Executive summary
Green Technology Book 2023

WIPO

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Finding momentum

We are in a state of climate emergency. Limiting its catastrophic impact requires an unprecedented systems transformation. However, there is hope. The sources of greenhouse gas (GHG) emissions are many, but so are the technologies to address them.

There are sufficient options available across all sectors to at least halve emissions by 2030.[1] And technology and innovation are a key part of the solution. Eighty percent of the technologies we need to achieve the 2030 climate goals are already on the market[2] – with many more emerging. Technologies for lowering energy consumption, electrifying transport and enabling material efficiency are just some of the many options presented in this year's *Green Technology Book*. National innovation ecosystems are the source of all these new opportunities. A well-functioning innovation ecosystem is underpinned by an efficient and fair intellectual property rights system, which in itself stimulates innovation and disseminates technology to global markets.

This is the year of the Global Stocktake, where countries revise their national climate plans with the aim of raising ambitions for the coming years. And beyond nation-state level, a growing body of non-state actors, among them the private sector, academia and civil society, are working tirelessly to realize the vision set out in the Paris Agreement.

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Knowledge that inspires action

The first edition of the *Green Technology Book* addressed climate change adaptation technologies. In this second edition, we make climate change mitigation solutions tangible by showing the wealth of mature and emerging innovation and technologies available. This publication analyses 10 sectors within three major categories:

- **Cities**
  - Efficient heating and cooling
  - Smart mobility
  - Material efficiency and sustainable waste management
- **Agriculture and land use**
  - Livestock
  - Soils, land use change and forestry
  - Rice cultivation
  - Data and precision farming

- **Industry**
  - Iron and steel
  - Cement
  - Industry 4.0

Over 600 climate mitigation and adaptation technologies – and growing – have been identified for the *Green Technology Book* collection in the WIPO GREEN Database of needs and technologies.[3] This publication showcases a selection of those related to climate mitigation. Solution providers can upload an overview of their technology to the Database, making it a continually expanding source of green innovation and technology. By bringing the technologies to the forefront, we aim to inspire action. Now is the time to rapidly develop and deploy solutions that overcome carbon lock-in and drive forward transformational change.

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Designing circular and smart cities

Cities are where the climate battle will be largely won – or lost. They are where buildings are erected, energy and food consumed, waste generated and people and goods transported. On a vehicular level, the rapid scaling of electric cars has far exceeded expectations in many cities. Advances in battery technology, vehicle–grid integration and charging stations have been important enablers. However, while the electric vehicles market is growing, so is the trend toward highly fuel-consuming SUVs, which alone accounted for one-third of the total growth in oil demand between 2021 and 2022.[4] Furthermore, electric car prices are still out of reach for most people, particularly in emerging and developing countries. While many new electrified options for personal use and goods transport have emerged, including two-wheeled options, the effective reduction of transport sector emissions depends upon innovations that go beyond individual vehicles. For instance, better policies for compact cities and public transport can be practically supported by technologies such as intelligent traffic management systems, urban modelling tools and mobility-as-a-service platforms.

Energy-efficient heating and cooling technologies and alternative refrigerants are already on the market. Examples include new types of heat pumps, modern insulation materials and smart technologies able to adjust heating and cooling flow to match a building's demand. Yet, these are often not the foremost consumer choice, necessitating further innovation to make these solutions both more affordable and accessible. At the same time, the number of air conditioners installed worldwide is soaring, and heating is the biggest energy end-user. In a growing number of cities, district heating and cooling (district level centralized systems) helps reduce energy usage and enables renewable energy integration. However, emissions reduction in these sectors must go beyond improving operational efficiency. Technology can help address heating and cooling demand by enabling climate-smart design of buildings. Passive heating and cooling techniques have been around for centuries. Several countries are now modernizing these well-tried techniques and promoting their design principles through building codes and energy efficiency standards.

This publication further recognizes material efficiency and sustainable waste management in cities as a major lever for emissions reduction. From construction materials and wood to plastic and glass, the expected doubling of material use by 2050 urgently requires innovative solutions for enhanced circularity. Such solutions are no longer an option, but a necessity for climate action. Advances in sorting technologies, such as robotics and optical scanners, enable higher waste recovery rates. Innovative recycling technologies can now handle materials otherwise hard to recycle, such as tires and wind turbine blades.

Some waste management technologies are themselves a major source of emissions. Countries such as Denmark are moving away from materials incineration, because of its inefficiency and high emissions rate. Several emerging recycling technologies, such as chemical recycling, have been found to be energy-consuming, necessitating more focused life-cycle thinking directed at technology viability from a climate perspective. This also highlights the need for innovation and technologies that are more upstream. Deposit return and refill stations for anything from bottles and cans to water and detergents are growing in popularity in many cities. Meanwhile, digital tools support better building and product design to enable reusability, such as material passports. Furthermore, online platforms for co-ownership and the sharing of anything from cars and tools to office buildings reduce manufacturing demand for new things.

