OUR CARBON FUTURE

Reversing global warming while delivering shared prosperity

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Contents

Executive **summary**

Around the world, governments, businesses and citizens face a twin challenge: how to reverse global warming and, simultaneously, deliver economic prosperity for a rapidly expanding global population.

Addressing this twin challenge requires a radical shift in the way we use carbon to create economic value. We must transition from an economy powered by fossil fuels to one powered by clean energy and carbon drawn down from the atmosphere — and do so quickly.

This paper is principally about how we can do this. It explores the mindset shifts required around carbon, arguing that we must learn to see it not only as a source of existential risk, but also as a source of immense opportunity. It reviews the status of relevant R&D, as well as corporate action across three key value nexuses: cities, materials and food.

Our conclusions: many elements of a new carbon economy are already in place; pathways to scale are emergent; the opportunities for those who move fast — and in the right direction — are huge; and, crucially, the moment for courageous leadership is now.

This paper builds on work published by the Carbon Productivity Consortium in 2017 (for more, see www.carbonproductivity.com) in addition to dozens of conversations with senior business executives, and experts on carbon and climate change. We are immensely grateful to the individuals and organisations who have informed the ideas in this paper by sharing their expertise and experience with us.

An early draft was shared with participants at a New Carbon Economy Workshop hosted by Volans and the Center for Carbon Removal in London in May 2018 — and we warmly thank those who provided feedback.

This paper is dedicated to the memory of Richard Northcote, without whose vision and encouragement it would not exist.

The paper's principal authors are Lorraine Smith and Richard Roberts of Volans. If you have any comments or questions, please contact Richard at r.roberts@volans.com.

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Glossary of key terms

New Carbon Economy[1]: A growing, inclusive economy that removes and sequesters more carbon from the atmosphere than it emits.

Carbon Productivity[2]: A measure of the economic value derived from carbon in all its forms. Conceptually, Carbon Productivity is to the New Carbon Economy what Labour Productivity is to today's economy.

Return on Carbon Employed[3]: A measure of the value (financial, environmental or social) created per unit of fossil carbon input.

Drawdown[4]: The moment at which total atmospheric carbon dioxide (CO_2) peaks and begins to fall on an annual basis. In other words, the moment at which we have successfully transitioned, globally, to a New Carbon Economy.

Carbon removal[5]: An umbrella term for a range of strategies to capture excess carbon in the atmosphere and either store or use it in biological or technological cycles and sinks (e.g. in soils, materials, and underground geologic formations).

Climate positive: A label applied to entities (primarily organisations) that are responsible for a net reduction in the quantity of carbon in the atmosphere. That is to say, they remove more CO_2 — or, through their products and services, avoid more CO_2 being emitted — than they are responsible for emitting themselves.

A note on terms we avoid

A key message of this paper is that we need to learn to see carbon as more than just emissions. The language we use to frame different actions can have a significant impact on the way they are perceived. Psychological studies suggest that framing climate action in positive terms is more effective than using negative frames.[6]

With this in mind, we try to avoid terms like carbon negative, negative emissions, decarbonisation, low carbon and zero carbon (though we acknowledge that much excellent and important work is being done under all of these headings).

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[1] http://www.centerforcarbonremoval.org/new-carbon-economy/

[2] http://carbonproductivity.com/

[3] *Prototype for a Carbon Productivity Tool: Framework, Metrics and Methodologies*, https://bit.ly/2v8SSHQ

[4] http://www.drawdown.org/

[5] http://www.centerforcarbonremoval.org/what-is-carbon-removal/

[6] See especially Per Espen Stoknes, *What We Think about When We Try Not to Think about Global Warming* (2015).

Towards a **New Carbon Economy**

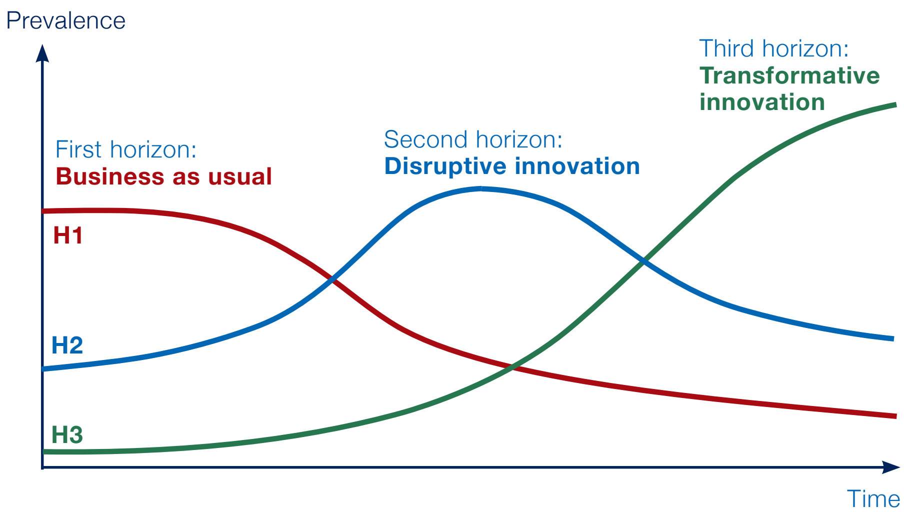
Driven by a mix of rapid technological change, population growth and ever more obvious environmental limits, global capitalism is headed into a period of profound transformation.

The World Economic Forum talks in terms of a 'Fourth Industrial Revolution'.[7] The Generation Foundation labels it the 'Sustainability Revolution', which, they argue, "appears to have the scale of the Industrial Revolution and the Agricultural Revolution — and the speed of the Information Revolution. Compared to these three previous revolutions, the Sustainability Revolution is likely to be the most significant event in economic history."[8]

Such statements may sound hyperbolic to some, but we find the underlying analysis credible and in line with our own research. The shift to an economy that sequesters more carbon than it emits — i.e. a New Carbon Economy — will happen as part of the broader Sustainability Revolution that is re-shaping the economic landscape.

Predicting precisely how, and over what timescales, this revolution will play out is a fool's errand. Nonetheless, it helps to have a framework for conceptualising what lies ahead. We find the 'Three Horizons' framework developed by Bill Sharpe of the International Futures Forum (see diagram below) a useful model.[9]

Figure 1: Three Horizons map of the journey to a New Carbon Economy



Source: Volans, adapted from Bill Sharpe

H1 / Business as usual: economy is largely fossil fuel powered; efficiency measures make some emission reductions possible, but the process of decoupling emissions from growth is too slow to align with a below 2°C pathway.

H2 / Disruptive innovation: experimentation with solutions that deliver radical emissions reduction and increased carbon sequestration goes off the scale; Carbon Productivity — the value created per unit of CO2 emitted — begins to climb sharply.

H3 / Transformative innovation: economy is regenerative and circular by design; value is now created by restoring — rather than disrupting — the natural carbon cycle.

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[7] World Economic Forum, 'The Fourth Industrial Revolution: what it means, how to respond', https://bit.ly/1pBfye4

[8] Generation Foundation, *The Transformation of Growth: How Sustainable Capitalism Can Drive a New Economic Order*, https://bit.ly/2yR6yKM

[9] Bill Sharpe, *Three Horizons: The Patterning of Hope* (2013).

The New Carbon Economy is a description of the third horizon (H3) reality we are aiming for. Some of the other concepts and tools introduced in this paper are part of the second horizon (H2) world of experimentation and innovation. They are important insofar as they help move us towards the third horizon/New Carbon Economy, but their usefulness may be time-limited.

H2 concepts like Carbon Productivity and Return on Carbon Employed are designed to tap into existing (H1) mindsets and learned behaviours — to maximise productivity and returns — whilst bridging towards a very different future (H3), in which industrial value creation and the carbon cycle are brought into harmony with one another. When this transformed world is realised, terms like Carbon Productivity will either become obsolete or go through their own process of transformation, shedding old meanings and taking on new ones.

There is another, less optimistic, possibility, which is that concepts like Carbon Productivity, rather than helping to bridge towards the New Carbon Economy, actually help to sustain today's failing system, by making it marginally less bad. Several respondents to an earlier draft of this paper raised concerns that, in focusing heavily on concepts like productivity, we may be trying to solve global warming with the same mindset that caused the problem.

This is a risk we take seriously and we recognise the need to guard against it. However, on balance, we see it as a risk worth taking for the simple reason that we cannot afford to wait for a new paradigm to emerge fully-fledged. (In any case, new paradigms never emerge fully-fledged: transformative change is always messy and multi-layered.)

