Material mix from the **food processor**

Valerio Molinari and his team at the **Max Planck Institute of Colloids and Interfaces** in Potsdam have equipped their laboratory with a pasta machine, pizza oven and mixer. What's more, the scientists often use waste from the forestry or food industries in their experiments. They can use these simple resources to manufacture wood-based materials, bioplastics and biofuels.

TEXT **PETER HERGERSBERG**

It was a cookery contest with scientific implications. "My boss and I had a discussion about what goes into a proper ragù," says Valerio Molinari from Italy, adding with mock disgust, "In Germany they call it bolognese sauce – heresy!" In consequence, the researcher, who was doing his doctorate at the Max Planck Institute of Colloids and Interfaces at the time, and his Director Markus Antonietti set up an Italian cookery contest. In the Department's small kitchenette, the two scientists each cooked for around 20 colleagues using their own recipes. No vote was planned; if necessary, the contest could have been decided by the number of half-full plates left at the end of the evening.

In the end, both variations turned out to be very popular despite their differences. "As a good scientist, Markus Antonietti is keen on experimenting – he calls his style 'fusion'," says Valerio Molinari. "For my part, I cook the sauce just like my grandmother did."

While the culinary results of the contest soon disappeared, the researchers were left with an idea that had first been put on the table that evening: the idea of practicing technical chemistry with kitchen equipment and ingredients.

ONE INCENTIVE: MATERIALS THAT ARE EASY TO MAKE

This idea actually came quite naturally: after all, chemistry is always happening in saucepans, frying pans and baking tins. Nearly 30 years ago, some chefs made quite a fuss about enhancing their creations using methods employed in chemical labs – this was known as molecular gastronomy. But how would this work in reverse? A pizza oven, a pasta machine, or even a fancy utensil like a sous vide cooker on the lab bench? And semolina, vanilla or egg whites to create materials made from renewable sources? Valerio Molinari and Markus Antonietti had never heard of such a thing, even though chemists often talk about cooking in connection with their experiments.

"It goes without saying that kitchen utensils can't set the temperature as precisely or be programed as flexibly as a lab device that mixes and heats substances for chemical reactions," explains Molinari. "In principle, though, they do the same thing at a fraction of the cost." This is one of the main motivations behind the kitchen lab, which Molinari – now as the leader of a small research group – constructed about four years ago.

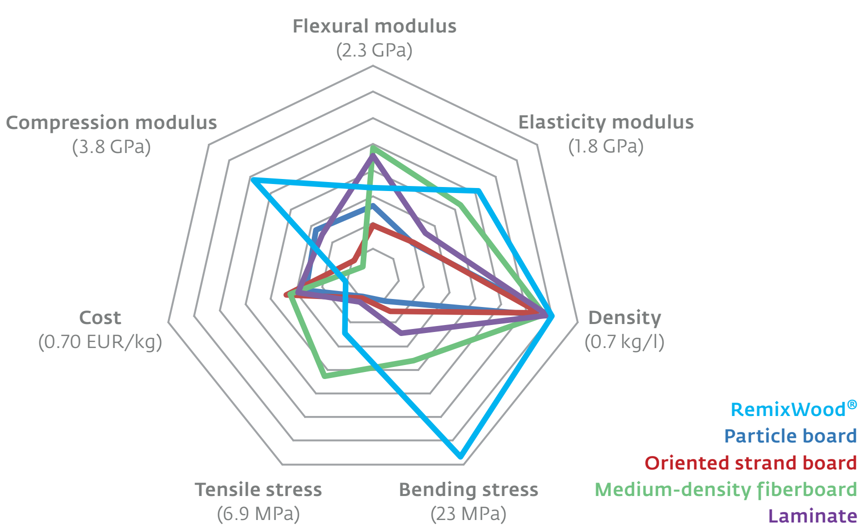
"The chemical industry often reacts sceptically to developments in academic research," he says. The developments that scientists present so proudly work well with expensive laboratory equipment and the extremely pure chemicals normally used for research purposes, However, it is often impossible to use these great innovations in industrial

