

## VISION PAPER

# 1. *Bio-revolution: From Genes to Global Solutions in Crop Production 2025/2052 and Beyond*

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Symbol for Synthetic Biology



Symbol for Artificial Intelligence

## PROLOG

The concluding take-home messages in the monograph “Future of Agriculture” (Kern, M., 2000a,b) presented at EXPO Hanover, Germany, August 15-17, 2000, were: “Over the last few decades, progress has been made at a previously unimaginable rate in the most varied branches of scientific research – agriculture included. At the present time, in the year 2000, we can draw on a potential of over six billion people – as compared with only one billion in 1850 – for the knowledge we will need tomorrow. It must be remembered that developments in agriculture are properly understood in hindsight, but we will need foresight to build up knowledge and technologies and put them into use at the right moment. We should not make the mistake, as almost all generations do, of underestimating our own potential for innovation, i.e. for new ideas and discovery. It is already time to tackle the question: **“What will be equivalent in the twenty-first century of the discovery of the electron and of DNA?”**”

Today, in 2025, it can be said that this is “**artificial intelligence**”.

**Benchmarks in Agriculture:** From Precision Agriculture (Kern, M., 2000), via DNA-®evolution of Agriculture (Kern, M., 2015), via Digital Agriculture (Kern, M., 2015), via Decision AI Impowered Agriculture (Kern, M., 2019, 2023), via

Molecular Agriculture (Kern, M., 2023), via “Agriculture 5.0” (Kern, M., 2025), via Second Green Revolution (Kern, M., 2026) via Designed Agriculture (Kern, M., 2030 in press) to Space/Mars Agriculture (Kern, M., 2052\* in prep.).

## 1. INTRODUCTION

In 2015 “**The DNA-@evolution of Agriculture**” was the title of a paper from the author published in: Production and Processing of Food Crops for Value Addition: Technology and Genetic Options. (eds.): R.K. Behl, A.P. Singh, A.B. Lal, and G. Haesaert, Agrobios International) Publishers, pp 1-6, Book pages 1-347, ISBN: 978-93-81191-05-7.

**The abstract is quoted as follows:**

“By 2050, world food, feed, and biofuels requirements will more than double because of population growth, dramatically changing consumption patterns, food losses, food waste and increasing demand for pet food (Kern, M., 2011, 2012, 2015a, 2018a; 2022; 2023a; 2025c). This means we will have to produce more crops worldwide during this period than over the last 10,000 years put together.

But several studies have shown that yield trends of global key or food security crops are insufficient to double global crop production by 2050. Nevertheless, yields of crops and productivity of agriculture must be increased to boost production to meet global rising demands” (Kern, M., 2015).

In 2021, Harbinson, J. *et al.* (7/2021) confirmed and specified the strategic global requirements for establishing a roadmap for designing the crops of the future in Europe, “**The CropBooster Program**” (Horizon 2020 project of the European Union, 11/2018-4/2022). “However, achieving this is a daunting task. To sustainably meet the health needs of all people by 2050, we must close yield gaps and increase global crop yields by 70–110%, while simultaneously increasing the diversity of our crops, radically improving nutrient and water use efficiency, and rapidly transforming agriculture from a greenhouse gas emitter to a carbon sink. Furthermore, achieving a circular bio-based economy could require an additional 30% increase in crop yields, bringing the total required increase in global crop yields by 2050 to 100–140%” (Harbinson, J. *et al.*, 7/2021).

“To close the gap, there is a need for a second green @evolution – a green **DNA-@evolution in agriculture**. The green branch of DNA will pollinate agriculture by using functional genomics, marker-assisted selection, genomics-assisted breeding, genetic engineering, genome engineering, synthetic biology, and digital cells to improve plants of the future in time.

New genomic knowledge will make plant breeding much easier, shorter and better. Genomic research lays the foundations for a greener @evolution in agriculture and will boost plant breeding to a severe higher cultural level.

Key breeding goals are determined and prioritized to solve actual and future challenges. Top priority is given to crop functional genomics and the impact of different soils (Factor S<sup>n</sup>) as well as water availabilities (Factor W<sup>n</sup>) especially in greenhouses and fields.

- ▶ **Factor S<sup>n</sup> (“SSSS SSSS SSSS SSSS SSSS SSSS WSSL”):** Secrets, Sand, Salt, Silt, Scree, Sediment, Slime, Soil, Save Soil\*, Sequestration of Carbon\*, Search, Science, Sagacity, Sanity, Seeds, Synthetic Biology\*, Supercharger Crops\*, Second Green Revolution\*, Sawyer, Sowing, Satellite\*, Sun, Sustainability, Societies\*, and Water Safeguarding Sustainable Life. (\*added in 2025)
- ▶ **Factor W<sup>n</sup> (“WWWW WWWW WWWW WWWW WWWW”):** Rain Water, Green Water, Underground Water, Drinking Water, Potable Water, Water Floods, Water Level, Water Management, Water Scarcity, Water Supply, Water Use, Watering, Water Pollution, Water Technology, Water Conservation Technology, Water Agronomy, Water Value, Water Use Efficiency, Tolerance to Water Excess, and Tolerance to Water Deficiency are relevant aspects Safeguarding Sustainable Development.

Farmers, scientists, politicians, the public at large, and young people especially should be encouraged to be optimistic and to go for and improve the **DNA-@evolution** of agriculture to add value to agriculture, to societies and to enable a peaceful life on earth (Kern, M., 2015).

“Agriculture, the mother of all sciences has always been, and continues to be, one of the ways in which humankind has improved the basis of human existence on earth. A world without agriculture and agriculture without DNA is a paradox. DNA is the key source for crop development, breeding, biotechnology, genomics, genome engineering, synthetic biology, and last but not least for bio-sustainability of humankind.” (Kern, M., 2014)

Genetics – modifying the building blocks of life, Robotics – building autonomous machines to do our bidding, Artificial Intelligence – machines that learn, Nanotechnology – building things atom by atom. Taken together, these form the acronym **G-R-A-I-N** (Mulhall, 2002). This megamerger of super sciences may transform who and what we are.

Very soon, genome maps will be completed of all organisms of interest, and the translation, i.e. finding and using key functions of relevant genes, is proceeding at a rapid pace. From more than 300 000 known land plants, more than 100 plant genomes (Mittler and Shulaev, 2013) including wheat (Science, 7/2014) have been published to date; 1,000 will be documented within the next couple of years. An actual overview of the first 50 plant genomes is given by Todd and Jackson (2013). In 2025, it can be reported: **“Mission completed!”**

At the end of 2014, Poltronieri and Hong (11/2014) edited an excellent book titled: **“Applied Plant Genomics and Biotechnology”** covering recent advances in

the post-genomic era, discussing how different varieties respond to abiotic and biotic stresses, investigating epigenetic modifications and epigenetic memory through analysis of DNA methylation states, applicative uses of RNA silencing and RNA interference in plant physiology and in experimental transgenics, and plants modified to produce high-value pharmaceutical proteins. The book provides an overview of the ongoing activities in the field of applied biotechnology, discusses the future developments in plant functional genomics and explores the new technology.

The quality and traits of seed genotypes are key prerequisites for crop yield and quality. Consequently, it is essential to make the right improvement in the right way. Key breeding goals must be determined and prioritized to solve actual and future challenges.

## 2. 2<sup>ND</sup> GREEN REVOLUTION (KERN, M., 6/1997) AND GOALS FOR BREEDING THE IDEAL CROP

**Some goals sowing the seeds for the ideal crop** are given by the author modified after Pennesi, 2010:

- ▶ **Improving the nutrient content of seeds and edible plant parts.** Vitamin A fortification is already here; soybeans with omega-3 fatty acids are on the way. More vitamins, specific amino acids, minerals, improved fatty acid spectrum, specific enzymes and higher protein content are other goals. For biofuels, the right mix of plant cell-wall components is needed to ease processing.
- ▶ **Feed crops with reduced toxins and anti-nutritive factors.** A combination of genetic engineering and conventional breeding may be expected to lead to a reduction of anti-nutritive factors such as protease inhibitors, tannins, phytohaemoglutinins, cyanogens, glucosinates, sanapine (Brassica group), gossypol (cotton) and anti-nutritive oligosaccharides (soybean) in feed crops.
- ▶ **No more sex.** Hybrid seeds often produce more vigorous plants, but the seeds of those hybrids are often inferior. Farmers can't always afford to buy new hybrid seeds. One proposed solution is to get hybrids to reproduce asexually through a process called apomixis. Apomixis in rice, for example, could save small farmers \$US 4 billion a year.
- ▶ **Installing warning lights.** A pigment gene that turns on in times of stress could cause a crop's leaves or stems to change color, and alert farmers to take remedial action. Some think that sensors installed in soil or the air could also do this job.
- ▶ **More crops per drop.** Restructuring root and leaf architecture and upgrading of drought-response biochemical pathways could increase

water-use efficiency. Shallower roots, for instance, can better tap soil-surface moisture.