We need *both* to adapt existing mindsets, systems and behaviours *and* to invent new ones. It's too late for an either/or approach. Given the climate crisis we already face, we must find ways to engage today's economic engine to deliver on the needs of tomorrow — and if thinking in terms of productivity, efficiency, value and growth helps us do that, so much the better.

The **Carbon Productivity challenge**

The concept of Carbon Productivity[10] was born of a recognition that we — business leaders, policy-makers, investors, citizens — face a twin challenge: how to reverse global warming and, simultaneously, deliver economic prosperity for a rapidly expanding global population.

The implications are profound: an economic transformation at least on the scale of the Industrial Revolution is required — but on a significantly accelerated timeline. The Industrial Revolution spurred a tenfold (or 10X) increase in labour productivity in the United States, but it took 125 years (from 1830 to 1955).[11] We must now do the same with carbon, globally — *and in less than a third of the time*. At the heart of this new Industrial Revolution is a radical shift in the way we use carbon to create economic value.

> "If humanity has changed the climate by mistake, can we change it with intent?"
>
> **Interface, Climate Take Back[12]**

The principles of Carbon Productivity

So how do we enable this radical shift? There are three guiding principles that should, in our view, inform those designing tomorrow's metrics, products and business models:

1. Take into account the carbon impacts of the entire lifecycle of a product, including material and energy inputs, production processes, product design and use, and after-use disposal or recovery of materials.
2. Consider CO_2 emissions generated, future emissions avoided ***and*** carbon removed from the atmosphere — recognising the need for the sum of the second and third to outweigh the first.
3. Look at financial value and carbon impacts in an integrated way, recognising the need to optimise both at the same time (and for both to be part of the same strategic discussion, rather than being addressed by separate organisational silos).

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[10] The term 'Carbon Productivity' was originally coined in a 2008 McKinsey paper, *The Carbon Productivity challenge: Curbing climate change and sustaining economic growth*, https://mck.co/2OA8Hzs

[11] Ibid.

Existing Carbon Productivity tools and metrics

At its simplest, Carbon Productivity is about reversing global warming while delivering shared prosperity. Though it is a decade since the term was coined, this is still an emergent agenda. Our collective understanding both of carbon and of economic value[13] is in a state of flux — and will likely remain so for the foreseeable future.

For this reason, there is as yet no single, universally applicable Carbon Productivity metric, though there are a number of useful proxies already in circulation. These include:

A) GDP produced per unit of carbon equivalents (CO_2e) emitted

This is the metric used in the McKinsey Global Institute's 2008 report, *The Carbon Productivity challenge: Curbing climate change and sustaining economic growth*.[14] The report argued that, in order to meet commonly discussed climate goals whilst sustaining economic growth rates, GDP per ton of CO_2 would need to increase tenfold by 2050 — equivalent to roughly 6% a year. For comparison, global Carbon Productivity, thus defined, improved by an average of just 1.4% a year between 2000 and 2016.[15]

This way of measuring Carbon Productivity is particularly relevant for policy-makers. We encourage political leaders at all levels to adopt it as a key performance indicator for the economy (in much the way that labour productivity is used today).

B) Financial, Environmental (and Social) Return on Carbon Employed

In 2017, the Carbon Productivity Consortium[16] developed the concept of 'return on carbon employed' (ROCE) as a way of measuring Carbon Productivity within a company. ROCE looks at the value created per unit of fossil carbon input. Specifically, two measures were developed:

- Financial Return on Carbon Employed (FROCE): revenues per unit of non-renewable carbon input.
- Environmental Return on Carbon Employed (EROCE): fossil carbon consumption avoided/forced in use and after-use per unit of fossil carbon input.[17]

[13] A proper exploration of the debate around what constitutes economic value falls beyond the scope of this paper. Mariana Mazzucato's 2018 book, *The Value of Everything: Making and Taking in the Global Economy* provides a helpful introduction to the topic while throwing down the gauntlet for economists to re-examine their assumptions about what constitutes economic value.

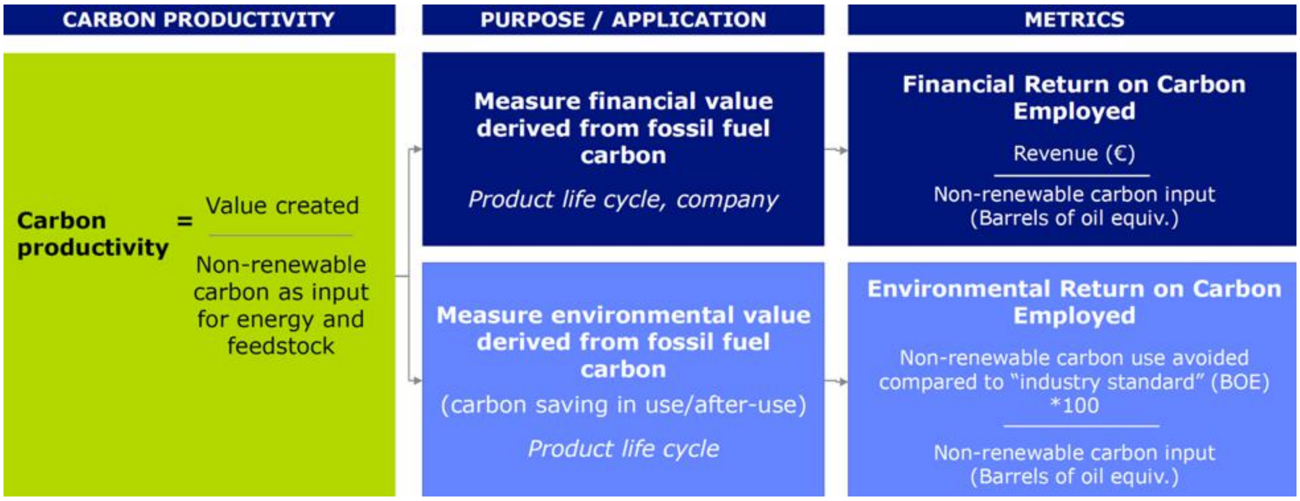
[14] *The Carbon Productivity challenge: Curbing climate change and sustaining economic growth*, https://mck.co/2OA8Hzs

[15] PwC, *Is Paris possible? The Low Carbon Economy Index 2017*, https://pwc.to/2gXiuQQ

[16] The 2017 Carbon Productivity Consortium objective: to seed the breakthrough idea of Carbon Productivity across industry and beyond, transforming it from a concept to a lever for change. Members: Covestro, Futerra, Future-Fit Foundation, Innovation Arts, SYSTEMIQ and Volans.

[17] The development of these metrics was led by SYSTEMIQ and Future-Fit Foundation, with Covestro providing the test-bed for application of FROCE and EROCE. For more detail of the methodology and development process, see https://bit.ly/2v8SSHQ

Figure 2: Prototype Carbon Productivity metrics



Source: Carbon Productivity Consortium

A logical corollary of these two would be to also measure Social Return on Carbon Employed (SROCE), though such a metric is yet to be developed.

