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CONTENTS

Special Report:

PFAS in Drinking Water: A Persistent International Health Threat

Natural Resources Defense Council

PFAS are a group of thousands of man-made chemicals that have become widely used since the 1950s due to their wide range of applications in consumer products and industrial processes. Their water- and oil-repellant properties have made them popular in many common products, including non-stick cookware, water resistant clothing, stain-resistant carpets, rugs, and furniture, some food packaging, and firefighting foams, among others. Exposure to these chemicals comes not only through direct contact with products that use it, but also through drinking water, air, food, and dust.

PFAS are chemically defined by their carbon-fluorine bonds, which make them thermally stable and resistant to degradation. While this characteristic is what has made them useful in many of their applications, it has also made them more and more ubiquitous in the environment with the passage of time. They are, to some extent, water-soluble, and have been found in drinking water sources around the world, including treated drinking water. Their water-solubility also allows them to persist in the blood serum of humans. PFAS can be found in the bodies of almost all Americans and people around the world. Exposure to the chemicals comes from a variety of sources due to their ubiquity in the environment. In addition to exposure through drinking water, humans are exposed to PFAS through contaminated household dust from PFAS-treated upholstery and carpeting, as well as food and food packaging.

"PFAS in Drinking Water 2019" was produced by the Natural Resources Defense Council (NRDC) to outline relevant scientific information about per- and polyfluoroalkyl substances (PFAS) in order to inform public policy. This article summarizes key concepts from NRDC's report.

The two most common PFAS chemicals are known as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). These chemicals have been studied more extensively than other PFAS, and their negative health impacts are far better understood. Although PFOS and PFOA were voluntarily phased out by U.S. manufacturers in 2010 due to health concerns, they are still persistently widespread in the environment. U.S. manufacturers have replaced them in their commercial applications with other forms of PFAS which have similar chemical properties but are less well-studied.

Overview of Health Impacts

A significant amount of research has been conducted about the health impacts of exposure to many types of PFAS. The Agency for Toxic Substances and Disease Registry (ATSDR), an agency within the U.S. Department of Health and Human Services which performs risk assessment and evaluation of chemicals, released a draft Toxicological Profile for Perfluoroalkyls in June 2018.[1]

Exposure to PFOA and PFOS has been found to increase cancer risk in humans and animals, according to numerous toxicological studies. While the most common forms of cancer associated with these chemicals are kidney and testicular cancer, there is evidence that exposure could heighten risk for other types of cancer as well. The potential impacts on cancer risk of other PFAS chemicals, such as PFNA, PFHsX, and GenX, have been studied far less than those of PFOA and PFOS. However, "their chemical similarity to PFOA and PFOS and the data that is available suggests that there is reason to be concerned about increased cancer risk."[2]

[1] Agency for Toxic Substances and Disease Registry, 2018. Toxicological Profile for Perfluoroalkyls. Draft for Public Comment, June 2018.

In general, infants and young children are at a particularly high risk for health impacts associated with exposure to toxic chemicals. Studies have found a variety of risk factors for PFAS health impacts associated specifically with infants and young children. Consuming more water per unit of body weight than adults, young children may be at heightened risk to exposure in communities with PFAS in drinking water. Additionally, still-developing immune systems and rapidly increasing body weight may increase risk. "Exposure to PFAS before birth or in early childhood may result in decreased birth weight, decreased immune responses, and hormonal effects later in life."[3]

PFAS exposure can also cause immunotoxicity, or adverse impacts on the immune system caused by exposure to toxic substances. This has been found to occur at lower levels of PFAS exposure than other health impacts. Studies have linked PFAS exposure to a suppression of the body's antibody response and disease resistance capabilities. This decreased antibody response can have an impact on the efficacy of vaccines. Exposure to PFAS heightens the chance that, upon receiving a vaccine, the antibody level attained will not be sufficient to provide long-term protection from infectious disease. PFAS have also been connected to heightened risk for other conditions such as asthma and ulcerative colitis.

As public concern about PFAS has increased in recent years and certain types have been phased out, they have often been replaced by "short-chain" PFAS. This category of PFAS has been touted as safer than long-chain alternatives due to their supposed shorter half-life in humans. However, recent research has shown that they

Renewable Natural Resources Foundation

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[2] Natural Resources Defense Council, PFAS in Drinking Water 2019: Scientific and Policy Assessment for Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water at 18 (2019, https://www.nrdc.org/sites/default/files/media-uploads/nrdc_pfas_report.pdf).

[3] Natural Resources Defense Council at 20.

accumulate in internal organs, sometimes at higher concentrations than long-chain PFAS. They are still highly persistent and mobile in the environment, and our current understanding of their health risks remains limited.

Each PFAS chemical that has been thoroughly studied for its health impacts has been found to have significant health risks. Therefore, a Maximum Contaminant Level Goal of zero should be set for all PFAS.

Importantly, people are exposed to many different forms of PFAS from different sources. While the health impacts of individual chemicals may differ slightly, "a person is concurrently exposed to dozens of PFAS chemicals daily, and their exposures extend throughout their lifetimes…. Because PFAS are chemically related, they may have additive or synergetic effects on target systems."[4] This means that exposure to multiple categories of PFAS can combine to form negative health outcomes greater than or equal to the sum of each chemical's individual impact.

Regulation of PFAS

"PFAS in Drinking Water 2019" concluded that existing regulatory and non-regulatory thresholds for PFAS are not sufficient to protect human health. The EPA has issued a health advisory for combined PFOA and PFOS concentrations in drinking water of 70 parts per trillion (ppt).[5] However, this category of advisory is non-regulatory and non-enforceable. At the state level, some health thresholds have been set as low as 10 ppt, although these are also mostly non-enforceable. Most of these thresholds only apply to PFOA and PFOS since they are based on known adverse health effects, which are better understood for PFOA and PFOS than for other PFAS.

The report estimates that, to fully protect the most vulnerable populations from the most sensitive health effects of PFAS, accounting for uncertainties in the assessment of toxic substances, Maximum Contaminant Level Goals (MCLGs) should be set at 0 to 2 ppt. An MCLG is defined as "the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, allowing for adequate levels of safety."[6] This metric is used by the EPA under the Safe Drinking Water Act to consider health risk of water pollutants to the most vulnerable populations, and is a non-enforceable goal. They are purely a measure of safe levels to avoid negative health impacts, and do not consider technical limitations of achieving the goal water quality, such as monitoring and treatment limitations.

The piecemeal implementation of PFAS regulation makes it more difficult to completely phase out all harmful chemicals in the category. When PFOA and PFOS had been studied thoroughly enough to warrant an EPA health advisory, they were phased out in most of their applications, only to be replaced by other PFAS with similar properties that have not been studied as thoroughly. This will continue if the category of chemicals is not regulated and monitored as a group.

Water treatment options

Several water treatment options exist for removing PFAS from water with varying degrees of efficacy, as outlined in "PFAS in Drinking Water 2019." While it is not currently possible to remove all PFAS from drinking water with available treatment technologies, analyses have found that maximum contaminant levels (MCLs) of 2 ppt are achievable for PFOA, PFOS, PFNA, and PFHxS, and levels of 5 ppt are possible for GenX.

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[4] Natural Resources Defense Council at 25.

[5] U.S. Environmental Protection Agency, Drinking Water Health Advisories for PFOA and PFOS (https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos).

[6] Natural Resources Defense Council at 26.

A variety of treatment methods have been found to be effective in removing PFAS from drinking water. The most thoroughly studied method is Granular Activated Carbon (GAC) treatment. Under the Safe Drinking Water Act, "standards for synthetic organic contaminants such as PFAS must be 'feasible,' and that term is defined to be a level that is at least as stringent as the level that can be achieved by Granular Activated Carbon."[7] GAC removes synthetic organic contaminants by adsorbing them from the water; it is effective in this because it is a highly porous material and has a lot of surface area to which contaminants can adsorb. This method has already been in use for over 15 years to remove PFOS and PFOA from water. "In sum, use of GAC by multiple water utilities at scale have achieved reductions of greater than 90 percent to below detection limits for certain PFAS chemicals, including PFOS, PFOA, PFNA, PFHxS, and GenX. GAC has not been demonstrated to be effective for removing other PFAS chemicals, particularly short-chain PFAS."[8] While it is effective in removing many types of PFAS from drinking water, GAC becomes progressively less effective as chain length shortens.

While the goal for exposure to these chemicals in drinking water should be zero, the limitations of detection and water treatment do not currently allow for them to be fully removed.

Reverse Osmosis (RO) treatment has also been found to be effective in removing PFAS from drinking water. The process "can be more than 90 percent effective at removing a wide range of PFAS, including shorter chain PFAS."[9] Given GAC's deficiency in removing shorter chain PFAS from drinking water, RO is a more effective method for removing all PFAS. They have similar problems related to generating contaminated waste in the purification process, and for either method, "PFAS in Drinking Water 2019" recommends that "states evaluate the safest disposal method for contaminated waste, and that disposal require full destruction of PFAS compounds before entering the environment."[10] The report also notes some reservations about the technology, including the fact that "it often has a higher capital cost, it can require a 10 to 20 percent higher treatment capacity because it produces a reject stream, and it requires safe disposal of the reject water which will have higher concentrations of contaminants than the source water."[11] However, they still recommend RO over GAC and Ion Exchange Treatment because it is the most effective technology in removing total PFAS (as opposed to only certain types), and provides the most protection against unidentified types of PFAS. "Additionally, frequent changeout of GAC or IX to maintain removal efficiency can make the lifecycle costs more expensive than alternatives, such as RO."[12]

Conclusion and Recommendations

"PFAS in Drinking Water 2019" ended with a series of recommendations for reducing public exposure to PFAS through drinking water. The four policy actions they recommended are:

1) **Comprehensive monitoring of drinking water**: Past national testing for PFAS almost certainly underestimates the number of people exposed due to various limitations in the testing methods. NRDS recommends that states "perform both site investigations for at-risk sites and a comprehensive statewide survey of public drinking water systems."[13] They also recommend that the results of these surveys be made public for access by residents, researchers, and the public.