- ▶ **Improving nitrogen efficiency.** Fertilizers are costly for farmers and the environment. Improving a plant's uptake and use would be a big help. Better yet, build into the plant the genes necessary to carry out nitrogen fixation, a job that may one day fall on artificial chromosomes.
- ▶ **Improving phosphorous uptake.** This will boost crop yields by triggering more roots, resulting in higher phosphorus uptake.
- ▶ **Utilization of phosphite.** Crops are enabled to use phosphite. The effectiveness of such systems in controlling weeds and fertilization suggests that this crop system would reduce production costs and energy consumption by replacing separate applications of fertilizer and herbicides with a single treatment.
- ▶ **Tougher pest defenses.** Adding genes for toxins that kill only pest insects or nematodes can help, as can the addition of genes that attract the enemies of these pests.
- ▶ **Resilience against abiotic stress factors.** Drought and salt tolerant crops are on the way.
- ▶ **Resilience against micro- and nanoplastics** (Kern, M., 2024).
- ▶ **Longer shelf life.** Enhanced control of ripening and senescence could reduce the amount of spoiled harvest.
- ▶ **Improving CO<sub>2</sub> assimilation – improving the “Green Powerhouse” of crops.** Re-engineering of the rubisco enzyme system, which uses carbon dioxide from the air and, by means of photosynthesis, converts the energy from sunlight into the sugars that are the building blocks of life. This method will enhance crop yield potential, increase biomass production in crops, especially in bioenergy crops/trees, and contribute to a more efficient carbon sequestration.
- ▶ **Improving the crop plan or crop structure.** For example, roots, stem stability, leaves, infructescence, fruits and seeds.
- ▶ **De Novo design of crops.** Synthetic biology has the potential for *de novo* design of crops for the future.
- ▶ **Multipurpose crops.** Increasing the flexibility of key crops used as food, feed, fiber or fuel.
- ▶ **Transformation of crop production** for health care, pharmaceuticals from plants, transformation of the production of pharmaceuticals, plant-made pharmaceuticals, plant bio-pharming, and pharma-farming (Kern, M., 2006; 2007).
- ▶ **Insertion of animal- or human-based genes in plants** to overcome allergic reactions.

All the goals mentioned are currently highly relevant but are centered on the overarching goal of climate change and increasing dioxide levels. Some

goals from the “CropBooster-P” roadmap for future plant breeding in Europe (Harbinson, J. *et al.*, 7/2021; Baekelandt, A., *et al.*, 11/2022; Harbinson, J. *et al.*, 12/2022) are listed here:

- increasing yield
- having the same yield in less time to allow more than one harvest per year
- having superior nutritional quality
- increasing crop biomass produced per unit area per year
- improving underutilized crops- increasing resource efficiency
- increasing resilience to climate change combined with increased carbon dioxide levels
- increasing resilience and sustainability
- accelerating quick recovery from stress
- boosting photosynthesis to capture energy and store this energy (‘supercharger crops’)
- enabling to sequester carbon and carbon farming to move agriculture away from a greenhouse gas emitter to a carbon sink
- providing crops to enable fossil-fuel-free farming systems

Furthermore, the European roadmap “CropBooster-P” (12/2022) calls for a **Second Green Revolution** for European Agriculture.

“Securing a European supply of high-quality food, feed, biomass for bio-based products and energy, is a priority for Europe, and global societies. A Second Green Revolution in crop production is required to meet future crop biomass demands without significant increases in agricultural land use. This represents a huge challenge to biologists, plant breeders, agricultural technologists, economists and farmers. But to date research and innovation has been small scale and fragmented.” (The author highly recommends reading this EU-roadmap “CropBooster-P”.)

A review article published by an international group of 10 scientists from China, United Arab Emirates, Australia, USA, and India propagating novel strategies for designing climate-smart crops to ensure sustainable agriculture and future food security (Raza, A. A., *et al.*, 2/2025). They underline the necessity to design future crops employing cutting-edge breeding technologies for enhanced and sustainable productivity as well as with minimal environmental footprints.

### Two comments

1. The require for a second green revolution is fully in line with what the author of this article pointed out and called for many years ago – There is a need for a **second green @evolution – a green @evolution in agriculture**, but not only in Europe!”

2. Furthermore, the focus on climate resistant crops, carbon farming and moving agriculture away from a greenhouse gas emitter to a carbon sink, also confirms and underlines the author's plea for **climate resilient crops** and **fossil-fuel-free farming (F<sup>4</sup>)** systems (Kern, M., 2002; 2017; 2018b; 2023b).

**It is crystal clear; there is need for a second green *®evolution* – a green *®evolution* in agriculture.** While global demand for agricultural produce continues to rise, limited arable land, decreasing growth rates of crop yield, water shortages and climate change create enormous challenges on the supply side.

For further information see: "Food security at the crossroads – A Wake-up Call" (Kern, M., 2012, 2012a) and "Food security at the crossroads – A Wake-up Call in 2012! / An Emergency Call in 2025!" (Kern, M., 2025a), as well as "Most of the 17 SDGs Are not on Track to Be Achieved by 2030!" (Kern, M., 2025b).

To meet these demands now and in the future, we need nothing less than a "**second green *®evolution***". This is an essential necessity, because analyzed yield trends of key crops such as maize, rice, wheat and soybean are insufficient to double global production by 2050 outlined in detail by Ray *et al.* (2013). Current projections of crop yield from "CropBooster-P" (Harbinson, J. *et al.*, 12/2022) suggest we will fall 40-70% short of demand by 2050.

As an example, over the last 30 years, there were an estimated 470 draught-related disasters around the world (IPCC, 2012) and draughts have become longer and more intensive in many regions. By 2050, draught-tolerant crop varieties can enable farmers to adapt to these conditions and can safeguard higher yields around the world (CropLife International, 2015). Worldwide yield improvements with draught-tolerance traits will be in a range of 5-7% North America, 11% North Africa, 17% East Africa, 7-9% North Africa & Middle East, 11-12% South Asia, 7-8%, East Asia & Pacific and 11% Oceania (IFPRI, 2014) to reduce the gap.

In 2015, the actual challenge was: How to come from improved genotypes *via* functional genomics and gene engineering to fruitful phenotypes in the field – in time?

Up to now, most of plant functional genomics are analyzed in laboratories and greenhouses, but not in the field. This must be changed as quickly as possible.

In 2000, it was forecasted by the author that 18.9% of global crop production will be based on biotechnology. It was assumed that 1.6 billion people will owe their food to the use of genetically modified crops. Worldwide more than 70 transgenic plants were registered (cotton, chicory, potato, pumpkin, corn, soybean, oilseed rape, papaya, tobacco, tomato, clove) and more than 25,000 field trials have been carried out. The global area under

genetically optimized crops was 40 million hectares (Kern, M., 1998, 1998a, 1999, 2000, 2001, 2001a).

In 2024, 28 countries cultivated a range of 10 different GM crops and the area of GM crops increased to 209,8 million hectares (GM.AgBioInvestor, 4/2025), which accounts for approximately 13.4% of the global crop land area (1,54 million hectares). This suggests that since 2000, around 70% of the forecasts regarding the use of genetically modified plants have been realized by 2025. Before 2011 advanced nations planted more GM crops than developing countries and since 2012, the planting area of GMO crops in developing countries has consistently outpaced that of developed countries (Cheng, X. *et al.*, 2024). It is projected that the GM seeds market will grow from \$US 45.0 billion in 2025 to \$US 67.7 billion in 2030 (Knowledge Sourcing Intelligence, 2025).

In 2002 the author published a paper titled: “Plant Biotechnology: Perspectives for Developing Countries between 2002 and 2025” (Kern, M., 2002). For example, it was outlined that only a small amount of 6% of food produced in Africa will be generated by GMOs.

“The uneven diffusion of technology – both old and new – is well documented in the UNDP report 2001. If developing countries have no or only limited access to biotechnology as such, they will increasingly fall behind industrialized nations. They run the risk of missing out on potential opportunities in the field of biotechnology. Ismail Serageldin, former chairman of CGIAR (Consultative Group on International Research) has described this as “*scientific apartheid*”.

In 2000, the green bio-revolution did not start in most of African countries. Two key reasons for that:

1. Biotechnology has difficulty finding lucrative market segments in African countries. When introducing this technology, private firms concentrate on profitable markets, notably in the industrial countries.
2. In the EU the risks associated with GMOs are the subject of much debate and controversy. The conclusion drawn from this is that, as long as the risks associated with these technologies are not 100% clear, there should be no transfer of these technologies to developing countries.” (Kern, M., 2002).

Maina, J. (8/2025) published a paper titled: “Africa’s quiet biotech revolution: Gene editing emerges from Europe’s anti-GMO shadow”. For decades, European regulations have dominated the global conversation on agricultural biotechnology in many regions of the globe. From field to trade port, the EU’s strict GMO rules have long dictated what Global South farmers can grow, how crops are regulated, and where they can be sold. But in a quit policy shift, a few African nations are starting to resist this orthodoxy. Nigeria,

Kenya, Ghana and Malawi are now embracing gene editing on their own terms, crafting regulatory frameworks that treat CRISPR and similar tools not as GMOs, but as something different. Many African countries are adopting product-based regulations like Argentina, Brazil, United States and Canada.” The use of genetically modified plants in agriculture has been hindered primarily by Austria, Germany, and France, as well as several influential non-governmental organizations such as Greenpeace.

A group of scientists from Zimbabwe (Ndudzo A. *et al.*, 3/2024) have conducted a bibliographic review concerning applications and implications of CRISPR-mediated genome editing in crop improvement in the African context. They concluded, that “the adoption of CRISPR-assisted crop improvement in breeding strategies can help smallholder farmers in low middle income countries of Africa to adapt to climate change without productivity loss. By harnessing this technology, smallholder farmers can benefit from growing climate resilient crops with improved yields and stress resistance thereby contributing to food security and sustainable agriculture on the continent.”

Well, by pressing forward **DNA-®evolution** of crops through implementation of functional genomics, marker-assisted selection, genomics-assisted breeding, genetic engineering, genome engineering (Doudna and Charpentier, 2014), synthetic biology, and digital plant cells as well as the (*IntelligenceGREEN*) **I-GREEN-®evolution** (Kern, M., 2015) forward in agriculture and through implementation of digital systems such as smartphones, apps, global positioning systems (GPSs), sensors, robotics, drones, unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), and others, the changing world will be able to address **Factor F<sup>n</sup>** (“**FFFF FFFF FFFF FFFF**”): Future Farming, Food, Feed, Fitness, Fuel, Fiber, Flowers, Freshwater, Fishery, Forestry, Flora, Fauna, Fun, Fortune, Freedom, which are milestones on a roadmap for tackling the challenges of the 21<sup>st</sup> Century (Kern, M., 2002).