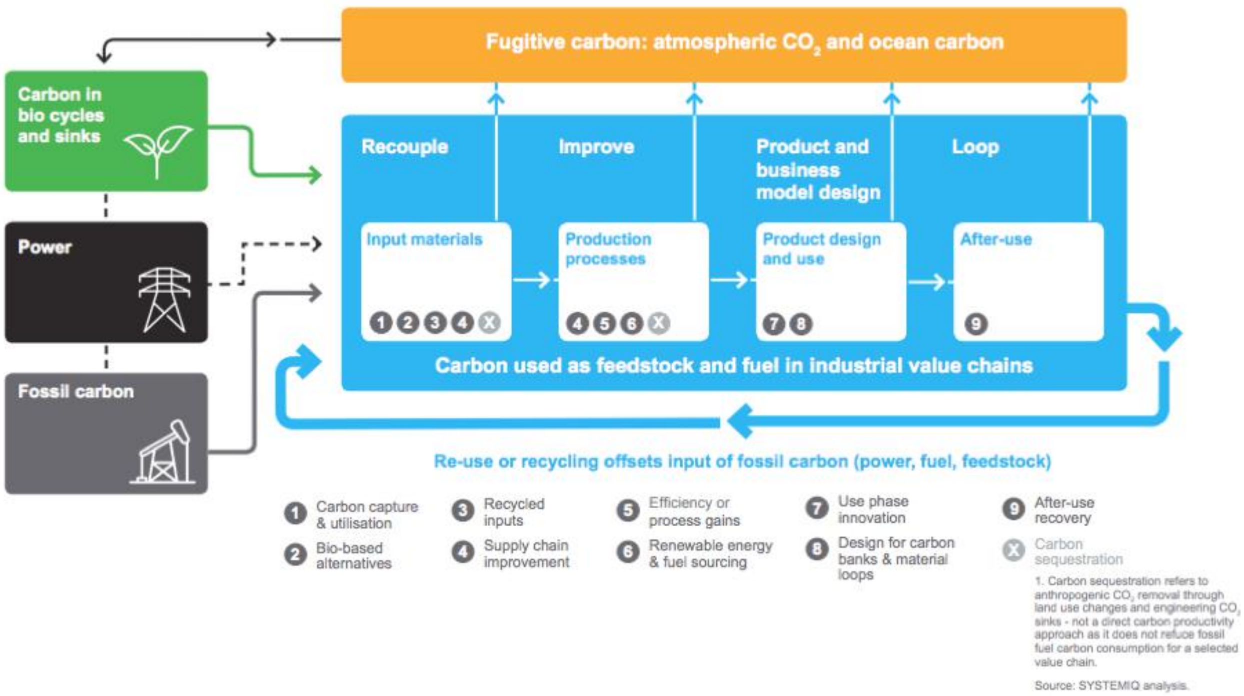
These metrics will need to evolve over time to embrace the potential for creating financial and environmental value with no 'non-renewable carbon input', or even whilst removing carbon from the atmosphere (i.e. when the equation's denominator is zero or negative).

Nonetheless, the metrics in their current form are applicable to any company that uses fossil carbon inputs to create physical products. We encourage business leaders to use FROCE and EROCE to track the performance of their product portfolio and to inform decisions about which new products to invest in.

Carbon Productivity improvement framework

The Carbon Productivity Consortium also developed a prototype improvement framework, identifying nine levers to decouple industrial value creation from fossil carbon consumption. (As figure 3 shows, there are actually ten intervention points, but the use of input materials or production processes that sequester carbon was not directly addressed in the prototype version of the tool.)

Figure 3: Prototype Carbon Productivity metrics



Source: Carbon Productivity Consortium[18]

This is not an exhaustive list of tools and metrics. Other, complementary methodologies — carbon handprinting[19], for example — are beginning to emerge. Considerable further iteration, experimentation and refinement is needed. Nonetheless, we can see the beginnings of a set of performance indicators for different actors across business, policy and finance.

[18] Carbon Productivity Consortium, *Prototype for a Carbon Productivity Tool: Framework, Metrics and Methodologies*, https://bit.ly/2v8SSHQ

[19] https://www.vtt.fi/sites/handprint/background-and-motivation, http://www.handprinter.org/

Why we need a Carbon Productivity revolution

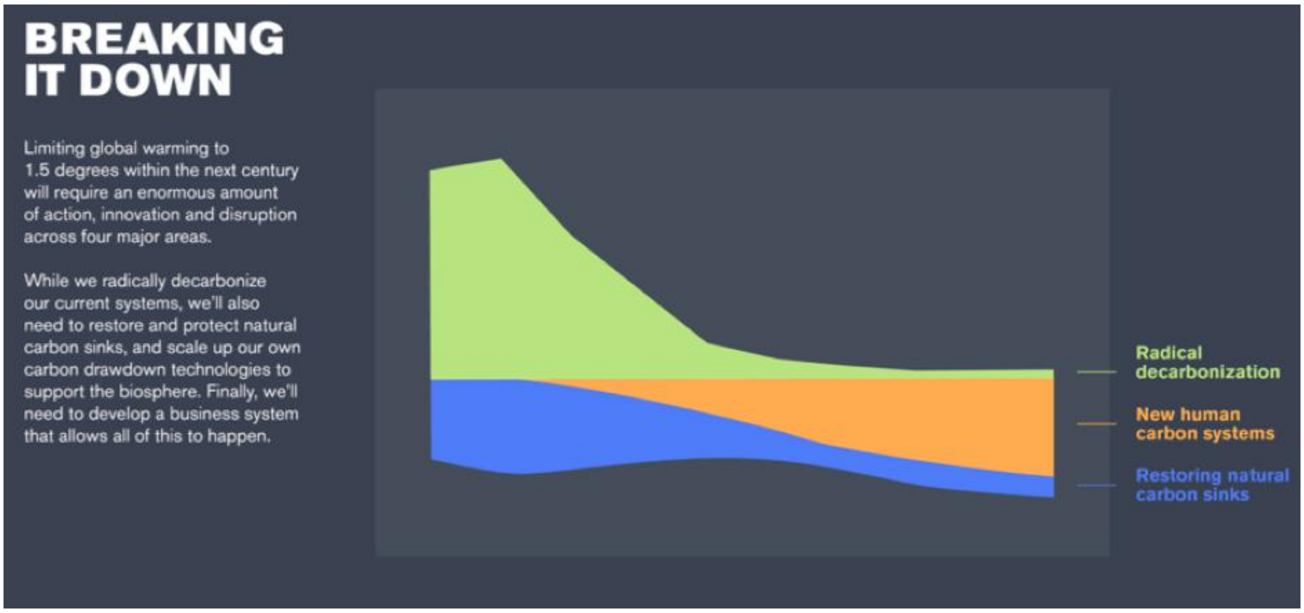
For more than 200 years, the principle way humans have generated value from carbon has been by digging fossil fuels out of the ground and burning them for energy. This process releases CO_2 and other 'waste gases' into the atmosphere, causing global warming. Global temperatures have already increased by approximately 1°C since the start of the Industrial Revolution — and far from slowing down, the pace of warming has actually accelerated in recent decades.[20]

This economic model has now run out of road. To limit global warming to 2°C — the upper threshold set by the Paris Agreement — our remaining 'budget' of CO_2 emissions is roughly 700 gigatons. To meet the more ambitious goal of limiting global warming to 1.5°C, our remaining budget is roughly zero.[21]

This means we face an imperative to cut global CO_2 emissions to zero very rapidly — leaving much of the world's known fossil fuel reserves unburned. Importantly, we must also remove significant quantities of carbon from the atmosphere and sequester it in biological and/or technological sinks.

The Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report identified 116 pathways to stabilise global temperatures at or below 2°C above pre-industrial levels. Of these, all but 15 require significant removal of atmospheric CO_2; the remaining 15 are based on global emissions peaking in 2010, which they didn't.[22]

Figure 4: Interface's breakdown of "Climate Take Back"



Source: Slide presentation by Erin Meezan, CSO, Interface at the 2017 Carbon Productivity Basecamp[23]

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[20] https://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php

[21] The Mercator Research Institute on Global Commons and Climate Change provides three estimates (upper, medium and lower) of our remaining carbon budget for both 2°C and 1.5°C. The figures quoted in this paper are the medium estimate. https://www.mcc-berlin.net/en/research/co2-budget.html

[22] 'UK launches 'world first' research programme into negative emissions', https://bit.ly/2p2v6Jo

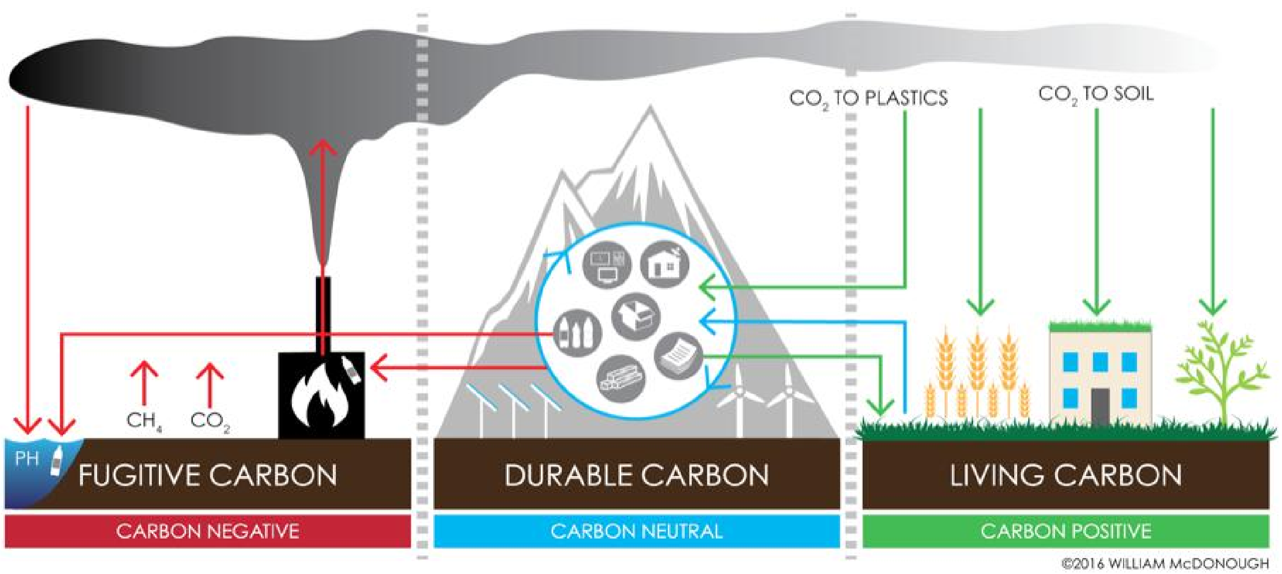
[23] http://carbonproductivity.com/basecamp-event/

