What 250 Years of Innovation History Reveals About Our Green Future

If history is any indication,
an unstoppable wave of competitive innovations is heading our way again.

https://thereader.mitpress.mit.edu/what-250-years-of-innovation-history-reveals-about-our-green-future/

By: Per Espen Stoknes

INNOVATIONS ARE OFTEN DIFFICULT TO IMAGINE BEFORE THEY ARRIVE. It isn't until they've diffused into widespread use that they seem natural, ordinary, commonsensical.

Yet becoming aware of how limited our untrained mind is when imagining a different world is fundamental to forming a new narrative of the future. This is core to the discipline of scenario thinking: Without good stories to help us envision something very different from the present, we humans are easily stuck in our conventional mental programming.

We like to keep doing what we've always done. Psychologists call this the status quo bias, a strong, automatic emotional bias that prefers the current state of affairs over change. It feels even better if we can reinforce that status quo preference with a "good," seemingly rational explanation. This all-too-human response has been with us for ages. And it is still alive and well today, shaping our society, even as conversations about sustainability abound.

This article is adapted from Per Espen Stoknes's book "Tomorrow's Economy: A Guide to Creating Healthy Green Growth."

So, how can we separate ourselves from an ecologically destructive, fossil-fueled economy and its underlying infrastructure? How can or will this vast, seemingly locked-in, path-dependent system change in time? The current fossil, food, and financial systems, and the corruption interwoven with them, are so rigid that it's incredibly hard to imagine that they ever can or will transform.

And yet, from 2060 or thereabouts, we might look back and view it as inevitable that these systems *did change*. Radically. And faster than expected. Change will prevail, I believe, but not because of a surge in idealism or a breakthrough in new morals that makes forward-looking politicians courageously decide to close down the fossil-fuel era. If history tells us anything it's that our inertia will be swept away because of an unstoppable wave of competitive innovations heading our way.

Becoming aware of how limited our untrained mind is when imagining a different world is fundamental to forming a new narrative of the future.

Deep and extensive research has been done on the waves of innovation that have led to major societal shifts since the start of the industrial revolution. Since the first wave of factories and spinning jennies — the first weaving machines of the 1760s — we've seen that time and again a set of fundamentally interconnected innovations change the value-creating logic of the economy.

Each wave of technological innovation — lasting 40 to 70 years — fundamentally overthrew the old order in a few decades, killing off a lot of old companies, institutions, and infrastructure.

Each wave also created vast new domains of opportunity and riches for those whose innovations were ready to ride the swell at just the right time. In other words, each wave of innovation spurred what economist Joseph Schumpeter named "creative destruction."

Five Historic Waves of Innovation

Among the economic historians who have studied waves of innovation and how they impact the economy as well as our society at large we find Schumpeter, widely considered the father of innovation economics, Nikolai Kondratieff, and later Carlota Perez. These are not your typical mainstream economists. Since innovation can be erratic and uneven, it rarely fits well into the smooth, elegant equilibrium models that conventional economists prefer. In analyzing messy history, these innovation economists prefer to use the metaphor of waves: They come, swell, boom, break, and recede. Their exact timing is hard to predict. And after peaking, they leave nothing dry.

As they tell us, there have been five main waves of innovation since the beginning of the industrial revolution. There is much we can glean from these waves that will help us understand the unfolding of a new sixth wave, which has just begun: a green innovation wave riding on top of digitalization that will usher in an era defined by a transition to radical resource productivity, driven by renewables and circular material flows.

Wave One: Mechanization (1760–1830)
Imagine it's 1750 and you're a visionary riding your horse down to the British Parliament in London — the pinnacle of power in the capital of the empire. You unmount the saddle, walk in, and declare to the lords with a shrill voice and charismatic confidence that in just 30 to 40 years, one person will manage to weave as much as 100 to 200 skilled laborers do in one day. "And, by the way," you shout, "this will change the structure of the economy forever." After half a second of thought, they declare, "All my eye, what fiddle-faddle!" And throw you out. Everybody knew that this was a ridiculous prediction, since the speed of weaving had been the same for centuries and centuries. Why should it change all of a sudden?