### 3. I-GREEN-®EVOLUTION AND CRISPR GENE EDITING

Between 1996 and 2019, 249 genetically modified crops and ornamental plants were launched on the market in 25 different countries. Most of these were in China (101), the USA (78), and Japan (17).

Most market-oriented applications were carried out on rice (81) and tomatoes (26), followed by the most important staple foods corn (25), wheat (14), potatoes (14), and soybeans (12). Most traits were agronomic traits (43), followed by food and feed quality (35) and biotic stress tolerance (23) (Menz, J. *et al.*, 10/2020).

Currently, more than 500 products are being developed worldwide using gene-editing technologies, with a focus on staple crops such as wheat, rice

and corn, bioenergy crops, vegetables, fruits, ornamental plants, legumes, forage crops, and grasses (Bullion, A. and Malhotra, B., 1/2023).

The global market for genome-edited crops reached a volume of US\$ 3.41 billion in 2024 and is expected to reach US\$10.6 billion by the end of 2033 (DataIntello, 2024).

A rough overview of the topic of *plant gene editing* based purely on numbers was provided by a Google search on August 30, 2025, using the keywords: “plant gene editing” + ‘pro’ and “plant gene editing” + “con.” This yielded 525,000 hits. In connection with ‘pro’, 63% of the hits were found, and in connection with ‘con’, only 37%.

CRISPR technologies provide versatility and efficiency in editing native genomes without the need to introduce foreign DNA. This is a significant difference from GMOs, which use foreign DNA.

Some pros and cons from different authors concerning *CRISPR technologies* are listed here:

### 3.1. Pros of Crispr Plant Gene Editing

1. Is fast (1)
2. Has a flexible design (1)
3. Is easy to use (2)
4. Is cost effective, (1, 4, 6)
5. Is affordable (2, 5)
6. Is accessible (4, 5)
7. Is versatile (2)
8. Shows rapid advancements (4)
9. Shows high precision in gene editing (3, 4, 5, 6)
10. Makes precise cuts and edits with remarkable accuracy (4)
11. Utilizes native repair machinery for intended changes (6)
12. Reduces the risk of Off-Target-Effects (4)
13. Enables multiplexed gene editing (1)
14. Enables gene stacking (6)
15. Induces male sterility in plants (6)
16. No need to introduce foreign DNA – it is a ‘non-intrusive’ method (6)
17. Paves the way for advances in agricultural biotechnology (5)
18. Improves the multi-nutritional value of crops (2, 4, 6)
19. Improves population health, e.g. can eliminate allergens (2)
20. Offers solutions for food scarcity challenge (5)
21. Enhances crop yields (4)
22. Creates resistance to pests and diseases (4)
23. Reduces the use of pesticides and herbicides (6)
24. Has the potential to enhance food security and sustainability (2, 3)
25. Contributes to adapt to climate change by providing resilient crops (2)

26. Enables more sustainable practices (2, 5)
27. Enables the improvement of carbon sequestration in plants and soil to slow down climate change
28. Shortens greatly the development time of novel crops as compared to GM or conventional breeding techniques (6)
29. Improves farming productivity (2)
30. Increases farmer's income (6)
31. Increases regional economic values (6)
32. Enables environmental conservation efforts (4)
33. Offers options to control invasive species (4, 5)
34. Contributes to protect endangered species (4, 5)
35. Fosters global collaboration (4, 5)
36. Democratizes genetic research (5)
37. Is an essential tool in fundamental research to understand gene functions and life processes (5)

(1) Thomas, C., (10/2023), (2) Automata Technologies, (2025), (3) Lubio Science, (7/2024), (4) Roberts, J., (9/2024), (5) ProsPlusCons.com (2025), (6) Hamdan, M.F. and Tan, B.C., (12/2024).

### 3.2. Cons of Crispr Plant Gene Editing

1. Off-target effects – unwanted alterations on non-target genes (1, 2, 3, 4, 5, 6)
2. Has efficiency limitations – activity itself may not occur (1, 2, 4)
3. Has the potential to develop new diseases or disrupt essential genes (4)
4. Can trigger unintended consequences, genetic errors, (4, 5)
5. May cross with wild plants (6)
6. Narrows the genetic pool by loss of genetic diversity (2, 4, 5)
7. Is not consistently regulated – has legal and regulatory challenges (2, 4, 5)
8. Has to clarify intellectual property issues (4)
9. Lacks long-term data concerning risk and benefits (4, 5)
10. Makes the edited crop indistinguishable from conventional food (6)
11. Has unclear public perception and acceptance (4)
12. Can cause socio-economic disparities (4)
13. Has potential for misuse and creation of bioweapons (4, 5)

In this short summary, it is striking that: in the 'pro' section: 'Shows high precision in gene editing' (3, 4, 5, 6) is at the forefront. In contrast, in the 'con' section: 'Off-target effects and unwanted alterations on non-target genes' (1, 2, 3, 4, 5, 6) are listed. The precision of CRISPR technologies is a critical factor and needs careful consideration and testing due to the challenges posed by off-target effects. Base editing & prime editing – the newer techniques are on the way to overcome this issue. Furthermore, the use of bioinformatics

and artificial intelligence tools will predict potential off-targets effects more precisely and avoid negative side effects.

#### 4. **AI-GREEN-®EVOLUTION (ARTIFICIAL INTELLIGENCE GREEN-®EVOLUTION)**

Living organisms, including plants/crops, constantly struggle to maintain balance in a changing environment. They can only survive by adapting or being resistant to external disturbances. Existing species-specific DNA sets cannot keep pace with the accelerating and dynamic changes in the environment. The changing environment “disrupts” or even “eliminates” life but does not determine DNA. Only small modifications and transitions, i.e., mutations, are triggered (Heschl, A. and Peschl, M., 1992). Consequently, the DNA-based master plan must be adapted or improved.

The use of artificial intelligence and the development of “genetic algorithms” will improve our understanding of biological processes and enable the creation of new crops that can meet the environmental challenges of today and tomorrow.

In 2025, *AI-GREEN-®evolution* is an essential key milestone to empower agricultural production processes.

Some improvements triggered by ‘*Artificial Intelligence*’ (Kern, M., 2025a) are listed here:

- ▶ Deciphers plant DNA, that can transform agriculture (Ralls, E., 4/2025)
- ▶ Improves the range of plant breeding methods
- ▶ Accelerates and streamlines plant breeding and genetic improvements
- ▶ Shortens streamlining the breeding cycles and improving accuracy in varietal selection
- ▶ Improves accuracy in assembling complex genomes (Wojcik-Gront, E. *et al.*, 2024)
- ▶ Minimizes off-target effects of plant gene editing
- ▶ Contributes to the development of beneficial traits and reducing off-target effects
- ▶ Improves prediction of missing genome fragments (Wojcik-Gront, E. *et al.*, 2024)
- ▶ Predicts and compiles coding domains (Wojcik-Gront, E. *et al.*, 2024)
- ▶ Predicts correlations between phenotypes and genotypes under different environment conditions by simulating thousands of growth scenarios
- ▶ Improves seed quality through AI-driven learning platforms for machine learning, deep learning, computer vision and data analysis, less time-consuming, improved accuracy, efficiency, and cost-effectiveness (Sairone, 2025)

- ▶ Provides machine learning programs enabling breeders to develop new crops/varieties
- ▶ Determines the ideal cultivar for different environments
- ▶ Synergizes gene editing in the field of carbon sequestration to mitigate climate change
- ▶ Provides highly productive fuel crops (Giddings, L.V. *et al.*, 9/2020)
- ▶ Designs de novo artificial cells/plants/crops
- ▶ Enables ChatGPT for biotechnology and designed products (NSCEB, 4/2025)
- ▶ Enables the production of bio-fortified products, vaccines and pharmaceuticals (Kern, M., 2023) as well as micronutrients (Kumar, M. *et al.*, 2025).
- ▶ Fosters the development of plant molecular farming by using mRNA technology and nanoengineering to improve human health. For reference, have a look at the vision paper titled: “Global Trends to Improve Human Health (2022-2052): Plant Molecular Farming and Edible Plant-Based Vaccines” (Kern, M., 2023).

The AI-empowered gene editing revolution is only just beginning (Caccamo, M., 8/2025) and scientists are only just scratching the surface of the potential advances. Records on the EU Saga database covering 1,000 peer-reviewed studies are documenting that gene editing techniques have now been applied to not fewer than 76 crop species, by researchers in 58 different countries. The number of studies dealing with different traits are for: biotic stress tolerance (218), abiotic stress tolerance (106), improved plant yield/feed quality (200), increased plant yield and growth (216), industrial utilization (117), herbicide tolerance (59), product colour/flavour (56) and storage performance (28). Caccamo, M. calls it: “*A truly global phenomenon!*” New AI tools will push forward the necessary second green revolution in agriculture.

## 5. PLANT BREEDING

Selection, crossbreeding, selective breeding, combination breeding, cloning, mutation breeding, the Green Revolution, green genetic engineering, GMOs, plant gene editing, and AI-powered plant breeding are essential milestones on the path to the crops we live with and from. Good seed is the basic agricultural input for and required for sustainable agriculture. “Seed is in fact the hub around which all other strategies to improve productivity resolve,” said Sehgal (1999) (Kern, M., 2000). All breeding has always been geared toward a natural environment, and cultivated crops had to withstand corresponding biotic and abiotic environmental stress factors. Conventional and gene-edited DNA-optimized crops have been and continue to be adapted to natural and local conditions through innovation.

