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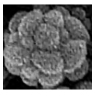
Vision Paper

A Critical Overview on Reviews about Micro- and Nanoplastics, 2025/2050: The Invisible and Neglected Epidemic Pollution That Threatens Food Security and Safety, the Environment, and Human Health

Dr. Manfred J. Kern, Director, AgriExcellence e.K.

55296 Lörzweiler, Germany

Manfred.Kern@agriexcellence.de



100nm

Symbol of Nanoplastics

Introduction:

We all live in the 'Plasticene', an era in Earth's history, within the Anthropocene, since 1950s. (A plasticene Lexicon, Haram, L.E. et al., 2020).

In future there will be evidence that plastic waste will show up globally in sedimentary records (Skinner, C., 2019). We are living in the 'Plastic Waste Age!' (Kern, M., 2024).

Plastics, microplastics, and nanoplastics are potentially everywhere in the world.

Plastic market will grow from $US 457.7 billion in 2022 to $US 643,4 billion by 2029 worldwide (Gitnux Marketing Report, 2024).

Plastic production will triple worldwide by 2060 (OECD, 2022).

Plastic waste is also projected to almost triple by 2060 (OECD, 2022).

Plastic waste (34%) is generated in high-income countries, which account for only 16% of the world's population (Karlsson, T. et al., 3/2023).

Plastic pollution worldwide: 50% unbranded, 50% branded items, top 5 brands accounting for 24% of plastic pollution, 56 companies accounting for more than 50% (Cowger, W. et al., 4/2024).

Plastic provides 1.2 million jobs in plastic production, 5.1 million in plastic manufacturing and 11.4 million in plastic waste pickers worldwide (Worthington, H., and Gambarin, A., 4/2024).

Plastic technologies can save lives but also pose invisible threats to the environment and human health. For example, specific nanoplastic particles are versatile tools in nanomedicine (Saha, S. et al., 3/2024).

Overfilled garbage can, plastic waste, Safaga, Egypt (Kern, 5/2023)

Shortly before Easter: Overfilled garbage can, plastic waste, Domplatz, Mainz, Germany (Kern, 27.03.2024)

Plastic, microplastics and nanoplastics pollution is inextricably linked to food safety, human health, and climate change. They are an invisible, insidious, underestimated, and neglected threat to humans and the environment.

Plastic, microplastics and nanoplastics: microplastics (MPs), (1 µm to 5 mm); nanoplastics (NPs); (1 nm to 1 µm); exist in various forms and are based on fossil fuels (14% of global oil production); in 2020, over 367 million tons were produced worldwide; total global production of plastics reached 8. 3 billion tons; 6.3 billion tons are plastic waste; another 34 billion tons are predicted by 2050; 12 billion tons of this will be plastic waste; 1 kg of plastic generates 4.2 kg of CO_2 during its lifetime (Ashworth, J., 7/2022); the majority of plastic pollution comes from packaging materials, construction materials, household waste, medical waste, sports equipment, fishing gear, car parts, electronic devices and agribusiness components (Ekner-Grzyb et al., 10/2022); they are degraded by thermal, photo- and oxidative processes, by hydrolysis and by microorganisms; they are persistent and take an estimated 250-1000 years to fully degrade; 6% are recycled; 19% are incinerated and further contribute to global CO_2 emissions; most plastics end up in landfills or in the environment - in oceans, rivers, at both poles of the earth, on mountain tops, in snow, in soils, gardens and fields.

A:

Literature Recherche (3/2022 - 4/2024)

For this critical overview, peer-reviewed scientific paper, books, overviews, mini-reviews, reviews, and critical reviews were thoroughly studied. The focus of this critical overview is on impacts of MPs and NPs on plants/crops, agriculture, and food security/safety.

- Period: **March 1, 2022 - April 1, 2024**
- Number of articles reviewed: **222**
- Number of reviews studied: **70 (2020: 4; 2021: 7; 2022: 17; 2023: 32; 2024: 10)**

Key Findings from a 'google' Literature Recherche, 3/2023:

1. **Plants/Crops**: a hidden and unknown biological hazard (Pathan, S.I., et al., 9/2020); affect crops (Jiang, M. et al., 12/2022); are a threat to plants (Dang, F. et al., 10/2022); cause an oxidative reaction (Ekner-Grzyb, A. et al., 10/2022); induce oxidative stress and impair plant growth (Singh, N. et al., 4/2023); inhibit photosynthesis (Li, Y. et al., 11/2021; Zhou, P. et al., 12/2022); toxic to plants (Wang, F. et al., 10/2022); accumulates on plant grains (Jiang, M. et al., 9/2022); accumulates on roots (Dume, I., 3/2022); leads to an impairment of crop yields (Gao, H. et al., 11/2022); accumulation in crops, fruits and vegetables (Conti, G.O. et al., 5/2020; Campanale, C., et al., 1/2022; Ya-di, Z. et al., 5/2022; Kadac-Czapska, K. et al., 10/2022; Gerretsen, I., 1/2023); has negative effects on plant-pollinator interactions and pollination biology (Shah, S. et al., 4/2023); they pass into bee brood and are incorporated into honey and wax (Alma, A.M. et al., 1/2023); microplastics in the air accumulate in bees, which act as "bioindicators" (Kelly, M., 5/2021); they affect the growth, production and quality of seeds (Spano, C. et al., 2/2022); they reduce seed germination (Haseena, S. et al., 1/2021; Srividya, A. et al, 3/2023); delay seed germination, reduce transpiration, reduce biomass and plant production (Okeke, E.S. et al., 2/2023); reduction in seed vigor and relative root elongation (Li, T. et al., 10/2022); decrease in gene expression in plants (Lozano, Y.M. et al., 11/2022); risks to biota (Azeen, I. et al., 2/2022; Gao, M. et al., 2/2023; Maddela, N.R. et al., 2/2023); immediate concerns (Roy, T. et al., 10/2022).

2. **Agriculture**: changing agricultural crops (Cat, L.A., 5/2019); new environmental pollutants in agriculture (eip-agri, European Union, 3/2022); global concentrations of microplastics in soil < 13000 items/kg dry soil and 4.5 mg/kg dry soil (Büks, F. and Kaupenjohann, M., 12/2020); contamination of agricultural soils (Sa'adu, I. and Farsang, A. 2/2023); "White Revolution" becomes "White Pollution"; new environmental pollutants in agriculture (Lwanga, E.H., 3/2022; Briassoulis, D., 9/2023; Hofmann, T., 9/2023); devastation of our agricultural system (Okeke, E.S. et al., 2/2023); worrisome factor in agriculture (Mishra, B.K., 7/2022); risk to organic farming products (Kafel, P., 3/2022); find their way into our fruits and vegetables (Oliveri Conti, G. et al, 5/2020; Gerretsen, I., 1/2023; Zhou, P. et al, 1/2023); are environmental problems in agriculture (Sa'adu, I. and Farsang, A. 2/2023); a vector for contaminants of concern (Stapleton, M.J. and Hai, F.I., 1/2023); infiltrating food (Gerretsen, I., 1/2023); growing concern about food production

(Correa, T.R. et al., 11/2023); emerging threat to food safety (De-la-Torre, G. E., 5/2022; Okeke, E.S. et al., 2/2023); undermining food safety (Jones, D. L., 10/2022; Walker, L., 10/2022); emerging food contaminants as a challenge to food safety (European Commission, 1/2022; Rubio-Armendariz, C., 1/2022; Sun, L. et al., 2023); call to action (FAO, 2021; FAO, 2022).

3. **Animals/Humans**: EFSA: "Too early" to say they pose a food safety risk (Borrows, D., 2016); daily intake by humans unknown (Cox, K.D. et al. 6/2019); absorption (Joksimovic, N. et al., 10/2022); contamination (Kim, Y.N. et al., 4/2020; He, Y. et al., 10/2021); entry into the human body (Cirino, E., 2/2022); may cause asthma, cardiac disease, allergies (Prata, J.C., 2018); found in human blood (Ho, S., 2018); cause oxidative stress, could cause immune homeostasis imbalance (Feng, Y. et al., 2/2023); increase nutritional risk (Sun, X.-D. et al., 6/2020); is a future health risk (Scheiben, D., 1/2023; FAO, 2023); an invisible threat to humans (Joksimovic, N. et al., 10/2022); an emerging threat to human health (Ghosh, S. et al., 7/2023); "damages" human organs (Ali, N. et al., 1/2024); may be fueling a dramatic rise in bowel diseases (Yan, Z. et l., 2022); potential risk factor for heart attack, stroke or death (Marfella, R. et al., 3/2024); may play a role in Parkinson's disease (Liu, Z., 2023); have negative impact on human forebrain organoid development (Hua, T. et al., 4/2022); impairs vital functions (Sarkar, A., 9/2022); causes metabolic disorders, triggers DNA damage (Li, Y. et al., 8/2023); migrates into the human placenta (Carrington, D., 2/2024); bottle-fed infants ingest >0.66 million microplastics per year (Su, Y. et al., 11/2021); 0.016 mg/kg/d MPs lead to abnormal male sperm quality in rats (Zhang, C. et al, 4/2022); transferred between cells during cell division of cancer cells (Brynzk-Schneider, E. at al., 2/2024); transgenerational toxicity in mice and rats, threat to fertility in mammals of both sexes (He, Y. and Yin, R., 6/2023); may significantly impair and jeopardize male fertility (D'Angelo, S. and Meccariello, R., 3/2021); poses an immediate challenge to human reproductive health (Yang, S. et al., 7/2023); may also affect your dogs and cats (Gantt, E., 6/2022).