Regenerative agriculture and ag tech

Global food systems and the agricultural sector are under pressure. There is a pronounced need to produce more in order to feed a growing world population, often accompanied by a demand for more processed and high-emitting products. The environmental and climate change footprint of the agricultural sector is large, with methane emissions being particularly important. Agriculture, land use and land management account for around 22 percent of GHG emissions,[5] occupy 38 percent of the Earth's surface[6] and are responsible for 70 percent of global freshwater withdrawals.[7] It is therefore a sector where climate change mitigation is critical. Furthermore, the sector is highly vulnerable to climate change impacts and the type of climate change adaptation measures described in last year's *Green Technology Book* are urgently needed.

This edition focuses on the major emitting sectors within agriculture, and also considers the merits of the highly sophisticated technology frontier in data and precision farming. Livestock is a major source of emissions, primarily due to the methane produced by ruminant livestock. Emissions can be combatted through supply- and demand-side measures. On the supply side, there is strong correlation between productivity and emissions per amount of meat or milk produced, meaning meat and dairy product emissions can be reduced through increased productivity. Provided that such productivity increase does not create new environmental impacts or degrade animal welfare, it may contribute to limiting land and water usage.

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But innovation is providing new options. One of the more promising is feed additives. Seaweed added to livestock feed can directly affect the enteric fermentation process to dramatically reduce methane production. Much innovation is also directed toward addressing meat demand through the quest for meat alternatives acceptable to the general consumer. Several such alternatives are currently being made available to consumers. However, while the benefits to avoided animal cruelty of this approach are obvious, the net environmental gains have yet to be determined. Replacing animal protein with plant and fungi-derived alternatives in the mass production of a broad range of processed food products may have a greater potential impact in this regard.

Chapter 3, Agriculture and land use, further touches upon range and land management. Soil stores vast amounts of carbon in a relatively stable form. Intensive agricultural practices and chemical fertilizers which cause soil degradation and erosion, as well as deforestation, lead to the release of this carbon stock. Careful management of land, regenerative agriculture and innovations that increase soil carbon all have a high mitigation potential. However, this is dependent on their becoming integral to the agricultural practice of a vast number of farmers.

Rice cultivation is a crop system of particular climate concern, because it involves flooding fields, which releases methane. In a rice producing region such as South East Asia, rice cultivation is responsible for between 25 and 33 percent of methane emissions.[8, 9, 10] It also uses a large amount of freshwater, making the practice highly vulnerable to climate change impacts. Productivity enhancements involving reduced water usage on less land can help reduce emissions. New cropping systems in which fields are flooded for a shorter period of time have shown promising results in those places where they can be implemented.

As in many other sectors, information technology and data can assist in a transition toward lower-emitting systems. In agriculture, advanced technologies are able to limit waste, reduce inputs such as fertilizer, pesticides and water, and optimize plant growth conditions. The drastic step of foregoing soil usage altogether and moving production indoors through hydroponics and vertical farming is already established and continually evolving, with important emissions reduction potential. Various semi- or fully autonomous farm machines are able to fulfill agricultural tasks more effectively, with a high degree of precision. Furthermore, systems and tools that support farmers in their decision-making and help them access funding for a shift to regenerative agricultural practices are becoming more widespread and simpler to use. Open access, high-resolution satellite images play an important role in this. Many of the advanced machines and new technologies are not yet a common sight in low-income rural areas. However, new modes of access, ownership and agricultural service-based business models may facilitate a broader deployment among smallholder farmers.

Decarbonizing steel and cement

Steel and cement are major GHG emitters. They are often considered to be two hard-to-decarbonize sectors. However, this narrative masks the fact that solutions do exist. One particularly high-impact way of reducing cement emissions is to reduce clinker usage. Clinker is a common ingredient in cement made by heating raw materials such as limestone in a process requiring high temperatures and emitting greenhouse gases. Partially replacing clinker with alternative materials has some of the greatest potential for reducing cement emissions. Yet, at the same time the clinker-to-cement ratio is increasing around the world.

Many steel furnaces are reaching their end of life. Replacing them with conventional high-emitting blast furnaces will cause a decades-long carbon lock-in until their investment value has depreciated. Decarbonization of steel and cement is challenging, but not impossible. We know which technologies are needed, but are not implementing them at the scale required. Several climate-friendly steel and cement production technologies are already mature and available, including direct reduced iron (DRI), electrification and the use of clinker substitutes.

However, simply reducing emissions from steel and cement production will not suffice. To effectively reduce total sector emissions amid booming demand, the management of these two materials, as well as their demand, warrants far greater attention. Construction projects often use excessive amounts of steel and cement. Millions of buildings and offices around the world either stand empty or are demolished before reaching their end of life. Extending a building's usefulness and lifetime, designing for efficient material usage and employing lightweight, low-carbon materials are all central to emissions reduction. Digital-sharing platforms and design tools, advanced recycling technologies and material innovation are key enablers of such a circular supply chain.

