

The 12 innovations we need to save humanity and the planet

Which inventions should we prioritise to safeguard the environment and human health and happiness? From better batteries and photovoltaic paint to a universal vaccine precursor, **Vaclav Smil** shares his wish list

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By **Vaclav Smil**



Supertotto

I HAVE never been a fan of science fiction. I am highly suspicious of any too-good-to-be-true claims about “epoch-making” discoveries. But I have also written extensively about the transformative impacts of inventions, from synthetic ammonia for fertiliser production and semiconductor devices in electronics to the [5-in-1 vaccine](#), which immunises against a range of diseases. What’s more, it seems obvious to me that we need new fundamental advances like to cope with the multitude of economic, social and environmental challenges we

currently face. I address potential advances in my new book, *Invention and Innovation: A brief history of hype and failure*.

Identifying the top priorities for possible breakthroughs isn't easy, not least because there is so much room for improvement. Consider energy. [Bill Gates has noted that](#): "Half the technology needed to get to zero emissions either doesn't exist yet or is too expensive for much of the world to afford." You could say the same about every scientific and technical category. Moreover, any list of the most desirable inventions is bound to be subjective. If you see mine as rather conservative, I plead guilty: there is no faster-than-light travel, no terraforming of other planets.

Instead, my top 12 innovations, which I set out here, cover a range of issues that we urgently need to address. They focus on areas that will have the biggest impact on human well-being and the environment and where there is already knowledge to build on. My wish list even includes three changes that all of us can get to work on right now (see "[Bigger and better](#)").

ADVERTISING



A universal vaccine precursor

Humanity faces more risk from communicable diseases than ever. They can arise in tropical forests or in large cities, then spread rapidly around the world by global travel and transmit easily in overcrowded urban environments. We have been made painfully aware of this over the past three years by the coronavirus pandemic. It also highlighted the importance of vaccines – and the urgent need for better ones.

Vaccination has come a long way: it has eradicated smallpox and helped control many other serious diseases, including polio, measles and tetanus. Today, there are several types of vaccine and we know how to employ them against a range of pathogens. Nevertheless, when a

new disease arises, we must still develop a vaccine from scratch. And that takes time. We have seen [the arrival of mRNA vaccines](#), which use the genetic material known as messenger RNA to tell our cells to produce a protein that teaches our bodies to recognise an invader. Speedy genetic sequencing is vital to the technology. The mRNA advance has drastically reduced the time it takes to invent new vaccines – from months or years to days. But even Pfizer/BioNTech’s record-breaking covid-19 vaccine roll-out took nine months. That is plenty of time for an aggressive new pathogen to kill many millions of people.

Read more:

[Interview: The women behind the Oxford/AstraZeneca covid-19 vaccine](#)

Ideally, to reduce this delay, we would have an off-the-shelf, universal vaccine precursor that could be “activated” in the lab by a sample of a new viral or bacterial pathogen to create a vaccine that was safe, reliable and could be produced without using complex industrial techniques that are inaccessible to all but the largest pharmaceutical companies. So far, the closest we have come to this is research on “pan” vaccines that cover all viruses in a particular class, such as coronaviruses. In November 2022, researchers announced they had created a [universal flu vaccine](#) that works on all 20 known subtypes of influenza A and B in mice. But what would a universal precursor look like and how could it be tuned to create any desired vaccine? For now, we just don’t know.

A cure for Alzheimer’s

Since its creation in the 1930s, the US Food and Drug Administration (FDA) has approved more than 1800 treatments for human diseases. There are drugs that treat or even cure an impressive range of potentially fatal maladies, including various cancers, bacterial infections and high blood pressure. Others are designed to alleviate the symptoms of unpleasant but non-life-threatening conditions, from dermatitis and migraines to restless leg syndrome. Unfortunately, dementia – of which Alzheimer’s disease is the most common form – isn’t among the curable conditions. And, as populations age, this poses an ever-greater problem for humanity. Already, Alzheimer’s affects about 2 per cent of the US population and some 44 million people worldwide. Dementia currently [costs the world about 1 per cent of its GDP](#).