Let me quote:

- ▶ **Swift, Jonathan (1667-1745)** from England, who wrote these lines, when the world population was 750 million:
  - “... that whoever could make two ears of corn, or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country, than the whole race of politicians put together.”
- ▶ **Magini, Ignatz (1819)** from Austria:
  - “To acclimatize non-indigenous cereals in our regions, we must reproduce the conditions under which they thrive in their country of origin and as far as possible eliminate the factors which cause them to fail.”
  - “At the same time, we should not subject them to excessive artificial refinements, thereby turning them into weaklings attracting a host of diseases which we seldom observe in the wild growing plants.”

Unfortunately, there is another abiotic stress factor on the globe that has hardly been considered so far: micro- and nanoplastics. Plastics, micro- and nanoplastics are potentially everywhere in the world. They are inextricably linked to food safety, plant, animal and human health, water and the environment. Most of them are invisible, insidious, underestimated, and neglected threats to humans and the environment. Studies on the mode of action and mechanisms of micro- and nanoplastics on seeds and plants have shown that they can have cytotoxic and genotoxic effects, cause DNA damage, induce genetic changes, decrease germination rate, can significantly alter the gene expression pattern (in: Maddela, N.R. *et al.*, 2/2023). To make seeds resistant to micro- and nanoplastics, appropriate breeding programs must therefore be established (Kern, M., 2024).

Soil, water, sun, fertilization, plant protection, agricultural technology, etc. are key factors for many agricultural production systems, addressed by Kern, M. (2000): ‘rationalized agriculture’, ‘value added agriculture’, ‘high input agriculture’, ‘low external input farming’, ‘hydroponic agriculture’, ‘precision farming’, ‘prescription farming’, ‘site-specific farming’, ‘subsistence farming’, ‘organic farming’, ‘integrated farming’, ‘progressive farming’, ‘plant molecular farming’, ‘pioneering farming’, ‘knowledge intensive agriculture’, ‘plastic agriculture’ (Kern, M., 2000, 2023), ‘DNA-agriculture’, ‘digital agriculture’ (Kern, M., 2015), ‘diversified agriculture’, ‘decent agriculture’, ‘decision agriculture’/ ‘agriculture 5.0’, ‘designed agriculture’, (Kern, M., 2025), ‘I-GREEN/AI-GREEN agriculture’ (‘Plant Breeding 5.0’), ‘cellular agriculture’, ‘controlled environmental agriculture (CEA)’, ‘space agriculture’, ‘Mars agriculture’, ‘artificial agriculture’ (Kern, M., in prep. 2026). All forms

of farming/agriculture are using specified crops, which means that they use very specific DNA.

Furthermore, it has to be considered, that between 2015 and 2050 more than a doubling of crop production, a nearby doubling of meat production, a tripling of plant-based protein production (food & feed), and a tripling of fruit and vegetable production is necessary to feed 9.7 billion people living on earth in a healthy way (Kern, M., 2016a, b), and that climate change and other '*black swans*' such as soil degradation will make agriculture increasingly volatile.

Until now, plant breeding has always focused on increasing yields, boosting biomass production, disease and pest resistance, improving nutrient content, cold resistance, adaptation to regional climate conditions, end-use qualities, etc.

Well, with the increasing use of soil, there is a growing trend worldwide toward soil overuse and carbon depletion (Kern, M., 2010). This affects approximately 20-25% of all soils globally.

To protect the soil, sequester CO<sub>2</sub>, and mitigate climate change, plant breeding programs should rethink and focus on the following (Kern, M., 11/2025d):

- ▶ Mitigate climate change without compromising yield (Rizi, M.S. and Mohammadi, M., 5/2023)
- ▶ Ensure crops maintaining their nutritional value while benefiting from accelerated growth (Acorn Horticulture, 7/2025)
- ▶ Accelerate growing period cycles, shorter growing-period durations (Minoli, S. *et al.*, 11/2022)
- ▶ Use the 'CO<sub>2</sub>-fertilization' effect to increase photosynthesis and biomass production
- ▶ Overcome the 'dilution' effect, the reduction of plant vitamins, minerals, nutrients and overall quality
- ▶ Boost storage of soil carbon
- ▶ Reduce carbon from atmosphere
- ▶ Produce more and deeper roots (Rizi, M.S. and Mohammadi, M., 5/2023)
- ▶ Store carbon in deeper soil layers
- ▶ Be resilient under changing environments (e.g: draught and heat, water stress, cold)
- ▶ Increase early heat stress tolerance e.g. in wheat (Rajotia, M.S. *et al.*, 1/2025)
- ▶ Resist to abrupt sunlight reduction scenarios (ASRS) caused by a major nuclear war, major volcanic eruption or asteroid or comet (Rivers, M. *et al.*, 9/2024), or 'engineered pandemics' (Avin, S. *et al.*, 2/2018) such as e.g. 'micro- and nanoplastics' (Kern M., 2024)
- ▶ Grow with lower sunlight
- ▶ Be resilient to elevated ultraviolet radiation (Xia, L. *et al.*, 8/2022)

- ▶ Adapted to modified changes of photoperiods (Boyd, M. and Wilson, N., 2023)
- ▶ Resistant to 'nuclear winter' periods (Rivers, M. *et al.*, 9/2024)
- ▶ Enable stockpiles of ASRS resilient seeds as a backup (Martinez, J.B. *et al.*, 2/2025)
- ▶ Be resilient to colt during 'nuclear winter' (Alvarado, K.A. *et al.*, 12/2019)
- ▶ Provide transplantable crops to overcome 'nuclear winter' (Alvarado, K.A. *et al.*, 12/2019)
- ▶ Be resilient to majorly disrupted global cyberspace, electrical grid and/or industrial infrastructure (Martinez, J.B. *et al.*, 2/ 2025)
- ▶ Improve N<sub>2</sub> fixation from the air
- ▶ Improve water efficiency
- ▶ Resist to phytopathogenic diseases; these are usually transmitted by vectors such as the cicada *Pentastiridus leporinus* (Hemiptera: Cixiidae) and include diseases such as *Stolbur phytoplasma* in sugar beets and potatoes, *Arsenophorus phytopstogenicus* in sugar beets, potatoes, onions, or bacterial wilt in carrots and beetroot
- ▶ Resist to micro- and nanoplastics in the soil and environment (Kern, M., 2024)
- ▶ Protect plant carbon from microbes (Poffenbarger, H. *et al.*, 3/2023)
- ▶ Overcome the fact that many crop varieties are more susceptible to biotrophic viral pathogens (e.g. soybean) (Sanchez-Lucas, R. and Luna, E., 3/2025)
- ▶ Avoid weakening the plant immune systems
- ▶ Maximize plant carbon fixation during fallow period (Poffenbarger, H. *et al.*, 3/2023)
- ▶ Identify and manipulate genes associated with suberin synthesis
- ▶ Develop crops which are significantly synergized by biochar (Li, J. *et al.*, 1/2025)
- ▶ Develop crops which are significantly synergized by biochar plus microbial inoculants (Ge, A.-H. *et al.*, 3/2025)
- ▶ Develop crops which are significantly synergized by biochar plus nano-encapsulation of biofertilizer (Markets and Markets, 5/2025a; 5/2025b)
- ▶ Enable crop microbiome engineering (Pattr, D. *et al.*, 9/2025)
- ▶ Improve energy efficiency in biofuel crops by actively removing CO<sub>2</sub> from the atmosphere (Babbar, S. *et al.*, 4/2025)
- ▶ Improve cover crops such as CoverCress
- ▶ Transform annual crops to perennial crops, e.g. Kernza® grain, (Land Institute, USA, 5/2022), perennial rice (Zhang, S. *et al.*, 11/2022; Xu, H. *et al.*, 4/2025)
- ▶ Include understudied crops, orphan crops, landreaces, and crop wild relatives (Byrne, P.F., *et al.*, 2020)

- ▶ Utilize relevant characteristics of  $C_4$  plants to enhance the  $CO_2$  absorption capacity of  $C_3$  plants (Zhao, M. *et al.*, 3/2025)
- ▶ Design carbon storage crops.

With '**Plant Breeding 5.0**' and '**Agriculture 5.0**' (Kern, M., 2025) it is possible to create added value for agriculture by improving soil productivity, sequestering  $CO_2$  from the atmosphere, combating climate change, reducing the carbon footprint, protecting the environment and enabling sustainable life on Earth.

## 6. ORGANIC FARMING

Organic agriculture is the type of agriculture system that converges to the state that relies on ecosystem-based management rather than external agriculture inputs (US, S. and Kulkarni, V.V., 7/2023). In 2025, 99 million hectares (6.6 %) of global agriculture area was organic agriculture. This production system is a private sector with its own developed concept, philosophy, values, directions, guidelines, rules, norms, standards and certification.

In 2017, Nuijten, E. *et al.* described the development of guiding principles for the evaluation of breeding techniques by the organic sector. At that time around 95% of organic production in industrialized countries was based on crop varieties that were bred for conventional agriculture where mineral nitrogen fertilization and chemical-synthetic pest, disease and weed control are not limiting factors. Most crops worldwide were developed by classical radiation breeding, whereby many genomic mutations were produced, which cannot be expressed in nature. Most of organic seeds used today have gone through this process.

Radiation mutation breeding has been used for nearly 100 years and has successfully improved crops by increasing genetic variation worldwide. In 2021, "3,365 mutant varieties have been registered in the Mutant Variety Database of the International Atomic Energy Agency (IAEA) and more than 1,000 new varieties have been used and promoted worldwide." (Ma, L. *et al.*, 12/2021).

Mutation breeding refers to the method of using artificial mutagenesis to obtain new biological cultivars, mainly through chemical or radiation mutagenesis. Chemical mutagenesis refers to the biochemical reaction between chemical agents and genetic material, and the result is mostly pointing mutations in genes. Comparatively, radiation mutagenesis has characteristics of more complex genetic mutations and more beneficial mutant phenotypes. (Ma, L. *et al.* 12/2021).