B:

Reviewing Reviews – A Critical Overview

Reviews inform, evaluate, summarize, and bring together existing studies in a specific area. A review (review paper, systematic review) compares, contrasts, and provides decision-makers, and the general public with scientifically sound information. This is the main intention of this overview of selected editorials:

B1:

Okeke, E.S., et al., 11/2022, Panacea for the nanoplastics wave in Africa: a review of the state of the art:

- Number of articles reviewed: 241.
- Review of impacts, consumption, and remediation strategies for NPs in a holistic manner.
- Focus on pollution of marine ecosystems by MPs and NPs.
- Describe the threat of plastic, MP, and NP pollution to all life forms.
- Explain the paradigm shift from MPs to NPs in Africa.
- Explain the problems of dealing with pollution from NPs.

- “Plastic is a valuable resource (ease to use, long durability, thin weight, flexibility, and affordability), yet it is also an unwanted and unsustainable waste of a particular resource.
- Plastic consumption in 54 African countries is estimated at approximately 19.7 Mt.
- Beside plastic imports from Europe and Asia, most African countries have substantial plastic processing and production activities using imported primary polymers.

- The indiscriminate introduction, circulation and poor handling of plastic products result in serious pollution.
- In certain African countries, anti-plastic pollution laws, regulations, or policies do not exist.
- In countries where regulatory laws already exist, their implementation and enforcement are woefully ineffective.
- Corruptibility of waste management enforcement authorities corrodes citizens' desire to obey waste disposal legislation.
- New rules and regulations are essential to control the utilization of plastic products and NPs.
- Although Africa has been quickly developing and consuming enormous volumes of plastic products as part of its economic development, no viable plastic waste management procedures exist.
- For effective control of plastic wastes, the entire populace must be adequately involved as this gives them a sense of belonging and to be committed to the successful implementation of plastic waste legislation. Educating the public is essential to attain environmental buy-in. Public awareness of plastic pollution must be established. Authors strongly recommend that plastic education and awareness be included in school curricula across Africa's educational system.
- Studies on the elimination of NPs are still an emerging field of rapidly evolving research. NPs pollution research e.g. long-term data for monitoring, risk assessments, or successful implementation options in Africa is severely hampered by a lack of scientific facilities, limiting research activities to options for external collaborations.
- Research on effects of NPs on terrestrial and atmospheric habitats is sparse, relevant research is required in all ecosystems."

The "state of the art report" by this international group of scientists from Nigeria, China and Kenya is a "beacon" in the field of plastics, MP and NP, not only for Africa but for the whole world. In fact, African countries are seriously suffering from macroplastic pollution, and the problem is getting worse.

Macroplastics and microplastics evolve differently as per capita income increases (OECD, 2022) Macroplastics are a key problem for low-income people and countries, while microplastics play a greater role in high-income countries. Worldwide, microplastic pollution will increase from 2.7 to 5.8 million tons (OECD, 2022).

However, the future-oriented and forward-looking group has taken a holistic view of nanoplastics, which will increase disproportionately in Africa and everywhere in the coming decades. They focus mainly on the impact of macroplastics, MP, and NP on marine ecosystems and call for closing the gap in the terrestrial and atmospheric ecosystems. The authors do not address relevant impacts on the food chain, healthy diets and human health.

They also write that they want to close the gap in the area of international know-how transfer and cooperation. This has been a persistent problem in all African countries for centuries and exists in so many areas. Knowledge transfer and capacity building are essential to improve living conditions in these countries, as described by Kern, M. (2001, 2014, 2019).

Very important are the recommendations to develop and implement efficient and effective regulations for plastics, MPs and NPs. Creating awareness and public engagement are important prerequisites for tackling problems. Last, but not least, education on plastic reduction and management should be included in school curricula everywhere. This is in line with the examples listed by the author at the end of this paper under "Outlook".

Assuming, that the quantity and heterogeneity of MP and NP will increase dramatically in the coming years and decades despite all efforts, reliable and robust methods and structures should be established to determine the accumulation rates of these plastic structures in ecosystems, water, soil, plants, animals, food, humans, and the atmosphere. This should be done without delay to prevent early, fatal, or sub-lethal damage and socio-economic losses. The establishment of an MP/NP pollution alert system based on risk assessments would be appropriate.

B2:

Sun, Y. et al., (8/2022), Key findings: Bibliomertrics is the quantitative analysis of patterns in scientific literature to review a field of research and analyze its emerging trends, scientometric reviews are more specific, comprehensive, and objective:

- Time range of the articles analyzed: **January 1, 2000 - December 31, 2021**
- Number of articles analyzed: **435**.
- The first paper on the health risk of MP in soil was published in 2009.
- Most studies on the response of plants to MP in soil are short-term experiments in pots.
- Emerging MP pose a serious risk to the environment as they disrupt ecological balance and biodiversity.
- MP are adsorbents for other toxic pollutants.
- There are few studies on the risk analysis of MP in soil for human health.
- There are virtually no long-term experiments on chronic reactions of MP in soils, microorganisms, plants, and humans.
- The massive emission and accumulation of MP can lead to varying degrees of destruction of the soil-plant, soil-human and soil-microbe systems.
- Newly occurring MP can remain in the soil for decades and pose a serious threat to the environment by destroying the ecological balance and biodiversity.
- The emission of MP will increase in the future.
- Non-biodegradable substances will gradually be phased out.
- The pollution of soils by many MPs is mainly due to inadequate planning and policies for plastic waste management.
- China is currently a leader in the field of MP research.

There is an urgent need that long-term experiments on acute and chronic reactions of MPs and NPs in soils, microorganisms, plants, animals, and humans are realized in order, based on scientific data, to be able to carry out appropriate life cycle and risk assessments.

B3:

Allen, S. et al., (6/2022): Micro(nano)plastics source, fate, and effects: What we know after ten years of research, **(January 1,2012 – December 31, 2021),** Key findings:

- "*Historically, while researchers recognized that most plastic pollution was derived from land-based sources, it was generally believed that microplastic particles (i.e., plastic fragments <5 mm) was only a marine pollution issue with effects largely impacting marine biota.*
- *However, over the last decade MNP research has progressed rapidly with recent discoveries of MNPs in freshwater, snow, ice, soil, terrestrial biota, air and even found in ocean spray. MNPs have now been found in every environmental compartment on earth, within tissues and gastrointestinal tracts of thousands of species, including humans, resulting in harmful effects.*
- *General plastic pollution publications have increased from ∼200 papers per year at the beginning of the decade to >2000 publications per year in 2021.*
- *Microplastic publications have similarly risen from 2000 in 2021.*
- *Nanoplastic research (≤12%) has been lower in overall publication rate but follows the same increasing publication trend.*
- *Atmospheric and soil related research has only really gained significant ground since 2018/2019, after the early remote area and atmospheric transport research was published*

demonstrating the borderless nature of atmospheric plastic pollution and the ubiquitous (beyond agriculture and roads) pollution of soils.

- *The last decade has seen rapid increases in macro to nano plastic environmental and human pollution research, and this research is continuing to advance.*
- *Recent soil research has established that MNP are present throughout the soil structure, can be seen in the soil archives (soils, sediment, and peat), telling a story of plastic pollution through the last 60 years, and form plasticglomerates.*
- *Soils are estimated to contain 4 to 23 times the MNP quantity of the oceans and are one of the direct pathways of MNP into the food web.*
- *Soils have been identified as a source of plastic to the atmosphere through wind erosion and to groundwater through infiltration.*
- *Soils also function as a transport pathway and (temporary) sink for MNP.*
- *MNP exposure assessments of soil fauna illustrate, altered biomes, reduced mobility, reduced reproduction, oxidative stress and metabolic malfunction, or increased motility.*
- *The extent of soil MNP pollution, its short- and long-term impact are relatively unknown."*

B4:

Bethanis, J. and Golia, E.E. (2/2024), Key findings: Bibliometric analysis of various types of plastics in several grain- crops and fruits and vegetables:

- Period of articles analyzed: **2020-2022.**
- Number of articles analyzed: **81**.
- Most articles come from China (71%), while only 5% come from Germany.
- Exposure to micro- or nanoplastics significantly affects root and shoot growth.
- Lettuce appears to be the most sensitive plant, while wheat is the most resistant.
- Rice and maize show negative effects to a lesser extent.
- In any case, the accumulation of MP affects the health and functionality of soils and exposes plants, and therefore humans, to a serious risk that can spread through the food chain.
- However, the current state of knowledge does not provide a solid basis for assessing and characterizing the nutritional risk posed by MP in the food chain.
- Only 4.5% of the experiments were conducted under field conditions.
- Considering that different plants react differently to MP exposure, the current data is insufficient for many plant species.

Lwanga, E.H. et al. (2017) presented the first field study showing that microplastics can enter the terrestrial food chain. They were able to show that microplastics were transferred from the soil (0.87 particles/g) via earthworm carts (14.8 particles/g) to chicken stomachs (10.2 particles/g) and chicken droppings (129.8 particles/g). Chicken is a traditional dish in Mexico. The authors calculated a possible annual intake of 840 plastic particles per person.

In early 2023, Horky, P. et al. at the Faculty of Agriculture of Mendel University and the Czech Academy of Sciences in Brno, Czech Republic (Stephens, J., 4/2023), started a project (2023-2025) entitled "Development of an analytical platform for monitoring the microplastic cycle in agricultural production". The aim of the project is to develop a unique detection platform (microfluidic chip) for micro/nanoplastics in agricultural products, soils, crops (wheat) and animals (chickens). The authors are also considering applications in human tissue.

The research results are in progress.

