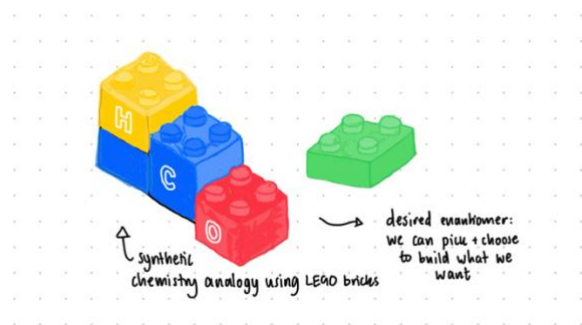


Can synthetic chemistry create sustainable food sources for a growing population?

To first understand why our current food sources are unsustainable, it is necessary to consider what is meant by the term ‘sustainable.’ According to the Food and Agriculture Organisation of the United Nations (FAO), sustainability can be defined as “the management and conservation of the natural resource base” such as land and water in a manner that “ensures the attainment and continued satisfaction of human needs for present and future generations.” This involves using technology and innovation appropriately, so it does not harm the environment (“non-degrading”), while also being economically realistic, and socially acceptable (FAO, Rome, 1998). In the context of food, this means developing systems that are efficient, low-waste, and capable of lasting long-term without exhausting the environment’s resources. However due to factors such as deforestation, water waste, fertilisers and the ever-growing pressure of population growth, sustainable food sourcing and production is now “one of the main drivers of nature’s decline”, using 40% of all habitable land therefore the “leading cause of habitat loss” and is responsible for over a quarter of greenhouse gas emissions and 70% of water use (WWF and Zoological Society of London, 2024). In light of these findings, it is clear that our food systems are in urgent need to be reconstructed and adapted to not only meet the demands for a growing population which is forecasted to exceed 10 billion by 2050, placing further pressure on finite resources (Oxford Martin Programme: Future of Food, n.d) but also for them to be maintainable for the long term without detrimental impacts on society and the planet. This is where synthetic chemistry can come into play.

Synthetic chemistry is a branch of chemistry which focuses on developing ways of making new chemicals while also improving the way existing chemicals are synthesised (Manahan, n.d). The vital role of synthetic chemistry is evident in our daily lives, from medicines like paracetamol to artificial sweeteners. The range of applications which synthetic chemistry interacts with makes it a versatile and effective method to achieve concepts which may seem currently out of reach. To underpin what synthetic chemistry enables chemists to do, we can use the common analogy of building with LEGO. Imagine building a house or car with LEGO bricks, the creator has the ability to choose the exact pieces they want, including their colour, shape, and size, to finally fit them together in a precise way to make their desired product. Along the



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way, the creator had the opportunity to rearrange or disassemble parts or add new pieces in, carefully building intermediate structures before finally arriving at their completed design. Essentially, synthetic chemistry follows this process however the LEGO bricks are substituted for atoms and molecules. This opportunity to tailor the development of chemical compounds for a specific purpose or function results in less waste and more efficient manufacturing. In addition to this, synthetic chemistry allows us to access compounds that are not found in nature (leading to the production of ‘novel’ molecules), opening entirely new possibilities for not only sustainable food production but also more health-focused food sources.

One real-world example of how synthetic chemistry has benefited us is through the creation of an alternative to vitamin B12. The natural form of Vitamin B12 is essential for red blood cell production, optimal functioning of the nervous system and DNA synthesis. However, it is primarily found in animal-derived foods making it difficult for certain populations, particularly vegetarians, vegans, and people in low-resource areas, to obtain sufficient amounts leading to increased risk of procuring vitamin B12 deficiency (Tilt, 2025).

Biosynthetic chemistry has enabled the development of cyanocobalamin, a lab-made, non-natural form of vitamin B12 that does not exist in nature. Here we can briefly introduce the topic of biosynthetic chemistry. Biosynthetic chemistry can be understood as the “process of making complex products from simpler components through chemical reactions at the cellular level” (Leavings et al, 2023) and is considered a subfield within synthetic chemistry, differing in the sense that biosynthetic chemistry relies on natural mechanisms in living organisms. The complementary nature of synthetic chemistry and biology open a wide variety of molecules that can be produced (Maison, 2023). Cyanocobalamin, a stabilised form of vitamin B12, is made by fermenting a selection of bacteria that have been modified to produce higher levels of the vitamin (for example recombinant *E. coli*), followed by chemical processing (Quadram Institute, n.d). Unlike other vitamin analogues that serve medicinal purposes, cyanocobalamin is designed for nutritional supplementation and food fortification - which is “the practice of deliberately increasing the content of one or more micronutrients (i.e. vitamins and minerals) in a food...to improve nutritional quality of the food supply...produce a public health benefit with minimal risk to health. As well as...helping to restore the micronutrient content lost during processing” (World Health Organisation, n.d). This synthetic form is not only chemically stable and inexpensive to produce at scale, but also

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helps reduce dependence on animal agriculture, which is resource-intensive and contributes significantly to environmental degradation. As a result, cyanocobalamin represents a clear example of how branches within synthetic chemistry can create a new, sustainable food source.