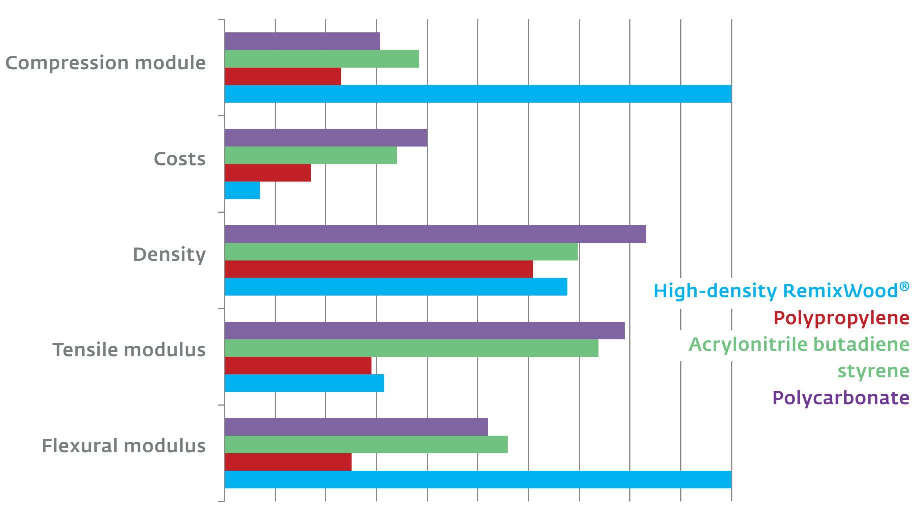
An indigestible baking mixture: researchers in Potsdam kneading a dough made of waste from the paper and food industries; this turns into a durable wood-based material when baked in the oven.

Photo: Valerio Molinari / MPI of Colloids and Interfaces production facilities. "By using kitchen equipment and natural ingredients, we are demonstrating that our materials are easy to make."

Despite being inedible, the Potsdam-based researchers' creations could be a mouthwatering prospect for furniture manufacturers, the cosmetics industry or biofuel producers – not least because Valerio Molinari and his team have been relying heavily on renewable resources ever since the start. They even purchase some of the ingredients for their recipes in the supermarket.

RemixWood®, for example, is a special product developed in the lab. Valerio Molinari developed this material together with former Group Leader Nina Fechler, who now works at the Charité, Berlin's university hospital. This material has many of the properties of wood but is more durable and can be processed into almost any shape. It could therefore be used instead of particle board when manufacturing furniture, for example. Another advantage of the material is that it could be an alternative to plastic, as it is more rigid, less prone to warp and cheaper than some widely used plastics. Some of the sustainable components it contains were even formerly classified as waste. "What's more, our RemixWood® – unlike a lot of particle boards – doesn't release formaldehyde, because this isn't needed during processing," says Molinari.





A WOOD-BASED MATERIAL MADE OF INDUSTRIAL WASTE

Molinari and Shekova are accelerating the process of developing the material. Shekova is testing the ideas put forward by Molinari and his colleagues by performing systematic experiments. "She's much more organized than I am," says Molinari, while the lab technician prepares various pastes: RemixWood® and some of its predecessors in their raw state. For this, she starts by weighing a plastic bowl full of cellulose, which is stored in the lab in a large plastic bucket. "We use inferior cellulose left over from paper production," explains Molinari. "You could say that it's the framework on which our materials are built."

Above The researchers in Potsdam compared the costs and mechanical properties of RemixWood® and other wood-based materials with the same density. Their reasonably priced material has outstanding compression and elasticity moduli. The modulus measures the force required to deform a material in a specific way, e.g. by compression. RemixWood® can also withstand considerable bending stress before it breaks.

Below RemixWood® compares favorably to various plastics due to its low cost and high compression and flexural moduli.

Graphics: Valerio Molinari / MPI of Colloids and Interfaces

Versatile material: Irina Shekova makes RemixWood® with various degrees of density by submitting the paste to varying amounts of pressure. One of the material's components is lignin, which comes from the woody parts of plants, i.e. from nutshells or bamboo (below).

