SAVING WATER FOR NATURE

Ten Grand Challenges for Water and Biodiversity Conservation

CONSERVATION X LABS

GORDON AND BETTY MOORE FOUNDATION

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Martinez, B. and J. Sullivan (2019).
Saving Water for Nature: Ten Grand Challenges for Water and Biodiversity Conservation. Washington, D.C.
Conservation X Labs.
www.conservationxlabs.com

ABOUT CONSERVATION X LABS

Conservation X Labs (CXL) is a leading technology and innovation startup based in Washington, DC, harnessing exponential technology, open innovation, and entrepreneurship to improve the efficacy, speed, cost, and scale of global conservation efforts and democratize science and technology to end human-induced extinction. Founded in 2015, CXL has launched multiple global open innovation competitions with a diverse coalition of public, social, and private sector organizations and has developed award-winning technologies in partnership with leading universities including the DNA Barcode Scanner, a field-based genetic species analysis tool. Conservation X Labs founders and team have a powerful track record of building successful innovative global platforms, programs, and technologies that have brought measurable change in some of the world's most challenging environments.

To inspire a broader community and source and develop other conservation innovations, CXL employs its Digital Makerspace (www.conservationx.com), a mass collaboration and crowdsourcing platform to bring together the science, entrepreneurship, and technology communities and start projects and co-create tech-enabled solutions to conservation problems. The platform hosts an online community ideating on new conservation technology solutions; provides tools, processes, and connections to advance and develop technology solutions; and facilitates marketing opportunities and access to prototyping funding through the Con X Tech Prize to distribute and/or commercialize the solutions and maximize conservation impact. You can join the tribe on the Digital Makerspace at www.conservationx.com.

CONSERVATION X LABS

To learn about our mission and work, please visit our website at www.conservationxlabs.com.

Direct all inquiries about this document to water@conservationxlabs.org.

Sign up to stay informed about the Water and Biodiversity Challenge: https://conservationxlabs.com/water-challenge.

ABOUT THE COVER

What we put in the ocean ends up back in our systems. All drains lead to the ocean, so do not litter or throw things into the gutter or drain! Keep our blue plastic free! This rather obvious work illustrates how post-consumer waste gets stuck in the gyres and circulated through the marine ecosystem through the entire column depth of water! It also bioaccumulates into all marine wildlife, and ultimately ends up in our own bodies when we consume sea food. Be conscious of your impact on the world around you, and vote wisely with your wallet. Every decision you make has consequences—it's why Indonesia is ablaze, because we each elected to purchase unsustainably produced Palm-oil laden products. When the buying stops the scale of destruction drops!

"All The Way", Asher Jay, 2015

ABOUT ASHER JAY

Asher Jay is an international adventurer and public figure whose compelling paintings, sculptures, installations, animations, ad campaigns, and films all have a single purpose: to incite global action on behalf of wildlife conservation.

Asher's travels to the frontline have made her witness and story-teller, combatting illegal wildlife trafficking, promoting habitat sanctuaries and illuminating humanitarian emergencies. Her core message, again and again: biodiversity loss during the Anthropocene—the Age of Man.

Jay just opened two permanent exhibits at National Geographic Encounter in New York's Times Square—a large scale wall-mounted installation entitled Piece of the Planet, and an immersive, soundscaped installation called "Message in a Bottle." Much of her best-known work spotlights the illegal ivory trade. In 2013, grassroots group March for Elephants asked her to visualize the blood ivory story on a huge, animated digital billboard also in main hub of the Big Apple, Times Square. Viewed by 1.5 million people, the internationally crowd-funded initiative aimed to provoke public pressure for revising laws that permit ivory to be imported, traded and sold. Asher also participated in the Faberge Big Egg Hunt in New York, where her oval ornament helped raise money for anti-poaching efforts in Amboseli.

A nomadic globe trotter who fell in love with New York while studying at Parson's New School of Design, Asher Jay is determined to motivate you to understand you have real power in determining nature's fate, and your—our—wild future. See www.asherjay.com for more information

EXECUTIVE SUMMARY

Water is fundamental to all life on Earth, supporting vital ecosystems and a growing, urbanized human population. Competing economic and ecological demands of water and its security in the face of a changing climate put both people and biodiversity at risk. To prevent extinction, not only of the planet's biodiversity but also of the human species, we must seek to transform the ways we use, manage, and conserve water to maintain biodiverse freshwater ecosystems. Although our planet's conservation problems may seem daunting and more acute than ever, there has never been a greater era of opportunity for human ingenuity and of potential for technological advances and innovations to meet these challenges. The problems facing freshwater ecosystems need revolutionary, rather than evolutionary, solutions to meet the scale of the problems at hand. These solutions must reach the hands of many and successfully scale to achieve the impact and results that are needed.

As part of its mission to end human-induced species extinction, Conservation X Labs and the Gordon and Betty Moore Foundation will launch a global competition, ***Saving Water for Nature: Grand Challenges for Water & Biodiversity Conservation***, in 2019 in partnership with diverse strategic partners to incentivize, source, and scale innovations that solve pressing and emerging water and biodiversity conservation problems. This report proposes a set of **Ten Grand Challenges for Water and Biodiversity Conservation**. Over the course of 2018, Conservation X Labs conducted an extensive literature review and broad consultations, as well as researched past and ongoing prize and challenge competitions that address water and biodiversity conservation to develop the Grand Challenges proposed in this document. The research process was supplemented by two ideation meetings, the Water Little Think (March 2018) and the Water Big Think (May 2018), that convened world-renown experts from a variety of relevant sectors and institutions—conservation, multinational corporations, academia, and international development—to help prioritize the topics for a set of Grand Challenges.

The topics we describe in this report are those that are most suitable for a challenge competition model. To prioritize these challenges for a global competition, each one was analyzed and evaluated against six criteria (see the ***Selection Criteria***, page 5), which determined the prioritization and order. Half of the criteria were focused on the potential impact on biodiversity conservation of the challenge, and on the ability to address the underlying drivers of water quality and quantity, while the second set of criteria looked at the potential suitability of the problem as an open innovation challenge. analysis, the top three challenges address food waste, agricultural runoff, and protein production, and these are the most promising topics for an open innovation challenge. Challenges 4-7 also represent a set of suitable challenge topics that impact water and biodiversity conservation, while challenges 8-10 represent critical problems, but they are less suited to the challenge model.

A funder could choose to invest in a single challenge where it feels it would get the greatest impact, or diversify across multiple sectors, where it wants to have the broadest reach across water, or alternatively, choose related challenges, again launched sequentially that are concentrated in a specific area to build a community. For example, the agriculture-focused challenges (Challenges 1–3) could be launched in parallel, and the challenges that address water pollution and waste could also be launched together (Challenges 5 and 7). Given that water is a theme of these challenges, there are a number of potential combinations of challenges—Challenge 8 (Water-Positive Cities) and Challenge 9 (Resilient Wetlands) have synergies with the waste and water pollution challenges. Additionally, we could launch multiple challenges to address a few sectors, like combating invasive species, endocrine disrupters, agriculture, and mining.

Ten Grand Challenges for Water & Biodiversity Conservation

1. **Waste-Less Foods:** Innovations for Global Food, Feed, and Fiber Supply Chains
2. **Greening the Green Revolution:** Nutrient-Free Agricultural Runoff to Benefit Nature Worldwide
3. **De-Watering Protein:** Decreasing Protein's Environmental Footprint
4. **The Artisanal Mining Challenge:** Transforming Small-Scale Mining for Water and Biodiversity Conservation
5. **The Ten Rivers Challenge:** Innovating the Trash Stream
6. **Space Invaders:** Prevent, Detect, and Eliminate Aquatic Invasive Species
7. **"Micro"-Management:** Prevent, Recover, Reuse, and Eliminate Micromaterials and Endocrine Active Compounds in the Environment
8. **Water-Positive Cities:** Water Systems and Biodiversity Under Rapid Urbanization
9. **Resilient Wetlands:** Conserving and Restoring Wetlands for Biodiversity
10. **The Dam Challenge:** Replacing the Services Provided by Dams while Mitigating Ecological Harm

CHALLENGE SELECTION CRITERIA

Using the following criteria, we ranked challenges by their ability to achieve the greatest enduring impact and their focus on drivers rather than symptoms of extinction to create broad systematic change at scale. All ten challenges could be run, and this document could serve as the basis for continued work in freshwater ecosystems with open innovation. Please see the Introduction for detailed descriptions of the scores and criteria scales.

TABLE 1: CRITERIA

CRITERION	DESCRIPTION
1. WHAT IS THE IMPACT OF SOLVING THE PROBLEM ON GLOBAL BIODIVERSITY?	With this criterion, we seek to understand the problem's impact on water quality, quantity, and the timing of flow, and how that impact affects biodiversity. Specifically, we qualitatively assessed this impact based on available research or data across nine biodiversity metrics related to species extinction.
2. WHAT IS THE IMPACT OF A CHALLENGE ON SOLVING THE PROBLEM?	What impact would a solution have on the problem? Based on the known and imagined solutions to the problem that could be sourced with a challenge, will the challenge entice new solvers, reconceptualize the problem, or garner new public interest? Is this a moonshot?
3. HOW CROWDED IS THE INNOVATION LANDSCAPE?	This criterion assesses the competitive landscape for a prize or challenge. Would this challenge hosted by Conservation X Labs be duplicative of other current or previous challenges or prizes? Has the problem been solved or is close to being solved? Is there already substantial investment, or many innovators working on the problem?
4. WHAT IS THE DIRECT AND/ OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS?	Is there an obvious direct or indirect market that can sustain and scale the impact of the solution, and what is the size of the market? Is the market limited by legal, policy, cultural, access, or other significant barriers that need to be overcome?
5. WHAT IS THE TECHNOLOGICAL READINESS OF THE POTENTIAL SOLUTIONS?	A challenge can help drive the adoption of new solutions and inspire stakeholder action, but the solutions have to be ready for uptake. Based on the current solutions and potential, imagined solutions, where are the solutions on a modified version of NASA's Technology Readiness Scale?
6. WHAT IS THE SUITABILITY OF A CHALLENGE?	Not every problem makes a strong challenge or prize. Such tools are useful when the objective is clear, but the way to achieve it is not, and where there are many potential solvers who are willing to absorb risk. Is this a better grant than an open innovation competition?

CHALLENGE SCORE SUMMARY

We collected data to evaluate each of the criteria. Table 2 visually depicts the rankings for each challenge using a scale of 1 to 5 and visual representation of the scores using circles comparable to a pie chart. A score of 1 (or an open circle) is the lowest score for each criterion. The total score is summed over the six criteria. The challenges are ordered by this scoring system and ranked from 1-10; ties in total scores were resolved by placing the challenge with the greatest biodiversity impact first, as biodiversity conservation is the highest priority. Using the criteria, we list the challenges in order of recommendation by their impact and suitability as a challenge.

TABLE 2: CHALLENGE SCORE

CHALLENGE	1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
CHALLENGE 1: WASTE-LESS FOODS	◕	◕	◑	●	◕	◕	24
CHALLENGE 2: GREENING THE GREEN REVOLUTION	◕	◕	◔	●	◕	◕	23
CHALLENGE 3: DE-WATERING PROTEIN	●	◑	◔	●	◑	◕	22
CHALLENGE 4: THE ARTISANAL MINING CHALLENGE	◕	◕	●	◔	◔	◕	21
CHALLENGE 5: THE TEN RIVERS CHALLENGE	◑	◕	◕	◔	◕	◕	21
CHALLENGE 6: AQUATIC INVASIVE SPECIES	●	◑	◑	◑	◔	◕	20
CHALLENGE 7: “MICRO”-MANAGEMENT	◑	◕	◑	◑	◑	◕	20
CHALLENGE 8: WATER-POSITIVE CITIES	◔	◑	◑	◕	◕	◑	19
CHALLENGE 9: RESILIENT WETLANDS	●	◑	◔	◔	◑	◑	18
CHALLENGE 10: THE DAM CHALLENGE	◕	◔	◕	◑	◔	◔	17

RANKING BY BIODIVERSITY & CHALLENGE IMPACT METRICS

In addition to ranking the challenges by their overall score, we ranked the challenges by considering the criteria around impact on water & biodiversity, and whether the problems would make good challenge or prize competitions. There were a few surprises from this analysis: while the challenges addressing artisanal mining and innovating the trash stream scored relatively low on total biodiversity impact because it is unclear whether the problems lead to the extinction of species, they would still make excellent challenges based on the other criteria.

SUMMARY OF CHALLENGE SCORING

Biodiversity Impact Metrics (Criteria 1, 4, & 5)	Challenge Metrics (Criteria 2, 3 & 6)
1. De-Watering Protein (13)	1. Artisanal Mining Challenge (13)
2. Waste-Less Foods (13)	2. Ten Rivers Challenge (12)
3. Greening the Green Rev. (13)	3. Waste-Less Foods (11)
4. Space Invaders: Aquatic Invasive Species (10)	4. “Micro”-Management (11)
5. Resilient Wetlands (10)	5. Greening the Green Rev. (10)
6. Water-Positive Cities (10)	6. Space Invaders: Aquatic Invasive Species (10)
7. The Dam Challenge (9)	7. Water-Positive Cities (9)
8. “Micro”-Management (9)	8. De-Watering Protein (9)
9. Ten Rivers Challenge (9)	9. Resilient Wetlands (8)
10. Artisanal Mining Challenge (8)	10. The Dam Challenge (8)

In the next section, a short explanation is given for the respective rankings each challenge received in the Biodiversity Impact Metrics and Challenge Metrics that span the six criteria. The first category focuses on Impact Metrics (Impact on Biodiversity (1), Market Size (4), and Technological Readiness (5)). The second category focuses on Challenge Metrics (Impact of a Challenge (2), Competitive Landscape (3), and Suitability for a Challenge (6)). See Appendix II for the rankings by each selection criteria and these two combined metrics.

CHALLENGE 1: WASTE-LESS FOODS: INNOVATIONS FOR GLOBAL FOOD, FEED, & FIBER SUPPLY CHAINS

SUBCHALLENGES

A. **Keep Food Better, Longer:** Create innovations for the developed and developing world that improve the supply chain for food, fiber, and feed such that these products survive with less perishable loss. Innovations can exist throughout the supply chain, from field to consumption, and could include technological, financial, and behavioral innovations that improve the ability to deliver products at market rates with little to no waste. Solutions should address barriers to efficient supply chains for perishable goods at low cost. Examples may include:

   1. **Storage Against Spoilage:** Develop storage and packaging technologies that increase the shelf life of food products or facilitate the storage of foods for at least 2 years without the threat of spoilage from pests, fungal pathogens (such as aflatoxins and rusts), and other unexpected spoilage events.

   2. **Transportation & Cold Chain Efficiency:** Create systems to leapfrog the need for expensive cold chains including hyper-efficient cooling technologies, packaging and storage, and transportation to deliver fresh fruits, vegetables, and animal products at market rates

B. **Make the Unusable, Usable (Waste as Business):** Develop low-cost, accessible, market-driven innovations that create novel products or serve new markets with food, feed, and fiber waste (unused, unharvested, or byproducts) to create circular economies. Solutions should have the potential to expand at scale, harness consumer preferences and cultural practices, and seek to leverage markets to capitalize on waste as a business opportunity.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◕	◕	◑	●	◕	◕	24

SUMMARY ANALYSIS

Impact Metrics: While biodiversity impact did not receive a maximum score, food waste and inefficiencies in the food, feed, and fiber supply chain drive agricultural expansion, particularly in the developing world, destroying habitat and causing excessive water use and agricultural inputs globally. The combination of the massive, accessible market size, the technological readiness to scale solutions, and the growing public and industry interest in the problem indicates that it is a promising challenge.

Challenge Metrics: Although the competitive landscape is crowded both in open innovation and private investment, a challenge may be an optimal method to source solutions and possesses a high likelihood of creating transformative solutions to address food waste along the supply chain from field to consumer.

CHALLENGE 2: GREENING THE GREEN REVOLUTION: NUTRIENT-FREE AGRICULTURAL RUNOFF TO BENEFIT NATURE WORLDWIDE

SUBCHALLENGES

Both of these subchallenges seek breakthroughs to re-engineer crops and agricultural production so that excess nutrients do not runoff into waterways.

A. **Agricultural inputs in excess:** In regions where agricultural inputs are used in excess, develop solutions that leapfrog expensive infrastructure to grow more food, feed, and fiber while eliminating runoff of inputs, but maintaining yield without significantly increasing costs.

B. **Agricultural inputs are scarce:** In regions where agricultural inputs are scarce, develop solutions that leapfrog expensive infrastructure to grow more food, feed, and fiber while eliminating runoff of inputs.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◕	◕	◔	●	◕	◕	23

SUMMARY ANALYSIS

Impact Metrics: Nutrient effluent drives large-scale degradation of waterways and aquatic habitats in addition to land-use changes from agriculture. Due to this high biodiversity impact, a massive market size for agricultural products, and the technological capacity to create a second Green Revolution, this challenge could source solutions with significant impact to solve this global problem.

Challenge Metrics: Across the challenge metrics for impact and suitability, this challenge has a high likelihood of transformative change through an open innovation competition. However, the agriculture competitive landscape is quite crowded with a large array of investment and open innovation activity.

CHALLENGE 3: DE-WATERING PROTEIN: DECREASING PROTEIN'S ENVIRONMENTAL FOOTPRINT

SUBCHALLENGES

A. **Optimize replacements for animal-based proteins:** Increase the number of high-protein crops available as replacement products for animal protein through identification of new substitutes and/or development of new processes that improve the taste and texture of ingredients in plant-based meat production, but improve on the environmental impact of soy and other existing crops.

B. **Innovations that recreate the texture, structure, and taste of animal protein:** Improve consumer uptake of animal-free whole-meats (e.g., steaks, pork chops, bacon) to appeal to meat-eaters, for example, through material science and engineering of plant-based ingredients to improve the texture, structure, taste, and mouthfeel of products.

C. **Transform traditional livestock production:** Make traditional livestock production more efficient in the use of feed, water, land, and carbon, with no contamination of water resources while producing a product that is price competitive without a decrease in productivity. Solutions may include price-competitive, low-water, and low-carbon footprint alternative feeds for livestock (feeds should have similar, or better, nutritional value, and cost the same, or less, per kg to produce compared to conventional feeds).

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
●	◑	◔	●	◕	◕	23

SUMMARY ANALYSIS

Impact Metrics: The biodiversity impact of protein production cannot be overstated as it draws a majority of agricultural water use and land-use change. Significant barriers exist for technological capacity to create scalable, accessible solutions despite a large market for protein products and replacements.

Challenge Metrics: The competitive landscape represents a very crowded space for a potential challenge. While a challenge might be appropriate and suitable to tackle this problem, it does not offer the only pathway to achieve transformative innovations.

CHALLENGE 4: THE ARTISANAL MINING CHALLENGE: TRANSFORMING SMALL-SCALE MINING FOR WATER AND BIODIVERSITY CONSERVATION

SUBCHALLENGES

A. **The Global Mining Data Challenge:** Everyone, no matter their income or occupation, should have easy access to information about toxic chemicals in the waterways on which they depend. Develop frugal innovations that democratize access and analysis of data and information on the presence and concentration of mercury, cyanide, and other contaminants in water from Artisanal Scale Mining (ASM).

B. **Transform artisanal mining and remediation:** Eliminate or remediate water contamination and environmental damage to wildlife, watersheds, and ecosystems caused by artisanal, small-scale, and informal mining.

C. **Reform mining economics and supply chain:** Develop innovations that account for the humanitarian, social, and environmental costs of ASM commodities and drive consumer demand and preferences to low-impact sources.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◕	◕	●	◔	◔	◕	21

SUMMARY ANALYSIS

Impact Metrics: Small-scale mining presents growing biodiversity, economic development, and human health challenges as land-use changes in biodiverse regions and mercury pollution of waterways pose threats. Despite the demonstrable negative impacts of this form of mining, the market potential and technological readiness are severely lacking due to uncertainty on the uptake of solutions, who pays for their scaling, and pathways to legitimacy of this economic practice.

Challenge Metrics: This problem presents an optimal opportunity for a challenge to tackle a complex issue by attracting new solvers and generating investment due to a largely open competitive landscape. The potential impact and suitability of a challenge to produce transformative innovations for everything from mining practices to the global gold supply chain is high.

CHALLENGE 5: THE TEN RIVERS CHALLENGE: INNOVATING THE TRASH STREAM

SUBCHALLENGES

A. **Prevent trash from entering water in the developing world:** Create frugal, scalable solutions to prevent the leakage (and leaching) of materials and chemicals into water resources from informal and unregulated landfills or recycling operations, or the lack thereof. This subchallenge includes incentives, technologies, and approaches to ensure that no waste enters the water cycle through wastewater systems, storm water systems, groundwater, or surface water bodies, particularly in the rapidly growing coastal and riparian cities of the developing world.

B. **Waste-no-more – designing products to never be wasted:** Transform and re-design products and processes in order to make the “end of life” processes for discarded products fully sustainable so that no toxic waste is released into the environment (e.g., plastic packaging, electronics, building materials, etc.).

C. **Transparency in waste:** Innovations that offer access to data on the amount of waste, content of waste, and origin of waste to support decisions and systems changes that improve transparency in the waste management sector.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◐	◕	◕	◔	◕	◕	21

SUMMARY ANALYSIS

Impact Metrics: This challenge tackles cirtical biodiversity and development problems concerning complex, inefficient waste streams that result in polluted waterways. It is difficult to assess who will pay for solutions, which limits market size, while technological readiness appears poised to deliver critical innovations from consumption of goods to final disposal.

Challenge Metrics: Although a multitude of open innovation competitions and private investments have focused on plastics, few, if any have considered the trash stream as a whole. This is a unique space and opportunity for a challenge. A challenge would likely be an optimal and suitable method to source and develop solutions to global trash and waste stream issues.

CHALLENGE 6: SPACE INVADERS: PREVENT, DETECT, AND ELIMINATE AQUATIC INVASIVE SPECIES

SUBCHALLENGES

A. **Early detection for prevention & rapid response:** Detect the presence of aquatic organisms rapidly, at scale, and for a low cost *in situ*.

B. **Eliminate aquatic invasive species (AIS):** Develop cost-effective solutions to eliminate existing AIS populations without harmful environmental externalities to native populations or the ecosystem.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
●	◑	◑	◑	◔	◕	20

SUMMARY ANALYSIS

Impact Metrics: Invasive species pose a global threat to aquatic biodiversity, supplanting ecological niches and driving extinctions throughout the world. However, combined with a medium-sized market opportunity for solutions and a lower degree of technological readiness to ensure eradication of introduced species, this challenge would require more significant investment and time to drive impact.

Challenge Metrics: Invasive species challenges have launched for individual species, indicating both a high suitability for a challenge model and a somewhat competitive landscape, although a global call for invasive species detection and eradication solutions would be unique. However, it is difficult to forecast whether the innovations for this challenge would be sufficiently transformative and effective.

CHALLENGE 7: "MICRO"-MANAGEMENT: PREVENT, RECOVER, REUSE, AND ELIMINATE MICROMATERIALS AND ENDOCRINE ACTIVE COMPOUNDS IN THE ENVIRONMENT

SUBCHALLENGES

This challenge seeks low cost solutions that prevent, recover, reuse, and eliminate, transform or degrade:

A. **Endocrine Disrupting Compounds (EDCs):** Chemical compounds that affect endocrine systems (e.g., estrogens, progestins, androgens, bisphenols, pesticides, perfluorinated compounds, phthalates, organotins and perchlorate).

B. **Microplastics:** Plastic particles less than 5 millimeters long that originate from primary sources (e.g., glitter, microbeads used in cosmetics and personal care products) and secondary sources of plastics (e.g., the breakdown of larger plastic items).

C. **Synthetic Microfibers:** Synthetic fibers (e.g., polyester, acrylic, nylon, rayon) that are less than 5 millimeters long.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◑	◕	◑	◑	◑	◕	20

SUMMARY ANALYSIS

Impact Metrics: The biodiversity impacts of EDCs, microplastics, and microfibers are not fully known, although initial studies indicate chronic environmental exposure leads to disruptions in reproduction and survival of aquatic species. The market for filtration is well established, yet questions remain about the market uptake of more expensive, advanced technologies as well as the technological readiness to provide these kinds of tools at accessible price points, particularly for EDCs.

Challenge Metrics: This challenge has a high likelihood of producing transformative solutions due to its high suitability for a challenge competition model. This is, however, a relatively competitive space that is receiving increased attention due to the universal presence of these micromaterials in water, particularly with respect to synthetic fibers and microplastics. EDCs remain an open field of opportunity for innovation.

CHALLENGE 8: WATER-POSITIVE CITIES: WATER SYSTEMS AND BIODIVERSITY UNDER RAPID URBANIZATION

SUBCHALLENGES

A. **Decentralized biodiversity-positive water systems:** Create decentralized but networked systems to treat and distribute water within a city. Solutions would have measurable, positive impacts to biodiversity such as through reduced water imports, restored natural habitats, and exports of high-quality water to downstream ecosystems. Solutions should be cost-effective and scalable systems and/or technologies to treat, manage, and redistribute water from multiple sources (storm water, wastewater, greywater, etc.) within an urban center.

B. **Systems & materials for biodiversity and water-positive new cities:** Develop scalable, sustainable, cost-effective materials and systems for constructing new urban spaces that enable greater groundwater recharge, provide endemic habitat, prevent flooding, and prevent untreated storm or wastewater from entering waterways.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◔	◕	◑	◕	◕	◑	19

SUMMARY ANALYSIS

Impact Metrics: Rapid urbanization poses biodiversity risks both upstream and downstream of cities, yet the overall impact on extinctions from cities is likely low compared to alternative land-use changes. However, the potential market size of city-wide solutions, and increasing trend towards urbanization globally, coupled with a relatively high degree of technological readiness for solutions indicates a high capacity to solve this problem.

Challenge Metrics: The competitive landscape is relatively crowded in the urban and city design space as multiple open innovation competitions and private investment sources have incentivized new systems, designs, and processes for burgeoning urban areas. Due to this landscape and the high cost and time threshold to scale solutions, a challenge would be suitable and appropriate, though not necessarily optimal, to address this problem.

CHALLENGE 9: RESILIENT WETLANDS: CONSERVING AND RESTORING WETLANDS FOR BIODIVERSITY

SUBCHALLENGES

A. **Revolutionize Resilience:** Innovate technologies that maintain beneficial functions for natural and restored wetlands, given the impacts of environmental change and agricultural and urban expansion. Solutions may include developing wetland vegetation that is resilient to salinization, flooding, or natural disasters.

B. **Restore for function:** Innovations that improve artificial and restored wetlands (inland and coastal) to achieve functional physical, hydrologic, and soil conditions, including the soil chemistry, microbial communities, and biogeochemical processes that maintain the benefits provided by wetlands to sustain biodiversity.

C. **Incentivize Conservation:** Incentivize the conservation and restoration of functional and degraded wetlands or prevent the conversion of wetlands to alternative land uses by harnessing innovative financial, behavioral, or other scalable mechanisms to make wetlands economically viable and beneficial.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
●	◑	◔	◔	◑	◑	18

SUMMARY ANALYSIS

Impact Metrics: Wetlands are vital habitats for a wide variety of species worldwide that are experiencing rapid decline, threatened by land-use and environmental change. Wetlands degradation and destruction presents a truly global biodiversity impact. Despite this outsized biodiversity impact, the relatively small market size for solutions due to the externalized costs of ecosystem services, and limited technological readiness to produce adequate innovations limits this challenge's efficacy.

Challenge Metrics: The competitive landscape for wetlands is quite crowded, particularly regarding financial and behavioral innovations that incentivize restoration and conservation. There may still be additional financial innovations and technological solutions for improving artificial or constructed wetlands. However, the impact of a challenge would be mildly transformative and such a program would be appropriate and suitable.

CHALLENGE 10: THE DAM CHALLENGE: REPLACING THE SERVICES PROVIDED BY DAMS WHILE MITIGATING ECOLOGICAL HARM

SUBCHALLENGES

A. **Understand Dam Impacts:** Create scalable, low-cost data tools to equip decision makers to better understand, predict, and manage the cumulative upstream and downstream economic and biodiversity impacts of dams at scale.

B. **Mitigate Existing Dams:** Scalable solutions to mitigate the ecological damage caused by dams both upstream and downstream to maintain critical human and environmental functions including fisheries, sedimentation, and seasonal flows, and prevent the accumulation of toxic contaminants.

C. **Reframing Dams Design Challenge:** Revolutionize traditional design of dams to create biodiversity-positive dams of the future to meet a growing global demand for power.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◕	◔	◕	◑	◔	◔	17

SUMMARY ANALYSIS

Impact Metrics: Dams drive extinction by fragmenting vulnerable and migratory populations and altering the flow of water and sediment upstream and downstream. The global proliferation of dams drives a large biodiversity impact, although overall impacts on extinctions are not yet clear. The market for scaling solutions remains decentralized and contains significant technological barriers to widespread use of solutions.

Challenge Metrics: The competitive landscape suggests that a challenge would be unique and could perhaps solicit novel designs and modular innovations to existing dams. However, the relative impact of a design challenge, or even a data challenge, is projected to be low due to the high-cost and long timeline associated with building water infrastructure projects like dams.

SAVING WATER FOR NATURE

Ten Grand Challenges for Water and Biodiversity Conservation

INTRODUCTION

Water is the centerpiece of life on Earth. Water quality and quantity are inherently connected to biodiversity conservation: Freshwater ecosystems provide habitat for about 10% of Earth's biodiversity,[1] and humans rely on the global supply of freshwater to meet basic needs of food and shelter. Humans have manipulated waterways throughout recorded history to meet these needs.

10% of the Planet's biodiversity lives in freshwater ecosystems

9 billion people are expected to inhabit the Earth by 2050

Globally, populations of freshwater species have declined by **83% since 1970**

Fish extinction rates are over **100x higher** than their natural rates in in the U.S. and Europe

With the human population projected to reach 9 billion by 2050 and harrowing climate change predictions in place,[2] Earth is facing a matrix of complex, compounding problems that will jeopardize the future of the freshwater ecosystems on which humans and biodiversity depend. In the U.S. and Europe, fish extinction rates are over 100x higher than their natural rates. Globally, populations of freshwater species have declined 83% since 1970.[3] The past and projected decline of aquatic ecological integrity has enormous implications for political, economic, environmental, and social stability.

Stressors on freshwater ecosystems, stemming from global demand for energy, food, water, plastics, metals and natural resources, and the consumer products they form, will continue to grow as the population grows and incomes rise. Rapid urbanization is expected around the globe, but especially in Asia and Africa. The ecological integrity of freshwater ecosystems is threatened by a number of issues, including poor water governance, massive water engineering efforts such as dams and irrigation, extreme weather, climate change, land cover change, and invasive species, as well as competing uses of freshwater for agriculture, municipal water use, and industrial processes.[4,5,6] We may not yet know the full extent of ecological damage of emerging issues under climate change and population growth predictions. Our pursuit of scientific knowledge should run in parallel with deploying scalable and impactful solutions to avoid the worst-case scenarios.

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1 Dias MS, Tedesco PA, Hugueny B, et al. (2017) Anthropogenic stressors and riverine fish extinctions. Ecol Indic 79:37–46. doi: 10.1016/j.ecolind.2017.03.053 and, see pages 30-31 of https://www.wnf.nl/custom/LPR_2016_fullreport/

2 IPCC, 2018: Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, Y. Chen, S. Connors, M. Gomis, E. Lonnoy, J. B. R. Matthews, W. Moufouma-Okia, C. Péan, R. Pidcock, N. Reay, M. Tignor, T. Waterfield, X. Zhou (eds.)]. In Press. https://www.ipcc.ch/report/sr15/

3 Grooten M, Almond REA (2018) Living Planet Report 2018: Aiming higher. Gland, Switzerland. https://www.worldwildlife.org/pages/living-planet-report-2018 Accessed 5 Nov 2018

We see great opportunity for transformative change to conserve Earth's water and biodiversity. Rather than lamenting the problems associated with rapid growth of the human population, we need to channel global human ingenuity toward creating and implementing a different and better future. Our goal at Conservation X Labs is to incentivize and harness this ingenuity through innovation and technological advances and help bring the best innovations to scale in order to positively transform humanity's impact on freshwater ecosystems and biodiversity.

This report proposes a set of *Grand Challenges for Water and Biodiversity Conservation* to address drivers of freshwater ecosystem degradation. The Challenges, in summary, are as follows:

TABLE 1: SUMMARY LIST OF PROPOSED GRAND CHALLENGES FOR WATER AND BIODIVERSITY CONSERVATION

#	CHALLENGE TITLE
1	Waste-Less Foods: Innovations for Global Food, Feed, and Fiber Supply Chains
2	Greening the Green Revolution: Nutrient-Free Agriculture Runoff to Benefit Nature Worldwide
3	De-Watering Protein: Decreasing Protein's Environmental Footprint
4	The Artisanal Mining Challenge: Transforming Small-Scale Mining for Water and Biodiversity Conservation
5	The Ten Rivers Challenge: Innovating the Trash Stream
6	Space Invaders: Prevent, Detect, and Eliminate Aquatic Invasive Species
7	"Micro"-Management: Prevent, Recover, Reuse, and Eliminate Micromaterials and Endocrine Active Compounds in the Environment
8	Water-Positive Cities: Water Systems and Biodiversity under Rapid Urbanization
9	Resilient Wetlands: Conserving and Restoring Wetlands for Biodiversity
10	The Dam Challenge: Replacing the Services Provided by Dams while Mitigating Ecological Harm

4 He F, Zarfl C, Bremerich V, et al. (2017) Disappearing giants: A review of threats to freshwater megafauna. Wiley Interdiscip Rev Water 4:e1208. doi: 10.1002/wat2.1208

5 Vörösmarty CJC, Mcintyre PB, Gessner MO, et al. (2010) Global threats to human water security and river biodiversity. Nature 467:555–561. doi: http://dx.doi.org/10.1038/nature09440

6 Reid AJ, Carlson AK, Creed IF, et al (2018) Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol Rev. doi: 10.1111/brv.12480

PRIZES AND CHALLENGES

The problems facing freshwater ecosystems need revolutionary, rather than evolutionary, solutions to scale over the next decade. Our first step in achieving this goal is to launch a global Grand Challenge addressing the problems faced in this proposal.

Prizes and challenges can be a relatively straightforward approach to finding solutions yet require highly strategic implementation to efficiently and successfully identify impactful and innovative solutions. Conservation X Labs manages open innovation competitions as prizes and challenges and distinguishes the two based on the goals of the competitions.

Prizes set a clear objective or goal and award a single winner—the team or individual who achieves the objective first or most effectively. Prizes are intended to move the needle in terms of potential solutions, demonstrate a breakthrough, or, literally, show that the impossible is now possible. Monetary prizes, such as offering a lump sum to the winners of a contest, can help spur private-sector action and development. These lump sums can represent a return on investment for the winners and use the psychology of gamification to incentivize previously untapped innovators and encourage them to engage with difficult problems.

Challenges are similar to prizes in the way they tap into the wisdom and experience of "unusual suspects," but have a broader goal statement. Unlike prizes, they reward a handful of winners, rather than a single winner. Each winner may have a different manner or approach to reaching the goal. They seek to build communities of practice and spur cross-sectoral collaboration and participation to solve large, seemingly intractable public problems. By bringing together insight and experience from a variety of actors with different backgrounds, Grand Challenges can inspire out-of-the-box thinking and innovative approaches to problem solving.

THE PROCESS

The Grand Challenges for Water and Biodiversity Conservation were crafted over several months of desk research and literature review, expert consultation, in-person convenings, and prioritization exercises using set criteria.

Conservation X Labs began the process of identifying themes for a Grand Challenge by conducting an extensive literature search and, subsequently, mapping the topics where water use and water quality have direct or indirect effects on biodiversity. The outcome of this mapping process is captured in ***Figure 1*** (on page 30).

After mapping out the problem space, we explored existing efforts to incentivize innovations in water quality, water quantity, and biodiversity conservation. This research was summarized in earlier drafts of a working paper, referred to as the Landscape Analysis. The **Landscape Analysis** was used as the basis for two meetings. The first meeting—the Water Little Think—convened ten subject-matter experts in Washington, D.C. to review and provide feedback on the challenge topics presented in the first Landscape Analysis (see a list of attendees as well as people who were interviewed during the course of this design process in **Appendix A**).

The feedback from this first meeting was incorporated into a revised draft of the Landscape Analysis, which became the basis for our Big Think meeting, held in May 2018 on the shores of Lake Tahoe. The **Water and Conservation Big Think** was an exclusive, high-level meeting to envision challenges that would create breakthroughs at the intersection of freshwater and biodiversity conservation. Conservation X Labs invited a curated and select group of 32 global experts from diverse disciplines within conservation, multinational corporations, academia, and international development to identify “moonshots”.[7] The Big Think methodology is an ideation workshop that uses a collaborative engagement approach to tackle complex and systemic problems. The approach facilitates the knowledge of a network to uncover synergies and co-design novel solutions. The Water and Conservation Big Think was designed to widen the problem-solving lens and tap the collective intelligence that resides within and outside of the freshwater management and conservation community. In advance of the meeting, we asked the participants to review the Landscape Analysis and the proposed challenges and help prioritize challenge areas based on a few key questions: What are the biggest challenges? Where are the greatest opportunities for impacting biodiversity and water conservation and where are they most likely to occur? What insights from your personal and professional experience can you bring and share to help improve the potential impact of the challenges?

During the Big Think, the participants were given an overview of open innovation approaches; pitched a potential set of problems from the Landscape Analysis; invited to deconstruct and reconstruct the challenges, remix them, or propose new ones; and asked to vote to prioritize the problem statements and challenge options. The majority of participants agreed that global agricultural practices and urban growth are major drivers of negative impacts on water quality, quantity, and biodiversity. In addition to the challenges that rose to the top through voting and prioritization activities, a number of the participants strongly advocated for other potential challenges, including mining, invasive species, and food waste. The Big Think allowed us to review and rethink the draft Landscape Analysis, identify new frames for potential challenges around agriculture and changes in the developing world, particularly in cities, and follow new research leads.

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7 Moonshot: A seemingly impossible goal that, if achieved, moves humanity forward exponentially by 10x rather than incrementally by 10%. https://www.huffingtonpost.com/entry/what-is-a-moonshot_us_59ace5abe4b0c50640cd6096

Following the Big Think, the Conservation X Labs team conducted further research and refined the challenges based on feedback from the Big Think. We then circulated a revised draft to the Big Think community for review and comment and conducted additional consultation. Our research solidified the focus on cities and rapid urbanization as a lens for the challenges, and we developed additional challenges based on this insight. Following another round of revisions after the Big Think, we developed a core set of 10 challenges. However, there was broad recognition that we needed an evidence-based approach to be able to rank the challenges.

In the final step of developing the Landscape Analysis, the Conservation X Labs team focused on developing the criteria that allowed us to rank the challenges in terms of their impact on biodiversity conservation and the water problem they are addressing. The final step was to analyze each challenge based on the criteria, obtain additional evidence for each challenge against each criterion and rank the final list based on our assessment of the evidence.

SELECTION CRITERIA

Several critical challenges face water and biodiversity conservation and they arguably all need to be solved in the near future. However, we used the following criteria to rank the challenges and identify which would achieve the greatest enduring impact, push boundaries, and focus on drivers rather than symptoms, to create and bring systematic change at scale through an open innovation challenge model.

We developed the following criteria to prioritize the challenges:

TABLE 2: CHALLENGE SELECTION CRITERIA

#	CRITERION
1	What is the impact of solving the problem on global biodiversity?
2	What is the impact of a challenge on solving the problem?
3	How crowded is the innovation landscape?
4	What is the direct and/or indirect market size to scale and sustain potential solutions?
5	What is the technological readiness of the potential solutions?
6	What is the suitability of a challenge?

