WELCOME TO THE AGE OF WOOD

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Did you hear about the wooden car, with wooden wheels, a wooden chassis and a wooden engine? *It wooden go.*

Or would it? In a few years' time, when people really are driving wooden cars, that joke will be headed for the junkyard.

"Wood could be used in cars," says materials scientist Liangbing Hu at the University of Maryland. He recently received a massive grant to build cars out of high-tech wood, and he doesn't have the road to himself. Engineers in Japan are also working on a wooden concept car due to be unveiled at the Tokyo Olympics in 2020.

But cars are just the green shoots of a growing wood revolution. In materials science labs and design studios around the world, people are working on an entire civilisation built from wood. In this future, steel, concrete, plastics and even electronics have been felled by wood.

Wooden cars ply streets towered over by wooden skyscrapers with wooden windows. Wooden aeroplanes fly overhead, powered by wooden batteries. People wear wooden clothes and use mobile phones made from wood. It may sound like toy town, but it is deadly serious.

The stages of human civilisation have always been crudely measured by material progress. The Stone Age gave way to the Bronze Age and then the Iron Age. Today, we live in the hydrocarbon age, fuelled by coal, oil and gas. They supply our energy needs and make possible the materials that define our civilisation: steel, concrete and plastic.

But this has to end. To avoid trashing the planet with plastic waste and carbon dioxide, we will have to stop using hydrocarbons, and soon. The way to get there could be to create a circular economy built on sustainable materials, especially wood.

Wood has long been part of the material mix, of course, used in buildings, tools and for energy. But in the not-too-distant future, it may be the dominant material. "Everything that is made from fossil-based materials today can be made from a tree tomorrow," says Åsa Ek, chief executive of Finnish-owned materials company Cellutech.

But not wood as you know it. Sure, raw wood has many useful properties: it is strong, yet light and flexible. It is beautiful and economical. It literally grows on trees.

But it also has some serious disadvantages that caused it to be overtaken by other materials. Its properties are unpredictable. It burns, cracks and rots.

It is bulky and non-transparent. But the same can be said of other raw materials. Crude oil, iron ore and the basic ingredients for concrete are of little use as they are. To unlock their potential they have to be processed.

The same is true of wood – we just have to discover how, and then build the infrastructure to do it. When we have cracked that, we will enter the Wood Age.

The first place where wood is likely to replace unsustainable materials is in buildings. It already has a long history as a construction material, but its disadvantages mean that new buildings are mostly made from steel and concrete. These are great for construction but appalling for the environment.

Steel production accounts for about 3 per cent of the world's greenhouse gas emissions and concrete about 5 per cent. That is not sustainable.

According to the recent report from the Intergovernmental Panel on Climate Change on keeping warming below 1.5°C, the drastic emissions cuts required mean building construction has to be carbon neutral by 2020. That almost certainly means radically cutting down on steel and concrete.

Luckily, this is already starting to happen thanks to a wood-based material called cross-laminated timber (CLT), which can replace both. CLT is made by gluing sheets of wood together – usually from Norway spruce or beech trees – to create large, flat slabs. These can be stacked to make buildings like giant Jenga blocks.

Unlike Jenga, there is no risk of this stuff falling down.

Steel and concrete in construction account for 8% of global carbon emissions

CLT is wood turned up to 11: it is pimped up timber. "It's an engineered material, not like a plank you get from a hardware store," says Darshil Shah, an engineer at the University of Cambridge's Centre for Natural Material Innovation. Unlike raw wood, it has predictable and reliable material properties, created by layering the grain of each sheet at right angles to the previous one. That imparts a steely strength and also makes CLT long-lived and surprisingly fire-resistant.

CLT was invented in the 1990s, but is growing in popularity thanks to an ongoing race to build the world's tallest wooden skyscraper. The current leader is an 18-storey student residence in Vancouver, Canada, which was finished in 2017. This year it will be overtaken by a block in Brumunddal, Norway. And more are on the drawing board, including an 80-storey, 300-metre tower planted right in the middle of London's Barbican Centre.

Shah says the skyscrapers are raising awareness, but the real action is in mid-rise buildings. An eight-storey wooden building can be prefabricated off-site and put together in a few days. The material can be grown in sustainably managed forests and, given how many of those there are, it is as if the wood for a single apartment takes just 7 seconds to grow.

And while CLT costs a bit more than steel and concrete, it makes construction quicker. Rather than spewing carbon dioxide, it locks carbon away for the lifetime of the building, typically 60 to 70 years. This carbon storage can be a small but useful brake on climate change.