B5:

Maddela, N.R. et al., 2/2023, Several adverse effects of MNPs on plant functionalities have been reported:

For instance,

- A reduction in the root length, the fresh weight of the plant and chlorophyll content (Sun, X.-D. et al., 2020).
- Decrement in shoot/root ratio (Lian, J. et al., 2020).
- Induction of genetic changes (Lian, J. et al., 2022).
- Reduction in seed setting and root/shoot ratio (Qi, Y. et al., 2018).
- Altered metabolic pathways (Wu, X. et al., 2020).
- Decrement in seed germination rate (Bosker, T. et al., 2019).
- Reduction in dry biomass and plant height (Lian, J. et al., 2021).
- Reduction in the photosynthetic metabolism of leaves, and interference in the mineral nutrition metabolism in the roots, stems, and leaves (Fu, Q. et al., 2022).

Importantly,

- MNPs can also exhibit indirect negative effects on plant growth and performance by altering the soil's physical/chemical properties (Kim, S.W. et al., 2020).
- Negative impacts on soil microbiome (Wang, F. et al., 2022) and invertebrates (Wang, Q. et al., 2022).
- An essential factor in inducing different phytotoxicities (Sun, X. -D. et al., 2020).
- Conversely, the negatively charged NPs of PS showed a higher accumulation in the apoplast and xylem.
- Can significantly alter the gene expression pattern in a tissue-specific manner in *Triticum aestivum* L. (Sun, X.-D. et al., 2020).
- When together with co-pollutants, the phytotoxicities are even worse.
- Cause variable effects on the biometrical, biochemical, and physiological properties, including cytotoxic and genotoxic effects, depending on the physical/chemical properties of particles, plant species, and the exposure time (Wang, F. et al., 2023).

Singh, A. et al. (2021) as well as (Beniwal, J. et al, 7/2023) published that phenotyping of plant stress and bridging the gap between genotypes, phenotypes and the environment is essential for selecting stress-resistant varieties and enabling better stress management strategies in crop production. The increasing possibilities of machine learning (ML) methods in combination with image-based phenotyping can provide new insights into plants and stress factors. This can help to safeguard crop yields and ensure food security. Plants are stressed by biotic (pathogens, insects, pests, and weeds) and abiotic (temperature stress, nutrient deficiency, salinity, flooding, drought, toxicity, herbicides) factors. Unfortunately, the authors did not consider abiotic stress factors such as MPs and NPs. This will be necessary to make future crops, fruits, and vegetables more resistant to these new stress triggers.

C:

C1:

Kern, M. (3/2023-4/2024): Some Characteristics of the Abiotic Stressors Microplastics/Nanoplastics:

- Man made
- Production began in the 1940s
- Mainly based on fossil oil
- No uniform materiality or composition
- More than 10,000 chemicals are used in the production of plastics (Wiesinger, H. et al., 2021)
- Over 2,400 substances are classified as potentially hazardous (persistence, bioaccumulation, toxicity, health hazards) (Wiesinger, H. et al., 2021)

- 6 main types (PS, PE, PP, PVC, PET, PA), for characterization see Kung, H-C. et al. (1/2023)
- Wide range of variation (concentration, size, shape, surface changes, accumulation, vectors for co-pollutants/pollutants)
- Permanent restructuring, dynamic changes
- Contribution to global CO_2 emissions (Karali, N. et al., 4/2024)
- Sources are: Packaging materials, construction materials, household medical waste and sports equipment, fishing equipment, automotive parts, electronic equipment, agribusiness
- Transport to and within all ecosystems (horizontal/vertical) by wind (Prata, J.C., 2018), rain, irrigation, solar radiation, climate, trade, agricultural practices
- Unevenly distributed across the world and do not stop at borders
- Possible effects on cloud formation processes (Aeschlimann, M. et al., 2022)
- One third of all plastics produced end up in the soil
- Between 1.5 and 6.6 million tons of microplastics are found in the world's agricultural soils (Kedzierski, M. et al., 4/2023)
- Soil is a reservoir for micro-/nanoplastics (Sajjad, M. et al., 2/2022)
- Arable soils are taken up by roots and transferred to food crops, posing a significant threat to the terrestrial food chain
- They can enter terrestrial food webs, e.g. from soil via earthworms to chickens (Lwanga, E.H. et al., 2017)
- They serve as vectors for other pollutants, e.g. for antimicrobial substances (Ullah, R. et al., 8/2021)
- Increased transport of the COVID-19 virus
- Are hidden and unknown biohazards
- Pollution of groundwater (Moeck, C. et al., 12/2022)
- Reduce the proportional biomass of earthworms in agricultural soils by 50 % and increase mortality by 30 % (Balos et al., 4/2024)
- Represent about 0.07% of the 4900 MT of plastics discarded between 1950 and 2015 (Geyer, R. et al, 2017)
- Between 31,000 and 42,000 tons of MP are applied to European soils annually (Lofty, J. et al., 2022)
- Persistent, long shelf life, decomposition of 20 to 600 years
- Cumulative
- Accumulation in crops, fruit, vegetables (Silva, G.C. et al., 7/2021) and animals
- Field trials on yield reduction are not available
- Impairment of interactions between plants and pollinators
- Damage to agricultural systems
- Undermining of food and nutrition security
- New threats to human and children's health
- Multifunctional
- Cytotoxic, genotoxic
- Endocrine-disruptor, mimic natural hormones ((Borriello, L. et al., 11/2023)
- Toxicity is related to particle size - ‘The smaller the particle size, the greater the toxicity‘ (nanoplastics more toxic than microplastics)
- In Germany (2014-2017), 97% to 100% of blood and urine samples from 2,500 children aged 3 to 17 years showed plastic toxicity (Ho, S., 10/2019)
- Potential risk during pregnancy in animals (Ragusa, A. et al., 9/2022; Wang, M. et al., 3/2023)
- Risk to human fertility
- Causes DNA damage
- In mice and rats, metabolic disorders, reproductive disorders, immune system disorders, neurological development and cognitive abilities were found in the surviving offspring, and

these events were directly related to the intergenerational transfer of MP and NP (He, Y. and Yin, R., 6/2023)
- Potential trigger for Parkinson's disease and related dementias (Liu, Z. et al., 11/2023)
- The induction of fibriosis in wildlife, a new pathology "plasticity" (Charlton-Howard, H.S. et al., 2/2023)
- The role of M-NPL in vivo is poorly understood due to lack of clinical and epidemiologic studies (Khan, A. and Jia, Z., 2/2023)
- More or less all 17 UN-SDGs are undermined
- Actually, 3/2024: a "tip of the iceberg" - a "Trojan horse" (Yu, Q. et al., 5/2023)
- An invisible and neglected epidemic/pandemic pollution - a new abiotic threat
- Threats vary from country to country
- It is very likely that the peak of release of toxic substances from the sum of all micro/nanoplastic materials present in the environment on earth will not be reached (Rillig, M.C. et al., 2/2021)
- Forecasted plastic production: 450 million tons (2021) to >1200 million tons (2050), China produces 32% of global production (OECD, 2022)
- Forecast by 2060: tripling of plastic waste to >1000 million tons
- Forecast by 2050: Microplastics - "exponential" growth
- Forecast by 2050: nanoplastics - probably "hyper-exponential" growth
- Technically inadequately managed and not efficiently regulated
- Nowhere is there a master plan to solve the problem
- Low public awareness

Food Security and Food Safety

It must be considered:
- "That between 2015 and 2050, more than doubling of crop production, an approximate doubling of meat production, a tripling of plant protein production (food and feed) and a tripling of fruit and vegetable production will be necessary to feed 9.7 billion people on earth in a healthy way."
- "That climate change and other "black swans" will make agriculture increasingly volatile Kern, M., 2010, 2012, 2016a, b, 2018a)."

Since 1996, the author has published more than 30 papers, a lead paper outlining the global food security challenge 2025/2050. An expanded lead paper was presented in 2012 entitled: "Food Security at the Crossroads (Anno 1864, 1894, 1924, 1954, 1984, 2014, 2044, 2074) - A Wake up Call." In 2023, "food security" is not just a global challenge - it is a catastrophe - a real but not necessary catastrophe - a global failure of humanity - and the catastrophe is getting worse!
With an additional 40 billion US dollars per year, a world without hunger by 2030 would be possible, but there is a lack of political courage and commitment.
More than 1.1 billion people will suffer from food insecurity and hunger in the coming years, caused by conflicts and wars in Ukraine, Israel, Palestine, North Africa, South Sudan, Yemen, Iran, North Korea, etc. Regarding the future of agriculture in 2025/2050, some headlines of vision papers and opening lectures summarize the priorities for further improvements in sustainable agriculture and food and nutrition security.

- "Global Food Security / Nutrition Security 2025/2050: Impact of Pollinator Services in Agriculture", 2016 (Kern, M., 2018a),
- "Changing Horizons: Renewable Energy for a "*Fossil-Fuel-Free Farming*" – Vision 2025/2050", presented during the International Conference on Innovative Technologies and Sustainable agriculture at the Raja Balwant Singh Engineering Technical Campus, Bichpuri, Agra (U.P.), India, February 26-28, 2018 (Kern, M., 2018b),

- “Challenges of Sustainable Bio-Economy: De-Materialization, De-Carbonization, Re-Cycling and Re-Arrangement of Resources – Vision 2025/2050”, presented during the International Conference on Sustainable Agriculture, Energy, Environment and Technology (ICSAEET-2018), Maharshi Dayanand University, Rohtak, Haryana, India, February 25-25, 2018 (Kern, M., 2018c),
- “Meat Alternatives (“Plant-Based-Meat”) Will Plow up Agriculture in the Future by 2025/2050!? (Kern, 2021),
- “Catching Cash Cows: Animal-, Plant-, Insect-, Microorganisms-, Cell-, Methane-, Electricity-, Air, and Fraud-Based Protein by 2025/2050!?”, (Kern, M., 10/2020),
- “2025: Global Trends to Improve Human Health – From Basic Food via Functional Food, Personalized Food, and Pharma-Food to Bio-Pharmaca, COVID-19 Vaccines, Pharma-Farming and Personalized Medicine (2006-2022, 2052)”, (Kern, M., 2/2022, drafted Vision paper),
- “Global Trends to Improve Human Health (2022-2052): Plant Molecular Farming and Edible Plant-Based Vaccines”, (Kern, M., 2022).
- “Global Food Trends to Improve Human Health”, (Kern, M., 2023a, b).