[7] Natural Resources Defense Council at 51.

[8] Natural Resources Defense Council at 53-54.

[9] Natural Resources Defense Council at 54.

[10] Natural Resources Defense Council at 55.

[11] Natural Resources Defense Council at 57.

[12] Natural Resources Defense Council at 57.

2) **Set a MCLG of zero for total PFAS**: Each PFAS chemical that has been thoroughly studied for its health impacts has been found to have significant health risks. Since each chemical in the PFAS class is similar in its properties, there is reason to believe that less-studied chemicals pose similar health risks. Therefore, a Maximum Contaminant Level Goal of zero should be set for all PFAS. Setting this standard for the entire class of chemicals is important because, if PFAS chemicals are regulated one-by-one, they will be quickly replaced by similar PFAS chemicals with similar chemical properties.

3) **Immediately set a Combined MCL of 2 ppt for PFOA, PFOS, PFNA, PFHxS, and a MCL of 5 ppt for GenX**: While the goal for exposure to these chemicals in drinking water should be zero, the limitations of detection and water treatment do not currently allow for them to be fully removed. Therefore, a maximum contaminant level should be set of 2 or 5 ppt for these chemicals. These standards have been determined to be achievable through methods like granular activated carbon and reverse osmosis.

4) **Develop a treatment technique requirement for the PFAS class within two years**: There is not currently a reliable method for assessing the total concentration of all PFAS in drinking water. The report recommends "that states explore an analytical method, or combination of methods, that can be used as a surrogate for total PFAS."[14] For treatment of water to remove PFAS the report recommends reverse osmosis, which has been demonstrated to be the most effective of all available technologies in removing all types of PFAS from drinking water.

The full report "PFAS in Drinking Water 2019: Scientific Assessment for Addressing Per- and Polyfluoroalkyl Substances in Drinking Water" can be accessed here.

[13] Natural Resources Defense Council at 58.

[14] Natural Resources Defense Council at 64.

Creating a Sustainable Food Future

World Resources Institute

Editor's Note: How can the growing global population be fed without destroying the environment and worsening social inequities in the process? The World Resources Institute, in partnership with the World Bank Group, United Nations Environment, the United Nations Development Programme, the Centre de coopération internationale en recherche agronomique pour le développement, and the Institut national de la recherche agronomique, proposes an answer to this question in the report entitled "Creating A Sustainable Food Future - A Menu of Solutions to Feed Nearly 10 Billion People by 2050 Synthesis Report."[1] The report offers numerous policy proposals and technical opportunities to meet global food, land-use, and greenhouse gas (GHG) emissions goals in 2050.

This summary prepared by RNRF provides an overview of policy issues and recommendations of this report.

I. Introduction

Food is vital to our survival but its production comes at a significant environmental cost. Agriculture, and related land-use alterations, produce one-quarter of annual greenhouse gas (GHG) emissions and occupy nearly half of the planet's vegetated land. Yet, hundreds of millions of people remain hungry.

It is projected that the global population will increase to 9.8 billion by 2050 – up from 7 billion in 2010. Due to the population increase, as well as growing incomes throughout the developing world, food demand will increase significantly. The report provides a "menu" of options to meet increasing food demand in ways that reduce poverty, stimulate economic development, and address climate concerns while avoiding deforestation and restoring lands and forests.

II. Challenges

To achieve the ambitious goals of a sustainable food future three gaps must be closed by 2050: (1) the food gap, (2) the land gap, and (3) the GHG mitigation gap. The daunting challenge of simultaneously closing these gaps will be extraordinarily difficult but the report contends that a sustainable food future is attainable if governments, the private sector and society at large act now, and with determination.

The Food Gap

The food gap is "the increase above the amount of food (measures as crop calories) produced in 2010, to the amount that the world will require in 2050, based on projected demand."[2] The report estimates the food gap "to be 7,4000 trillion calories, or 56 percent more crop calories than were produced in 2010."[3] This gap will be driven by rising food demand due to population growth and by the increasing demand of more resource-intensive foods (e.g. animal-based foods) as incomes grow. Moreover, foods that rely heavily on pasture for their production (e.g. meat and milk) are estimated to increase by 68 percent.

To close the food gap, measures that decrease unnecessary demand growth and increase supply must be implemented. Demand-reducing measures will make increasing food production a more manageable challenge to address. The report finds the claim that current food overabundance would be able to meet future needs without producing more food as unrealistic because the hypothetical presumes

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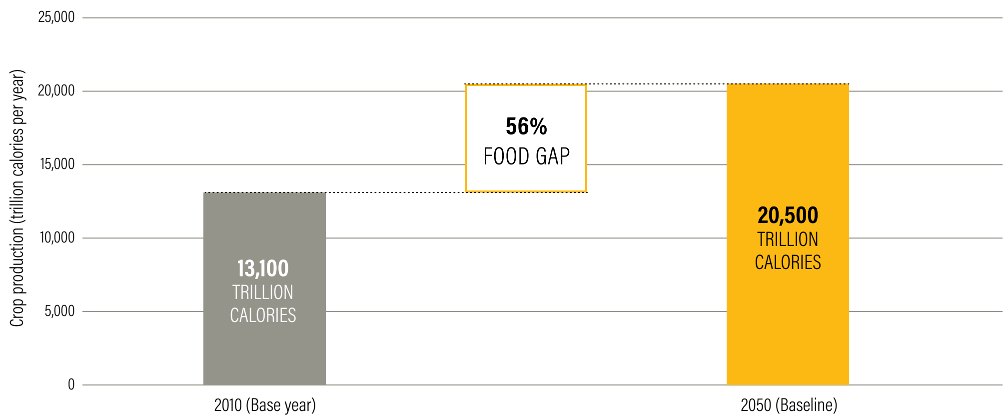
[1] The full *Creating A Sustainable Food Future - A Menu of Solutions to Feed Nearly 10 Billion People by 2050,* was published in 2019, https://wrr-food.wri.org/sites/default/files/2019-07/WRR_Food_Full_Report_0.pdf.

[2] Tim Searchinger et al., *Creating A Sustainable Food Future – A Menu of Solutions to Feed Nearly 10 Billion People by 2050 Synthesis Report*, World Resources Institute, 7 (2018).

[3] Tim Searchinger et al. at 1 (To measure the size of these gaps, the report used a new model, GlobAgri-WRR, developed in a partnership between Le Centre de coopération internationale en recherche agronomique pour le développement, L'Institut national de la recherche agronomique, World Resources Institute, and Princeton University).

numerous future conditions that will likely not take place, such as eliminating nearly all meat consumption by 2050. The report instead advocates for the measures examined in this report to practically close the food gap.

Figure 1 | **The world needs to close a food gap of 56 percent by 2050**

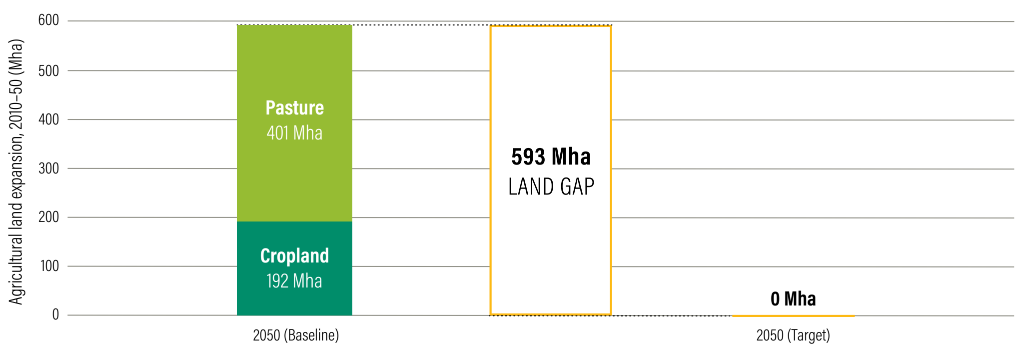


Note: Includes all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels.
Source: WRI analysis based on FAO (2017a); UNDESA (2017); and Alexandratos and Bruinsma (2012).

The Land Gap

In order to produce more food without clearing more land for agriculture, the report advocates that agricultural land area be held to the area in use in 2010. Therefore, the land gap is "the difference between the projected area of land needed to meet global food demand in 2050 and the amount of land in agricultural use in 2010."[4] Doing so would avoid further clearing of land for agriculture that devastates forests and ecosystems and further contributes to climate changes through the emission of stored carbon from vegetation and soils.

Figure 2 | **The world needs to close a land gap of 593 million hectares to avoid further agricultural expansion**



Note: "Cropland" increase includes aquaculture ponds.
Source: GlobAgri-WRR model.