Technologies that enable more efficient steel and cement usage hold significant promise for achieving climate targets. Yet, more attention is currently directed toward emerging technologies, such as carbon capture and storage (CCS), carbon capture, utilization and storage (CCUS) and green hydrogen. It is likely that the focus on improving production processes and carbon capture rather than on efficient material usage reflects a lack of financial and market incentives for manufacturers. At the same time, the implementation of CCS, CCUS and green hydrogen technologies is still very slow and has made no significant impact, especially in the major steel- and cement-producing nations. These two sectors have also been slow in adopting frontier digital technologies to optimize energy usage and processes. Steel and cement are sectors in particular need of further technology research and development if they are to achieve net zero CO_2 emissions by 2050.

Climate technologies must address both supply and demand

Governments and cities must rapidly develop and scale climate mitigation technologies. However, now more than ever, the choice of technology matters. Simply optimizing current systems will not be enough to realize climate goals. In most countries, the central role of renewable energy in phasing out fossil fuels has been recognized. Less attention has been given to the role of technology and innovation in managing our growing material and resource demand, and in enhancing circularity. This is despite material usage being the main driver of a triple planetary crisis composed of climate change, biodiversity loss and health-related pollution impacts.

Many reports on climate technologies focus on their role in reducing supply-side emissions, for instance, through fuel switching and energy efficiency. The *Green Technology Book* is different in that it also recognizes the huge untapped potential of demand-side management. With resource demand growing exponentially, we need to rethink ways of providing basic human services, including food, shelter and mobility – and of doing more with less.

Technology is a key part of the puzzle. It can enable developed, emerging and developing economies to use resources more efficiently. It also allows us to substitute high-carbon materials and systematically integrate climate perspectives into the development of our cities, buildings, products and food systems. As stated recently by the Intergovernmental Panel on Climate Change (IPCC), *avoiding*, *shifting* and *improving* demand for services has the potential to reduce GHG emissions by between 40 and 70 percent globally by 2050.[11, 12]

This requires changes to our investments, policies and behavior. Technology and innovation have the power to enable systems change rather than ways of simply improving business as usual, with many technologies affording no-regret options for developed and developing economies alike. Digital technologies deserve special mention here, given their potential to better match supply and demand, avoid unnecessary production waste and enable the design and use of circular systems. This publication highlights a broad range of technologies addressing activities across cities, agriculture and land use, and industry.

Notes

1 IPCC (2022). Climate change 2022: Mitigation of climate change. Technical summary. Working Group III contribution to IPCC sixth assessment report., Cambridge, UK: Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/.

2 IEA (2021). Net Zero by 2050. A roadmap for the global energy sector. Paris: International Energy Agency (EIA). Available at: https://www.iea.org/reports/net-zero-by-2050.

3 The Introduction provides more information on how we define, identify and select the proven, frontier and horizon technologies showcased in the Green Technology Book.

4 Cozzi, L., et al. (2023). As their sales continue to rise, SUVs' global CO_2 emissions are nearing 1 billion tonnes. International Energy Agency (IEA). Available at: https://www.iea.org/commentaries/as-their-sales-continue-to-rise-suvs-global-co2-emissions-are-nearing-1-billion-tonnes [accessed September 2023].

5 IPCC (2023). Synthesis report (SYR) of the IPCC sixth assessment report (AR6). Summary for policymakers. Geneva: Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc.ch/report/ar6/syr/.

6 FAO (2023). Land use in agriculture by the numbers. Food and Agriculture Organization of the United Nations (FAO). Available at: http://www.fao.org/sustainability/news/detail/en/c/1274219/ [accessed May 2023].

7 World Bank (2023). Water in agriculture. World Bank. Available at: https://www.worldbank.org/en/topic/water-in-agriculture [accessed May 2023].

8 Umali-Deininger, D. (2022). Greening the rice we eat. Washington, DC: World Bank. available: https://blogs.worldbank.org/eastasiapacific/greening-rice-we-eat?cid=SHR_BlogSiteEmail_EN_EXT

9 Kurnik, J. and K. Devine (2022). Innovation in reducing methane emissions from the food sector: Side of rice, hold the methane. World Wildlife Fund. Available at: https://www.worldwildlife.org/blogs/sustainability-works/posts/innovation-in-reducing-methane-emissions-from-the-food-sector-side-of-rice-hold-the-methane [accessed July 2023].

10 WRI (2023). Our world in data: Emissions by sector. World Reesources Institute (WRI). Available at: https://ourworldindata.org/emissions-by-sector [accessed June 2023].

11 This estimate relates to potential emissions reduction in buildings, overland transport and food by 2050 (high confidence).

12 IPCC (2023). Synthesis report (SYR) of the IPCC sixth assessment report (AR6). Summary for policymakers. Geneva: Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc.ch/report/ar6/syr/.

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