Reimagining our relationship with carbon

Carbon comes in many forms. In a 2016 *Nature* article on the 'New Language of Carbon'[24], William McDonough offered a simple framework for thinking about this critical element. He identifies three categories of carbon:

- **Living carbon**: organic, flowing in biological cycles, providing fresh food, healthy forests and fertile soil. Something we want to cultivate and grow.
- **Durable carbon**: locked in stable solids such as coal and limestone or recyclable polymers that are used and reused. Ranges from reusable fibers like paper and cloth, to building and infrastructure elements that can last for generations and then be reused.
- **Fugitive carbon**: has ended up somewhere unwanted and can be toxic. Includes carbon dioxide released into the atmosphere by burning fossil fuels, 'waste to energy' plants, methane leaks, deforestation, much industrial agriculture and urban development.

Figure 5: The New Language of Carbon



Source: William McDonough website[25]

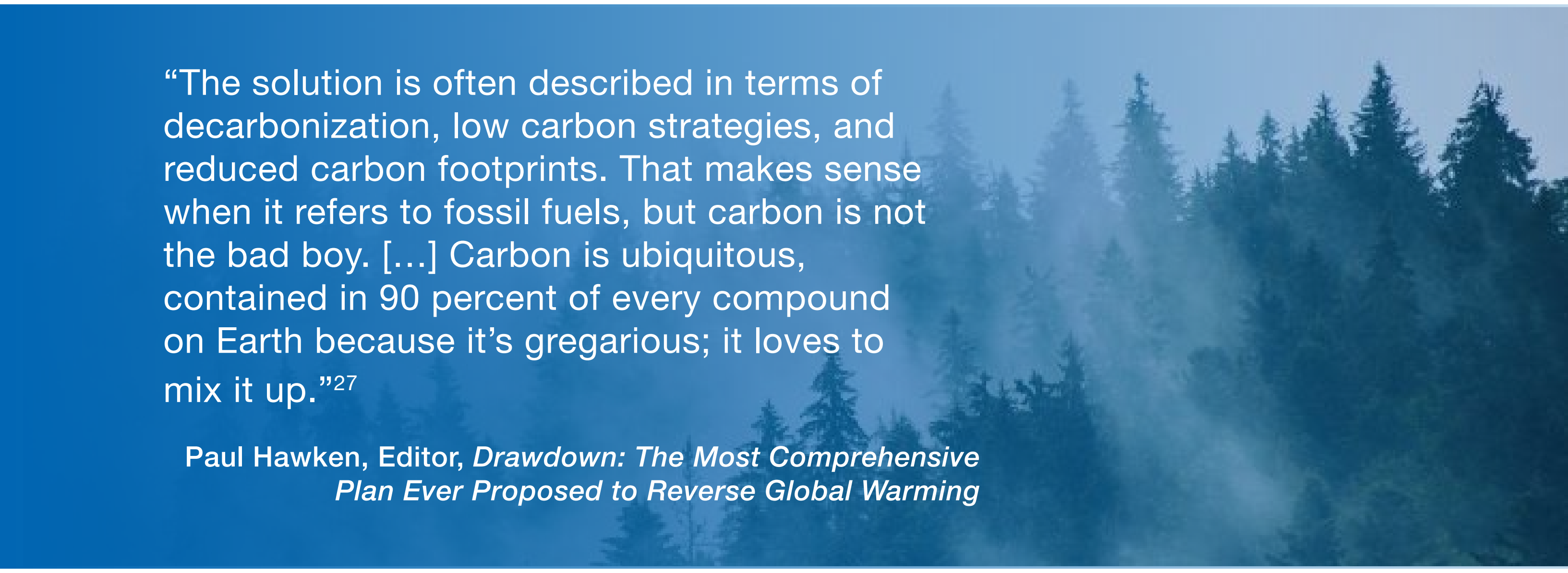
Put simply, the challenge is to build an economy that reduces fugitive carbon and increases both durable and living forms of carbon.[26]

[24] https://www.nature.com/news/carbon-is-not-the-enemy-1.20976

[25] 'Carbon is not the enemy', https://bit.ly/2iY7Par

[26] There are, of course, potential downsides to durable carbon too, notably in terms of waste and disposal. Plastics in the ocean are a case in point.

Shifting the goalposts: from reducing to reversing



> "The solution is often described in terms of decarbonization, low carbon strategies, and reduced carbon footprints. That makes sense when it refers to fossil fuels, but carbon is not the bad boy. […] Carbon is ubiquitous, contained in 90 percent of every compound on Earth because it's gregarious; it loves to mix it up."[27]
>
> **Paul Hawken, Editor,** ***Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming***

Ambitious as the 1.5-2°C goal is from where we stand today, there is a growing contingent within the climate movement that dares to name a yet more ambitious goal: reversing global warming. As Paul Hawken put it in his speech at the Carbon Productivity basecamp in 2017, "If you're going down the wrong road, slowing down isn't enough. You have to stop and turn around."

This proposed shifting of the goalposts has implications for what we measure. Over the past couple of decades, extraordinary progress has been made in developing a robust infrastructure for disclosure of emissions data. More than 6,300 companies and 500 cities disclose emissions data to the Carbon Disclosure Project (CDP). Investors with assets worth more than $87 trillion make use of that data — as do corporate procurement teams with collective purchasing power of more than $3 trillion.[28]

Now we need to build the same level of transparency, backed by rigorous standards, around carbon removal and Carbon Productivity. Methodologies are emergent, but, as yet, we lack an equivalent to the Greenhouse Gas Protocol[29] for carbon removal.

Similarly, shifting the goal from reducing emissions to reversing global warming has implications for the targets and incentives that companies, investors and policy-makers set. According to CDP, 9 out of 10 companies now have emissions reduction targets in place.[30] More than 100 companies have set approved Science-Based Targets.[31] While this progress is welcome, the next frontier is to set targets that go beyond zero emissions — aiming instead for a net positive impact on the climate.

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[27] http://greenmoneyjournal.com/hawken/

[28] https://www.cdp.net/en/info/about-us

[29] http://www.ghgprotocol.org/

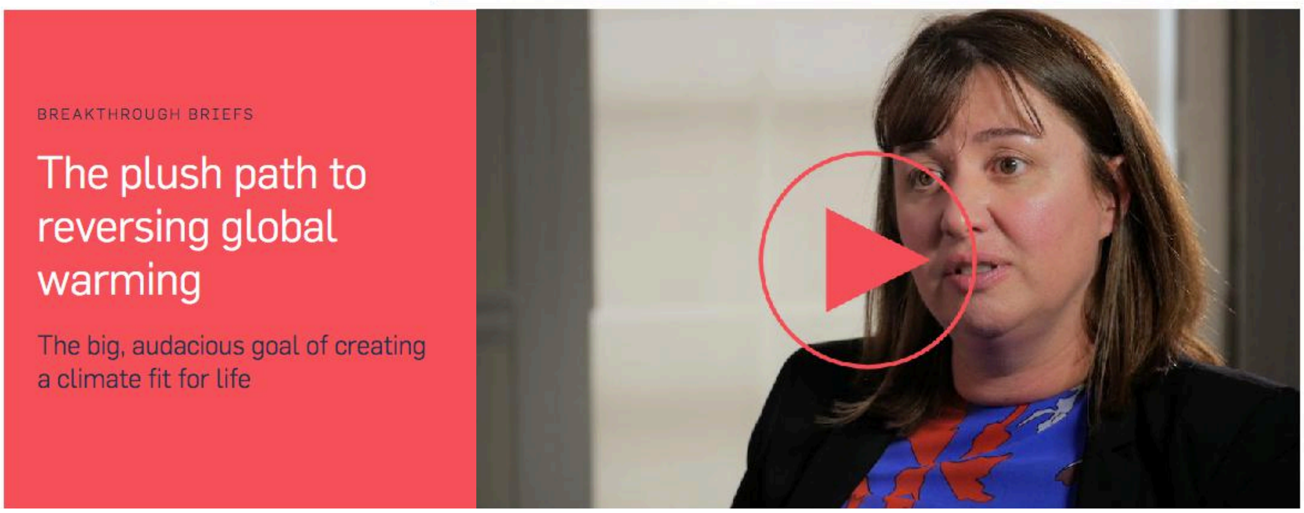
[30] https://www.cdp.net/en/research/global-reports/tracking-climate-progress-2017