Challenge Scoring & Ranking System

In this document, each challenge is ranked based on the six criteria. The table below visually and numerically depicts how the scores are determined for each challenge using a scale of open circles (the lowest score of 1) to closed circles (the highest score of 5). The example below shows a score of 20 out of a total of 30 points. It scores the lowest on biodiversity impact (1 out of 5), and highest in technology readiness and challenge suitability categories (5 out of 5).

EXAMPLE SCORE FOR A CHALLENGE

1. Biodiversity Impact	2. Impact of Challenge	3. Compet. Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
○	◑	◔	◕	●	●	20

1. WHAT IS THE IMPACT OF SOLVING THE PROBLEM ON GLOBAL BIODIVERSITY?

This criterion seeks to understand the problem's impact on water quality and quantity, and how these measures affect biodiversity. We qualitatively assessed this impact based on available research or data regarding:

1. **Geographic range of the species, populations, communities, and ecosystems directly affected by the problem:** Is this a global problem, or is it limited to a narrow number of populations, species, or ecosystems, even if the drivers for the problem are global in scope?
2. **Uniqueness (% endemism) of habitat:** Are the species, populations, communities, and ecosystems affected unique?
3. **Diversity of a habitat:** The number, abundance, and diversity of species as measured by biodiversity metrics, such as the Simpson's Diversity Index.
4. **Ecological species importance:** Are the impacted species keystone and apex species such that the problem will disrupt functioning ecosystems?
5. **Endangered-ness:** Relative number of endangered or rare species threatened by the problem.
6. **Extinction risk:** Are the impacted species at a greater risk of extinction due to the problem dramatically affecting their life history (birth and death rates?)
7. **Ecological function:** What necessary ecological functions are negatively impacted by the problem? For example, does the problem impact the producers, consumers, or decomposers in the food-web of an ecosystem? Does it impact the biogeochemical or hydrological processes?
8. **Human cultural value of biodiversity:** Cultural values are intertwined with our notion of ecosystem services—what we determine as "benefits" provided by functioning ecosystems are influenced by diverse cultural constructs. Does the problem severely impact cultural values?
9. **Reversibility:** Can the impact of the problem be reversed if not solved?

WHAT IS THE IMPACT OF SOLVING THE PROBLEM ON GLOBAL BIODIVERSITY*?

***IMPACT TO BIODIVERSITY BASED ON THE FACTORS ABOVE**

SYMBOL	DESCRIPTION
○	None
◔	Small
◑	Medium
◕	Large
●	Global

2. WHAT IS THE IMPACT OF A CHALLENGE ON SOLVING THE PROBLEM?

This criterion seeks to understand what impact a successful challenge would have on the problem. Will the imagined solutions to the challenge be “moonshots”—radical and adventurous ideas? Based on the known and imagined solutions to the problem that could be sourced and potentially scaled with a challenge, will those solutions be transformative? Will the challenge reconceptualize how we address the problem, engage the public’s imagination, entice new solvers from new disciplines, or build new markets?

SYMBOL	DESCRIPTION
○	The imagined solutions to the challenge are not transformative (do not have the potential to reconceptualize fields, build markets, or harness existing incentives for change).
◔	The imagined solutions to the challenge will be incremental.
◑	The imagined solutions to the challenge will be mildly transformative.
◕	The imagined solutions to the challenge will be transformative.
●	The imagined solutions to the challenge will be very transformative, have the potential to reconceptualize fields, build markets, or harness existing incentives for change. This is a moonshot.

3. HOW CROWDED IS THE INNOVATION LANDSCAPE?

Selected challenges should be additive and influential. This criterion assesses the competitive landscape for a prize or challenge in terms of the current or existing prizes or challenges and/or in terms of investment in this area.

- Would a challenge hosted by Conservation X Labs be duplicative or additive to other existing prizes, challenges, accelerators, and incubators that are addressing similar or complementary problems?
- Are there numerous innovations in the space? Are many companies successfully working on the problem? Is substantial funding or investment into research and development dedicated to solving this problem? Is the problem on the verge of being solved?

SYMBOL	DESCRIPTION
○	Numerous innovations, research, and companies in this space receiving investment (VC, philanthropic, corporate) and/or generating revenue.
◔	Some innovations and research in this space receiving investment (VC, philanthropic, corporate) and /or existing challenges, accelerators, or incubators driving innovation.
◑	Some innovations and research in this space and/or existing (or former) challenges, prizes, accelerators or incubators driving innovation.
◕	Few innovations or research in this space and/or existing challenges, accelerators, or incubators driving innovation.
●	Few innovations or research in this space and/or no known existing challenges, prizes, accelerators, or incubators driving innovation.

4. WHAT IS THE DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS?

For solutions to have enduring impact, they must not only be effective but also sustainable and scalable without the help of philanthropy. We created a criterion to measure enduring impact through the following questions:

- Is there an obvious direct and/or indirect market that can sustain and scale the impact of the solution? If so, what is the approximate size of the market?
- Do potential solutions provide a compelling value proposition by solving a significant problem or by providing a significant benefit, that people are willing to pay for?
- Is the market limited by legal, policy, cultural, or other significant barriers that need to be overcome?

SYMBOL	DESCRIPTION
○	No obvious indirect or direct market(s) to scale solutions.
◔	No obvious indirect or direct market(s) to scale solutions, but there is philanthropic and/or government funding that allow solutions and enterprises to persist.
◑	Small or limited indirect or direct market(s) to scale solutions.
◕	Indirect or direct market demand to scale solutions, but limited by legal, policy, cultural, or other significant market barriers that need to be overcome.
●	Large, global indirect or direct market(s) to scale solutions.

5. WHAT IS THE TECHNOLOGICAL READINESS OF THE POTENTIAL SOLUTIONS?

Some potentially transformative solutions may need years or even decades to reach proof-of-concept or prototype stages. Solutions may also require high degrees of uncertainty or technological risk to reach their full potential. The challenge can help drive the adoption of new solutions and inspire stakeholder action, but the solutions have to be ready for uptake. This criterion is measured among the landscape of existing solutions.

- Based on the current solutions and imagined potential solutions, where are the solutions on a modified version of NASA's Technology Readiness Scale?

SYMBOL	DESCRIPTION
○	The potential solutions may take decades to develop. Equivalent to Technology Readiness Level (TRL) 1.
◔	Additional research may be necessary, or the potential solutions may take years to scale. TRL 2-3.
◑	Proof of concept for solution developed and tested. Potential pathways to scale. TRL 4-5.
◕	Prototypes developed and being tested for production. No further research necessary. Pathway to scale clear. TRL 6.
●	No further research or technological development is necessary for deployment of the technology. No barriers to scale. TRL 7 and above.

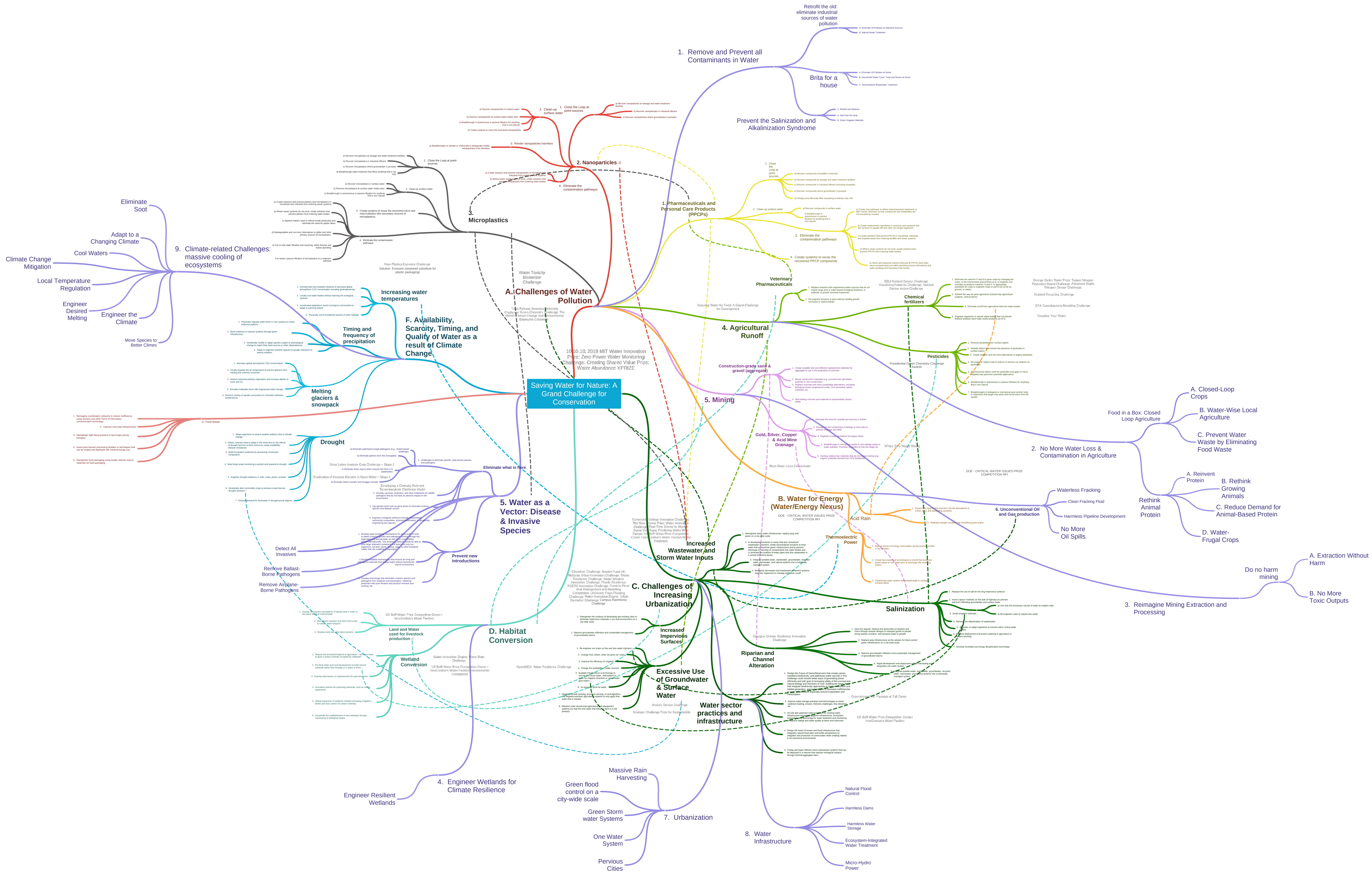
6. WHAT IS THE SUITABILITY OF A CHALLENGE?

Not every problem in the water space makes a strong challenge. Some problems are best addressed through further research and investment into existing solutions, rather than through a prize or a challenge. Prizes and challenges are useful tools for solving problems in which the objective is clear, but the way to achieve it is not. By attracting diverse talent and a range of potential solutions from unusual suspects, prizes draw out many possible solutions, many of them unexpected, and steer the effort in directions that established experts might not think to go but where the solution may nonetheless lie. Moreover, prizes and challenges shift the risk to the applicant. When the risk is too high, as in when addressing the problem involves major technological advances or redesign of infrastructure, this risk shift serves as a disincentive. We created a criterion to measure the suitability of each potential challenge.

- Is the problem better managed through a traditional grant funding program because the number of potential solvers is limited, the way to achieve the goal is clear, the end goal is unclear, or the risks for trying to solve the challenge or prize are too high?
- Will the challenge effectively incentivize the development and scaling of new solutions to address the problem?

SYMBOL	DESCRIPTION
○	A challenge will provide no additional incentive or value over an RFP or other traditional means to source solutions.
◔	Low confidence of challenge effectiveness to incentivize development and scaling of solutions.
◑	A challenge is appropriate but sub-optimal.
◕	A challenge is optimal but not the only method or model.
●	A challenge is optimal and the only model for incentivizing new solutions to the problem at hand.

FIGURE 1. DIAGRAM MAPPING THE WATER AND BIODIVERSITY CHALLENGE SPACE. SOME OF THE PROBLEMS LIST CURRENT OR PREVIOUS OPEN INNOVATION INITIATIVES TO SOURCE SOLUTIONS.



THE CHALLENGES

Conservation X Labs proposes the following set of *Grand Challenges for Water and Biodiversity Conservation*. We describe each challenge in detail in the following pages, according to their rank. In each section, we provide our summary assessment of the ranking criteria and discuss the importance of the problem and the evidence supporting our assessment of the criteria.

Ten Grand Challenges for Water and Biodiversity Conservation

1. **Waste-Less Foods:** Innovations for Global Food, Feed, and Fiber Supply Chains
2. **Greening the Green Revolution:** Nutrient-Free Agricultural Runoff to Benefit Nature Worldwide
3. **De-Watering Protein:** Decreasing Protein's Environmental Footprint
4. **The Artisanal Mining Challenge:** Transforming Small-Scale Mining for Water and Biodiversity Conservation
5. **The Ten Rivers Challenge:** Innovating the Trash Stream
6. **Space Invaders:** Prevent, Detect, and Eliminate Aquatic Invasive Species
7. **"Micro"-Management:** Prevent, Recover, Reuse, and Eliminate Micromaterials and Endocrine Active Compounds in the Environment
8. **Water-Positive Cities:** Water Systems and Biodiversity Under Rapid Urbanization
9. **Make Wetlands Great Again:** Conserving and Restoring Wetlands for Biodiversity
10. **The Dam Challenge: Challenge:** Replacing the Services Provided by Dams while Mitigating Ecological Harm

Challenge 1

Waste-Less Foods: Innovations for Global Food, Feed, & Fiber Supply Chains

SNAPSHOT: FOOD WASTE

*About one third, **1.3 billion tons, of total food production** is lost every year.*
*Global food waste equates to about **45 trillion gallons of water** lost per year worldwide.*

Food waste occurs along the value chain:

- *Production & waste on the fields*
- *Handling and storage & post-harvest waste*
- *Processing*
- *Distribution and Market*
- *Consumption*

In developed countries,
40% of the food waste occurs at the end of the value chain.

In less developed countries,
40% of the food waste occurs at the beginning of the value chain.

CHALLENGE 1: WASTE-LESS FOODS: INNOVATIONS FOR GLOBAL FOOD, FEED, AND FIBER SUPPLY CHAINS

This challenge seeks scalable solutions that will prevent food waste at every step in the supply chain. Solutions are intended to maximize water and energy efficiency in the production and use of food, feed, and fiber throughout their supply chains at radically lower cost. As a result of dramatically improved efficiency, less food would be wasted: less product would be lost along the supply chain requiring less product to be produced and, thus, less water would be wasted and consumed. Solutions should have no net negative effect on the environment or human well-being, *i.e.* no processes or materials that would directly or indirectly damage water or air quality or cause other forms of environmental damage above the current baseline. Solutions should aim for frugal engineering and design principles to serve developed and developing world contexts. Solutions can displace an existing technology or product or introduce a novel technology or process where none currently exists.

SUBCHALLENGES

A. **Keep Food Better, Longer:** Create innovations for the developed and developing world that improve the supply chain for food, fiber, and feed such that these products survive longer, with less perishable loss, including of nutrients and quality, without creating other environmental impacts. Innovations can exist throughout the supply chain, from field to consumption, and could include technological, financial, and behavioral innovations that improve the ability to deliver products at market rates with little to no waste. Solutions should address barriers to efficient supply chains for perishable goods at low cost. Examples may include:

1. **Storage Against Spoilage:** Develop storage and packaging technologies that increase the shelf life of food products or facilitate the storage of foods without the threat of spoilage from pests, fungal pathogens (such as aflatoxins and rusts), or other unexpected spoilage events, but with no significant collateral impacts on the environment or human health.
2. **Transportation & Cold Chain Efficiency:** Create systems to leapfrog the need for expensive cold chains including hyper-efficient cooling technologies, packaging and storage, and transportation to deliver fresh fruits, vegetables, and animal products at market rates, without a significant collateral impact on the environment or climate.

B. **Make the Unusable, Usable (Waste as Business):** Develop low-cost, accessible, market-driven innovations that create novel products or serve new markets with food, feed, and fiber waste (unused, unharvested, or byproducts) to create circular economies. Solutions should have the potential to expand at scale, harness consumer preferences and cultural practices, and seek to leverage markets to capitalize on waste as a business opportunity.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◕	◕	◑	●	◕	◕	24

PROBLEM SUMMARY

Growing food, feed, and fiber is by far the largest use of water and land by humans. Therefore, when we waste food, feed, and fiber, we waste significant amounts of water, and demand more land to cover for lost productivity. Alarmingly, about one third (1.3 billion tons) of total food production is lost every year.[8] Reducing food waste presents a significant opportunity to save water for nature.

Food waste encompasses all discarded products that are safe for human consumption. Food waste occurs along the entire supply chain but is more prevalent at particular nodes such as (1) harvest (e.g., food left on fields to rot, meat and fish spoilage before reaching consumers) and (2) market sale (rejected by consumers). Where food waste occurs along the supply chain varies in developed and developing economies due to factors including infrastructure, consumer attitudes and values, markets, and common practices.

Food waste is a global phenomenon, and estimates indicate that although industrialized and developing nations produce comparable total amounts of food waste, the causes of waste vary. In Europe and North America, *per capita* food waste at the point of consumption is 95–115 kg/year compared to 6–11 kg/year in sub-Saharan Africa and South/Southeast Asia.[9] In developed countries, 40% of the food waste occurs at the end of the value chain, when consumers either purchase too much perishable food for a single-family home or choose not to purchase imperfect produce.[10] In less developed countries, 40% of food waste occurs during harvest, post-harvest, and during the distribution of goods to markets.

In developing economies, significant investment has improved cold chains (temperature-controlled supply chains) and other forms of infrastructure to connect rural farms with markets in burgeoning urban areas. Without a cold chain, it is extremely difficult to transport highly perishable food without spoilage. Similarly, post-harvest storage facilities and food packaging methods are either insufficient or non-existent in rural areas of developing countries.

In developed nations, waste is more prevalent further along the supply chain, up to the point of consumption, often due to consumer preferences and retailer inefficiencies, and it leaves a tremendous amount of food to rot in landfills. It is critical to design environmentally sustainable solutions that get at the root of the food, feed, and fiber waste problems and can scale in both developing and developed economies.

8 The Guardian, "Produced but never eaten: A visual guide to food waste." https://www.theguardian.com/environment/ng-interactive/2015/aug/12/produced-but-never-eaten-a-visual-guide-to-food-waste Accessed 27 March 2018

9 http://www.fao.org/platform-food-loss-waste/food-waste/definition/en/ Accessed 8 Nov 2018

10 FAO. "SAVE FOOD: Global Initiative on Food Loss and Waste Reduction." http://www.fao.org/save-food/resources/keyfindings/en/ Accessed 30 March 2018

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

BIODIVERSITY IMPACT


The amount of water lost in food waste is a proxy for the amount of water diverted from aquatic ecosystems. Food waste equates to about 45 trillion gallons of water lost per year worldwide.[11] By some estimates, the waste in food production equates to 300 km^3 of water wasted in irrigation, and the price of this loss of water is estimated globally at USD 164 billion per year.[12]

Feeding a world of nine billion people with the finite water and natural resources at our disposal is a critical challenge for humanity and biodiversity conservation. Food waste is not only a question of development and food security, but is also of great importance for conservation of water resources, the global carbon footprint of food, and impacts on vital aquatic ecosystems that lie at the base of the food, feed, and fiber supply chains.

Irrigated waters are withdrawn from surface water and groundwater, which alters the hydrology and ecological functions of water bodies. Groundwater and surface water moderate the amount of water and flow throughout water basins. Thus, unsustainable (or wasted) water withdrawals for irrigation can have cascading effects, including changes to aquatic and terrestrial species composition and increased saltwater intrusion. Irrigation is preferred where possible because irrigated crops tend to be more productive than rain-fed crops. In the U.S., about 33% of water withdrawal is used for irrigation,[13] and globally, irrigation accounts for about 70% of water withdrawals.[14] India, China, and the U.S. are the largest consumers of groundwater for irrigation.[15] In particularly arid regions of the world, like the American West or sub-Saharan Africa, agricultural production diverts surface and ground water at unsustainable rates, which reduces water availability for other competing uses, and this is likely to be compounded by climate change.[16]

When researchers employed lifecycle analysis and connected food waste to the inputs required to produce those resources, it became clear that the global food waste problem places increasing stress on water resources. One study found that around one quarter of the produced food supply (614 kcal/cap/day)[17] is lost within the food supply chain. The production of the wasted food crops accounts for 24% of total freshwater resources used in food crop production (27 m^3/cap/yr), 23% of total global cropland area (31×10^{-3} ha/cap/yr), and 23% of total global fertilizer use (4.3 kg/cap/yr).[18]

11 Lipinski, B. et al. 2013. "Reducing Food Loss and Waste." Working Paper, Installment 2 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute. Available online at http://www.worldresourcesreport.org.

12 FAO (2014). "Food Wastage Footprint: Food Cost-Accounting." http://www.fao.org/3/a-i3991e.pdf Accessed 30 March 2018

13 Maupin MA, Kenny JF, Hutson SS, Lovelace JK, Barber NL, Linsey KS. 2010. Estimated Use of Water in the United States in 2010. USGS Circular 1405.

14 http://www.worldbank.org/en/topic/water-in-agriculture Accessed 7 Nov 2018

15 Siebert S, Burke J, Faures JM, Frenken K, Hoogeveen J, Döll P, Portmann FT (2010). Groundwater use for irrigation - A global inventory. Hydrology and Earth System Sciences 14:1863–1880. doi: 10.5194/hess-14-1863-2010

16 IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

17 kcal/cap/day = Kilocalories/capita/day

18 Kummu M, de Moel H, Porkka M, et al. (2012) Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci Total Environ 438:477–489. doi: 10.1016/j.scitotenv.2012.08.092

2. IMPACT OF A CHALLENGE

IMPACT OF CHALLENGE

It is a moonshot to eliminate all food waste; innovations could transform how we manage food production and consumption globally. A challenge is a viable mechanism to source and scale innovations as evidenced by the OpenIDEO Food Waste challenge. An additional food waste challenge is not the only mechanism to source solutions though, given that corporations, government agencies, and start-ups are making improvements and commitments; food waste is also an economic loss. A challenge that is more focused on food waste problems in the developing world could incentivize new scalable innovations and benefit emerging economies.

Solutions to the food waste problem would help reduce water and land use as well as agricultural inputs like fertilizers and pesticides by creating a better understanding of demand and more efficient supply chains. However, solving the problem of food waste is less direct than others challenges, and it will be difficult to measure the direct benefits that innovations have on biodiversity and water.

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE

Much attention has been paid to food waste as an issue, particularly as it relates to improving food security and economic opportunity for farmers in the developing world. There are large investments in cold chain solutions in developing countries, but only a few innovation challenges have been undertaken to date. In developed countries, a large number of start-ups, global food producers, and retailers are aiming to reduce food waste through new services, products, investment, or initiatives.

Innovation Landscape. A notable prize-backed challenge in this space was OpenIDEO's Food Waste Challenge in 2016. This challenge generated 453 solutions from around the world, demonstrating the opportunity for crowdsourcing innovative solutions.[19] One winner received investment from the Closed Loop Fund. When interviewed, OpenIDEO suggested that there is room to build off their food waste challenge. In particular, there is more opportunity in solutions around "Waste as a Business" to tackle the question of why we have food waste to begin with. In addition, few innovations and solutions from developing economies were finalists in the challenge. The challenge gained public exposure and grew a community that spurred an industry around using and reducing food waste, in part because they hosted a number of hackathon-type events during the challenge. OpenIDEO also developed the Food Waste Alliance, an online community to help accelerate the ideas from the competition.

Another notable current challenge is the Global LEAP Off-Grid Cold Chain Challenge, which is a prize-like competition incentivizing the creation of off-grid, energy-efficient, and cost-effective cold-storage devices to improve the cold chain in developing economies.[20]

19 https://challenges.openideo.com/challenge/food-waste/top-ideas Accessed 8 Nov 2018
20 http://globalleap.org/coldchain/ Accessed 8 Nov 2018

Public & Private Sector Investment. The OpenIDEO Food Waste Challenge included a number of industry, philanthropic, and private investment partners. As noted later in Challenge 3, food production companies are advancing food-related start-ups through direct investment or support through incubators and accelerators. In addition, the USDA and EPA launched the U.S. Food Waste Challenge in 2013 and sourced thousands of ideas and suggestions to combat food waste issues, some of which are being implemented through government programs such as school meals and government research. The USDA has enabled a community of businesses and organizations to combat food waste.[21] Since 2016, more than 20 corporations have made public commitments to be named "U.S. Food Loss and Waste 2030 Champions" by the USDA.[22]

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

The global annual cost of food waste is about USD 2.6 trillion.[23] Capturing even a small share of this market represents a large opportunity. Moreover, the demand for fresh fruits, vegetables, meats, and dairy will continue to grow globally, and with it, food waste losses. Furthermore, because food waste occurs throughout the supply chain, the opportunity for niche market segments that address regional problems is quite high, from solutions that prevent crop waste on farm fields, to leapfrogging expensive and inefficient cold chain solutions, to reducing waste at the point of the consumer.

MARKET SIZE

In the U.S., food waste is estimated at between 30–40% of the food supply (this corresponded to approximately 133 billion pounds and USD 161 billion worth of food in 2010). [24] This percentage suggests that half of increased future food security needs could be met by addressing food waste. Globally, the existing food waste management market is quite substantial, estimated to be USD 42.37 billion by 2022, and is segmented by waste type (e.g., cereals, dairy products), application (e.g., food waste as animal feed, fertilizers), end user (primary food producers, food manufacturers), process (e.g., composting via anaerobic digestion), and region;[25] the largest segment in 2016 was fruit and vegetable waste due to short shelf life and improper handling.

The market for cold chain systems and technologies is even larger: USD 148 billion in 2017 and projected to grow to USD 448 billion by 2025.[26] The innovations that result from this challenge may be able to scale due to the existing food waste management and agribusiness markets (see Challenge 2) and the demand for food. The greatest opportunity for solutions to scale lies in turning food waste into revenue and profit, including business-to-business (B2B) solutions to reduce inefficiencies in the supply chain.

21 https://www.usda.gov/oce/foodwaste/usda_commitments.html Accessed 8 Nov 2018

22 https://www.usda.gov/foodlossandwaste. U.S. Food Loss and Waste 2030 Champions are businesses and organizations that have made a public commitment to reduce food loss and waste in their operations in the U.S. by 50% by the year 2030. Since 2016, 21 corporations have been named U.S. Food Loss and Waste 2030 Champions. These champions include Ahold USA, Blue Apron, Bon Appétit Management Company, Campbell Soup Company, Conagra Brands, Delhaize America, General Mills, Kellogg Company, PepsiCo, Sodexo, Unilever, Walmart, Wegman's Food Markets, Weis Markets, and YUM! Brands.

23 FAO Food Wastage Footprint. http://www.fao.org/nr/sustainability/food-loss-and-waste/en/ Accessed 8 Nov 2018

24 USDA Food Loss and Waste. https://www.usda.gov/foodlossandwaste Accessed 8 Nov 2018

25 https://www.marketsandmarkets.com/PressReleases/food-waste-management.asp Accessed 8 Nov 2018

26 https://www.grandviewresearch.com/press-release/global-cold-chain-market Accessed 8 Nov 2018

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READNIESS

Because this is a global problem with market opportunity, innovation has been proceeding rapidly in areas as diverse as reducing consumer rejection of food, improving cold chain technologies, and limiting the waste of crops in fields.

The OpenIDEO Food Waste Challenge produced significant data about both the diversity of technologies and behavior change campaigns around reducing food. OpenIDEO estimates that there are currently more than 40 food waste start-ups at various stages of market readiness.[27] The solutions generated by the OpenIDEO Challenge are in a state of technological development that would make them appropriate for a challenge (generally around TRL 3–7). Of the OpenIDEO finalists, many solutions focused on innovations for developed economies, including changing consumer behavior, technologies to connect demand with usable food, and upcycling food waste into new food products.[28]

In the U.S., ReFED[29] is a clearinghouse for both technical and behavioral approaches to reduce waste, and the organization has analyzed and outlined a number of solution categories and innovations to address food waste. One company called LeanPath provides analytics and data for food facilities to prevent food waste toward the end of the value chain. ReFED estimates that data tools for food production facilities such as LeanPath can provide the greatest impact on water conservation.[30]

Improved packaging and storage and better understanding of supply and demand are additional problems that need more scalable innovations. Some examples of existing innovations include the following: **Hermetic Grain Storage Technology**, which is a three-layered bag-like device that reduces food waste;[31] **LiquiGlide**, a nontoxic coating applied to food packaging to increase the consumers' ability to get all of the food out of packaging like condiment bottles in order to reduce waste;[32] **Apeel**, a startup that created plant-derived coatings to keep produce fresh;[33] **Modified Atmosphere Packaging (MAP)**, a technology that substitutes the atmosphere inside a package with a protective gas mix (a combination of oxygen, carbon dioxide, and nitrogen) to extend freshness of food;[34] and a clay-based **Film Technology** that both prevents the infiltration of oxygen, which speeds the ripening process, and limits the escape of water vapor and gas.[35]

Cold chain innovations have included more efficient refrigeration as well as some materials that require less (or no) refrigeration.[36] More innovation is needed in this space and development agencies in governments such as the UK are acting on this need by sponsoring activities such as the Global LEAP Off-Grid Cold Chain Challenge.[37] Some of the cutting edge cold chain technologies to date include Promethean Power systems, mobile refrigeration units designed for small-scale milk production in developing countries, and mPower, a cold chain startup that created a modular refrigerator to keep produce fresh from farm to market.[38]

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27 Personal communication, Open IDEO estimate
28 See solutions here: https://challenges.openideo.com/challenge/food-waste/top-ideas Accessed 8 Nov 2018
29 http://www.refed.com/about Accessed 8 Nov 2018
30 https://www.leanpath.com/ Accessed 8 Nov 2018
31 http://www.knowledgebank.irri.org/step-by-step-production/postharvest/storage/grain-storage-systems/hermetic-storage-systems Accessed 8 Nov 2018
32 Carr A (2012) MIT's Freaky Non-Stick Coating Keeps Ketchup Flowing. FastCompany. https://www.fastcompany.com/1679878/mits-freaky-non-stick-coating-keeps-ketchup-flowing Accessed 8 Nov 2018
33 https://apeelsciences.com Accessed 8 Nov 2018
34 Visser W (2014) Tackling the food waste challenge with technology. https://www.theguardian.com/sustainable-business/tackling-food-waste-technology-refrigeration-packaging Accessed 8 Nov 2018
35 Sherman E (2017). Clay-Based Packaging Could Keep Your Food Fresher for Longer. Food & Wine. http://www.foodandwine.com/news/packaing-keeps-food-fresher-longer Accessed 8 Nov 2018
36 Global Leap Awards. http://globalleap.org/coldchain/ Accessed 8 Nov 2018
37 Promethean Power Systems. https://coolectrica.com/ Accessed 8 Nov 2018
38 MPower. https://mpowerco.org/ Accessed 8 Nov 2018

On the surface, the technological readiness level of the cold-chain solution space is at 7+; however, most cold chain solutions still employ vapor compression technology that use refrigerants with global warming potential (GWP) values much greater than those of carbon dioxide. In addition, mobile cooling technologies can have high leak rates of the refrigerants. Further, the energy efficiencies of these cooling technologies are typically very low, contributing large indirect CO_2 emissions as a result of the electricity needed to power the devices. Thus, there is a great need for innovation in cold chain technologies to significantly improve the GWP. A TRL value of 4–6 is more realistic for frugal, energy-efficient, and refrigerant-free devices within the cold chain.

6. SUITABILITY OF A CHALLENGE

SUITABILITY

Food waste is currently a popular issue, and OpenIDEO has already demonstrated the suitability of a challenge to incentivize and accelerate solutions. They ran a very successful challenge that created a large online community of practice and brought a number of corporate sponsors and partners to the table. USDA has also solicited commitments from a number of corporations, and those companies may look to new innovations to help meet their commitments by 2030. Therefore, there is a large base of partners and investment opportunities on which to build a successive challenge.

Another challenge in this space may elicit new solutions, especially for the developing world, where there is a demonstrated need for innovation. The greatest opportunities for innovation in developing economies lie in the beginning of the value chain: preventing food from rotting in the fields (before food gets to markets) and in improving the cold chain. A challenge could be successful in expanding the types of solutions and their reach, and it could create new market segments within agribusiness and food delivery in developing countries.

The discontinuities in markets for reducing food waste are likely a driver of system-wide inefficiencies. Challenges have the ability to ferret out inefficiencies and identify opportunities for innovation that will have both impact and market opportunity. A challenge in this space could lead to relevant solutions that reduce food waste and, as a result, lead to reductions in water and resource use that will benefit biodiversity globally.

Challenge 2

Greening the Green Revolution: Nutrient-Free Agricultural Runoff to Benefit Nature Worldwide

SNAPSHOT: NUTRIENT RUNOFF

*Excess nutrients like **Nitrogen (N)** and **Phosphorus (P)** runoff into waterways and cause eutrophication.*

*Agricultural production covers about **50% of the world's habitable land surface**.*

*The Gulf of Mexico has the **largest hypoxic dead zone** measuring over **6,000 miles in 2015**.*

*In 2013, **China, India, the U.S., and Brazil** were the leaders in N and P application, **accounting for 63% of global consumption.***

CHALLENGE 2: GREENING THE GREEN REVOLUTION: NUTRIENT-FREE AGRICULTURAL RUNOFF TO BENEFIT NATURE WORLDWIDE

Through the 1950s and 60s, the Green Revolution[39] led to increased crop production in developing countries due to increased use of pesticides and fertilizers and changes in the crop varieties used. Today, in some parts of the world, food, feed, and fiber are produced using an excess of inputs (e.g., N, P, pesticides, inorganic salts) or outputs (e.g., animal waste, sedimentation), which contaminate water sources through runoff or by leaching through soils into groundwater. In other parts of the world, farmed soils are depleted of nutrients and farmers do not have access to nutrient-rich fertilizers or other resources that would greatly improve crop production and food security. This challenge seeks scalable and frugal solutions to address water quality problems associated with agricultural inputs and outputs—nutrients, pesticides, sedimentation, inorganic salts, and animal waste—based on the regional context.

Solutions may effectively eliminate inputs, capture and reuse inputs before they reach water, or replace sources of contaminants with non-toxic alternatives. This is not a challenge to capture nutrients in waterways. Solutions should be frugal and scalable so that farms can leapfrog expensive infrastructure to grow more food, feed, and fiber without adding unreasonable marginal costs. In addition, solutions should be designed so that they can scale without government intervention and should not increase labor requirements or land-use footprints.

SUBCHALLENGES

Both of these subchallenges seek breakthroughs to re-engineer crops and agricultural production so that excess nutrients do not runoff into waterways.

A. **Agricultural inputs in excess:** In regions where agricultural inputs are used in excess, develop solutions that leapfrog expensive infrastructure to grow more food, feed, and fiber while eliminating runoff of inputs, but maintaining yield without significantly increasing costs.

B. **Agricultural inputs are scarce:** In regions where agricultural inputs are scarce, develop solutions that leapfrog expensive infrastructure to grow more food, feed, and fiber while eliminating runoff of inputs.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◕	◕	◔	●	◕	◕	23

39 The Green Revolution led to an increase in production of food grains (such as rice and wheat) due to the introduction of high-yielding varieties, greater use of pesticides, and better management techniques including fertilizers. See: https://en.wikipedia.org/wiki/Green_Revolution Accessed 8 Nov 2018

PROBLEM SUMMARY

Agricultural production today is incredibly resource intensive, covering about 50% of the world's habitable land surface and responsible for polluting vast stretches of water. Current approaches to agricultural intensification require increased application of nutrients in order to maintain soil productivity because intensive crop growth removes nutrients faster than they can be replenished naturally. The top three macronutrients applied to soil for agricultural intensification are nitrogen (N), phosphorus (P), and potassium (K). While excessive inputs of N and P can cause eutrophication, K is not a limiting nutrient in freshwater systems; excessive inputs of K into freshwater (e.g., via potash) can contribute to the salinization and alkalinization of freshwater.[41, 42] Finally, soil erosion due to farming practices can cause sedimentation in water.

Nitrogen is provided to the soil organically through: application of manure and detritus; growing nitrogen fixing cover plants (like peas and beans); adding bacterial probiotics; or as ammonia in artificial fertilizers. Phosphorus is found in manure, guano, and sewage treatment sludge, but in its natural state as rock phosphate it is inaccessible to plants. When these chemical or organic (e.g., manure, sewage sludge) sources of nutrients are applied in excess, they enter surface water through runoff and volatilization (N), or they leach through soils into groundwater. Nitrogen and phosphorus also enter waterbodies through storm water and wastewater effluent, but in the U.S., nutrients from agricultural runoff are an order of magnitude higher than other sources of inputs into water.[43]

In 2013, China, India, the U.S., and Brazil were the leaders in N and P application, accounting for 63% of global consumption.[44] Developed countries intensified the use of N and P in the 1970s and 1980s. Developing countries are just starting to intensify their use of macronutrients in agriculture and a number of countries in Africa still have low nutrient inputs.[45] In areas where soils are nutrient-poor, governments and international aid organizations have sponsored programs to increase access to fertilizers. A challenge that calls for innovations to limit nutrient application flies in the face of intensified agricultural practices. Yet, some states are realizing the downsides of excess nutrients in water and their impact on drinking water quality; residents in Iowa are noticing health effects due to excess nitrates in their water and they are investing in expensive municipal water filtration and testing systems.[46]

40 See charts and maps at Max Roser and Hannah Ritchie (2017) - "Fertilizer and Pesticides". Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/fertilizer-and-pesticides Accessed 8 Nov 2018

41 Freshwater salinization syndrome is characterized by the coupling of salinization (increased specific conductance of water over time) and alkalinization (increased pH of water over time) of freshwater bodies due to inputs of inorganic salts from anthropogenic sources and the accelerated weathering of minerals.

42 Kaushal SS, Likens GE, Pace ML, et al (2018) Freshwater salinization syndrome on a continental scale. Proc Natl Acad Sci 115:E574–E583. doi: 10.1073/pnas.1711234115

43 Ruddy BC, Lorenz DL, Mueller DK (2006) County-Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States, 1982 – 2001. USGS Scientific Investigations Report 2006–5012.