There are some drugs that provide temporary relief from Alzheimer’s symptoms. For example, donepezil, galantamine and rivastigmine prevent the breakdown of acetylcholine, a chemical messenger in the brain important for alertness, memory, thought and judgement, while galantamine regulates the activity of another neurotransmitter called glutamate. But these

medications often have severe side effects. Moreover, they are unable to slow or halt progression of the disease.

Finding a cure for Alzheimer's is challenging because it is a **complex and poorly understood condition**. Hypotheses about what causes it range from inflammation to the misfolding of proteins in the brain. The FDA only **approved the first drug to target a supposed underlying cause** in 2021. Aducanumab decreases the amount of plaques of a protein called beta-amyloid in the brain, although in clinical trials it failed to clearly demonstrate any benefits on people's everyday functioning, thinking or memory. The following year came the **announcement of the first Alzheimer's drug – lecanemab – that claimed to slow cognitive decline**. However, its effectiveness is in dispute and, moreover, **it has some severe side effects**. By any standard, a cure for Alzheimer's must rank near the top of the most desirable scientific advances. Few other medical interventions would bring as much help to individuals, support to stricken families and relief to overstretched healthcare systems.



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Nitrogen-fixing cereals

As the human population passes 8 billion, ever-greater amounts of nitrogen-based fertilisers are being used to grow plants to feed us. In 2020, crops received 113 million tonnes of it, 40 percent more than in 2000. However, as a result of evaporation, leaching, erosion and its

conversion to nitrogen gas by soil microbes, only about half of the applied nitrogen ends up in crops – sometimes as little as 20 per cent. This loss is very unwelcome right now with fertiliser prices being so high. Worse still, it [causes massive environmental damage](#), such as acid rain, the contamination of water by nitrates and the formation of oxygen-depleted “dead zones” in shallow coastal regions.

Unlike staple cereal crops, leguminous plants such as peas and beans require little or no nitrogen fertilisation. They get their nitrogen directly from symbiotic bacteria associated with their roots. The idea of conferring similar nitrogen-fixing abilities on grains, vegetables and other crops has been around for a century. It was even championed by Norman Borlaug, who [won the 1970 Nobel peace prize](#) for developing high-yielding crop varieties that required heavy applications of nitrogen. In his acceptance speech, Borlaug expressed a hope that, by the 1990s, humanity would have “green, vigorous, high-yielding fields of wheat, rice, maize, sorghums and millets, which are obtaining, free of expense, 100 kilograms of nitrogen per hectare from nodule-forming, nitrogen-fixing bacteria”.

Since then, there has been some progress in identifying nitrogen-fixing genes and experimentally transferring them to non-leguminous plants. But nitrogen-fixing cereals remain a dream and nobody knows how long it will take to become reality.

More efficient photosynthesis

Evolution has left plants with an inherently inefficient way of converting energy into biomass. Only around half of the solar radiation reaching a plant is usable in photosynthesis and that falls to 44 per cent after subtracting the reflected green light, leaving the blue-and-red part of the spectrum. More losses occur in the process of turning this light into chemical energy, so that just 4.5 per cent of solar energy is converted into carbohydrates. And that is a theoretical maximum. Limited supplies of water and nutrients mean that photosynthesis typically converts less than 1 per cent of incident solar radiation into biomass. Even a relatively small improvement would make a [big difference in crop yields](#), which are currently stagnating or only increasing slowly.

Research in the past decade suggests three paths towards this goal. One is to [improve the efficiency of rubisco](#), the enzyme that speeds up the process of synthesising new biomass. Another is to find genes that make roots more efficient at gathering water and nutrients and [use synthetic engineering to incorporate these into plants](#). The third would build on the discovery of [rice plants with higher yields](#), faster growth and more efficient use of nitrogen. We need more advances like these to substantially increase yields from crops if we are to adequately feed a human population that may well [grow to 10 billion by 2050](#).



er batteries

If we are to replace a large share of fossil fuels with electricity, we must find better ways of storing it. Currently, the potential energy in pumped hydro projects account for more than 90 per cent of electricity storage worldwide. However, when it comes to electrifying transport, what we need are batteries that deliver more energy for their size – more watt-hours per litre (Wh/l).

