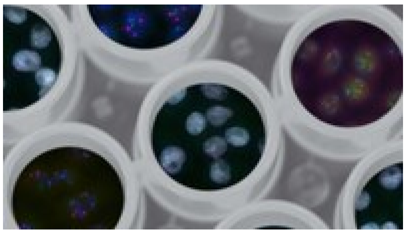
Drivers of change

Synthetic biology and the environment



New approaches to biodiversity conservation or unexpected but irreversible forms of environmental disruption?

While the term ‘synthetic biology’ dates back to the beginning of the 20th century (Leduc, 1912), it has been used only recently to refer to an **interdisciplinary scientific area that applies engineering principles to biology**. Synthetic biology approaches, originally adopted in the United States, involve a range of genome-editing technologies aiming at ‘design[ing] and construct[ing] novel biologically based parts, devices and systems, as well as re-design[ing] existing natural biological systems’ (Roberts et al., 2013). At the EU level, a high-level group has proposed the following definition:

> Synthetic biology is the application of science, technology and engineering to facilitate and accelerate the design, manufacture and/or modification of genetic materials in living organisms.
>
> SCENIHR-SCCS-SCHER, 2015

The genome is the complete set of genes in a cell or organism, which contains all the information necessary for that organism’s function. Humans have tried to alter the genomes of plants and animals for thousands of years, first using selective breedingto pass on desirable traits from generation to generation. With the discovery of DNA in the 1950s, molecular biology techniques enabled specific genetic material to be inserted from one organism into another, and eventually led to genetic engineering in the 1970s when enzymes were used to ‘cut and paste’ DNA (SEP, 2016) and produce genetically modified organisms (GMOs). **DNA sequencing and synthesis became increasingly cheap and enabled the emergence of synthetic biology, which involves not only the transfer of individual genes but also the assembly of entirely new sequences of DNA and entire genomes.**

Synthetic biology is still an emerging field, and technologies and materials are currently in development. Areas of research include DNA-based circuits (mimicking electronic logic components), synthetic metabolic pathway engineering (to produce specific molecules), synthetic genomics (removing non-essential genes from the genome), protocell construction (reducing complexity at the cellular level), and xenobiology (focusing on biology not found in nature) (CBD, 2015).

Overall implications (non-environmental)

Current and near-term commercial and industrial applications concern mainly the pharmaceutical, chemical, agricultural and energy sectors. They aim at 'creating micro-organisms that synthesise products for fuels, pharmaceuticals, chemicals, flavourings and fragrances' (CBD, 2015). For instance, microbes (e.g.Escherichia coli), yeast and microalgae are engineered to produce alternatives to naturally occurring or petroleum-based molecules. So far, notable examples include the engineering of yeast that synthesises artemisinin (a drug used to treat malaria), pharmaceuticals (e.g. insulin), biofuels (e.g. produced by algae) or flavourings (e.g. vanillin). Other potential applications in development in these sectors include the production of antibiotics, bacteriophages (viruses infecting potentially harmful bacteria) and biomaterials, as well as waste processing and water purification (SEP, 2016).

Seen by many of its proponents as an attempt to 'design life according to humanity's needs' (Engelhard, 2016), synthetic biology could have potentially huge impacts on society, the economy, the environment and even life as we know it. Genome pioneer Craig Venter claims that synthetic organisms 'are going to potentially create a new industrial revolution if we can really get cells to do the production we want' (BBC, 2010). In 2012, the World Economic Forum in Davos listed synthetic biology as an area that is likely to have a 'major impact' on the world economy in the future (World Economic Forum, 2012). The market for synthetic biology products and applications was estimated at USD 4.4 billion in 2017 and is expected to reach USD 13.9 billion by 2023 (BCC Research, 2018).

Compared with more established genetic modification techniques, however, many aspects of synthetic biology are entirely novel and cross-cutting in nature. Consequently, it remains very difficult to assess precisely the overall impact for Europe. At the EU level, synthetic biology is expected to provide new responses to societal challenges relating to health and well-being; resource efficiency, climate change and energy; sustainable agriculture and forestry and food security; and environmental sustainability. For example, synthetic biology could 'provide innovative solutions for the conversion of our current unsustainable fossil-based industries into sustainable and competitive bio-based industries for bio-products (e.g. chemicals, polymers) and bioenergy, for new antibiotics and vaccines, and new diagnostics and treatments for cancer and rare diseases' (EC, 2015).

As with previous controversies around nanotechnologies or biofuels, much will depend on the socio-political acceptance of synthetic biology itself. There are currently many ethical and safety concerns around this emerging field, which are well illustrated by exploring its potential environmental implications.

Implications for the European environment

Synthetic biology may provide solutions to environmental challenges such as climate change, sustainable management of natural resources, provision of clean water and reduction of pollution. But it also creates substantial risks for ecosystems. Currently, there are many scientific uncertainties surrounding the introduction of novel, synthetic organisms into the environment, in particular regarding effects on biodiversity. A report commissioned by the European Commission (SEP, 2016) identified a variety of potential benefits, including:

- a reduction in the effects of human land use on biodiversity, e.g. through genetically modified (GM) crops, thus allowing a reduction in pesticide use, or algae-based biofuel production requiring less land (Redford et al., 2014);
- bioremediation of polluted industrial sites, e.g. through the use of synthetically engineered microbes that can degrade persistent chemicals;
- the use of synthetic alternatives to products currently extracted from plants and animals;
- restoration or conservation of genetic diversity, including the prospect of restoring extinct species (IUCN, 2018);
- protection of species at risk, e.g. by making bees more resistant to pesticides;
- control of disease vectors, e.g. by making mosquitoes resistant to the parasite that causes malaria;
- pollution detection, e.g. through biodetectors sensing the presence of micro-pollutants.