44 Lu C, Tian H (2017) Global nitrogen and phosphorus fertilizer use for agriculture production in the past half century: Shifted hot spots and nutrient imbalance. Earth Syst Sci Data 9:181–192. doi: 10.5194/essd-9-181-2017

45 Ibid

46 Schapiro M (2018) In the Heart of the Corn Belt, an Uphill Battle for Clean Water. Yale Environment 360. https://e360.yale.edu/features/in-the-heart-of-the-corn-belt-an-uphill-battle-for-clean-water-iowa Accessed 8 Nov 201

The global benefits of crop genetic improvement during the past Green Revolution are estimated in billions of dollars, mostly due to improvements in the three main staples: rice, wheat, and maize.[47] The Green Revolution contributed to widespread poverty reduction and avoided the conversion of thousands of acres of land into agricultural production, but the technologies, investments, and policies during the Green Revolution period favored and focused on intensifying crops where the return would be high, namely where there is access to water through irrigation and high rainfall.[48] To feed the growing human population while protecting biodiversity, farmers need to adopt innovations that intensify production in marginal and resource-poor agricultural lands and build in tolerance to climatic and biotic stresses such as drought, submergence, and warmer average temperatures.[49]

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

BIODIVERSITY IMPACT

Excessive nutrient use is not yet a global phenomenon, but the regional impacts of excessive nutrient use can be detrimental to aquatic life. High concentrations of N (nitrates) in water can cause health problems in humans and death in amphibians and fish.[50] In one study of North American water samples, 19.8% of the environmental concentrations of nitrate in aquatic sites bordering the Great Lakes ranged between 2.5 and 100 mg/L, which exceeds sublethal and lethal concentrations for amphibians.[51]

In addition, high concentrations of nitrogen and phosphorous in waterbodies contribute to eutrophication, a process that promotes the rapid growth of aquatic plants and algae, which can deoxygenate waterbodies. In some cases, algal growth can lead to harmful algal blooms, which negatively impact freshwater bodies because they produce toxins that move up the food chain and kill fish and animals (and can be harmful to humans). Eutrophication can also lead to hypoxia or anoxia in waterbodies. This occurs when algal cells die and the bacterial decay process depletes oxygen in the water column, leading to die-offs of oxygen-dependent aquatic organisms. Eutrophication of freshwater bodies can destroy ecological functions and collapse communities in an entire aquatic ecosystem. Excess nutrients and eutrophication in aquatic systems can contribute to a long-term and complex change process leading to a “tipping point,” where the entire ecosystem shifts from one state to another (e.g., from a clear, nutrient-poor lake to a nutrient-rich, turbid lake) thereby changing the aquatic and terrestrial community assemblages of flora and fauna.[52]

Hypoxia is not limited to freshwater. Rivers carry excess nutrients out to sea where hypoxic “dead zones” form. Because dead zones are depleted of oxygen, they cannot support oxygen-dependent marine life. The Gulf of Mexico, which receives nutrient-rich waters from the Mississippi River basin, has the largest hypoxic dead zone measuring at 5,840 miles in 2013 and over 6,000 miles in 2015. Other coastal hypoxic dead zones occur around the world due to runoff from agriculture and other anthropogenic sources—numerous

47 Pingali PL (2012) Green Revolution: Impacts, limits, and the path ahead. Proc Natl Acad Sci 109:12302–12308. doi: 10.1073/pnas.0912953109
48 Ibid
49 Ibid
50 Rouse JD, Bishop CA, Struger J (1999) Nitrogen pollution: An assessment of its threat to amphibian survival. Environ Health Perspect 107:799–803. doi: 10.1289/ehp.99107799
51 Ibid
52 Langdon PG, Dearing JA, Dyke JG, Wang R (2016) Identifying and anticipating tipping points in lake ecosystems. Pages Mag 24:16–17. doi: 10.1002/ecy.1558

coastal hypoxic areas were recently detected along the east and west coasts of North America, Central and South America, Europe, India, Australia, and a few locations in the East China Sea and South China Sea.[53] In addition, marine hypoxic zones are exacerbated by climate change and warming water temperatures.[54]

Potassium-based agricultural inputs, along with a number of other dissolved salts, affect freshwater systems as well. Most aquatic species thrive at pH levels between 6–8, while alkaline waters are characterized by pH levels from 8–9. An increase in pH due to an excess of dissolved salts (such as from K-based fertilizers) is a threat to freshwater aquatic organisms. For example, zooplankton are critical primary producers in the aquatic food chain, but they cannot survive in water bodies with high pH.[55] Salinization of freshwater bodies impacts a species' ability to osmoregulate, and although some freshwater species can withstand some salinity, cellular damage and possibly death results in highly saline waters.[56] Finally, sedimentation is both beneficial and detrimental to freshwater systems. Rivers have natural pulse flows that carry sediments downstream, which provides materials for microhabitats and nutrients for organisms in deltas and wetlands. But sedimentation can be detrimental to water quality when agricultural contaminants such as pesticides and other toxins bind to sediments and runoff into water, or when sedimentation is a chronic event that blocks sunlight from reaching the entire water column, thus preventing primary productivity.

In regions where soils are less productive and fertilizer use is low, such as in much of sub-Saharan Africa and Amazonia, eutrophication may be a localized problem, but when present it is likely due to untreated sewage rather than agricultural runoff of fertilizers.[57] A number of factors limit access to fertilizers and techniques that improve the productivity and sustainability of crops in sub-Saharan Africa. These factors may include issues that are beyond the control of small-scale farmers, such as global climate and market-economics, access to markets to purchase fertilizer and seeds or sell produce, labor shortages, limited farm credit, and poor governance.[58]

53 Breitburg D, Levin LA, Oschlies A, et al (2018) Declining oxygen in the global ocean and coastal waters. Science 359:eaam7240. doi: 10.1126/science.aam7240

54 Ibid

55 O'Brien WJ, de Noyelles F Jr. (1972) Photosynthetically elevated pH as a factor in zooplankton mortality in nutrient enriched ponds. Ecology 53:605–614. doi: 10.2307/1934774

56 Cañedo-Argüelles M, Kefford BJ, Piscart C, et al (2013) Salinisation of rivers: An urgent ecological issue. Environ

57 Mungai LM, Snapp S, Messina JP, et al (2016) Smallholder farms and the potential for sustainable intensification. Front Plant Sci 7:1–17. doi: 10.3389/fpls.2016.01720

58 Ibid

2. IMPACT OF A CHALLENGE

IMPACT OF CHALLENGE

If agricultural production globally used the right amount of inputs to both intensify production and eliminate water pollution, then the downstream problems of eutrophication, hypoxia, and freshwater salinization may occur less frequently and be less widespread geographically. Considerable investment, research, and innovations aiming to increase crop productivity are already underway. Open innovation has addressed nutrient sensors and recovery technologies in water.

However, preventing nutrient runoff at the source has not received as much attention through open innovation competitions. The moonshot is to maximize crop productivity while eliminating nutrient runoff into waterways. Achieving such an objective could make this challenge highly transformative, in effect, greening the green revolution.

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE

Although many resources are put into improving agriculture productivity and crop yields through open innovation and existing public and private research and development funding, this challenge serves as a call to action to increase productivity ***without*** adding harmful inputs, like nutrients, into waterways. There are also a number of investment and acceleration opportunities for start-ups in agribusiness.

Open Innovation Landscape. Previous and current global competitions have focused on agricultural innovations that reduce water use, sensors to detect and measure nutrients in water, and technologies to remove N or P from water. Other relevant challenges have sourced innovations to purify or desalinate water used in agriculture for local re-use.

The George Barley Water Prize is a current competition that is incubating the development of innovations to remove phosphorus from water to ultimately improve water quality in the Florida Everglades.[59] Tulane University recently concluded the Nitrogen Reduction Grand Challenge and awarded USD 1 million to an innovation called Adapt-N, which uses software models, real-time weather information, and local soil and crop management factors to monitor a field's nitrogen status and derive an optimum daily nitrogen rate recommendation.[60] The Nutrient Sensor Action Challenge seeks technological demonstrations of innovations that collect and display data via low-cost nitrogen and phosphorus sensors, and previous challenges by the same coalition of U.S. EPA-led government agencies solicited nutrient data visualization solutions as well as prototype testing of nitrogen sensors for use in wastewater treatment systems to monitor the long-term performance of industrial N removal.[61]

Solutions in USAID's Securing Water for Food Challenge were awarded grants for a number of scalable innovations and projects that addressed improving crop yield while using less water in developing countries. The challenge did not specifically reward water quality or nutrient-related innovations, but there *were* solutions for water quality submitted to the challenge.[62]

The OpenIDEO Water Resilience Challenge selected ten technologies that will make agriculture and water systems more resilient in the face of climate threats. The solutions were data and tech solutions designed to conserve water use, and one solution was a water quality monitoring tool to test for arsenic.[63]

59 George Barley Prize. http://www.barleyprize.com/#/ Accessed 8 Nov 2018

60 Tulane University Nitrogen Reduction Grand Challenge. http://www2.tulane.edu/tulaneprize/waterprize/competitors-adaptn.cfm Accessed 8 Nov 2018

61 Nutrient Sensor Action Challenge. https://www.epa.gov/innovation/nutrient-sensor-action-challenge Accessed 8 Nov 2018

62 USAID, personal communication. https://securingwaterforfood.org

63 https://challenges.openideo.com/challenge/water-resilience/top-ideas Accessed 8 Nov 2018

The U.S. Bureau of Reclamation concluded its More Water, Less Concentrate prize by awarding eight ideas that will maximize fresh water production from inland desalination systems in a cost-effective and environmentally sound manner. In addition, at the conclusion of the DESAL Prize, USAID and the U.S. Bureau of Reclamation awarded prize money to two teams for their brackish water desalination technologies: a team from MIT and Jain Irrigation Systems created a photovoltaic-powered electrodialysis reversal system, and a team from UTEP Center for Inland Desalination Systems was awarded for their Zero Discharge Desalination technology.

Public and Private Sector Investment. The growth of government and private sector investment in agricultural technologies has helped facilitate the development and scaling of new agricultural practices and efficiency technologies. For example, the Advantage Capital Agribusiness Partners invests in U.S. companies involved in all aspects of agribusiness value chains.[66] AgTech Week is a U.S.-based event that annually convenes agribusiness, investors, government agencies, and technology companies to facilitate investment and innovation.[67] Tech Connect World Innovation Expo and Conference has an agricultural innovation focus and also convenes innovators, government agencies, and investors.[68] In addition, AgFunder is an online investment platform for startups in the agrifood business.[69]

The global agricultural research institute, CGIAR, has an annual research portfolio of just over USD 900 million, and the organization provides a mechanism for national governments, multilateral funding and development agencies, and private foundations to finance the world's most innovative agricultural research.[70] Multiple sources of funding and investment are crucial as public spending on agricultural R&D by high-income countries has been falling in recent years.[71]

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

MARKET SIZE

The global food and agribusiness markets are massive, about USD 5 trillion and growing,[72] with multiple segments and opportunities to scale innovations from this challenge.

The global fertilizers market alone, including organic (manure, fish meal, etc.) and synthetic/inorganic (N, P, K, etc.) nutrients is estimated to reach USD 151.8 billion by 2020.[73] However, the biofertilizers market share is growing, and it is expected to exceed USD 3 billion by 2024. The projected increase is due to a combination of decreasing arable land availability resulting from excessive synthetic fertilizer consumption, increasing consumer preference for organic food, beneficial EU regulations and subsidies for biofertilizers, and widespread health awareness trends.[74]

Innovations that prevent nutrient runoff from farms need to appeal to farmers and offer incentives beyond the promise of nutrient-free runoff. Key barriers to scale in the developing world include costs, accessibility of particular technologies, and risks associated with adopting new technologies or crops.

64 Water Prize Competition Center. https://www.usbr.gov/research/challenges/ Accessed 8 Nov 2018
65 Desal Prize. https://challenge.gov/a/buzz/pages/usaid-desal-prize/ Accessed 8 Nov 2018
66 https://www.advantagecap.com/how-we-invest/business-lines/advantage-capital-agribusiness-partners/ Accessed 8 Nov 2018
67 AgTech Nexus https://atn.highquestevents.com/ehome/usa18 Accessed 8 Nov 2018
68 TechConnect https://www.techconnectworld.com/World2017/sym/Materials_for_Agriculture.html Accessed 8 Nov 2018
69 AgFunder https://agfunder.com/how-it-works Accessed 8 Nov 2018
70 CGIAR https://www.cgiar.org/funders/ Accessed 8 Nov 2018
71 Heisey P and Fuglie K (2018) Agricultural Research in High-Income Countries Faces New Challenges as Public Funding Stalls. USDA ERS Amber Waves. https://www.ers.usda.gov/amber-waves/2018/may/agricultural-research-in-high-income-countries-faces-new-challenges-as-public-funding-stalls/ Accessed 8 Nov 2018
72 Goedde L, Horil M, Sanghvi S (2015) Pursuing the global opportunity in food and agribusiness. McKinsey&Company. http://www.mckinsey.com/insights/Food_Agriculture/Pursuing_the_global_opportunity_in_food_and_agribusiness?cid=other-eml-alt-mip-mck-oth-15 Accessed 8 Nov 2018
73 https://www.marketwatch.com/press-release/fertilizers-market-to-reach-1518-billion-usd-by-2020---industryarc-analysis-2016-03-10-10203317 Accessed 8 Nov 2018
74 https://globenewswire.com/news-release/2017/12/29/1275925/0/en/Biofertilizers-Market-to-reach-3bn-by-2024-Global-Market-Insights-Inc.html Accessed 8 Nov 2018

In the U.S., consumers and municipalities pay for centralized water treatment; farms are not directly responsible or accountable for the costs borne by excess nutrients and agricultural contaminants. However, there are some cases of public perception about water quality shifting, and this may help drive the adoption of solutions. For example, in Des Moines, Iowa, the residents are noticing the negative health effects of excess nitrates in their water. The Des Moines Water Works utility paid USD 4.1 million in 1991 to install a nitrate removal facility, and the city (and tax payers) expect to spend USD 15 million to update the facility due to the high cost of cleaning up nitrates in water and the noticeable, negative health effects of excess nitrates.[75]

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS
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Biofertilizers utilize beneficial microbes that keep the soil environment rich in numerous micro- and macronutrients through nitrogen fixation, phosphate and potassium solubilization or mineralization, release of plant growth regulating substances, production of antibiotics, and biodegradation of organic matter in the soil.[76] Various biofertilizers are currently on the market and this is an active area of agricultural research.

More recently, scientists identified a gene that enhances plants' ability to absorb nitrogen, and this finding could be used to breed high-yield varieties of rice, wheat, and other staple crops that would need less fertilizer.[77]

Dow AgroSciences LLC, a winner of the Presidential Green Chemistry Challenge (2016 Greener Reaction Conditions Award) developed Instinct,[78] a nitrification inhibitor, which prevents soil bacteria from converting nitrogen into nitrate, increases nitrogen use efficiency, and reduces nitrogen loss through leaching and nitrous oxide emissions. In 2014, this technology increased crop production by an estimated 50 million bushels of corn and reduced emissions by 664,000 metric tons of carbon dioxide. Although additional testing and research is needed for some of these technologies, the technology readiness level ranges from 4–7.

6. SUITABILITY OF A CHALLENGE

SUITABILITY
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The problem of water contamination due to agricultural inputs and outputs is important and critical to solve. Previous and current challenges have focused on detecting the concentrations of nutrients in water and remediating contaminated waters, but this challenge would incentivize solutions that prevent water pollution at the source. This challenge seeks solutions further "upstream" to prevent nutrients from polluting waters while improving crop yields. There are a number of technologies and innovations that could be scaled to respond to this challenge, such as biofertilizers, engineered crops, or more effective use of crops to absorb and use excess N, P, and K to prevent these contaminants from reaching waterways.

Despite the drop in public investment in agricultural R&D in the U.S. (and other high-income countries), there are a number of private investors and opportunities for acceleration for start-ups in the agribusiness sector. The scalability of solutions faces some barriers, including the large market share held by the

75 Elmer M (2017) Water Works plans $15 million for expanded nitrate facility. Des Moines Register 24 May 2017. https://www.desmoinesregister.com/story/news/2017/05/25/water-works-plans-15-million-expanded-nitrate-facility/336648001/ Accessed 8 Nov 2018

76 Kato MSA, Kato OR, Denich M, Vlek PLG (1999) Fire-free alternatives to slash-and-burn for shifting cultivation in the eastern Amazon region: the role of fertilizers. F Crop Res 62:225–237. doi: https://doi.org/10.1016/S0378-4290(99)00021-0

77 Li S, Tian Y, Wu K, et al (2018) Modulating plant growth–metabolism coordination for sustainable agriculture. Nature. doi: 10.1038/s41586-018-0415-5

78 Presidential Green Chemistry Challenge. https://www.epa.gov/greenchemistry/presidential-green-chemistry-challenge-2016-greener-reaction-conditions-award Accessed 8 Nov 2018

inorganic and synthetic fertilizer industry and a lack of financing, insurance, or incentives for farmers to adopt non-polluting innovations.

A challenge could elicit and help scale solutions to prevent nutrient runoff and improve crop yields globally, but it is not the only useful method or model due to the numerous public, industry, and private investors in the space and global recognition that both too much and too little fertilizer is causing damage.

This proposed challenge is not about cleaning polluted water and recovering nutrients that are already in waterways. Rather, the challenge is to prevent agricultural runoff at the source. A challenge may be timely and provide an additional financial incentive to boost innovations, as there are already calls to action within the agriculture and food security fields to innovate for the second Green Revolution.

Challenge 3

De-Watering Protein: Decreasing Protein's Environmental Footprint

SNAPSHOT: PROTEIN PRODUCTION

70% increase *in food production by 2050,* ***2.4 times greater*** *nitrogen use,* ***2.7 times greater*** *phosphorus use,* ***1.9 times greater*** *water use, and* ***2.7 times greater*** *pesticide use.*

Global livestock production currently accounts for about ***one third of the total*** *water use in agriculture.*

The annual global nitrogen (N) inputs from manure is over ***100 million metric tons****, about the same amount as synthetic N-fertilizer applications.*

In the U.S., per capita meat consumption is ***three times*** *the global average.*

The water footprint per gram of protein for milk, eggs, and chicken meat is about ***1.5 times larger*** *than for legumes.*

CHALLENGE 3: DE-WATERING PROTEIN: DECREASING PROTEIN'S ENVIRONMENTAL FOOTPRINT

This challenge seeks novel processes and solutions that minimize or eliminate the negative effects on the environment of all protein production (including animal husbandry, cellular agriculture, aquaculture, and plant and insect replacement products) through significant reduction in or elimination of: water, fertilizers (N, P), pesticides, antibiotics, inorganic salts, carbon and methane production, and other materials or processes that damage water quality and the environment as compared with existing livestock and protein production at scale). Solutions should include a calculation of water, land, and energy used per gram of protein over the lifecycle of production.

SUBCHALLENGES

A. **Optimize replacements for animal-based proteins:** Increase the number of high-protein crops available as replacement products for animal protein through identification of new substitutes and/or development of new processes that improve the taste and texture of ingredients in plant-based meat production, but improve on the environmental impact of soy and other existing crops.

B. **Innovations that recreate the texture, structure, and taste of animal protein:** Improve consumer uptake of animal-free whole-meats (e.g., steaks, pork chops, bacon) to appeal to meat-eaters, for example, through material science and engineering of plant-based ingredients to improve the texture, structure, taste, and mouthfeel of products.

C. **Transform traditional livestock production:** Make traditional livestock production more efficient in the use of feed, water, land, and carbon, with no contamination of water resources while producing a product that is price competitive without a decrease in productivity. Solutions may include price-competitive, low-water & low-carbon footprint alternative feeds for livestock (feeds should have similar, or better, nutritional value, and cost the same, or less, per kg to produce compared to conventional feeds).

CRITERIA & SCORE:

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
●	◑	◔	●	◑	◕	22

PROBLEM SUMMARY

By 2050, the global population will increase to 9.6 billion people and billions will move into middle class and urban environments. This population growth will result in a need to increase food production by 70%, which equates to a billion more hectares of land coming into cultivation using today's methods. In order to meet the demand of the growing human population and middle class, scientists predict expansion and intensification of tropical agriculture, especially in sub-Saharan Africa and South America, leading to the rapid loss and alteration of tropical old-growth forests, woodlands, and semi-arid environments.[79]

79 Laurance WF, Sayer J, Cassman KG (2014) Agricultural expansion and its impacts on tropical nature. Trends Ecol Evol 29:107–116. doi: 10.1016/j.tree.2013.12.001

Moreover, producing 70% more food also correlates with 2.4 times greater nitrogen use, 2.7 times greater phosphorus use, 1.9 times greater water use, and 2.7 times greater pesticide use. This increase in production and use of inputs will have a profound effect on freshwater systems, habitats, and biodiversity.

Global livestock production currently accounts for about one third of the total water use in agriculture, or 2,422 cubic gigameters of water per year (87.2% green, 6.2% blue, and 6.6% grey water; see footnote for definitions).[80] In addition, livestock production contributes to water pollution and eutrophication through inputs of animal waste, fertilizers, and pesticides to grow feed crops—the annual global nitrogen (N) inputs from manure is over 100 million metric tons, about the same amount as synthetic N-fertilizer applications.[81]

The amount of animal protein consumed will significantly increase in the next few decades. In the U.S., per capita meat consumption is three times the global average. Consumption of meat is strongly correlated to rising incomes in developing countries and, therefore, as billions of people rise into the middle class in China and India, the demand for meat will also increase.[82] Urban populations tend to eat more meat than their rural counterparts, in part because urban and peri-urban infrastructure has institutionalized cold transport chains, which are essential for the mass transport of animal products.[83]

Per ton of product, animal products have a larger water footprint than do plants with the equivalent amounts of calories, protein, and fat. The water footprint per gram of protein for milk, eggs, and chicken meat is about 1.5 times larger than for legumes.[84] For beef, the water footprint per gram of protein is 6 times larger than for legumes. All other animal products (with the exception of butter) have larger water footprints per gram of fat when compared to oil crops.[85]

Ninety-eight percent of the large water footprint of animal products is the water required to grow livestock feed crops (e.g., soy, wheat, maize, etc.). Three main factors drive the water footprint of feed in animal production: the feed conversion efficiency of the animal (the more feed required per unit of animal product, the more water necessary to produce the feed), the feed composition (some feed ingredients require more water than others), and the origin of the feed (geographic location determines the source of water). The type of production system (grazing, mixed, industrial) is also important because it influences all three factors: grazing systems rely more on green water whereas industrial production systems rely on more blue water and surface water withdrawals.

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80 Mekonnen MM, Hoekstra AY (2010) The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands. http://waterfootprint.org/media/downloads/Report-48-WaterFootprint-AnimalProducts-Vol1_1.pdf. Mekonnen defines the types of water as: blue water = surface and groundwater; green water = rainwater, in that it does not turn into runoff and is used for consumption; grey water = amount of water needed to assimilate pollutants from production back into the hydrologic cycle. Accessed 11 March 2018

81 FAO (2018) Nitrogen inputs to agricultural soils from livestock manure. New statistics. Integrated Crop Management v. 24. FAO, Rome.

82 Schroeder TC, Barkley AP, Schroeder KC (2010) Income growth and international meat consumption. International Meat Consumption Journal of International Food & Agribusiness Marketing, 7:15–30. doi, : 10.1300/J047v07n03_02

83 Union of Concerned Scientists (2012). "Grade A Choice?: Solutions for Deforestation Free Meat." Meat. https://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/Solutions-for-Deforestation-Free-Meat.pdf Accessed 11 March 2018

84 The global average water footprint per ton of crop increases from sugar crops (roughly 200 m3/ton) and vegetables (~300 m3/ton) to pulses (~4000 m3/ton) and nuts (~9000 m3/ton). For animal products, the water footprint increases from milk (~1000 m3/ton) and eggs (~3300 m3/ton) to beef (~15400 m3/ton). See Mekonnen and Hoekstra (2010).

85 Mekonnen MM, Hoekstra AY (2010) The green, blue and grey water footprint of farm animals and animal products. Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands. http://waterfootprint.org/media/downloads/Report-48-WaterFootprint-AnimalProducts-Vol1_1.pdf. Accessed 11 March 2018.

Agricultural production of animal-based meat not only impacts water quantity on a global scale, it also affects water quality due to agricultural inputs (e.g., pesticides and fertilizers) needed to grow feed crops and outputs from livestock. Industrialized factory farming practices such as confined animal feedlots (CAFOs) concentrate agricultural pollution (e.g., antibiotics, growth hormones, and manure).[86] The resulting contaminated waste is either stored in large holding lagoons or allowed to flow into rivers, streams, and lakes through runoff or direct discharge, impacting local human communities and nearby watersheds. In the production of feed crops, pesticides and herbicides are applied to maximize yield, and these inputs contaminate water sources when they enter aquatic ecosystems primarily through agricultural runoff and the improper storage of the chemicals.[87] In the U.S., corn and soybeans occupy the largest agricultural land coverage and see the highest use of pesticides due to the prevalence of these two products in livestock feeds and human diets.[88]

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

BIODIVERSITY IMPACT
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Protein production has both direct and indirect, out-sized effects on biodiversity and water conservation. The vast majority of water used in animal protein production goes toward water inputs for animal feed crops. In addition, the production of animal-based protein leads to a loss of global biodiversity because agricultural production can fundamentally alter the functionality of ecosystems by replacing diverse communities with simplified habitats of monocultures; redirecting and redistributing water, thus changing the hydrological cycle of regions; adding toxic compounds to the aquatic environment through sedimentation and runoff; introducing non-native and invasive species; and stripping soils of nutrients and ecologically beneficial microbial communities. Conversion of land for production of food, timber, fiber, feed, and fuel is a main driver of biodiversity loss.[89] Thus, the challenge is to create adequate protein for humans while minimizing impacts on water quantity and quality and addressing a major driver of global biodiversity loss.

Agriculture globally occupies 50% of habitable land; as a result, a number of ecosystems have been converted and fragmented due to agricultural expansion.[90] Livestock production takes up nearly 80% of global agricultural land, but it produces less than 20% of the world's supply of calories.[91] In the U.S., 40% of the contiguous U.S. land cover is used for pasture and to grow feed crops for animal protein production.[92]

86 Burkholder J, Libra B, Weyer P, Heathcote S, Kolpin D, Thorne PS, Wichman M. (2007). Impacts of waste from concentrated animal feeding Concentrated Animal Feeding Operations on water quality. Environmental Health Perspectives 115:308–312. doi: 10.1289/ehp.8839.

87 Appelgren, BG (1994). Agricultural and Environmental Legislation - Lithuania, Technical Report. FAO-LEG: TCP/LIT/2352, Technical Cooperation Programme, FAO, Rome.

88 Fernandez-Cornejo J, Nehring R, Osteen C, Wechsler S, Martin A, Vialou A. Pesticide Use in U.S. Agriculture: 21 Selected Crops, 1960-2008, EIB-124, U.S. Department of Agriculture, Economic Research Service, May 2014. https://www.ers.usda.gov/webdocs/publications/43854/46734_eib124.pdf

89 IAASTD (2009) Agriculture at a Crossroads: Global Report. Washington, D.C. http://www.fao.org/fileadmin/templates/est/Investment/Agriculture_at_a_Crossroads_Global_Report_IAASTD.pdf Accessed 3 Nov 2018

90 See Our World in Data: https://ourworldindata.org/agricultural-land-by-global-diets Accessed 8 Nov 2018

91 Ibid

92 Merrill D and Leatherby L (2018) Here's How America Uses Its Land. Bloomberg. 31 July 2018. https://www.bloomberg.com/graphics/2018-us-land-use/ Accessed 8 Nov 2018

Worldwide, an estimated 2,300 species are threatened by the expansion of livestock farming.[93] In the U.S., livestock grazing is one of the greatest direct threats to the persistence of endangered and threatened species, affecting 14% of threatened or endangered animals and 33% of threatened or endangered plants.[94]

More than three-quarters of the land previously cleared in the Amazon River basin is now used either as pasture for livestock or to raise feed crops for domestic and international markets.[95] Cattle ranching has created small patches and isolated forest fragments in Amazonia. This mosaic of different land cover affects native species differently—for example, wide-ranging birds and mammals are more vulnerable to extinction than species with localized ranges and movements.[96] A 2009 study by the UN Environment Program reported that deforestation in the Amazon has led to the extinction of about 26 known species, and another 644 species of known plants and animals are threatened by extinction with increasing deforestation rates.[97] However, much of the diversity in the Amazon rainforest has not been explored or catalogued by researchers, so this projection is likely an underestimate.[98]

More directly, agricultural production withdraws and redirects water from ecosystems, which alters water availability for aquatic species. Deforestation also affects evapotranspiration and local rainfall. One stark example is in the Cerrado biome of Brazil. Global markets for livestock feed and water-intensive crops are driving the conversion of the Cerrado to agricultural production. The Cerrado is a “vital” source of water as 8 out of 12 of Brazil’s major river basins and three major aquifers rely on the Cerrado as a source for their water.[99] The Cerrado’s native vegetation used to cover 2 million km^2, or more than 20% of Brazil. However, less than half of the Cerrado remains today due to the expansion of international agribusiness—industrial farming has expanded to grow irrigated water-intensive crops such as soy, cotton, and corn for global markets.[100] The conversion of the Cerrado has reduced evapotranspiration by an average of 60% during the dry season, which can reduce regional rainfall and thus lead to a vicious cycle where farms need to pump more water to irrigate crops.[101]

Dietary change has the potential for a great impact on land and water use. Theoretically, if people shift to a diet that completely excludes animal products, the footprint of food production could be reduced dramatically: Land use by 3.1 billion ha (a 76% reduction), including a 19% reduction in arable land; greenhouse gas emissions by 6.6 billion metric tons of CO2 equivalent (a 49% reduction); eutrophication by 49%; and scarcity-weighted freshwater withdrawals by 19%.[102]

Livestock production is a way of life with cultural significance that should not be dismissed when considering replacements and innovations in the space of animal meat production. Yet, a number of ecosystems have been drained, flooded, burned, and otherwise converted to agricultural land, effectively changing the hydrology and species composition of landscapes—services that are also valuable to humans. Transforming the way that humans grow and consume protein may have one of the greatest positive impacts on water and biodiversity conservation.

93 Maxwell SL, Fuller RA, Brooks TM, Watson JEM (2016) Biodiversity: The ravages of guns, nets and bulldozers. Nature 536:143–145. doi: 10.1038/536143a

94 Wilcove DS, Rothstein D, Dubow J, et al. (1998) Quantifying Threats to Imperiled Species in the United States. Bioscience 48:607–615. doi: 10.2307/131342095

95 Machovina B, Feeley KJ, Ripple WJ (2015) Biodiversity conservation: The key is reducing meat consumption. Sci Total Environ 536:419–431. doi: https://doi.org/10.1016/j.scitotenv.2015.07.022

96 Laurance WF, Camargo JLC, Luizão RCC, et al. (2011) The fate of Amazonian forest fragments: A 32-year investigation. Biol Conserv 144:56–67. doi: 10.1016/j.biocon.2010.09.021

97 UNEP (2009) Environment Outlook in Amazonia: GEOAmazonia. Panama City, Panama

98 Giam X, Scheffers BR, Sodhi NS, et al. (2012) Reservoirs of richness: Least disturbed tropical forests are centres of undescribed species diversity. Proceedings Biol Sci 279:67–76. doi: 10.1098/rspb.2011.0433

99 Prager A, Milhorance F (2018) Cerrado: Agribusiness may be killing Brazil’s ‘birthplace of waters’. Mongabay Series: Amazon Agribusiness, Cerrado. In: Mongabay. https://news.mongabay.com/2018/03/cerrado-agribusiness-may-be-killing-brazils-birthplace-of-waters/. Accessed 4 Nov 2018

100 Ibid

101 Spera SA, Galford GL, Coe MT, et al. (2016) Land-use change affects water recycling in Brazil’s last agricultural frontier. Glob Chang Biol 22:3405–3413. doi: 10.1111/gcb.13298

102 Poore J, Nemecek T (2018) Reducing food’s environmental impacts through producers and consumers. Science 992:987–992.

2. IMPACT OF A CHALLENGE

IMPACT OF CHALLENGE

Animal-based protein production has an out-sized global impact on land use, water quality and quantity, and greenhouse gas production. A true moonshot is removing live animals from the process of producing meat and proteins, but this moonshot involves a number of socioeconomic and cultural issues that cannot easily be achieved solely through a challenge.

This challenge will support incremental but necessary advances in order to increase the marketability of transformative, alternative proteins. There are a number of innovations underway to replace livestock production as we know it, including plant-based meat replacements, cellular meat (and other lab-based animal products), and improvements to livestock production practices. The big ideas may already be out there, gaining significant investment through grants and venture capital, as well as through incubators and accelerators focused on advances in food science.

A challenge to de-water protein for a measurable impact on biodiversity conservation will bring attention to the field. Although there is some pushback from livestock and meat industry associations regarding the marketing and regulation of cellular meat and plant-based meat products,[103] major food production companies have recently invested in this space (see Competitive Landscape below). Rather than trying to alienate the meat-production sector, this challenge should aim to engage traditional meat producers as part of the solution set.

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE

A challenge hosted by Conservation X Labs will be somewhat duplicative of current and previous initiatives, but there is an opportunity to use a challenge to add to the current efforts in order to help scale and commercialize innovations.

Open Innovation Landscape. Global competitions in agricultural production in the developing world and alternative feeds have supported market entry and early scaling for some solutions relevant to this proposed challenge. The Blue Economy Challenge run by Conservation X Labs, the Australian Government, and Second Muse awarded grants in 2016 to insect-based aquaculture feed companies, and companies have received follow-on investment through accelerator programs and wider recognition as a result of the competition. One of the prize winners, AgriProtein, was a finalist for the “Future Protein Award,” which was awarded by the German nova-Institute at an inaugural conference, “Revolution in Food and Biomass Production” (REFAB) in October 2018; finalists included hemp, microbial, and insect-based feed and alternative protein companies.[104] The Fish Free Feed Prize (F3, concluded in 2017) and the fish-free Fish Oil Challenge (concludes in 2019) awards companies that produce and sell target quantities of fish free feed and oil. Finally, USAID’s Securing Water for Food Challenge, completed in 2018, awarded a number of innovations that benefited small-scale farmers in developing economies to reduce their water use in agricultural production.[105]

103 Purdy C (2018) US ranchers want to use the federal government as a proxy to fight high-tech meat companies. Quartz Series: It’s a Beef. In: Quartz. https://qz.com/1249622/the-us-beef-industry-is-divided-over-whether-to-call-clean-meat-meat/. Accessed 7 Nov 2018.

104 Koeleman, E (2018) Awarding the best concept for a future-proof protein supply. News. In: All About Feed. https://www.allaboutfeed.net/New-Proteins/Articles/2018/9/Awarding-the-best-concept-for-a-future-proof-protein-supply-335854E/. Accessed 7 Nov 2018

105 To learn more about the challenge and solutions, please see https://securingwaterforfood.org/

Public & Private Sector Investment. Private sector investment and research programs have supported protein and feed replacements and market entry of some products, although cost of production and customer uptake remain barriers to scale. Many plant-based meat replacement products are already on the market and distributed worldwide (e.g., Infinite Foods, a distributor in sub-Saharan Africa[106]). In September 2017, China signed a USD 300 million deal to buy lab-grown meat from three Israeli companies—SuperMeat, Future Meat Technologies, and Meat the Future—and in January 2018, Europe's third-largest poultry producer announced its investment in SuperMeat. In addition, in May 2018, Tyson Foods' venture-capital arm invested USD 2.2 million in Future Meat Technologies. Cargill and Tyson Foods have both invested in another cellular meat company, Memphis Meats. Plant-based meat replacement companies are also receiving investment from key players in the industry: Tyson Foods has invested in the plant-based company, Beyond Meat, and Leonardo DiCaprio donated USD 20 million to the company.[107] Beyond Meat is currently selling plant-based burgers in grocery stores throughout the U.S., and, as of September 2018, White Castle in the U.S. sells a plant-based Impossible Burger slider for the competitive price of USD 1.99.

In addition, several key organizations are funding research, acceleration, and industry pre-competitive initiatives. The Good Food Institute recently released two RFPs that will fund research to accelerate the development and production of alternative proteins and cellular meat, but the RFPs do not support customer discovery. New Harvest is a non-profit research institute in New York that funds clean meat (including milk and leather) start-ups, and provides R&D support. Finally, the Forum for the Future Protein Challenge 2040 has outlined the challenges of providing protein for the growing human population; they encourage growth in the industry through a "pre-competitive" space and aggregate stories regarding feed replacements and consumer preferences. In addition, WWF and industry partners such as Cargill, McDonalds, and Zoetis, have created the Global Roundtable for Sustainable Beef to improve the sustainability of beef production.[108]

Accelerators for advancing these products in the marketplace have developed recently. Oceans X Labs, the first conservation technology accelerator run by Conservation X Labs, supported two microbial-based fish feed alternatives, KnipBio and NovoNutrients, while the companies were raising their seed-round funding. In 2018, Kraft Heinz launched an incubator program called Springboard Brands to accelerate start-ups to shape the future of food and beverages.[109] Campbell Soup Company (a member of the Plant Based Foods Association) announced in April 2018 the creation of an accelerator unit within the company to incubate small brands and drive long-term innovation.[110]

106 https://www.infinitefoods.com/about Accessed 8 Nov 2018

107 Kowitt B (2017) Leonardo DiCaprio Is Investing in the Plant-Based Food Startup Beyond Meat. Fortune http://fortune.com/2017/10/17/leonardo-dicaprio-beyond-meat-investment/ Accessed 4 Nov 2018

108 https://grsbeef.org/ Accessed 8 Nov 2018

109 https://www.springboardbrands.com/ Accessed 8 Nov 2018

110 Campbell Creates Accelerator Unit. https://www.specialtyfood.com/news/article/campbell-creates-accelerator-unit/ Accessed 8 Nov 2018

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

MARKET SIZE
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The global beef market is expected to reach USD 2,151 billion by 2020[111] and China currently imports around USD 13 billion worth of meat annually to help feed its population of more than 1.4 billion people.[112] It is not clear what percentage of this market is "sustainable beef," but major beef producers and retailers are pursuing efforts and initiatives for sustainable beef production.[113]

Plant-based proteins have already entered the marketplace, but the suite of products is limited to replacements in which texture, mouth feel, and taste composition has been replicated with a level of fidelity that appeals to consumers. There is opportunity to expand and scale the diversity of plant-based proteins. In the markets for both animal-based protein replacements and alternative feeds, the cost of production, competitive pricing, and consumer preference remain the highest barriers to global scaling. Clean meat is expensive to produce, but recent significant investments may help drive down the cost.

Plant-based meat and clean meat. The global plant protein market was valued at over USD 5 billion in 2017 and it is expected to grow by 7.1% during the period of 2018–2023. The increasing demand for a non-meat diet accounts for much of this projected growth and is leading to the growth in plant protein ingredients.[114]

Plant-based proteins need to appeal to meat-eaters in order to have an impact on the consumption of animal-based meat products; according to Impossible Burger, about 70% of their customers are meat eaters, but it is not clear whether the Impossible Burger and similar products regularly replace meat consumption. Replacing animal-based protein is not limited to developed economies. Infinite Foods, a distributor, manufacturer, and licensor of plant-based protein in sub-Saharan Africa, is operating within a market of 1 billion consumers eating USD 70 billion worth of milk and meat protein annually.

The global cultured meat market is projected to reach USD 15.5 million by 2021. More optimistically, New Crop Capital projects that the cellular and clean meat market is potentially a trillion-dollar opportunity.[115] The market is primarily driven by increasing meat consumption globally, increasing manufacturing capacity, and a growing number of investors, including major food industry giants such as Cargill and Tyson Foods investing in cellular agriculture-based technology. [116] A major barrier to scaling cellular meat includes the high production cost: a pound of lab-raised Memphis Meats currently costs USD 2400 but the company aims to reduce the cost to under USD 5 per pound.[117]

Alternative feed ingredients for livestock. The animal feed market is a USD 11.4 billion export industry for the U.S. (including pet food). Currently, the main ingredients in feed are corn (50.3%), soybean meal (12.7%), dried distiller grains (12.6%), and many "other" ingredients (24.4%).[118] In the U.S., animal feed production mills (including pet food manufacturing facilities) generate USD 297 billion in sales.

111 https://www.grandviewresearch.com/press-release/global-beef-market Accessed 8 Nov 2018

112 Robert R (2017) China signs $300m deal to buy lab-grown meat from Israel in move welcomed by vegans. In: Independent. https://www.independent.co.uk/news/world/asia/china-israel-trade-deal-lab-grown-meat-veganism-vegetarianism-a7950901.html Accessed 4 Nov 2018

113 https://grsbeef.org/ Accessed 8 Nov 2018

114 https://www.mordorintelligence.com/industry-reports/plant-protein-market Accessed 8 Nov 2018

115 Stone Z (2018) The High cost of lab-to-table meat. In: Wired. https://www.wired.com/story/the-high-cost-of-lab-to-table-meat/. Accessed 4 Nov 2018

116 https://www.prnewswire.com/news-releases/global-cultured-meat-market-2023-by-source-end-use-and-region-300646962.html Accessed 8 Nov 2018

117 Stone Z (2018) The High cost of lab-to-table meat. In: Wired. https://www.wired.com/story/the-high-cost-of-lab-to-table-meat/. Accessed 4 Nov 2018

118 http://www.afia.org/industryinfo Accessed 8 Nov 2018

This established market provides an opportunity for alternative high-protein feed ingredients to scale, but these alternatives need to be comparable in price to the current sources of protein (e.g., soy, fishmeal, corn, etc.) in order to get uptake from farmers at scale. The cost of soy and fishmeal ingredients in animal feed is about EUR 0.30–3.00/kg whereas black-soldier fly larvae meal sells for about EUR 3.00–9.00/kg.[119] The global insect-based feed market was about USD 580 million in 2017 and it is expected to increase to USD 1 billion by 2025, and North America and Europe rank as the top two markets for insect-based feed.[120] For some feed ingredient alternatives, the cost to manufacture at scale (e.g., using large-scale bioreactors) needs to decrease before they are competitive in the marketplace.