It should also be noted that "**soil is more valuable than gold!**" (Kern, M., 2010). We must recognize that soil has a higher value than gold. Unfortunately, the world does not yet appreciate this important fact. For farmers, soil is the source of our food, the future of humanity. But for the urbanized world, soil is just dirt, mud, and no one has a proper understanding of it. Millions of tons of microplastics/nanoplastics have and will pollute our soils in the future. It is to be expected that they will destabilize the most important basis of human life.
Currently, there is no evaluated data on the actual impact of microplastics/nanoplastics on global food security until 2050/2100. There are no short- and long-term field trials showing a significant reduction in fruit and vegetable yields or soil fertility. The international, national, and local socio-economic consequences have not yet been investigated. The effects on global food security cannot be estimated at present. Nevertheless, it can be assumed that negative effects are likely in the future.

Three comprehensive studies on 'Microplastics in human food chains and their impact on food safety' from India (Jadhav, E.B. et al., 11/2021), Indonesia/Bangladesh (Al Mamun, A. et al., 2/2023) and Iran (Saeedi, M., 3/2024) describe in detail the contamination of seafood, foods of plant and animal origin, beverages, food additives and plastic food packaging by microplastics. Microplastics/nanoplastics have the potential to accumulate in food webs and be spread into organisms and human food chains. All authors point to a direct and negative link between microplastics and food safety in a variety of ways. Nevertheless, more dietary exposure assessments, more verified methods for rapid detection techniques and more in-deep research of toxicological mechanisms and clinical/epidemical studies are requested.
Because of the threat to human health posed by microplastics/nanoplastics, it is crucial to ensure food safety from the outset and to control the use of plastics through strict regulations for proper management. Ultimately, the key challenge is how to reduce or eliminate food contamination with microplastics/nanoplastics.

A recent mapping of human intake of microplastics in 109 countries between 1990 and 2018 shows that the minimum daily intake is 100-200 mg/capita/day in East and South Asian countries, <500 mg/capita/day in Egypt and <100 mg/capita/day in Europe, with 57% of non-differentiated plastic particles in food coming mainly from aquatic sources, especially in East and Southeast Asia (Zhao, X. and You, F., 4/2024). The weekly intake of microplastics per capita is equivalent to a hotel or bank account plastic card. Unfortunately, the authors do not address the effects on human health at all. However, they call for global food quality monitoring to limit microplastics dietary intake and its potential health risks.

Well, the threats are more likely to affect water, air, climate change, soil, plants, animals, and ultimately human health. Currently, the increasing, multivariable threats from plastics and microplastics/nanoplastics

are a new, upcoming "*black swan: 2025*" - invisible, insidious, and comparable to e.g. epidemic/pandemic diseases such as Ebola, COVID-19 virus, terrorists, or wars (Kern, M., 2016c, 2023a).
The problem of microplastics/nanoplastics is not well recognized, not well understood and not well managed. Unfortunately, they have exponential growth rates if humanity does not tackle the problems as soon as possible. Nevertheless, there is still hope that these threats will be better managed than the comparisons shown.

C2:

Kern, M. (3/2023-4/2024): A Roadmap for a Microplastics/Nanopastics Research Agenda:

Plants/Crops/Agriculture/Environment/Animal/Human Health

- Global monitoring of distribution and accumulation in all ecosystems
- Country-specific effects on flora and fauna
- Species-specific effects on crops, fruit and vegetables
- Risk analysis in relation to crops, soil, food, animal/human health
- Collateral effects with other biotic and abiotic pollutants
- Effects on the long-term functionality of soil and microbiome
- Impact and optimization of agricultural plastics, "plastic culture" (FAO, 2021; Hofmann, T. et al., 9/2023)
- Effects on horticulture
- Long-term trials, field trials
- Field trials on yield and quality reduction
- Evaluation of the economic impact on plant production
- Specific breeding programs for resistant seeds
- Effects on plant pollinators
- Effects of nanoplastics on the vitality of bee colonies and social insects
- Field trials on the transfer along the terrestrial food chain
- Risk assessment along the food and feed chain
- Short/long-term assessment of the impact on global and local food/feed safety
- Life cycle analysis agriculture, environment, health
- Determination of global, regional, national and personal plastic footprint
- Assessment of chronic reactions to biota
- Analysis of cytotoxic and genotoxic effects in living organisms
- Clinical and epidemic health studies
- Effects on mammalian/human fertility and reproduction (Colegio Brasileiro de Reproducao Animal, 6/2023)
- Analysis of transgenerational translocation in mammals/humans
- Impact on biodiversity
- Effects on climate change
- Impact on the atmosphere
- Impact on all 17 UN SDGs
- Development of solutions to combat the invisible, insidious and neglected threats
- Usability and implementation of "artificial intelligence" and learning machines (Zhang, Y. et al., 1/2023); Withana, P.A. et al., 2024) in agriculture and food value chains
- Development and use of "recyclebots" (robots for plastic recycling), (Aschenbrenner, D. et al., 2023)
- Solutions to overcome mismanagement and combat the criminal trade in plastic waste
- How to mitigate plastic pollution by reducing the amount of plastic produced and marketed (Boriello, L. et al., 11/2023)

- Development and implementation of suitable management plans
- How to replace plastic with alternative material
- How to reduce post-collection environmental losses
- Development of ways to raise awareness to regulate the reduction of plastic pollution
- Improving the scientific basis for policy and regulatory decisions
- How can scientific knowledge be translated into action?
- Communicating the pandemic threat to the general public in simple forms (articles, social media, TV, media campaigns)
- Development of didactic tools for scientists, teachers, schools, universities and media (e.g. webEcoist, "Trashed Planet: Our Global Pollution Hangover", 2010).

C3:

Kern, M. (3/2023-4/2024): A Brief Response to the Activities of National and International Organizations in the Field of Microplastics/Nanoplastics:

1. **OECD: Global Plastics Outlook, Policy Scenarios to 2060 (2022)**

- "*Economic growth and improvements in living standards are the main drivers of plastics use.*
- *The global gross domestic product (GDP) is projected to more than triple between 2019 and 2060, with living standards increasing in all countries, faster in non-OECD countries.*
- *Global plastics use is projected to nearly triple from 2019 levels, driven by economic and population growth by 2060. Projected growth in plastics use varies significantly by region. While OECD countries are projected to double their plastics use, emerging economies are expected to see drastic increases, from a six-fold increase in Sub-Saharan Africa to a triple in Asia. Still, OECD countries are set to remain the largest consumers of plastics on an average per capita basis in 2060.*
- *Half of all plastic waste generated is still being landfilled and less than a fifth recycled. Improvements in waste management partially mitigate increases in the amount of mismanaged waste, which however still nearly doubles.*
- *Meanwhile, microplastic leakage seems to follow a different trajectory: it keeps increasing in all countries and it is projected to more than double in absolute weight between 2019 and 2060.*
- *Interventions to address emissions of microplastics (e.g. from tyre abrasion) are generally less advanced, as this form of leakage has not yet received the same level of scrutiny as macroplastics, it occurs all along the lifecycle of products, the cost-effectiveness of mitigation interventions is not yet fully understood, and policy action remains limited currently.*
- *Even though some saturation occurs at higher levels of income, OECD countries are expected to continue to contribute to nearly a third of global microplastics leakage.*
- *In the absence of significantly more stringent, ambitious, and coordinated action, the global community is far from achieving its long-term objective of ending plastic pollution.*
- *More urgent and stringent policies would therefore further slowdown the build-up of plastics in the environment, while clean-up efforts will be required for the plastics that are already present in the environment.*
- *In the absence of new policies, the entire lifecycle of primary plastics is set to continue to contribute in significant ways to increased greenhouse gas (GHG) emissions.*
- *Furthermore, capacity development and technology transfer will also be needed to support rapidly developing countries in improving their waste management systems.*
- *A substantial share of the costs of these policies is in the investment required in waste management systems. In the Regional Action policy package, these amount to USD 320 bn*

globally. In OECD countries, the bulk of investments mainly go towards improvements of recycling capacities, while non-OECD countries primarily need investments in both recycling and waste mismanagement.
- *Developing economies will face higher costs than the global average.*
- *Co-ordinated and ambitious global efforts can almost eliminate plastic pollution by 2060.*"

This global plastics outlook from the OECD describes the prospects for plastics and microplastics between 2019 and 2060. The basic scenarios presented sound very realistic and open our eyes to the enormous dimensions of the challenges facing humanity around macroplastics and microplastics. The emerging issue of nanoplastics is not mentioned at all. The scenarios for achieving zero plastic pollution by 2060 are well done. However, there is no indication in this roadmap of how likely it is that the necessary measures will be implemented to tackle the exponentially growing plastic problem. The exorbitant challenges are extraordinary in developing countries, especially in sub-Saharan Africa. Global, regional, national, and local cooperation and the willingness of everyone are the cornerstones to tackle these enormous problems and threats to present and future life on our globe.