Photos: Valerio Molinari / MPI of Colloids and Interfaces (2)

Next, Irina Shekova spoons yellow powder from another bucket into the mixture: this is gluten, which mills remove from certain flours because it clogs some people's intestines, as a result of which they are no longer able to digest food. Despite being life-threatening for some, this property is exactly what Molinari finds so interesting about gluten. Gluten is a mixture of various proteins that are brittle when dry but become tough and sticky when wet.

Shekova and Molinari mix cellulose and gluten with various other ingredients to create assorted pastes. They spread the mixtures in square tins reminiscent of Christmas cookie molds, although they don't leave a design in the dough. The material is baked in a device that is unlikely to be found in any kitchen: a combination of oven and press that is reminiscent of one of the grim-looking nutcrackers from Germany's Ore Mountains. Molinari puts the paste-filled tins into the heatable jaws of the hydraulic press and uses the lever to compress them under ten tons of weight. This makes the material very firm and dense. If the researchers wish to manufacture a lighter material, less pressure is used.

The compressed pastes are then baked at 135 degrees Celsius. An appetizing aroma spreads throughout the lab while they are cooking. This is because Molinari added vanilla to one of the mixtures as an additional adhesive, as gluten alone does not bind the chain molecules in the cellulose sufficiently. The researchers have also tested turmeric for this purpose. This gives the paste an intensive yellow color and a spicy note. "We started by using vanilla and turmeric, because these substances – like ordinary adhesives – contain a chemical group called phenol," explains Molinari.

However, neither of these substances yielded optimum results. Vanilla produced a usable material, but this spice is relatively difficult to manufacture and is consequently more suitable for vanilla cookies than for furniture. Turmeric was also a contender for use as a binding agent in RemixWood®; however, the product it yielded was crumbly. "We finally hit on the idea of using lignin, which also contains plenty of phenol groups," says Molinari. Lignin makes straw and wood rigid and is left as waste when cellulose and hemicellulose are extracted from lignocellulose, e.g. while being made into paper.

FLAME-RETARDANT INTERIOR

Before using the biopolymer in their wood-based material, the researchers treat it chemically to make it bond better with other components. The prepared lignin, cellulose and gluten are kneaded into a dark brown dough that looks just like an appetizing dark bread. However, once it is baked, the mixture becomes harder than particle board – you could easily break your teeth on it. With its long, widely branching chain molecules, lignin not only makes the material particularly stable but is also cheap and plentiful, being as it is a waste product from the paper industry. The fact that two of the components come from wood inspired Nina Fechler to create the name RemixWood®.

The material not only scores points for being stable and sustainable, it can also be furnished with various extras. "Using powders to manufacture RemixWood® means that we can also give it a variety of properties," says Molinari. Normally, wood-based materials can only be treated on the outside, for example with flame retardants or fungicides. As soon as the product becomes worn, it loses its protective layer. "These properties are also found in the interior of our material," says Molinari. It can also be dyed all the way through or even turned into a wooden magnet by adding magnetic particles.

Due to its many advantages, Nina Fechler and Valerio Molinari believe that RemixWood® will be a market success. "We are hoping that a company will pick up on this material and find practical applications for it, for example as a substitute for particle board in furniture or for conventional plastics," says Valerio Molinari.

Nikki Man is also working on an alternative to plastics made from fossil resources; this consists of bioplastic sheets. She too is mixing various pastes to demonstrate the properties of various compounds. For this, she is mixing gluten glycerol, which when dry is less brittle than ordinary gluten, with other components such as lignin. However, she is also working on a mixture containing chitosan, a nitrogenous polysaccharide extracted from the chitin found in the exoskeletons of shrimp. The chemist mixes the pastes thoroughly and forms them into spheres the size of marzipan balls. She then flattens these spheres between two metal plates, puts them in the nutcracker oven and compresses them to the thickness of foil. While the mixtures melt to form bioplastics, Nikki Man talks about another project.