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS

Plant-based meat and clean meat. Food scientists are examining animal products at the molecular level and sourcing plants with matching proteins and nutrients to create plant-based meats, eggs, and dairy products that are healthier and perhaps more environmentally sustainable than conventional animal products. Companies developing plant-based meat and protein alternatives are already producing significant quantities of product. These products are typically marketed to vegans or vegetarians (perhaps with the exception of Impossible Foods and Beyond Meat) instead of as a direct meat replacement. Some of the companies include: Impossible Foods, Beyond Meat, Quorn, Sweet Earth Foods, SunFed Foods, Seattle Food Tech, Terramino Foods, JUST, and NotCo.

Based on an analysis by the Good Food Institute (GFI), a number of products successfully replicate ground beef and chicken with relatively high fidelity, but few products replicate pork and other poultry. Although there are many products that resemble processed or ground meats, plant-based meat companies have not been as successful at replicating whole meat products such as steaks, pork chops, or bacon.

Clean meat (also known as cellular agriculture) is created by growing meat outside of an animal starting with a cell sample, thus eliminating the need for factory farming and slaughter. The result is 100% real meat without the need for antibiotics, growth hormones, or the land and water footprint associated with raising livestock. Clean meat companies are in the earliest stage of development and are not yet producing large quantities—scalability is a huge hurdle for clean meats. Some of the well-known clean meat companies include Memphis Meats, a beef replacement company receiving considerable attention due to high-profile investors; Mosa Meats, cellular, lab-grown hamburger; Super Meat, a Tel-Aviv-based biotechnology company creating chicken replacement meat; Wild Type, creating clean salmon meat; and Integriculture, a Japan-based cellular agriculture company developing clean meat, clean foie gras, and other cellular agriculture products.

In addition to the well-established animal-free milk replacements such as soy and almond milk, which require large amounts of water for production, a number of companies are creating products that mimic the taste and consistency of actual animal-based products. Some of these companies include Perfect Day, brewing milk from cell culture and fermentation; Clara Foods, creating egg white replacements; and BioNascent, creating an infant formula from essential amino acids and carbohydrates.

Technology readiness levels vary widely across the potential solutions for these animal protein replacements. Plant-based meat replacements are widely available in many forms (TRL 7+) but struggle to be relevant to larger consumer groups (TRL 4). Clean meats have been created in the lab, but have large technical hurdles to overcome before they can start to scale (TRL 2–3).

119 Koeleman, E (2016) Insect meal allowance expected in 2020. In: All About Feed. https://www.allaboutfeed.net/New-Proteins/Articles/2016/12/Insect-meal-allowance-expected-in-2020-68992E/. Accessed 7 Nov 2018

120 https://www.retaildive.com/press-release/20181008-global-insect-feed-market-insights-analysis-segmentation-application-le/ Accessed 8 Nov 2018

Plant-based proteins. About 60% of the plant-based proteins on the market, which are used as ingredients in creating plant-based meat replacements, are derived from soy and approximately 10% are wheat-based. Consumers and plant-based meat replacement companies seek more diverse protein sources beyond soy and wheat. The Good Food Institute found that few companies are involved in the production and distribution of these proteins in large enough volumes to provide alternatives to plant-based meat manufacturers with a smaller environmental footprint. The opportunity here lies in researching less-common crops to find high-protein varieties and testing other high-protein ingredients to better mimic the taste and texture of animal-based proteins. The TRL is low, perhaps on the order of 1–2, for soy and wheat protein alternatives that are readily available ingredients for plant-based meat replacements.

Genetic modification. Gene editing tools such as CRISPR can potentially contribute to improving feed, livestock production, and plant-based proteins. Similarly, this tool may be used to improve the genomes of crops to design high protein and more sustainable food systems. A USAID-funded collaboration in Wheat Genomics[121] is researching and developing heat-tolerant, high-yielding, and farmer-accepted wheat varieties to improve wheat production and yields, and DuPont Pioneer scientists developed drought-tolerant corn varieties using gene editing.[122] Similar projects across the globe have led to an increased uptake in more efficient, productive, and sustainable cereals. The U.S. Department of Energy's ARPA-E recently initiated the ROOTS program to develop sensing tools to characterize plant roots in situ, which will enable plant breeders to select varieties with root systems that confer increased water use efficiency, and nitrogen use efficiency.[123]

These gene editing tools are still in the earliest stages of development, within a TRL range of 2–3 and requiring much more research before they can be scaled.

Feed ingredient alternatives. There are a number of innovative companies emerging that develop protein and feed ingredient alternatives using insects (e.g., mealworm, black soldier fly larvae), micro- and macro-algae, and the microbial conversion of by-products (CO2, methane, distiller's dried grains). Conservation X Labs has accelerated two start-ups creating feed ingredients from by-products—NovoNutrients and KnipBio. Both companies are raising and securing private investment and starting to scale manufacturing for customers. However, they are not yet manufacturing on the scale of AgriProtein, mentioned earlier, a company that currently occupies about 44% of the global insect feed market.[124]

In addition to replacing feed ingredients for animals, these protein supplements could potentially be used to replace important dietary proteins traditionally provided by animal-based meat. The majority of these companies are selling protein powders and animal feed replacements, but do not sell direct meat replacements yet. These feed ingredient alternatives are fairly well along in terms of technology readiness and fit into the TRL 5–7+ category.

121 Applied Wheat Genomics Innovation, Lab Kansas State University. http://www.k-state.edu/wheat-innovation-lab/ Accessed 8 Nov 2018

122 Shi et al. (2017) ARGOS8 variants generated by CRISPR-Cas9 improve maize grain yield under field drought stress conditions. Plant Biotech J. 15:207–216. doi: 10.1111/pbi.12603

123 ARPA-E Roots Program https://arpa-e.energy.gov/?q=arpa-e-programs/roots Accessed 8 Nov 2018

124 https://www.retaildive.com/press-release/20181008-global-insect-feed-market-insights-analysis-segmentation-application-le Accessed 8 Nov 2018

6. SUITABILITY FOR A CHALLENGE

SUITABILITY

There are a number of innovations underway to replace animals in meat production, from plant-based meat-replacements to cellular meat (and other animal products), as well as innovations and initiatives to improve livestock production practices. A challenge will support incremental but necessary advances in order to increase the marketability of alternative proteins and meat replacements and potentially help decrease production costs, which, over time, could lead to a transformation of how people consume protein.

The Good Food Institute (GFI) published a commercialization document[125] that clearly lays out opportunities that need research, innovation, investment, and infrastructure in the emerging animal-based protein replacement markets so that cellular and plant-based meat products can get to scale and reach a larger customer base, like the flexitarians.[126]

Opportunities for innovation through a challenge or prize competition include optimizing crops for high protein content or other desirable attributes for plant-based meat production and improving the texture, taste, and mouthfeel of plant-based meats to appeal to meat-eating consumers. We likely will not see new meat replacement products as a result of this challenge, but we might see improved products and new high-protein ingredients.

The alternative feed and feed ingredient industry is in its nascence, but previous challenges and competitions and pre-competitive initiatives have driven some investment and innovation in start-ups. A challenge will bring attention to the field, but the start-ups really need large sums of investment to expand manufacturing capacity, build up a customer base, and drive down the cost and risk to be adopted by farmers.

The proposed challenge topics may make the most sense as a prize-like model or a staged competition where judges or potential customers and retailers could test the products. In addition, as a Conservation X Labs challenge, the competition should include a requirement or provide support for a standardized measurement of the life cycle of products to ensure that products do, in fact, use less water and land than the animal-based protein alternatives.

125 Contact GFI for this document: Commercialization Opportunities in the Plant-Based and Clean Meat Markets: A Guide for Entrepreneurs and Industry. https://www.gfi.org/

126 The "flexitarian" diet describes people who occasionally eat meat but seek plant-based alternatives that have the look, taste, mouthfeel, and nutrition of meat.

Challenge 4

The Artisanal Mining Challenge: Transforming Small-Scale Mining for Water and Biodiversity Conservation

PHOTO: COURTESY OF JASON HOUSTON

SNAPSHOT: MINING

Artisanal or informal-scale mining (ASM) *uses rudimentary extraction processes with little or no mechanization, the operations have very little to no capital investment, the practices are labor-intensive, and in some cases it is illegal.*

Global ASM accounts for ***~15-20% of mined diamonds and gold****.*

Artisanal scale gold mining accounts for ***40% of global mercury emissions****, & it's the* ***single greatest source*** *of mercury contamination on the planet.*

In Peru alone, about ***100,000 acres of rainforest*** *has been lost to artisanal scale gold mining.*

CHALLENGE 4: THE ARTISANAL MINING CHALLENGE: TRANSFORMING SMALL-SCALE MINING FOR WATER AND BIODIVERSITY CONSERVATION

This challenge is a call to create scalable, cost-effective, feasible, and field-ready innovations and solutions to radically transform the current practices and systems associated with artisanal and informal gold and other rare and precious metal mining operations. The solutions should aim to eliminate toxic contaminants such as mercury, cyanide, or other heavy metals from entering waterways, and reduce habitat loss for terrestrial and aquatic species in core biodiversity regions such as dry and wet tropical forests in the Amazon, sub-Saharan Africa, and Southeast Asia.

SUBCHALLENGES

A. **The Global Mining Data Challenge:** Everyone, no matter their income or occupation, should have easy access to information about toxic chemicals in the waterways on which they depend. Develop frugal innovations that democratize access and analysis of data and information on the presence and concentration of mercury, cyanide, and other contaminants in water from Artisanal Scale Mining (ASM).

B. **Transform artisanal mining and remediation:** Eliminate or remediate water contamination and environmental damage to wildlife, watersheds, and ecosystems caused by artisanal, small-scale, and informal mining.

C. **Reform mining economics and supply chain:** Develop innovations that account for the humanitarian, social, and environmental costs of ASM commodities and drive consumer demand and preferences to low-impact sources.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◕	◕	●	◔	◔	◕	21

PROBLEM SUMMARY

Human demand for raw materials and metals to produce new technologies such as medical equipment, computers, renewable energy, and infrastructure will continue to grow with the increasing human population. This demand will become especially relevant as society transitions from a fossil fuel-based economy to a renewable energy economy that is more reliant on batteries, wind turbines, photovoltaic systems, and electric cars, all of which require a number of raw materials that need to be mined or recovered from old products.

The mining industry affects the landscapes and economies of both developed and developing countries. There are two types of mining industries in the world. Industrialized and legal mining employs people around the world, is financed by major mining corporations and investors, and is frequently regulated and managed through other oversight mechanisms. Industrial scale mining practices contribute to water contamination and water withdrawal, but these operations are held accountable largely within regulatory or investment frameworks. In contrast, artisanal or informal-scale mining (ASM) tends to use rudimentary extraction processes with little or no mechanization, the operations have very little to no capital investment, the practices are labor-intensive, and in some cases (but not all), artisanal mining is illegal in that operations occur in protected areas or without permits.[127]

The growing global market for mined materials has driven the growth of informal activity in areas with limited oversight and economic opportunities. Artisanal scale mining operations occur in more than 80 countries, and they are a source of livelihood in a number of developing countries, particularly in East and Southeast Asia, sub-Saharan Africa, and South America.[128] According to a 2017 USAID report on ASM, the practice accounts for an estimated 15–20% of gold, 15–20% of diamonds, and 70-80% of colored stones (excluding jade) mined globally. Artisanal scale mining operations also include silver, copper, lithium, and other rare and precious earth metals. In Africa, ASM production focuses primarily on gold and diamonds, and in Ecuador, the Philippines, and Peru, gold constitutes a majority of ASM production. In addition, ASM frequently coincides with highly biodiverse regions of the world.

Consumers cannot determine the origin of mined materials like gold because illegally or informally mined materials get mixed with materials from legal, industrial sources at various entry points in the supply chain (e.g., refineries). Therefore, in the case of ASGM gold, it is currently difficult to inform consumers because companies cannot trace responsibly-sourced gold.

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

The negative environmental impacts of mining on water and biodiversity differ by mineral and by mining stage—exploration, mining, and post-mining. Depending on the material being mined and the geology, there are different processes for extracting minerals with varying environmental consequences. According to a cradle-to-gate life cycle assessment of metals, the platinum group metals (used in jewelry, catalytic converters, medical implants, and petroleum) and gold (used in jewelry, microchips, aerospace engineering, design, and dentistry) have the largest negative impact on the environment, including freshwater eutrophication and global warming potential.[129]

BIODIVERSITY IMPACT
◕

To extract and process gold from sediments and hard rock, artisanal and small-scale gold mining (ASGM) employs a few methods. One method involves dredging rivers or streams to collect water and sediment to separate gold flakes through chemical-free gravity concentration techniques including sluicing, panning, or centrifuges. Another method is the amalgamation of gold with mercury, a process by which metallic gold is mixed with liquid elemental mercury in water to form an amalgam, and the waste is then washed from the amalgam. Cyanide leaching to extract gold is considered “safer” and is more common in the world than extraction with liquid mercury, but it is still a dangerous technique,

127 USAID (2017) USAID global environmental management support (GEMS) sector environmental guideline: Artisanal and small-scale mining. Washington, D.C. https://rmportal.net/library/usaid-global-environmental-management-support-gems-sector-environmental-guideline-artisanal-and-small-scale-mining. Accessed 7 Nov 2018

128 Ibid

129 Nuss P, Eckelman MJ (2014) Life cycle assessment of metals: A scientific synthesis. PLoS One. doi: 10.1371/journal.pone.0101298

and sometimes used in conjunction with mercury amalgamation.[130] Cyanide makes mercury more mobile,[131] which can lead to greater land, water, and air contamination than occurs with either mercury amalgamation or cyanide leaching alone.[132]

Many artisanal miners prefer mercury amalgamation because it improves the purity of gold. The current practices of informal gold mining are local and severe, and it is not yet clear how many species have gone extinct or are threatened because of ASM. Informal gold mining methods lead to the removal of all forest species and the organic soil horizons underlying them.[133] In addition, ASGM is the predominant global source of mercury emissions to air and accounts for 40% of all mercury dispersed by humans into the environment, making it the single greatest source of mercury contamination on the planet.[134] Current estimates indicate that at least 1,400 tons of mercury are dispersed annually into aquatic ecosystems from small-scale mining globally.[135] Contaminated slurry water in ASGM tends to get dumped back into freshwater systems, and mercury also enters terrestrial and aquatic ecosystems when it is vaporized after processing the gold.

Mercury is toxic for aquatic organisms. In water, mercury can be transformed by bacteria into methylmercury, which is absorbed into the body much more easily than elemental mercury. Once in a living organism, methylmercury can migrate through cells and cross the blood–brain and placental barriers. Mercury bioaccumulates in primary producers (like algae), and can be transferred up the food chain to fish and large predators. Because fish migrate, mercury-contaminated fish in Peruvian rivers have been found 560 km downstream from ASGM sites.[136] Mercury disrupts vertebrate neurological and hormonal systems, causing a variety of negative outcomes including smaller egg size in waterfowl, slow response times to predators, and changes in reproductive behavior due to disruption of the endocrine system; all of these effects can lead to decreased birth rates and increased death rates, thus affecting population sizes.[137]

According to the World Health Organization, people living near ASGM sites are exposed to mercury concentrations up to ten times the international standard through vaporized mercury and environmental deposition. Mercury contamination leads to neurological and nervous system health issues, particularly for children and other vulnerable populations.[138]

"Artisanal and small-scale mining" (ASM) is a misnomer, because it implies either that the mining practices have a small footprint or do not use sophisticated technology or machinery. The reality is far different. From 2013-2018 in Peru, ASGM resulted in over 170,000 acres of primary rainforest destruction, most of this in protected areas.[139] Gold ASM has occurred in Peru for a number of centuries but, in 2011, the practice grew to employ about 80,000 people in Madre de Dios and other biodiverse regions of the country, a significant and growing number due to the high price of gold.[140]

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130 USAID (2017) USAID global environmental management support (GEMS) sector environmental guideline: Artisanal and small-scale mining. Washington, D.C. https://rm-portal.net/library/usaid-global-environmental-management-support-gems-sector-environmental-guideline-artisanal-and-small-scale-mining. Accessed 7 Nov 2018

131 Cyanide dissolves mercury, and when this mixture is released into the environment, mercury can be converted to toxic methyl mercury by aquatic microbes.

132 USAID (2017) USAID global environmental management support (GEMS) sector environmental guideline: Artisanal and small-scale mining. Washington, D.C. https://rm-portal.net/library/usaid-global-environmental-management-support-gems-sector-environmental-guideline-artisanal-and-small-scale-mining. Accessed 7 Nov 2018

133 Asner GP, Tupayachi R (2017) Accelerated losses of protected forests from gold mining in the Peruvian Amazon. Environ Res Lett. doi: 10.1088/1748-9326/aa7dab

134 UN Environment. Reducing mercury in Artisanal and Small-Scale Gold Mining (ASGM). http://web.unep.org/globalmercurypartnership/our-work/reducing-mercury-artisanal-and-small-scale-gold-mining-asgm Accessed 8 Nov 2018

135 UNEP, 2013. Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport. UNEP Chemicals Branch, Geneva, Switzerland. http://wedocs.unep.org/bitstream/handle/20.500.11822/7984/-Global%20Mercury%20Assessment-201367.pdf?sequence=3&isAllowed=y Accessed 7 Nov 2018

136 Hance, J (2015) Mercury fish: gold mining puts downstream communities at risk in Peru. In: Mongabay. https://news.mongabay.com/2015/02/mercury-fish-gold-mining-puts-downstream-communities-at-risk-in-peru/. Accessed 7 Nov 2018

137 Kessler, R (2013) Mercury's Silent Toll on the World's Wildlife. In: Yale Environment 360. https://e360.yale.edu/features/mercurys_silent_toll_on_the_worlds_wildlife. Accessed 16 April 2018

138 World Health Organization (2013) Mercury Exposure and Health Impacts among Individuals in the Artisanal and Small-Scale Gold Mining (ASGM) Community. http://www.who.int/ipcs/assessment/public_health/mercury_asgm.pdf. Accessed 7 Nov 2018

139 Neal K, Roberts A (2018) Rainforest destruction from gold mining hits all-time high in Peru. Wake Forest News, November 8 2018. https://news.wfu.edu/2018/11/08/rainforest-destruction-from-gold-mining-hits-all-time-high-in-peru/. Accessed 3 Dec 2018

140 Langeland AL, Hardin RD, Neitzel RL (2017) Mercury levels in human hair and farmed fish near artisanal and small-scale gold mining communities in the Madre de Dios River Basin, Peru. Int J Environ Res Public Health.14: E302. doi: 10.3390/ijerph14030302

The number of people "employed" by the ASM industry may be an indicator of the potential for environmental damage. In the Democratic Republic of Congo there are between 200,000 and 3 million Congolese working in ASM (gold, tin, tungsten, tantalum); in Mozambique, ASGM is the second largest "employer" after agriculture. Global estimates place the total number of small-scale miners at 10–15 million individuals, at least 4–5 million of which are women and children.[141]

2. IMPACT OF A CHALLENGE

IMPACT OF CHALLENGE

Artisanal mining techniques have not changed for thousands of years. A challenge would incentivize solutions that could transform the practice and industry. In addition, solutions to this problem could potentially decrease or eliminate the largest anthropogenic source of mercury pollution. At a minimum, innovations that help ASM can better equip and drive policy-making and enforcement with real-time data, improve informal mining practices to limit environmental impacts, and reform the global supply chain for these materials to incentivize change.

There is a concern that a challenge will legitimize the informal and illegal practices; however, global attention to the problem can mobilize a new movement and reconceptualize how humans source and value mined materials, which may lead to new markets and a more environmentally sustainable industry.

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE

Open Innovation Landscape. No previous or current innovation competitions have directly sourced innovations for ASM. The XPRIZE Foundation supported a team from the Chilean Mining Consortium to develop and scope a Zero Waste Mining XPRIZE focused on industrial mining waste, but it was never launched.[142]

A prize or challenge would bring needed attention to this global biodiversity and human development problem and ignite innovation in the space for better data, mining processes, and international supply chains.

Public & Private Sector Investment. Industrial mining receives significant attention and adopts innovation due to regulations, whereas artisanal and small-scale mining often goes unnoticed or is actively avoided by private or corporate investors.

USAID has invested in legitimate small-scale mining development programs in nations like Colombia that have seen increased activity in the sector. Such programs have focused primarily on community development, remediation through existing pathways of reforestation, and legalization and regulatory capacity development in the countries.[143]

Some corporate initiatives are addressing the environmental impact of gold and gemstone mining. Brilliant Earth is a jewelry company that uses primarily recycled and re-refined precious metals. The company donates 5% of their profits to mining communities, and they have donated some funds to programs designed to reduce the environmental impact of gold mining, such as training in mercury-free techniques.[144] A challenge or prize combined with an advanced market commitment from an established customer for these metal products (e.g., jewelers, refiners) would leverage combined investment to create scalable change. Policy considerations would also be necessary given some nations' stances on the small-scale mining issue.[145]

141 UNEP, 2013. Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport. UNEP Chemicals Branch, Geneva, Switzerland.

142 XPRIZE Announces Teams Designing Impact Proposals for Future XPRIZE Competitions to Be Unveiled at 2017 Visioneers Summit. https://www.businesswire.com/news/home/20170524005677/en/XPRIZE-Announces-Teams-Designing-Impact-Proposals-Future. Accessed 8 Nov 2018

143 USAID Fact Sheet: Artisanal Gold Mining (2018). https://www.usaid.gov/news-information/fact-sheets/artisanal-gold-mining Accessed 8 Nov 2018

144 https://www.brilliantearth.com/recycled-gold-jewelry/ Accessed 8 Nov 2018

145 WWF (2018) Healthy rivers healthy people: Addressing the mercury crisis in the Amazon. http://awsassets.panda.org/downloads/healthy_rivers_healthy_people.pdf Accessed 3 Dec 2018

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

MARKET SIZE

Artisanal and small-scale mining occurs because there is global demand for mining materials at hyper-low costs, and a labor market that is willing to meet it. As long as people demand mined materials, there will be markets for the raw materials. However, because most ASM is not regulated or held accountable by private investors, solutions need to improve the return on the workers' investments or provide some other tangible benefit in order for widespread adoption and scalability to occur.

The World Bank estimates that there are approximately 100 million artisanal and small-scale miners across 80 countries and that such production accounts for 80% of global sapphire, 20% of gold mining and up to 20% of diamond mining.[146] The International Institute for Environment and Development estimated that 15–20% of minerals and metals in the global market derive from artisanal mining, entering the supply chain at bundling and refining stages.[147] Industrial mines for metals such as gold are often planned and executed along longer timelines than informal mining operations. The global market for mined gold was valued in 2010 at USD 160 billion.[148] The annual production of mines ranges from 2,500–3,000 tons of gold with the average price of gold per ounce in 2017 valued at around USD 1,250.[149] Estimates for 2017, therefore, place the approximate current value of gold mining globally around USD 220.5 billion, conservatively.

The markets for gold and precious materials will ensure that raw materials continue to be mined, but these markets do not guarantee demand for solutions to improve the environmental sustainability of ASM. The largest sector of the global gold market is jewelry, accounting for about 50% of total global demand for gold, with India and China as the largest markets (about 50% of the current gold demand by volume).[150]

Innovations to improve ASGM may be comparable to the global diamond market. Currently, the global diamond market has adapted a near-total market share for conflict-free diamonds (the Kimberly Process, around USD 14 billion market). Critics of the Kimberly Process, which was developed in the early 2000s to ensure rough-mined diamonds were not funding rebel groups, note that the process does not account for the environmental and social conditions under which the stones are mined.[151] This omission has led to growth in sustainably sourced and e-commerce based jewelers like Brilliant Earth, a company that ensures its gemstones come from areas with strict environmental and social standards from mining.[152]

Annually, 75% of the gold market derives from mining, while the remainder is recycled from jewelry (90%) and technology (10%).[153] Certified recycled gold material or certifications for gold sourcing could help shift demand away from the most environmentally and socially costly ASGM at the consumer level and open up market opportunities for new solutions.

146 The World Bank (2013) Brief: Artisanal and Small-Scale Mining. http://www.worldbank.org/en/topic/extractiveindustries/brief/artisanal-and-small-scale-mining. Accessed 7 Nov 2018

147 Ibid

148 World Gold Council (2011) Liquidity in the global gold market. https://www.gold.org/sites/default/files/documents/gold-investment-research/liquidity_in_the_global_gold_market.pdf. Accessed 7 Nov 2018

149 https://www.statista.com/statistics/268027/change-in-gold-price-since-1990/ Accessed 8 Nov 2018

150 World Gold Council https://www.gold.org/about-gold/gold-demand/sectors-of-demand Accessed 8 Nov 2018

151 The Financial Times (2015) 'Blood Diamond' Agreement fails consumers, says NGO. https://www.ft.com/content/439dad56-fc3a-11e7-9b32-d7d59aace167. Accessed 7 Nov 2018

152 https://www.brilliantearth.com/why-buy-from-brilliant-earth/ Accessed 8 Nov 2018

153 World Gold Council https://www.gold.org/about-gold/gold-supply Accessed 8 Nov 2018

Services are starting to cater to a diversified market of younger consumers seeking more responsible products. Demand is difficult to quantify in this case, but market indicators demonstrate that a shift in consumer preferences is directing some business decisions by larger gemstone and jewelry companies, including purchasing sustainable jewelry companies to appeal to a younger demographic. Yet another disrupting force in the diamond market, lab-grown diamonds offer a less expensive but high quality product that is gaining market share of the USD 14 billion rough stone market, increasing from less than 1% (USD 75–200 million) to projections of almost 7.5% over the next decade.[154]

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS

Data solutions. Satellite and areal imagery can pinpoint and measure the area of mining sites,[155] and technologies exist to measure mercury, cyanide, and other metals in the environment. However, these data and technologies are not readily available to people or communities who are affected by ASM.

Non-toxic extraction processes. Methods exist to extract and refine gold without using cyanide and mercury (see USAID's report[156]), but these techniques are not widely adopted. Mercury and cyanide lead to a more pure product, and mercury is widely available.

Remediation and mitigation technologies. Due to regulatory frameworks, industrial mining has developed technologies and solutions to mitigate problems caused by precious metal mining, such as acid mine drainage, but similar approaches have not been developed or implemented on a large scale to address the environmental problems of ASM. Biomining is a relatively new technique in which a few bacteria species are used to remove the gold-containing sulfide matrix from ore, thereby reducing the amount of chemical processing needed.[157] Two novel technologies that could help to mitigate mining waste and increase efficiency are plasma technology and the use of copper-eating bacteria. Toss Plasma Technologies[158] (now PLASNOVA, Inc.) developed a radio frequency plasma technology that heats complex ores to ultrahigh temperatures to break down the ore structure and free up the precious metals contained within. Vale[159] is a Brazilian mining company that formed a partnership with the University of Sao Paolo to study the bacteria present in their copper processing waste pools to determine if a species might consume the 0.07% of copper usually lost in the refining process. Once the bacteria are identified, they intend to deploy them to help clean the waste and extract the "lost" copper for introduction to the market. These technologies still require additional research and development before widescale deployment is possible (TRL 2–5).

Alternatives to mining. Recycling technologies for gold or novel production methods could help drive marketplace change as well. The Diamond Foundry, a lab-grown gemstone company, is backed by USD 100 million in venture capital, and they produce quality diamonds using solar technology at a fraction of

154 Morgan Stanley Research (2016) Game of Stones: Disrupting the Diamond Trade. https://www.morganstanley.com/ideas/diamond-market-lab-grown-disruption Accessed 7 Nov 2018

155 Asner GP, Llactayo W, Tupayachi R, Luna ER (2013) Elevated rates of gold mining in the Amazon revealed through high-resolution monitoring. Proc Natl Acad Sci 110:18454–18459. doi: 10.1073/pnas.1318271110

156 USAID (2017) USAID global environmental management support (GEMS) sector environmental guideline: Artisanal and small-scale mining. Washington, D.C. https://rmportal.net/library/usaid-global-environmental-management-support-gems-sector-environmental-guideline-artisanal-and-small-scale-mining. Accessed 7 Nov 2018

157 Fashola MO, Ngole-Jeme VM, Babalola OO (2016) Heavy metal pollution from gold mines: Environmental effects and bacterial strategies for resistance. Int J Environ Res Public Health 13:E1047. doi: 10.3390/ijerph13111047

158 Duddu, P (2014) Ten technologies with the power to transform mining. In: Mining Technology. https://www.mining-technology.com/features/featureten-technologies-with-the-power-to-transform-mining-4211240/. Accessed 7 Nov 2018

159 The bacteria worth billions. Vale. http://www.vale.com/australia/en/initiatives/innovation/copper-eating-bacteria/Pages/default.aspx Accessed 8 Nov 2018

the human and environmental cost of traditional mining techniques.[160] Although still a relatively small player in the space, Brilliant Earth sources a majority of its gold and platinum from recycled materials[161] and the company leads the market for sustainable gemstones and jewelry with USD 32.9 million in revenue annually.[162]

6. SUITABILITY OF A CHALLENGE

This challenge might elicit new innovations for providing accessible data to ASM miners and affected communities and thus could cause workers to change ASM mining practices to prevent water contamination. There are no obvious direct markets to scale data accessibility solutions, so these ideas may need to rely on philanthropic or public–private partnerships or innovative business models to sustain and scale innovations. This challenge should seek corporate mining and jewelry partners (or other large donors) interested in helping to formalize and improve artisanal-scale mining.

SUITABILITY
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In addition, given the informal and sometimes illegal nature of ASM, adoption and scaling of solutions will remain a challenge. Solutions may scale in operations where there are programs attempting to organize and legitimize ASM, or where workers are willing to pay for improved techniques for better health.

160 https://diamondfoundry.com/pages/our-diamonds Accessed 8 Nov 2018
161 https://www.brilliantearth.com/why-buy-from-brilliant-earth/ Accessed 8 Nov 2018
162 https://www.crunchbase.com/organization/brilliant-earth#section-competitors-revenue-by-owler Accessed 8 Nov 2018

Challenge 5

The Ten Rivers Challenge: Innovating the Trash Stream

SNAPSHOT: TEN RIVERS CHALLENGE

*The world generates about **2.01 billion metric tons of waste annually**, and this is projected to grow to **3.40 billion metric tons** by 2050.*

*In low-income countries, about **93% of waste is burned or dumped in roads, open land, or waterways.***

*Ten rivers, 8 of which are in Asia, carry **88-95% of the world's 2.75 million tons of river-based plastic** pollution to the ocean each year.*

*Waste includes: **plastics, toxic heavy metals**, and **persistent environmental contaminants** that can bioaccumulate in the fatty tissues of organisms and cause **neurotoxicity, reproductive toxicity, and thyroid toxicity in animals**.*

CHALLENGE 5: THE TEN RIVERS CHALLENGE: INNOVATING THE TRASH STREAM

Trash is everywhere, but it does not need to be. This challenge seeks innovations that will leapfrog existing conventional systems and solutions to water contamination caused by waste. In many parts of the world, there is a lack of appropriate, effective, financially sustainable, and safe waste management infrastructure.

This challenge specifically seeks solutions that will significantly curb plastic pollution as well as other waste that threatens aquatic biodiversity, such as materials that biodegrade into toxic components including e-waste, toxic heavy metals, and persistent organic pollutants. Solutions may be updates to existing waste collection, sorting, and recycling systems, and/or they may be technologies to prevent waste from reaching aquatic systems by innovating throughout the waste stream itself. Innovating the waste stream could include waste management tools, landfill technology, recyclable or compostable product/packaging design, and interventions at natural choke points in the waste stream. Solutions could be new technologies, materials, products, and systems, including systems to change consumer behavior through financial or other innovations. This challenge seeks frugal innovations that will work in growing cities in developing countries.

Solutions should have a clear path to scale through an existing or new market. They should also be scalable without requiring government interventions such as direct subsidy or regulatory fiat. In addition, solutions need to demonstrate a positive benefit to biodiversity and water, and avoid negative effects on the environment (e.g., impacting air quality through incineration).

SUBCHALLENGES

A. **Prevent trash from entering water in the developing world:** Create frugal, scalable solutions to prevent the leakage (and leaching) of materials and chemicals into water resources from informal and unregulated landfills or recycling operations, or the lack thereof. This subchallenge includes incentives, technologies, and approaches to ensure that no waste enters the water cycle through wastewater systems, storm water systems, groundwater, or surface water bodies, particularly in the rapidly growing coastal and riparian cities of the developing world.

B. **Waste-no-more – designing products to never be wasted:** Transform and re-design products and processes in order to make the “end of life” processes for discarded products fully sustainable so that no toxic waste is released into the environment (e.g., plastic packaging, electronics, building materials, etc.).

C. **Transparency in waste:** Innovations that offer access to data on the amount of waste, content of waste, and origin of waste to support decisions and systems changes that improve transparency in the waste management sector.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◑	◕	◕	◔	◕	◕	21

PROBLEM SUMMARY

Much of humanity's solid waste eventually ends up in aquatic systems, carried downstream from cities and landfills, where it can have significant impacts on biodiversity and ecosystems. Solid waste generated on land can end up flowing to the ocean by a number of means, including transport by rivers. By one analysis, of the top 10 rivers delivering plastic waste to the ocean (88-95%), eight rivers are located in Asia: the Yangtze, Yellow, Hai, Pearl, Amur, Mekong, Indus, and Ganges Delta in Asia, and the Niger and Nile in Africa.[163] Although the impacts of solid waste on water and biodiversity may be concentrated geographically, the problems and sources of solid waste in water are global problems, even in regions where material recovery facilities (MRFs) and infrastructure exists to collect and manage the waste stream.

The waste problem begins with the design and manufacture of goods. Very few consumer products, and especially product packaging, are designed to be recycled, reused, or biodegraded. As a result, waste is composed of a vast array of materials and in diverse forms that make it difficult to capture, reuse, recycle, or sustainably dispose of. Formal MRFs have to sort all the waste and determine how to safely discard everything, but they have very little control over the quality, quantity, and types of materials that are sent to their facilities. When trash cannot be composted or recycled into a new product, the end-of-life options are limited to landfills and incineration (e.g., 58–62% of global plastic waste is disposed of in landfills or the natural environment and 24% is incinerated),[164] both of which can be sources of water pollution due to airborne deposition and leeching and leakage into aquatic systems.

In many parts of the world, formal MRFs do not exist. In low-income countries, about 93% of waste is burned or dumped in roads, open land, or waterways, compared with only 2% in high-income countries.[165] The informal waste recovery industry employs about 15 million people (mainly picking for plastics, metals, glass, and paper). The people "employed" as informal waste recyclers face public health issues due to their primitive techniques, improper management of secondary pollutants, and insufficient occupational health protections. In addition, informal landfills and waste recycling can lead to environmental pollution of toxic heavy metals (such as lead or chromium) and persistent organic pollutants including polycyclic aromatic hydrocarbons and brominated flame retardants.[166]

Trash is not just a local problem: "scrap" is exported around the world. Approximately one-third of recycled materials in the U.S. is exported in the scrap industry. Prior to its 2018 ban on foreign scrap, China was the largest importer and the largest consumer of recycled materials. The scrap industry included more than 1.42 million tons of plastic exported annually, worth about USD 495 million.[167] Not all of the exported scrap gets recycled for use in the Chinese manufacturing industry though, and the rejected waste is discarded along with the rest of the waste generated by China.

The world generates about 2.01 billion metric tons of waste annually, and this is projected to grow to 3.40 billion metric tons by 2050.[168] Waste generation is rapidly increasing with the growing human population, especially in low-income and middle-income countries. The regions where waste generation is projected to grow fastest, and nearly double or triple by 2050, are Africa, South Asia, and the Middle East and North Africa.[169] Currently, in these regions, more than half of waste is not collected and managed, but it is openly dumped.[170] E-waste is one of the many waste streams (e.g., industrial, agricultural, construction, medical, hazardous) that will continue to grow. Annual global

163 Schmidt C, Krauth T, Wagner S (2017) Export of Plastic Debris by Rivers into the Sea. Environ Sci Technol 51:12246–12253. doi: 10.1021/acs.est.7b02368

164 OECD (2018) Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses, OECD Publishing, Paris, https://doi.org/10.1787/9789264301016-en.

165 The World Bank (2018) Solid Waste Management Brief. http://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management. Accessed 7 Nov 2018

166 Yang H, Ma M, Thompson JR, Flower RJ (2018) Waste management, informal recycling, environmental pollution and public health. J Epidemiol Community Health 72:237–243. doi: 10.1136/jech-2016-208597

167 http://www.isri.org/news-publications/news-details/2017/07/18/isri-statement-on-china's-intent-to-ban-certain-scrap-imports

168 Kaza S, Yao LC, Bhada-Tata P, Van Woerden F (2018) What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series. Washington, DC: World Bank

169 Ibid

170 Ibid

waste from electrical and electronic equipment has increased from 33.8 to 49.8 million metric tons between 2010 and 2018,[171] and North America is a leader in exporting electronic waste to other countries such as China and Japan.[172]

Creating a circular economy for manufactured goods and products offers a real opportunity for innovation to reduce the amount of waste generated by humans. The Ellen MacArthur Foundation defines this as a model based on the following principles: design for no waste and pollution; keep products and materials in use; and regenerate natural systems.[173] This model requires innovations in material science, chemical depolymerization, and systems and product design, as well as consumer behavior change across industries and economies, all executed via viable business plans so that the easiest and most affordable goods are also the best things for the environment.

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

BIODIVERSITY IMPACT

The effects of waste on biodiversity include physical impacts on marine and aquatic wildlife through the consumption and biomagnification of persistent compounds and plastics. Plastic pollution is known to physically alter some waterways, including clogging wetland outflows. In addition to physical impacts on biodiversity, waste contains toxins, heavy metals, and persistent organic compounds, which can have significant impacts on plant and animal health. Pollutants such as heavy metals can affect the health of ecosystems by moving throughout aquatic food webs via biomagnification.

Informal and crude waste facilities have local negative effects on the environment and human health, but when contaminants make their way into waterways, including through simple storm events or vaporizing into the air, they can have a much larger geographic impact. Informal e-waste dumping and recycling sites are particularly harmful sources of toxic heavy metals in soil and water, including lead, chromium, barium, zinc, copper, and persistent organic compounds such as polybrominated diphenyl ether homologues (flame retardants).[174] E-waste is disposed of globally, but there are a few locales that receive a majority of the world's discarded computers, mobile phones, and other electronics: the largest e-waste recycling districts are in Guiyu (China), Delhi and Bangalore (India), Karachi (Pakistan), and Accra (Ghana).[175] Guiyu handles about 70% of the world's e-waste. Heavy metals like silver, arsenic, cadmium, lead, and mercury serve no biological function in aquatic or terrestrial life, and a number of heavy metals are toxic to organisms. For example, lead contamination in fish and wildlife causes nerve damage and other complications, and high rates of exposure could cause death. Polybrominated diphenyl ethers are persistent environmental contaminants that bioaccumulate in the fatty tissues of organisms; they are endocrine disrupting compounds that can cause neurotoxicity, reproductive toxicity, and thyroid toxicity in animals.