[31] http://sciencebasedtargets.org/

> “Reducing emissions isn’t enough. We need to clean up the carbon that’s already in the air.”
>
> **Center for Carbon Removal**

Interface, the carpet tile manufacturer with a 25-year track record of being a sustainability leader, is once again pushing the boundaries of ambition. In 2017, the company unveiled a new mission — Climate Take Back — which focuses on going beyond zero emissions.[32]

Apart from anything else, there is an important psychological dimension to this shift from negative language and reduction goals to positive ones. As Interface Chief Sustainability Officer, Erin Meezan, puts it: “Would you rather be working on a challenge that says create a product that shows we can reverse global warming, or knock off another 10% in terms of the carbon footprint of the product? What’s more exciting? You want to work on the product that’s going to manifest an intention to solve the biggest issue facing humanity. Who doesn’t want to do that?”[33]



Source: Interview with Erin Meezan on Project Breakthrough — a collaboration between Volans and the UN Global Compact.[34]

[33] http://breakthrough.unglobalcompact.org/briefs/carbon-productivity-video/

[34] http://breakthrough.unglobalcompact.org/briefs/erin-meezan-interface/

Carbon Productivity and long-term value

The prevailing narrative today is that halting global warming will come at an enormous cost to the global economy. Estimates of these costs vary widely, but the assumption that costs will outweigh savings and revenues is widespread — and misleading. In fact, reversing global warming could provide an economic prize of considerable scale.

Many models of the long-term costs of climate action underestimate both the costs of inaction and the potential for climate solutions to deliver significant cost reductions and new revenue generation opportunities.[35]

To get a sense of the scale of economic opportunity linked to reversing global warming, consider the following data points (further examples in the next section):

- Project Drawdown's analysis of 80 solutions that would together reduce atmospheric CO_2 by more than 1000 gigatons estimates that the lifetime savings of those solutions (spread over the course of 30 years) would outweigh costs by almost $45 trillion — equivalent to a rate of return of roughly 150%.[36]
- The Global CO_2 Initiative estimates that the market for products that sequester carbon will be in the range of $800 billion to $1.1 trillion a year by 2030, whilst removing the equivalent of 10% of annual global CO_2 emissions from the atmosphere.[37]

A price on carbon in line with the recommendations of the High-Level Commission on Carbon Prices[38] (at least $40-80/t$CO_2$ by 2020 and $50-100/t$CO_2$ by 2030) would make these economic opportunities even more attractive. But the scale of the market opportunity is compelling even in the absence of effective action from global policy-makers.

[35] Additional examples include Dimitri Zenghelis, 'Decarbonisation: Innovation and the Economics of Climate Change' in Jacobs and Mazzucato (eds), *Rethinking Capitalism: Economics and Policy for Sustainable and Inclusive Growth* (2016).

[36] http://www.drawdown.org/solutions-summary-by-rank

[37] *A Roadmap for the Global Implementation of Carbon Utilization Technologies,* https://bit.ly/2KglZho

[38] *Report of the High-Level Commission on Carbon Prices,* https://bit.ly/2qwj8YJ

Carbon Productivity **today**

This section reviews recent developments in policy and R&D, as well as the state of carbon productive innovation across three key value nexuses: cities, materials and food.

The good news is that there is a wide and growing spectrum of solutions already in the marketplace — too many for us to attempt a comprehensive overview in this paper. The challenge now is to accelerate the speed and scale with which they evolve, in a way that is commensurate with the ultimate goal: reversing global warming whilst creating shared prosperity.

Stages of progress: from incremental gains to transformation

Most corporate climate action strategies typically fall into one of three categories, as outlined in figure 6 on page 16.

- Level A involves pursuing operational efficiencies (reducing scope 1 and 2 emissions).[39]
- Level B takes a more holistic value chain perspective (covering scope 1-3 emissions).
- Level C — the most ambitious — sets targets that go beyond zero emissions, embedding the principles of Carbon Productivity (creating value by reducing atmospheric carbon) in the business model.

These three levels of activity are not mutually exclusive; rather, they represent stages on a journey, with each building on what's gone before. Level C represents a flipping of the paradigm, in the sense that it changes the goal from a negative one — minimising emissions — to a positive one — reversing global warming – but, even so, operational efficiencies and life-cycle thinking remain important in the new paradigm.

[39] See GHG Protocol FAQs document for an explanation of Scope 1, 2 and 3 emissions, https://bit.ly/2v7LEUv

Figure 6: Stages of progress towards a New Carbon Economy

A. Emissions reduction / eco-efficiency applied to operations	B. Life-cycle thinking / carbon footprint considered	C. Core business model seeks to go beyond zero emissions
Goal • Reduce GHG emissions across operations • Implement, measure and report efficiency measures ***Metrics*** • Financial Return on Carbon Employed • Energy sourced from renewables • Energy use across operations • Employee commuting • Fleet management	***Goal*** • Calculate, benchmark and reduce "carbon footprint" of full value chain/product life cycles • Assess risk/opportunity vis à vis climate ***Metrics*** • Environmental Return on Carbon Employed • LCA, carbon footprinting • Reporting in line with international standards, e.g. CDP, Taskforce on Climate-Related Financial Disclosures[40]	***Goal*** • Generate economic value while removing / avoiding more carbon than is emitted • Value creation and restoration of carbon cycle are fully aligned ***Metrics*** • Evolved version of Return on Carbon Employed that incorporates potential for non-renewable carbon inputs to be zero • "Carbon handprinting"[41]
Early phase, mainstream 1990s – 2005	***Midpoint, gaining traction*** 2005 - present	***Emergent future*** Present - 2030

Source: Volans 2018

Strategies for adopting Carbon Productivity will vary based on sector and other market factors. For example, a retail company sourcing more energy from solar fits into category A, as it relates to how they power their operations. However, the company manufacturing the solar panels fits into C as reducing 'fugitive' CO_2 is core to the way they generate economic value. Meanwhile, the investor reviewing the retail company within its portfolio may be undertaking an assessment more aligned with B.

For the retailer to shift into category C, it would need to close material loops, maximise carbon sequestration opportunities in its supply chain, employ net zero building principles and consider how its products enable customers to lead more carbon productive lives.[42]

[40] Taskforce on Climate-Related Financial Disclosures, https://bit.ly/2s4O2bh

[41] https://www.vtt.fi/sites/handprint, https://www.handprinter.org/

[42] For a more detailed view of how to improve Carbon Productivity, see the 'nine levers to decouple industrial value creation from fossil carbon consumption' framework developed by SYSTEMIQ and the Future-Fit Foundation, on behalf of the Carbon Productivity Consortium: http://carbonproductivity.com/carbon-productivity-tool/

Carbon pricing & policy

In order for industry to embrace Carbon Productivity as a key performance indicator — and to drive improvement at the necessary pace and scale — policy-makers need to set the right incentives (and disincentives).

Carbon pricing has long been the favoured climate solution of economists, but efforts to introduce an effective price on carbon (whether through carbon taxation or emissions trading schemes) have been continually frustrated in many jurisdictions.