2. **World Economic Forum: "When It Comes to Decarbonizing Plastics, 2050 Is Closer than It Seems", (2/2023)**

- "*Material circularity provides the majority of carbon emissions abatement potential. By 2050, a reduction of 65% of the emissions generated by European industry today can be achieved, utilizing methods such as reuse and design for recycling as well as mechanical and chemical recycling.*
- *The remaining emissions reduction potential is expected to come from decarbonizing the production of virgin plastic materials themselves. The use of renewable sources of power, as well as green hydrogen, are key factors.*
- *The promise and potential of the 'European Green Deal' executed soundly, is that of a catalyst that can help transition Europe towards circular models that form a competitive advantage in the coming era of scarcity.*
- *Of course, setting targets — especially lofty ones — is easy. This is in even more true if the "bill" is due decades from now, at a time when those who underwrote such commitments will no longer be at the helm.*
- *To avoid the resulting moral hazard, we must continually monitor our progress.*"

The production of plastics is based on more than 95% fossil energy. Replacing this resource is a key factor. Efficient and cost-effective technical alternatives must be developed and implemented in order to achieve the decarbonization of plastics production. This is an important contribution to reducing the impact on climate change.

Nevertheless, there are important questions to be answered: "What will the prices of oil and natural gas be in 2030, 2040 or 2050, and who will have free access to these resources?"

Bioeconomy, decarbonization, reuse and recycling are the order of the day and should be implemented in all production processes. This also applies to agricultural production systems, as Kern, M. (2018c, 2023c) describes: "Challenges of Sustainable Bio-Economy: De-Materialization, De-Carbonization; Re-Cycling and Re-Arrangement of Resources - Vision 2025/2050" and "Climate Resilient Agriculture (2025/2050): Climate Resilient Crops + Fossil Fuel Free Agriculture". These are the prerequisites for the "NEW Millennium Agriculture".

The report of the International Advisory Council on Global Bioeconomy (IACGB) (Dietz, T. et al., 4/2024) emphasizes the central role of the bioeconomy and outlines strategies that improve the resilience of global supply chains very well.

3. **UN Environment Program, UN-Report (2023): Turning off the Tap – How the World Can End Plastic Pollution and Create a Circular Economy**

The latest UN report by the UNEP Environment Program (2023) entitled "Turning off the Tap - How the world can end plastic pollution and create a circular economy" shows models of possible plastic futures for short-lived plastics in 2020 and 2040 under the business-as-usual scenario and under the system change scenario. This report is intended to serve as a compass to inform decision-makers and stakeholders about the entire plastics value chain and the necessary measures.

The key focus is to boost the circular plastic economy.

- "*The vision of a circular, zero-pollution plastics economy is one that eliminates unnecessary production and consumption, avoids negative impacts on ecosystems and human health, keeps products and materials in the economy and safely collects and disposes waste that cannot be economically processed. This results in permanently increasing material circularity, reducing greenhouse gas emissions, and stopping plastic pollution. Achieving this vision requires a fundamental shift to ensure that people responsibly consume, produce, and manage plastic globally. This can be achieved with a system's change. This implies investments in increased recycling capacity (downstream) coupled with incentives to use recycled plastic in new products (upstream) and the manufacture of products (midstream) that are economically recyclable. Furthermore, international action to create a flourishing circular plastics economy globally that benefits all countries. For instance, eliminating the manufacture of a problematic product in one country is less effective if that product can still be exported to a neighboring country.*"

It is claimed that the system change described is feasible. However, the question arises as to whether it is probable or just wishful thinking, a nicely calculated goal, economically interesting data within the circular economy, or just a compass for rough orientation in the future world of plastics. There are no milestones, no timelines for recalculations or when a new position will be established.

In this context, the words of J.W. von Goethe (1795/96) fit very well: "To act is easy, to think is difficult, to act as one thinks is the hardest."

As far as the current UN Sustainable Development Goals are concerned, micro-nanoplastic pollution undermines all 17 UN Sustainable Development Goals. Only under Goal 14, which specifically refers to reducing the impact of plastics on the marine environment. For all other SDGs, there is no specific mention of targets aimed at reducing (micro)plastics or of indicators to measure their reduction (Walker, T.R., 2021).

It is quite clear that humanity does not seem to be approaching the end of the "plastic age". Plastics will play an increasingly important role in human life. The use of plastics brings many social benefits and offers new prospects for further development. Plastics make life easier and better. Unfortunately, past, and present production, use and disposal are by no means sustainable. However, an indiscriminate call to stop sounds very unrealistic and even utopian.

The fourth session of the Intergovernmental Negotiating Committee in Ottawa, Canada, in April 2024 (>2,500 delegates representing 170 members and over 480 observer organizations/lobbyists) failed to achieve a breakthrough in the development of an international legally binding instrument to eliminate plastic pollution. No agreement was reached on limiting plastic production. 15 oil- and plastic-producing countries rejected a limit on plastic production by 2040. A global treaty on plastics should focus on reuse, recycling, circular economy, and waste management. (UNEP, press release, April 29, 2024). This position is by no means new.

The first plastic water bottle was introduced in France in 1968. In the 1970s, surveys showed that consumers' environmental awareness of the use of plastics in packaging and packaging, especially disposable packaging, was increasing. “However, neither plastic producers nor the French mineral water manufactures took any action during the 1970s regarding plastic wastage; they considered that it was up to the public authorities to develop consumer education and waste recycling programs” (Marty, N., 2020).

Meanwhile, the negative effects of plastics, microplastics and nanoplastics on the marine environment are obvious.

In contrast:

- Thompson, R.C. et al. (2009a, b) complain, that research gaps are existing and data concerning the impact of microplastics on terrestrial habitats, on agricultural land, and in freshwater do not exist.
- Rillig, M.C. (2012) stated: “*Yet the terrestrial landmasses are conspicuously empty on maps of global microplastic distribution: they have simply not been studied*.” The author raised the questions: “*Why have microplastics not been studied in soils and terrestrial systems*?" - ”*Can they have adverse effects*?” He concluded: “*The occurrence of microplastics in soil is eminently plausible and should be systematically examined.*” He did not address the potential impact on the food web.
- Rocha-Santos, T., and Duarte, A.C. (2015) stated that concerning the terrestrial environment, there are no studies in soils, related organisms, or atmospheric aerosols available.
- Lwanga, E.H. et al. (2017) presented the first scientific data, that microplastic can enter terrestrial food webs. Microplastics from the soil were picked up by earthworms and finally accumulated in chickens.
- FAO (2021,2022) assessed the impact of plastics in agriculture as well as food commodities (see the following).

4. FAO (2021): Assessment of Agricultural Plastics and Their Sustainability – A Call for Action

In total, only 3.5% of global plastic production is used for agricultural production, i.e. 10 million tons of plastic are used for plant and animal production. This is a small proportion in absolute terms, but this number of plastics and micro/nano-plastics is directly linked to the production of plants, vegetables, fruit and animals. These types of plastics and their degraded particles are important sources of contamination, leading to accumulation in soils, terrestrial and aquatic environments. They can enter and accumulate in the food chain, threatening food security, food safety and potentially human health. Estimates of agricultural plastic waste range from 2 to 6.5 million tons (Galati, A. et al., 9/2020).

In modern agriculture, a wide range of plastic products are used to improve agricultural and horticultural production: Mulch films (2.5 million tons), heating films, tunnels, and greenhouse films (3.5 million tons) as well as nets, irrigation hoses and pipes, sacks and bags, bulk containers, silage films (1. 4 million t), bottles, trays for planters, holding straps and clips, coatings for fertilizers, pesticides and seeds, spray containers, pesticide containers (0.3 million tons), protective fleeces, fruit protection devices, harvest crates, pallets, protective nets, tree protection devices, ropes, lines, traps, and enclosures. Except for durable structures (greenhouse films), most products are intended for single use and have a lifespan of less than 12 months, after which they become waste - macro-micro-nanoplastics.

Some relevant results are:

- “This FAO report provides irrefutable evidence to support action towards the better management of plastics in agrifood systems before and after reaching end-of-life.

- As the demand for agricultural plastics continues to grow, there is an urgent need to better monitor the quantities of plastic products used and that leak into the environment of agriculture.
- Asia was estimated to be the largest user of plastics in agricultural production accounting to almost 50%.
- Research on the harm caused by plastics to terrestrial and freshwater ecosystems currently falls far behind that of the marine environment.
- Inappropriate disposal of agricultural plastic at dumpsites prone on fires, or open burning on farms, are sources of toxic emissions.
- There is no overarching international policy or legislative instrument that addresses all aspects of plastics in agrifood value chains and throughout their lifecycle.
- It is recommended that governments begin to collect data on agricultural plastics used and their fate.
- The report identifies alternatives and interventions to improve the circularity and sound management of agricultural plastics based on the 6R model (Refuse, Redesign, Reduce, Reuse, Recycle, and Recover).
- Existing knowledge gaps were identified: global flows and fates of agricultural plastics, life cycle assessments of fossil-based and bio-based agricultural plastics, pathways and impacts of plastics, micro- and nanoplastics on agroecosystems, food safety and human health, behavior, and rate of degradation of biodegradable products in different environments.
- The urgency for coordinated and decisive action cannot be understated."

This last quoted sentence is fully confirmed by the wide range of scientific evidence presented in this critical review. There is no time to lose to improve the use of plastics in agriculture and address the issues at hand.

The 6Re model covers technical issues only, however the challenges are more complex. Therefore, a 33Re model is formulated as a take home message at the end of this critical outlook.