Nevertheless, without appropriate varieties that are relevant for organic agriculture, farmers cannot be successful. Plant breeding plays a major role in success of any farming system by breeding cultivars specific for particular

farming systems. Some requirements for organic plant breeding modified after Sharma, S. *et al.*, (2018) and US, S. and Kulkarni, V.V. (7/2023) are listed here:

- ▶ Select varieties under organic conditions
- ▶ Should not use genetic engineering in plant breeding and not use genetically modified crops, GMOs are absolutely prohibited
- ▶ The genome is respected as an impartible entity and genome editing is completely prohibited.
- ▶ The cell is respected as an impartible entity. Technical interventions like cell fusion, protoplast fusion and care are not allowed
- ▶ Plant varieties can be protected, but not patented
- ▶ New breedings should be well adapted to local nutrient and climate conditions
- ▶ New organic crops should be nutrient efficient and highly responsive to natural nutrients supplied to them
- ▶ Should have durable resistance and tolerance against pests and diseases
- ▶ Should have high level of tolerance against soil and seed borne diseases
- ▶ Should have a high weed competition or tolerance
- ▶ Should improve legume symbiotic effectiveness
- ▶ Should enable higher yields
- ▶ Should have an improved yield stability
- ▶ Should have better storability and longer shelf life
- ▶ Should have a better human nutritional quality
- ▶ Should focus on a broader spectrum of crops
- ▶ Should be done in a participatory process with farmers and other chain players.

Some plant breeding techniques are discussed, however the authors concluded: “Not only the cultivars specific for organic condition but also there is need for development of new breeding techniques and tools that are specially designed for organic conditions, which will make breeding easy for organic farming”, US, S. and Kulkarni, V.V. (7/2023).

In 2025, new breeding methods which technically alter the DNA or RNA by methods of genetic engineering including CRISPR technologies are not compatible with organic breeding principles, as this violates the integrity of the genome.

Well, one strategic target of organic plant breeding is to overcome the average yield gap of approximately 20% between conventional and organic agriculture.

This goal will be difficult or impossible to achieve if organic plant breeding does not find or allow suitable methods. This gap will widen even further if

conventional seed breeding significantly increases yields using gene editing and AI in future.

Organic agriculture has excluded itself from the first green revolution and will also miss out on the second green DNA revolution by rejecting new breeding methods.

## 7. PLASTICULTURE

The global total area of plastic-covered greenhouses (PCG) is 3019 million hectares (20% of global crop land), including walk-in tunnels (high tunnels; HT), low tunnels (LT), and plastic mulched farmland (PMF) (Jiménez-Lao, R. *et al.*, 8/2020). This type of production is implemented to protect crops from adverse conditions, such as heat, cold, heavy rain, hail, wind, harmful insects, and diseases, optimizing the use of water, nutrients and increasing soil temperature. More or less all crops used in plasticulture originate from rainfed agriculture or greenhouse agriculture.

## 8. CONTROLLED ENVIRONMENTAL AGRICULTURE (CEA) – CLIMATE-RESILIENT SYSTEMS

According to estimates by Ravensberger, P. *et al.* (2/2024), approximately 700,000 hectares (0.05% of the total crop land area) worldwide, excluding China, are protected horticultural areas, of which 53,000 hectares are high-tech greenhouses. Only a few hundred hectares are used for indoor/vertical farming without the use of sunlight. The estimated current area of CEA in China was 1,894,215 hectares.

The author would like to refrain from providing extensive explanations on this topic at this point and refer you to a review by Bhattarai, K. *et al.* (1/2025) entitled: "Improvement of crop production in controlled environment agriculture through breeding". "Currently, CEA producers rely on cultivars bred for production in open-field agriculture. The review aims to cover specific breeding opportunities and needs for a wide range of horticultural crops either already being used in CEA systems or with potential for CEA production. It reviews many of the tools available to breeders including genomics-informed breeding, marker-assisted selection, precision breeding, high-throughput phenotyping, and potential sources of germplasm suitable of CEA breeding." Some CEA breeding targets are listed here:

- ▶ Modified crop canopy with a small stature to maximize space utilization
- ▶ Shortened crop cycles to allow multiple crop cycles
- ▶ Adapted to low light conditions to reduce energy usage
- ▶ Enhanced photosynthetic efficiency to maintain or increase yields
- ▶ Enhanced cold and heat tolerance to reduce energy consumption

- ▶ Adapted to soilless substrates such as hydroponics, aquaponics, aeroponics
- ▶ Optimized nutrient uptake
- ▶ Enhanced nutritional content
- ▶ Biofortified plants to produce nutraceuticals, medicine and pharmaceuticals
- ▶ Improved flavor
- ▶ Prolonged shelf life
- ▶ Increased pollination efficiency
- ▶ Improved parthenocarpy
- ▶ Improved resistance to CEA diseases and pests
- ▶ Improved growing systems for perennial crops (small trees, fruit trees, small pot trees)
- ▶ Improved nursery stock production to produce high quality, elite materials free from pests and diseases
- ▶ Resilient growth during ‘nuclear winter’ (Avin, S. *et al.*, 2/2018)
- ▶ Improved transplantable crops to overcome ‘nuclear winter’ (Alvarado, K.A. *et al.*, 12/2019).

The CEA market size is expected to grow from \$US 96.1 billion in 2024 to \$US 507.0 billion in 2034 (Market.US Report, 3/2025). CEA will use all advanced precision breeding techniques including gene editing and revolutionize urban agriculture to provide sufficient nutritious fruits and vegetables and enhancing food security and sustainability.

## 9. CELLULAR AGRICULTURE (KERN, M., 2019/2022) / MOLECULAR AGRICULTURE (KERN, M., 2023)

After 125 years, the visions/dreams of the famous chemist **Professor Marcellin Berthelot** about “**Foods in the Year 2000**”, that synthesized food will displace agriculture published in 1894 seems to be on the way to be realized. However, options are not coming exclusively from chemistry, but more from biology and biotechnology.

### 9.1. Alternative Production of Fruits and Vegetables

‘*Cellular agriculture*’, ‘*labriculture*’, and ‘*integriculture*’ are new word creations based on new production technologies of fruits and vegetables named: ‘*in vitro fruits/vegs*’, ‘*cellular fruits/vegs*’, ‘*cell-based fruits/vegs*’, ‘*cell-cultured fruits/vegs*’, ‘*cultured fruits/vegs*’, ‘*fermented fruits/vegs*’, ‘*resource efficient fruits/vegs*’, ‘*ethical fruits/vegs*’, ‘*artificial fruits/vegs*’, ‘*synthetic fruits/vegs*’, ‘*lab grown fruits/vegs*’, ‘*home cultured fruits/vegs*’, ‘*mitated fruits/vegs*’, ‘*processed fruits/vegs*’, ‘*reinvented fruits/vegs*’, ‘*fake fruits/vegs*’, ‘*Frankenstein*’ fruits/vegs’, ‘*clean fruits/vegs*’ or ‘*super fruits/vegs*’ etc.

Plant cell cultures are increasingly developed to produce healthy fruits and vegetables during the whole year by using minimal land resources. Food vending machines, home “**Bioreactors**” personal “**Food Computers**” or so called “**Food Servers**” are on their way to provide people at home, restaurants or supermarkets with fresh fruits and vegetables. Furthermore, plant cell cultures are key prerequisites for vertical agriculture, especially established in or close by urban area and space agriculture.

“Go green. Go clean. Go plant based. Do it for your health. Do it to save the planet. Do it to save the animals.” are key credos of the new spectacles in agriculture and food production (Radke, A., 3/2019).

## 9.2. Alternative Production of Meat

“*Cellular agriculture*”, “*labriculture*”, and “*integriculture*” are new word creations based on new production technologies for meat named: “in vitro meat”, “cellular meat”, “cell-based meat”, “cell-cultured meat”, “cultured meat”, “fermented meat”, “animal-free meat”, “slaughter-free meat”, “cruelty-free meat”, “resource-efficient meat”, “ethical meat”, “artificial meat”, “synthetic meat”, “lab grown meat”, “home cultured meat”, “zombie meat”, “blood-free meat”, “imitated meat”, “simulated meat”, “faux-meat”, “non-meat”, “methane-based meat”, “processed meat”, “reinvented meat”, “beyond meat”, “fake meat”, “Frankenburger ‘Shmeat’” or “clean meat” etc.

Key parameters for the future market of “*Fruits and Vegetables Alternatives*” as well as “*Meat Alternatives*” among others are the following ones: Quality, taste, flavor, texture, convenience, price, profitability, target groups in markets, affordability, availability, nature based vs science based, GMO-debate, natural vs artificial, nutritional profile, long-lasting impact on human health, food safety, fair regulations, appropriate labelling, progress in personalized nutrition (Kern, M., 1/2007), general benefits (health, environment, animal welfare), CO<sub>2</sub> footprint, use of non-fossil energy, bio-based product manufacturing, sustainable utilization of resources, transparency, consumer acceptance, consumer preferences, consumer demand, changing eating habits, respecting religions and cultural levels, social consensus, reactions of the horticulture and livestock industry, improvements in fruits and vegetables as well as meat production, information, media/social media reflections, fake news, image creation, visibility, etc.

Key words such as: “*Fourth Industrial Revolution*”, “*Second Domestication*” or “*2<sup>nd</sup> Red Revolution*” are intensively propagated in various media to promote “*Cellular agriculture*” and alternatives to meat-like products and alternative meat production methods.

On the other hand, a new era for pork began in the livestock sector in the spring of 2025. In the US, genetically modified pigs that are resistant to porcine reproductive and respiratory syndrome (PRRS) were approved

for consumption. This viral disease cost the US pork industry \$1.2 billion annually from 2016 to 2020. PRRS is the most economically significant viral disease in pigs worldwide. Gene-edited pigs will not be available on the market until 2026 at the earliest (Benjamin, M., 7/3/2025). The public reception is still uncertain.