According to a 2017 report on greenhouse gas removal by the Royal Society and the UK Royal Academy of Engineering, switching to timber in construction could instantly wipe a billion tonnes off the world's annual carbon emissions. That is 2.3 per cent of the total – not a huge amount, but in a world where we have to do everything, immediately, it isn't to be sniffed at.

And as cities grow, the potential of CLT does too. Around 65 per cent of the urban infrastructure that will be needed in 2030 has yet to be built. If it is constructed with concrete and steel, we have little chance of keeping temperatures down.

CLT does not eliminate the old materials completely, but reduces them by up to 80 per cent. "We still use concrete for foundations," say Shah. "But a wood building is about a third of the weight of a steel and concrete building. That means we require less deep foundations so it reduces the amount tremendously." Wood also improves a building's insulation, further cutting its carbon footprint.

In the not-too-distant future, wood could even be used in place of glass in windows. A few years ago, scientists at the Wallenberg Wood Science Center in Stockholm, Sweden, invented a way to extract the pigments from wood. The result was a transparent material that can be used like glass, but with better insulating properties – another small step toward a zero-carbon future.

If all this conjures up images of soaring wooden structures resembling the interior of a Scandinavian design studio, think again. The buildings are usually clad, so the wooden structure is hidden. That is a shame, says Shah. "People don't realise that they are timber. Public perception is one of the key things that needs to be addressed."

I went to have a look at 24 Murray Grove, a nine-storey block of flats in London. When it was completed in 2009, it was the tallest timber building in the world. I also dropped in on nearby Dalston Lane, which was completed last year and is the largest CLT building in the world measured by volume. From the outside, you would never know either was built from wood. Nonetheless, says Shah, for mid-rise buildings "CLT might be industry standard in five to 10 years".

Even then, there is more to be done to optimise CLT's carbon footprint. The glue, which comprises about 5 per cent of the final material, is made from petrochemicals. The wood has to be dried in kilns that are often powered by fossil fuels. The drying process consumes about 90 per cent of the energy required to make CLT, says Shah.

The answer to both may be… yet more wood. Wood is already used as a sustainable biofuel, and scaling up that industry plays a major role in all scenarios that keep global warming to manageable levels. It is considered to be a carbon-neutral biofuel, as long as trees are replanted.

Wood is also being developed as a source of raw materials to replace the oil-based compounds that dominate today's chemicals market. This is where wood as we know it starts to disappear, and its integral components come to the fore.

Wood is a complex mixture of organic chemicals. About 40 per cent of it is nanocellulose, bundles of long, strong fibres that are like a natural version of Kevlar, the synthetic material used in bulletproof vests.

"It's a very strong fibre with excellent mechanical properties," says Lars Berglund, director of the Wallenberg Wood Science Center. A further 30 per cent is lignin, a rich mix of organic compounds not dissimilar to crude oil.

The rest is a starch-like substance called hemicellulose. These three components work together to create wood's material properties, and they can all be extracted and processed into useful – and valuable – compounds.

Wood can be turned into a transparent material that can be used like glass

Petrochemicals are another gigantic environmental problem. According to the International Energy Agency, their production consumes about as much energy as steel and cement combined and requires a lot of materials derived from oil. Demand for these by this industry is soaring.

"We would like to replace these fossil resources with trees," says Berglund. To that end, he and his colleagues are working to create a wood refinery that, like an oil refinery, takes crude wood and processes it into valuable end products.

At present, it is little more than a pilot plant made from lab equipment, but in the future it could develop into a massive – and massively sustainable – "arbo-chemicals" industry.

Applications for the end products of this are coming fast. The most advanced are based on nanocellulose. "It's really catching on," says Berglund. "You can make all sorts of exciting materials out of it."

Nanocellulose is already used as a petrochemical substitute in paints, glues, cosmetics, nappies, packaging and electronics. The car industry is exploring it as a replacement for glass fibres in bodywork. Many more uses are likely to follow.

Around 5000 scientific papers are published each year on new applications for nanocellulose, says Berglund – including for clothing.

It can even replace plastic

Next in the queue is lignin. "Lignin is the coming revolution," says Berglund. Today it is a waste product from wood pulp and paper processing, with most of it getting burned for energy or used as an additive in concrete.

But these are a waste, says Berglund. "Lignins are valuable chemicals. There's a lot of activity in chemical companies trying to use it to replace petroleum-based products. The most exciting development is in coatings, adhesives and resins."