Hofmann, T. et al. (9/2023): Plastics Can Be Used More Sustainably in Agriculture

Hofmann, T. et al. (9/2023) update the data situation agricultural plastics of the FAO (2021) and provide further future-oriented information on how plastics can be produced more sustainably and used in agriculture. They address *the following:*

- *"Rational use, reduction, collection, reuse, and innovative recycling are key measures to curb plastic pollution in agriculture.*
- *Plastics that cannot be collected must be biodegradable in an environmentally benign manner.*
- *No plastic residues should accumulate in soils.*
- *Alternatives with smaller environmental impacts should be used and endorsed within a clear socio-economic framework.*
- *Presently, biodegradable plastics are 20-80% more expensive to produce.*
- *Mandatory use of environmentally benign additives is necessary to reduce toxicity burdens.*
- *A full substitution of plastics is currently not possible without increasing the overall environmental footprint ang jeopardizing food security. Clear policy guidelines are required to ensure a just transition.*
- *Monitoring and reporting of plastics used in agriculture with detailed post-use treatment analysis will help to ensure that reduction strategies are effective.*
- *In China, without the use of mulch film, an additional 3.9 million hectares of arable land would be required to produce the same amount of food. Nationwide, plastic mulch films led to a 45.5% increase in crop yield on average in 51 different crop species (Sun, D. et al., 7/2020).*
- *For plastic mulch films, the major obstacle to recycling is the contamination with soil adhering (<80%) to the plastics when they are recovered from the field after harvest.*

- *More than 10,000 chemicals are used in the production of plastics, whereby, over 2,400 substances are identified as substances of potential concern as they meet one or more of the persistence, bioaccumulation, and toxicity criteria in the European Union (Wiesinger, H. et al., 6/2021).*
- *Currently, there are no comprehensive programs regarding the life cycle implications of plastics and practical know-how on new skills and practices to cover all life cycle phases of plastics/agricultural plastics in the societies.*
- *The reduction of plastic pollution is a question of perceptions and behavior, as well as of the materials available, production practices on farms, and contextual constraints."*

The report is a "state of the art" report by an international group of scientists from Austria, Canada, China, Switzerland, the USA and Germany and provides an excellent roadmap for further improvements in the use of plastics in agriculture in order to protect our most important resources - our soils and limited arable land - for the people living on earth today and in the future.

The authors refer to the upcoming United Nations Plastics Treaty (UNEA Resolution 5/14) entitled "End plastic pollution: Towards an international legally binding instrument", (6/2022). This plastics treaty is due to be adopted at the end of 2024. Let's see how it works.

The recommended international legally binding instrument reaffirms the 2030 Agenda for Sustainable Development from 2015 and the Rio Declaration on Environment and Development from Rio de Janeiro in 1992. It includes microplastics, focuses on marine plastic/microplastic pollution, also mentions impacts on other environmental sectors without further differentiation and emphasizes the urgent need for solutions, cooperation, coordination and complementarity between relevant regional and international conventions and instruments.

The treaty on plastics will come very late! The focus on the marine environment is right. However, it is important and necessary to extend this focus to terrestrial ecosystems, soils, arable land, water, food and feed production, human health, the atmosphere, and climate change. There is no time to lose and again more than 30 years to wait to achieve international legally binding commitments in these areas of more sustainable plastics/micro/nanoplastics management.

5. **FAO (2022): Microplastics in Food Commodities – A Food Safety Review on Human Exposure through Dietary Sources**

This document provides an overview of the literature available up to the end of 2020 on the occurrence of microplastics and associated contaminants in food. It estimates the dietary exposure of consumers to these materials, highlights some gaps in knowledge regarding their public health significance and provides some recommendations for future work on microplastic particles to support food safety governance.

The authors refer to the European Commission Directive 2002/72/EC, which contains a list of all monomers, additives and other substances that may be used in the manufacture of plastic materials for food contact. This list also contains limit values for migration into food. The Commission Regulation or the Union list does not include many NIAS (non-intentionally added substance) whose presence in food is not allowed; however, it sets a migration limit of 0.010 mg/kg for non-authorized substances in food (except for mutagenic, carcinogenic or reprotoxic substances) that migrate through the functional barrier in multilayer packaging. This directive expired in 2011 (see position 6).

It also mentions that human exposure to micro/nanoparticles is not a significant public health problem per se. It would be nice if this statement could still be made in 2050 and beyond!

6. **World Wildlife Fund, WWF, towards a Treaty to End Plastic Pollution (5/2023)**

   - *"WWF Calls for a Global Ban on 'Harmful and Unnecessary' Single-Use Plastic Items, Such as Vapes, Cutlery, e-Cigarettes, and Cosmetic Microplastics, Ahead of Key UN Plastic Pollution Treaty Talks" in Paris (McCarthy, S., 5/2023).*

The focus is on marine plastic pollution and does not include terrestrial or atmospheric pollution from micro- and nanoplastics. Despite national regulations and voluntary measures, plastic pollution has not been stopped, and the situation is getting worse. Globally agreed rules on paper are a first step but are not enough to get the rapidly growing problem of plastic pollution under control in time.

7. **European Commission (2/2023a), Future Brief: Nanoplastics: State of Knowledge and Environmental and Human Health Impacts**

   Some key results are listed here:

   - *"Annual plastic production currently exceeds 380 million tons ... [and] it is estimated that roughly 32% of plastic waste might find its first receptacle in soils or continental aquatic ecosystems. Approximately 4 977 million tons have accumulated in landfills and the natural environment (de Souza Machado et al., 2018).*
   - *Most of the research on environmental fate of micro- and nanoplastics has focused on water pollution. Pollution of soil and of the air has received less attention, and so these are areas where more research efforts could usefully be focused on coming years.*
   - *It is estimated that, on average, an adult person consumes around 39,000–52,000 particles a year or 5 g of plastic every week — the equivalent of a credit card (Schwarzfischer and Rogler, 2022).*
   - *Information can be extracted from the fields of nanomedicine and nanotoxicology, where a wide variety of engineered nanoparticles were found to cross the epithelial barrier in both in vivo and in vitro models (Rubio, Marcos, and Hernández, 2019).*
   - *The deliberate regulatory response is lagging the pace of nanoplastic release and abundance in the environment. Recent and ongoing efforts to regulate intentionally added microplastics have run into debate about the most appropriate lower size limit for classifying microplastics. This debate has been mainly inspired by the difficulty of enforcement when detection is so challenging at smaller sizes. However, scientific evidence does not support a cutoff point for the environmental and human effects of plastics at a particular size limit; indeed, while the relation between physicochemical properties and (adverse) biological effects appears complex and evades simple threshold descriptions, the smaller the plastic particles, the more likely they can cross biological membranes and the more thoroughly they can permeate organisms.*
   - *It is clear from the research presented here that the full lifecycle of plastics – from 'cradle' to 'grave' – is not complete when we can no longer see the plastic: plastics continue to have environmental effects far past the point they become invisible. Failure to control these invisible pollutants, which are already permeating the terrestrial, atmospheric, aquatic, and biological environments, contributes to an escalating hazard, the full proportions of which we may not fully understand until it is too late."*

The EU Commission is fully aware of the problem of plastic pollution, particularly the threat posed by microplastics and nanoplastics. The Commission confirms that the regulations for these invisible pollutants are lagging. There is no agreed master plan or management plan with critical milestones. The EU Commission is driving forward a wide range of projects in this area to understand the behavior of nanoplastics, their biological hazards and possible remedies. Ongoing research projects focus on aquatic ecosystems, human health and public awareness. Pollution of soils, arable land, plants or terrestrial ecosystems by micro-/nanoplastics is only mentioned and will be included in future research programs. Necessary research projects on the accumulation of MP or NPS in crops, fruit and vegetables, animals or on safety issues along the food chain, and the health of humans and animals are not considered at all. This needs to be changed, as much scientific data indicates that these invisible pollutants endanger life in various forms. With reference to the frequently applied "precautionary principle", an MP/NPs alert monitoring system with scientifically based limit concentrations should be developed and implemented in Europe without delay, especially in food and feed production, i.e. for food safety and the atmosphere. Assessments of the feasibility of setting NOELs (no observed effect levels) for micro-/nanoplastics would be very helpful. Such limits would limit the exposure and intake of micro/nanoplastics through the daily diet. In addition, the development and application of a "code of conduct" covering all aspects of plastics in the entire agri-food value chain should be implemented in a timely manner. Such developments, assessments and systems would help to protect the health and lives of people today as well as resources for future generations.

In July 2023, the **European Commission** issued **Regulation 2023/1442** amending **Annex I to Regulation (EU) No. 10/20211** on plastic materials and articles intended to come into contact with food (EC, 7/2023c). Plastic food contact materials (FCMs) that comply with **Regulation (EU) No 10/2011** can be placed on the market until February 2025 only, i.e. 18 months after the entry into force of the new **Regulation 2023/1442**. Such plastic FCM products may remain on the market until exhaustion of stocks.

A similar regulation should be adopted to the area of food production systems by setting appropriate migration or accumulation limits for micro/nano-plastics, such as:

- "'Overall migration limit' (OML) means the maximum permitted number of non-volatile substances released from a material or article into food simulants,
- 'Food simulant' (FS) means a test medium imitating food; in its behaviour the food simulant mimics migration from food contact materials,
- 'Specific migration limit' (SML) means the maximum permitted amount of a given substance released from a material or article into food or food simulants,
- 'Total specific migration limit' (SML(T)) means the maximum permitted sum of substances released in food or food simulants expressed as total of moiety of the substances indicated."