The extent of the land gap depends on how rapidly crop and livestock yields can be improved. If nothing changes, agricultural land would expand by 3.3 billion hectares, decimating the world's forests and savannas. Predicted crop yields[5] and livestock and pasture productivity gains[6] could potentially halt the expansion of agricultural areas to 593 Mha. If future crop yields and pasture and livestock productivity increase at slower rates than projected, however, agricultural areas could expand by 855 Mha by 2050.

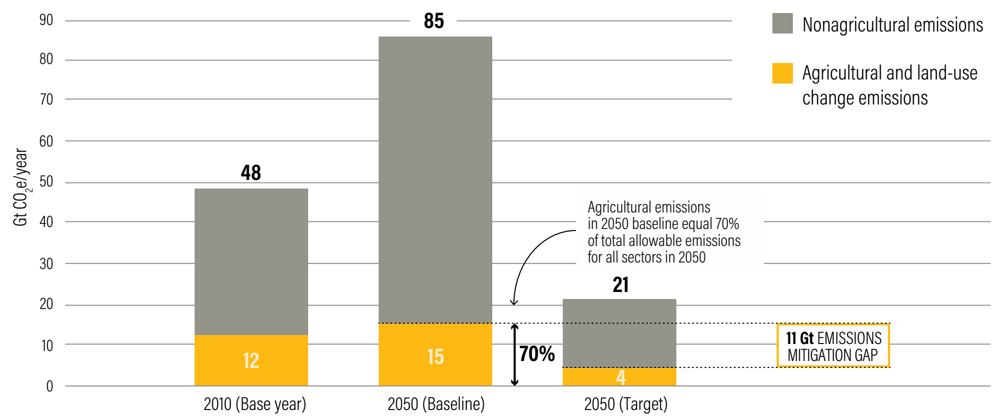
The report notes that although future yield growth is uncertain, one thing is certain. Crop and pasture yields must increase at rapid rates, even faster than previously achieved, to meet projected food demand and avoid

[4] Tim Searchinger et al. at 8.
[5] Crop yield are predicted using the Food and Agriculture Organization of the United Nations' projection that crop yields will increase, on average, at roughly the same rate as they did between 1961 and 2010.
[6] Livestock and pasture productivity gains are predicted using the GlobAgri-WRR model.

further devastation of forests and savannas.

The GHG Mitigation Gap

Figure 3 | **Agricultural emissions are likely to be ~70 percent of total allowable emissions for all sectors by 2050, creating an 11 gigaton mitigation gap**



The GHG mitigation is "the difference between agriculture-related GHG emissions projected for 2050 and an agricultural emissions target for 2050 that is necessary to help stabilize the climate at globally agreed targets."[7] In 2010, agriculture production and land-use change from expanded agriculture operations produced one quarter of total human-caused GHG emissions – amounting to approximately 12 gigatons (Gt). The report predicts total agricultural GHG emissions to be approximately 15 Gt per year in 2050 – "9 Gt of annual emissions from agricultural production and an annual average of 6 Gt between 2010 and 2050 from agricultural expansion and drained peat- lands."[8]

The report importantly pointed out that in order to halt climate warming to 2 degrees Celsius (2°C) above preindustrial levels, the global target of the Paris Agreement, total emissions (not just agriculture) must amount to no more than roughly 21 Gt by 2050 and subsequently decrease rapidly. "Although agriculture is likely to generate less than 2 percent of global GDP, it alone would fill about 70 percent of the allowable "emissions budget" in 2050 (15 of 21 Gt), leaving almost no space for emissions from other economic sectors and making achievement of even the 2°C target impossible."[9] As a result of this reality, the report determined the GHG mitigation gap to be 11 Gt – the difference between the 15 Gt of predicted annual emissions in 2050 and a target of 4 Gt. This assessment calls for a roughly 75 percent reduction in projected emissions to keep global warming below 2°C.

III. Menu of Solutions

The report presents a detailed menu of options that provides the world with a framework for a sustainable food future. The menu items are broken up into five "courses," follows:

- **Course 1: Reduce Growth in demand for Food and Other Agricultural Products**
- **Course 2: Increase Food Production Without Expanding Agricultural Land**
- **Course 3: Protect and Restore Natural Ecosystems and Limit Agricultural Land-Shifting**
- **Course 4: Increase Fish Supply**
- **Course 5: Reduce GHG Emissions from Agricultural Production**

Each of these courses is broken down further into individual menu actions items. The overall aim of these menu items is to close the three gaps, but the report also applies certain sustainability criteria on the items. These sustainability criteria include (1) to reduce poverty and hunger, (2) to provide opportunities for women farmers since women's income gains disproportionally reduce hunger in the household, and (3) to avoid additional

[7] Tim Searchinger et al. at 9.
[8] Tim Searchinger et al. at 9.
[9] Tim Searchinger et al. at 9.

overuse and pollution of fresh water sources. The report stresses that in order for these actions to be effective, they must be timely instituted at scale and with necessary public and private sector support.

Course 1: Reduce Growth in Demand for Food and Other Agricultural Products

Reducing demand for food in socially and economically advantageous ways is integral to achieving a sustainable food future.

Menu Item: Reduce Food Loss and Waste

Each year, an exorbitant amount of food – roughly one-third by weight and one-quarter by calories – is lost or wasted worldwide. "Globally, food loss and waste results in nearly $1 trillion in economic losses, contributes to food insecurity in some developing countries, squanders agricultural land and water resources, and generates roughly one-quarter of all agricultural GHG emissions."[10] There are many ways to reduce food loss and waste in developed countries including altering consumer habits that encourage waste (e.g. using cafeteria trays) or through improving retail inventory management operations. For developing countries, techniques such as improved harvesting equipment and agricultural practices that provide more consistent quality crops can greatly reduce food loss and waste.

Tackling food loss and waste is an enormous and complex task because the food chain includes so many links, each of which has waste issues that contribute to the overall problem. To make progress on this issue, the report suggests several targeted actions. First, "governments and companies should adopt food loss and waste reduction targets aligned with Sustainable Development Goal Target 12.3, which calls for reducing food loss and waste by 50 percent by 2030."[11] Food loss and waste hotspots should also be identified, reduced, and monitored by major food supply actors. The report acknowledges that technological innovation is needed to bring about the drastic changes needed to sufficiently reduce food loss and waste. According to the report, "reducing food loss and waste by 25 percent globally would reduce the food calorie gap by 12 percent, the land use gap by 27 percent, and the GHG mitigation gap by 15 percent."[12]

Menu Item: Shift to Healthier and More Sustainable Diets

The report predicts "consumption of animal-based foods to rise 68 percent between 2010 and 2050, with an 88 percent increase in consumption of ruminant meat (meat from cattle, sheep, and goats)."[13] In the United States, beef takes up almost half of land use and emissions tied to U.S. diets but only provides 3 percent of the calories. By merely shifting from beef to pork or chicken, huge environmental benefits would take place. Consumption of ruminant meat must be reduced.

On a global scale, "if consumers shifted 30 percent of their expected consumption of ruminant meat in 2050 to plant-based proteins, the shift would, by itself, close half the GHG mitigation gap and nearly all of the land gap."[14] Practically speaking, a shift on this scale would require approximately 2 billion people living in high ruminant meat consuming countries to reduce their consumption to 1.5 servings per person per week. The shift still permits global consumption of ruminant meats to increase by one-third between 2010 and 2050 instead of the projected 88 percent.

The report explains that continued product innovation (e.g. plant-based meats, blended meat-plant products), promoting and marketing plant-based foods and plant-rich dishes, and government supported policies and pricing are needed to bring about a large-scale shift in diet.

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[10] Tim Searchinger et al. at 14.
[11] Tim Searchinger et al. at 14.
[12] Tim Searchinger et al. at 14.
[13] Tim Searchinger et al. at 15.
[14] Tim Searchinger et al. at 15.

Menu Item: Avoid Competition from Bioenergy for Food Crops and Land

Bioenergy comes from crops grown on dedicated land, which further drives global land competition and expands the food, land, and GHG mitigation gaps. If biofuel use is greatly increased, as many governments plan to do, the food gap could be increased from 56 to 78 percent. However, "phasing out existing levels of biofuel use would reduce the crop calorie gap from 56 to 49 percent."[15] It is crucial to the sustainable food future that increased bioenergy use be averted. To bring this about, the report recommends that governments phase out bioenergy subsidies and correct "flawed accounting" that considers bioenergy as carbon neural in renewable energy directives and emissions trading laws.

Menu Item: Achieve Replacement-Level Fertility Rates

Projected population increase, approximately half of which will occur in Africa, is the driving factor increasing food demand. Replacement-level fertility rates (~2.1 children per woman) must be achieved worldwide to achieve a sustainable food future. Many countries are on track to meet this goal, with the exception of Sub-Saharan Africa.

Sub-Saharan Africa has a projected fertility rate of 3.2 in 2050. "As a result, sub-Saharan Africa's population, which was 880 million in 2010, is projected to reach 2.2 billion by 2050 and 4 billion by 2100."[16] This explosive population growth further exacerbates food insecurity in a region that struggles with food security. To counter these issues, the report advocates for voluntary reductions in fertility levels by increasing educational opportunities for girls, reducing infant and child mortality, and providing increased access to reproductive health services. If replacement-level fertility rates are implemented by 2050, the population would only grow to 1.8 billion – closing one-quarter of the land gap and reducing the GHG mitigation gap by 17 percent.

Course 2: Increase Food Production Without Expanding Agricultural Land

The report emphasizes that boosting the natural resource productivity of agriculture is the most important element to achieving a sustainable food future.