The laggard is hemicellulose. This starchy substance is hard to process, says Berglund, but progress is being made. The ultimate aim is to use it to replace the ultimate petrochemical product, plastic.

Nothing epitomises the petrochemical age like plastics. They are cheap, plentiful and useful, but environmentally disastrous. What is not recycled ends up in landfill, as a feedstock for waste-to-energy plants or as almost-indestructible litter. It often ends up crumbling into microplastics, particles of 5 millimetres or less, which are a hazard to the environment and possibly to human health.

Biodegradable substitutes are nothing new. For example, polylactic acid, made from starch, has been used commercially since the mid-1980s. But the existing options aren't ideal. For example, they don't biodegrade well outside industrial composters and they consume valuable, food-grade carbohydrates.

The solution? You guessed it – more wood. Several companies in the Nordic region are working on turning forests into plastics. The European Union's upcoming ban on single-use plastics such as straws, cups and cotton buds can only accelerate the progress. "This is an enormous opportunity to replace single-use plastics with wood," says Berglund.

One company well-placed to take advantage is Stora Enso, a former copper mining firm in Finland that traces its history back to the 13th century.

In recent years, it has reinvented itself as "the renewable materials company", developing a range of wood-based alternatives to plastics. Its Durasense material, for example, is a 60/40 mixture of wood and polypropylene that can be reused up to six times.

Another pioneering firm is Paptic, also from Finland, which is developing a material made from wood fibres to replace plastic bags. As yet, nobody has cracked the big one – drinks bottles – but numerous companies are reportedly working on it.

To see what the future of plastic might look like, I visited the HQ of a start-up called Sulapac in Helsinki, Finland. Its eponymous material is 88 per cent waste wood plus a proprietary binding product made from sugar cane waste. Sulapac won't reveal what the binder is, but says it allows the wood waste to be heated to 200°C and hence processed in existing plastic moulding machinery.

For the moment, Sulapac's only commercial products are jars for expensive cosmetics, but its ambitions are much bigger. "We can't yet replace single-use plastics or long-life products such as scissor handles, but everything short-term we want to replace," says co-founder Suvi Haimi. That means items like plastic cutlery, pens, combs, toothbrushes and phone cases.

Sulapac material is designed to be 100 per cent biodegradable and microplastic-free. Its ideal final resting place is an industrial composter, but if it finishes up in the environment, it degrades completely within a year. "Wherever it ends up, it is better than plastic," says Haimi. And Sulapac is beautiful, warm and smooth, like a cross between wood and ceramic.

The ambitions for repurposing wood don't stop there. In Liangbing Hu's lab at the University of Maryland, scientists are working on using it as a replacement for some of the world's most advanced materials.

Earlier this year, he and his colleagues announced a development significant enough to be published in the journal Nature: a technology totransform soft wood into a material stronger and tougher than high-performance steel and even the titanium alloys that are used in aerospace engineering.

If you drop densified wood on the floor it sounds like steel

Densified wood – they really ought to call it superwood – is made by chemically removing about half of the lignin then brutally compressing what is left at high temperature. This causes the cell structures to collapse and the nanocellulose fibres to align and bond.

The resulting material is a fifth the thickness of wood, but 12 times stronger and three times more durable. It thus possesses a desirable combination of strength and toughness.

"It looks like wood though it's much lighter, and if you drop it on the floor it sounds like steel," says Hu. "It has the potential to replace steel wherever strength is needed but weight isn't." Initially that means the bodywork of vehicles and aeroplanes – Hu recently received a $3.6 million grant to develop the material as a steel substitute in cars – and perhaps ultimately moving parts.