In 1859, when Gaston Planté invented the lead-acid cell, it had an energy density of around 60 Wh/l. Today, hundreds of millions of such batteries are under the hoods of vehicles powered by internal combustion engines, and they deliver about 90 Wh/l. Modern nickel-cadmium batteries can store 150 Wh/l. But lithium-ion batteries – developed during the 1980s and used today to power electric cars as well as cellphones, laptops and other portable consumer electronics – are currently the best choice. And they have even more potential. The top commercial lithium-ion performer – used in millions of electric vehicles – is Panasonic's model 2170, with an energy density of 755 Wh/l. California's Amprius Technologies is developing lithium batteries that can store 1150 Wh/l, making them an order of magnitude more energy-dense than the best lead-acid storage.

Despite these improvements, the energy density of batteries remains far inferior to that in the liquid fuels that dominate all forms of transport: petrol rates at 9600 Wh/l, aviation kerosene at 10,300 Wh/l and diesel fuel at 10,700 Wh/l. How fast could we narrow the gap? During the past 50 years, the highest energy density of mass-produced batteries has increased fivefold. If we can match that rate over the next 50 years, we would reach 3750 Wh/l. That would make the electrification of heavy road and maritime transport far easier than it is today, but it would still be insufficient for an electric Boeing 787. [We need super-batteries](#), and the sooner the better.

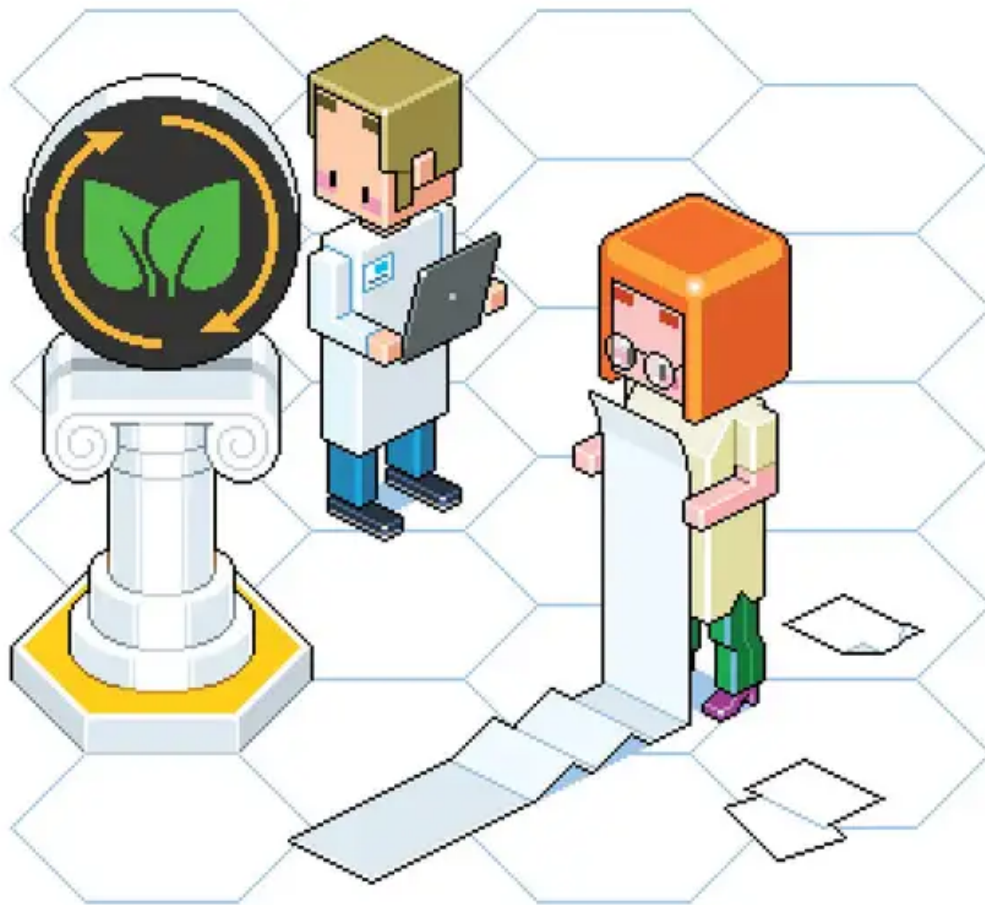
Self-cleaning, photovoltaic 'paint'