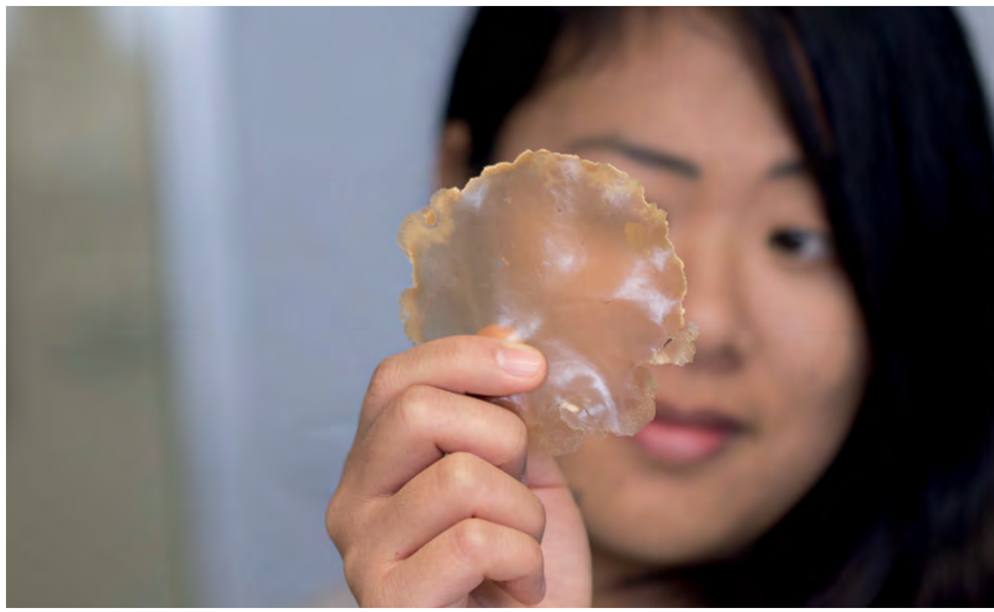
"We want to produce stable emulsions, for example for cosmetic production and the pharmaceutical industry," explains the chemist. Many emulsions consists of oil droplets finely dispersed in a watery medium – however, without some kind of agent, they will not usually stay this way for long. Oil and vinegar in salad dressing, for example, separate quickly unless the dressing is stabilized by adding mustard. Cosmetic and pharmaceutical creams are often stabilized by adding microplastics, which at some point contaminate water supplies and can also end up in the human food chain.

AN EMULSION IS STABILIZED IN THE SOUS VIDE COOKER

In her search for an alternative to environmentally harmful plastic particles, Nikki Man combines laboratory chemistry with culinary techniques and also borrows ideas from mayonnaise. This mixture of oil and vinegar or lemon juice gets its wonderfully creamy texture from the lecithin and proteins found in egg yolk. The chemist also utilizes the stabilizing effects of proteins in her oil-in-water emulsions by adding the protein albumin, extracted from cattle serum, to her mixtures. She then dips an ultrasonic wand of the type used in laboratories into her mixtures to make the emulsions particularly homogeneous. The fine, inaudible shock waves break up the oil into microdroplets or even nanodroplets that are coated in protein molecules and are all roughly the same size.

Now the emulsion has to undergo one more procedure which Nikki Man borrowed from the kitchen. "This is our sous vide cooker," says the researcher proudly, pointing to a wand suspended in water-filled glass basin the size of a microwave oven. Such devices were first used by French chefs to prepare vacuum-sealed meat in order to make it particularly tender at temperatures of less than 100 degrees Celsius. Nikki Man uses the moderately warm water to convert the protein coating of her emulsified oil droplets