But this essay will explore how the synthetic chemistry already used in food science can be developed further to make the concept of creating sustainable food sources a more attractive and viable long-term option, particularly through the introduction of a topic in organic chemistry I find most interesting - optical isomerism. Optical isomerism can be simply explained to be structures that are mirror images of each other and are therefore non-superimposable (cannot be placed on top of each other and perfectly overlap). Molecules that exhibit optical isomerism are called enantiomers, a good example of them are your left and right hand. In chemistry, molecules that are enantiomers are also chiral, which means one carbon atom is bonded to four different groups, something simple like a hydrogen atom or perhaps a chlorine or an alcohol group. A food related enantiomer example is L-Glucose and D-Glucose. The enzymes in our bodies are chiral, meaning they can tell the difference between the mirror-image molecules, but they can only recognise D-glucose (which the primary energy source we use). However, L-glucose is not metabolised in the same way and so simply passes through the body without giving calories. Hence, it has been discussed that L-glucose has the potential to be a low-calorie sweetener, formed through synthetic chemistry (ECHEMI, 2022). This would mean that both versions of glucose could be useful to the body, rather than wasting one mirror molecule.

The idea I would like to propose for the use of synthetic chemistry in the production of sustainable food sources for a growing population focuses on the concepts of optical isomerism. It is the creation of specific enantiomers of nutrients that are biologically active - reducing waste and improving efficiency in lab-grown food sources. Using synthetic chemistry, we could design and produce the exact enantiomer of an amino acid or vitamin need in the body and add it to lab-grown food sources to make it nutritionally complete. This process is called enantioselective synthesis, and it plays an important role in the field of pharmaceuticals, as different enantiomers of a molecule often have different biological activity. Enantioselective synthesis is defined as a chemical reaction that results in one desired enantiomer, which would reduce waste as traditional synthesis often makes a mixture of enantiomers (racemic), meaning half the product is wasted as it can be inactive or harmful.

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Synthetic chemistry provides the framework for constructing desired enantiomers because it gives chemists the ability to control the 3D arrangement of molecules.

To ensure that this concept aligns with the goals of sustainability, I will refer to the five guiding principles of sustainability. These include:

1. Improving efficiency in the use of resources
2. Conservation, protection, and enhancement of our natural ecosystems
3. Taking into account rural livelihoods and society well-being, protecting, and improving them
4. Continuing to strengthen the resilience of people, communities, and ecosystems
5. Promoting the fair treatment of both natural and human systems

(FAO, 2014)

Enantioselective synthesis aligns closely with the first guiding principle of sustainability - improving efficiency in the use of resources. Using enantioselective synthesis, no raw materials are wasted on inactive forms, leading to less waste material being produced. This in turn results in lower energy consumption and reduced emissions per unit of nutrient produced, improving efficiency in the use of resources. Furthermore, by reliably producing biologically active molecules in controlled conditions, the dependence on natural sources, which can be subject to seasonal/geographical limitations, or are environmentally vulnerable, would be significantly less likely. It could also mean we could reach the target of sustainable food production systems for a growing population without expanding agricultural land and disturbing ecosystems. This idea of using enantioselective synthesis can relieve the pressure on small-scale farmers or fisheries to produce more food, which often leads to overfishing and over-farming, practices that has negative effects on the environment (Anderson, 2023). Both factors link to principle 2 and 3 of sustainability, considering the livelihoods of rural communities as well as the impact on the ecosystem. According to Population Matters, a charity that campaigns for a sustainable future in order to protect our environment and improve people's lives, we are "feeding billions, failing nature" and being "unsustainable and unfair" as it is evident that our current food systems are failing to provide adequate protection for both people and the planet (Hewitt, 2024). However, I believe that through this process the fair treatment of human and ecosystems is an achievement (linking with principle 5), by enabling the creation of nutritionally complete lab-grown and fortified foods, making

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sustainable, balanced food sources accessible to more people worldwide without compromising environmental health. Finally, all these elements can merge to align with principle 4 and lead to the continued growth and resilience of people, communities, and ecosystems.

Moving onto the method in which enantioselective synthesis could be carried out, several approaches have been developed however the most efficient are those that involve chiral catalysts. Catalysts can drive the reaction towards producing a specific enantiomer by binding to the reactant in a particular orientation that will influence the formation of one enantiomer over the other. This is the chiral catalyst method which is particularly efficient because they can guide the reaction toward the desired enantiomer of a particular molecule without being consumed, allowing them to be reused or recycled, making it a sustainable alternative to typical industrial methods (Libre Texts Chemistry, 2025). This method could mean that catalysts could be reused to synthesise the nutritionally packed food source to provide for a growing demand.

Thinking further, regarding aspects such as regulation of these chemically synthesised food sources, we can refer to processes used in the pharmaceutical field - as mentioned earlier, enantioselective synthesis is a process used in drug development. In an interview with an Associate Director of EU Regulatory Affairs at Johnson & Johnson Innovative Medicines, it can be understood that regulatory principles followed by large pharmaceutical companies can be implemented in food production as well. It would be very important for the regulatory system to mirror pharmaceutical-level precision; this would therefore include a way to ensure that the food sources are made to high-quality standards plus undergo safety and quality control testing. As pharmaceutical products go through multiple levels of nonclinical and clinical testing prior to being marketed, it will be important to consider similar levels of testing methodology being placed in the approach of using enantioselective synthesis to produce food sources (C. Eapen, personal communication, 2025).

In conclusion, enantioselective synthesis offers a promising pathway towards achieving sustainable food. Through the precision of synthetic chemistry, we can achieve the need for nutritionally balanced food sources in a fair and efficient manner, while also providing for an increasing demand. With advancing technologies, this approach has the potential to scale sustainably, protecting ecosystems, while also improving human wellbeing. Ultimately,

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enantioselective synthesis represents a crucial step towards a future where we can feed billions without failing nature.

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