171 Yang H, Ma M, Thompson JR, Flower RJ (2018) Waste management, informal recycling, environmental pollution and public health. J Epidemiol Community Health 72:237–243. doi: 10.1136/jech-2016-208597

172 https://www.alliedmarketresearch.com/e-waste-management-market Accessed 8 Nov 2018

173 Ellen MacArthur Foundation. Circular Economy. https://www.ellenmacarthurfoundation.org/circular-economy/concept Accessed 8 Nov 2018

174 Yang H, Ma M, Thompson JR, Flower RJ (2018) Waste management, informal recycling, environmental pollution and public health. J Epidemiol Community Health 72:237–243. doi: 10.1136/jech-2016-208597

175 Safe Minds (2018). https://safeminds.org/10-sources-of-mercury-you-can-do-something-about-e-waste/ Accessed 8 Nov 2018

Macro- and microplastics are found throughout marine and fresh water systems, and aquatic organisms are known to ingest plastics. Plastics contain organic contaminants, including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, petroleum hydrocarbons, organochlorine pesticides, polybrominated diphenylethers, alkylphenols, and bisphenol A (BPA), at varying and non-standardized concentrations. Plasticizers and other plastic additives can leach from waste disposal sites into groundwater and/or surface waters. For example, BPA concentrations in leachates from municipal waste disposal sites in tropical Asia ranged in orders of magnitude, from micrograms per liter to milligrams per liter.[176] BPA is an endocrine disrupting compound that can impair the reproductive success of fish and cause other physiological impacts on invertebrates and terrestrial organisms.[177, 178] BPA is no longer used in a number of consumer products, but unless materials have been incinerated, BPA-containing waste still exists in the environment. Plastic incineration can also release airborne toxic compounds including dioxins, furans, mercury, and polychlorinated bisphenols into the atmosphere. These airborne toxic compounds fall to the ground, re-contaminating water and soil.

Compounds classified as persistent organic pollutants (POPs; detailed in Challenge 7) are toxic chemicals that persist for long periods of time in the environment and can spread through trophic levels via biomagnification in wildlife. Some POPs are found in pesticides (e.g., Lindane), others are used in common household products and industrial processes such as polychlorinated biphenyls (PCBs) and perflourinated chemicals (PFCs). PCBs were formerly used in hundreds of industrial and commercial applications; these compounds are still found in the environment and cause reproductive failure in fish at low doses and can kill fish at higher doses. PFCs are used in a number of products for waterproofing, anti-stick, stain resistance, and firefighting properties. PFCs include perfluorooctanoic acid (PFOA), which is used to make Teflon™ products, and studies show that chronic, low-dose exposure of zebrafish to PFOA alters development, survival, and fecundity.[179]

2. IMPACT OF A CHALLENGE

A moonshot would be to eliminate waste that contaminates water, air, and soil. This moonshot may be a possibility for some of the worst offenders, including e-waste, plastics, and POPs. Solutions to this challenge could transform the way products are produced and disposed of and could potentially change the way people consume goods.

IMPACT OF CHALLENGE

People are becoming increasingly aware of plastic trash in oceans and waterways and there have been some responses in developed countries, including municipalities instituting bans or charging fees for plastic bags and consumer adoption of alternatives to single-use plastic items like straws and cups. The opportunity to innovate remains high, especially in regions that lack formal waste management facilities.

Recycling fossil-fuel based plastics can temporarily extend the life of materials. Depolymerization techniques for plastics can close the loop on production of some plastics. This challenge may also incentivize solutions that will revolutionize the way in which people produce and dispose of goods so that trash no longer flows out to sea or leaches toxic materials into groundwater and surface water.

176 Teuten EL, Saquing JM, Knappe DRU, et al. (2009) Transport and release of chemicals from plastics to the environment and to wildlife. Philos Trans R Soc B Biol Sci 364:2027–2045. doi: 10.1098/rstb.2008.0284

177 Bhandari RK, Vom Saal FS, Tillitt DE (2015) Transgenerational effects from early developmental exposures to bisphenol A or 17α-ethinylestradiol in medaka, Oryzias latipes. Sci Rep 5:1–5. doi: 10.1038/srep09303

178 Flint S, Markle T, Thompson S, Wallace E (2012) Bisphenol A exposure, effects, and policy: A wildlife perspective. J Environ Manage 104:19–34. doi: 10.1016/j.jenvman.2012.03.021

179 Jantzen CE, Toor F, Annunziato KA, Cooper KR (2017) Effects of chronic perfluorooctanoic acid (PFOA) at low concentration on morphometrics, gene expression, and fecundity in zebrafish (Danio rerio). Reprod Toxicol 69:34–42. doi: 10.1016/j.cogdev.2010.08.003.Personal

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE

A few noteworthy global innovation competitions have incentivized circular economies or decreases in waste production, including replacements for fossil-fuel feedstock for plastics, circular economies, new materials for single-use products, and up-cycling or down-cycling waste into new products. However, none of these open innovation competitions have directly addressed the waste management systems in developing economies where there would be the greatest impact.

Open Innovation Landscape. Launch Water (2010) sourced Ambercycle, which is a company that is scaling a chemical process to transform PET into PTA to separate fibers in waste clothing. Ambercycle will soon produce and sell t-shirts from a product called Moral Fiber.[180] The Launch Circular Design Challenge (2018) is supporting ten innovators with ideas, products, and services that "make it much more convenient, valuable, and accessible for customers and companies to repair, reuse, resell and recycle products."[181] Launch Textiles (2014) awarded solutions to transform the system of textiles, fabrics, and fibers to one that has a minimal environmental impact; some solutions included companies creating closed loop recycling of fabrics and textiles, new feedstock for textiles, cleaner manufacturing and green chemistry, and sustainable procurement and investment.

Launch Green Chemistry (2015) awarded innovations that leverage or advance green chemistry to transform the system of materials and manufacturing. Relevant innovations addressed some non-hydrocarbon-based plastics, bio-based additives for plastics, and non-toxic coatings for metals.[182] The Ellen MacArthur Foundation and the New Plastics Economy Innovation Challenge[183] awarded companies creating non-fossil-fuel-based feedstock for plastics and re-designed single-use products (e.g., protective films, plastic alternatives such as algae-based and fully compostable feedstocks, and coffee cups). This challenge is part of a larger, high-profile and broadly-structured program around plastics that includes shifting supply-chain methods and consumer behavior and has had some meaningful successes so far. Additional incentives both in the form of a prize and advanced market commitment would build upon this work and elevate innovations on the waste stream.

Public & Private Sector Investment. The majority of private and public investment in the trash stream is in technologies and companies that support the creation of recycled materials. Although MRFs and waste management infrastructure is expensive to initiate and maintain, some investors have begun to incentivize innovations where formal waste management systems do not yet exist.

Circulate Capital recently launched an initiative to invest in early stage companies in Southeast Asia that divert plastic from the environment across the product and waste stream.[184] Schmidt Marine Technology Partners has also invested in waste stream innovations applicable to the developed and developing world, including BioCellection (technology to recycle hard-to-recycle plastics such as plastic packaging, while also reducing the negative byproducts of plastic recycling), Ambercycle (see above), and AMP Robotics (see below).

180 Ambercycle & Moral Fiber. https://www.unorthodoxphilanthropy.org/ambercycle.html Accessed 8 Nov 2018
181 https://www.launch.org/news/meet-the-2018-launch-circular-innovators/ Accessed 8 Nov 2018
182 Launch Green Chemistry https://www.launch.org/circular/green-chemistry/ Accessed 8 Nov 2018
183 New Plastics Economy https://newplasticseconomy.org/projects/innovation-prize Accessed 8 Nov 2018
184 Circular Capital https://www.circulatecapital.com/rfp Accessed 8 Nov 2018

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

MARKET SIZE

There is no obvious, direct market to scale innovations outside of services provided by waste management facilities, but a few indirect markets may provide opportunities for innovations to scale. There is value in waste, but developing and developed countries need better business models both to keep waste out of water, and to capture the monetary value. This requires a good understanding of what customers are willing to pay for, and more generally, what are people willing to pay in order to have clean rivers and oceans?

There is some opportunity to scale materials that can replace plastics, but new materials would need to be available at a price point that is less than virgin plastic feedstock. Typical fossil-fuel-based plastics are not circular because their end of life options are limited to incineration as a fuel source, or downcycling into new plastic products that will eventually be incinerated. Chemical processes to break down waste into marketable products is yet another potential opportunity to scale innovations.

Another potential market for innovation is alternatives to plastic packaging. As of 2017, the plastic packaging market was valued at close to USD 198 billion and it is rapidly growing in segments such as food and beverages and personal care products. The plastic bag segment is expected to have moderate growth even with rising concerns due to the disposal of plastic grocery bags.[185]

There is potential to scale innovations within the global e-waste management market as well, which is estimated to grow to USD 49.4 billion by 2020. It is described as one of the fastest growing waste streams.[186]

The existing recycling market is large, valued at more than USD 100 billion annually. Considering that very little recyclable waste is actually recycled (e.g., only about 9% of plastic globally[187]) there is great opportunity to capture market value from waste. The global plastic recycling market is estimated to reach USD 56.8 billion by 2024.[188] The demand is primarily for recycled PET and HDPE plastics, and packaging and construction are projected to account for much of the demand for recycled feedstocks (see also Challenge 7). However, unless recycled products can be broken down into non-toxic constituents, recycled products eventually become part of the waste stream.

185 https://www.grandviewresearch.com/press-release/global-plastic-packaging-market Accessed 8 Nov 2018
186 https://www.alliedmarketresearch.com/e-waste-management-market Accessed 8 Nov 2018
187 Geyer G, Jambeck JR, Lavender Law K (2017). Production, use, and fate of all plastics ever made. Science Advances 3(7): e1700782. doi : 10.1126/sciadv.1700782
188 https://www.transparencymarketresearch.com/plastic-recycling-market.html Accessed 8 Nov 2018

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS

Re-engineered materials include a diverse suite of products that are generally not yet ready for market, often due to problems in the supply chain or market incumbency. In addition, some innovations are able to intervene in the waste stream to identify and remove waste products before they get to aquatic ecosystems. Preventing leakage and other problems in informal landfills and recycling facilities may be more of a problem of economics or regulation, and not due to the lack of availability of technologies for improving these facilities. A number of existing companies are deploying and scaling technologies relevant to this challenge with TRLs ranging from 4–7+.

Transparency & data in waste stream. A few data and transparency technologies are currently scaling in North America. AMP Robotics is a company that has created computer vision-supported sorting and data tracking robots for waste on a conveyer belt. This technology will be piloted in at least one material recovery factory (MRF) in 2018/2019.[189] Recycle Bank partners with cities and haulers to encourage consumers to recycle via an awards system.[190] It has seen tremendous success, demonstrating the capacity for influencing consumer behavior. Finally, the startup Sustainability Cloud claims to be a waste-to-profit marketplace, providing transparency in the waste stream by tracking material from its source into the end product.[191] While some of these solutions require further testing, these are all technologies with clear path to broad deployment and have technology readiness levels of 4–6.

Closed-loop manufacturing & products. Dell Computer launched "the OptiPlex 3030," a computer made of old electronics using a closed-loop recycling process. Dell has also started using recycled plastics in its other desktops and monitors.[192] The New Plastics Economy Challenge supported a few replacement and re-designed materials and products for single-use items that are compostable or will break down into non-toxic chemical constituents (e.g., coffee cups, coffee cup lids, non-plastic water bottles, and food packaging).

Upcycling and downcycling of waste into products. This field is a rapidly burgeoning area, with large companies including Adidas and PepsiCo, as well as many startups, creating products made from plastic waste. Some examples of repurposing plastic waste into products include Bureo,[193] which recycles fishing nets and creates a reusable feedstock for sunglasses, skateboard decks, and "netplus" material (used in Patagonia jackets). Carbonlite[194] repurposes food grade post-consumer recycled PET into new plastic bottles. Lastly, Worn Again Technologies[195] can separate, decontaminate, and extract polyester polymers and cellulose from cotton, non-reusable textiles, and PET bottles and packaging and turn them back into new textile raw materials. The question remains as to whether recycled plastic feedstock reduces the demand for virgin plastic feedstock.

Depolymerization. There are technologies that break down plastics into its core components and into energy sources. These are still being studied and tested at the lab scale with some exceptions. See Challenge 7 for a discussion of depolymerization and microplastics.

189 https://www.amprobotics.com/ Accessed 8 Nov 2018
190 https://www.recyclebank.com/about-us/ Accessed 8 Nov 2018
191 https://soalliance.org/ocean-solutions-accelerator/ Accessed 8 Nov 2018
192 https://www.alliedmarketresearch.com/e-waste-management-market Accessed 8 Nov 2018
193 https://bureo.co Accessed 8 Nov 2018
194 http://www.carbonliterecycling.com Accessed 8 Nov 2018
195 http://wornagain.co.uk Accessed 8 Nov 2018

6. SUITABILITY OF A CHALLENGE

SUITABILITY


This problem is well-suited to a challenge because the outcome (preventing trash from getting in waterways) is clear, but the best pathway to get to that outcome is not clear. The global waste problem cannot be solved through one challenge or one set of solutions. However, a global competition could drive more investment into solutions with good business plans, raise interest around the problem, and attract new solvers from new sectors to address it. Through research by the Ellen MacArthur Foundation and others, the truly innovative and transformative solutions are far upstream of solutions that collect the trash already floating in waters and oceans. Innovations that upcycle or downcycle fossil-fuel based plastics or collect plastics from waterways are seen as incremental solutions. In addition, the greatest opportunity for innovation lies within the developing economies in Southeast Asia and Africa that lack formal waste management systems and release the majority of their trash into informal landfills and waterways.

There have been a number of innovation competitions and a few investment opportunities for innovations in this space. The most transformative solutions may be transparency in the waste management system, circular economies for products and materials, and fully degrading waste into marketable non-toxic components.

Innovation is needed in the design and manufacturing of products and packaging, which will require collaboration and communication between multiple sectors including packaging manufacturers, food and drug regulatory agencies, consumers, and material recovery facilities (MRFs). In addition, MRFs in developed economies can drive innovation if there is more transparency and data about the composition of waste coming into their facilities.

A challenge could be extremely impactful, as there is already value in waste, but that value is not yet captured in environmentally or financially sustainable mechanisms.

Challenge 6

Space Invaders: Prevent, Detect, and Eliminate Aquatic Invasive Species

SNAPSHOT: INVASIVE SPECIES

Of the 680 extinct animal species, at least ***91 have gone extinct due to the effects of invasive species.***

In Lake Victoria alone, the large invasive freshwater Nile perch has driven the extinction ***of more than half (around 200) of the cichlid species.***

Over ***400 of the 1,300 species*** *listed under the Endangered Species Act are at risk due to threats caused by invasive species.*

The U.S. Great Lakes are inhabited by about ***180 different invasive species.***

Zebra mussels are threatening the ***extinction of at least 30 freshwater mussels*** *in the Great Lakes.*

CHALLENGE 6: SPACE INVADERS: PREVENT, DETECT, AND ELIMINATE AQUATIC INVASIVE SPECIES

This challenge seeks simple, scalable, cost-effective solutions to (a) rapidly detect the presence of aquatic organisms *in situ* (plants, animals, algae, fungi, pathogens, and parasites) at the species level in aqueous environments at critical points of entry and time when intervention can prevent establishment or harm, or (b) eliminate established populations of aquatic invasive species without causing harm to native species or inadvertent effects to the environment.

SUBCHALLENGES

A. **Early detection for prevention & rapid response:** Detect the presence of aquatic organisms rapidly, at scale, and for a low cost *in situ*.

B. **Eliminate aquatic invasive species (AIS):** Develop cost-effective solutions to eliminate existing AIS populations without harmful environmental externalities to native populations or the ecosystem.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
●	◑	◑	◑	◔	◕	20

PROBLEM SUMMARY

Invasive species are introduced to a new ecosystem through the global transport enterprise: the movement of people, conveyances, and commodities from one ecosystem to another. Invasive species (including pathogens and parasites) both directly and indirectly harm native species and ecosystems through competition for resources, transforming the physical and biological environment, predation, introduction of disease, and hybridization. They are a primary driver of biodiversity loss in freshwater and estuarine ecosystems.[196,197] This proposed challenge is an overdue response to a 1999 Ramsar Convention on Wetlands resolution that recognized the urgency in addressing invasive species impacts in aquatic ecosystems.[198]

Stopping the further influx and spread of aquatic invasive species requires understanding the major pathways responsible for their movement and introduction. These pathways include ballast water and biofouling of ships and recreational watercraft; the legal and illegal trade in ornamental and exotic plants and animals (facilitated by increased electronic commerce);[199] and the channelization and movement of water for transportation, consumption, and industrial purposes. In addition, accidental escapes and intentional releases of non-native pet and aquarium fish species account for a number of introductions in the U.S. Aquarium release is the largest source of introduced fish in Florida (e.g., invasive lionfish), and the second largest source in the country.[200,201]

196 Strayer DL, Dudgeon D (2010) Freshwater biodiversity conservation: recent progress and future challenges. J North Am Benthol Soc 29:344–358. doi: 10.1899/08-171.1

197 Ciruna KA, Meyerson LA, Gutierrez A (2004) The ecological and socio-economic impacts of invasive alien species in inland water ecosystems. Washington, D.C.

198 See Ramsar Resolution VII.14: Invasive species and wetlands: http://archive.ramsar.org/cda/en/ramsar-documents-resol-resolution-vii-14/main/ramsar/1-31-107%5E20830_4000_0__ Accessed 8 Nov 2018

199 Reid AJ, Carlson AK, Creed IF, et al (2018) Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol Rev. doi: 10.1111/brv.12480

200 Della Venezia L, Samson J, Leung B, Thuiller W (2017) The rich get richer: Invasion risk across North America from the aquarium pathway under climate change. Diversity and Distributions 24:285–296. doi: 10.1111/ddi.12681

201 Smithsonian.com (2009). "Invasion of the Lionfish." https://www.smithsonianmag.com/science-nature/invasion-of-the-lionfish-131647135/ Accessed 12 April 2018

Prevention is the most cost-effective strategy for addressing invasive species. However, even the most effective biosecurity systems in the world are not perfect; some invasive species will undoubtedly bypass prevention measures and become established where they can reproduce and spread. Under such circumstances, the introduced populations need to be rapidly identified and eradicated or contained as quickly as possible in order to avoid cascading impacts. The losses from, and long-term management of, established invasive species can reach billions of dollars annually.[202]

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

Invasive species are a leading cause of species extinctions. According to the IUCN Red List database, of the 680 extinct animal species, at least 91 went extinct due to the direct or indirect effects of invasive species.[203] However, this number is likely an underestimate because in Lake Victoria alone, the introduction of the freshwater Nile perch (*Lates niloticus*) has driven more than half (around 200) of the native cichlid species to extinction.[204]

BIODIVERSITY IMPACT

Invasive species are a global problem as they have reached every continent. A global assessment found that the U.S., France, New Zealand, and Australia have the greatest number of invasive species per area, and, recently, a warming climate opened up sensitive habitats for invasive species to start colonizing in the Arctic.[205]

Invasive species by definition cause harm, or have the potential to cause harm. They can have detrimental effects on species, populations, communities, and entire ecosystems directly through predation and hybridization, or indirectly through competition, disease transmission, or alteration of the habitat quality (including physical modification). The extinction risk differs by native species and the invaders, yet there are examples of invasive species driving native species to extinction, and thus, changing communities and ecosystem functions.

Under the U.S. Endangered Species Act, over 400 of the 1,300 species listed are at risk due to threats caused by invasive species.[206] Invasive species have dramatic effects on isolated ecosystems such as small islands and freshwater systems. They pose a particular risk to small island developing states by threatening the ecosystems, livelihoods, economies, and public health of inhabitants. Islands, which can be a metaphor for isolated and unique habitat with a high degree of endemism, are more prone to invasion by non-native species because of the lack of natural competitors and predators that control populations in their native ecosystems. Species within those habitats may also demonstrate predator naivety—they lack the behaviors that enable them to escape predation because of the previous lack of such predators. In addition, islands often have ecological niches that have not been filled because of the distance from colonizing populations, also increasing the probability of successful invasions. For example, the invasive brown tree snake (*Boiga irregularis*) on the island of Guam caused the local extinction of over half of the island's native bird and lizard species, and two out of three native bat species.[207]

202 Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol Econ 52:273–288. doi: 10.1016/j.ecolecon.2004.10.002

203 Clavero M, García-Berthou E (2005) Invasive species are a leading cause of animal extinctions. Trends Ecol Evol 20:110. doi: 10.1016/j.tree.2005.01.003

204 Global Invasive Species Database. http://www.iucngisd.org/gisd/100_worst.php Accessed 8 Nov 2018

205 Thyrring, J et al (2018) Climate change draws invasive species to the Arctic. In: Science Nordic http://sciencenordic.com/climate-change-draws-invasive-species-arctic Accessed 7 Nov 2018

206 U.S. Fish and Wildlife Service (2018) Economic Impacts of Invasive Species. https://www.fws.gov/verobeach/PythonPDF/CostofInvasivesFactSheet.pdf Accessed 12 April 2018

207 Global Invasive Species Database (2018) Brown Tree Snake page. http://www.iucngisd.org/gisd/species.php?sc=54 Accessed 7 Nov 2018

Aquatic invasive species wreak havoc in major freshwater ecosystems around the world. Water hyacinth (*Eichhornia crassipes*) is an aquatic plant that grows so thick in new habitats across Africa and China that it clogs freshwater bodies and reduces dissolved oxygen, which leads to a shift from high-oxygen-demanding fish species to lower-oxygen-tolerating fish species.[208] In the Great Lakes of the U.S., it has taken over 30 years of scientific study to understand the impact of the invasive zebra mussel (*Dreissena polymorpha*).[209] Zebra mussels alter the aquatic ecosystems because they are able to grow in massive clusters and they are voracious consumers of the primary producers in an aquatic system—microscopic algae and phytoplankton. Zebra mussels are threatening the extinction of at least 30 freshwater mussels in the Great Lakes, and losses of native crayfish and snail populations have been attributed to zebra mussel colonization. Zebra mussels can also cause increases in toxic blue-green algae, including *Microcystis*, which produces a poison that causes liver damage in humans and wildlife. A similar species, the Golden Mussel (*Limnoperna fortune*), has invaded rivers to the south of the Amazon River Basin, and if this mussel makes it to the Amazon River, it has the potential to dramatically harm endemic and unique aquatic communities.

Yet another group of invasive species making their way up the Mississippi River basin to the Great Lakes are multiple freshwater fish species known collectively as “Asian carp.” These species have higher reproduction rates than native freshwater fish in the Mississippi River and its tributaries, and thus are out-competing the native fish species. Finally, invasive pythons (*Python spp.*) in the Everglades have decimated native populations of terrestrial and aquatic mammals, birds, and reptiles, including the endangered American alligator, in some cases by more than 90%.[210]

2. IMPACT OF A CHALLENGE

This challenge might not be a moonshot, but it would bring attention to the global problem of invasive species and it could create additional markets for innovators with solutions and technologies from outside of the conservation science discipline. In general, it is more cost-effective to prevent the introduction of invasive species than it is to eradicate established populations. Therefore, this challenge could reconceptualize how invasive species practitioners prioritize resources to address invasive species if there are effective solutions to detect and eliminate all potential invasive species prior to establishing populations.

IMPACT OF CHALLENGE

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It is not impossible to eradicate established populations of invasive species—according to a study in 2013, out of more than 1000 attempted eradications of invasive species, 86% succeeded.[211] Rather than framing the eradication of invasive species as a set of seemingly overwhelming problems, this challenge can reinforce the message that the problems are solvable.

208 Yan S-H, Song W, Guo J-Y (2017) Advances in management and utilization of invasive water hyacinth (Eichhornia crassipes) in aquatic ecosystems – A review. Crit Rev Biotechnol 37:218–228. doi: 10.3109/07388551.2015.1132406

209 Minnesota Sea Grant (2018) Zebra Mussels Threaten Inland Waters: An Overview. http://www.seagrant.umn.edu/ais/zebramussels_threaten. Accessed 7 Nov 2018

210 Dorcas ME, Willson JD, Reed RN, Snow RW, Rochford MR, Miller MA, Meshaka Jr. WE,., Andreadis PT, Mazzotti FJ, Romagosa CM, Hart KM (2012). Several mammal declines coincide with proliferation of invasive Burmese pythons in Everglades National Park. Proc Natl Acad SciPNAS 109: 2418–2422, doi: 10.1073/pnas.1115226109

211 Simberloff D, Martin JL, Genovesi P, et al (2013) Impacts of biological invasions: What’s what and the way forward. Trends Ecol Evol 28:58–66. doi: 10.1016/j.tree.2012.07.01

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE
◑

Open Innovation Landscape. There are a few challenges underway in the invasive species space already, but they focus on eradication, detection, or deterrence of specific species in the U.S. rather than being broader calls to action. Conservation X Labs is currently running a challenge to source frugal field tools to detect and track the spread of the invasive fungal pathogens causing Rapid 'Ōhi'a Death, which is killing native 'ōhi'a trees in Hawaii. The Great Lakes Invasive Carp[212] challenge recently concluded by awarding four innovators for their ideas and designs to prevent and deter Asian carp from invading the Great Lakes. The U.S. Bureau of Reclamation launched a challenge in 2017 to source solutions and ideas to eradicate invasive zebra and quagga mussels from large lakes, reservoirs, and rivers.[213] These challenges do not appear to include testing, market entry, and acceleration support to increase the impact or help scale the innovations.

Public & Private Sector Investment. Historically, federal, state, and philanthropic funding has driven innovation to detect and respond to invasive species (see e.g., the U.S. National Invasive Species Information Center,[214] the Australian Government Department of the Environment and Energy,[215] and the New Zealand Predator Free 2050 initiative).[216] Recent policies and public investment have also shaped the competitive landscape around invasive species, increasing investment and creating incentives for innovation. The Obama Administration invested USD 4 million in ballast technology upgrades for the Great Lakes region and increased testing capabilities in the Great Lakes and Chesapeake Bay to limit the introduction of invasive species into those ecosystems.[217] The Ballast Water Management (BWM) Convention under the International Marine Organization, which went into force in 2017, creates an international framework of standards for all shipping and ports that is intended to decrease the introduction of aquatic invasive species.[218] Such policy incentives present opportunities for technologies to enter the marketplace. As a result of the BWM Convention, the UN formed the Global Industry Alliance for Marine Biosecurity (GIA), to catalyze and promote new technological solutions to serve a global ballast water treatment technology market valued at USD 30–50 billion.[219] The GIA builds on an initial investment of USD 12 million to build capacity in emerging markets to reduce invasive species.

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

MARKET SIZE
◑

Unless innovators are able to appeal to a wider customer base through a sustainable business model, the primary markets and customers to scale solutions are governments and possibly non-profit conservation organizations.

The market size for solutions to detect and eliminate invasive species can be informed by the costs associated with the damage caused by invasive species and the costs to eradicate them following introduction into a waterway. The estimated costs of damage are significant; the total economic damage in the

212 https://innocentive.com/ar/challenge/9933993 Accessed 8 Nov 2018
213 https://www.usbr.gov/research/challenges/mussels.html Accessed 8 Nov 2018
214 https://www.invasivespeciesinfo.gov/toolkit/grants.shtml Accessed 8 Nov 2018
215 http://www.environment.gov.au/biodiversity/invasive-species Accessed 8 Nov 2018
216 Key J (2016) New Zealand to be Predator Free by 2050. Press Release by the Australian Prime Minister, John Key. https://www.beehive.govt.nz/release/new-zealand-be-predator-free-2050 Accessed 8 Nov 2018
217 https://www.marad.dot.gov/environment-and-safety/office-of-environment/environmental-technology-assistance-initiative/ Accessed 8 Nov 2018
218 http://www.imo.org/en/about/conventions/listofconventions/pages/international-convention-for-the-control-and-management-of-ships%27-ballast-water-and-sediments-(bwm).aspx Accessed 8 Nov 2018
219 http://www.undp.org/content/undp/en/home/presscenter/pressreleases/2017/09/08/-global-treaty-to-halt-invasive-aquatic-species-enters-into-force.html Accessed 8 Nov 2018

U.S. due to terrestrial and aquatic invasive species was estimated at over USD 120 billion per year in 2005.[220] Some species cause more economic damage than others, and it is therefore easier to attach a monetary value to particular species. For example, zebra and quagga mussels alone cause millions of dollars of damage by biofouling pipes and other aquatic infrastructure. Asian carp are threatening the Great Lakes, a globally unique aquatic ecosystem, and a recreational fishing industry valued between USD 400 million and 1.3 billion annually.[221]

Prevention programs and early eradication efforts are the most cost-effective solutions to combat invasive species. For introduced plants in New Zealand, early extirpation costs, on average, 40 times less than attempts to extirpate widely established populations.[222] In Australia, the national plant quarantine program screens out potential invaders and, even after accounting for lost revenue from the few species that might be excluded in the process, the screening program could save the Australian economy USD 1.67 billion over 50 years.[223]

In both Europe and California, the invasive Pacific alga (*Caulerpa taxifolia*) was detected early in small patches. In California, a USD 7 million eradication effort mounted within 6 months of discovery successfully eradicated the species over 2 years. In the Mediterranean, the species was not eradicated early, and it has spread to thousands of hectares off the coasts of Spain, France, Monaco, Italy, Croatia, and Tunisia; *C. taxifolia* is now considered "ineradicable" with the current technology.[224] Markets, therefore, may have the greatest potential to reach deployment at scale for early detection and removal technologies, although technologies that drastically lower the price of eradication of widespread invasive species may have viable pathways in the marketplace as well.

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS

Field detection/prevention of establishment. Multiple studies have used eDNA to analyze water samples to detect the presence of invasive species in waterbodies and ballast water.[225] The combination of computer vision and images from camera traps have been used to detect terrestrial invasive species like brown tree snakes in Guam.[226] Computer vision technology was awarded a recent monetary prize in The Great Lakes Invasive Carp Challenge: the solution is a system that channels fish into a holding area where recognition software would then identify and divert invasive carp for harvest.[227] Citizen science programs and technologies have also enhanced the capacity for more rapid detection. The Center for Invasive Species and Ecosystem Health at the University of Georgia created a suite of mobile application software ("apps") capitalizing on the ubiquity of smartphones and the public's interest in pests and invasive species. These BugWood apps mobilize and encourage citizen scientists to report observations and data about invasive species for early detection.

220 Pimentel D, Morrison D, Zuniga R (2005) Opportunities for applying biomedical production and manufacturing methods to the development of the clean meat industry. Ecological Economics 52:273–288.

221 Ready RC, Lauber TB, Poe GL, Rudstam LG, Stedman RC, Connelly NA (2016). Impacts of Aquatic Invasive Species on Sport Fish and Recreational Fishing in the Great Lakes: Possible Future Scenarios. HDRU Series No.16-1. Ithaca, NY: Cornell University.

222 Simberloff D, Martin JL, Genovesi P, et al (2013) Impacts of biological invasions: What's what and the way forward. Trends Ecol Evol 28:58–66. doi: 10.1016/j.tree.2012.07.013

223 Ibid

224 Ibid

225 Borrell YJ, Miralles L, Do Huu H, et al (2017) DNA in a bottle - Rapid metabarcoding survey for early alerts of invasive species in ports. PLoS One 12:1–17. doi: 10.1371/journal.pone.0183347

226 Klein DJ, McKown MW, Tershy BR (2015) Deep Learning for Large Scale Biodiversity Monitoring. In: Bloomberg Data for Good Exchange Conference.

227 https://www.michigan.gov/som/0,4669,7-192-29701_74909_74922-464686--,00.html Accessed 8 Nov 2018

The technology readiness of the different solutions for field detection varies. Analyzing eDNA in water samples and using a combination or computer vision and images from camera traps are tested and proven concepts, but machine-vision-assisted camera traps and field-ready eDNA test kits are further away from scaling (somewhere around a TRL of 3–5). Citizen science detection apps are already deployed in the field with some success. The machine learning-enabled technology separating invasive carp species (and other species identification) is further away from scalability, in the range of a TRL of 2–4.

Elimination and removal of invasive species. One example of a semi-autonomous detection and elimination robot is the crown-of-thorns starfish (COTS) detection system, the COTSBot. It is an underwater robot that uses computer vision to identify and eradicate COTS in real time, but there needs to be a viable business model to finance and deploy more units to have an impact on the invasive COTS population.[228] In 2016, the Oxitec company successfully released genetically modified male *Aedes aegypti* mosquitoes, the vector of dengue fever, Zika virus, and chikungunya, into a couple of wild populations. These modified male mosquitoes can mate with wild females, but the resultant offspring die before they reach maturity.[229] This is currently an expensive innovation as the company needs to continuously release the male mosquitoes to eradicate the disease vector, and Oxitec needs to undergo intensive social license campaigns where they test their product. Gene drives and other genetic technologies may also have the potential to eradicate and control invasive species. Unlike the Oxitec method, gene drives have not yet been implemented in the field, but the process enables genetic modifications to be driven throughout a population without having to introduce large numbers of modified organisms. Researchers are currently studying gene drives in laboratory settings on invasive species with a relatively fast generation time, including insect-borne pathogens, rodents, and mussels.[230, 231]

There is a wide range of technology readiness for the potential invasive species removal solutions. Computer-vision-enabled robots and genetically modified species are proven technologies that have been deployed in field settings and could readily be scaled with appropriate investment, social acceptance, and business models (TRL 6–7). However, gene drives are still being tested in laboratory settings and are closer to a TRL of 1–3.

228 New robot has crown-of-thorns starfish in its sights (2015). Queensland University of Technology News. https://www.qut.edu.au/about/news/news?news-id=95438 Accessed 8 Nov 2018

229 Winskill P, Carvalho DO, Capurro ML, et al (2015) Dispersal of Engineered Male Aedes aegypti Mosquitoes. PLoS Negl Trop Dis 9:1–18. doi: 10.1371/journal.pntd.0004156

230 Sinkins SP, Gould F (2006) Gene drive systems for insect disease vectors. Nat Rev Genet 7:427–435. doi: 10.1038/nrg1870

231 Esvelt KM, Smidler AL, Catteruccia F, Church GM (2014) Concerning RNA-guided gene drives for the alteration of wild populations. Elife 3:e03401. doi: 10.7554/eLife.03401

6. SUITABILITY OF A CHALLENGE

SUITABILITY
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A challenge is optimal, but is not the only method to source solutions to detect and eliminate invasive species. Many fields outside of invasive species ecology can offer transformative solutions to effectively detect and eliminate all potential invasive species at all entry points and eliminate established populations of invasive species without harming native species (e.g., robotics, molecular and synthetic biology). In addition, a challenge could elevate the issue of invasive species globally, and make people more aware of and want to prevent the damage caused by invasive species.

The presence of other challenges, the scale of negative impacts on aquatic and terrestrial biodiversity, the lack of innovation in the space, and the number of relevant technologies from adjacent fields suggest that this issue is well suited for a challenge. In addition, this challenge is not seeking the impossible, given that previous eradication efforts have succeeded, but rather pursuing bold and ambitious, but most likely achievable, goals. A prize-backed challenge could attract new solvers to the space and provide an additional niche market to help scale technologies that are perhaps being developed for other markets.

This challenge could have multiple regional partners interested in detecting and combatting specific invasive species but the call to action should be kept broad, unlike previous challenges addressing specific invasive species. This challenge may be better suited as a staged competition to build in the capacity to test the efficacy of solutions.

There are a couple of risks regarding a broad invasive species challenge. First, who is willing to pay for the innovations to detect and eliminate invasive species besides government agencies or philanthropic donors? Can applicants come up with sustainable and compelling business plans that suggest a pathway to financial sustainability to help scale the innovation? Second, the potential customers of eradication solutions would need credible evidence that the solutions do not cause harm to native species or ecosystems—this validation or testing could be part of the challenge design.

Challenge 7

“Micro”-Management: Prevent, Recover, Reuse, and Eliminate Micromaterials and Endocrine Active Compounds in the Environment

SNAPSHOT: EMERGING CONTAMINANTS

*Exposure to EDCs in freshwaters has caused **intersex in male alligators, frogs, and at least 37 fish species**.*

***Microplastics** are found throughout the water column in fresh water around the world and in **most of the human drinking water supply**.*

*Global plastic production has increased exponentially since the 1960s, with **production in 2013 at 299 million tons**.*

*In water, microplastics provide a **surface** for **pathogenic bacteria** and **persistent contaminants** like **PCBs, DDT, and PFCs**.*

CHALLENGE 7: "MICRO"-MANAGEMENT: PREVENT, RECOVER, REUSE, AND ELIMINATE MICROMATERIALS AND ENDOCRINE ACTIVE COMPOUNDS IN THE ENVIRONMENT

Endocrine disrupting compounds (EDCs) are used in a variety of manufactured products, including pharmaceuticals, personal care products, and plasticizers. Plastics leach EDCs in the environment, and microplastics are known to adsorb other contaminants and carry pathogens in aquatic environments. This challenge seeks scalable solutions to prevent the release of these materials into the environment and/or recover, reuse, or eliminate microplastics, synthetic microfibers, and EDCs in waterways or other substrates (e.g., soil and sludge).

Solutions may include innovations and mechanisms to prevent the release of micromaterials and EDCs at the sources where they enter the environment; safely recover these compounds and materials in the environment; and recycle or safely eliminate, transform, or degrade the captured microplastics, microfibers, and EDCs into non-toxic (and non-endocrine active) components. Solutions should minimize the negative effects on the environment with no increased use of materials or processes that would damage water or air quality or cause other forms of environmental damage. In addition, solutions should be scalable and cost-effective technologies that are accessible to users regardless of their status or wealth.

SUBCHALLENGES

This challenge seeks low cost solutions that prevent, recover, reuse, and eliminate, transform or degrade:

A. **Endocrine Disrupting Compounds (EDCs):** Chemical compounds that affect endocrine systems (e.g., estrogens, progestins, androgens, bisphenols, pesticides, perfluorinated compounds, phthalates, organotins and perchlorate).

B. **Microplastics:** Plastic particles less than 5 millimeters long that originate from primary sources (e.g., glitter, microbeads used in cosmetics and personal care products) and secondary sources of plastics (e.g., the breakdown of larger plastic items).