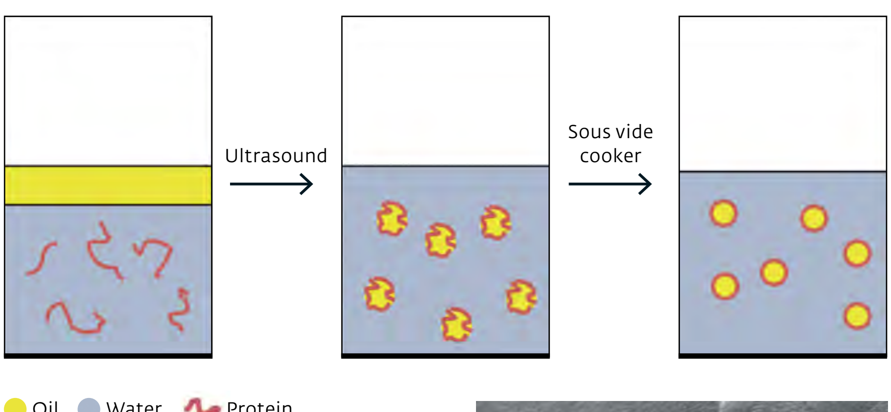
Plastic made from renewable resources: Nikki Man mixes various ingredients to make bioplastic sheets. Gluten and glycerol yield a transparent material.

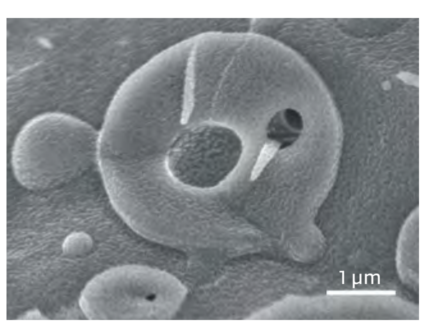


into stable shells, thus making the emulsion more durable. There are lab devices that can keep water baths at a constant, precise temperature, but these are many times more expensive than the kitchen version.

While the researcher explains how her emulsions are prepared in the sous vide cooker and shows computer images of the oil-filled protein spheres taken by a scanning electron microscope, the bioplastic finishes cooking in the oven press. The gluten glycerol and lignin sheet, ocher yellow in color and sprinkled with dark dots, can only be removed from the carrier plate with difficulty and shatters at the first attempt to bend it. The transparent, reddish brown version containing chitosan fares somewhat better, but is still not flexible enough for tear-resistant packaging. "We now want to test a chemically modified form of lignin, which mixes better with other components and should therefore contain fewer predetermined breaking points," says Nikki Man.

If the plan succeeds, the researchers will have found a way to produce a flexible variety of RemixWood®. This wood-based material is itself inflexible, as Valerio Molinari and Marius Bäumel found out. "We got a pasta machine especially for testing purposes," says Molinari. They used the machine to make spaghetti, tagliatelle and penne out of the paste. These noodles are also easy to shape when raw; Molinari even used them to weave a braid. Unfortunately, the material was no longer as elastic when it came out





An ultrasonic wand is inserted in a mixture of oil, water and protein to produce uniformly sized oil droplets coated in protein. The moderate heat of the sous vide cooker then stabilizes the protein coatings and consequently the entire emulsion. The size of the oil droplets depends on the quantity of oil in the mixture. An image taken by a scanning electron microscope (right) shows an oil droplet in a mixture containing 30 percent oil.

Photos: Valerio Molinari / MPI of Colloids and Interfaces Graphics; graphic: Nikki Man / MPI of Colloids and Interfaces

Catalytic pasta: Valerio Molinari (top left) and Marius Bäumel turn a dough containing a large quantity of wheat semolina into thick spaghetti. After cutting it up, they roast it to obtain highly porous pellets (right). These serve as carrier material for a catalyst that facilitates the efficient production of the biofuel DMF.

of the oven; under gentle pressure, the braid simply crumbled away.

However, this vital piece of Italian kitchen equipment still turned out to be a good investment, since the researchers have now found a pasta recipe with a promising application. They call their creation catalytic pasta. It can be used as a chemical moderator, for example in the production of biofuels and other bioproducts manufactured by the chemicals industry.

Molinari hit on the idea of using catalytic pasta for the production of biofuel in cooperation with his office neighbor Majd Al-Naji. He too leads a working group at the Max Planck Institute of Colloids and Interfaces, where he is seeking ways to do chemistry with renewable resources. “We want to convert agricultural and forestry waste into fuel and source materials for the chemicals industry,” says the chemist.