[Solar is the best option](#) for generating renewable electricity. Even if you don't consider wind turbines to be eyesores, they consume enormous amounts of materials – up to 400 tonnes per megawatt of installed capacity, which is more than 60 times as much as gas turbines. They also often require long-distance transmission to bring electricity from windy regions to big cities. In contrast, photovoltaic installations, whose semiconducting materials convert solar energy to electricity, use around 60 tonnes of material per megawatt of power and can be installed in any sunny location. Modern versions are also quite durable and maintain their performance for at least two decades, which is comparable with wind turbines.

So far, most new solar energy comes from large installations on unused land. Cities would be a better location. They already house more than half of humanity, will be home to some 70 per cent of people by 2050 and are by far the largest consumers of electricity. So, it would be a boon to have photovoltaic coatings that could be applied, almost like paint, to any urban

surface, connected to inverters located in individual buildings and fed into local grids. Of course, it would help if those coatings were also self-cleaning.

We have made some progress towards such surfaces. [Solar cells can now be made from plastic](#) and [electricity-generating solar windows](#) are on the market. Furthermore, glass-maker Pilkington produces self-cleaning windows, whose photo-catalytic and hydrophilic coatings react with sunlight to break down and loosen organic dirt. The next step will be to make these materials inexpensive and adaptable. Then, we can install them on a scale limited only by the size of our walls and windows.



Supertotto

Greener plastics

The worldwide production of plastics is approaching 400 million tonnes a year. Meanwhile, our efforts to reduce their harmful environmental impacts are pitiful. The benefit of banning single-use shopping bags, for example, is dwarfed by the growth in other single-use plastics such as blister packs and the ubiquitous clamshells used in food packaging. Meanwhile, only a [small proportion of all the plastic we discard is recycled or incinerated](#). In high-income countries, most ends up in landfill. In low-income countries, especially in Asia, a lot enters

the ocean, where macro and microplastics are accumulating in surface waters and even in the deepest trenches.


Biodegradable alternatives, derived from crops or produced by microorganisms, are available. However, they aren't widely used, accounting for less than 1 per cent of all production. Besides, plastics perform so many different functions that we need to invent a variety of green alternatives that are both cheap and strong. To eliminate competition with food production, these shouldn't be made from crop-derived compounds, but from readily available organic waste, microbes and inorganic material. This remains an enormous challenge – with equally enormous rewards.

Reinforced concrete without cement or steel

The dominant material of modern civilisation is reinforced concrete. It comprises a mixture of cement, water and aggregates strengthened with steel rods. Cement, in turn, is commonly made from limestone, shells and chalk combined with shale, clay, slate, slag from blast furnaces, sand and iron ore. Global production of cement now surpasses 4 billion tonnes a year and [this energy intensive process](#) accounts for about 8 per cent of global carbon emissions. Cement is mixed with water and aggregates – mostly sand – to make 14 billion tonnes of concrete, and this leads to [depletion of river and beach sands](#) – desert sand is a poor choice because its grains are rounded by wind erosion and so too smooth.

Concrete can be made without cement, by substituting fly ash or blast furnace slag, but the supply of these materials is limited and will decline still further as coal combustion decreases and new iron-smelting techniques are adopted. In 2021, Japanese researchers announced they had found a [way to make concrete without cement](#), by directly bonding sand particles (including those from deserts) using a simple reaction in alcohol with a catalyst. Efforts to substitute the steel rods in reinforced concrete with a greener alternative are more advanced. German engineers have constructed the world's first building made from [concrete reinforced with carbon fibres](#). However, it was only a demonstration project and the carbon concrete was about 20 times as expensive as the standard product. In the future, the biggest demand for concrete will be from low-income countries, so we need to combine the two technologies in a material that is cheaper than today's reinforced concrete and then scale up production globally.