The European Commission Regulation (EU) 2023/2055 - Restriction of microplastics intentionally added to products

In 2023, the European Commission (2023b, d) issued a new regulation to prevent microplastic pollution. The "restriction of microplastics" includes all synthetic polymer particles under 5 millimeters that are organic, insoluble, and poorly degradable. The European Commission has adopted measures that ban both the sale of microplastics and of products to which microplastics have been deliberately added and which release these particles when used.

"The aim is to reduce emissions of intentionally used microplastics from as many products as possible. Some examples of common products that fall under the restriction are:

- The granules used on artificial sports fields - the largest source of intentionally used microplastics in the environment.
- Cosmetics in which microplastics are used for various purposes, e.g. to exfoliate the skin (microbeads) or to achieve a certain texture, fragrance, or color.
- Detergents, plasticizers, glitter, fertilizers, pesticides, toys, medicines, and medical devices, to name but a few".

The introduced restrictions on microplastics are a big step towards reducing man-made pollution.

8. CropLife Europe Microplastic Position Paper (4/2021)

CropLife Europe member companies:

- *They are actively looking at alternatives to replace long-lasting polymers with biodegradable materials as rapidly as possible.*
- *They need appropriate transition timelines of 11 years – up to the year 2032.*
- *The enforceable size limit of coatings will not be below 100 nm.*

This is a private sector initiative - a step forward, as no nanopolymers smaller than 100 nm are to be produced by 2032. The timescales sound realistic. The development of biodegradable alternatives is state of the art.

9. Exploring Plastic-Management in China (Liu, C. and Liu, C., 6/2023)

- *"China is the top producer and consumer of plastics and creates the most plastic waste globally.*
- *China is trying to implement policies to tackle plastics at the macro-level. The current policy research mainly focuses on plastic ban, and restriction orders.*
- *Plastic-bag-recycling programs remain underdeveloped and that the uptake of environmentally friendly products for public use has not become mainstream.*
- *China has a national marine-litter strategy. Since 2016 microplastics were incorporated, but for marine litter only.*
- *China has increased their plastic-waste-recycling rate, whereby there is an underdeveloped recycling system for plastic waste, low levels of waste collection and classification, and the entry threshold for the recycling industry of plastics.*
- *Meanwhile, many local governments and private sectors have undertaken initiatives to address plastic pollution. Beijing launched its Plastic Pollution Control Action Plan for 2020-2025 to reduce disposable plastic products, establish a yearly reporting system for key plastic industries, and create a culture of low plastic usage.*
- *China is establishing a tracking system for plastics along the supply chain and develop consumer-based solutions targeting consumer's daily lives and social practice to prevent plastic waste generation. A new behavior, awareness, and knowledge need to be instilled by educating consumers and creating enabling conditions to tackle plastic pollution on the*
- *macrolevel as well as MP-level. The policy effectiveness is still yet to be determined.*
- *Nevertheless, plastic products are an important basis for China's petrochemical industry producing products for agriculture, construction, daily living, automotive, pharmaceutical, and other industries.*

- *Triggered by socio-economic progress in China, the demand for plastics will continue to grow."*

Most of the scientific work on the impact of plastics, MP and NP on the world comes from China. However, it is difficult to understand that regulations and measures in China have so far only focused on marine ecosystems. The wide range of scientific data in the field of terrestrial ecosystems, such as soils, agricultural systems, or the atmosphere, is not considered at all. The reduction or elimination of existing and future levels of NP in all areas is not mentioned at all. This needs to be changed as soon as possible to avoid negative impacts on life in China and worldwide.

10. 20 New Delhi Leaders' Declaration (9/2023) – "One Earth – One Family – One Future"

- "***Ending Plastic Pollution***"
- "*We are determined to end plastic pollution. In this context, we welcome the resolution UNEP/EA.5/Res.14 which established an Intergovernmental Negotiating Committee (INC) to develop an international legally binding instrument on plastic pollution, including the marine environment, with the ambition of completing its work by the end of 2024. We will also build on the G20 Marine Litter Action Plan as elucidated in the Osaka Blue Ocean Vision.*"
- *... to end plastic pollution – until when?* - No timeline at all.
- *... to develop an international legally binding instrument* - Let's see end 2024, what it will be.
- *... on plastic pollution, including the marine environment* - The terrestrial environments, soil, agricultural land, or the atmosphere are not addressed at all.

In July 2022, the Indian government banned the use of certain single-use plastic items with low utility value by law. Earplugs with plastic sticks, plastic sticks for balloons, plastic flags, candy sticks, ice cream sticks, polystyrene (thermoplastic for decorative purposes), plastic plates, cups, glasses, cutlery such as forks, spoons, knives, straws, bowls, wrapping or packaging films around candy boxes, invitation cards and cigarette packets, plastic, or PVC banners less than 100 microns thick, stirrers, etc. Even though the plastic ban is in place, the blatant violations continue, and no serious action is taken against the violators (Sharma, S., 6/2023).

No timelines or figures are given on how many plastics, micro/nanoplastics, are expected to be reduced by 2025/2040 or what percentage of total plastic waste this will be in India in the best-case scenario. Success in the fight against plastic depends on people, whether they follow the rules or not.

Actually, the authors of an India - Australia Industry and Research Collaboration for Reducing Plastic Waste in India come to almost the same conclusions (Dhodapkar, R. et al., 2023): "*Management of plastics has historically been dealt with by government at State and Municipal levels, through regulatory strategies of bans and fines, and by education and awareness campaigns fed by civil society actors. These interventions have mainly been from the waste management perspective, directed predominantly at individual behavior shifts and with some success.*" Furthermore, the plastic waste is mostly handled by the informal sector, which is dominated by low skilled labor, manual segregation, uncertain pay and lack of social security, weak medical and human health support, and most of the plastic waste ends up in landfills, burnt, or leaked into the environment.

This interdisciplinary strategic study is truly an excellent roadmap worth reading on how a country like India can achieve near-zero plastic waste by 2035 by establishing a circular economy. "*A circular economy would use as little virgin plastic as possible and maximize the use of recycled material. It would substitute its use with alternative material, extend the use of plastic materials, collect waste and end-of-life plastic and recycle it for its next use.*"

The roadmap:

- "is a comprehensive view of the entire value chain of the plastic economy and provides systemic recommendations for addressing the challenge.

- is a motivation to unlock opportunities in the transition to a greener, more inclusive and circular economy as a strategy to achieve Sustainable Development Goals (SDG) and zero targets.

- is a living framework document supported by robust research and recommendations for policy and industrial strategies, technology interventions, and community and social actions.

- is a guideline how technology, business and industry successfully implemented in India have a huge potential for informing and replicating in emerging economies of the Asia Pacific, Africa and Latin America, thus the roadmap can stimulate and lead transformative change at global scale.

- is a device for plastic manufacturers and plastic product manufacturers, who connect with the waste management agencies at industry levels.

- is a good example for a successful collaboration of Indian and Australian (CSIRO) research partners, industry, government and community."

A good roadmap is available, but people must take the lead to tackling a key challenge of the globe and human mankind. Let's track progress, specific goals, milestones and timelines by 2025/2030/2035.

11. Business Coalition for a Global Plastic Treaty (3/2024)

The Business Coalition for a Global Plastic Treaty, representing more than 200 organizations, has written a letter to the White House and President J.R. Biden calling for government leadership in the fight against global plastic pollution. They called for the development of a coherent and effective policy framework based on globally binding rules. The Business Coalition for Global Plastic Treaty supports a legally binding treaty that creates the right conditions to create a circular economy for plastics and end plastic pollution. The coalition demands:

- "*Clear goals, targets, and obligations, with a sense of urgency,*
- *A timeline for the phasing out of problematic plastics,*
- *Harmonized regulatory and financial incentives,*
- *Mechanisms to ensure dedicated, ongoing, and sufficient funding for the after-use collection and treatment of plastic,*
- *Provisions to protect and respect the livelihoods, health, labor, and human rights of all people involved in the plastics vale chain,*
- *Supporting policy impact assessment,*
- *Improving the transparency of plastic flows through harmonized monitoring American leadership towards ending plastic pollution.*"

The intentions sound good, however, the coalition has only addressed (macro)plastics in general but dealing with microplastics/nanoplastics should be included.

Well, it will take many years with countless national meetings and conferences before a global plastics agreement is reached. It will take centuries to develop and implement effective and efficient master plans to tackle plastic, microplastic and nanoplastic pollution around the world. Nevertheless, we must move in this direction because we have no time to lose!

The White House has yet to respond.

D:

Conclusion:

Plastics are very useful and are used by everyone on the planet.
In addition to the societal benefits that plastics have provided for more than 70 years, such as medical plastics that protect public health and save lives; lightweight plastics that reduce gas emissions and lower transportation costs; plastics in the automotive industry that increase safety; plastics in agriculture that increase yield and improve food safety and quality; plastic containers that enable food and water storage and make life easier, etc.., it is time to protect the marine, terrestrial and atmospheric environment, soil, soil organisms, water, crops, animals and people. Current and future generations of humanity are highly exposed to plastics, microplastics and nanoplastics through food consumption. Plastic, microplastic and nanoplastic pollution is inextricably linked to food safety, human health, and climate change. They pose an invisible, insidious, underestimated, and neglected threat to people and the environment. They do not stop at borders but are hidden and unknown biohazards. They are emerging "black swans".

Despite all positive efforts, the quantity and heterogeneity of micro-/nanoplastics will increase dramatically in the coming years and decades. Reliable and robust technologies and structures need to be established at the local level to determine the accumulation rates of these plastic structures in all ecosystems. This must be done immediately to prevent early, fatal, or sub-lethal damage and socio-economic losses.