Menu Item: Increase Livestock and Pasture Productivity

Pasture for livestock accounts for two-thirds of all agricultural land and as result its productivity has a significant impact on future land use and emissions. Increasing output per animal can be attainted "through improved food quality, breeding, and health care; and by increasing feed output per hectare."[17] While pasture productivity can be improved by "proper fertilization, growing legumes, rotational grazing, and adding supplemental feeds in dry season and during the last few months of 'finishing.'"[18] To achieve the scale of improvement needed, the report recommends that most ruminant farmers shift from low-management operations to intensive grazing and forage management; governments in developing countries establish livestock productivity targets tied to financial and technical assistance, and; improvement tracking systems should be implemented to help guide investments and monitor impacts.

Menu Item: Improve Crop Breeding to Boost Yields

Crop breeding can increase crops yields and help crops cope with environmental limitations. Traditionally, yield gains were driven by incremental crop breeding— "the assessment and selection of the best performing existing crops, followed by purification, rebreeding, production, and distribution."[19] Genetically modified organisms (GMOs), involving the insertion of genes from one plant into another, are also used to increase yields. There is some debate about whether inserting biological pesticides in plants via GMOs could create pesticide resistance in weeds and insects, leading to more pesticide use in the future.

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[15] Tim Searchinger et al. at 18.
[16] Tim Searchinger et al. at 23.
[17] Tim Searchinger et al. at 23.
[18] Tim Searchinger et al. at 23.
[19] Tim Searchinger et al. at 24.

Gene editing has the greatest potential, according to the report. Gene editing allows for crops to survive new diseases make them more efficient at absorbing GHG emissions. CRISPR-Cas9, a gene editing system, significantly increases opportunities in crop breeding. "CRISPR enables researchers to alter genetic codes cheaply and quickly in precise locations, insert new genes, move existing genes around, and control expression of existing genes."[20] The report recommends that research budgets for crop-breeding be significantly increased.

Menu Item: Improve Soil and Water Management

Another path to boosting crop yields is to rejuvenate degraded soils. Degradation is especially extreme in drylands that cover a significant portion of Africa and hold less water due to the loss of organic matter – making them less responsive to fertilizers. The report posits that incorporating the cultivation and conservation of trees into agriculture, known as agroforestry, is a promising approach to addressing this issue. Implementing these and other strategies to revitalize soil will take significant coordinated effort and have many obstacles to overcome. Namely, plants need to be breed with increased disease resistance to survive in the region and necessary fertilizers must be readily and cheaply available.

The report advocates for governments and international aid agencies in drylands (e.g. the Sahel) to "increase support for rainwater harvesting, agroforestry, farmer-to-farmer education, and reform of tree-ownership laws that can impede farmers' adoption of agroforestry."[21] For areas outside of drylands, targeted financial help to farmers may be a tactic to achieve incremental improvements that could motivate farmer efforts on a larger scale.

Menu Item: Plant Existing Cropland More Frequently

A significant portion of cropland goes unharvested each year – more than 400 Mha according to Food and Agriculture Organization (FAO) data. The FAO also shows that approximately 150 Mha is planted twice or more each year – known as "double cropping." "The ratio of harvests each year (harvested area) to quantity of cropland is known as the "cropping intensity," a ratio that FAO currently estimates at 82 percent."[22] The report contends that food production could be boosted without expanding croplands if existing cropland is planted and harvested more frequently. This could be done by double cropping or reducing fallow land. The report assumes an increase in cropping intensity to 85 percent but if it points out that an additional 5 percent increase would reduce the land gap by 14 percent. More study is needed to better determine the promise higher cropping intensity holds and how it can be practically implemented.

Menu Item: Adapt to Climate Change

While it is certain that climate change will negatively impact agriculture, the extent of this damage is uncertain. Some estimates predict global crop yield, without adaptation measures, to decline by at least 5 percent by 2050, with many predicting larger declines. In the short term, some crops will reap benefits from the added carbon dioxide brought by climate change and the extending growing season from warmer temperatures. However, climate change will also bring extreme heat that will damage crops including maize, wheat, and coffee.

New and extensive measures are needed to address the already clear climate impacts coming for global agriculture. Farmers will need regional crop-breeding systems to suit the changing local condition as well as small-scale irrigation and water conservation systems to deal with varying rainfall. Research organizations and the private sector must investigate breeding crops with climate change resistant traits, such as withstanding extreme heat. Additionally, governments will need to fund adaptation measures for predictable climate impacts such as sea level rise.

It is worth noting that the menu items in Course 2 are needed first merely to achieve the report's baseline. The

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[20] Tim Searchinger et al. at 24.
[21] Tim Searchinger et al. at 25.
[22] Tim Searchinger et al. at 26.

report acknowledges that "closing the land gap will requires demand-side measures (Course 1) and action to protect and restore natural ecosystems (Course 3), and why closing the GHG mitigation gap completely will require action across all courses."[23]

Course 3: Protect and Restore Natural Ecosystems and Limit Agricultural Land-Shifting

Agricultural land is not only expanding, it is shifting from developed to developing countries and to more productive, densely vegetated, areas resulting in further environmental degradation. This country shift, along with land shifting, "result in gross forest losses that are much larger than net losses"[24] that must be addressed.

Menu Item: Link Productivity Gains with Protection of Natural Ecosystems

Increasing agricultural productivity gains must be linked with protecting natural ecosystems. Doing so would discourage the conversion of natural lands to take advantage of this increased agricultural productivity. Governments possess the power to do this because in many countries the majority of natural lands are held by governments. For land in private ownership, "governments can combine enforcement with support for agricultural improvement on existing farmland to build social support."[25] Governments can also protect Indigenous Peoples' lands by protecting forests and recognizing local rights in these areas. The report urges governments and the private sector to clearly link agricultural improvement and natural ecosystem protection through numerous avenues including international finance, agricultural loans, supply chain commitments, and land-use planning.

Menu Item: Limit Inevitable Cropland Expansion to Lands with Low Environmental Opportunity Costs

Certain agricultural land expansion is unavoidable due to increasing food demand in Africa as well as global demand for vegetable oil in Southeast Asia. To curb negative impacts, this inevitable expansion should be conducted in areas that will cause less environmental damage. "Evaluation of land conversion requires assessing not only the loss of existing carbon but also the forgone carbon sequestration on lands that would otherwise regenerate, for example, on cut-over areas."[26]

The report proposes several tools that could help governments and aid agencies to connect agricultural improvement and natural landscape protection. For example, "tools and models must estimate likely yields and effects on biodiversity and carbon of different development patterns, incorporate information on various obstacles, and allow a wide range of stakeholders to explore acceptable alternatives."[27] Incorporating analyses of agricultural potential and existing farming systems with these tools could be used to guide use of agricultural improvement funds. These assessment tools will need to be used by governments to direct land-use regulations, manage publish lands, and plan road routes.

Menu Item: Reforest Abandoned, Unproductive, and Liberated Agricultural Lands

Reforestation of abandoned agricultural land or restoration of other natural ecosystems will be required to compensate for the inescapable agricultural land shift. The report asserts that the potential for reforestation is often overstated. In reality, "larger-scale reforestation to mitigate climate change will be possible only if agricultural land is 'liberated' through highly successful efforts to slow growth in food demand and intensify production on existing land."[28] Therefore, reforestation should be restricted to low productivity land with little potential for agricultural improvement, such as the degraded pastures in Brazil's Atlantic Forest region.

There should also be a greater emphasis by governments on creating diverse natural forests during reforestation – as opposed to single-species forests that lack biodiversity. The report points to practical lessons that

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[23] Tim Searchinger et al. at 28.
[24] Tim Searchinger et al. at 32.
[25] Tim Searchinger et al. at 33.
[26] Tim Searchinger et al. at 34.
[27] Tim Searchinger et al. at 34.
[28] Tim Searchinger et al. at 35.

government should heed during reforestation efforts. Costs can be kept down by keeping disturbances (e.g. fire and livestock grazing) away from land selected for reforestation. Lines of concessional credit can be extended within traditional agricultural loans for replanting trees and government funding can be provided to nurseries of native tree species. Monitoring programs will also need to be in place for protection enforcement and progress updates.

Menu Item: Conserve and Restore Peatlands

Peatlands are "wetlands that built up massive carbon-rich soils over hundreds of thousands of years."[29] The report argues that restoring the world's drained peatlands – much of which are used purely for grazing and hold little other agricultural use – should be the highest priority. The report estimates that "this small area is responsible for roughly 2 percent of annual human-caused GHG emissions."[30] Peatland restoration holds great potential since "eliminating half of peatland emissions would close the global GHG emissions gap by 5 percent, while eliminating 75 percent would close the GHG mitigation gap by 7 percent."[31] However, global restoration efforts are lacking.

The report listed the following actions that need to be taken to improve restoration including more funding for restoration itself as well as compensation to farmers and communities that do not partake in other land uses. Improved mapping and data collection will be needed to effectively restore peatlands since they cannot be recognized via satellite. Stringent laws are also required to stop peatlands from being converted into agricultural land.

Course 4: Increase fish supply

Fish, both finfish and shellfish, are critically important to billions of people living in developing countries. The report projects "fish consumption to rise to 58 percent between 2010 and 2050, but the wild fish catch peaked at 94 million tons in the mid-1990s and has since stagnated or perhaps declined."[32] As a result, wild fisheries management must be improved and aquaculture productivity increased.