With regard to molecular agriculture and edible plant-based vaccines, please refer to a vision paper titled: “Global Trends to Improve Human Health (2022-2052): Plant Molecular Farming and Edible Plant-Based Vaccines” (Kern, M., 2023).

Fair regulations and an appropriate labelling of “*Fruits and Vegetables Alternatives*”, “*Meat Alternatives*” as well as “*Molecular Agriculture*” will be fundamental for the growth of these new industries. Currently, plant-based food alternatives via cellular or molecular agriculture have not yet achieved mass-consumer appeal. Challenges and opportunities for cellular agriculture to produce foods of the future are well described by McNulty, M.J. *et al.* (6/2025).

## 10. MISSION TO MARS BY 2030/2040 AND BEYOND

### 10.1. Some Milestones Before the Mission to Mars

#### ***Space Crops / Extraterrestrial Crop***

- ▶ In 1982, a plant (foam cress) was grown in space for the first time in a small greenhouse on the Russian space station Salyut 7.
- ▶ In 1983, it was proven in the American space shuttle Columbia that sunflowers showed rotational growth despite the absence of gravity
- ▶ In 2019, the Chinese Chang’e 4 mission demonstrated that cotton seeds germinated on the moon. This was the first biological experiment to grow plants outside of Earth, (Hartmann, C., 4/2025).
- ▶ As the son of a vine growing family, the author would like to mention initiatives in the field of vine breeding and space travel.

In 2020, the European start-up “Space Cargo Unlimited” exposed 320 cuttings of Merlot and Cabernet Sauvignon vines to weightlessness on the ISS for 312 days. The company reported that the vines would bear fruit earlier, have improved resistance to downy mildew, and possibly also have improved resistance to pests (Silkes Weinblatt, 2/2023). The extent to which the changes triggered in these space grape varieties will benefit viticulture on Earth remains to be seen, especially since the development of a new grape variety takes 20 to 30 years.

Viticulture on the moon or Mars seems pure utopia today. Nevertheless, the terroir would certainly be very specific but also fascinating. But for now,

after more than 8,000 years of viticulture, wine from Earth is excellent and fantastic – from Rhine-Hesse/Rhineland-Palatinate in Germany, of course.

- ▶ In 2022, NASA was studying opportunities for in-space production (open growing systems, closed autonomous growing systems, influence of space conditions on plants at the cellular level) (Space Ambition and Baranov, K.S., 11/2022).
- ▶ In 2022, China's agency focused on space mutagenesis (i.e., space breeding), more than 300 kg seeds of more than 70 crops were sent to space to explore the role of microgravity, cosmic radiation and other aspects of the space environmental plant growth. Subtle changes of DNA could be found within the plants. Chinese state officials claimed, that "the experiments have produced more new types of mutated plants in China that ever have been approved for large-scale cultivation, ranging from grains to vegetables and fruits" (Space Ambition and Baranov, K.S., 11/2022).
- ▶ In 2024, after return of Shenzhou-18 spacecraft to Earth, China underlined his interest in space-induced mutation breeding. Since 1987, China has conducted over 3,000 space breeding experiments, resulting in more than 260 approved varieties of staple grains and hundreds of new varieties of vegetables, fruits, forestry, and flowers for the benefit of farmers, producers, and society (Chen, H., 11/2024).
- ▶ In 2024, an artificial lunar landscape with dust and rocks was opened in Cologne, Germany as a "Luna" training hall for astronauts. There, they are to learn how to grow vegetables, lettuce, and herbs in greenhouses using as few resources as possible (Tagesschau, 9/2024).
- ▶ In 2025, India did grow mung beans and fenugreek plants in microgravity during the private Axiom Space Ax-4 mission on the ISS. This underlined India's plans for human space flights and the possible set up of its own space station later this decade (Nasir, S., 6/2025).

## 10.2. Mission Mars

- ▶ Is 54.6 million kilometers away from Earth
- ▶ Its environment is very harsh, extremely cold, dry, and lacks breathable oxygen
- ▶ Has no magnetic field
- ▶ Has a thin atmosphere.

## 10.3. Mars Mission and Nutrition

- ▶ A mission to Mars and back to Earth takes 30 months (6 months flight + 18 months optimal travel window + 6 months return flight).
- ▶ Astronauts' nutrition is a major challenge; they need food for 30 months.

- ▶ Pre-packaged food should have a shelf life of 5 years (unchanged quality, nutrients preserving, extreme stability, sufficient acceptance, good taste, health-promoting and compensation for body weight loss) (Ivy, C., 10/2024).
- ▶ There is only limited space for packaged food.
- ▶ Important characteristics: dehydrated, thermostabilized, medium moisture content, natural foods from agricultural cultivation (nuts, cookies), irradiated, frozen, fresh, chilled, vacuum-packed.
- ▶ A wide variety of space food is needed to counteract “menu fatigue.”
- ▶ Astronauts choose their menu for space five months before their flight.
- ▶ Growing plants on board is the biggest challenge.
- ▶ Using various cellular technologies to create alternative food products like cell-based meat, milk, fruits, and others (Space Ambition and Baranov, K.S., 11/2022).
- ▶ Needs cutting edge technologies for bioregenerative life support systems (BLSS).
- ▶ Seed supplies must be taken along to be grown later on board and on Mars.
- ▶ Plants that can grow in extraterrestrial environments are needed.

#### **10.4. Mars Mission and Extraterrestrial Conditions**

- ▶ The environment on Mars is extremely unfavorable for agriculture
- ▶ Nutrient-poor soil, low nitrogen content
- ▶ Dust on the moon is sharp-edged and misshapen dust particles, relatively sticky, like flour, penetrates the smallest cracks and damages the lungs
- ▶ Dust on Mars consists of fine-grained particles, mainly iron oxides and silicon dioxide
- ▶ Dust storms can cover the entire planet
- ▶ Lack of sunlight compared to Earth (only 43%) (Maity, T. and Saxena, A., 4/2024)
- ▶ Lack of sufficient water
- ▶ Reduced gravity
- ▶ Little or no supply from the earth
- ▶ Coping with unpredictable challenges
- ▶ Need for small-scale robot-assisted agriculture
- ▶ Robots will use AI to establish autonomous bases for food production
- ▶ Need for a robust, solid, and sustainable system for space catering on Mars that is as self-sufficient as possible
- ▶ NASA plans to build a nuclear reactor on the moon by 2030—a pilot project for the Mars mission.

## 10.5. Mission Mars—New Mars and Space Crops Should

- ▶ Ensure no contamination by microorganisms from Earth
- ▶ Grow in hot and cold conditions
- ▶ Be drought-tolerant and require less water
- ▶ Use only soil-independent agricultural techniques such as aquaponics, hydroponics, aeroponics, and vertical farming, which are suitable options for production systems
- ▶ Enable higher yields with fewer nutrients and fewer resources
- ▶ Use light energy efficiently
- ▶ Be tolerant of high concentrations of dissolved organic and inorganic chemicals
- ▶ Tolerate an environment with high CO<sub>2</sub> levels
- ▶ Have a high harvest index
- ▶ Have a short growth cycle
- ▶ Enable a complete seed-to-seed life cycle
- ▶ Have low maintenance
- ▶ Radiation resistant to withstand high radiation levels in space
- ▶ Be tested by ground studies modelling extraterrestrial conditions (Buncheck, J.M. *et al.*, 1/2924)
- ▶ Be tested in space flight testing systems (Buncheck, J.M. *et al.*, 1/2024)
- ▶ Growth in zero gravity and overcoming “gravitropism”
- ▶ Compensate the microgravity-impact on gene expression and cell metabolism, as well as activation of cellular defense mechanisms
- ▶ Exhibit improved nutrient uptake due to low nitrogen and phosphorus content
- ▶ Have improved and efficient DNA repair systems
- ▶ Be created by design.

Plant synthetic biology will be a key for well suited for Martian conditions (Llorente, B. *et al.*,

2018; Conde-Pueyo, N. *et al.*, 2020) as well as ‘Nuclear Winters’ following a nuclear war or a major volcanic eruption.

Synthetic biology may be the only way to service and thrive on Mars and beyond (Mc Kee, S., 4/2025).

Further reference should be made to two papers on the prospects for synthetic biology in 21<sup>st</sup> century agriculture (Ye, X. *et al.*, 12/2024) and the necessary training of synthetic biologists (Karim, A. *et al.*, 6/2024).

Four recent review articles from the Republic of Korea, China, India, and Denmark/Germany a dealing with plant responses to microgravity (Farooq, M. *et al.*, 2/2024), the selection and breeding of plants suitable for space agriculture (Nie, H. *et al.*, 6/2025) and the effects of microgravity on pathogens and plant-associated microbes (Guha, A.A. *et al.*, 8/2025), and the impact on

gene regulation in plants (Corydon, T.J. *et al.*, 3/2023) are recommended to open up new horizons in the field of future space agriculture.

Yes, indeed, we live in an age of space exploration, DNA modifications and DNA design of new organisms.

## 11. ETHICS / DUAL USE / MISUSE OF BIOTECHNOLOGY

Gene editing technology is a tool only, and not good or bad, but raises legal and ethical concerns.

The runnig *"BIO Revolution"* is triggering a *"GENETHICS Revolution"*. *"Genethics"*, a portmanteau of *"genetics"* and *"ethics,"* is a multidisciplinary field that explores the profound implications of genetic research and technology on human health, society, and the environment. This cutting-edge discipline seeks to bridge the gap between scientific advancements and ethical considerations, ensuring that the benefits of genetic discoveries are harnessed responsibly and equitably (Genethics, 2023).