Micro/nanoplastic pollution undermines all 17 UN Sustainable Development Goals. Nevertheless, legal, internationally binding regulations are still pending, although they are urgently needed. Ongoing plastic regulations should be implemented as soon as possible and focus not only on the marine environment, but also on the terrestrial and atmospheric environment. Some already implemented restrictions on microplastics, e.g. in Europe (European Commission Regulation (EU) 2023/2055) as well as the ban on exports of plastic waste from the EU to non-OECD countries (European Parliament, Waste Shipment Regulation, (WSR), 2024/..., 3/2024) are important steps towards reducing man-made plastic/microplastic pollution.

Plastics, microplastics and nanoplastics accumulate primarily in terrestrial ecosystems, on agricultural land and in water. Consequently, their uptake and transfer into food pose a significant risk to the terrestrial food chain. They affect more or less all organisms in agricultural systems. They reduce the yield and quality of crops, fruit, and vegetables. However, field trials on yield and quality reduction and long-term effects on soil quality are scarce, but will be conducted in the coming years. Life cycle analyses must be carried out to make the risks and hazards transparent. Technologies based on artificial intelligence (a.i.) will significantly improve soil health, healthy crops and healthy food and feed in the future.
The establishment of warning systems for plastic, microplastic and nanoplastic pollution based on risk assessments is also within reach with the help of a.i.

Studies on the mode of action and mechanisms of action of micro/nanoplastics on seeds have shown that micro/nanoplastics can have cytotoxic and genotoxic effects. To make seeds resistant to micro/nanoplastics, appropriate breeding programs must therefore be established.
Some pioneering studies point the way to the future. The integration of a.i. will help to visualize micro/nanoplastics and better interpret their impact on environmental systems. Machine learning (ML) technology coupled with image-based phenotyping can determine a wide range of plant growth stressors (Singh, A. et al., 2021) and bridge the gap between genotypes, phenotypes, and the environment (Beniwal,

J. et al., 7/2023). Abiotic stress factors such as micro-/nanoplastics should be included in breeding programs to increase the resilience of crops.
Machine learning, i.e. computational algorithms that map micro-/nanoplastics in the environment, are now available and can also characterize soil properties (Withnana, P.A. et al., 2024).
In addition, the use of robots in combination with a.i. will significantly improve recycling processes and contribute in particular to the improvement of "*plastic culture*" (Aschenbrenner, D. et al., 2023).

Research into the effects of micro-/nanoplastics and the prevention of negative effects on all habitats must be promoted in all countries of the world. Knowledge transfer, transfer, and introduction of suitable technologies as well as international cooperation between the public and private sectors are essential instruments for tackling the problems at hand.

Bioeconomy, decarbonization, reuse and recycling are the order of the day and must be implemented in all production processes, especially in the improvement and replacement of plastics in agriculture. The "plastic culture" must be improved to avoid negative impacts on food production today and in the future.
In addition, the production of biodegradable plastics without fossil fuels will make an important contribution to sustainable and climate-friendly food production.
Complementary, the systematic review paper presented by Beltran, M. et al. (4/2021) on “Food Plastic Packaging Transition towards Circular Bioeconomy” is interesting to be mentioned here. This paper analyzes the driving forces behind the changes in food plastic packaging and examines how socio-technical configurations can influence niches on the path towards a circular bioeconomy, in particular bio-based biodegradable plastics. The literature suggests that one possible transition pathway is for bio-based biodegradable materials to serve as “carriers of food waste”.

Numerous scientific data prove the negative effects of micro-/nanoplastics on many organisms and the environment. However, the role of micro-/nanoplastics on humans in vivo is still insufficiently researched, as no clinical and epidemiological studies are yet available. It is only a matter of time before such studies are available to clarify this important issue and determine the tolerable daily intake (TDI) of various micro-/nanoplastics. Nevertheless, in line with the precautionary principle, it is wise to avoid negative effects in advance so as not to pay a bitter bill later.

The dangers posed by micro-/nano-plastics are barely recognized worldwide. Unfortunately, there are no effective and efficient preventive and protective measures or overall concepts to deal with these emerging problems worldwide. Human contact with micro/nanoplastics is not a significant public health problem per se worldwide.

In addition to any scientific, technical, or political efforts to effectively control plastics and micro-/nanoplastics, the entire population must be adequately involved (Hawkins, G., 2017). Plastic was not originally designed to be wasted. The proliferation of plastic packaging, particularly food packaging, the rise of the fast-food industry, convenience, the focus on single use and the throwaway mentality (Pilapitiya, P.G.C.N.T., and Ratnayake, A.S., 1/2024) were not seen as a heavy burden on people living on the globe today and in the future.
The document "Turning the Tide - A Call to Collective Action", published by the Global Commission on the Economics of Water (3/2023), uses the phrase "We must..." 14 times in its seven-point call to collective action and 53 times "We must..." in its new framework for the economics of water. "We" sounds very generalizing, very altruistic, and reflective and does not address the individual. Micro/nanoplastics are so anonymous and invisible that you personally cannot see any direct impact on your health or life. In the future, when medical/clinical data makes the threats more obvious and transparent, everyone may wake up.

Creating awareness is one prerequisite, educating the general public is another, to address challenges in a timely and proper manner.

However, the people of our time are responsible for ensuring a healthy world for all. Our societies on earth must solve the problem, there is no one who will do it for us.

E:

E1:

Call to Act

Climate change and plastic pollution are directly linked; rethinking the future of plastics; reduction to the minimum necessary; need for new plastic strategies; need for waste management plans; replacement of fossil fuels with renewable energy; replacement with bio-based and biodegradable plastics; implementation of a circular economy; implementation of technical and social innovations along the plastic value chain.

E2:

Appeal: Bring the epidemic of plastic, micro- and nanoplastic pollution under control as soon as possible!

F:

Outlook:

How to bring the message across?

F1:

Recommendations for scientists - Scientists should make their knowledge available at different levels, such as:

Scientific abstract, graphic abstract, scientific full paper, keynote lecture, text for press release, text for yellow press release, text for newspaper, text for 16-year-old student, text for social media, smart headline, five keywords, scientific cartoon.

F2:

Knowledge transfer, Education

Some glimmers of hope: current, practical, simple, recommendable, and encouraging examples that involve and engage young people, teachers, schools, media, social media, and the public in the personal reduction of plastic and micro/nanoplastics:

- Training program in England and France: "Plastics in Agriculture Lessons" - "Plastics in Agriculture-sources and Pathways of Plastic from Agriculture" (European Union, Interreg France/England, Preventing Plastic Pollution, Environment Agency, 2021).

- "How much plastic is in our soils?", Citizen Science Award: "SoilPlastic App", 2023 for the determination of microplastics in soils by "Citizen Scientists", students or laypersons (AGES, Austria, 2023).

- In almost all cities and municipalities in Germany, volunteers carry out waste collections twice a year on roads, cycle paths and field paths, ditches, car parks, public facilities, and squares with a focus on plastic (2024).

- "Planet Plastic" exhibition at Nieder-Olmer Gymnasium about the effects of plastic consumption (Hoffmann, M., 28.06.2023).

- Contribution to the regional competition for schools "Jugend forscht/Youth Researches": 3rd winner "What triggers microplastics in plants? Gustav Heinemann School in Rüsselsheim (Jung, H., 2/2024).

- Teaching unit for upper secondary level: "Microplastics as an environmental problem". The aim of the teaching materials is to sensitize students to the harmful effects of microplastics on living organisms (Eduversum GmbH, Lehrer-Online, https://www.lehrer-online.de/unterricht/sekundarstufen/naturwissenschaften/chemie/unterrichtseinheit/ue/mikroplastik-als-umweltproblem/, 2024).

- "Flood of plastic: garbage carpet on the dream beach", volunteers collect garbage from the river in Bali, Indonesia (dpa, 23.03.2024).

- Avoid unnecessary plastic - plastic fasting: The impact on people and the environment can be reduced in everyday life by simple means, e.g. avoiding plastic products, especially short-lived products; reducing single-use plastic waste; avoiding clothing with synthetic fibers; choosing plastic-free hygiene products; using reusable containers; disposing of plastic waste correctly (Hartmann, N., 26.03.2024).

F3:

Take Home Messages: How you/we can reduce plastic waste? – by going for **33 Re's** …:

2009: **3 Re's**: **Re**duce, **Re**use, **Re**cycle (Song J.H. et al., 2009)

2009: **4 Re's**: **Re**duce, **Re**use, **Re**cycle, **Re**cover (Hopewell, J. et al., 2009)

2009: **5 Re's**: **Re**duce, **Re**use, **Re**cycle, **Re**cover, **Re**design (Thompson, R.C. et al., 2009)

2021: **6 Re's**: **Re**fuse, **Re**design, **Re**duce, **Re**use, **Re**cycle, **Re**cover (FAO, 2021)

2024: **33 Re's**: **Re**think, **Re**orient, **Re**flect, **Re**search, **Re**port, **Re**duce, **Re**fuse, **Re**ject, **Re**use, **Re**create, **Re**design, **Re**shape, **Re**model, **Re**process, **Re**condition, **Re**brand, **Re**pair, **Re**move, **Re**place, **Re**purpose, **Re**fill, **Re**cycle, **Re**cycleBot, **Re**pRap, **Re**suspend, **Re**cover, **Re**manufacture, **Re**furbish, **Re**texture, **Re**mediate, **Re**gulate, **Re**strict, **Re**act! – **in Time!** (Kern, M., 3/2024).

G:

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