Nonetheless, there is growing momentum around the world. According to the Carbon Pricing Leadership Coalition, 42 national and 25 subnational jurisdictions were pricing carbon as of 2017, covering 22% of global emissions. When existing and planned initiatives are taken into account, they cover almost half of global emissions.[43]

In order for carbon pricing to incentivise the full spectrum of solutions necessary to achieve Drawdown (the point at which the quantity of CO_2 in the atmosphere peaks and begins to fall), a key challenge will be to ensure next-generation pricing mechanisms take into account carbon removal/sequestration as well as emissions.

Nori – creating a market for carbon removal

Nori, a US-based start-up, plans to launch the world's first CO_2 removal marketplace, using a transparent and secure platform that will allow anyone in the world to pay to remove excess carbon dioxide from the atmosphere.[44] It will be a voluntary marketplace connecting suppliers directly with buyers, using a blockchain-based cryptocurrency, with each token tied to one ton of physical carbon sequestered in soil. The mission of the organisation is to reverse climate change, and they have openly declared that they hope this is the first of several marketplaces that will make it easier and more profitable to remove carbon from the atmosphere.[45]

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[43] https://www.carbonpricingleadership.org/who/

[44] https://nori.com/

[45] https://nori.com/podcast/8-aldyen-donnelly-director-of-carbon-economics-for-nori

The R&D landscape

In our conversations with corporate stakeholders, we have heard repeated calls for a better R&D infrastructure to fund and enable the required leaps in technology development and adoption. No single company can make the shift required without action across whole value chains. This will require a level of R&D that supersedes any one corporate shop.

People recall a time of research collaborations such as Bell Labs[46], which enabled technological advancements in the early part of the 20th century through significant cross-industry and governmental investment in R&D. A similar scope of effort is now urgently needed in the area of carbon removal. There are several programmes of moderate scale already established (see examples below). There remains a need for greater ambition, effort and resourcing to enable cross-sector and industry-level shifts.

Example 1: Center for Negative Carbon Emissions

Arizona State University's Center for Negative Carbon Emissions focuses on carbon management technologies that can capture CO_2 directly from the air. They also consider the economic, political, social and environmental ramifications related to affordable air capture technology. They feature several demonstration projects on their website[47], and their interdisciplinary research approach includes:

- Demonstration and development of prototype technologies to close the carbon cycle and create net negative emissions.
- Advancement of fundamental sciences supporting this new technology base.
- Systems analysis and engineering studies of rapid transition to new energy infrastructures.
- Models of the underlying mechanisms within air capture technology.
- Study of the interactions of these new technologies with policy development and of the societal implications of these changes.
- Analysis to determine the optimal positioning of these technologies to best serve societal needs.

Example 2: NRG COSIA Carbon XPRIZE

The NRG COSIA Carbon XPRIZE sets a challenge for innovation teams to convert CO_2 into valuable products. With prize money of $20 million on offer, the challenge has ignited significant interest and helped accelerate the development and deployment of a range of Carbon Capture and Use (CCU) ventures. The 10 finalists from around the world take diverse approaches to turning CO_2 emissions into products, including concrete, liquid fuels, plastics and carbon fiber, illustrating a range of commercial opportunities that are poised to grow.[48] Scaling the early-stage innovation fostered by the XPRIZE remains a challenge, as many of the technologies are not yet perceived to be investment-ready by mainstream venture capital funds, but the pipeline is beginning to build.

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[46] https://en.wikipedia.org/wiki/Bell_Labs

[47] https://cnce.engineering.asu.edu/research/

[48] XPRIZE, '$20M NRG COSIA Carbon XPRIZE', https://bit.ly/2HmLE82

Carbon Productivity in practice

So when the right policies and R&D environment allow the principles of Carbon Productivity to flourish across different industries and value chains, what does it look like? Over the next few pages, we highlight some key developments across three key value nexuses in the global economy: cities, materials and food.

Cities

Picture a city where for every mile travelled in a private or public vehicle, more carbon is sequestered than emitted. Offices and homes self-generate heating and cooling, or create it using power from renewable sources that are connected to a smart grid to optimise energy use. The buildings themselves are constructed from materials that take carbon dioxide from the air and lock it up for decades, even centuries. Integrated into this cityscape are living, biodiverse ecosystems — used for food production, recreation, water filtration, temperature moderation and more — which draw carbon from the atmosphere down into the soil.

This vision may sound far-fetched, but in reality, most of the technologies required to transform the Carbon Productivity of tomorrow's cities already exist today.

Maximising the **energy efficiency** of buildings is a form of low-hanging (and bountiful) fruit when it comes to enhancing the Carbon Productivity of our cities.

Project Drawdown calculates that if just one in ten new buildings achieves net zero performance by 2050, this would lead to a 7 gigaton net reduction in atmospheric CO_2 (equivalent to roughly 20% of current annual global emissions).[49] Improving the energy efficiency of buildings is, meanwhile, projected to be a $555-770 billion a year market opportunity by 2030.[50]

Given this, it is perhaps no surprise that investor interest in green buildings is on the rise. Over the period from 2014 to 2017, Citibank delivered $2.8 billion of financing for green buildings and energy efficiency.[51]

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[49] http://www.drawdown.org/solutions/buildings-and-cities/net-zero-buildings

[50] Business & Sustainable Development Commission, *Better Business, Better World,* https://bit.ly/2mfsljM

[51] Citi group, *Sustainable Growth at Citi,* http://citi.us/2whYbVh

Vert Asset Management, a US-based ESG fund manager, argues that property owners and tenants have ample scope to profit from energy efficiency retrofits and building improvements, as better buildings command a higher price/rent and, in the case of commercial premises, enhance worker productivity. The investment case for green buildings, they conclude, is straightforward.[52]

Even some seemingly well-worn sustainability stories, such as **lighting retrofits**, still have huge potential. According to The Climate Group, lighting accounts for nearly 6% of global CO_2 emissions. A global switch to energy efficient light emitting diode (LED) technology could save over 1,400 million tons of CO_2. The economic co-benefits are substantial too: Los Angeles, an early adopter of LED street lighting, reduced its energy bills by 63%.[53]

Combining LED lighting with new business models and/or other emerging technologies, such as smart sensors, has the potential to drive this transformation further and faster. **Signify** (formerly Philips Lighting) is at the leading edge of this revolution, having developed two new offerings in recent years:

- Circular lighting: the company has begun to roll out a “pay-per-lux” business model whereby it retains ownership of the light fittings and customers pay for performance.[54]
- Connected lighting: integrating sensors into light fittings opens up a whole realm of additional opportunities, from smarter energy usage to monitoring air quality and, even, fighting crime.[55]

Another area of innovation in the built environment is the use of **cross laminated timber**. According to the United States Department of Agriculture’s *Wood Handbook*[56], the carbon emitted to produce a ton of framing lumber is roughly eight times less than that emitted to produce a ton of concrete. What’s more, when sustainably sourced, the use of timber as a building material can help sequester carbon: a strong market for timber can help incentivise reforestation (though, clearly, there is a risk that some timber will come from unsustainable sources and will therefore contribute to deforestation).[57]

That said, we do not envisage the carbon productive cities of the future being entirely built from timber. Innovations in cement, concrete and steel production are critical too – both to reduce the emissions associated with the production of those materials, and, in the case of cement and concrete, to increase the potential for carbon sequestration (see more in Materials section below).

Innovation is needed across many other dimensions of city life, from mobility systems to lifestyles. Across each area, the basic story is clear: there is huge potential for cities to evolve into places where people can thrive in a way that boosts Carbon Productivity.

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[52] Vert Asset Management, *Investing for Sustainability: Real Estate,* https://bit.ly/2M8XxA7

[53] https://www.theclimategroup.org/project/led-scale

[54] http://breakthrough.unglobalcompact.org/briefs/philips-intelligent-light/

[55] Computerworld.com, ‘Los Angeles tests gunshot sensors on light poles’, https://bit.ly/2Kicdet

[56] USDA, *Wood Handbook*, https://bit.ly/2LBUwMB

[57] http://naturalclimatesolutions.org/

Materials

Imagine if every substance we used to build our homes, our transportation systems, our everyday household products — *everything* — was made in a way that created value for society while avoiding emissions. Imagine materials designed to fufil their purpose — be it insulating, conducting or strengthening — to the highest standard, and doing so in a way that sets us on a pathway to drawing down more carbon than we emit.

Once again, the technological breakthroughs required to make this future a reality have, for the most part, already been made.