C. **Synthetic Microfibers:** Synthetic fibers (e.g., polyester, acrylic, nylon, rayon) that are less than 5 millimeters long.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◑	◕	◑	◑	◑	◕	20

PROBLEM SUMMARY

Over 200 active ingredients[232] found in medicines and personal care products have been identified in waters globally.[233] The most frequently detected compounds in freshwater samples from around the world are ingredients in non-prescription and prescription pharmaceuticals, including estrogen-based hormones, and human and veterinary antibiotics—all of which may disrupt endocrine functions (hormones) and fertility in humans and wildlife.[234,235] These compounds enter freshwater through a variety of pathways.[236] For much of the global population, water is contaminated through direct discharge due to a lack of sanitation and water treatment systems. Based on 2015 statistics, only 27% of the global population (1.9 billion people) used private sanitation facilities that were connected to sewers with wastewater treatment, and most of these treatment systems are located in developed countries within North America and Europe.[237]

Even where sewer systems and wastewater treatment plants exist, they are not designed to treat or remove all compounds and materials, including microplastics and EDCs from pharmaceuticals and personal care products.[238,239] Treated wastewater effluent gets discharged back into the environment, and the treated water can contain a number of EDCs. In addition, industrial effluent and runoff from solid waste disposal sites, like non-engineered landfills or informal dumping sites, contributes pollutants to waterways as well, including EDCs, macro- and microplastics, pharmaceuticals, heavy metals, and other toxic compounds that leach from discarded products.[240]

Humans are not the only sources of EDCs in waterways. Livestock are administered hormones such as estrogen, progesterone, and testosterone to increase their growth rate and feed conversion efficiency; much like in humans, the partially metabolized growth hormones are excreted by livestock back into waterways.[241]

Plastics are another source of water contamination. Most of today's plastics are made from fossil-fuel feedstocks. Plastics are ubiquitous and used in many everyday single-use and durable products. There are no comprehensive studies or research on how much plastic is in the environment, but we do know

232 Active ingredients are also known as biologically or pharmaceutically active compounds that can induce a biological reaction in organisms.
233 Hughes SR, Kay P, Brown LE (2013) Global synthesis and critical evaluation of pharmaceutical data sets collected from river systems. Environ Sci Technol 47:661–677. doi: 10.1021/es3030148
234 See Overturf MD, Anderson JC, Pandelides Z, et al (2015) Pharmaceuticals and personal care products: A critical review of the impacts on fish reproduction. Crit Rev Toxicol 45:469–491. doi: 10.3109/10408444.2015.1038499
235 See also Miège C, Choubert JM, Ribeiro L, et al (2009) Fate of pharmaceuticals and personal care products in wastewater treatment plants - Conception of a database and first results. Environ Pollut 157:1721–1726. doi: 10.1016/j.envpol.2008.11.045
236 See Aris AZ, Shamsuddin AS, Praveena SM (2014) Occurrence of 17α-ethynylestradiol (EE2) in the environment and effect on exposed biota: A review. Environ Int 69:104–119. doi: 10.1016/j.envint.2014.04.011.
237 Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2017. Licence: CC BY-NC-SA 3.0 IGO
238 The Society of Chemical Manufacturers and Affiliates reports that there are about 25,000 chemicals in commerce, although not all of these chemicals are contaminants that pose a threat to humans or biodiversity. See Roundtable on Environmental Health Sciences, Research, and Medicine; Board on Population Health and Public Health Practice; Institute of Medicine. Identifying and Reducing Environmental Health Risks of Chemicals in Our Society: Workshop Summary (2014) Washington DC. National Academies Press.
239 Kümmerer K, Dionysiou DD, Olsson O, Fatta-Kassinos D (2018) A Path to Clean Water. Science 361:222–224. doi: 10.1126/science.aau2405
240 Gwenzi W, Chaukura N (2018) Organic contaminants in African aquatic systems: Current knowledge, health risks, and future research directions. Sci Total Environ 619–620:1493–1514. doi: 10.1016/j.scitotenv.2017.11.121
241 Food and Drug Administration. "Steroid Hormone Implants Used for Growth in Food-Producing Animals." Page last updated: 10/12/2017. https://www.fda.gov/animalveterinary/safetyhealth/productsafetyinformation/ucm055436.htm Accessed 8 Nov 2018

that global plastic production has increased exponentially since the 1960s, with production in 2013 at 299 million tons.[242] Water bodies carry plastic products that we can see with the naked-eye, as well as microplastics (characterized as particles <5 mm), which can breakdown to nano sizes in water. There are two types of microplastics, based on their origin—primary and secondary. Primary microplastics are manufactured products, such as scrubbers in cleaning and cosmetic products, glitter, and pellets for plastic production feedstock. The sources of secondary microplastics include fibers or fragments resulting from the breakdown of larger plastic items in the environment, such as fishing nets, clothing fibers, line fibers, plastic films, industrial raw materials, consumer products, and household items, including pellets or polymer fragments from biodegradable plastics. A significant household contribution to microplastics pollution comes from laundering synthetic textiles (estimated at 588,000 kilotons per year), which are discharged with sewage water.[243] Nylon and polypropylene are common synthetic textiles manufactured with polymers, while polyethylene and polypropylene are commonly used as microbeads or glitter in cosmetics.[244]

Microplastics have been detected in oceans and freshwater systems around the world. Some sewage and water treatment facilities are able to remove up to 99.9% of microplastic particles from wastewater, but the volume of water that passes through these facilities still allows for a significant amount of small plastic particles and fibers to bypass the filtration systems.[245] In addition, the particles that are removed from the wastewater are retained within the sewage sludge, and this is typically applied to agricultural land as a fertilizer; thus, microplastics get back into waterways through agricultural runoff.[246]

EDCs and microplastics are grouped together in this challenge because the current production of plastics and synthetic textiles involves endocrine active compounds such as plasticizers and brominated flame retardants, which can leach out of microplastics and microfibers in water. In addition, microplastics are known to adsorb other contaminants, including some EDCs, and pathogenic bacteria in the environment.[247, 248]

To date, there are no large-scale monitoring mechanisms tracking the distributions and concentrations of EDCs, microplastics, or macroplastics. Microplastics and microfibers are not collected, except in cases where consumers add filters to their washing machines, such as the Cora Ball, which captures 1/3 of the microfibers per load. Microfibers and microplastics are not recycled because they are not collected in large quantities and/or they are mixed materials, and recyclers need pure (or known) mixtures of fibers to use as feedstock for new items.

242 Eerkes-Medrano D, Thompson RC, Aldridge DC (2015) Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritization of research needs. Water Res 75:63–82. doi: 10.1016/j.watres.2015.02.012

243 Boucher, J. and Friot D. (2017). Primary Microplastics in the Oceans: A Global Evaluation of Sources. Gland, Switzerland: IUCN. 43pp.

244 Horton AA, Walton A, Spurgeon DJ, et al (2017) Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci Total Environ 586:127–141. doi: 10.1016/j.scitotenv.2017.01.190

245 Ibid

246 Ibid

247 Viršek MK, Lovšin MN, Koren Š, et al (2017) Microplastics as a vector for the transport of the bacterial fish pathogen species Aeromonas salmonicida. Mar Pollut Bull 125:301–309. doi: 10.1016/j.marpolbul.2017.08.024

248 Horton AA, Walton A, Spurgeon DJ, et al (2017) Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci Total Environ 586:127–141. doi: 10.1016/j.scitotenv.2017.01.190

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

BIODIVERSITY IMPACT

Plastic pollution is a global problem; however, this challenge does not rank as highly in this criterion because of the paucity of scientific evidence that EDCs and microplastics have a long-term negative effect on biodiversity conservation. Plastics in aquatic environments can persist for up to 50 years, and their complete mineralization may take hundreds or thousands of years. The extent of ecological damage caused by exposure to microplastics and EDCs in the environment is unknown because these are emerging contaminants, but field and lab observations of fish and other aquatic organisms consuming microplastics indicate potentially devastating effects on populations,[250] and studies documenting decreased fertility and intersex development (e.g., male fish grow ovaries and eggs in testes) in aquatic species after exposure to EDCs.[251]

Endocrine disrupting compounds. EDCs have been reported in freshwaters around the world, and there are documented cases of intersex alteration among alligators, frogs, and fish upon exposure to EDCs.[252] Since about 2000, researchers have found at least 37 fish species where the males feminized (e.g., grew eggs in their testes) as a result of EDC exposure in lakes and rivers throughout North America, Europe, and other parts of the world.[253] The feminization of male fish is associated with exposure to estrogen-based hormones such as 17β-estradiol, estrone, synthetic estrogen used in birth control pills (17α-ethynylestradiol, EE2), and other EDCs that mimic estrogens. Many studies have shown estrogenic responses of male fish after exposure to wastewater effluent.[254,255] The feminization of males can affect the population dynamics by decreasing reproductive success of individuals. One whole-lake experimental study in Canada nearly collapsed a wild population of fathead minnow (*Pimephales promelas*) over 7 years of chronic exposure to environmentally relevant concentrations of EE2.[256]

However, the long-term effects or risks posed by the various EDCs (in low concentrations or in mixtures) to ecological health in controlled and field settings are not well understood, nor is the release of these compounds into the environment regulated.[257] Comprehensive scientific evidence on the negative impacts of all EDCs and the metabolites at environmentally relevant concentrations *does not exist*. The pharmaceutically active compounds are not isolated in nature, they exist as mixtures—some are degraded into active and inactive metabolites, and some compounds bioaccumulate in species and biomagnify through the food chain.

249 Driedger AGJ, Dürr HH, Mitchell K, Van Cappellen P (2015) Plastic debris in the Laurentian Great Lakes: A review. J Great Lakes Res 41:9–19. doi: 10.1016/j.jglr.2014.12.020

250 Horton AA, Walton A, Spurgeon DJ, et al (2017) Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci Total Environ 586:127–141. doi: 10.1016/j.scitotenv.2017.01.190

251 Overturf MD, Anderson JC, Pandelides Z, et al (2015) Pharmaceuticals and personal care products: A critical review of the impacts on fish reproduction. Crit Rev Toxicol 45:469–491. doi: 10.3109/10408444.2015.1038499

252 Horton AA, Walton A, Spurgeon DJ, et al (2017) Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci Total Environ 586:127–141. doi: 10.1016/j.scitotenv.2017.01.190

253 Bahamonde PA, Munkittrick KR, Martyniuk CJ (2013) Intersex in teleost fish: Are we distinguishing endocrine disruption from natural phenomena? Gen Comp Endocrinol 192:25–35. doi: https://doi.org/10.1016/j.ygcen.2013.04.005

254 Marcogliese DJ, Blaise C, Cyr D, et al (2015) Effects of a major municipal effluent on the St. Lawrence River: A case study. Ambio 44:257–274. doi: 10.1007/s13280-014-0577-9

255 Iwanowicz LR, Blazer VS, Pinkney AE, et al (2016) Evidence of estrogenic endocrine disruption in smallmouth and largemouth bass inhabiting Northeast U.S. national wildlife refuge waters: A reconnaissance study. Ecotoxicol Environ Saf 124:50–59. doi: 10.1016/j.ecoenv.2015.09.035

256 Kidd KA, Blanchfield PJ, Mills KH, et al (2007) Collapse of a fish population after exposure to a synthetic estrogen. Proc Natl Acad Sci 104:8897–8901. doi: 10.1073/pnas.0609568104

Microplastics. Plastics are composed of additive chemicals that are toxic or act as endocrine disruptors (e.g., plasticizers such as bisphenol-A and phthalates). These chemical additives can leach out of plastics into the environment, especially in high temperatures or with UV degradation.

Aquatic wildlife are known to consume microplastics, possibly because the fragments may look and smell like food.[258] The aquatic filter feeder and food source for numerous aquatic species, *Daphnia magna*, was observed ingesting nano- and microplastics in laboratory settings, and synthetic microfibers were found in the digestive systems of fish collected from freshwater sources.[259] A recent study showed that nano-sized plastics (20 nm to 70μm) cross the blood–brain barrier in fish and can cause brain damage.[260] Microplastic particles have the potential to accumulate in aquatic and terrestrial communities through biomagnification, with unknown long-term consequences on ecosystems.

The consumption of microplastics by animals is problematic not only because there are no nutritional benefits to be gained from plastics, but because plastics can be vectors for other contaminants. Plastics have a propensity to pick up pathogenic bacteria[261] and hydrophobic, non-essential trace elements and persistent contaminants in water, including persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs), DDT, and perfluorinated chemicals (PFCs).[262,263] At least one feeding experiment showed that PCBs could transfer from contaminated plastics to wildlife (streaked shearwater chicks).[264]

The fact that microplastics can carry POPs is worrisome given the impact that DDT had on the reproductive health of birds of prey in the past. POPs are by design persistent in the environment, and they are transported by wind and water, thereby affecting people and wildlife long after release and far from where they are used and manufactured. Recently, scientists determined that PCBs will likely cause some wild orca (*Orcinus orca*) populations to collapse. While PCB production is banned in most countries, PCBs have biomagnified through the marine food chain to where high concentrations are found in the blubber of orcas, and, as a result, some populations have low to no reproductive success.[265]

2. IMPACT OF A CHALLENGE

EDCs, microplastics, and microfibers are ubiquitous in waterways globally. While the impact of these substances on biodiversity continues to be studied and evaluated, data does exist showing links between exposure and impacts to health and reproductive success of aquatic species. These compounds and materials currently get into waterways because the existing technologies for filtration, waste management, depolymerization, and green chemistry are not scaled, and manufacturers continue to produce the offending products to meet global demand.

IMPACT OF CHALLENGE

258 Savoca MS, Tyson CW, McGill M, Slager CJ (2017) Odours from marine plastic debris induce food search behaviours in a forage fish. Proc R Soc B Biol Sci. doi: 10.1098/rspb.2017.1000

259 Horton AA, Walton A, Spurgeon DJ, et al (2017) Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci Total Environ 586:127–141. doi: 10.1016/j.scitotenv.2017.01.190

260 Mattsson K, Johnson E V., Malmendal A, et al (2017) Brain damage and behavioural disorders in fish induced by plastic nanoparticles delivered through the food chain. Sci Rep 7:1–7. doi: 10.1038/s41598-017-10813-0

261 Viršek MK, Lovšin MN, Koren Š, et al (2017) Microplastics as a vector for the transport of the bacterial fish pathogen species Aeromonas salmonicida. Mar Pollut Bull 125:301–309. doi: 10.1016/j.marpolbul.2017.08.024

262 PCBs were formerly used in hundreds of industrial and commercial applications and these compounds are still found in the environment. In low doses they cause reproductive failure in fish populations and in high doses they kill fish. PFCs are used in a number of products for waterproofing, anti-stick, stain resistance, and firefighting properties. PFCs include perfluorooctanoic acid (PFOA), which is used to make Teflon™ products, and studies show that chronic, low-dose exposure of zebrafish to PFOA alters development, survival, and fecundity. See Jantzen CE, Toor F, Annunziato KA, Cooper KR (2017) Effects of chronic perfluorooctanoic acid (PFOA) at low concentration on morphometrics, gene expression, and fecundity in zebrafish (Danio rerio). Reprod Toxicol 69:34–42. doi: 10.1016/j.cogdev.2010.08.003.Personal

263 Holland ER, Mallory ML, Shutler D (2016) Plastics and other anthropogenic debris in freshwater birds from Canada. Sci Total Environ 571:251–258. doi: 10.1016/j.scitotenv.2016.07.158

264 Ryan PG, Connell AD, Gardner BD (1988) Plastic Ingestion and PCBs in Seabirds: Is There a Relationship? Mar Pollut Bull 19:174–176. doi: 10.1016/0025-326x(88)90674-1

265 Desforges JP, Hall A, McConnell B, et al (2018) Predicting global killer whale population collapse from PCB pollution. Science 361:1373–1376. doi: 10.1126/science.aat195

Scientists at the Endocrine Disruption Exchange (TEDX) suggested that a global challenge addressing preventing EDCs from entering into the environment (and/or safely recovering these compounds and materials in the environment, recycling, eliminating, transforming, or degrading them into non-toxic and non-endocrine active compounds) would be beneficial as they are not aware of past or current challenge-like initiatives to drive innovation.

It would be a moonshot to prevent, remove, or eliminate microplastics and EDCs from the environment. However, given the lack of scientific evidence, it is difficult to assess how much biodiversity will benefit as a result of a successful challenge. EDCs and microplastics are gaining a lot of attention in the media, and some consumer products (e.g., drinking water filters) are marketing to consumers' fears of ingesting these materials. A challenge could incentivize more interest and investment and scale innovations in the space of green chemistry replacements and water treatment given the existing markets.

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE

Open Innovation Landscape. No global competitions have directly incentivized innovations regarding EDCs, but there have been competitions and incentivized calls to action to combat global macroplastic pollution.

Regarding microplastics and microfibers, there could be some overlap in the innovations and initiatives elicited by the Ellen MacArthur Foundation and the New Plastics Economy, which focused on creating circularity in the plastics market. With the interest paid to the trash stream and plastic waste, there is a growing set of industry and philanthropic partners interested in transforming plastics because it has impacts beyond freshwater ecosystems to drinking water and ocean pollution. Microplastics and microfibers are currently not addressed through the open innovation landscape.

Green chemistry is a growing field that has been supported through open innovation and public and private investment. The annual Green Chemistry Award is sponsored by the American Chemical Society (ACS). ACS awards prizes to leaders in the field of Green Chemistry based on nominations, and the prize has broad categories to encourage research and innovation, but the prize does not seem directed toward replacing specific chemicals like EDCs.[266]

In addition, the Launch Green Chemistry challenge in 2015 awarded a couple of relevant solutions for plastic feedstock and plasticizer alternatives, as well as the creation of the online Green Chemistry Innovation Forum,[267] a community of practice managed by ACS.

Public & Private Sector Investment. Public and private sector investment in capture technologies, particularly at wastewater treatment plants, and green chemistry have been the primary modes of investment for innovations. Academic and research programs in the field of Green Chemistry exist in over 12 countries and, in the U.S., government grants support a portion of academic research and small business development through the National Science Foundation, the U.S. Environmental Protection Agency, and Small Business Innovative Research Programs (SBIR). In addition, industries are reacting to the economic benefit of producing "green" products because of the growth in the global market for green chemistry, which includes bio-based chemicals, renewable feedstocks, green polymers, and less-toxic chemical formulations. This market is projected to grow from USD 11 billion

266 https://www.acs.org/content/acs/en/funding-and-awards/awards/gci.html Accessed 8 Nov 2018
267 https://communities.acs.org/community/science/sustainability/green-chemistry-innovation Accessed 8 Nov 2018

in 2015 to USD 98.5 billion by 2020.[268] In North America alone, that growth will see a rise from USD 3 billion to USD 20 billion. This market growth has some major companies like Clorox investing in the development of “greener” products.[269]

Finally, a number of accelerators and incubators are supporting innovations that address the plastic problem, including the Sustainable Oceans Alliance (SOA),[270] HUB Amsterdam,[271] Circulate Capital,[272] and the Think Beyond Plastic accelerator.[273]

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

There is no direct market for EDC removal or prevention, nor is there a direct market for the elimination of microplastics. However, there are some indirect markets. Consumer demand for clean water, increasing urban populations, and water regulations are driving growth in the markets for water treatment, green chemistry, plastic alternatives, and environmental remediation. In addition, policies and consumer awareness are providing some pathways for growth.

MARKET SIZE

Safe and healthy drinking water. Consumer willingness to pay for filters or testing providing them with the confidence that their water is free of contaminants, as well as bottled water, is evidence of market demand for these solutions. The importance of clean water and the adoption of purifier systems is expected to boost the global market of water treatment systems by 2025.[274] The global water treatment systems market size is projected to be USD 44.01 billion by 2025. Bottled water is a USD 13 billion dollar industry, driven by convenience and a perception that bottled water is healthier.[275] The opportunity to scale innovations lies in whether water filters or cities can successfully market to consumers that they should care that their drinking water contains microplastics or EDCs, and offer an alternative to bottled water.

Green chemistry. The global market for “green chemistry” alternatives is predicted to grow to USD 98.5 billion by 2020. This diverse market has the potential to decrease chemical waste and contaminants released to the air, water, and land, and it has spawned multiple new areas of research including green solvents, bio-based transformations and materials, alternative energy science, molecular self-assembly, next-generation catalyst design, and molecular design for reduced hazard.[276] The use of green chemical alternatives spans multiple industries and products, including plastic production and ingredients in personal care products. The key to scaling is that alternative compounds need to cost less than the fossil-fuel based feedstocks and toxic compounds currently available to manufacturers. As costs come down, consumer demand and a growing coalition of private and public sector organizations will continue to invest in and scale these products. Some major buyers have committed to purchasing materials with safer, green ingredients and retailers like Walmart and Target have adopted policies to source safer products.[277]

268 Bernick, L (2016) The $100 billion case for safer chemistry. In: Green Biz. https://www.greenbiz.com/article/100-billion-business-case-safer-chemistry. Accessed 7 Nov 2018

269 Criddle, C & Bergman, R (2010) Green Chemistry is good for business. In: Forbes. https://www.forbes.com/2010/08/17/green-chemistry-business-environment-opinions-contributors-craig-criddle-robert-bergman.html#6f7b4bab3708. Accessed 7 Nov 2018

270 https://soalliance.org/startups/ Accessed 8 Nov 2018

271 https://amsterdam.impacthub.net/program/plastic-free-ocean-accelerator/ Accessed 8 Nov 2018

272 https://www.sustainablebrands.com/news_and_views/next_economy/sustainable_brands/circulate_capital_incubator_network_accelerate_ocean_ Accessed 8 Nov 2018

273 https://www.thinkbeyondplastic.com/ Accessed 8 Nov 2018

274 Private and public water treatment systems: https://www.grandviewresearch.com/industry-analysis/water-treatment-systems-market Accessed 8 Nov 2018

275 Taylor K (2016) Consumers have a new mentality that is helping Coca-Cola and Pepsi pull off the ‘marketing trick of the century’. Business Insider. 21 Feb 2016. https://www.businessinsider.com/the-real-reason-we-buy-bottled-water-2016-2 Accessed 8 Nov 2018

276 Austin HP, Allen MD, Donohoe BS, et al (2018) Characterization and engineering of a plastic-degrading aromatic polyesterase. Proc Natl Acad Sci 15:E4350–E4357. doi: 10.1073/pnas.1718804115

277 Bernick, L (2016) The $100 billion case for safer chemistry. Green Biz. https://www.greenbiz.com/article/100-billion-business-case-safer-chemistry. Accessed 7 Nov 2018

Environmental remediation. Yet another potential market to scale innovations is environmental clean-up and remediation. The global market for environmental remediation is relatively large, and it is expected to be worth USD 123.13 billion by 2022. The major driver for the growth of the market is the large number of initiatives undertaken by governments for environmental protection and pollution control, especially groundwater remediation due to contamination by oil, gas, and other chemicals.[278]

Recycled plastic and plastic alternatives. It may be difficult for non-hydrocarbon-based plastic alternatives or recycled feedstock to compete with the abundance of plastic feedstock. The global market for plastics is tied to oil and gas production, and the world may be experiencing a glut in plastic pellet production (e.g., polyethylene and polypropylene pellets, the feedstock for plastic products) due to the North American shale oil boom. More than 24 million metric tons of new plastic pellet production capacity of polyethylene is predicted to enter the market by 2020, and a third of that new capacity will come from the U.S.[279] In addition, global plastic recycling rates are low, and the market share of recycled plastics is less than 10%.[280] One major barrier is that the cost to recycle plastics is higher than the cost to incinerate them or put them in a landfill, due in part to the technical challenge that plastics are co-mingled with food residues and other materials.[281]

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS

A number of water filtration and purification products are on the market, designed for developed and developing economies, which enable consumers to filter out potential pathogenic viruses, bacteria, and protozoa.[282] A few innovations and products claim to remove microplastics, microfibers, and EDCs from drinking water and washing machine effluent (see below). Some lab-scale innovations can break down EDCs into non-toxic components. In addition, microplastics and microfibers are not upcycled or downcycled for reuse in other products because no market exists for these materials (they are not collected on a large enough scale and, because they are mixed materials, it is difficult to separate them/determine their content). At best, these materials may be incinerated if they are collected on a large enough scale.

Endocrine disrupting compounds and wastewater treatment. Researchers at Carnegie Mellon University recently discovered that TAML activator enzymes can remove the EDC bisphenol A (BPA) from water.[283] Currently, waste water treatment processes include activated carbon, biofiltration (biological treatment that exploits the microbial-degradation potential), biological augmentation (the addition of archaea or bacterial cultures required to speed up the rate of degradation of a contaminant), filtration (no less than 100 µm to microplastics less than 5 µm) and plastic and non-plastic nanoparticles (between 0.1 and 0.001 µm). These filters are not present in every wastewater treatment facility, and much of the world does not have access to sewered or treated water. However, one company, Aqwind Solutions[284] created a split aeration process for wastewater treatment that requires significantly less energy to operate and can function as a combined system for treating both agricultural and human wastewater in communities. Another company, Advanced BioCatalytics,[285] created a non-toxic biological treatment solution that can remove a number of agricultural and industrial contaminants at the pollution source.

278 https://www.marketsandmarkets.com/PressReleases/environmental- Accessed 8 Nov 2018
279 https://www.marketplace.org/2016/05/19/sustainability/plastic-glut-poised-flood-global-market Accessed 8 Nov 2018
280 OECD (2018), Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses, OECD Publishing, Paris, https://doi.org/10.1787/9789264301016-en
281 Ibid
282 See for example: https://inhabitat.com/6-water-purifying-devices-for-clean-drinking-water-in-the-developing-world/ Accessed 8 Nov 2018
283 Pavlak A (2017). Catalysts Developed at Carnegie Mellon Efficiently and Rapidly Remove BPA from Water. Mellon College of Science News. https://www.cmu.edu/mcs/news-events/2017/0802-BPA-TAMLs.html Accessed 8 Nov 2018
284 http://aqwind.com/our-tech/ Accessed 8 Nov 2018
285 http://www.abiocat.com/ Accessed 8 Nov 2018

A number of consumer and industry green chemistry information and data products help people make informed decisions to avoid EDCs and other toxic chemicals in products, including Chemsec,[286] The Chemsec MarketPlace,[287] The Safer Chemicals Healthy Families Coalition's Mind the Store campaign,[288] The Tiered Protocol for Endocrine Disruption (the TiPED tool),[289] EDC-free Europe coalition,[290] Green Screen,[291] and Zero Discharge of Hazardous Chemicals (ZDHC) coalition.[292]

The technology readiness level of the BPA-removing TAML enzyme is still at the earliest stages of laboratory development and needs further demonstration (TRL 2–3) whereas numerous wastewater filtration technologies are deployed to remove micro- and nanoparticles (TRL 7+); however, these are very expensive and cost is a significant barrier to global use.

Microplastics. There some emerging technologies to monitor and gather data on the extent of microplastics in waterways, but no one is collecting microplastics on a large scale. Draper Labs and the U.S. EPA, as well as Northeastern University, are creating a sensor to detect microplastics in water, and Sea Turtles Forever,[293] an Oregon-based non-profit, developed a Marine Microplastic Debris Removal Program with an easily constructed, low-cost, patented static-charged filtration (SCF) device to remove plastics as small as 100 µm from beaches.

In addition, some wastewater treatment facilities can remove up to 99% of microplastics, but they cannot/do not remove these materials from sludge or soils.

Depolymerization. Some recent lab-based discoveries may help "remove" microplastics from water. Researchers discovered a bacterium that breaks polyethylene terephthalate (PET) plastic into the chemical building block constituents.[294] Some depolymerization techniques are starting to scale for PET and other macrosized plastics (see Biocellection[295]): researchers are studying how fungi and bacteria might degrade and translate core components of PET into energy sources,[296] and a French company called Carbios is scaling a depolymerization technology for polyester and polyamide plastic waste.[297] Depolymerization technologies that break down plastics into its core components and into energy sources are still being studied and tested in the lab scale with some exceptions (TRL 1–7+), and markets need to be created for the reuse of the core components.

Plastic replacements. A number of existing companies use non-fossil-fuel-based feedstocks to create plastic-like products. Grow Plastics[298] and Green Dot Bioplastics[299] are supplying the basic materials for a host of manufacturers to replace additives in plastic manufacturing. Evoware and Skipping Rocks Labs are creating edible and biodegradable seaweed-based packaging for foods and liquids.[300] Finally, researchers at the University of Bath have developed biodegradable and mineralizable cellulose

286 https://chemsec.org/ Accessed 8 Nov 2018
287 https://marketplace.chemsec.org/ Accessed 8 Nov 2018
288 https://saferchemicals.org/mind-the-store/ Accessed 8 Nov 2018
289 http://www.tipedinfo.com/ Accessed 8 Nov 2018
290 https://www.edc-free-europe.org/ Accessed 8 Nov 2018
291 https://www.greenscreenchemicals.org/ Accessed 8 Nov 2018
292 Framework for the Prioritization of Hazardous Chemicals (2014) Revision 1. https://www.roadmaptozero.com/fileadmin/layout/media/downloads/en/FrameworkPrioritisationReportRev1.pdf Accessed 7 Nov 2018
293 https://www.seaturtlesforever.org/programs/marine-plastic-debris/ Accessed 7 Nov 2018
294 Austin HP, Allen MD, Donohoe BS, et al (2018) Characterization and engineering of a plastic-degrading aromatic polyesterase. Proc Natl Acad Sci 115:E4350–E4357. doi: 10.1073/pnas.1718804115
295 https://www.biocellection.com/ Accessed 7 Nov 2018
296 Quaglia, D (2017) Synbio for bioremediation: fighting plastic pollution. In: PLOS Blogs: Synbio Community. http://blogs.plos.org/synbio/2017/03/07/syn-bio-for-bioremediation-fighting-plastic-pollution/ Accessed 7 Nov 2018
297 https://carbios.fr/technologies/le-biorecyclage/ Accessed 8 Nov 2018
298 http://growplastics.com Accessed 8 Nov 2018
299 https://www.greendotbioplastics.com/materials/starch-composites/ Accessed 8 Nov 2018
300 https://newplasticseconomy.org/projects/innovation-prize Accessed 8 Nov 2018

microbeads that could replace polyethylene and polypropylene microbeads commonly used in cosmetics, sunscreens, toothpaste, and body wash. Replacement materials for plastics are well-developed and have started somewhat of a post-plastic industry (TRL 5–7+); however, microbeads are still in the earliest stages of being developed at the lab scale (TRL 2–3).

Microfibers. The Cora Ball,[302] Guppy Bag,[303] LUV-R,[304] and the Filtrol160[305] are all household devices for laundry machines to catch microfibers shed from clothes. Nazava,[306] an Indonesian and Dutch company, developed a household ceramic filter that can treat water from a variety of sources for consumption. TAPP Water[307] has created a biodegradable water filter to intercept micromaterials (e.g., microplastics) specifically for a North American customer base. These products are all commercially available at a TRL of 7+.

6. SUITABILITY OF A CHALLENGE

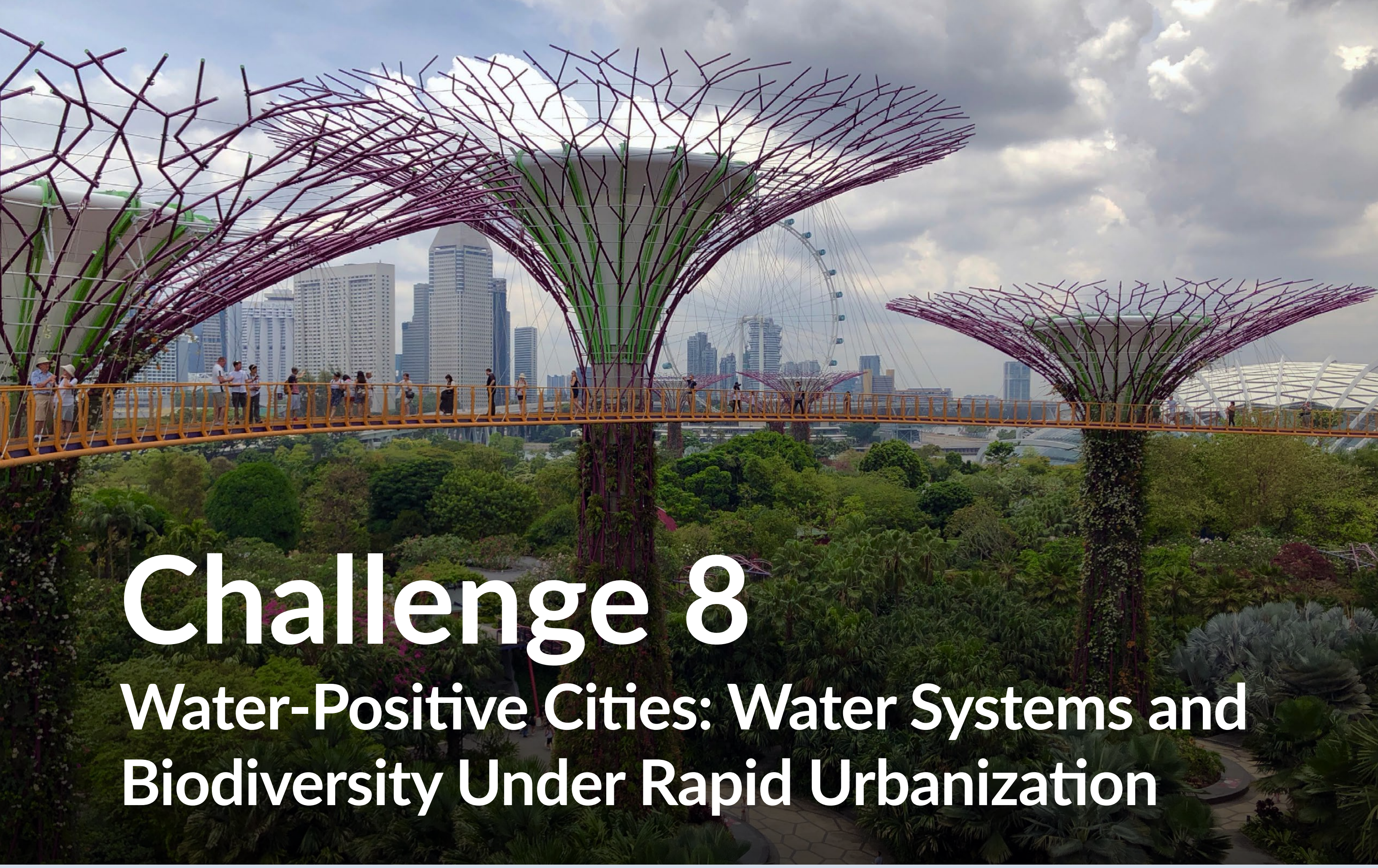
This topic is well-suited for a challenge because the outcome is clear but the pathway to achieve this outcome is not. In addition, there has not yet been a global challenge seeking solutions to prevent EDCs from entering waterways (or to remove or degrade those existing), but there have been a number of challenges and other initiatives to drive innovation in green chemistry, replacing the fossil-fuel based feedstock for plastics, and recycling mixed-grade plastics.

SUITABILITY

Public awareness of EDCs and microplastics seems to be on the rise (e.g., widespread bans of BPA in plastic products in the U.S., and popular press articles about microplastics in common consumer products like drinking water,[308] and table salt[309]). There are also a number of consumer-based and industry-based information sources and campaigns to drive decision making, so with this backdrop of consumer, producer, and retailer awareness, there is an opportunity for a challenge to capitalize on those existing data sources and industry commitments to drive technological and chemical innovations.

A challenge could help drive attention, activity, and innovation for this set of under-served, but growing problems. However, since the potential solutions range in technological readiness and the markets may not yet be well-defined, innovators would need to demonstrate viable pathways for investment and scaling into the global marketplace through well-thought-out business plans. This challenge should be designed with a testing phase or as a staged competition to build-in the capacity to evaluate the efficacy of solutions and confirm that the solutions do not have negative impacts on biodiversity or water.

302 https://coraball.com Accessed 8 Nov 2018
303 http://guppyfriend.com/en/ Accessed 8 Nov 2018
304 http://www.environmentalenhancements.com/index.html Accessed 8 Nov 2018
305 http://www.septicsafe.com/filtrol-160-lint-filter-with-1-filter-bag/ Accessed 8 Nov 2018
306 https://www.nazava.com/about-the-waterfilter/ Accessed 8 Nov 2018
307 https://tappwater.co/us/faucet-water-filter/ Accessed 8 Nov 2018
308 Redfearn, G (2018) WHO launches health review after microplastics found in 90% of bottled water. In: The Guardian. https://www.theguardian.com/environment/2018/mar/15/microplastics-found-in-more-than-90-of-bottled-water-study-says. Accessed 7 Nov 2018
309 Parker, L (2018) Microplastics found in 90% of table salt. In: National Geographic. https://www.nationalgeographic.com/environment/2018/10/microplastics-found-90-percent-table-salt-sea-salt/. Accessed 7 Nov 2018



Challenge 8

Water-Positive Cities: Water Systems and Biodiversity Under Rapid Urbanization

SNAPSHOT: URBANIZATION

By 2050, 68% of the world population *will live in urban areas.*

The greatest areas of urban growth are in low and lower-middle income nations primarily in ***sub-Saharan Africa and South Asia.***

Around ***37% of the global population resides in cities upstream of water bodies****, and population centers are negatively correlated with water quality.*

Urban landscapes with 50-90% impervious surface cover can lose ***40-83% of rainfall*** *to surface runoff;* ***forested landscapes lose only 3%****.*

CHALLENGE 8: WATER-POSITIVE CITIES: WATER SYSTEMS AND BIODIVERSITY UNDER RAPID URBANIZATION

Cities are often thought of as a source of environmental degradation. This challenge seeks to design and transform the new cities of the 21st century so that they are forces for good, and sites that produce positive biodiversity benefits. This challenge will incentivize "water-positive cities" through solutions to sanitation, groundwater, water use, and pollution that leave water systems more productive for nature than before. Solutions may improve sanitation and effluent management to minimize water pollution, increase permeability of urban surfaces, and improve water infrastructure systems and technologies to deliver water services to urban populations.

This challenge promotes the belief that water-positive cities can enhance biodiversity upstream, in situ, and downstream. Building these cities requires innovations that enhance a city's capacity to be a force for, rather than against, biodiversity conservation. Solutions should have measurable positive effects on biodiversity within that city's watershed as well as no net negative effect on the upstream, downstream, or urban environments (e.g., no increased use of agricultural nutrients (N, P), pesticides, antibiotics, inorganic salts, sedimentation, or other materials or sources of pollution that would damage water quality and the environment). Solutions should also be feasible without necessitating government intervention such as large subsidies, regulatory fiat, or required central management.

SUBCHALLENGES

A. **Decentralized biodiversity-positive water systems:** Create decentralized but networked systems to treat and distribute water within a city. Solutions would have measurable, positive impacts to biodiversity such as through reduced water imports, restored natural habitats, and exports of high-quality water to downstream ecosystems. Solutions should be cost-effective and scalable systems and/or technologies to treat, manage, and redistribute water from multiple sources (storm water, wastewater, greywater, etc.) within an urban center.

B. **Systems & materials for biodiversity and water-positive new cities:** Develop scalable, sustainable, cost-effective materials and systems for constructing new urban spaces that enable greater groundwater recharge, provide endemic habitat, prevent flooding, and prevent untreated storm or wastewater from entering waterways.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◔	◑	◑	◕	◕	◑	19

PROBLEM SUMMARY

Cities have historically been a force for biodiversity loss, particularly in upstream, in situ, and downstream aquatic ecosystems. For most of human history, the growth of cities and urban centers concentrated around fertile ground for growing agriculture and access to water. With industrialization in the 19th century, cities became mechanisms to support the needs of laborers who worked in factories connected to growing supply chains. Planning was driven by private business ventures. Urbanization and the industrial revolution brought massive levels of pollution to urban waterways, necessitating better management, planning, and policy regimes for cities. Urban planning gave rise to zoning, which designates areas of cities for certain purposes to separate manufacturing and industry from human habitation, with mixed success.

As rapid urbanization yields new and burgeoning urban spaces, there is a need for a new paradigm for cities—a Water-Positive City. A Water-Positive City improves water quality, serves as a habitat for biodiversity, reduces pollution, and manages water quantity to meet the needs of its inhabitants and biodiversity upstream, in situ, and downstream. New innovations for managing, providing, and constructing systems for water can make cities a force for, rather than against, biodiversity conservation.

In the past three decades, increased economic opportunity from service- and manufacturing-based economies has driven the growth of cities, especially in the developing world. By 2050, 68% of the world's population will live in urban areas, with 90% of the increase in Asia and Africa.[310] Currently 54% of the global population resides in urban centers.[311] Urbanization is most prominent in India and China, which will account for a combined 40% of global urban population growth from 2005–2025.[312] Throughout Asia and Africa, cities and megacities present market opportunities for industries and core stressors on aquatic ecosystems. The development of peri-urban environments, which may lack proper management or pollution controls, has had unchecked and poorly monitored impacts on water.

Treated wastewater tends to be discharged into surface waters rather than being decontaminated for distribution and reuse as greywater. In areas with wastewater treatment infrastructure, this is due in part to the cost and logistics of retroactively building grey water decontamination and distribution systems. It would cost the city of San Francisco USD 1.8 billion dollars to implement greywater decontamination systems in single-family homes and multistory buildings, with implementation in single-family homes being the least economically feasible.[313] Even where greywater decontamination and distribution infrastructure exists (e.g., Orange County, CA, where it is used to recharge groundwater), persistent messaging is required to convince public perceptions that greywater is safe. Furthermore, in wealthy cities where attempts have been made, local and state policies either create cumbersome permitting processes for household implementation or are nonexistent for governing new greywater decontamination systems.[314]

In biodiverse regions in the developing world, rapid urbanization and population growth pose threats to valuable, unique aquatic ecosystems. One estimate indicates that despite covering 2.3% of Earth's

310 United Nations Department of Economic And Social Affairs (2018) 2018 Revision of World Urbanization Prospects. https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html. Accessed 7 Nov 2018

311 World Health Organization (2018). "Global Health Observatory (GHO) data: Urban population growth." http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/ Accessed 12 April 2018

312 Dobbs R, Sankhe S. Comparing Urbanization in China and India. July 2010. https://www.mckinsey.com/global-themes/urbanization/comparing-urbanization-in-china-and-india Accessed 16 April 2018

313 Munoz, NJ, "What Is the Economic Feasibility Of Implementing Grey Water Infrastructure At The Citywide Level?" (2016). Master's Projects and Capstones. 353. https://repository.usfca.edu/capstone/353 Accessed 4 April 2018

314 Orlowiski, A (2015). "Orange County has led the way as a model for recycling water, but here's what's being done to do more." The Orange County Register. https://www.ocregister.com/2015/08/18/orange-county-has-led-the-way-as-a-model-for-recycling-water-but-heres-whats-being-done-to-do-more/ Accessed 12 April 2018

surface, biodiverse regions account for 35% of Earth's ecosystem services.[315] Urban growth will encroach upon these ecosystems due to increased demands for resources, both directly for land use and indirectly to facilitate growing water and food systems. This growth will place significant global stress on the management of water resources, including large-scale wastewater and storm water management and access to potable drinking water. This trend creates an opportunity to revolutionize cities and the systems that support water provision and management in them. Whether retrofitting existing, aging infrastructure in legacy cities or reconceptualizing management in burgeoning urban areas around the world, cities can be designed to be water-positive for nature.