### 11.1. Agriculture/Environment and Ethics

Congreves, K.A. (5/2025) from Canada outlined in her paper: *"Agricultural environmental ethics: an emerging way to understand and solve sustainability challenges"*, that the goal is to guide agricultural scientists in understanding the role and necessity of an ethical foundation for agriculture. They must care for the environment and its resources and should be aware that agricultural systems are inherently anthropogenic and involve humans. Nevertheless, they have to save and protect the environment while emphasizing human responsibility.

### 11.2. Gene Editing in Plant Breeding and Ethics

A bibliometric review made in Malaysia covering data from 2010 to 2022 and focusing on scientific journal articles worldwide (Idris, S. H., *et al.*, 7/2023) titled: *"Ethical and legal implications of gene editing in plant breeding: a systematic literature review"* -

- ▶ Describes the heterogeneity in international regulatory approaches
- ▶ Emphasizes that consumer acceptance of gene edited food crops (GE) is higher than for genetically modified crops (GM)
- ▶ Provides solutions to counterattack negative climate change impacts
- ▶ Improves sustainability of agriculture
- ▶ Enhances genetic crop diversity
- ▶ Outlines, that (NGTs) should be regulated fairly, responsibly and considering essential elements such as conservation, biodiversity, the intrinsic value of nature, as well as well-being, welfare, choice, and

fair trade; the processes should be transparent, science-based, risk-proportionate, and appropriate for the intended use

- ▶ Reports, that many countries perform regulatory evaluations based on their novel characteristics rather than processes used to create them.

Another bibliometric review made in India covering data from 2014 to 2023 and focusing on China, USA, and India (Kolkar, S.U. *et al.*, 5/2024) titled: “CRISPR in agriculture and its ethical implications: A bibliometric analysis” -

- ▶ Underscores the significant advantages of CRISPR in agriculture
- ▶ Explains that the implementation of genetically modified (GM) crops and genetically edited (GE) crops was limited by the lack of consensus among international bodies on *the adoption of new genomic techniques (NGTs)*
- ▶ Requests urgent regulatory decisions on the production and use of (GM, G, NGTs)
- ▶ Raises concerns about potentially dangerous or controversial practices, such as bioterrorism, biohacking, eugenics, and military applications
- ▶ Calls for coordinated policy and regulatory response across countries and governments levels.

## A real historic milestone in the UK, 11/2025!

Since November 2025, England has been the first country in Europe to legalize the development and sale of gene-edited plants and foods. It provides scientists, plant breeders, and farmers with a more appropriate and scientifically sound legal framework for the use of precision breeding techniques such as gene editing to improve productivity, climate resilience, and sustainability.

The implementation of this law is a historic milestone in the UK. It is the first time that the use of advanced genetic technologies in British agriculture has been enabled rather than restricted (NIAB, Caccamo, M., 11/2025).

### 11.3. Dual Use – Weaponizing of Ai-Empowered Gene Editing

Key issues from the report of the NSCEB\* (National Security Commission on Emerging Biotechnology) titled: “*Charting the Future of Biotechnology – An action plan for American security and prosperity*” (NSCEB, 4/2025).

In this alarming and holistic report (NSCEB, 4/2025), based on data from 1,800 consultations with farmers, scientists, entrepreneurs, engineers, generals, academics, and regulators, conducted between April 2023 and February 2025 in laboratories, factories, fields, hospitals, and bases, the commission has developed a series of high-priority recommendations that, taken together, are intended to ensure that the US can overtake and outpace China in the race for biotechnology. **The commission actually believes that the US is falling behind China in key areas of emerging biotechnology,**

**while China is experiencing rapid growth – and this is happening at a time when the world is being shaken by numerous crises and conflicts.**

- ▶ “We stand at the edge of a new industrial revolution, one that depends on our ability to engineer biology. Emerging biotechnology, coupled with artificial intelligence, will transform everything from the way we defend and build our nation to how we nourish and provide care for Americans.
- ▶ Estimates, that by 2020, most people on the planet will have consumed, used, worn, or been treated by a product of emerging biotechnology. By 2050s there will be the ability to collect rare minerals from the moon and Mars, using robotic missions to bio mine in space.
- ▶ Modern biotechnology is an American innovation.
- ▶ We must defend our biotechnology IP and data against Chinese state-sponsored corporate espionage.
- ▶ Now, thanks to breakthroughs in artificial intelligence (AI), engineering, and automation, biology is becoming more than just a field of discovery, it is becoming a field of design. – But, in wrong hands, it could be used in wrong hands to develop powerful weapons. Countries that win the innovation race tend to win actual wars, too.
- ▶ Falling further behind would signal a global power shift toward China.
- ▶ With AI, along with gene editing tools like CRISPR, scientists will soon be able to create materials from scratch, prevent illnesses at the level of genetic code, and develop more resilient crops and livestock. **China has emerged as a powerhouse in AI-enabled biotechnology.**
- ▶ **The Commission has every reason to believe that the CCP (Chinese Communist Party) will weaponize biotechnology.**
- ▶ Based on two years of research and consultation with private and public experts, this report comes to a sobering, even frightening, conclusion: China is quickly ascending to biotechnology dominance, having made biotechnology a strategic priority for 20 years. **To remain competitive, the United States must take swift action in the next three years. Otherwise, we risk falling behind, a setback from which we may never recover.**
- ▶ Congress must establish a National Biotechnology Coordination Office (NBCO) within the Executive Office of the President with a director, appointed by the President, who would coordinate interagency actions on biotechnology competition and regulation.
- ▶ Congress must direct the Department of Homeland Security to ensure that biotechnology infrastructure and data are covered under ‘critical infrastructure’.
- ▶ While biology represents a paradigm shift in warfare, the Department of Defense (DOD) is not deploying biotechnology-enabled capabilities, leaving our military vulnerable. We must develop these technologies in line with American values before the CCP advances them without ethical

constraints. **Congress must direct the Department of Defense to consult with stakeholders to define principles for ethical use of biotechnology for the U.S. military.** With biotechnology, platoons will be able to synthesize food, munitions, and therapeutics directly on the front lines using technologies that could fit in a backpack, instead of relying on materials produced thousands of miles away at home.

- ▶ Biotechnology will save lives on the battlefield and prevent the need for costly or dangerous refuel or resupply missions.
- ▶ America's greatest strength has always been its people, yet the United States currently lacks a biliterate workforce. Federal departments and agencies must ensure that their employees are appropriately skilled and trained to advance and secure biotechnology. We must also strengthen our domestic biotechnology workforce and sustain the pipeline of talent, both at home and from abroad.
- ▶ **The Commission's main recommendation is this: the U.S. government should dedicate a minimum of \$15 billion over the next five years to unleash more private capital into our national biotechnology sector.**
- ▶ Biotechnology can revolutionize agricultural production in America. Agriculture Biotechnology is already the norm in much of American agriculture. Over 90 percent of U.S. soybeans, corn, and cotton are enhanced using biotechnology to help farmers reduce the need for land, water, and chemical inputs. We are already starting to see the benefits of biotechnology for agriculture, with cattle that can stay cooler and continue to produce milk in hot conditions and custom soil microorganisms that can pull nitrogen from the air and reduce fertilizer needs. These technologies will be a game-changer for America's farmers, while giving consumers across the country access to less expensive and more nutritious food.
- ▶ In agriculture, the Chinese government uses its regulatory system to delay approval for American developed seeds and require larger-than-normal samples of seeds. This allows China to develop its own versions of American seed varieties in a fraction of the time it would otherwise take.
- ▶ In recent years, China has become the largest funder of agricultural R&D in the world, surpassing the United States and the EU.<sup>316</sup> In 2019, for the first time in history, **China applied for more international patents than the United States. Many of these Chinese applications were for agricultural patents that use CRISPR.**
- ▶ Livestock diseases cost farmers \$358.4 billion each year globally in lost production, driving up food costs for Americans. Modify a plant pathogen so that it specifically targets crops grown in the United States, and those existing diseases will become superspreaders that decimate livestock, cripple farmers' livelihoods, skyrocket costs at the grocery store, and make Americans go hungry.

- ▶ Enter artificial intelligence (AI). Today, AI is beginning to decipher the patterns that govern the behavior of biological systems. Thanks to AI's tremendous modeling power, in the future we will no longer need to know (or expend human effort and time determining) exactly how a biological system works to harness it. Instead, we will be able to program cells as we program computers, accurately and precisely engineering biology to achieve desired results.
- ▶ For the United States, achieving global biotechnology superiority is an imperative. If America secures its position as the greatest biotechnology power in the world, we will see major gains in five critical areas: defense, supply chains, agriculture, healthcare, and computing.
- ▶ Biotechnology is also the best defense against bioweapons. The United States does not and will not have an offensive bioweapons program. Other countries do. The best deterrent is to master biotechnology so that the United States can prevent, detect, and respond to any biological event.
- ▶ The future of warfare will no doubt involve biotechnology, whether or not the United States takes the lead in that field. There is no sensible choice but to ensure that America maintains superior and overwhelming capabilities, while maintaining our prohibition on the development and use of bioweapons.
- ▶ China is investing heavily in gene editing, bionic robots, human-machine teaming, and biomanufacturing, and it is targeting these technologies for military applications. To accelerate its progress, it has collapsed the barriers between civilian and defense research." (NSCEB, 4/2025).

The 49 recommendations of NSCEB cover six pillars (number of recommendations in brackets) such as:

1. "Prioritize Biotechnology at the National Level (3)
2. Mobilize the Private Sector to Get U.S. Products to Scale (13)
3. Maximize the Benefits of Biotechnology for Defense (10)
4. Out-Innovate Our Strategic Competitors (9)
5. Build the Biotechnology Workforce of the Future (7)
6. Mobilize the Collective Strengths of Our Allies and Partners (7)".