It also identified a number of potentially significant risks, including:

- transfer of genetic material to wild populations, leading to a loss of biodiversity;
- diffusion of toxic effects on other organisms;
- invasive effects on native species;
- introduction of new diseases by replacing the population of the original disease vector with another (CBD, 2015);
- negative economic effects on small-scale farmers, challenged by the production of synthetic alternatives to their natural products;

- large-scale increases of biomass, which could reduce soil fertility and structure (CBD, 2015);
- privatisation of nature and restricted access for public benefit;
- changes in people's perceptions of nature and biodiversity (e.g. focus on commercial value and profit potential);
- policymakers, scientists and industry being distracted from addressing the deeper underlying causes of biodiversity loss, including potentially less commitment to protecting endangered species (if extinct species can be restored synthetically).

Among the set of synthetic biology technologies, a particular genetic modification technique called CRISPR/Cas9[1] highlights the existence of unpredictable but significant risks to biodiversity. CRISPR is a set of DNA sequences found in bacteria that can be used to edit genes. In combination with the Cas9 enzyme, CRISPR can cut the genome at any location of choice (SEP, 2016). As noted by the European Parliamentary Research Service (EPRS), 'the CRISPR-Cas9 system currently stands out as the fastest, cheapest and most reliable system for "editing" genes [and] is seen as the biggest game changer in the gene editing field' (EPRS, 2017).

So far, gene drive systems such as CRIPSR/Cas9 are being used to engineer disease-resistant wheat and rice and to create vitamin-enriched fruit crops, but using them to eradicate populations of disease-carrying mosquitoes is also being considered. Designed to operate autonomously in nature and spread modified DNA into entire populations, gene drives have 'the potential to overcome the natural pattern of heredity and are therefore also called mutagenic chain reaction' (Liebert et al., 2017). Some scientists have warned that such technologies represent 'a new stage and depth of the power and intervention into ecosystems', potentially driving 'these ecosystems beyond their tipping points' (Liebert et al., 2017). Unintended changes could be irreversible.

Such applications of synthetic biology raise a variety of concerns. For example, how will genetically engineered mosquitoes affect the rest of the ecosystem? Is it possible for the gene drive to mutate and affect other species? Will we be able to recognise, monitor and control GMOs after their release in the environment? How do we decide if the application is safe to use or even to test? How do we factor in inevitable human errors and ignorance? (Liebert et al., 2016; SEP, 2016).

Implications for environmental policy in Europe

At the international level, synthetic biology was identified by the Secretariat of the Convention on Biological Diversity as a 'new and emerging issue' in 2012. At its 11th meeting, the Conference of the Parties to the Convention on Biological Diversity decided to urge Parties to take a precautionary approach when addressing threats of significant reduction or loss of biological diversity posed by organisms, components and products resulting from synthetic biology. Countries have recognised the global dimension of this issue, as organisms and effects could easily spread across borders.

Sustainability transitions

Regulatory authorities around the world are considering the social, ethical and environmental implications of the gene drive system. In 2016, the International Union for Conservation of Nature (IUCN) commissioned a 'broad assessment of the current state of science and policy around synthetic biology techniques as they relate to biodiversity' (IUCN, 2018).

At the EU level, the independent Scientific Committees on Emerging and Newly Identified Health Risks (SCENIHR), on Health and Environmental Risks (SCHER), and on Consumer Safety (SCCS) have stated in their 2014 opinion that, for the foreseeable future (10 years), 'current GMO risk assessment requirement and approaches remain applicable' but that new developments may require adapting existing methods used for risk and safety assessments (SCENIHR-SCHER-SCCS, 2014). Challenges would include the integration of modified cells into or with living organisms, future developments of autonomous modified cells, use of non-standard biochemical systems in living cells increased speed of modifications by new technologies and an evolving 'do-it-yourself biology' among the citizen science community.

This brief belongs to a series of 'rapid assessments' on the implications of emerging trends for the environment and environmental policies in Europe. The identification of the topic results from a participatory horizon-scanning process run by experts from the Eionet National Reference Centres on Forward Looking Information and Services (NRC FLIS) during the period 2018-2019. The brief was drafted with support from the European Environment Agency (EEA) and the European Topic Centre on Waste Materials and the Green Economy (ETC WMGE). It is conceived as a living document that should be enriched through interactions with other knowledge communities and stakeholders, and evolve according to technological developments.

Type of signal: **Emerging trend**

Geographical scope: **Global, European, national**

Origin of signal: **Technological**

Time horizon of expected significant impact: **Mid- to long-term**

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Main related EU policies

- EU biodiversity strategy
- Environment action programme to 2030
- Bioeconomy strategy

Footnote

1. CRISPR for 'clustered regularly interspaced short palindromic repeats' and Cas9 for 'CRISPR-associated protein 9'.

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