A planetary sunshade

The last item on my list is a bit of a wildcard. [It is a controversial idea](#), but if we fail to make better progress at controlling greenhouse gas emissions, we may have to resort to blocking some of the incoming radiation from the sun. Doing that in space by using a giant shield or  ol would be a less intrusive option than injecting radiation-absorbing aerosols into the

stratosphere. The sunshield idea has been around for decades, but is still far beyond our capacities to translate into reality.

Forming a sunshade capable of deflecting between 1 and 2 per cent of sunlight would involve either deploying billions of small, light autonomous sail-craft or a massive barrier, which might take the form of a disc, a very light lens or a thin wire mesh. This barrier would need to be parked about 1.5 million kilometres away, at the point between the sun and Earth where their gravitational forces cancel out so that an object can stay in position.

There are two gigantic problems with this plan. First, it would mean launching something in the order of 10 million tonnes of equipment into space. Even with optimistic assumptions, that would cost many trillions of dollars. Second, even if technically possible, the project would require a binding global consensus and legal framework before it could go ahead. The likelihood of such an agreement would increase if the design were adjustable and controllable. Nevertheless, this innovation seems far less likely to happen any time soon than the other items on my wish list.



Bigger and better

We don't necessarily need new inventions to make big improvements for humanity and the planet. A few quick wins could come from doing what we already know, only better and on larger scales. Here (and continued on page 42) are three things we can do right now that would have huge impacts.

Eliminate micronutrient deficiencies

Around a quarter of the world's population is anaemic due to a lack of dietary iron. In most countries of sub-Saharan Africa, the prevalence is between 40 and 50 per cent. About 250 million people don't have enough vitamin A, which can lead to blindness and reduced immunity. Iodine deficiency affects about 2 billion people. It increases infant mortality and can result in stunting and goitre. And zinc deficiency, which causes skin lesions and hair loss, affects at least 17 per cent of the global population. Yet measures such as providing vitamin and mineral supplements and fortifying oils and fats with vitamin A, flours with iron, and salt with iodine are inexpensive and very effective. Eliminating micronutrient deficiencies is perhaps the most rewarding development we could make immediately: only vaccination in childhood yields greater return on the relatively modest investment.

Fit better windows

Cutting energy demand is the best way to reduce humanity's carbon footprint without any new inventions. One obvious way to do this is by reducing the amount we waste. In high-income countries, buildings account for between 35 and 40 per cent of total energy demand – and windows are their most inefficient component. Double glazing reduces the heat loss of a single-glazed window by 50 per cent and triple glazing cuts another 50 per cent. Special coatings on glass and filling the spaces between panes with insulating argon cuts the overall loss by about 85 per cent compared with a single pane. Swapping out windows isn't cheap, but this technical fix is applicable to billions of windows worldwide. It would also have decades-long benefits: buildings typically have longer lifespans than cars (at around 12 years) and industrial processes (commonly from 20 to 30 years). Here is a massive opportunity to cut energy use, saving money and decarbonising at the same time.

Maximise recycling

We use huge amounts of energy and raw materials to produce a growing array of items, but [we still recycle only a fraction of what is profitable](#) – and even less of what would be desirable when all environmental costs are taken into consideration. Recycling rates are particularly low for plastic – just 9 per cent – half of which ends up in landfill. Less than 20 per cent of electronic waste is recycled, even though it contains more gold, silver, copper and rare-earth metals than any known mineral ores. Only about 60 per cent of paper is recycled. Globally, some three-quarters of aluminium is recycled, but national rates can be far lower: in the US, it is just 50 per cent. The benefits of recycling are well known, technical solutions are available and opportunities abound. There is no excuse. We should be doing far better.

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