Menu Item: Improve Wild Fisheries Management

Overfishing is a serious issue worldwide. "According to FAO, 33 percent of marine stocks were overfished in 2015, with another 60 percent fished at maximum sustainable levels."[33] Another study from World Bank determined that to allow fish stocks to rebuild, fishing would have to decline by 5 percent annually for 10 years. Recognized solutions to overfishing include limiting the number of fishers, capping catch levels to allow the fish population to replenish, protecting vital fish habitat, and avoiding fishing during breeding peeks and in critical breeding areas.

Attaining these seemingly straightforward solutions is complicated by social and pollical issues. Socially, it is difficult to convince individual fishers that they should abstain from reaping a public resource for the greater good. Politically, poorer countries lack strong laws and enforcement capabilities to control the waters off their coasts – a reality that foreign fleets from richer countries exploit.

To get fishers on board with reducing fish catch levels, the report recommends using catch shares, which limit overall fish catch and distribute shares of the catch among fishers. This gives fishers an interest in preserving a robust fishery. Community-based co-management systems can help compensate for weak oversight. These systems "combine territorial fishing rights and no-take reserves designed and supported by coastal fishing communities."[34] Putting an end to enormous fishing subsidies, which total approximately $45 billion each year,

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[29] Tim Searchinger et al. at 36.
[30] Tim Searchinger et al. at 36.
[31] Tim Searchinger et al. at 36.
[32] Tim Searchinger et al. at 39.
[33] Tim Searchinger et al. at 40.
[34] Tim Searchinger et al. at 40.

could also drastically reduce overfishing. Overall, combating overfishing is incredibly difficult and the report thus assumes a “10 percent reduction in wild fish catch between 2010 and 2050,”[35] and even this assessment requires major reforms.

Menu Item: Improve Productivity and Environmental Performance of Aquaculture

Since the 1990s, global fish supply growth has come from aquaculture. According to report projections, “aquaculture production would need to more than double between 2010 and 2050 to meet projected fish demand.”[36] While GHG emissions from aquaculture are much less than ruminant meats, and on par with poultry and pork production, there are still environmental issues. For example, critical wetland habitats (e.g. mangroves) are converted for aquaculture use, wild-caught fish are used to make fish feeds, the process requires significant freshwater use and can lead to water pollution. Aquaculture also faces high rates of fish disease. Overall, aquaculture will have to become more land-efficient, “especially because available land is constrained in Asia, where nearly 90 percent of aquaculture production occurs.”[37]

The report sets out several tactics to make aquaculture more sustainable while also meeting increasing fish demand including selective breeding, technological advancements in fish oil alternatives and disease control, pollution controls (e.g. water recirculation), spatial planning for aquaculture facility siting, and greater development of marine-based systems.

Course 5: Reduce GHG Emissions from Agricultural Production

The methods discussed earlier in this report work in tandem with efforts to reduce emissions since increasing productivity of livestock and reducing land-use demands also reduce emissions. However, even accounting for large productivity gains, the report predicts that GHG emissions from agricultural production will rise.

Menu Item: Reduce Enteric Fermentation Through New Technologies

Roughly half of all agricultural production emissions come from ruminant livestock. The primary source of these emissions is “enteric methane,” which is caused by microbes in ruminant stomachs. Efforts to reduce enteric methane thus far have been largely ineffective. Recently, however, the compound 3-nitrooxypropan (3-NOP) has shown promise in reducing methane emissions by 30 percent and potentially increasing animal growth rates. The report recommends that governments incentivize private sector employment of 3-NOP or other compounds by mandating use when the compounds are proven to mitigate emissions cost-effectively, fund large-scale 3-NOP projects, and continue funding research into reducing emissions from enteric fermentation.

Menu Item: Reduce Emissions Through Improved Manure Management

Manure is characterized as “managed” when farmers remove and dispose of manure produced by animals raised in confined areas. As the manure breaks down it emits both methane and nitrous oxide. “Pigs generate roughly half of these emissions, dairy cows just over one-third, and beef cows roughly 15 percent.”[38]

Most managed manure is kept in “dry” systems, “which account for 40 percent of total managed manure emissions despite low emissions rates.[39] Still, dry systems are preferable to “wet” systems that can have emissions 20 times higher per ton of manure. The report sees the separation of liquids from solids as an underappreciated technique to reduce emissions and increase the value of manure as fertilizer. Digesters, “which convert manure into methane for energy use,”[40] can also help decrease emission but can only be used for “wet” manure and must be monitored to keep methane leakage rates low.

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[35] Tim Searchinger et al. at 40.
[36] Tim Searchinger et al. at 41.
[37] Tim Searchinger et al. at 41.
[38] Tim Searchinger et al. at 46.
[39] Tim Searchinger et al. at 46.
[40] Tim Searchinger et al. at 46.

Progress towards improved manure management will also address many human health, environmental pollution and nuisance concerns. The report points to several encouraging approaches for improvement including phasing in regulations that encourage emission mitigation innovation, using government-funded programs to develop profitable technologies, and creating government programs to discover and rectify any leakages from digesters.

Menu Item: Reduce Emissions from Manure Left on Pasture

"Unmanaged" manure is the manure that is left in the fields where it is deposited. "According to standard emissions factors used by the IPCC, nitrogen deposited in feces and urine turns into nitrous oxide at roughly twice the rate of nitrogen in fertilizer."[41] Most studies hold little hope that this diffuse emission source can be effectively mitigated. The report, however, points to emerging mitigation technologies that show promise. These technologies include chemical nitrification inhibitors, which are applied to pastures and ingested by cows, and biological nitrification inhibition, which can be bred into planted grasses where manure is deposited. The report advocates for increased funding research into manure nitrification reduction methods and for governments to be proactive in implementing private sector incentives to use these nascent technologies.

Menu Item: Reduce Emissions from Fertilizers by Increasing Nitrogen Use Efficiency

Every year farmers apply fertilizers to crops and pastures but less than half of the nitrogen applied to farm fields is actually absorbed. The excess nitrogen either becomes runoff polluting waters or is released as gas (e.g. nitrous oxide) in the atmosphere. The report projects that emissions from fertilizers applied to crops, both synthetic fertilizers as well as manure, will increase from 1.3 Gt CO2e in 2010 to 1.7 Gt by 2050.

The percentage of nitrogen that is absorbed by crops rather than lost to the environment is known as the "nitrogen use efficiency" (NUE). The report asserts that innovations are necessary to improve NUE such as nitrification inhibitors or other "enhanced efficiency" fertilizers. However, nitrogen fertilizers are cheap and provide little incentive for farmers to change their ways. The report acknowledges this reality and suggests that governments implement flexible regulatory targets to drive fertilizer companies to create improved fertilizers, shift subsidies away from fertilizers where nitrogen use is excessive to support for higher NUE, support biological nitrification inhibition research, and finance on the grounds projects to purse high NUE using inhibitors and other state of the art technologies.

Menu Item: Adopt Emissions-Reducing Rice Management and Varieties

"The production of flooded or "paddy" rice contributed at least 10 percent of all global agricultural production GHG emissions in 2010, primarily in the form of methane."[42] Options to mitigate rice emissions include increasing rice yields, reducing methane production by removing rice straw from paddies before reflooding, reducing the growth of methane-producing bacteria by decreasing the duration of flooding, and breeding lower-methane rice. Employing "a single drawdown reduces emissions, and multiple drawdowns or dry planting plus one drawdown can reduce methane emissions by up to 90 percent."[43]

These tactics are not without obstacles – dry planting increases weed growth and while drawdowns decrease methane emissions they tend to increase the emission of nitrous oxide. As a result, the report proposes the initiation of a major breeding effort to shift to lower-methane rice, analysis into which farmers can employ drawdowns, program to rewards farmers who can participate, and increased efforts to boost rice yields through breeding and management.

Menu Item: Increase Agricultural Energy Efficiency and Shift to Nonfossil Energy Sources

The report predicts that "emissions from fossil energy use in agriculture will remain at about 1.6 Gt CO2e/year in 2050."[44] Mitigation efforts for emissions rely on switching to renewable energy sources (e.g. solar or wind

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[41] Tim Searchinger et al. at 47.

[42] Tim Searchinger et al. at 49.

[43] Tim Searchinger et al. at 49.

energy sources) and increasing efficiency. Hydrogen power generated by solar or wind power is another alternative energy option that is becoming more available due to declining solar electricity costs. The report estimates that "reducing emissions per unit of energy used by 75 percent, rather than the 25 percent in our baseline, would reduce the GHG mitigation gap by 8 percent."[45]

To reach this goal, the report suggests the following actions. Governments, large food purchasers, and aid agencies should incorporate efficiency programs and low-carbon energy sources into development efforts and supplier relationships with farmers. Funding into the production of nitrogen from renewable electricity should continue. Lastly, governments need to make a commitment to regulating fertilizer manufacturing emissions once viable low-carbon alternative technologies are accessible.