\*The NSCEB (National Security Commission on Emerging Biotechnology) is an independent commission currently comprised of 11 commissioners appointed by a bipartisan group of Members of the House and Senate in the USA. They include four Members of Congress—two from each chamber, and two from each party—and seven prominent industry leaders, academic experts, and former government officials from the defense and intelligence communities.

Some Remarks:

It is important to read these NSCEB recommendations. The Commission urges the U.S. government to make biotechnology a national priority.

The Commission believes that the U.S. has already fallen behind China in the field of gene editing and AI, and that China has emerged as a powerhouse in AI-enabled biotechnology. This is a reality that the U.S. must acknowledge. The Commission therefore calls for a swift response to these highly dynamic new developments.

Well, the proposed recommendations for the peaceful use of biotechnology currently seem unlikely to fall on fertile ground and be implemented immediately due to the erratic, i.e., not regular, certain, or expected behavior of some U.S. administrations. It is very unlikely, for different reasons, that the U.S. will win this “AI-biotech-race” in the next three years.

However, the specific comments on the militarization of biotechnology and developments in the field of “*intelligentized warfare*” using AI in China (Bresnick, S., 6/2024) are very disturbing. It is very likely that the newly renamed Department of War will follow the commission’s recommendations. This would possibly be the open starting signal for a military arms race in the field of AI-supported biotechnology – with unforeseeable consequences.

The current designs are not entirely new, see: (Luvinale, G. and N., 2020; US Department of Defense, 8/2023; Center for Security and Energy Technology, 6/2024; The China Briefing, 4/2025). We know of military applications of this cutting-edge technology in China, Russia, North Korea, and Iran. These countries have the knowledge and capability to develop and employ biological agents if necessary. Nevertheless, although the use of biological weapons spreads fear and terror, it is ultimately useless and absolute nonsense.

- ▶ “Congress must direct the Department of Defense to consult with stakeholders to define principles for ethical use of biotechnology for the U.S. military.”
- ▶ “Biotechnology is also the best defense against bioweapons. The United States does not and will not have an offensive bioweapons program. Other countries do. The best deterrent is to master biotechnology so that the United States can prevent, detect, and respond to any biological event.”

The Commission emphasizes a very essential and absolutely necessary point: the prohibition on the development and use of bioweapons.

Misuse or dual use of biotechnology must not happen, nowhere and under no circumstances!

In 2016, the author published a paper (Kern, M., 2016) titled: “*Global Epidemics, Pandemics, Terrorism: Risk Assessment and European Responses*” and addressed misuse and dual use of synthetic biology. “At the present time there are still no global regulations specifically covering synthetic biology or designed to mitigate any misuse of it, particularly by non-institutional experimenters (Carter *et al.*, 2014). There is only self-regulation in connection

with culture of individuals and corporate responsibility. The essential issue in this century of bioeconomy is to regulate and monitor “synthetic biology” in such a way that society is not deprived of the positive potential of this technology.”

As stated in the plenary closing lecture titled: “Entomology for the Third Millennium – Scientific and Technological Challenges” held at the XXI International Congress of Entomology, August 20-26, 2000, Foz do Iguassu, Brazil, it is necessary to reiterate today: We bear the responsibility of ensuring that small changes to the gigantic biological manuscript, the fundamental genetic code of life, do not become a “double-edged sword”, that threatens people, social stability, and the planet (Kern, M., 2000). Governments and scientists have the responsibility to establish guidelines and regulations to guarantee that gene editing is used ethical and responsibly – any misuse or unethical application must be prevented or excluded.

## 12. CONCLUSIONS

Evolution takes place by billions of new combinations of A and T and C and G, which on one side should be protected by man and on the other side, can or must be used (2018c).

The use of modern biotechnology methods raises complex questions relevant for humans, societies and ecosystems – today and in future. An adequate authorization or regulation of ‘synthetic biology’ of plants/crops in time will be necessary so that societies do not lose the positive and essential potential.

Last, but not least, we need a spiritual guide:

- ▶ “The world needs people looking ahead and not reacting superficially, who are inspired and not only about what is feasible, but who think long term for future generations of which we have only borrowed the present.
- ▶ The world needs people who are empowered by a vision, inspired by ethical considerations and possess the courage to look beyond the box.
- ▶ The world needs people who make accountable and responsible decisions, although there are discontinuity, instability, uncertainty, incalculability and unpredictability in order to avoid chaos, anxiety and to safeguard a positive future.”

As a take home message let me reiterate: “As for the future, your task is not to foresee, but to enable it” (The Wisdom of the Sands, Saint-Exupery, 1948).

**Well, let us share the following vision:** “To understand the dialogue of genes and develop it further – to decipher, marvel it and understand nature’s primary language, to add to it with a sense of responsibility and to make use of it in an ethically acceptable way, for without genes there can be no

seeing, speaking, hearing, feeling or smelling – there can be no language, no communication, no dialogue, no art, no ethics, no morality – and no agriculture, no life. To use the primary language of Nature, or: How can we find the way from the secrets of life to ethically acceptable innovations for the future?”

In considering and doing all this, we must integrate different scientific fields, including molecular biology, ancient DNA archaeology, genetics, plant breeding, computer science, computer modelling, engineering, gene editing, biometrics, bioinformatics, systems biology, and artificial intelligence so that genomics-assisted breeding can improve crop quality. Finally, suitable cultivars must be provided to farmers and producers – in time!

Farmers, scientists, politicians, the public at large, and young people especially should be encouraged to be optimistic and to go for and improve the DNA-*evolution* of agriculture to add value to agriculture, for the betterment of societies and to enable a peaceful life on earth.

### 13. APPENDIX

The author is fascinated by life on earth, by the life sciences and technologies, and would like to share his enthusiasm with every reader with this floral tribute from the bottom of his heart. It is intended to radiate beauty and tranquility, bring joy and confidence, broaden horizons, and inspire new ethically grounded innovations and new visions—for the people who live on earth today and in the future.



**FIG. 1.1:** Watercolor by *Dr. Birgit Sewekow*: “Flower Greetings from Earth via the International Space Station ISS” - Linking Nature, Sciences, Ethics, and Arts, 2008

The watercolor was created in 2008 on behalf of Dr. Manfred Kern. It is the fourth painting in a series intended to characterize the development of humankind and its growing scientific understanding and utilization of natural resources and processes, including technical implementation:

1. **Giuseppe Archimboldo:** In a still life-like manner, he composes works from fruits, plants, animals, and man-made heads and figures - a reaction to the decline of the Renaissance and the emerging scientific view (Mannerism, 1563), humans live off plants/animals
2. **Depiction of a bull composed of fruit and plants (1999)** - use of plants as animal feed and reference to the increase in animal production in the 20th century.
3. **Depiction of a car filled with plants as renewable raw materials (200)** - use of plants as energy crops for machines (transport and traffic) in the 21st century.
4. **The International Space Station (ISS)**, a masterpiece of technology, science, and organization, is a carrier for flowers. As noble, delicate beauties and conveyors of joyful color diversity, they are sent into space as a transnational greeting.

## **Watercolor Data (see Appendix 1)**

- ▶ Catalog of works WVZ 2262
- ▶ Size: 56x76 cm
- ▶ Technique: Pen and ink drawing/watercolor
- ▶ Year of creation: 2008
- ▶ Signature lower left: B. Sewekow 2008.

## **Idea Behind the Watercolor**

As an international research station, the ISS offers teams from all continents space for current and future project work in a wide variety of scientific fields. This fruitful international collaboration is a unique example of successful large-scale international research stations (such as CERN). This is reflected in both the selection and arrangement of the flowers on the ISS:

- ▶ All six continents were considered: Europe, America, Asia, Africa, Australia, and Antarctica
- ▶ Four flowers that are as typical as possible were selected for each continent, whether they are native to the area or have been cultivated there.
- ▶ The rose, a particularly noble cultivated flower of great beauty, is assigned to each continent.

## **Description of the Watercolor**

The space station has six wings covered with solar cells (see Appendix 2). These are numbered and serve as the location for the selected flower varieties. The connecting elements and the space station itself, regardless of continent, serve as support for the plants, which are intended to emphasize connection and stability.

## **Plant Assignment**

- ▶ Europe: 1. Tulips, 2. Roses, 3. Poppies, 4. Daffodils
- ▶ America: 1. Dahlias, 2. Sunflowers, 3. Roses, 4. Amaryllis
- ▶ Asia: 1. Roses, 2. Carnations, 3. Lotus, 4. Hydrangeas
- ▶ Africa: African violets, 2. Strelitzia, 3. Roses, 4. Gerberas
- ▶ Australia: 1./2. Orchids, 3./4. Roses (almost hidden).



### ***Plant Classification***

- ▶ Europe: 1. Tulips, 2. Roses, 3. Poppies, 4. Daffodils
- ▶ America: 1. Dahlias, 2. Sunflowers, 3. Roses, 4. Amaryllis
- ▶ Asia: 1. Roses, 2. Carnations, 3. Lotus, 4. Hydrangeas
- ▶ Africa: African violets, 2. Strelitzia, 3. Roses, 4. Gerberas
- ▶ Australia: 1./2. Orchids, 3./4. Roses (almost hidden)
- ▶ Antarctica: Apart from one species of carnation, there are practically no flowering plants. (Imported) orchids are depicted.
- ▶ Connecting element: decorated with pumpkins.
- ▶ Actual space station: covered with laburnum, delphinium, and pumpkin.
- ▶ Colors: The choice of colors and arrangement of flowers reflect a selected color rhythm. In the case of roses, it was possible to take advantage of the new breed (first created using genetic engineering) of the blue species (2008).

***Dr. Birgit Sewekow***

## **14. REMARKS**

Generative AI statement: The author declares that no Generative AI was used in the creation of this manuscript. Opinions expressed in this contribution are those of the author.

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