Before coal mines, machines such as spinning jennies, steam engines, and other mechanical wonders reshaped the country, British society was agrarian. Value was made from land, serfs, and rents, or from trade of mainly agricultural products. But with these novel technological possibilities, economic and social change followed. A new class rose beyond the nobility: the capital owners, those who controlled the mills and spinneries, the weaving and mechanical factories. They got super rich and — after a fight — gained political power, too, sometimes ousting the gentry and nobility.

The point is: Such innovation waves eventually transform the structure of the entire economy. After a period of exponential growth and frenzy, the impacts of the innovations reach everywhere in society. That's why such waves are sometimes called techno-economic paradigm shifts.

Wave Two: Steel, Steam, and Railways (1830–1900)
Now imagine that you are living in the Norway of 1830 and you have had a vision of the future: You can suddenly envision a world with railways and huge, long trains with tons and tons of cargo speeding through tunnels and forests, over steel bridges, and into great halls in the cities.

This vision feels important and significant, and you want to share it, to paint a picture in people's minds of an exciting, new future of mobility. So you mount your horse and head off to the parliament in the country's capital. You eagerly declare to anyone who cares to listen to you that, in 30 to 40 years, one person will be able to drive 200 or even 300 horse carriages of cargo in one day — without any horse! A long silence ensues. Then they throw you out.

Without converting iron to steel, effective rapid railways *are* impossible. Iron tracks are too soft to remain functional and secure for heavier and longer trains. The innovation of steel production made not just railways possible but also a whole new manner of construction, cheap enough also for high-rise buildings and larger ships.

Railways then made long-range travel and quick, cheap transport possible. It also made huge volumes of coal available to drive steam engines. Proud and grand shipping companies that for centuries had perfected wooden sailing vessels soon went broke. This not only changed trade but also spilled over to change cities, coasts, settlements, and agricultural production.

In turn, the transformation led to a new class of people and companies that rose to the top of the economic ladder. Business models that scaled up steel and railways to immense size tended to

generate centralized, monopolistic, hierarchical powers. The winner took all. Insane riches were made by the steel moguls and the railroad "robber barons." The Rockefellers, Vanderbilts, and Carnegies became the richest people on the planet. Their oversized power and influence extended into business and politics alike.

Wave Three: Industry (1900–1970)

Imagine that you're in Washington, DC, in 1908. You ride your horse down to see the horse-carriage manufacturers, the whip makers, the breeders, the saddle makers and blacksmiths. Then you say: "Horses will always be the way we get around, just as it's been for the last 8,000 years. Safest business in the world. You guys deliver terrific quality. I've seen the future: It will bring us better horses that run ever faster!"

Finally, after all those previous rejections, it feels good to be saying the comforting thing. You're embraced. They pay you one fat consultancy fee. You get two hugs and three cheers for your brilliant analysis.

The problem, of course, was *not* that electric or petroleum automobiles didn't exist at the time. They weren't unheard of or unimaginable. The problem was that an obscure technology — totally unrelated to horses — called the assembly line was coming into existence. And a fellow named Henry Ford had some radical ideas about another future — one that involved business-model innovations that included living wages and car loans.

With those, he could accelerate the rollout of cars to people who didn't have the means to finance their shiny new purchase upfront. Economies of scale made car prices fall and fall. Then cars sold by the millions. By 1920, cities had started to ban horses on roads inside city limits.

The Ford assembly line in 1913. (Wikimedia Commons/public domain)

Mass-production techniques made incredible volumes of consumer goods available at ever-lower costs.

The then-new mass-production techniques — along with electricity to power pumps, lighting, cooling, and heating — made incredible volumes of consumer goods available at ever-lower costs because resources were abundant and cheap. The combination of cars, trucks, highways, petroleum chemistry and a flood of new products kicked off modern life as we know it.

Economic growth surged, through the roaring 20s and then again after WWII. Again, those companies and owners that controlled the new innovations — the Fords, the Mellons, and later the Waltons, with the advent of Walmart — rose to the top of wealth from mass production and mass retail at the tail end of the wave. This wave of innovations spilled over into all corners of society, changing nearly every sector. The butcher on the corner, the family-owned watchmakers' shop, and mom-and-pop stores started their terminal decline.