Menu Item: Focus on Realistic Options to Sequester Carbon in Soils

Scientists are now realizing that the mechanics of carbon sequestration in soils is not fully understood and harder to accomplish than previously thought. In fact, "here is some evidence that croplands are actually losing soil carbon overall in ways neither we nor other researchers count."[46] As a result, the report does not include additional soil carbon sequestration as a mitigation strategy but instead focuses on avoiding further soil carbon losses. Realistic strategies to stabilize soil carbon include to "avoid conversion of carbon-rich ecosystems (e.g. forests), increase productivity of grasslands and croplands, which adds carbon in roots and residues, increase the use of agroforestry, which builds above-ground carbon, and pursue efforts to build soil carbon, despite the challenges, in areas where soil fertility is critical for food security."[47]

Voluntary measures will not be enough to close the GHG mitigation gap. Flexible technology-forcing regulations are needed for fertilizer, manure management, and enteric methane inhibitors. Governments should phase in regulations that requires fertilizer manufacturers to sell increasing percentages of "enhanced efficiency" product (e.g. fertilizers with nitrification inhibitors). This would encourage the development of improved products and is in line with past regulation of agricultural inputs (e.g. pesticides). Historically, manure management has been weakly regulated but pollution control regulation should be phased in to eventually cover all facilities and farms. Since enteric methane inhibitors technologies are undeveloped, governments should proactively require use of feed supplements or appropriate drugs once mitigation technique becomes cost-effective. Providing this certainty would attract private sector development thereby speeding up needed innovations. While many of these options require upfront costs, they are cost-effective when compared to the climate change mitigation strategies of other sectors and may even pay for themselves in the long run.

IV. Conclusion

The menu items described above emphasize technical opportunities but they cannot be implemented in isolation – they are dependent on cross-cutting public and private policies. Cross-cutting policies the report examines include linking boosted agricultural productivity to reducing rural poverty, designing climate policies that account for the varied and diffuse emission sources of the agriculture and avoid double counting of land and biomass. The report also highlights that the world needs to drastically increase research and development for agricultural emissions reduction. Overall, the report contends that "the only ways to meet growing human demands for both food and carbon storage are to use land more efficiently and to consume agricultural products more efficiently."[48]

For more information on *Creating A Sustainable Food Future - A Menu of Solutions to Feed Nearly 10 Billion People by 2050 Synthesis Report,* click **here**.

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[44] Tim Searchinger et al. at 50.
[45] Tim Searchinger et al. at 50.
[46] Tim Searchinger et al. at 51.
[47] Tim Searchinger et al. at 51.
[48] Tim Searchinger et al. at 72.

Managing Ocean Acidity and Hypoxia Along the Coasts

The West Coast Acidification and Hypoxia Science Panel

I. Introduction

The chemical makeup of the world's oceans is fragile and any alteration of this delicate balance can lead to long-lasting negative consequences. Humans activities, namely carbon dioxide (CO2) emissions, have vastly altered the chemistry of the oceans over the past two decades and will continue to do so at an alarming rate. This alteration process is called ocean acidification (OA) and is driven by the absorption of significant CO2 emissions into the oceans. The absorption of CO2 changes the pH level (a metric for acidity) of seawater, increasing its acidity. This increased acidity threatens marine organisms (by weakening their ability to grow shell and skeletal structures) and impacts entire food webs, ocean ecosystems and the industries and communities that depend on them.

Research indicates that the West Coast of North America will be hit particularly hard by this global phenomenon. On top of OA, climate change will bring more intense and expansive hypoxic zones – areas of low dissolved oxygen that stifle marine life – to the world's oceans. OA and hypoxia are already impacting West Coast ecosystems and are predicted to become more intense and expansive as climate change continues.

The chemical changes occurring in the oceans today will continue over the next several decades even if CO2 emissions are stabilized now. Due to this reality, the West Coast Ocean Acidification and Hypoxia Science Panel (the Panel), working in partnership with the California Ocean Science Trust, sought to develop the scientific foundation needed to make informed management decisions on the West Coast.

This article summarizes recommendations of The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions

II. Summary of Recommendations

The Panel set out eight recommendations to address the impacts and issues related to ocean acidification and hypoxia (OAH)[1] and provide a path forward. For each recommendation, the Panel described specific actions that can be quickly implemented. The Panel sought to "highlight avenues where new science can quickly catalyze management options for addressing OAH."[2]

a. Reduce local pollutant inputs that exacerbate OAH

Local organic carbon and nutrient pollutant discharges can worsen OA. The breakdown processes of both organic carbon and nutrient pollutants contribute to hypoxic conditions that exacerbate OA. As organic carbon is decomposed by bacteria, dissolved oxygen is consumed which causes the CO2 levels to increase and pH levels to decrease – generating hypoxic conditions. The discharge of nutrient pollutants (e.g. nitrogen and phosphorous) into seawater sparks the rapid growth of algae, which is in turn decomposed by bacteria that further decreases the dissolved-oxygen levels and increases seawater acidity.

Currently, there is insufficient scientific information to identify specific locations where reductions in local inputs can significantly mitigate OAH impacts. However, the Panel suggested that, in general, local actions will be the most effectives in semi-enclosed water bodies where local processes dominate over oceanic forcing (e.g. estuaries). The Panel also

[1] OAH references both OA and hypoxia collectively.

[2] Chan, F., Boehm, et al., *The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions,* California Ocean Science Trust, 6 (April 2016).

suggested that West Coast managers seek a broad range of tactics including regulatory-based strategies and incentive-based approaches. For instance, "upgrades to wastewater treatment plants or investment in water reuse could be incentivized to design facilities that reduce nutrient discharges."[3]

To implement the above recommendation, the Panel listed several actions including: (1) generate an inventory of areas where local pollutant inputs are likely to exacerbate OA, (2) develop robust predictive models of OAH; and, (3) develop an incentive-based strategy for reducing pollutant inputs.

b. Advance approaches that remove CO2 from seawater

The Panel recommended that West Coast managers advance approaches that remove CO2 from seawater. Emerging science indicates that carbon reduction tactics have the potential to remove CO2 from seawater and counterbalance the decreases in pH caused by OA. Two potential carbon reduction methods include biologically-based approaches and abiotic based approaches.

Biologically-based approaches harness the natural processes of marine photosynthetic organisms (e.g. algae and plants) to capture CO2. Seagrass beds and kelp forests rank among the world's most productive habitats and have the ability to positively alter ocean chemistry. For instance, aquatic vegetation, including seagrasses and kelps, extract CO2 from seawater and convert it into living tissue thereby mitigating OA impacts.

Abiotic methods are those that increase the alkalinity (buffering capacity) of seawater or physically remove CO2 from seawater. Alkalinity is increased by adding either synthetic base chemicals or natural base minerals to seawater. Engineered approaches, including electrochemistry, electrodialysis, vacuum extraction, and aeration with a CO2 -depleted gas, can be used to directly remove CO2 from seawater. For instance, "shellfish growers on the West Coast have begun to use alkalinity management to offset the increase in carbonate mineral corrosivity from OA in hatchery settings."[4] These engineering processes, however, are still under development. The Panel determined that additional research is needed to ascertain the implications of these techniques.

In addition to providing OA mitigation, preserving and restoring aquatic vegetation can provide other benefits. For instance, the sediments anchoring the aquatic vegetation can sequester CO2 and act as a carbon sink. The creation of habitat for fish and other organisms is also a potential benefit offered by aquatic vegetation.

The utilization of aquatic vegetation's carbon removal abilities is happening all along the West Coast, including off the coasts of Vancouver Island, Washington and Oregon. The Panel pointed to these examples to illustrate the potential of aquatic vegetation preservation and restoration techniques to mitigate OA in local ecosystems. Many outstanding questions remain about the effectiveness of these measures, but if proven fruitful, these techniques could provide managers with a much-needed tool to combat OA.

While these techniques hold promise, there remain unanswered questions regarding the application and scale of these techniques and how they will practically mitigate OA impacts. To clarify this uncertainty and ensure a path forward the Panel suggested the following actions: (1) use demonstration projects to evaluate which locations are optimal for implementing CO2 removal strategies, (2) generate an inventory of locations where conservation or restoration of aquatic vegetated habitats can be successfully applied to mitigate OA; and, (3) consider CO2 removal during the habitat restoration planning process.

c. Revise water quality

Water quality criteria are critical for properly managing water resources. Water quality criteria provide the metric used to determine the condition of a water body and to track progress for improving its water quality. Current water quality criteria, however, are severely lacking when it comes to evaluating OA conditions. New water quality criteria need to be created and expanded to include OA parameters beyond pH, such as aragonite saturation state. Aragonite saturation state "has been found to be more biologically relevant than pH for shell-

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[3] Chan, F., Boehm, et al., at 7.

[4] Chan, F., Boehm, et al., 35.

building in calcifying organisms."[5] To bring about this change, the Panel suggested that water quality agencies and experts agree on parameters that will be part of OAH criteria for inclusion in new water quality criteria.

d. Reducing co-occurring stressors on ecosystems

There are many obstacles to survival that marine organisms face in addition to OAH. These stressors include warming ocean temperatures, toxic contaminants, harvest, biological invasion and physical disturbances to nearshore habitats. It is vital for West Coast managers to consider these stressors in their management plans and act to reduce the co-occurring stressors on ecosystems. The Panel asserted that managers need to act to integrate OA effects into the management of ocean and coastal ecosystems and biological resources such as marine managed areas and fisheries.

e. Advance the adaptive capacity of marine species and ecosystems

Marine species and ecosystems are resilient and can adapt to changing surroundings – this ability is known as adaptive capacity. Adaptive capacity can be bolstered by implementing passive management measures, such as using protected areas, or proactive management measures. Possible proactive measures include selective breeding, direct modification of genetic material, and translocation of organisms with high adaptive capacity. The Panel acknowledged that these proactive measures could lead to unintended harmful ecological or economic consequences and cautioned against using them when other adaptation methods are available.