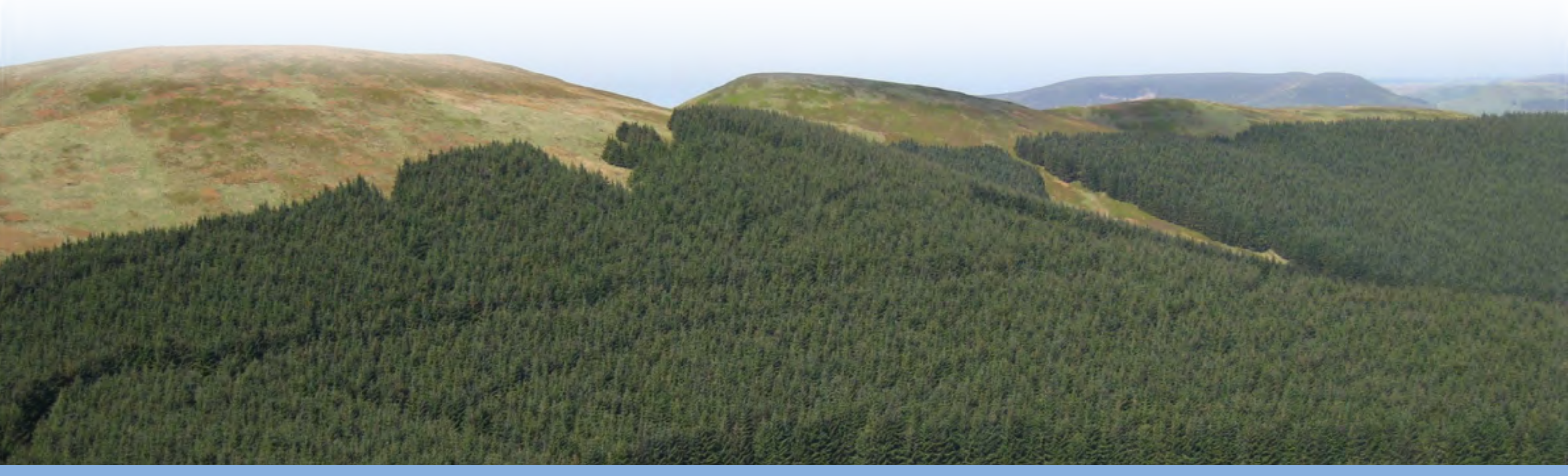
Hu and his colleagues are also looking at the potential for wood to replace expensive, heavy materials in energy storage devices. "We've been developing a technology called the wood battery where you put battery components into the pores," he says.

"One application is for cellphones and vehicles where weight is important. The other is for stationary batteries, where weight isn't that important, but you want the cost to be as low as possible. That's where wood comes in, it is very cheap."

Not to be outdone, Berglund has even made a wooden laser, using an organic dye embedded in the natural channels of transparent wood. "It's not a very good laser, but it is cheap and renewable," he says.

Right now, there are no obvious applications for it – maybe it could be embedded in furniture as a design feature, he says. But it is yet another demonstration of what is possible, and how scientists are changing the perception of wood as a material.

From these tiny acorns, is it really possible to grow a mighty wood-based economy? Materials science is part of the equation. To replace the materials of the 20th century, wood will have to overcome two other obstacles. One is demand for land. Is there enough to grow all the trees we need without affecting food production or causing mass deforestation?



This is a tough question. Sustainable forestry is key to keeping a lid on global warming, but managing the competing needs of agriculture, bioenergy and forest is already a difficult balancing act. Various scenarios for how the world can develop sustainably this century produce wildly different estimates of forest cover, ranging from increases of 500 million hectares to similar decreases.

And these models do not consider a massively expanded forest products industry. Switching to timber would immediately wipe a billion tonnes off global carbon emissions.

Where does it all come from?

But according to Himlal Baral, a senior scientist at the Center for International Forestry Research in Bogor, Indonesia, there is plenty of land to go around. "Certainly, there is competing demand for land," he says. "On the other hand, there is a huge amount of degraded and underutilised land available globally, between 1 and 6 billion hectares."

We could use such land, he says, to grow trees to make chemicals, structural materials and biofuels without competing with land needed for food or nature conservation. "Use of degraded and underutilised land for these products and services provides win-win solutions to mitigate climate change, and support rural livelihood and land restoration."

Berglund also sees little to worry about. "In the Nordic countries, this is absolutely not a problem. If you look at annual growth and how much is harvested, we are not using all our sustainable forests."

Price is another real obstacle. As yet, lignin isn't competitive with petrochemicals, and nanocellulose can cost as much as $3000 per kilogram, which is about 100 times the cost of Kevlar. But Berglund says we can't afford to worry about that.

"We cannot wait until the biobased materials are cost-competitive. We are in a situation with the environment where we need to switch to renewable resources now, and work out the economy along the way."

Hu is also optimistic. "I think we should gradually replace some of the old materials, and see how far wood can go." Whether this kind of optimism is enough to get the wood economy up and running, in the face of a strong market bias to petrochemicals, remains to be seen. "This material is abundant, biodegradable, renewable," says Hu. "It holds great promise. If you engineer it right, you can replace plastics, glass, metals, steel. You just need to be really open-minded."

Did you hear the one about the wooden car?

Yeah, it had laser headlights.

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