The extension of this innovation wave wasn't complete before the whole economy had been covered by mass consumption. A time traveler jumping from 1900 to 1960 would struggle to believe what their eyes were seeing.

The steel and rail barons, once mind-bogglingly rich, were now dwarfed by the new industry conglomerates.

Wave Four: Electronics, Television, and Aviation (1945–1990)

Few inventions have spawned as many innovations as the transistor, a semiconductor at the basis of all electronics. From its lowly beginnings in vacuum tubes, it has not just made radios better but has made telephone switchboards and televisions possible. This spawned television companies, telecommunications networks, and news-broadcasting networks.

With this, politics changed forever with the introduction of screened speeches, presidential debates, and live news. On-screen likability became more important than issues or content. One of many surprising consequences of electronics flooding the nations was the reshaping of minds through television, as it spread rapidly to almost all households.

The transistor also made computers possible. By the 1980s, IBM had catapulted to the top rung of the world's most valuable companies. In 1985, it was worth almost three times as much as the second-most valuable company, the petroleum behemoth Exxon, from the previous wave.

With advanced electronics and the availability of cheap oil, mass aviation also became feasible.

Flying fighter jets and Boeings by mechanical means only wasn't a very attractive option. Large aviation companies sprung up, airports mushroomed, and global trade took off.

Wave Five: The Digital and Internet Wave (1985–Present)

Given the many ways our lives are defined by the internet today, it's difficult to believe that the World Wide Web only got going during the late 1990s. It is still rocking all boats. Once again, we can't really say we saw it coming.

In the late '90s, I was involved with a multiclient scenario-planning project where we looked into the future of digital society. In 1996, many CEOs were still declaring that the internet was a fad.

Why would anyone want to purchase their loans, their newspapers, or plane tickets through such a wobbly, cumbersome channel? Back then, for most users going online involved a dial-up connection with slow analog signals over copper wires. There were already hundreds of television and radio channels, and you could reach anyone by landline phone, fax, or post. What would you need an internet for?

Like the other waves, it started in just a few fringe arenas in physics and defense labs off the radar of the general public. The internet erupted commercially during the late '90s, then frenzied and crashed in 2001 and 2008, and has since reached the maturity stage. Now it has spread to all parts of society. "Everything changes" through information technology and digitization. Today nearly half of the world's population has a mobile smartphone or tablet connected to the internet, something no one had only 15 years ago.

As with other tech waves, the fifth wave has given us new language. Just as prior waves got us talking about "hold your horses," "driving the highway," "watching telly," or "rebooting computers," our internet age has given us new words that we rarely reflect about, such as *website*, *googling*, and *tweeting*. When our language changes, what we're able to see and do expands too. As do our jobs. Our answers to that old question "What do you do?" change: "I design webpages and facilitate SoMe." That would be social media, by the way. In 1995, both the job itself and the answer would be utter gibberish. With each technical wave also come new social discourses. The two cocreate each other.

And also like other tech waves, the fifth wave has changed the structure and value creation of the overall economy. The petroleum and car companies used to be the world's most valuable corporations, back in the mass manufacturing industry-and-oil wave. Many environmentalists as well as investors still perceive these as large, mighty, stable, profitable entities. They were a core part of most investment portfolios for pension funds and hedge funds alike.

But already about 30 years into this fifth digital wave, the shift in value has come about: At the time of writing, the five largest companies by market capitalization in the world are from the fifth wave: Apple, Google, Microsoft, Amazon, and Facebook. Among the companies that owned the fossil-fuel industrial age, only ExxonMobil is large enough to hang on among the very top tiers of global corporations.

A business model is sometimes compared to cell DNA: It hardly changes when the organization is well established.