In order to advance the adaptive capacity, the Panel suggested the following actions: (1) inventory the co-location of protected areas and areas vulnerable to OAH, and, (2) evaluate the benefits and risks to active enhancement of adaptive capacity.

f. Establish a coordinated research strategy

Although OA presents a pressing global problem, "OA research is still in its infancy, with 75% of all acidification science studies published in the last five years, and only a handful of studies to date that have addressed the combined effects of OA and hypoxia, or OA and temperature, or OA and any other stressor."[6] Without the requisite OA research, a scientific foundation cannot be developed on which to base management decisions. More research on OAH and it impacts is greatly needed. The Panel suggested that agreement among the multiple organizations that fund OAH research be created to establish joint research priorities.

g. Build out and sustain a West Coast monitoring program that meets management needs

Monitoring is the key to effective environmental management. Monitoring allows managers to assess the effectiveness of management actions as well as observe and predict OAH conditions. The Panel recommended that a comprehensive monitoring program be developed – one that measures chemical parameters as well as broader interrelated physical oceanographic, biological and chemical variables. The Panel opined that local West Coast monitoring capabilities could be easily scaled up and coordinated at a regional level to achieve coast-wide changes.

To bring about an improved West Coast monitoring program, the Panel proposed the following actions: (1) define gaps between monitoring efforts and management needs, and (2) enhance comparability of and access to OAH data.

h. Expand scientific engagement to meet evolving management needs

The Panel's work not only created a scientific foundation and framework for OAH management measures, but fostered collaboration within the community of scientists and managers on the West Coast. This unprecedented cooperation helps to ensure that the development of OA scientific research and products are scientifically-sound

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[5] Chan, F., Boehm, et al., at 27.

[6] Chan, F., Boehm, et al., at 10.

moving forward. In an effort to continue this region-wide collaboration, the Panel advised that a science task force be created.[7]

III. Conclusion

OA is a pressing issue – its detrimental impacts are already being felt on the West Coast and will soon be felt worldwide. In its report, the Panel provided an integral framework for how to deal with this issue, while describing the stark reality facing the oceans if no action is taken. Overall, the world's oceans demand sweeping and comprehensive actions in order to curb OA.

For more information on *The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions*, click here.

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[6] Chan, F., Boehm, et al., at 10.

[7] In response to The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions, California created the California OAH Science Task Force in September 2016, available here. The Task Force provides scientific guidance to the Ocean Protection Council on ocean acidification and hypoxia issues in California and along the West Coast.

Welcome to the Pyrocene: A fire creature remakes a fire planet

Stephen J. Pyne

Earth is a fire planet, the only one we know.Yet there was a time when it did not burn. The oldest fossil charcoal dates back to the early Devonian Period, roughly 420 million years ago, not long after vascular plants colonized the continents. But that was long after the planet itself formed, 4.5 billion years ago. Earth burns now because it acquired life. Life in the oceans filled the atmosphere with oxygen. Life on land piled fuels. Lightning strikes, the occasional volcano, and the rare extraterrestrial impact then ignited fires.

People raised in urban and industrial societies tend to experience fire within built environments—contained in torches and hearths, or burning wild through structures. But the fundamental story of fire is how it burns in living landscapes, taking apart what photosynthesis puts together. It is an ecological process to which life must adapt, while biological evolution enables and shapes it in turn. Hurricanes and floods can occur without a particle of life present. Fire cannot. It more resembles a locust infestation than an ice storm.

Plant species and communities adapt to fire as they would to rain or sunlight. Some have evolved thick bark or fleshy leaves that shield them from heat; others require heat to propagate, like those with cones whose wax must melt in flame to free seeds. Such species can create conditions that promote fire, and they can suffer from its absence. To say of a species that it is adapted to fire is like saying it is adapted to rain. More accurately, it responds to fire's patterns, or what is known as a fire regime. A fire regime is a statistical concept like climate. Just as a given climate can hold many types of storms that come in rough rhythms, so a fire regime can contain many types of fires in particular arrangements.

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Lightning sets fire to a pine tree in Boulder, Colorado

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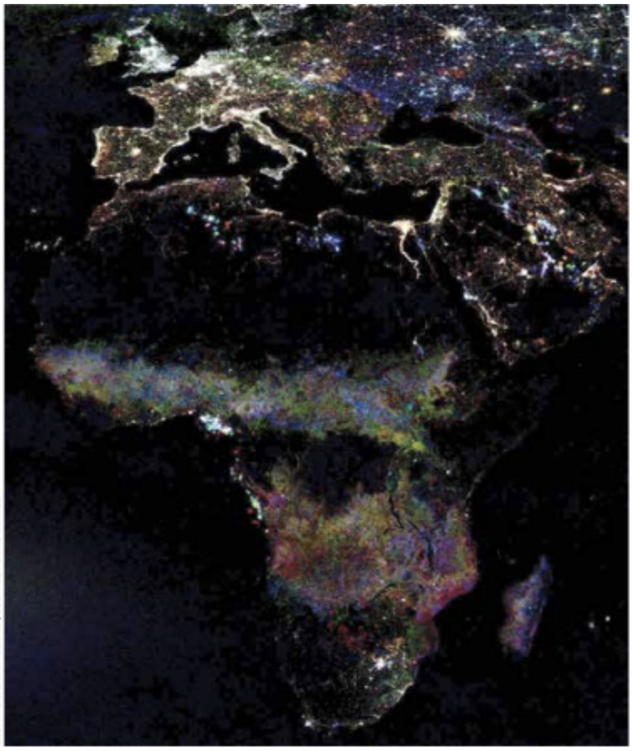

MODIS EUROPE AND AFRICA/NIGHTTIME LIGHT PROCESSED BY THE NOAA NATIONAL GEOPHYSICAL DATA CENTER, COURTESY CHRIS ELVIDGE

Satellite image of Europe and Africa at night: The bright lights come from the burning of fossil fuels or from such sources as nuclear or hydroelectric power that rely indirectly on industrial combustion. The pale lights of Sub-Sahara Africa mainly reflect the burning of surface biomass. The two kinds of fires generally compete, co-existing in a region only during a period of technological transition.

Fire and rain do interact, for what underlies the cadence of fire is a rhythm of wetting and drying. It has to be wet enough to grow fuels, then dry enough to allow them to burn. Forests burn during droughts, deserts after deluges. Places with routine patterns of wet and dry, such as monsoonal climates, burn regularly; dry-summer ("Mediterranean") climates have ideal wet-dry rhythms, though they often fail to connect with lightning, since thunderstorms occur unpredictably.

The Earth is vast, its "pyrogeography" varied and changing over geologic history. The upshot is that fire can appear lumpy in time and space. Some places burn annually, some not at all. Some intervals are flush with flame, some seem little more than pilot lights for more robust moments of conflagration. The Earth itself swings into and out of fire ages as it does ice ages. The Devonian only flickered with flame; the Permian Period, beginning about 300 million years ago, overflowed with it. Atmospheric oxygen levels have been higher or lower than today's 21 percent norm, from perhaps 15 percent in the Devonian to as much as 35 percent in the Permian.

The geologic record is rich in fire residues and transitions. Some coalbeds from the Carboniferous Period, which preceded the Permian, hold up to 70 percent fossil charcoal, called *fusain*. The 66-million-year-old "K-T" boundary between the Cretaceous and Paleogene periods is marked not only by iridium from the meteorite that wiped out the dinosaurs but also by fusain. The appearance of grasses in the Miocene, 23 million years ago, encouraged fire to spread in ways that damp-loving woody species could not.

Because Earth has life, and has had it so long, it has abundant stuff to burn. Living landscapes burn, half-buried peat burns, coal burns, even oil and gases escaping to the surface from deep rock burn. During mostly its history, Earth amassed more that could burn than did burn. It took something else to bring flame and fuel into closer alignment: a fire broker.

The genus *Homo* completed the cycle of fire for the circle of life. Life had long controlled oxygen and fuel; now it acquired the capacity to control ignition. As hominin species developed, so too did their ability to spread sparks. At one time not only early *H. sapiens* may have played with fire, but also Neanderthals and other members of our genus. But eventually we *sapiens* became fire's monopolists.

Fire brought us power. We got small guts and big heads because we learned to cook food. We went to the top of the food chain because we learned to cook landscapes. Now we have become a geologic force because we have begun to cook the planet. What we can't do directly with fire, we do indirectly. Fire allows us to cook sand, mud, ore, wood, and tar, yielding the products and technology to make tougher spears, metal tools and weapons, and machines that drive turbines and hurl projectiles. Without fire we are what so many origin myths portray, a minor species whose cleverness has no means to express itself.

Our alliance with fire may be our first Faustian bargain. Our environmental power is fundamentally a firepower. Yet fire, which thrived nicely without us, has also gained. We have expanded fire's domain, recoded its ecological patches and pulses, carried it to places that could never burn on their own, exhumed fuels from deep time and hurled their effluent into the future, even left the planet on plumes of fire. Our pact has rewired Earth's combustion characteristics. Together we have transformed what might have been another interglacial epoch into a fire age. The Pleistocene has yielded to a Pyrocene.

That did not happen instantly. The power of landscape fire derives from its capacity to propagate, and that resides in the topography, vegetation, and atmospheric conditions. People can kindle a spark, but the environment determines whether and how it will spread, and with what effects. We can improve the odds by the timing and placement of ignition, but nature imposes limits. A highly combustible prairie won't burn if it is covered with snow, or if mist replaces wind, or if stalks are flush with moisture and recent rain. We can bring fire to sites that have a suitable wet-dry cycle but lack consistent ignition. We can't force fire onto places that can't receive it.