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

BIODIVERSITY IMPACT

Urban centers concentrate people and use of resources. The direct effects of urban growth on water quality and biodiversity conservation include wastewater effluent and urban runoff, and water withdrawal for consumption and to grow food. Cities, especially new cities in developing economies, provide an opportunity to scale innovations to create the water-positive cities of the future.

Innovations can better manage urban wastewater. Treated and untreated wastewater contains significant contaminants, including nutrients, heavy metals, pathogenic bacteria and viruses, and toxic compounds, and these substances can have significant impacts on downstream habitats. One study found that around 37% of the global population resides in cities upstream of water bodies, and population centers are negatively correlated with water quality.[316] The study further indicated that the negative impacts on water quality tend to be concentrated in specific regions, often in the developing world, that are in major river basins such as India's Ganges and China's Yellow River.

Wastewater effluent and other sources of domestic wastes (e.g., leakage from septic tanks, decentralized, or non-sewered wastewater treatment systems) can increase and concentrate nutrient (N, P) and organic matter (e.g., animal waste, street litter, roadway oil) inputs to aquatic ecosystems. Sewage-derived particulate organic matter contributes significant annual increases of carbon (C), nitrogen (N), and phosphorus (P) into waterways and can cause eutrophication (see Challenge 2).[317] In addition, municipal wastewater effluent contains a number of compounds that are not fully-metabolized by humans or animals, such as endocrine disruptors and antibiotics from pharmaceuticals and personal care products (see Challenge 7).

In addition, impervious surfaces complicate urban water management. Up to 40% of the groundcover in U.S. cities is impervious to water, preventing what would otherwise be a mechanism for flood control and groundwater recharge.[318] During storm events, impervious cover reduces groundwater storage and increases surface runoff, resulting in increased delivery of storm water and contaminants into water sources.

315 Conservation International (2018). "Hotspots" https://www.conservation.org/How/Pages/Hotspots.aspx Accessed 16 July 2018

316 McDonald RI, Douglas I, Revenga C, et al (2011) Global urban growth and the geography of water availability, quality, and delivery. Ambio 40:437–446. doi: 10.1007/s13280-011-0152-6

317 Debruyn AMH, Rasmussen JB (2002) Organic Matter of Sewage-Derived Quantifying Assimilation By Riverine Benthos. Ecol Appl 12:511–520. doi: 10.2307/3060959

318 US Geological Survey (2011). "National Land Cover Database." https://www.mrlc.gov/nlcd2011.php Accessed 12 April 2018

Urban landscapes with 50–90% impervious surface cover can lose 40–83% of rainfall to surface runoff; forested landscapes lose only 3%.[319] Total impervious cover has been linked to numerous changes in freshwater stream biology, including flooding and physical changes in riparian areas, accumulation of pollutants like brake dust and oil from roads; increased abundance or biomass of algae and changes in algae species assemblages; decreased species abundance, richness, or diversity of macroinvertebrates indicator taxa assemblages; and decreased abundance, biomass, richness, or diversity of fishes.[320]

Estimates indicate that with current technological capacity, it will cost nearly three times more (USD 114 billion) annually to achieve the 2030 Sustainable Development Goals for water and sanitation services.[321] Some urban centers will have a greater impact than others on biodiversity, like Mexico City, Sao Paolo, and Cape Town, which are cities containing critical habitats and ecosystems that require concerted strategies to ensure water for human consumption and natural spaces.[322]

2. IMPACT OF A CHALLENGE

IMPACT OF CHALLENGE

It is difficult and perhaps not cost-effective to retrofit and change existing cities. This challenge may have a larger impact if solutions are implemented in the design and construction of new or rapidly growing cities. World Bank estimates indicate that with current population growth and water management practices, by 2030 the world will face a 40% shortfall between forecasted demand and available supply of water.[323] The majority of the increased demand will come from growing cities in the developing world. Extending basic water and sanitation health services to unserved populations will cost USD 28.4 billion per year from 2015 to 2030, or 0.10% of the global product (the equivalent of the sum of gross domestic product, GDP, across all countries).[324] A challenge could leverage public and private investment to create clear pathways for implementation of solutions in new and emerging cities, driving interest and activity in strategies that allow for the development of new cities in a way that supports rather than harms biodiversity.

Due to the outsized effect that cities have on aquatic ecosystems—affecting habitat, not only within their watershed but far upstream due to water extraction and far downstream due to wastewater and pollution—there is great opportunity to have an outsized impact on water for nature through a Water-Positive Cities challenge. Cities are natural leverage points, focusing energy and water use in a confined but populous area.

This challenge could be managed as a multi-year and multi-stage initiative where designs and solutions are carefully evaluated for their positive water and biodiversity impacts prior to receiving investment for city-wide implementation.

319 Elmqvist T, Setälä H, Handel SN, van der Ploeg S, Aronson J, Blignaut JN, Gómez-Baggethun E, Nowak DJ, Kronenberg J, de Groot R. (2015). Benefits of restoring ecosystem services in urban areas. Curr Opin Environ Sustain 14:101–108. doi: 10.1016/j.cosust.2015.05.001

320 Moore A, Palmer M (2005) Invertebrate Biodiversity in Agricultural and Urban Headwater Streams: Implications for Conservation and Management. Ecol Appl 15:1169–1177. doi: 10.1890/04-1484

321 Hutton, G & Varughese, M (2016) The Costs of Meeting the 2030 Sustainable Development Goal Targets on Drinking Water, Sanitation, and Hygeine Summary Report. http://documents.worldbank.org/curated/en/847191468000296045/pdf/103172-PUB-Box394556B-PUBLIC-EPI-K8632-ADD-SERIES.pdf. Accessed 7 Nov 2018

322 De Jong, F (2017) Which is the world's most biodiverse city?. In: The Guardian. https://www.theguardian.com/cities/2017/jul/03/which-worlds-most-biodiverse-city-extreme-cities. Accessed 7 Nov 2018

323 The World Bank: Water & Sanitation Overview. https://www.worldbank.org/en/topic/water/overview Accessed 7 Nov 2018

324 Hutton, G & Varughese, M (2016) The Costs of Meeting the 2030 Sustainable Development Goal Targets on Drinking Water, Sanitation, and Hygeine Summary Report. http://documents.worldbank.org/curated/en/847191468000296045/pdf/103172-PUB-Box394556B-PUBLIC-EPI-K8632-ADD-SERIES.pdf. Accessed 7 Nov 2018

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE
◐

Open Innovation Landscape. There are a few notable examples of challenges with some focus on water in urban environments, but none of these open innovation programs focus solely on improving biodiversity outcomes through urban water innovation.

The Rockefeller Foundation is currently running the 100 Resilient Cities initiative. Within that framework, the loss of biodiversity and water-related issues (e.g., flooding, infrastructure failure, water security, drought, access to food and water) are among the "shocks and stresses" that need to be addressed in urban resilience planning and implementation. However, only one of the 100 Resilient Cities selected biodiversity conservation as a goal. The program provides funding, technical assistance, and capacity building to develop city-wide resilience strategies.[325]

The USAID Humanitarian Grand Challenge called for innovations to supply or locally generate 1) clean water and sanitation, 2) energy, 3) life-saving information, or 4) health supplies and services to help conflict-affected people. A few relevant water-related solutions came out of that challenge, including innovations for access to safe drinking water, solar-powered water pumps, and sensor-driven drip irrigation.

The Rebuild by Design Program[326] following Hurricane Sandy offered a competitive process to design comprehensive, neighborhood-scale systems to manage flooding and extreme weather events in and around New York City. The winning teams are working with cities and municipalities to build the designs within the next ten years. The financial incentives for top ideas are great, including a USD 1 billion federal grant program, local and state level spending, and social sector philanthropy.

A number of open innovation challenges have focused on water filtration and provision, especially in sanitation, but none have focused specifically on water for nature.[327]

Public & Private Sector Investment. Most investment in urban water innovation has come through public forms of development and deployment, not though open innovation techniques such as challenges. Because the majority of urban projects require significant planning and public funding, traditional approaches to innovation in this space have been driven by cities in higher income countries such as Singapore and The Netherlands. International aid organizations invest in sanitation and water technologies in the developing world that are low cost and functional, but these solutions have not been deployed at the scale of entire cities.

Public investment in infrastructure will need cost-saving technologies and methods to meet urban growth.[328] In the U.S., ReNUWit[329] is a National Science Foundation Engineering Research Center focused on funding, studying, developing, and consulting on urban water infrastructure technology projects that has developed numerous pilot projects in urban water management and treatment. Cost-saving products that are simultaneously good for biodiversity outcomes would likely find opportunities in the global marketplace of urban design and urban growth.

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325 http://100resilientcities.org/resources/#section-1 Accessed 8 Nov 2018

326 http://www.rebuildbydesign.org/our-work/sandy-projects Accessed 8 Nov 2018

327 Examples include: Water Innovation Engine: Urban Sanitation Challenge; The New Arizona Prize: Water Innovation Challenge; Campus RainWorks Challenge; Water Abundance XPrize; Nutrient Recycling Challenge; Real-time sTime ensor to monitor sewer overflows; Predicting Water Main Failure; MIT Water Innovation Prize; Glasgow Climate Resilience Innovation Challenge; Climathon Challenge; Newton Fund UK-Malaysia Urban Innovation Challenge; Global Resilience Challenge: Water Window; Innovation Challenge: Floods Resilience; Cumbria Flood Risk Management and Modelling Competition; University Flash Flooding Challenge; Zero Power Water Monitoring Challenge; RELX Group Environmental Challenge; Grainger Challenge Prize for Sustainability (removal of arsenic from groundwater at a household scale); OpenIDEO: Water Resilience Challenge; US Bureau of Reclamation Water Prize Competition Center / InnoCentive's Water Pavilion

328 Woetzel, J et al (2014) Tackling the world's affordable housing challenge. McKinsey Global Institute Report. https://www.mckinsey.com/featured-insights/urbanization/tackling-the-worlds-affordable-housing-challenge. Accessed 7 Nov 2018

329 http://renuwit.org/highlights/project-spotlights/ Accessed 8 Nov 2018

Investment for innovation has also occurred via The Gates Foundation's Water, Sanitation & Hygiene funding strategy. This program supports the Reinvent the Toilet Challenge to create sanitation systems for low-income customers, as well as other innovations to create practical and cost-effective sanitation infrastructure and public services for everyone.[330]

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

MARKET SIZE

Cities are built over a long time horizon and are paid for through a number of mechanisms including private investment and finance, government bonds, and amortized utility payments. The market for "building new cities" does not necessarily exist. Policies and regulations may also drive urban planning decisions. City-wide water distribution and treatment requires large investment in infrastructure. It is difficult to estimate the size of the direct market to scale solutions outside of purchases made by governments, private or public utilities, or through philanthropic grants.

In addition, the benefits of nature are not routinely or systematically monetized, so it is also difficult to capture the value of water and biodiversity, however it may be possible to estimate the costs of replacing nature's services in their absence. Efforts to create markets based on ecosystem services represent some opportunity, such as wetlands mitigation banking in the U.S., which is approximately a USD 2 billion annual market. [331]

A number of solutions to this challenge may be considered green infrastructure projects, or techniques that use vegetation, soils, and other elements and practices to restore natural processes to manage in urban environments. In 2015, governments, water utilities, companies, and communities spent nearly USD 25 billion on payments for green infrastructure for water, with some large green infrastructure projects reporting benefits to biodiversity conservation.[332]

Wastewater recycling and reuse is a potential global market to scale and sustain solutions. This market reached nearly USD 12.2 billion in 2016 and should reach USD 22.3 billion by 2021.[333] The increase continues to be driven by demand for water in water-stressed regions and an increasing need for filtration technologies; it is unclear what proportion of this market will be dominated by large-scale wastewater recycling and reuse technologies, or innovations that are usable at the single-home or community scale. Market research also indicates that the annual market value for new sanitation technologies for low-income customers could be more than USD 6 billion globally by 2030.[334]

There are already a number of options for water-permeable materials on the market. Over the next ten years, the fastest growing segment of the "pervious pavement" market is expected to be pervious concrete. The global market for pervious pavement is projected to grow from USD 12.13 billion in 2015 to USD 22.17 billion by 2026.[335] This market is mostly driven by the increasing demand for new construction all over the world, particularly in emerging economies of Asia-Pacific, the Middle East, and Latin America.

331 Yonavjak, L (2014) How privates capital is restoring U.S. wetlands. In: Forbes. https://www.forbes.com/sites/ashoka/2014/04/25/how-private-capital-is-restoring-u-s-wetlands/#1fa1ea4c5e83. Accessed 7 Nov 2018

332 Bennett G, Ruef F (2016) Alliances for Green Infrastructure: State of Watershed Investment 2016. https://www.forest-trends.org/publications/alliances-for-green-infrastructure/. Accessed 7 Nov 2018

333 https://www.bccresearch.com/market-research/membrane-and-separation-technology/water-recycling-resuse-markets-mst051c.html Accessed 7 Nov 2018

334 https://www.gatesfoundation.org/What-We-Do/Global-Growth-and-Opportunity/Water-Sanitation-and-Hygiene#TheOpportunity Accessed 7 Nov 2018

335 https://www.marketsandmarkets.com/PressReleases/pervious-pavement.asp Accessed 7 Nov 2018

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS

Green infrastructure and permeable replacements for hardscape. The U.S. Environmental Protection Agency created an online repository of green infrastructure tools and resources to support water management.[336] A number of solutions classified as green infrastructure have been designed to better manage water in urban centers and use biofilters from plants, but these solutions are not yet implemented on city-wide scales. Pervious pavement is also a staple technology in urban design, often implemented in localized scenarios across cities around the world. Some cities are implementing programs to improve the permeability of their urban centers. Chicago's Green Alleys[337] program has incorporated permeable pavements, open bottom-catch basins, high albedo reflective pavement, and recycled materials in roads around the city to reduce storm water runoff and heat pollution. In Los Angeles, several neighborhood-scale permeable, sustainable retrofits have been built,[338] as well as dedicated storm water capture and groundwater recharge stations. The Living Levee, a collaboration with the Bay Area Clean Water Agencies in California, is testing horizontal wetland levees to both control floods during storms and leach nitrates and other contaminants from wastewater. In Singapore, the water resource-limited nation has implemented a comprehensive water management strategy where a core facet is the collection, retention, and use of every drop of water in the country through a system of green infrastructure, storm water management, and water treatment and desalination facilities.[339] Singapore's signature A City in a Garden initiative has focused on protecting biodiversity and expanding green public space that can serve the dual concerns of water collection and treatment services.[340] DC Water (Washington, DC) embarked on the Clean Rivers Project with the goal of reducing the combined sewer and storm water outflows to local watersheds through a massive underground tunnel network and green infrastructure. Although the project costs USD 2.6 billion, the local government employed green bonds or Pay for Success programs to help defray costs.

Examples of innovations to support green infrastructure include Topmix Permeable,[341] a fast-draining concrete pavement that can absorb 1,000 liters of water per minute with increased structural integrity compared to current competitors. Solidia Technologies, a company with investment from the Oil and Gas Climate Initiative, developed a new approach to manufacture cement (a main ingredient in concrete) that uses CO_2 rather than water in its production, thereby using less water while creating a strong material that reduces greenhouse gas emissions. These enabling technologies are ready to deploy and have technology readiness levels of 6 and 7+.

Greywater treatment systems for households and communities. Lowering the cost of entry for household or community-level water treatment and reuse systems could help the uptake and increase potential benefits for consumers and water providers. Flotender[342] has created Residential Grey Water Systems for home use that capture used greywater, treat it to "appropriate" water standards, and provide connection to home gardening or irrigation systems. Matala[343] is a Taiwanese filtration system for both industrial and household wastewater treatment. Their Aqua2use Grey Water System[344] includes household grey water diversion and treatment devices that have been installed throughout the U.S. in over 800 homes. The technology filters effluent from households for outdoor and household reuse, and

336 Green Infrastructure Wizard (GIWiz). https://cfpub.epa.gov/giwiz/index.cfm Accessed 3Dec2018
337 https://www.cityofchicago.org/city/en/depts/cdot/provdrs/street/svcs/green_alleys.html Accessed 7 Nov 2018
338 https://www.lacitysan.org/ Accessed 7 Nov 2018
339 https://www.pub.gov.sg/watersupply/singaporewaterstory Accessed 7 Nov 2018
340 https://www.nparks.gov.sg/about-us/city-in-a-garden Accessed 7 Nov 2018
341 http://www.tarmac.com/solutions/readymix/topmix-permeable/ Accessed 7 Nov 2018
342 http://www.flotender.com/residential-grey-water-system-for-home-use.html Accessed 7 Nov 2018
343 http://www.matala.com.tw Accessed 7 Nov 2018
344 https://waterwisegroup.com Accessed 7 Nov 2018

the average family of four is estimated to save 40,000 gallons of water per year. Drinkwell[345] developed a scalable Hybrid Ion Exchange-Reverse Osmosis process for arsenic (As) and fluoride (F-) filtration systems that eliminates common sulfate precipitation and silica fouling; Drinkwell has implemented the filter in 200+ sites across India and Bangladesh to successfully treat ground water for As and F-. H20 Innovation[346] created an open-source and inexpensive flexible membrane bioreactor design (flexMBR) that facilitates choice of membranes for filtration. The design can accommodate future innovations in membrane functionality from different suppliers lowering long-run operations cost and increasing long-term functionality. A number of these technologies are ready to deploy and, although there is room for innovation, many of these solutions are on the scale of TRL 7+.

An emerging water treatment technology for centralized or decentralized use is the use of carbon nanotubes, as they require little chemical or energy input to filter and treat water and they possess antifouling and self-cleaning functions. Single carbon nanotubes can be incorporated into filtration sheets that are able to capture biological, chemical, and particulate matter from water, and ultimately produce clean water.[347] The technology is still being tested in academic labs with a few small-scale solutions on the market, with an estimated TRL in the 4–5 range; Portapure[348] has developed personal carbon nanotube drinking water filters and containers for use in areas without access to clean water.

Greywater treatment systems for municipalities. A range of technologies are in development for decentralized water systems and for application to a multitude of water filtration needs including desalinization technologies and decontamination systems for grey water, industrial effluent, and agricultural runoff treatment. Aqua2use offers high-end greywater filtration and treatment systems for use in toilets, laundry, and garden irrigation. While reducing water usage at the consumer level, such interventions rarely lower costs for centralized water system managers who have to maintain pipe networks and infrastructure regardless of the volume of flow used. Aquafresco,[349] a winner of the MIT Water Innovation Prize, developed a novel water recycling system for hotels and commercial laundry facilities to drastically cut water and detergent use. Freshwater Systems Co.,[350] a winner of the New Arizona Prize Water Innovation Challenge, applied solar heat to treat brackish and semi-salty groundwater for agricultural reuse. Natural Systems Utilities[351] provides water reclamation services and comprehensive reuse systems for companies and larger facilities for direct-use integrating nutrient treatment, filtration, and disinfection processes. A joint project between Duke University and RTI International,[352] as part of the Gates Foundation's Reinventing the Toilet Challenge, created an experimental toilet, which is being tested at a textile mill in Coimbatore, India. New classes of "green" chemicals are also being used to treat water. For example, Environmental Operating Solutions, Inc.[353] provides green chemicals to wastewater treatment systems that contribute to contaminant removal. These technologies are all ready for widescale deployment and have TRL of 7+.

Financial incentives and de-risking innovation. A key constraint of green infrastructure projects is that local governments and municipalities are risk-averse, resource-limited, and must deliver public utility services for their constituents. Local governments generally must deliver clean water for human use and treat used water

345 http://drinkwellsystems.com/#landing-page Accessed 7 Nov 2018

346 http://www.h2oinnovation.com/Afficher.aspx?section=93&langue=en Accessed 7 Nov 2018

347 Das R, Ali ME, Hamid SBA, Ramakrishna S, Chowdhury ZZ (2014) Carbon nanotube membranes for water purification: a bright future in water desalination. Desalination 336:97-109. Doi: https://doi.org/10.1016/j.desal.2013.12.026

348 https://www.portapure.com/nano-carbon-technology-2/ Accessed 7 Nov 2018

349 http://aquafresco.co Accessed 7 Nov 2018

350 Loomis, B (2016) Foundation names $250,00 water prize winner. In: AZ Central. https://www.azcentral.com/story/news/local/arizona-water/2016/11/03/foundation-names-250000-water-prize-winner/93255302/ Accessed 7 Nov 2018

351 https://www.nsuwater.com/solutions/water-reuse/ Accessed 7 Nov 2018

352 Kingery K (2018) Duke's Community-Based Toilet System Begins Testing in India. Duke University Pratt School of Engineering. http://pratt.duke.edu/about/news/coimbatore-sanitation?utm_source=twitter&utm_medium=social Accessed 7 Nov 2018

353 https://www.microc.com/products/ Accessed 7 Nov 2018

to reenter the water system. When they fail to do so in cases like Flint, Michigan, public health crises follow. There are a few novel financial approaches to support projects, like Environmental Impact Bonds or Pay for Success transactions, where private capital takes on the risk of implementing solutions and governments pay for the service only when impact benchmarks are met. DC Water and Quantified Ventures[354] developed the first transaction of its kind to reduce and manage storm water runoff and combined sewage overflows into the Potomac River watershed. The inaugural green infrastructure project in the Rock Creek sewer shed is supported by USD 25 million in upfront capital from the Calvert Foundation and Goldman Sachs Urban Investment Group. The Environmental Defense Fund and Louisiana's Coastal Protection and Restoration Authority[355] are exploring a similar approach to finance coastal wetland restoration and resilience in Louisiana.

Nutrient trading is another mechanism to incentivize entities to reduce nutrient pollution on a watershed scale. Nutrient trading has been around since the 1990s and some of the first examples are in the Great Lakes region of the United States.[356] Nutrient trading creates a market-based mechanism for nutrient producers (e.g., farmers, foresters, businesses, and water treatment facilities) to reduce pollution by selling their nutrient reductions as "credits" to other entities so they can meet their reduction requirements. Although they require extensive monitoring systems to verify quantities, nutrient trading programs are also being piloted in states bordering the Chesapeake Bay.[357]

In general, the TRL for the potential solutions to address this challenge are around 6–7+, but many of the innovations have not been scaled to the size of a city.

6. SUITABILITY OF A CHALLENGE

SUITABILITY
◑

A number of potential solutions and innovations are already being implemented or demonstrated on small scales, but innovators and cities are not evaluating or designing for a positive impact of these technologies on biodiversity. To have measurable water and biodiversity impact on the scale of a city, the best solutions are likely well-designed plans that incorporate a number of innovative materials and systems. There are already many urban challenges and initiatives to test and showcase the successful implementation of technologies such as green infrastructure and greywater reuse systems, so a challenge would be a familiar mechanism and could be effective for city leaders.

A challenge may also be an effective way to scale innovations beyond pilot projects while also measuring the positive impacts on water and biodiversity at the scale of a city. However, the implementation of the solutions on the scale of a city would take time and potentially millions or billions of dollars to build. This challenge may be most effective as a multistaged challenge over a longer time horizon (greater than one year) in order to first evaluate designs, then implement projects, and then take the time to measure impact through demonstrations of materials and systems on a city-wide scale. The prize purse would also need to be relatively large, and public and private investment and advanced market commitments would need to be leveraged to ensure market entry for new technologies. The Rockefeller 100 Resilient Cities initiative has developed relationships and partnerships with many cities around the world, so solutions sourced through a challenge may fit well within their framework as demonstration sites.

354 http://www.quantifiedventures.com/dc-water/ Accessed 7 Nov 2018

355 https://www.edf.org/ecosystems/environmental-impact-bonds-financing-wetlands-restoration Accessed 7 Nov 2018

356 Willamette Partnership, Forest Trends, & the National Network on Water Quality Trading (2018). Breaking Down Barriers: Priority Actions for Advancing Water Quality Trading. www.willamettepartnership.org/breaking-downbarriers-priority-actions-for-advancing-water-qualitytrading. Accessed 7 Nov 2018

357 Jones C, Mcgee B, Epstein L, et al (2017) Nutrient Trading By Municipal Stormwater Programs in Maryland and Virginia : Three Case Studies. 1–16.

Challenge 9

Resilient Wetlands: Conserving and Restoring Wetlands for Biodiversity

SNAPSHOT: WETLANDS

Global inland and coastal wetlands cover over 12.1 million km^2*, an area almost as large as Greenland.*

Globally, wetlands provide habitat for ***more than 100,000 known freshwater species****.*

Since 1900, about 64% of wetlands globally *have disappeared due to habitat conversion.*

76% of freshwater aquatic species that relied on wetlands *have declined or disappeared since 1900.*

CHALLENGE 9: RESILIENT WETLANDS: CONSERVING AND RESTORING WETLANDS FOR BIODIVERSITY

Wetlands serve a variety of beneficial functions including carbon storage and sinks; wildlife habitat, migration, and breeding sites; water decontamination and filtration; and flood control and natural disaster buffers. Globally, wetlands—including coastal, delta, and inland habitats—are drained, converted, or otherwise negatively impacted due to a number of diverse drivers. Wetlands must be made great once again.

This challenge seeks innovative solutions to incentivize the resilience, restoration, conservation, and construction of ecologically functional and valuable wetlands across multiple scales from one site to networks of habitat at an ecosystem scale to maximize impact on biodiversity.

SUBCHALLENGES

A. **Revolutionize Resilience:** Innovate technologies that maintain beneficial functions for natural and restored wetlands, given the impacts of environmental change and agricultural and urban expansion. Solutions may include developing wetland vegetation that is resilient to salinization, flooding, or natural disasters.

B. **Restore for function:** Innovations that improve artificial and restored wetlands (inland and coastal) to achieve functional physical, hydrologic, and soil conditions, including the soil chemistry, microbial communities, and biogeochemical processes that maintain the benefits provided by wetlands to sustain biodiversity.

C. **Incentivize Conservation:** Incentivize the conservation and restoration of functional and degraded wetlands or prevent the conversion of wetlands to alternative land uses by harnessing innovative financial, behavioral, or other scalable mechanisms to make wetlands economically viable and beneficial.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
●	◑	◔	◔	◑	◑	18

PROBLEM SUMMARY

The Ramsar Convention on Wetlands defines wetlands as sites that are both natural and artificial and comprise diverse ecosystems including inland and coastal marshes; fens; peatlands; and fresh, brackish, or salt-water bodies that are diverse in species composition, habitat, and hydrology.[358] Wetlands provide critical habitat for aquatic and terrestrial biodiversity, but they also provide a myriad of ecosystem services such as flood control, carbon storage, and filtration of toxic compounds or excessive nutrients from a watershed.

The leading anthropogenic drivers for wetland degradation include drainage for crop production or plantations; rural or urban development; logging; peat extraction; construction of canals, dykes, dams, and levees; and conversion of wetlands for fish production. Sea level rise will also increase erosion in

358 Ramsar Convention on Wetlands. (2018). Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat. https://www.global-wetland-outlook.ramsar.org Accessed 7 Nov 2018

mangrove environments and negatively impact species that are less tolerant to salt-water intrusion,[360] while drought will change the hydrologic regime and alter riparian and aquatic species composition. Wetlands are also sometimes intentionally drained for mosquito control programs to eliminate breeding sites.[361]

Wetlands provide critical ecosystem services, but climate change and expanded human development will continue to threaten the health of wetlands. Wetlands can filter toxic contaminants such as pharmaceuticals and nutrients and, in some cases, are more effective than wastewater treatment plants at filtering out contaminants.[362] However, the capacity for wetlands to act as filters for contaminants declines when too much water is withdrawn directly from wetlands or from the source water that feeds into wetlands.

Wetland restoration and mitigation actively occurs worldwide, yet these engineered efforts need to be resilient to environmental change, including climate change. Wetland restoration and resilience projects must focus on designing restoration that is adaptive to the expected long-term changes in the hydrologic regime, as well as address pollution and invasive species while preserving biodiversity and the benefits provided by well-functioning wetlands.[263]

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

BIODIVERSITY IMPACT
●

Global inland and coastal wetlands cover over 12.1 million km^2, an area almost as large as Greenland, with 54% permanently inundated and 46% seasonally inundated.[364] Wetlands serve a variety of ecological functions and provide ecosystem services that benefit human communities as a result. They are also vital habitats that support biodiverse communities including migratory species, aquatic nurseries, and unique habitats.

The Ramsar Convention states that urbanization and population growth impacts wetlands through changes in hydrological connectivity, habitat alteration, water tables and soil saturation, pollution, and, ultimately, a loss of species richness and abundance.[365] A decline in wetlands could lead to precipitous decline in biodiversity as a wide range of species rely on these habitats beyond the ecosystem services they provide to human communities.

Wetlands occur throughout the planet except in glaciated regions such as parts of Greenland and Antarctica, and researchers estimate that Asia has seen the largest loss in wetland acreage due to anthropogenic activities.[366] Globally, wetlands provide habitat for more than 100,000 known freshwater species. However, wetlands have experienced much loss: Up to 87% of global wetland resources have been lost since 1700.[367] Since 1900, about 64% of wetlands globally have disappeared due to habitat

359 Van Asselen S, Verburg PH, Vermaat JE, Janse JH (2013) Drivers of wetland conversion: A global meta-analysis. PLoS One 8:1–13. doi: 10.1371/journal.pone.0081292

360 Barros, DF, Albernaz, ALM. (2014). Possible impacts of climate change on wetlands and its biota in the Brazilian Amazon. Braz J Biol 74:),810–820. doi: 10.1590/1519-6984.04013

361 U.S. Environmental Protection Agency (2001). "Threats to Wetlands." https://nepis.epa.gov/Exe/ZyPDF.cgi/200053Q3.PDF?Dockey=200053Q3.PDF Accessed 7 Nov 2018

362 Storrs, C (2015). "Designing Wetlands to Remove Drugs and Chemical Pollutants." Yale 360. https://e360.yale.edu/features/designing_wetlands_to_remove_drugs_and_chemical_pollutants Accessed 7 Nov 2018

363 Erwin, KL (2009) Wetlands and global climate change: The role of wetland restoration in a changing world. Wetl Ecol Manag 17:71–84. doi: 10.1007/s11273-008-9119-1

364 Ramsar Convention on Wetlands. (2018). Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat. https://www.global-wetland-outlook.ramsar.org Accessed 7 Nov 2018

365 Ibid

366 Hu S, Niu Z, Chen Y, et al (2017) Global wetlands: Potential distribution, wetland loss, and status. Sci Total Environ 586:319–327. doi: 10.1016/j.scitotenv.2017.02.001

conversion, along with 76% of freshwater aquatic species that relied on wetlands.[368] Since 1970, inland and marine/coastal wetlands both declined by approximately 35%, where data are available: three times the rate of forest loss. In contrast, human-made wetlands, largely rice paddies and reservoirs, almost doubled over this period, now forming 12% of global wetlands.[369]

Wetlands support an abundance of both year-round species and seasonal species that use wetlands as migratory stopover sites and nurseries. However, since 1970, wetland loss has affected 81% of inland wetland-dependent species populations and 36% of coastal and marine species. WWF's 2016 Living Planet Report estimated a 39% decline in population abundance for 308 freshwater species in inland wetlands from 1970–2012.[370] Overall, available data suggest that wetland-dependent species such as fish, water birds, and turtles are in serious decline, with one-quarter threatened with extinction, particularly in the tropics.[371]

The global threat levels to wetlands are high for nearly all wetland-dependent species, with over 10% of species globally threatened. The highest levels of extinction risk with over 30% of species globally threatened, are for marine turtles, wetland-dependent megafauna, freshwater reptiles, amphibians, non-marine mollusks, corals, crabs, and crayfish. Water-bird species have relatively low extinction risk, although populations are generally in a long-term decline,[372] and migratory water birds face much higher extinction risks.[373] Wetland plants species also face higher extinction risks than grassland vegetation in temperate climates. Wetland habitats are vulnerable to extinction not only because of human land-use changes, but also due to climate change.[374]

In the U.S. alone, wetlands provide specialized habitat for more than 7,000 plant species. About one third of all plants and animals listed as threatened or endangered depend on wetlands for their survival, including whooping cranes, American crocodiles, the dwarf lake iris, and several orchid species.[375] Around 50% of endangered, threatened, and rare species are wetland dependent and around 30% of plant species are as well. The majority of these species are fish, mussels, and birds. Of the estimated 2,500 plants in the U.S. still in need of protection, it is estimated that 700 may be wetland related.[376] The prairie potholes of the U.S., which are depression wetlands carved by ancient glaciers, are breeding grounds for more than 50% of North American waterfowl.[377] A number of terrestrial species (e.g., bears and ungulates) also rely on wetlands for food sources and shelter. There is still much to learn about the biodiversity of wetlands globally, especially those located in remote regions like the Amazon River Basin. As an indication of how little is known, from 1999 to 2009, researchers identified 257 previously unknown species of freshwater fish in the Amazon River Basin alone.[378]

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369 Ramsar Convention on Wetlands. (2018). Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat. https://www.global-wetland-outlook.ramsar.org Accessed 7 Nov 2018

370 WWF (2016) Living Planet Report 2016: Risk and resilience in a new era. Gland, Switzerland. https://wwf.panda.org/knowledge_hub/all_publications/living_planet_report_2018/. Accessed 7 Nov 2018

371 Ramsar Convention on Wetlands. (2018). Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat. https://www.global-wetland-outlook.ramsar.org Accessed 7 Nov 2018

372 Ibid

373 Hardesty-Moore M, Deinet S, Freeman R, et al (2018) Migration in the Anthropocene: how collective navigation, environmental system and taxonomy shape the vulnerability of migratory species. Philosophical Transactions of the Royal Society B: Biological Sciences, 373 (1746). DOI: 10.1098/rstb.2017.0017. Migratory birds face higher extinction risk, so we assume this extends to migratory water birds.

374 Buse J, Boch S, Hilgersd J, Griebeler EM, (2015) Conservation of threatened habitat types under future climate change—lessons from plant-distribution models and current extinction trends in southern Germany. J. Nat. Conserv. 27, 18e25. doi: 10.1016/j.jnc.2015.06.001

375 U.S. Fish and Wildlife Service (2009). "Fish and Wildlife Habitat" American Wetlands Month. https://www.fws.gov/home/feature/2009/Wetland/fishandhabitat.htm Accessed 7 Nov 2018

376 Niering W.A. (1988) Endangered, Threatened and Rare Wetland Plants and Animals of the Continental United States. In: The Ecology and Management of Wetlands. Springer, New York, NY

377 U.S. Environmental Protection Agency (2016). "Prairie Potholes." Wetlands. https://www.fws.gov/home/feature/2009/Wetland/fishandhabitat.htm Accessed 13 April 2018

378 World Wildlife Fund (2010) Amazon Alive: A decade of discovery 1999-2009. https://www.wwf.or.jp/activities/lib/pdf_forest/conservation/20101026AmazonAlive.pdf Accessed 7 Nov 2018

2. IMPACT OF A CHALLENGE

IMPACT OF CHALLENGE

Wetlands are destroyed or degraded by a number of factors, including climate change and land-use change resulting from urbanization and agricultural development. We can quantify the ecosystem services that wetlands provide (e.g., buffers from flooding, water decontamination, vital habitats and breeding grounds). But, wetland mitigation banks, international regulatory protections like Ramsar, and other financial incentives to maintain wetland habitats have proven insufficient in reducing biodiversity decline in these habitats. This challenge would be mildly transformative: more resilient wetlands and perhaps novel behavioral mechanisms could contribute to changing the global outlook for wetlands, but the underlying drivers of wetland destruction would remain.

One set of potential solutions includes engineering resilience in wetland species. These solutions would reconceptualize how we approach wetland (and other ecosystems) restoration. Genetic modifications might prove to have truly transformative impacts globally. Although a challenge in this topic would engage the public's imagination, solutions would not be implemented in the near-term due to social acceptance and validation of laboratory research.

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE

Open Innovation Landscape. No previous or active challenges have focused directly on wetlands conservation or wetlands resilience, but the Rebuild by Design competition after Hurricane Sandy incentivized designs that protect inhabited coastal zones and incorporate green infrastructure, often including some form of artificial or constructed wetlands. The winning designs received large grants to implement the pilot design projects in collaboration with municipalities.

Public & Private Sector Investment. Green infrastructure projects and innovations discussed in Challenge 8 could be applied to this Wetlands Challenge as well, and provide opportunities to apply existing technologies to a new purpose or approach. Cities in the Netherlands have incorporated ecosystem services into regional planning and development initiatives particularly in Rotterdam, where critical wetland habitat exists around urban and peri-urban areas. Financial tools and mechanisms that mitigate risk to public entities and leverage private capital for environmental impact such as Environmental Impact Bonds could contribute to solving this problem. In addition, wetlands banking and other financial mitigation tools (e.g., used for carbon or land-use change) are used to protect or conserve existing wetland habitats. The Blue Carbon Initiative, an international organization, has created financial tools to conserve mangroves, tidal marshes, and seagrasses, which sequester and store "blue" carbon in coastal and marine vegetation and in the sediment. One such tool is blue carbon offsets for tourism activities. [379]

379 http://thebluecarboninitiative.org/carbon-projects/ Accessed 8 Nov 2018

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

MARKET SIZE

The markets to scale innovations for wetland resilience may come from the value inherent in the services that wetlands provide to human populations. Many have attempted to calculate the value of wetlands through monetary assessments. For example, based on the benefits provided by a set of ecosystem services, The Millennium Ecosystem Assessment valued wetlands at USD 15 trillion in 1997, and the estimated value of wetland storm protection services at USD 23.2 billion per year.[380]

Communities and industries that rely on the ecosystem services provided by wetlands might be further incentivized to pay for solutions to protect and restore wetlands. As an example, the existing ecological restoration industry rebuilds and restores damaged habitats after environmental damage or human impact. The ecological restoration industry is estimated at USD 25 billion per year and generates about 200,000 jobs.[381]

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS

Wetlands: Natural barriers and filters. There are numerous examples of regional wetland restoration projects that have been built to provide protection against storms and filter wastewater. Wetlands are also being constructed to treat wastewater, but they need to be built over large swaths of land in order to effectively treat large volumes of contaminated wastewater (on the order of 10,000–100,000 acres).[382] The Rebuild by Design Competition resulted in green infrastructure designs incorporating wetlands; for example, the New Meadowlands[383] was awarded USD 150 million to create a "Meadowpark" in the low-lying and flood-prone district along the Hackensack River in Carlstadt, NJ. This project will transform the industrial area into a public park and mixed-use space in part by restoring marshlands and building a system of berms.

MWH Global Inc[384] designed the Alewife Reservation Storm Water Wetland in Cambridge, MA. The project required diverting the city's combined sewer system to the Alewife Brook and planting 120,000 native plants, which resulted in an 84% reduction in sewer overflow and the creation of valuable recreation and water treatment spaces.