Optimising the Environmental Return on Carbon Employed (EROCE) of materials that go into everything from buildings to vehicles is a critical aspect of the Carbon Productivity revolution. Replacing metals and glass with **lighter weight, high-performance plastics** in automotive manufacturing can, for example, lead to a reduction in tailpipe emissions — an example of a good EROCE. Carbon-based materials can deliver a similarly attractive EROCE when used to insulate buildings or protect food from being spoilt between field and fork, amongst other use cases.

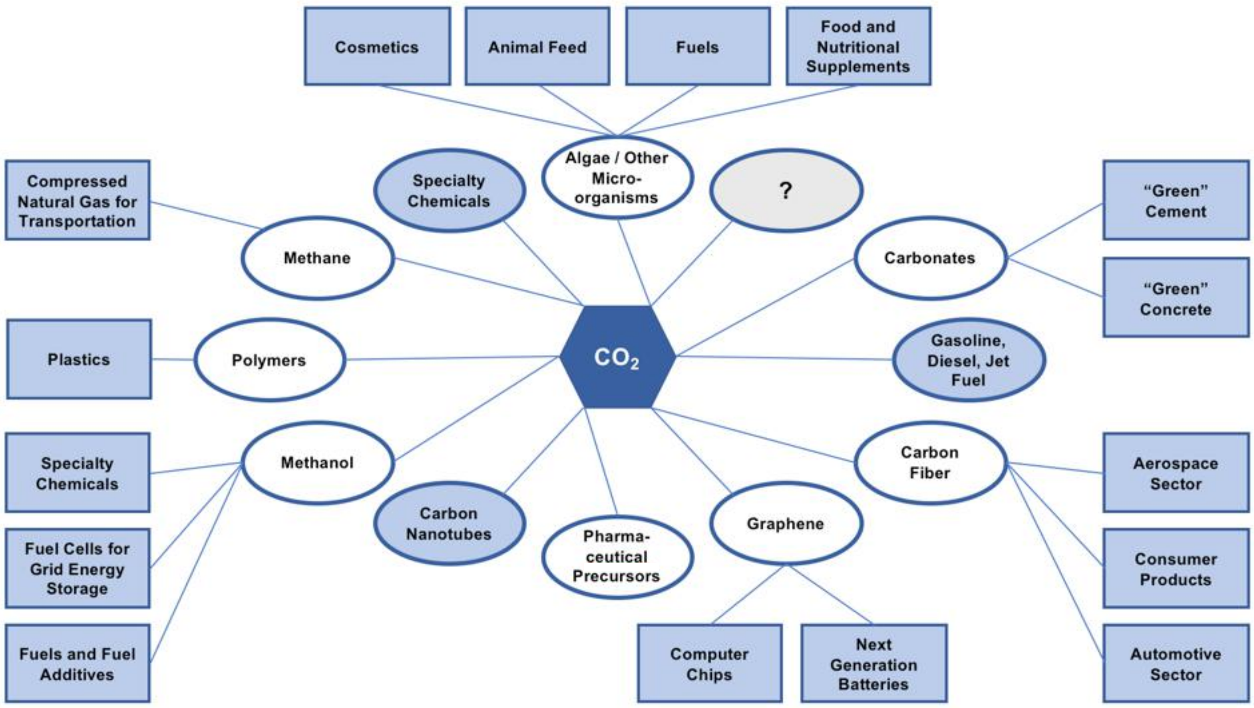
Given the catastrophic problem of **plastic waste** clogging up our land and water ecosystems, what happens to materials after use is clearly also a critical question. The Ellen MacArthur Foundation (EMF)'s New Plastics Economy report aims to set the standard in this area. Once again, the potential economic upside is significant too: EMF estimates that 95% of the value of plastic packaging, worth $80-120 billion annually, is currently lost to the economy.[58]

> "We challenge the world to reimagine what we can do with CO_2 emissions by incentivizing and accelerating the development of technologies that convert CO_2 into valuable products. These technologies have the potential to transform how the world approaches CO_2 mitigation, and reduce the cost of managing CO_2."
>
> **NRG COSIA Carbon XPRIZE**

Finally, there's the emerging potential to use **captured CO_2 as a feedstock** for new materials. The XPRIZE's Carbon Conversion Landscape Analysis (see figure 7 on next page) provides a helpful overview of where technologies are showing promise to convert CO_2 into valuable products.

[58] Ellen Macarthur Foundation, *New Plastics Economy,* https://bit.ly/2mp6VGI

Figure 7: Selection of products that can be made from CO_2



Source: Adapted from XPRIZE's 2014 report, Carbon Conversion Landscape Analysis[59]

Examples of enterprises that are beginning to apply and commercialise the potential of Carbon Capture and Use (CCU) technologies include:

- In 2016, **Covestro** became the first company in the world to commercialise a CO_2-based polymer — cardyon — which is used in upholstered furniture and mattresses. Up to 20% of the carbon in cardyon comes from CO_2.[60]
- **Interface** has developed a carpet tile prototype — Proof Positive[61] — that incorporates plant-derived carbon, thereby removing 3.7 pounds of CO_2 from the atmosphere with each square yard produced.[62] And because Interface has, over the last 20 years, developed a closed-loop recycling programme, the carbon is kept locked up in a 'durable' form for generations.
- **Cert** converts carbon dioxide into fuels and chemical feedstocks using only water and electricity, through a process that operates at room temperature and atmospheric pressure. Its target application is the production of ethylene, a major precursor to consumer plastic, made from CO_2.[63]

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[59] XPRIZE, *Carbon Conversion Landscape Analysis*, https://bit.ly/2KjKLgF
[60] https://www.covestro.com/en/cardyon/cardyon
[61] Interface's carpet tile prototype, 'Proof Positive', https://bit.ly/2xD1HJD
[62] strategy+business, 'Manufacturing Goes Carbon Negative', https://bit.ly/2rwapbh
[63] https://co2cert.com/

- **Carbon Upcycling Technologies** also uses CO_2 as a feedstock. Its products enhance characteristics such as UV protection and tensile strength in plastics, improved strength of concrete, improved capabilities in adhesives, longer lasting lithium battery capacity and more.[64]
- **Newlight Technologies** is converting CO_2 emitted from power generation facilities into pelletized polymers that can be used in electronics, apparel, furniture and packaging.[65]
- **Solidia**, in partnership with Air Liquide,[66] has developed a concrete curing process that reduces net emissions by up to 70% (compared with Ordinary Portland Cement, the most common type of cement in general use worldwide).
- **CarbonCure** sells equipment that enables manufacturers to replace air or steam in the concrete curing process with CO_2, thereby increasing the amount of CO_2 sequestered.[67] As of December 2017, CarbonCure's technology was being used in 50 concrete-making plants across North America.[68]

Mine rehabilitation is another important — and often overlooked — aspect of the materials value web. Mining is critical not just for electronics and vehicles but also for newly constructed sustainable transportation networks, net zero buildings, sustainable agriculture, smart grids and more. So the mining sector will also need to become significantly more carbon productive.

One high potential way to address climate impacts in mining is to increase the amount of carbon stored in mine waste, known as tailings. There is compelling research to support the relative ease with which mines could be redesigned to store CO_2, requiring no new technology. In some cases, the capacity of the mining waste to capture CO_2 is 10X greater than emissions.[69]

Food

Imagine a world where everyone has sufficient quantities of high-quality food, produced in a way that does not deplete the land but instead encourages a thriving, biodiverse ecosystem. This is a world where healthy soils deliver environmental benefits (retaining carbon and water), improve the nutritious value of food for consumers and improve yields for farmers.

[64] http://www.carbonupcycling.com/
[65] https://www.newlight.com/
[66] Air Liquide, 'Air Liquide contributes to the development of a new sustainable concrete', https://bit.ly/2vwNnDp
[67] https://www.carboncure.com/about, https://www.carboncure.com/xprize
[68] Quartz, 'The material that built the modern world is also destroying it. Here's a fix', https://bit.ly/2iXwaQp
[69] https://nori.com/podcast/9-dr-greg-dipple-university-of-british-columbia

If we look hard enough we can see this reimagined food system already starting to emerge. Some efforts are very grassroots (literally, as they aim to increase soil carbon within root systems among crops and other vegetation), while others leverage cutting edge technologies.

Roughly one third of the food produced for human consumption every year — approximately 1.3 billion tons — is lost or wasted.[70] Addressing this issue has major implications for global warming. According to Project Drawdown, a 50% reduction in **food waste** by 2050 could help avoid up to 26.2 gigatons of CO_2 emissions directly, as well as another potential 44.4 gigatons by avoiding deforestation to create new farmland.