That still leaves much of Earth open to anthropogenic burning to improve foraging and hunting and to protect against unwanted wildfires. Whether in Australian spinifex grassland, Siberian pine forest, or American oak-hickory forest, a common pattern emerges. Ignition follows routes of travel and those sites where people pause to extract some goods—whitetail deer, blueberries, or camas roots. The resulting lines of fire and fields of fire evolve over time and repeat across each year's seasons; together they provide a matrix within which any fire, of any origin, must burn. The most amenable landscapes are those rich in grass, which are annually available and which can respond quickly. For ab-original economies the usual formula is to burn early, burn light, burn often. Unless marine resources are abundant, an unburnable site is an unusable one.

Such habitats are largely gifts of nature. If people want more, they have to change those circumstances. Since they can do little about terrain—mountains and ravines are not easily leveled or filled—or about weather—people can't conjure up droughts or winds—that leaves the surface vegetation. Change the flora, and you change the fuels, which means you change the character of fire. You can even burn sites that could not, under natural conditions, carry flames.

How? Slash woods or organic soils and let them dry. Drain peat. Irrigate fields. Grow fallow. Loose cattle, sheep, pigs, and burros to eat, trample, tear at, and otherwise open up woods or brush, altering local sunlight and wind that renders vegetation more burnable. Fire fertilizes and fumigates, releasing chemicals readily accessible to cultigens, purging the native flora that are now considered weeds, and reconfiguring the microclimate.

This, for fire history, is the significance of agriculture, which lays down an altered pattern of pyric patches and pulses. In some systems the farm cycles around the landscape; in others, where rotational planting is the norm, the landscape in effect cycles through a fixed plot of land. Regardless, farming and herding have rewritten the character of landscapes, recoded their fire regimes, and put fire well beyond its natural dominions. Agricultural burning accounts for the greatest extent of anthropogenic fire.

Outside of floodplains (where water serves the role of fire), agriculture is an exercise in fire ecology. Fire does what so many fire ceremonies declare: it promotes the good and purges the bad. This perspective can also explain the long-baffling practice of fallowing. Agronomists have hated fallow since ancient times. It takes vital lands out of production, and worse, it is burned to prepare a field for new crops. Instead, we might pick up the other end of the stick and think in terms of fire ecology. The fallow was not burned to remove it, it was grown in order to *be* burned. Fire was not an afterthought: it was the purpose of the rotation.

Yet this suite of fire practices, too, has limits. It is possible to coax or coerce only so much out of a site before it degrades. Using the natural powers of fire kept fire within broadly ecological boundaries. Fire seasons might be expanded but not ignored; recycling biomass (or its constituent parts) could not make endlessly more biomass. Instead of renewing, acting as a biotic perpetual-motion machine, agricultural and pastoral fires might simply run down. If we want more fire, we need more fuel.

For most of human history the quest for fire has meant a search for more stuff to burn. That dynamic changed when people found a way to burn fossil biomass, first as peat and coal, and then as oil and gas. We evaded the limits of living landscapes by burning lithic ones.

The old quest for combustion sources has yielded to a new one for carbon sinks. There is now a virtually unbounded cache of fuels. The problem is what to do with all the effluent. The new fires—consider them industrial combustion—burn in machines, not in landscapes. They can burn day and night, winter and summer, through dry and wet. The old biotic borders have dissolved. Earth's lithic landscape no longer underlies the living one: it overlays it. We are taking stuff out of the geologic past and flinging it into the geologic future. Even the cadences of Earth's orbital cycles and wobbles that shape the rhythms of glacial epochs cannot, it seems, contain humanity's untrammeled fires. Climate history has become a subset of fire history. Fire is not simply filling the void of an interglacial but asserting itself with the power of a distinctive fire age. The so-called Anthropocene, the age of humans, might as aptly be termed the Pyrocene.

Its most publicized expression is global warming, followed by acidifying oceans, both driven by increased carbon dioxide in the atmosphere. But the new combustion subtracts as well as adds; it does not play well with the other forms of burning. It removes fire from landscapes, much as it removes flame from houses and factories, leading to two paradoxes, that for all our new firepower, many landscapes suffer from a fire deficit, and that most of our attempts to suppress fire in living landscapes only encourage worse fires. We have too much bad fire, too little good fire, and too much combustion overall.

We have two grand narratives for fire. The Promethean speaks of fire as power, as something abstracted from its natural setting, perhaps by force, and then directed as human hand and mind wish. The Primeval speaks of fire as a companion on our journey, of humans as keystone species and stewards for reconciling fire with land. Our future and that of the Earth depend on which of these narrative paths we choose to follow.

News and Announcements

American Geophysical Union

First Issue of AGU Advances Highlights Influential Science

AGU recently published the first issue of *AGU Advances*, AGU's new flagship journal. *AGU Advances* is a highly selective, gold open-access journal that publishes seminal research across the Earth and space sciences and related interdisciplinary fields. This research includes full-length research articles that advance our science and commentaries that discuss recent scientific results or trends and put them in context for a broader audience. AGU's editorial team also highlights important research published in Earth and space science and provides additional editorial content.

The research papers and associated content included in this first issue provide a great demonstration of the breadth of new research being published in Earth and space science, as well as excellent examples of the kinds of research papers and commentaries this journal will publish.

For more information, click here.

American Meteorological Society

Put Yourself in the Picture: The 2020 AMS Summer Policy Colloquium

June 1 signals the start of the 2020 AMS Summer Policy Colloquium. Each year since 2001, the colloquium has brought 30-40 early-to-mid-career scientists and engineers to Washington, D.C. for a ten-day introduction to science-for-policy and federal policy-for-science. (More than 600 people have participated over the years; President Trump's science advisor, Kelvin Droegemeier, was a Colloquium participant in 2002.)

Covid-19 has prompted us to modify and strengthen the format. This year will start with a number of virtual sessions running from June 1-9. If the pandemic and events allow, a 5-6-day face-to-face set of sessions will be scheduled for later this year. That will be followed by additional virtual sessions.

We still have a few participant openings. More information on the program, including registration procedures, can be found here. Any questions? Contact William H. Hooke at hooke@ametsoc.org.

American Society of Civil Engineers

ASCE Developing New Sustainability Standard

In civil engineering design, sustainability is too important to merely be implied or suggested.

So, ASCE's Committee on Sustainability is creating a performance-based, life-cycle sustainable infrastructure standard.

The committee's Standards Executive Committee has been developing "Standard Requirements for Sustainable Infrastructure" for nearly a year, aiming to have an innovative and essential industry standard ready for use in 2021.

"As we move toward a civil engineering industry that's based on sustainability, you now have to be able to answer the question: 'What is and what isn't sustainable?'" said John Frauenhoffer, P.E., M.ASCE, secretary for the Sustainable Infrastructure Standard Committee.

"What threshold of sustainability do you need to accomplish? It's important. And this will give civil engineers a benchmark as to what is sustainable as we attempt to move the industry to sustainable construction."

The proposed standard will be applicable across all infrastructure sectors, providing coherent and consistent performance-based objectives that can be included in procurement documents by owners, regulators, stakeholders and policymakers.

To read more, click here.

American Society of Landscape Architects Fund

American Society of Landscape Architects Creates Activity Book to Help Kids Learn About Landscape Architecture

In the midst of the COVID-19 pandemic, ASLA created a fun activity guide to help children who are stuck at home during nationwide quarantines due to social distancing.

While many parents and guardians are adjusting to the changes these quarantines have made towards academic learning, ASLA is providing families with a way to keep kids busy by introducing them to the world of landscape architecture. This free, downloadable activity book provides children ages 9-12 "the opportunity to see and sketch the many drawings, places, and landscapes created by landscape architects."

For more information, click here.

American Water Resources Association

2020 Annual Water Resources Conference

We are excited to announce that AWRA will hold its 2020 Annual Water Resources Conference as planned this November, though with major changes due to extraordinary circumstances. We will be "meeting" completely virtually. The Call for Abstracts has been extended until June 30, 2020. Stay tuned for more details on registration price and program so you can take part in the conference that has earned a reputation as one of the most diverse and inclusive conferences in water resources management.

AAFA has updated its Webinar Center making it easier to find the virtual content you need and want. Containing more than 25 recorded and live webinars, the AAFA Webinar Center houses information you need on a variety of water resources management areas. New webinars are added monthly!

For more information, click here.

Geological Society of America

International Declaration: Geoscience Expertise is Crucial for Meeting Global Societal Challenges

In May 2020, GSA signed onto a "Declaration of the Significance of Geoscience Expertise to Meet Global Societal Challenges." In this declaration, the organizations emphasize that humanity's ability to both anticipate and meet current and future challenges depends upon the development of innovative science and technology, to understand their origins and to implement successful strategies for addressing them. In the document, the societies also recognize their shared responsibility to utilize scientific research results to increase humanity's resilience to single, as well as multiple and interrelated, societal challenges, whose cascading effects can only be understood by carrying out complex analyses with which geoscientists have particular expertise.

In addition to reaffirming their commitment to use science to help humanity prevent, prepare for, and recover from regional and global crises, the organizations pledge to effectively communicate research results to improve the public trust in science. The societies, including the European Geosciences Union, American Geophysical Union, Asia Oceania Geosciences Society, Geological Society of America, Japan Geoscience Union and Geological Society of London, further agree to support policy makers and evidence-informed decision making for the benefit of society and the planet.

For more information, click here.

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