The order of things has shifted. And it is not just because Ford, IBM, Kodak, Walmart, and Shell have been shortsighted. It is largely because each new wave fundamentally changes the value-creation logic throughout the economy. Hence deeply ingrained business models "suddenly" shift from leading markets to becoming a drag. A business model is sometimes compared to cell DNA: It hardly changes when the organization is well established. It is deeply embedded in its organizational culture, reproducing itself. When its surrounding industrial ecosystem shifts, rather than rapidly adapting, it loses out to invasive and competing species that suddenly threaten to take over.

Wave Six: Green (2015–2060)

Imagine that tomorrow you drive your SUV to an oil company's annual meeting or a gathering of energy authorities, and tell them that in 20 to 30 years our society will get 100 to 200 times as much mileage and transport work done per barrel of oil burned, if any barrel is burned at all.

Perhaps you add that their situation is similar to that of the horse-carriage builders after 1910, punch-card manufacturers in the 1970s, mainframe computer companies of the '80s, the CD music industry in the '90s just before the advent of online music or Kodak before ubiquitous digital photography in the early 2000s.

After your speech, someone may ask if you arrived by car. Another might chime in, "See! You hypocrite. The car isn't going away anytime soon. And even your phone and clothes are made of petroleum." When waves of innovation put societies on the cusp of change, those most invested in the old ways rarely grasp the speed with which those ways will become obsolete.

For 200 years, innovators found ingenious ways to improve labor productivity. This was mainly accomplished by having machines (real capital) make people (labor) much more effective per hour. Now we have a world with more than seven billion people, most wanting work. But on an Earth that's restrained in what scientists call sources and sinks — or, in more general terms, raw materials and the air, water, land, and vegetation that can absorb carbon emissions and other pollution — it makes plain economic sense to innovate for optimizing *resource productivity*.

The evolution in lighting provides a case in point. The LED bulb gives off the same amount of light as an incandescent bulb but requires just one-tenth of the coal burned in a typical coal-fired power plant. If we then power a smart LED with a motion sensor on wind and solar power rather than power from a coal-fired plant, we can get the lighting we want with at least 99 percent less resource use than the old system.

From 2010 to 2018, average solar panel power costs per kilowatt-hour (kWh) fell nearly 80 percent, becoming cheaper than fossil fuel most places. The cost for solar modules, meanwhile, dropped over 90 percent from 2010 to 2020. And the U.S. Department of Energy aims to cut costs by another 60 percent by 2030. Not to mention battery prices have fallen 88 percent over the last decade. It's truly dramatic — a solar energy revolution.

But the potential goes far beyond solar panel power. One research project identified 21 major upcoming consumer innovations that have disruptive potential. Seven are in mobility: e-bikes, bike sharing, taxi-buses, ridesharing, car sharing, mobility as a service, and better telepresence.

Seven are in the power domain: photovoltaics like solar rooftop with storage, peer-to-peer electricity (selling to your neighbor), vehicle to grid (selling from the car battery back to the grid when demand is high), disaggregated feedback on your consumption (to lighting, washing, cooling, etc.), time-of-use pricing, managing demand (of washing or heating) according to load, and more energy service companies who will optimize your home consumption in exchange for a fixed fee.

And seven are in smarter consumption: peer-to-peer goods (sharing tools, sports gear, etc.), home sharing (like Airbnb), the Internet of Things at home, smarter appliances, prefabricated retrofits with click-on insulation plates, smarter and self-learning homes, and heat pumps. Now, that's an abundant wave of innovations coming toward us, enabling a Low Energy Demand (LED) future with better lives.

Even mainstream players like the World Economic Forum are now spotting what it calls an "innovation tsunami" that "has the potential to wash over the world's energy systems."

Other resource innovations are happening in buildings, foods, transportation, and industry. All of these are converging into the next (sixth) wave of disruptive innovation. And this wave is clearly on its way. Even mainstream players like the World Economic Forum are now spotting what it calls an "innovation tsunami" that "has the potential to wash over the world's energy systems." In a 2018 report it declared, "Anticipation of this tsunami has been a source of tremendous anxiety. Some firms and industries fear survival. Others foresee riding these powerful waves into new markets."

How will this tsunami impact us when it hits?