Engineering wetland resilience. Miami-Dade County and the Nature Conservancy[385] are examining living shorelines[386] to redesign the city's layout and better balance the hydrology and incursion of water into human communities. By measuring and studying the feasibility of such novel design principles, the project is responding to sea-level rise, saltwater incursion, and potential storm impacts. There are also existing process innovations to enhance wetland resilience. Approaches to saltwater intrusion and sea-level rise have focused on increasing the flow and availability of freshwater into areas with potential increases in salinity. Projects in the Mississippi River Delta like the Caernarvon Diversion[387] have increased the flows of

380 World Wildlife Fund (2018) The Value of Wetlands Fact Sheet. http://wwf.panda.org/our_work/water/intro/value/ Accessed 8 Nov 2018

381 Barrett, K (2015) Ecosystem restoration is a $25 billion industry that generates 220,000 jobs. In: Ecosystem Marketplace. https://www.forest-trends.org/ecosystem_marketplace/ecological-restoration-25-billion-industry-generates-220000-jobs/. Accessed 7 Nov 2018

382 Storrs, Carina (2015). "Designing Wetlands to Remove Drugs and Chemical Pollutants." Yale 360. https://e360.yale.edu/features/designing_wetlands_to_remove_drugs_and_chemical_pollutants Accessed 8 Nov 2018

383 http://www.rebuildbydesign.org/our-work/all-proposals/winning-projects/nj-meadowlands Accessed 7 Nov 2018

384 http://www.mwhglobal.com/project/alewife-reservation-stormwater-wetland/ Accessed 8 Nov 201

385 Sokol J (2016) To address flooding in Miami, the best way forward might be back. In: Undark. https://undark.org/article/miami-flood-climate-change-waterways-ever-glades/. Accessed 7 Nov 2018

386 Bolstad E (2016) "Living Shorelines" will get fast track to combat sea level rise. Scientific American E&E News. Accessed on 5 Nov 2018. https://www.scientificamerican.com/article/living-shorelines-will-get-fast-track-to-combat-sea-level-rise/

sediment and helped reduce or manage salinity levels in critical watersheds and coastal wetlands. Finally, techniques in synthetic biology are being researched for coral reef restoration so that reefs can adapt to the changing climate, and there may be similar applications for wetland species.

Existing financial and behavioral incentive systems. In the U.S., some private investment groups purchase and restore wetlands and receive a financial return on their investment when they sell mitigation credits to others who need to offset environmental impacts. One such firm, Ecosystem Investment Partners, has over USD 500 million in assets under three investment funds.[388] Additionally, in California, carbon offsets can be sold via managed wetlands or rice plantations.[389]

Aside from re-engineering wetland species through synthetic biology, most of the innovations, processes, and designs are far beyond proof of concept and have high TRLs.

6. SUITABILITY OF A CHALLENGE

Wetlands serve vital roles as habitats that enhance global biodiversity and provide valuable services such as filtering fresh water. Although this challenge would incentivize innovations to ensure that wetlands can adapt to a changing climate, it does not address underlying drivers of wetland destruction such as agricultural expansion and urbanization. A challenge may mobilize innovators to test and deploy innovations that make restored and artificial wetlands more ecologically functional and resilient in the long term, and it might elicit innovative financial mechanisms to incentivize wetland restoration. But, because wetland restoration is a multiyear process requiring investment in ecologically appropriate parcels of land, a challenge would be less likely to yield sufficient systematic change. Due to a combination of potential market failures and significant legal and policy barriers, a challenge would be appropriate but potentially suboptimal to address the drivers of wetland destruction.

SUITABILITY

387 White E and Kaplan D (2017) Restore or retreat? Saltwater intrusion and water management in coastal wetlands. Ecosystem Health and Sustainability 3(1):e01258. doi: 10.1002/ehs2.1258

388 https://ecosystempartners.com/ Accessed 7 Nov 2018

389 Hamrick K and Zwick S (2017) Can California Tap Carbon Markets To Save Its Delta (And Its Drinking Water)? In: Ecosystem Marketplace. https://www.forest-trends.org/ecosystem_marketplace/california-delta/ Accessed 7 Nov 2018

Challenge 10

The Dam Challenge: Replacing the Services Provided by Dams while Mitigating Ecological Harm

SNAPSHOT: DAMS

There are at least ***70,000 large dams worldwide exist with another 3,700 planned or under construction****, each with a capacity of more than at least 1 MW energy potential.*

Current construction rates indicate that more than ***90% percent of the world's rivers will be fragmented by at least one dam in the next 15 years.***

In the U.S. and Europe, ***fish extinction rates are over 100x higher than their natural rates.***

Globally populations of freshwater species have ***declined 83% globally since 1970 due to anthropogenic stressors*** *like dams and large-scale water diversion projects.*

CHALLENGE 10: THE DAM CHALLENGE: REPLACING THE SERVICES PROVIDED BY DAMS WHILE MITIGATING ECOLOGICAL HARM

This challenge seeks scalable solutions to replace the services provided by dams and reservoirs—delivering and deploying water for multiple uses, hydroelectric energy production, and flood prevention—while mitigating or preventing the ecological harm caused by dams. Solutions should maintain beneficial freshwater ecosystem processes like pulse flooding and sedimentation and limit negative impacts such as salt intrusion and nutrient pollution. Solutions will both be modular, incremental changes to existing dam infrastructure globally and whole-scale reimagining of dam projects for hydroelectric power capacity with limited ecological damage.

SUBCHALLENGES

A. **Understand Dam Impacts:** Create scalable, low-cost data tools to equip decision makers to better understand, predict, and manage the cumulative upstream and downstream economic and biodiversity impacts of dams at scale.

B. **Mitigate Existing Dams:** Scalable solutions to mitigate the ecological damage caused by dams both upstream and downstream to maintain critical human and environmental functions including fisheries, sedimentation, and seasonal flows, and prevent the accumulation of toxic contaminants.

C. **Reframing Dams Design Challenge:** Revolutionize traditional design of dams to create biodiversity-positive dams of the future to meet a growing global demand for power.

CRITERIA & SCORE

1. Biodiversity Impact	2. Impact of Challenge	3. Competitive Landscape	4. Market Size	5. Technological Readiness	6. Suitability	SCORE
◕	◔	◕	◑	◔	◔	17

PROBLEM SUMMARY

Water infrastructure (defined as human-constructed structures to transport and store water for use and consumption) fundamentally alters the stocks, flows, and hydrology of water systems and can have enormous impacts on terrestrial and aquatic ecosystems in a watershed. The rationale for implementing water infrastructure varies by region and depends on the needs, priorities, and capital of the surrounding human population. Dams facilitate irrigation and can increase agricultural production, provide access to drinking water, create power for population centers, and provide jobs in local economies.

Globally, natural river flows have been altered by a number of anthropogenic factors including dams, land use practices, urbanization, and excessive water withdrawal. Poor water governance has enabled these alterations, and they are likely to be exacerbated by the effects of climate change. There are currently at least 70,000 large dams worldwide with another 3,700 planned or under construction, each with a capacity of more than 1 MW; current construction rates indicate that more than 90% of the world's rivers will be fragmented by at least one dam in the next 15 years. The majority of dam growth will take place in Southeast Asia, South America, and Africa for hydroelectric electricity generation.

The growth rate for dams is exponential due in part to international agreements like the Paris Climate Accords driving a demand for renewable energy sources, as well as increased needs for growing and more well-off populations. Over 32 countries use hydropower to produce more than 80% of their electricity requirements and, even with intensive growth rates, hydropower's share in total global electricity production will rise only slightly from 16% to 18% by 2040 due to simultaneous increases in global energy demand.[390] The efficiency of hydropower as a power source is eclipsed by its outsized environmental impact. Dams alter the landscape and hydrology, affect water flow and sedimentation, and cause terrestrial and aquatic habitat fragmentation. Dams can also impact human communities through forced relocation or changing economic opportunities.

The expected growth of infrastructure and the need to upgrade old water infrastructure projects around the world provides an opportunity to develop and deploy novel technologies, systems of ecological restoration and maintenance, and green infrastructure programs that serve multiple purposes—ensuring water security and resource development while maintaining (and improving) aquatic ecosystems.

CRITERIA EVALUATION

1. BIODIVERSITY IMPACT

BIODIVERSITY IMPACT


In the U.S. and Europe, fish extinction rates are over 100x higher than their natural rates, and populations of freshwater species have declined 83% globally since 1970 due to anthropogenic stressors like dams and large-scale water diversion projects.[391] Currently, 3,700 dams are planned or under construction globally with at least 70,000 large dams and 300 mega dams (at least 150 meters tall or with requisite reservoir and dam volume) already completed.[392] The vast majority of planned dams are designed to generate hydroelectric power or create reservoirs for consumption or irrigation. These dams are projected to increase global hydroelectricity capacity by at least 70%, but ecosystems both upstream and downstream of these projects will be affected as they will decrease the number of free-flowing large river systems by 21%, primarily in South America.[393] Projects are proposed in large river systems with particularly high biodiversity values in Asia and Africa, primarily along river segments and tributaries that are receiving investment to match the needs of industry and growing populations.[394]

With the continuing construction of new dams, more than 90% of the world's rivers will be fragmented by at least one dam within the next 15 years.[395] The highest levels of development are in regions with emerging economies that are considered biodiversity hotspots with crucial fisheries and agricultural value, including along the Mekong (China, Laos, Cambodia), Amazon, and Congo basins where up

390 Zarfl C, Lumsdon A, Berlekamp J, Tydecks L, Tockner, K. (20152014). A global boom in hydropower dam construction. Aquatic Sciences. 77:161–170. doi: 10.1007/s00027-014-0377-0

391 Grooten M, Almond REA (2018) Living Planet Report 2018: Aiming higher. Gland, Switzerland

392 International Rivers, Questions and Answers about Large Dams: https://www.internationalrivers.org/questions-and-answers-about-large-dams Accessed 7 Nov 2018

393 Zarfl C, Lumsdon A, Berlekamp J, Tydecks L, Tockner K (2015) *A global boom in hydropower dam construction*. Aquat. Sci. 77: 161–170. doi: 10.1007/s00027-014-0377-0

394 Ibid

395 Lehner B. et al. (2011) *High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management.* Front. Ecol. Environ. 9:494–502. doi: 10.1890/100125

to 18% of global freshwater fish biodiversity exists.[396] Population growth in these regions and the concentration of life in cities will continue to drive the creation of dams for water storage, power, irrigation, and other national economic goals. The biodiversity impacts are not known, particularly the cumulative effects of multiple dams on a waterway, but major impacts on species abundance and regional extinctions due to fragmentation and large-scale hydrological changes are highly likely.

Dam density and river fragmentation can have an outsized impact on biodiversity.[397] Dams affect ecosystems both upstream, flooding riparian areas and plains and changing their biological, chemical, and geological compositions, and downstream, changing the temperature and timing of water flows.[398] Dams and reservoirs impact hydrology, geomorphology, salinity, nutrient and sediment loads, water flow, and water temperature, the very factors that regulate and sustain aquatic life. Changes in water depths, discharge, and sediment deposition patterns in reservoirs and dam tailwaters simplify or remove the niches for many species. Dams themselves obstruct migration to spawning or feeding grounds and fragment populations along the fluvial continuum.[399] Some estimates predict that 10,000–20,000 freshwater species are at risk of extinction; this estimate rivals losses during prehistoric geological transitions, such as from the Pleistocene to Holocene epochs.[400]

Although the overall impacts of dams, especially multi-dammed waterways, on extinctions are unclear, habitat fragmentation and degradation are perhaps dams' greatest impacts on biodiversity, particularly for vulnerable and migratory populations. Studies of dams have primarily focused on the effects on fish stocks and seasonal fish species like the Northern Pacific Salmon in the U.S., and their challenges with passage through constructed barriers. Some studies have documented the negative impacts of dams on freshwater fish in the tropics, obstructing the migratory or spawning patterns of fish and fundamentally shifting ecological niches and species' abundance.[401] Aquatic species can decline or disappear in particular stretches of waterways as a result of dams fragmenting aquatic habitats.[402] Endemic species and habitat specialists are most at risk of extinction from dams. For example, migratory catfish species populations have declined in Bolivia due in part to hydropower dams erected downstream, and Mekong dolphins are critically endangered by a growing number of hydropower dams in Laos and Cambodia.[403,404]

Dam construction has lasting impacts on terrestrial biodiversity. A study in Brazil in the central Amazon found that a single hydropower dam caused local extinctions of approximately 70% of native vertebrate populations, and only 25 (0.7%) of the 3,546 islands created by the dam inundation retained four fifths of a full complement of the species present prior to inundation.[405] Comparable studies in Southeast Asia have indicated similar impacts on terrestrial biodiversity.[406]

Dams not only impede the movement of aquatic species, nutrients, and sediments, but reservoirs also are sources of greenhouse gases due to land clearance and methane emissions. A 2016 meta-analysis of over 250 reservoirs around the world found that they contribute up to 25% more methane

396 Nijhuis M (2015) Harnessing the Mekong or killing it?. In: National Geographic. https://www.nationalgeographic.com/magazine/2015/05/mekong-river-dams/. Accessed 7 Nov 2018

397 Vörösmarty CJC, Mcintyre PB, Gessner MO, et al (2010) Global threats to human water security and river biodiversity. Nature 467:555–561. doi: http://dx.doi.org/10.1038/nature09440

398 Poff NL, Allan JD, Bain MB, et al (1997) The natural flow regime: A paradigm for river conservation and restoration. Bioscience 47:769–784. doi: 10.1207/1313099

399 Lees AC, Peres CA, Fearnside PM, et al (2016) Hydropower and the future of Amazonian biodiversity. Biodivers Conserv 25:451–466. doi: 10.1007/s10531-016-1072-3

400 Vörösmarty CJC, Mcintyre PB, Gessner MO, et al (2010) Global threats to human water security and river biodiversity. Nature 467:555–561. doi: 10.1038/nature09440

401 Carvajal-Quintero JD, Januchowski-Hartley SR, Maldonado-Ocampo JA, et al (2017) Damming Fragments Species' Ranges and Heightens Extinction Risk. Conserv Lett 10:708–716. doi: 10.1111/conl.12336

402 Baumsteiger J, Moyle PB (2017) Assessing extinction. *BioScience*, 67:357–366, doi: 10.1093/biosci/bix001

403 Fraser, B (2018) Dams nudge Amazon's ecosystems off-kilter. Science 358:508–509. doi: 10.1126/science.359.6375.508

404 Brownell RL Jr, Reeves RR, Thomas PO, Smith BD, Ryan GE (2017) Dams threaten rare Mekong dolphins. Science 355:805. doi: 10.1126/science.aam6406

405 Benchimol M, Peres CA (2015) Widespread forest vertebrate extinctions induced by a mega hydroelectric dam in lowland Amazonia. PLoS ONE 10: e0129818. doi: 10.1371/journal.pone.0129818

406 Ibid

than previously recognized.[407] Proposed emissions reductions of hydropower dams belie the other impacts including deforestation and emissions from the creation of reservoirs. In addition, reservoirs increase the surface area of water exposed to evaporation; the total loss of water from water storage is estimated to be 7% more than the totals of human and industrial water consumption.[408] Projections indicate that climate change will alter precipitation and evaporation rates, especially in more arid climates, thus impacting ecosystems and human water security in areas such as Cape Town, South Africa or California.[409]

There are also issues of accountability in assessing the lifespan of a dam, the cost of habitat restoration at the end of the dam's life-cycle, and penalties for dams that cause ecological damage over their lifespan. Dam removal can be an effective method to recover habitats and ecosystems but there are potential risks as well, such as enabling the downstream transport of legacy contaminants like PCBs that were previously trapped behind a dam.[410] However, in the removal of the Glines Canyon Dam in Washington state in 2014, researchers observed the return of salmon to the Elwha River and generally improved health of near-shore habitats.[411]

2. IMPACT OF A CHALLENGE

IMPACT OF CHALLENGE

The impact of solutions that re-design dam infrastructure will be greatest in developing countries where urban populations are growing, although some solutions might be retrofitted for the developed world. However, the possible innovations are not well-suited for a challenge. Dams are built for a number of purposes, and at multiple scales, including providing recreational facilities, hydroelectric power generation, flood control, water storage, and agricultural irrigation. Given that dams are built for multiple purposes, the solutions need to be fit for purpose, and on a case-by-case basis, for each proposed dam. The scale of the dam may also matter. Many dams are large projects that require investment, social acceptance, and long time frames to implement. A challenge may incentivize ideas and new designs for dams/hydropower/water storage, and possibly small-scale prototypes, but for some dams, the impact of the ideas will not be realized in the short term.

This challenge is not a moonshot. It is attempting to address competing interests: harnessing the energy in flowing water while maintaining the flow and ecological benefits of those moving waters. The core premise is to mitigate one dam-based problem at a time through incremental innovations. Current innovations focus on fish passage, particularly migratory fishery populations, but little if any attention has been paid to sediment deposits downstream, pulse flooding, or temperature regimes. At best, a challenge will incentivize solutions that minimize, but do not eliminate, the negative environmental impacts of large, engineered water storage and hydropower projects and some experimental designs for dams that could be applied in principle to a potential project.

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407 Deemer BR, Harrison JA, Li S, Beaulieu JJ, DelSontro T, Barros N, Bezerra-Neto JF, Powers SM, dos Santos MA, Vonk JA (2016) Greenhouse gas emissions from reservoir water surfaces: A new global synthesis, *BioScience* 66:949–964. d,oi: 10.1093/biosci/biw117

408 https://www.internationalrivers.org/resources/how-dams-affect-water-supply-1727; Shiklomanov IA (1998) World Water Resources: A New Appraisal and Assessment for the 21st Century. Paris. http://www.ce.utexas.edu/prof/mckinney/ce385d/papers/shiklomanov.pdf Accessed 5 Nov 2018

409 Cosgrove, C & Cosgrove, W (2012) The Dynamics of Global Water Futures Driving Forces 2011-2050. UNESCO. http://unesdoc.unesco.org/images/0021/002153/215377e.pdf. Accessed 7 Nov 2018

410 Hart DD, Johnson TE, Bushaw-Newton KL, et al. (2002) Dam Removal: Challenges and Opportunities for Ecological Research and River Restoration. BioScience. 52(8): 669–682. https://doi.org/10.1641/0006-3568(2002)052[0669:DRCAOF]2.0.CO;2

411 Howard, B (2016) River revives after largest dam removal in U.S. history. In: National Geographic. https://news.nationalgeographic.com/2016/06/largest-dam-removal-elwha-river-restoration-environment/ Accessed 7 Nov 2018

3. COMPETITIVE LANDSCAPE

COMPETITIVE LANDSCAPE

Open Innovation Landscape. Few prizes and challenges have addressed this problem. The U.S. Bureau of Reclamation has launched challenges and prizes to improve various aspects of dam functionality, like continuous power, sediment removal from reservoirs, and moving fish safely past tall dams.[412,413]

Public & Private Sector Investment. The majority of investment for dams and hydropower comes from public sources with private co-financing on specific projects. The Water Power Technologies Office of the U.S. Department of Energy is currently funding research and development to advance new "hydropower and pumped-storage technologies" to drive U.S. leadership in the emerging marine energy field, with the goal of delivering low-cost, reliable power and resiliency to the nation's electricity grids. In the future, these kinds of technologies may replace the need for inland large, hydropower projects.[414] In addition, the Department of Energy's Wave Energy Prize incentivized the development of decentralized marine hydropower.

Finally, the FutureDAMS project, led by The University of Manchester and the International Institute for Environment and Development (IIED), has committed £8 million to research dams and empower policymakers to understand their impacts when determining to start a dam project.[415] Although not direct investment, this project seeks to enrich existing research and help translate studies into practice.

4. DIRECT AND/OR INDIRECT MARKET SIZE TO SCALE AND SUSTAIN POTENTIAL SOLUTIONS

MARKET SIZE

Hydropower dams have three key qualities that drive their growth in demand—reliability, affordability, and clean power production—as nations seek to reach carbon emissions goals from the Paris Agreement. Market size might be measured by economic drivers such as the demand for power because the majority of funding for large infrastructure projects is from public sources. A McKinsey & Company report indicated a correlation between economic growth and electricity supply—areas of intense population and economic growth like sub-Saharan Africa, Asia, and South America, will experience the greatest pressure for public spending on power production.[416] China, Latin America, and Africa have the highest growth rates in hydropower dams with the most energy production potential throughout Asia and Africa.[417] Decentralized renewable energy continues to become more accessible to populations who previously lacked access to electricity. However, a growing urban population and demand for reliable power for industry will continue to fuel the growth of dams and hydropower as the major source of renewable energy compared to less reliable wind and solar power. The particular tension between climate change mitigation and biodiversity loss from hydropower dams is one that necessitates market-based solutions.

Hydropower provides 16% of global energy production and around 70% of the energy generated by renewable sources.[418] Currently, China, Canada, Brazil, and U.S. are the largest electricity producers from hydropower, with China leading by more than double any other nation.[419] Investment in dams

412 https://www.usbr.gov/research/challenges/index.html Accessed 8 Nov 2018
413 https://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=59159 Accessed 8 Nov 2018
414 https://www.energy.gov/eere/water/water-power-funding-opportunities Accessed 8 Nov 2018
415 http://www.futuredams.org/ Accessed 8 Nov 2018
416 Castellano A, et al. (2015) Powering Africa. In: McKinsey Report. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/powering-africa. Accessed 7 Nov 2018
417 World Energy Council (2016) World Energy Resources Hydropower 2016. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Hydropower_2016.pdf Accessed 7 Nov 2018
418 Ibid

has increased at least six-fold since 2010. A conservative average cost of hydropower and mega-dam construction is USD 2.8 million per MW with some of the largest projects totaling well over USD 5–10 billion and taking an average construction time of 8.6 years.[420] The annual future investment in hydropower dams may be as high as USD 220 billion under current projections.[421] Research has indicated that the "true cost" of a dam can run up to 98% higher than the projected construction costs, and dam construction often takes up to 40% longer than projected. An Oxford-led study suggests that at current levels, notwithstanding social and environmental impacts, the costs associated with dams are frequently too high to yield any net positive benefit.[422] Regardless of these high production prices, hydropower consistently ranks as one of the lowest costs per kilowatt/hour renewable energy sources over time, which continues to fuel the growing demand and market for dams.

As a result, both public and private sector entities have invested in hydropower projects not only in their own countries, but in other nations as well with large investment arms from the U.S. and China driving investment in multiple regions. Any potential solutions or designs incorporated into the growing market for hydropower dams would need to ensure the same cost efficiency for power production while providing key environmental benefits to the waterway. The reality is that private investment and government funding would be necessary for any market uptake to occur for these innovations. Solutions would either have to increase cost efficiency for operators or increase dam life expectancy significantly to motivate investors to support projects with higher ROI and lower maintenance costs.

Another approach to market entry for decreasing the impact of dams on biodiversity is designing and implementing modular changes to existing dams. In the U.S. alone, refurbishments and upgrades worth USD 800 million are initiated each year; the majority of projects include work on turbine-generator components.[423] The other factor for market uptake is willingness to pay for innovations, and one entry point might be solutions that can increase the lifespan of a dam. The U.S. Army Corp of Engineers estimates about a 50-year life expectancy for the dams it manages and estimates that upgrades to dams that have passed this threshold would cost nearly USD 24 billion (50x the current funding stream).[424] Opportunities to leap frog these costs could save nations billions of dollars in capital investment and would create incentives for market uptake resolving maintenance costs and silt deposits. There is no clear pathway or market to scale given the decentralized nature of dams in terms of who funds and manages them. In addition, externalities associated with their construction are not often absorbed by those entities. Once a dam is constructed, annual maintenance to maximize efficiency and reliability offers a market entry opportunity for new technologies that could be added into existing hydropower designs.

419 https://www.statista.com/statistics/474799/global-hydropower-generation-by-major-country/ Accessed 8 Nov 2018

420 Ansar A, Flyvberg B, Budzier A, Lunn D (2014) Should we build more large dams? The actual costs of hydropower megaproject development. Energy Policy 69:43–56. doi: 10.1016/j.enpol.2013.10.06966

421 Zarfl, C.,, Lumsdon, A.,, Berlekamp, J.,, Tydecks, L,. & Tockner, K (2015). *A global boom in hydropower dam construction.* Aquat. Sci. 77: 161–170. doi: 10.1007/s00027-014-0377-0

422 Ansar A, Flyvberg B, Budzier A, Lunn D (2014) Should we build more large dams? The actual costs of hydropower megaproject development. Energy Policy 69:43–56. doi: 10.1016/j.enpol.2013.10.069

423 U.S. Department of Energy (2018) 2017 Hydropower Market Report. https://www.energy.gov/sites/prod/files/2018/04/f51/Hydropower%20Market%20Report.pdf. Accessed 7 Nov 2018

424 U.S. Army Corps of Engineers, Dam Safety Facts & Figures: https://www.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/article/590578/dam-safety-facts-and-figures/. Accessed 7 Nov 2018

5. TECHNOLOGICAL READINESS OF POTENTIAL SOLUTIONS

TECHNOLOGICAL READINESS

Understand dam impacts. Greenhouse gas emissions released by hydroelectric facilities can be detected from satellites, and at least one nanosatellite, called "Claire", provides methane emissions in the form of heatmaps for a hydropower facility.[425] Underwater drones (ROVs, Remotely Operated underwater Vehicles) equipped with environmental sensors were used to monitor dam performance by the San Francisco Public Utilities Commission,[426] and ROVs may also a scalable technology to monitor biodiversity impacts of dams.

Reframing dams. Small hydropower projects (SHPs) have been tested around the world including in the Philippines where researchers developed the Gaia dam,[427] a runoff diversion dam that diverts excess storm and agricultural runoff water to miniature hydropower turbines. Verdant Power[428] deploys a Free Flow System (FFS) in rivers and tidal areas that utilizes horizontal-axis turbines that convert the kinetic energy of fast-moving water currents into electricity. Using a comparable design to that of a wind turbine, the FFS has been tested in the East River in New York City creating grid-connected power that harnessed both the ebb and flow of the tides. New approaches to hydropower are also in development although largely not scaled. Natel Energy's[429] hydropower projects are designed to minimize excavation, utilize water intake directly from a drop structure such as in irrigation canals, and be "fish-friendly" due to lower pressure drops and impact velocities. Lucidpipe Technologies installs turbines in the city's gravity-fed water pipes to generate power for households in Portland, OR.[430] Standard Modular Hydropower[431] is being studied at Oak Ridge National Laboratory, and researchers are testing whether standardized hydropower designs and equipment in new small hydropower developments could provide more sustainable sources of energy locally. However, when "small hydropower" is built in natural rivers and streams, it does not necessarily equate to less ecological damage, and adequate ecological assessments of SHPs to understand the impact on biodiversity have not yet been conducted.[432] SHPs tend to be installed in smaller waterways than large hydropower projects, but smaller streams and rivers, especially the headwaters, are crucial in maintaining hydrologic connectivity and biodiversity.[433]

Mitigate existing dams. Sensor Fish is an innovation that provides researchers with reliable feedback on changes in pressure, acceleration, strain, turbulence, and other forces as the neutrally buoyant device moves through hydroelectric facilities, providing engineers with crucial data to design turbines and systems that better support fish survival.[434] The Department of Energy's Water Power Program has also invested in developing and demonstrating more accurate water temperature management, dissolved oxygen models, and aerating turbines that enable hydropower plants to meet environmental standards, better match natural river flows, and increase electricity generation.[435]

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425 Ingram E (2017) Annual International Guide to Hydro Innovations and New Technology. Hydro Review. https://www.hydroworld.com/articles/hr/print/volume-36/issue-8/cover-story/annual-international-guide-to-hydro-innovations-and-new-technology.html Accessed 8 Nov 2018

426 Neto EC, Holanda GC, Varela AT, et al (2014) Autonomous Underwater Vehicle to Inspect Hydroelectric Dams. Int J Comput Appl 101:1–11.

427 ScienceDaily (2015) Engineering a multipurpose, environmentally friendly dam. https://www.sciencedaily.com/releases/2015/03/150323182619.htm Accessed 8 Nov 2018

428 Verdant Power RITE Project. https://www.verdantpower.com/rite Accessed 8 Nov 2018

429 https://www.natelenergy.com/ Accessed 8 Nov 2018

430 Boone, A (2018) How Portland is sourcing hydropower from its drinking water. In: City Lab. https://www.citylab.com/environment/2018/01/portlands-drinking-water-is-powering-the-grid/550721/. Accessed 7 Nov 2018

431 Oak Ridge National Laboratory. Standard Modular Hydropower. https://hydropower.ornl.gov/smh/ Accessed 8 Nov 2018

432 Couto TBA, Olden JD (2018) Global proliferation of small hydropower plants – science and policy. Front Ecol Environ 16:91–100. doi: 10.1002/fee.1746

433 Ibid

434 Zhiqun D, Carlson TJ, Duncan JP et al. (2010) Use of an autonomous sensor to evaluate the biological performance of the advanced turbine at Wanapum Dam. Journal of Renewable and Sustainable Energy 2: 053104 . doi:10.1063/1.3501336

435 For more information see:
https://www.energy.gov/eere/water/hydropower-market-acceleration-and-deployment#impacts and
http://www.safl.umn.edu/featured-story/environmentally-friendly-hydropower Accessed 8 Nov 2018

Better management of the ecosystems that surround the built infrastructure is also necessary. For example, the Cloud Forest Blue Energy Mechanism is an innovative incentive program in which a hydropower plant pays for measurable ecosystem benefits provided by cloud forests within the plant's catchment, like reduced sedimentation, increased water flow, and improved water.[436] The Freshwater Trust facilitates the Medford Water Quality Trading Program in Oregon where landowners are paid to plant trees along the Rogue River to offset the warm water discharged by Medford city's wastewater treatment plant. The trees cool the water and provide habitat for native species.[437]

Reservoirs can build up harmful chemicals and pollutants that runoff and accumulate in the bodies of water. A pilot project using an activated biochar technology called SediMite[438] to capture polychlorinated biphenyls (PCBs) at Mirror Lake in Delaware showed a 70% reduction in PCBs in the water and a 60% decline in PCBs in fish tissue one year after implementation.

All of these potential solutions are being deployed or have been proofed or piloted and in general have TRLs of 6 to 7+.

6. SUITABILITY OF A CHALLENGE

SUITABILITY

Dams cause large-scale ecological damage to waterways. Damage is reversible when dams are removed, as evidenced by the removal of the Glines Canyon Dam in Washington state in 2014. However, global dam removal is neither feasible nor a salient approach to this global problem for aquatic biodiversity. A number of factors, including large infrastructure, a long timescale to impact, high cost, and competing issues of generating energy from water flows while maintaining environmental functionality of flowing waters, suggest that an innovation competition is not the best fit for this challenge. The multiyear timescale and high cost to entry for any solutions or dam design would make it a complex challenge that would be less likely to produce scalable solutions different from the existing technological alternatives to hydropower created by dams. The greatest technological hurdle remains creating and demonstrating the capacity for innovations to minimize biodiversity impact while maintaining energy efficiency.

Addressing the problems caused by dams involves major technological advances in power generation and storage, as well as the redesign of infrastructure for water storage. The problem may be better managed through grant funding programs by agencies such as the U.S. Department of Energy and university or state research labs; the potential ideas would need sustained investment and would struggle to enter the existing marketplace without a potential initial user. A technology challenge following a prize model to design scalable, modular hydropower solutions, especially in the developing world, may be worthwhile, but it would not have an outsized positive impact on biodiversity conservation.

APPENDIX I: CONVENINGS & CONSULTATIONS SUPPORTING DESK RESEARCH

BIG THINK PARTICIPANTS, MAY 15–17, 2018, ZEPHYR POINT, NEVADA

Aileen Lee, Chief Program Officer, Environmental Conservation, Gordon and Betty Moore Foundation

Alexis Morgan, Global Water Stewardship Lead, WWF-Germany

Amy Berry, CEO, Tahoe Fund

Carrie Thompson, Deputy Assistant Administrator, Bureau for Economic Growth, Education and Environment, USAID

Colin McCormick, Senior Technical Advisor, Conservation X Labs

Dan Vermeer, Executive Director, Center for Energy, Development, and the Global Environment, Duke University

David Goodrich, Research Hydraulic Engineer, Agricultural Research Service, USDA

Evan Thomas, Associate Professor & Director, Mortenson Center, University of Colorado Boulder

Hilary Johnson, Director, Commonwealth Environmental Water Office, Australian Government Department of the Environment and Energy

Ian Harrison, Senior Manager in Freshwater Science and Policy and Co-Chair of the IUCN-SSC Freshwater Conservation Committee

Jamie Reaser, Executive Director, U.S. National Invasive Species Council Secretariat

Janet Coffey, Program Officer, Science Learning, Gordon and Betty Moore Foundation

Jason Clay, Senior Vice President for Markets and Food, WWF-U.S.

Jay Lund, Professor, Department of Civil and Environmental Engineering and Director, Center for Watershed Sciences, University of California, Davis

Kelly Kryc, Director of Conservation Policy and Leadership, New England Aquarium

Kimberly Caringer, Division Manager, Environmental Improvement Program, Tahoe Regional Planning Agency

Lala Faiz, Senior Investment Officer, USAID

Luis Fernandez, Director, Carnegie Amazon Mercury Ecosystem Project, Carnegie Institution for Science

Michele Thieme, Lead Conservation Scientist, Fresh Water, WWF-U.S.

Peter Gross, Water Skipper, Emerson Elemental

Rachel Strader, Program Officer, Marine Conservation Initiative, Gordon and Betty Moore Foundation

Ranjiv Khush, Co-Founder and Executive Director, Aquaya

Shashi Buluswar, CEO, Institute for Transformative Technologies, Lawrence Berkeley National Lab

Sonaar Luthra, CEO, Water Canary

Stan Bronson, Executive Director, Florida Earth Foundation

Steph Karba, Environmental Researcher, Patagonia

Steve Madsen, CTO and Co-Founder, Tersus Solutions

Wade Crowfoot, CEO, The Water Foundation

Conservation X Labs Facilitators

Alex Dehgan, Co-Founder & CEO

Barbara Martinez, Open Innovation Director

Cassie Hoffman, Field Director

Geir Gaseidnes, UX Designer

Jay Sullivan, Open Innovation Research Fellow

Paul Bunje, Co-Founder & COO

WATER LITTLE THINK PARTICIPANTS, MARCH 22, 2018, WASHINGTON, D.C.

Ann Bartuska, Vice President for Land, Water, and Nature, Resources for the Future

Colin McCormick, Senior Technical Advisor, Conservation X Labs; Energy Data Scientist, World Resources Institute

Daniel Juhn, Vice President, Conservation International

Denice Shaw, Senior Scientist & Project Lead, U.S. Environmental Protection Agency

Jamie Reaser, Executive Director, U.S. National Invasive Species Council Secretariat

Jenna Shinen, Bureau of Oceans and International Environmental and Scientific Affairs, U.S. Department of State

Jorge Gastelumendi, Director, Global Policy Lead for Water, The Nature Conservancy

Kelly Kryc, Director of Conservation Policy and Leadership, New England Aquarium

Lala Faiz, Senior Investment Officer, USAID

Stas Burgial, Assistant Director – Policy and Program Coordination, U.S. National Invasive Species Council Secretariat

Tammy White, Community Manager, Challenges & Prizes Community of Practice, U.S. General Services Administration (GSA)

Conservation X Labs Facilitators

Alex Dehgan, Co-Founder & CEO

Barbara Martinez, Open Innovation Director

Cassie Hoffman, Field Director

Chad Gallinat, Senior Program Manager

Elizabeth Tyson, Open Innovation Research Fellow

Paul Bunje, Co-Founder & COO

ADDITIONAL INTERVIEWS AND EXPERT FEEDBACK, 2018

Ashley Bolden, Senior Scientist, The Endocrine Disruption Exchange

Clay Miller, Environmental Protection Specialist, Office of Wetlands, Oceans, and Watersheds, U.S. EPA

Colin McCormick, Energy Data Scientist, World Resources institute

Devin Nieusma, Duke University

Dave Lee, Lead Technologist for ARPA-E, Booz Allen Hamilton

Jake Hanft, Program Analyst, Schmidt Marine Technology Partners

Kate Davenport, Co-President, Eureka Recycling

Katie Pelch, Senior Scientist, The Endocrine Disruption Exchange

Ku McMahon, Program Team Lead, Securing Water for Food, USAID

Luis Fernandez, Director, Carnegie Amazon Mercury Ecosystem Project, Carnegie Institution for Science

Lynn Hoffman, Co-President, Eureka Recycling

Matthew Ridenour, Community Lead, OpenIDEO

Rachael Miller, Founder/Chief Ocean Lover, Rozalia Project for a Clean Ocean

Rebecca Wassell, Yakima Basin Program Director, Mid-Columbia Fisheries Enhancement Group

Rob Kaplan, Founder & CEO, Circulate Capital

Saharah Moon Chapotin, Executive Director, United States Botanic Garden

Sam White, Director and Co-Founder, Promethean Power & Director and Co-Founder, Greentown Labs

Shannon O'Neill, Business Analyst, The Good Food Institute

Stephanie Pincetl, Professor in Residence, Director California Center for Sustainable Communities

Tom Johnson, Physical Scientist & Hydrologist, Office of Research and Development, U.S. EPA

James Dalton, Director – Global Water Programme, IUCN

APPENDIX II: CHALLENGE RANKINGS BY CRITERIA

1. BIODIVERSITY IMPACT

Max. Biodiversity Impact (5)
- De-Watering Protein
- Space Invaders: Aquatic Invasive Species
- Resilient Wetlands

High (4)
- Waste-Less Foods
- Greening the Green Revolution
- The Artisanal Mining Challenge
- The Dam Challenge

Medium (3)
- The Ten Rivers Challenge
- Micromaterials and Endocrine Compounds

Low (2)
- Water-Positive Cities

2. IMPACT OF A CHALLENGE

High Likelihood of Impact (4)
- Waste-Less Foods
- Greening the Green Revolution
- The Artisanal Mining Challenge
- The Ten Rivers Challenge
- Micromaterials and Endocrine Compounds

Medium (3)
- De-Watering Protein
- Space Invaders: Aquatic Invasive Species
- Resilient Wetlands
- Water-Positive Cities

Low (2)
- The Dam Challenge

3. COMPETITIVE LANDSCAPE

Max. Competitive Advantage (5)
- The Artisanal Mining Challenge

High (4)
- The Dam Challenge
- The Ten Rivers Challenge

Medium (3)
- Space Invaders: Aquatic Invasive Species
- Waste-Less Foods
- Micromaterials and Endocrine Active Compounds
- Water-Positive Cities

Low (2)
- De-Watering Protein
- Resilient Wetlands
- Greeting the Green Revolution

4. MARKET SIZE

Max. Market Size (5)
- Waste-Less Foods
- De-Watering Protein
- Greening the Green Revolution

Large (4)
- Water-Positive Cities

Medium (3)
- The Dam Challenge
- Space Invaders: Aquatic Invasive Species
- Micromaterials and Endocrine Compounds

Small (2)
- The Artisanal Mining Challenge
- The Ten Rivers Challenge
- Resilient Wetlands

5. TECHNOLOGICAL READINESS

High Readiness (4)
- Waste-Less Foods
- Greening the Green Revolution
- Water-Positive Cities
- The Ten Rivers Challenge

Medium Readiness (3)
- De-Watering Protein
- Micromaterials and Endocrine Compounds
- Resilient Wetlands

Low Readiness (2)
- The Dam Challenge
- Space Invaders: Aquatic Invasive Species
- The Artisanal Mining Challenge

6. SUITABILITY

High Suitability (4)
- Waste-Less Foods
- Greening the Green Revolution
- The Ten Rivers Challenge
- De-Watering Protein
- Micromaterials and Endocrine Active Compounds
- Space Invaders: Aquatic Invasive Species
- The Artisanal Mining Challenge

Medium Suitability (3)
- Water-Positive Cities
- Resilient Wetlands

Low Suitability (2)
- The Dam Challenge

CONSERVATION X LABS

GORDON AND BETTY MOORE FOUNDATION

https://conservationxlabs.com
https://conservationxlabs.com/water-challenge

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