests are comfortable enough to wear all day. In an interview, NYPD Police Commissioner Bill Bratton described the vests as the “Rolls Royce” of ballistics protection.

Taking on chainsaws: flexible safety gloves

Over 70% of industrial accidents occur because workers do not wear their uncomfortable safety equipment. So chainsaw manufacturer Stihl went in search of a glove that their cutters

would actually wear. They found Ansel's HyFlex 11-518, made from Dyneema® Diamond Technology – the same integrated yarn that Hunter Sportswear uses for their hockey gloves. Besides being thin, light and comfortable, HyFlex gloves also remain cool due to the fiber's heat-conducting properties. "This glove offers high cut resistance and leaves our employees with a safe feel for the parts," says Stihl's Roland Zürcher. Result: higher productivity and less insurance costs.

Tour de Derriere: bicycling bib shorts that don't shred

It's always a powerful image during Tour de France: bicyclists crashing and exposing their shredded thighs. In 2015, Team Giant-Alpecin debuted their Dyneema®-enhanced bib shorts to make such images a thing of the past – no rip, no red. The innovation, which will soon be available to amateur riders, is the result of close collaboration between the team, DSM Dyneema, fabric-manufacturer Taiana and the team's clothing supplier Etxeondo. "Riders need to feel safe and comfortable," says the team's CEO. "The protection and safety offered by incorporating Dyneema® helps substantially in the reduction of wounds and injuries of the riders which give a positive impact on their performance." Meanwhile, other companies are also using Dyneema® to construct bicycles, such as the String Bike that uses the fibers in its fail-safe, drive system.