Carlota Perez distinguishes five phases of each wave: eruption, frenzy, turning point, synergy, and maturity. Eruption occurs when there is intense funding for the new technologies, combined with a disdain of old assets. In the frenzy phase, there is a split between real values and the share or paper valuation. One can see inflated expectations in which the value of speculative financial and underlying production capital deviates wildly.

Remember the dot-com bubble in 2000, when any startup with a business plan involving e-commerce could find investors? The frenzy stage usually results in a financial bubble, followed by a crash. After the bust, a synergy phase gets a new golden age going again, followed by a coherent growth stage in which production, employment, and share value realign. Finally, at the maturity stage innovations reach market saturation, and there is less big innovation in main industries but more incremental improvements of the products and services. Hence, the economic margins and rate of return on capital slow down.

The Fall of Oil and Gas

The oil and gas industries are a perfect illustration. By the 1950s, the average energy return on energy invested (EROI) in the U.S. was down to 1:50 (from 1:100 in 1912). Today, EROI in U.S. conventional oil fields is down to about 1:9, and the shale oil wells of Bakken and similar oil fields may yield only 1:4. An immense amount of energy is now combusted to drill, press, boil steam, and inject and break the shale far under the ground.

That means some places now burn one barrel of oil (or the equivalent of gas) to produce as little as four new barrels. The yields decline quickly for each new shale well over time. It may drop more than 60 percent during a single year. Then they must drill and steam and frack again.

Yes, new technology and petroleum innovations may cut costs, and supply may increase when adding more rigs. Innovations within the fracking industries, including horizontal drilling, have increased oil and gas supply from both conventional and unconventional sources, such as tight oil or tar sands or heavy oil fields. What's common to all extraction, however, is that more energy is used on average for each unit of energy returned as time passes. And the later, newer fields and finds are on average more difficult to exploit and bring to market than the first, which are now mostly depleted.

This dynamic is playing out on a global level. The average EROI for petroleum has been sinking year by year since 2000, irrespective of high or low oil price, while solar and wind are seeing improving EROI. The question is not if renewables will overtake fossils but how quickly. There is a race between petroleum exploration innovation and the inevitable decline in the geological availability of remaining easy reserves. There are huge remaining reserves, but they are found in the ultra-deep sea, the Arctic, in heavy oils, tight rock formations, or in distant and politically unstable areas far away from the cities where the hungry cars and power stations want to explode and combust and burn all that dark, gooey ancient carbon-rich stuff.

What will soon become abundantly clear is that there is limited time left for profitably exploring, producing, and selling oil and gas.

What will soon become abundantly clear is that there is limited time left for profitably exploring, producing, and selling oil and gas. Why? Because we'll need less and less as cleaner, safer, healthier, and cheaper innovations win market shares and resource productivity improves dramatically.

When you start to look closer at what we use fossil fuels for, you discover that there are competing substitutes entering markets all over the place. Power, heating, materials, transport, buildings, and industrial processes: Each can — and I believe eventually will — be reduced to near-zero emissions, even in the harder-to-abate sectors.

The demand for fossil fuels is steadily decreasing in richer countries, and the financial climate risks are becoming clearer, at the same time as new supply is getting harder to extract. The shift

does not mainly depend on climate idealism in politics, or because all business suddenly wants to "go green."

Certainly, removing the current perverse public subsidy for fossil fuels and adding new government regulations, carbon taxes, and more business responsibility can all accelerate it. But the main drivers will be substitutes that are better, safer, healthier, and more profitable. We're not fully there yet today, nor will we be tomorrow. But we're not far away either.

The energy system is experiencing the creative disruption Schumpeter described: a full overhaul driven by newer, better, smarter solutions. Yes, old thinking, outdated regulations, lobbyists, corruption, bad risk management, underpriced emissions, and perverse governmental subsidies for fossil fuels can slow it down. But they can't stop it as we move forward in the 21st century.

The sixth wave is approaching, and quickly. What seems impossible today will soon be inevitable.

Per Espen Stoknes is a psychologist and economist and the author of "Tomorrow's Economy," from which this article is adapted. He's a TED global speaker and works as a professor and as the director for the Center for Sustainability and Energy at the BI Norwegian Business School in Oslo, Norway.