Dimethylfuran, DMF for short, is one of the possible candidates for the biofuel of tomorrow. The energy density of this substance is almost 50 percent higher than that of ethanol; moreover, it has an octane rating that makes it even better suited for use in combustion engines than ordinary gasoline. DMF can be obtained from lignocellulose, which is found for example in plant waste. However, chemists need a suitable catalyst to extract lignocellulose from this bioresource, as it is not very susceptible to chemical changes.

Fortunately chemists have already known for a long time that nickel nanoparticles in a suitable carrier material are very good at catalyzing the formation of DMF. A structure consist-

Photos: Valerio Molinari / MPI of Colloids and Interfaces (2) ing of carbon and nitrogen has proven to be a good base for the nickel particles; the larger the area it provides for the reaction, the better. This means a substance with countless fine pores is needed; this substance must be available in the form of pellets the size of pharmaceutical capsules. "Manufacturing large quantities of these pellets is a very complex process," says Molinari. He and Marius Bäumel have found a remedy in the form of an unconventional pasta recipe.

AN EFFICIENT CATALYST FOR BIOFUEL PRODUCTION

For the pasta dough, the researchers mix durum wheat semolina with glucose and urea. These ingredients then bond to form a carbon and nitrogen structure, with the carbon being primarily derived from the semolina. The researchers had this specially sent from Italy. "A specific dough consistency is essential for production in the pasta machine," says Marius Bäumel. "Original durum wheat semolina simply has the best properties and makes the perfect dough."

Zinc oxide nanopowder is added to the mixture together with fine salt – ordinary table salt is perfectly adequate. These two substances serve as placeholders for the pores and are washed or steamed out of the finished pasta. The researchers use the pasta machine to press out the dough in the form of thick, light-colored spaghetti that looks quite appetizing. However, all this changes when Molinari and Bäumel process it further.

They start by cutting the long strips of dough into short stumps, then put them into the oven to roast. When Marius Bäumel takes the sheet with the pasta pieces out of the oven several hours later, they are coal black and look as if they would be much more at home in the boiler of a biorefinery than on a plate. As soon as the chemists have removed the zinc oxide and salt from the pores, they soak the catalytic pasta in a nickel salt solution, with which it reacts chemically to form the nickel nanoparticles. "Because it's so porous, the pasta provides a surface area of 700 square meters per gram," says Marius Bäumel. "This means that ten grams have the surface area of a football pitch, which is more than most industrial catalysts can manage."

Studies performed by Al-Naji's team have shown that this large surface area also makes a difference in the production of DMF. The catalyst is extremely efficient and significantly cheaper than competing products produced commercially. "Producing the catalyst in the form of pasta is consequently also a promising approach for industrial companies," says Majd Al-Naji. In the next step, the scientists wish to set up a pilot facility to test the large-scale production of DMF. If the catalyst pellets also prove their worth in this situation, this will mean that another step has been taken toward the competitive industrial production of biofuel.

The fact that the catalyst is easy to manufacture is sure to be another point in its favor. This advantage could also stimulate the appetite of other chemicals companies. If so, the production of catalytic pasta may no longer be limited to the kitchen lab. The research carried out by Molinari's team could inspire other chemists to experiment with kitchen equipment and renewable materials instead of using expensive laboratory equipment and fossil resources. ◂

SUMMARY

- **In the kitchen lab, Max Planck researchers in Potsdam are experimenting with kitchen equipment and renewable raw materials, including waste from industrial processes.**
- **They are using cellulose, gluten and lignin to make RemixWood®, a cheap, durable wood-based material. Similar mixtures are used to produce bioplastics.**
- **Proteins could replace microplastics for stabilizing cosmetic products.**
- **With catalytic pasta, the scientists have found an efficient catalyst for the production of biofuel that is also easy to manufacture.**

GLOSSARY

Cellulose: This polysaccharide, which consists entirely of glucose, is an important component of the cell walls of plants; it is used to make paper.

Gluten: The protein compound found in grains is sticky and elastic when wet; this is what makes dough kneadable.

Hemicellulose: Polysaccharide which consists of various sugars and is also found in the cell walls of plants.

Catalyst: A substance that accelerates chemical reactions or guides them in a specific direction without being consumed.

Lignin: A biopolymer critical for the stability of wood cells.