At the same time, reducing food waste in value chains and amongst consumers could generate savings and revenues of $330-$625 billion a year by 2030 (part of an estimated overall $2.3 trillion a year opportunity in the food and agriculture nexus).[71]

Regenerative agriculture is another area where there is significant potential for creating win-win outcomes: sequestering carbon, improving profitability for farmers and increasing nutritional value for consumers all at the same time.

Codifying and communicating this for a wider supplier and consumer audience, the Rodale Institute launched a Regenerative Organic Certification process in 2018, which includes soil carbon and carbon sequestration in its measurement and reporting framework.[72] The Savory Institute also launched a 'Land to Market' verification initiative, designed to support the training and monitoring of farmers around the world to shift meat, dairy, wool and leather production to being regenerative.[73]

Silvopasture — the ancient practice of integrating trees and pasture into a single system for raising livestock — comes in at #9 in Project Drawdown's ranking of solutions by CO_2 reduction potential. By their estimates, if adoption were to spread from 351 million acres worldwide today to 554 million acres by 2050 (approximately a fifth of the total area that is theoretically suitable for silvopasture), this would reduce atmospheric CO_2 by 31.2 gigatons. The projected total investment required to implement this is $42 billion, whilst lifetime savings and revenue opportunities come in at a healthy $699 billion.[74]

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[70] http://www.fao.org/save-food/resources/keyfindings/en/

[71] AlphaBeta, *Valuing the SDG Prize in Food and Agriculture*, https://bit.ly/2OixpDs

[72] Rodale Institute, *Framework for Regenerative Organic Certification,* https://bit.ly/2vqIGe2

[73] https://www.savory.global/landtomarket/

[74] http://www.drawdown.org/solutions/food/silvopasture

To a significant extent, the goal of a more carbon productive food system is a question of getting the business and financing models right to unlock the full potential of existing solutions. Shifting mindsets and behaviours matter too: for example, adopting a **plant-rich diet** is ranked #4 by Project Drawdown (with a CO_2 reduction potential of 66 gigatons).

Technological breakthroughs also have a role to play in augmenting the food and agriculture system's Carbon Productivity potential. Two emergent examples:

- A group of biochemists at the Max Planck Institute for Terrestrial Microbiology in Germany are working on ways to **'turbo-boost' photosynthesis** (thereby also boosting carbon sequestration) using gene-editing tools, such as CRISPR.[75] When it comes to feeding a global population of nearly 10 billion people, some observers are pinning significant hopes on such gene-editing capabilities because turbo-boosting photosynthesis also means crops grow faster, improving agricultural yields.[76]
- Swiss company **Climeworks** is a pioneer of **'direct air capture'** — removing CO_2 from the atmosphere and supplying it to customers in the food and beverages sector (for carbonated drinks, for example) and to farmers using greenhouses, where pumping in additional CO_2 can increase the rate of photosynthesis and boost crop yields by up to 20%.

In short, there are many ways the food value nexus can shift towards greater Carbon Productivity — from the way food is grown, to the way it is packaged and transported, to the way waste is cycled back into valuable streams.

We see many of these innovations taking hold at a grassroots level. The challenge now is to do it on an industrial scale. This will require a combination of increased consumer awareness and demand (aided by certification schemes and front-of-pack labels), continuous technological innovation and significant levels of investment to reconfigure business models and supply chains.

[75] Popularmechanics.com, *New Way of Transforming CO2 Is More Efficient Than What Plants Do*, https://bit.ly/2LY3OCO
[76] Geoffrey Carr, 'Farming tomorrow' in Franklin (ed)., Megatech: Technology in 2050 (2017)

Conclusion: a six-point plan for **building the New Carbon Economy**

The intent in this paper has been to spotlight early signs of an emergent future. Clearly, there is much work still to be done to get us to an economy that, in aggregate, sequesters more carbon than it emits.

We see six crucial areas of activity to focus on in order to create the necessary enabling environment for the New Carbon Economy to flourish:

1. **Evolving a new data and reporting infrastructure**

   Over the past 20 years, organisations and initiatives like CDP and the GHG Protocol have catalysed a transparency revolution around emissions. Now we need to do the same for emissions avoidance and carbon removal.

   The key methodological issues to be resolved are to do with the permanence of some removal techniques and the identification of credible "business as usual" scenarios against which to benchmark when assessing avoided emissions.

2. **Closing the gap between economic and environmental policy**

   Many governments pay lip service to "clean growth", but if they are serious about it, Carbon Productivity needs to become a key performance indicator for economic policy-makers, much as labour productivity is used today.

   An obvious corollary of this is to use policy to fix the market's failure to properly price CO_2 emissions. In addition, next-generation carbon pricing mechanisms will need to evolve to build in incentives for carbon removal.

3. **Enabling investors to see the opportunity side of carbon**

   Rather than asking of plans to reverse global warming, "what will it cost?", we must learn to ask "what will the return on investment be?" Project Drawdown's analysis of 80 solutions that would together reduce atmospheric CO_2 by more than 1000 gigatons estimates that the lifetime savings of those solutions would outweigh costs by almost $45 trillion.

   The challenge now is to design business models and investment vehicles that allow individual companies and investors to capture the value associated with implementing these solutions.

4. **Making the story of a new carbon economy accessible and inspiring**

   The fact that today we can't even agree on whether a product that removes carbon from the atmosphere is "carbon negative" or "carbon positive" is symptomatic of a very serious problem: we lack the clarity and consistency of messaging needed to engage consumers and citizens as agents of change.

   Simplicity and possibility should be our watchwords. The New Carbon Economy needs to make sense to those who don't know their CCUS from their direct air capture. And we must shift the focus from the problem to potential solutions. Naive optimism doesn't help shift behaviours, but nor does apocalyptic dread.

5. **Equipping companies with tools to monitor and manage progress**

   Companies are not self-organising systems. High performance is driven by management systems that monitor and incentivise progress towards key organisational goals and targets.

   A whole suite of new management tools and metrics is needed to help companies manage progress towards becoming (ever more) climate positive. The ideas outlined in this paper are, we believe, a useful starting point to build from.

6. **Forging closer links between companies and the R&D community**

   Academic interest in carbon removal and emissions avoidance processes and technologies is growing fast. Thanks to institutions like the Center for Carbon Removal, parts of this field are becoming increasingly organised.

   The next step is to start bridging the gulf between researchers and the companies that will ultimately be critical to commercialising and scaling new solutions for carbon removal and emissions avoidance. More opportunities for multi-way dialogue are badly needed.

Our intent in laying out this six-point plan is to provide an organising framework for those in the field (ourselves included) to think about next steps. There is no silver bullet: we need to make progress on multiple fronts simultaneously. That progress will undoubtedly be uneven, with setbacks along the way – as well as breakthroughs and unexpected leaps forward.

But the long-term trajectory is clear: the New Carbon Economy is, ultimately, both possible and inevitable. There is no viable alternative.

Additional **inspiration**

In the preceding pages we have selected a few examples to illustrate how Carbon Productivity is relevant to key industrial value nexuses. The list below contains links to some key organisations and initiatives in the wider ecosystem.

As the **Biomimicry 3.8** website eloquently states, nature has been managing carbon for 3.8 billion years. Here are nine solutions related to climate change that take a biomimicry approach: https://synapse.bio/blog//biomimicrysolutionsreport-carbon**.**

On the **Carbon Productivity** website you will find more details of the prototype Carbon Productivity tool, an interactive map of key actors in the wider ecosystem, as well as details of past events, videos and articles. (http://www.carbonproductivity.com)

The **Center for Carbon Removal** provides an excellent overview — as well as examples of — carbon dioxide removal strategies. (http://www.centerforcarbonremoval.org/)

The **Global CO_2 Initiative** was created to accelerate the development of the Carbon Capture and Use industry — which they project could be worth $1 trillion by 2030 — and their site lists numerous ways in which CO_2 can be transformed into valuable products. (https://www.globalco2initiative.org/#transforming-co2)

The **International Energy Agency (IEA)** provides significant reports and context on their website, including a focus area on carbon capture and storage, clean energy technologies, and climate change. (https://www.iea.org/topics/)

The **NRG COSIA Carbon XPRIZE** finalists comprise a rich array of enterprises that are taking carbon-to-value innovation to new markets, and striving to scale. (https://carbon.xprize.org/)

Project Drawdown models and describes the most substantive solutions to global warming that already exist. (http://www.drawdown.org/)