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$15,000 "Eat it!" Lemelson-MIT Student Prize Graduate Winner

Charged Polymers for Sticky Agricultural Sprays, and Water Recovery in Cooling Towers

The Challenge:

Farmers use large quantities of pesticides to protect their plants and increase their yield, but only about 2 percent of these chemicals ultimately reach their intended target[1]. The other 98 percent of sprayed chemicals are wasted, sinking into the soil rather than landing and remaining on the plants as intended. This is problematic because the chemicals may contaminate the soil, surface water, and groundwater in areas much larger than the fields themselves. A study found that across the United States, pesticides could be detected 90 percent of the time in agricultural streams, 50 percent in shallow wells, and 33 percent in major deep aquifers[2]. Not only are these large chemical losses costly for the environment, they are also costly for the farmers.

One of the main reasons only two percent of sprayed chemicals stick to their intended target is that many plants are hydrophobic, meaning they naturally repel water. Droplets from sprays can easily bounce or roll off of plant surfaces and end up in the soil. Another major cause of spraying inefficiency is wind drift: when small droplets are sprayed, they can easily be carried away by wind and end up out of the field.

The most common solution that farmers currently rely on is adding a mix of surfactants to these chemicals, which are molecules that reduce the surface tension of the sprayed fluid and increase its ability to spread on a surface. Although fairly inexpensive, their efficiency varies from plant to plant and sometimes they have almost no effect on retention. Additionally, adding surfactants to the sprayed solutions results in the formation of smaller spray droplets, which exacerbate the problem of wind drift. Smaller droplets can lead to higher retention, but smaller droplets are also more easily affected by wind drift and can cause greater pesticide contamination. This tradeoff limits the maximum effect and explains why efficiencies are so low in practice.

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1 Pimentel, D. Amounts of pesticides reaching target pests: environmental impacts and ethics. J. Agric. Environ. Ethics 8, 17–29 (1995).

2 Gilliom, R. J. et al. Pesticides in the nation's streams and ground water, 1992-2001. (Geological Survey (US), 2006).

In a related problem, freshwater plays a critical role in many aspects of our lives – residential use, manufacturing, agriculture, energy production – and demand for freshwater will continue to rise as populations increase. According to studies by the United Nations and the U.S. State Department, we are on the path to an extreme freshwater shortage by 2030. Water-stressed regions often place drastic restrictions on water usage, primarily in the residential sector. However, the residential sector utilizes three times less water than the U.S.'s largest water user: power plants. Power plants use 165 billion gallons of water per day, which amounts to 50 percent of total U.S. freshwater withdrawals[3]. Reducing water consumption for energy generation is needed in the U.S., but will also be even more crucial in many regions with growing populations such as India, China, and the Middle East.

Figure 1: Comparison of current spray methods (left side of leaf) vs. sticky agricultural spray (right side of leaf)

The Solutions: Maher's primary invention is a novel additive based on natural polymer extracts from plants and animals that can be mixed with pesticides and other agricultural chemicals to change the liquid properties, causing the solution to more effectively stick to plants once sprayed. A polymer is a long molecule. Maher uses negatively and positively charged polymers in his additive that, once interacting with each other, create sparse hydrophilic spots that are 100 times thinner than a single strand of hair. This allows for 100 percent coverage of a plant's surface. The polymers are natural, biocompatible, and biodegradable, so they will not induce any additional pollution or health hazard.

Most recently, Maher and his team conducted trials on living citrus and grape trees to observe the effects of these additives over time. They observed the same enhancement in efficiency as in lab trials and noticed no signs of phytotoxicity, indicating that the additives would be safe to use on plants. This solution has the potential for significant environmental, societal, and economic impacts in the areas of agriculture, water, and health.

Pesticides are an essential input for efficient agriculture. Maher's invention allows for far more efficient crop treatment by increasing the retention and spreading of pesticides on plants. It has the capability to greatly impact the environment because pesticides would no longer contaminate soil, surface water or groundwater. It would also mitigate some of the health and environmental issues caused by wind drift by allowing the use of larger droplets that are less prone to drift. Finally, farmers would face lower costs due to less waste of costly chemicals.

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[3] Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade. (World Health Organization, 2006).

Maher's secondary invention is a collection system that uses electric fields to recover the vapor that is rejected from cooling towers used in power plants and reintroduces it back into the plant so that the same water can be used over and over again for cooling. The invention consists of three major components: **(1) a charging electrode** that charges the water and creates an electric field that accelerates the water towards **(2) the collector**, which consists of a dome-shaped metallic mesh to attract the water. The collector has an engineered coating to enhance the water delivery to **(3) a local water reservoir**, which collects the dripping water. Water is pumped from the reservoir back into the cooling cycle to start the process all over again, allowing the same water to be used repeatedly for cooling. This process uses very low power, requires little maintenance, and the technology can work in any type of thermoelectric power plant, including coal, gas, nuclear, concentrated solar, and geothermal.

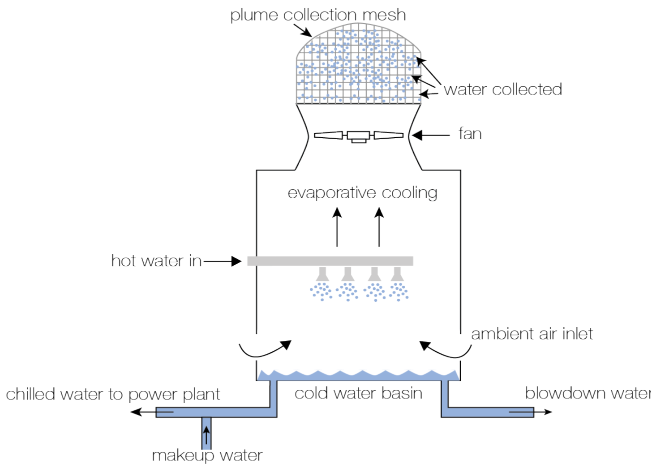

Figure 2: Depiction of how the secondary invention works

Figure 3: Example of a power plant with cooling towers that could potentially benefit from the Infinite Cooling technology

Based on data from their lab-scale prototype and a recent pilot program with MIT's cogeneration power plant, Maher predicts that for a 250MW power plant, this device would collect and save over 150 million gallons of water per year. This amounts to an estimated $1 million in annual water savings, which corresponds to 20-30 percent of water costs. These savings would have a massive, positive impact on maintaining robust freshwater reserves, and could reduce the impact of worldwide droughts by limiting the thermoelectric power industry's need for surface and groundwater reserves.

Commercialization: Maher plans to initially target a few crops for which his primary invention can have the biggest impact; such as those that use high amounts of pesticides and whose leaves are particularly hydrophobic. One of his target beachhead market crops is cotton. There are 10 million acres of cotton in the U.S. alone, with farmers spending about $100 per acre per year in pesticides, amounting to a potential initial market of $1 billion. Maher predicts that his invention could have a revenue opportunity of $150 million just for this market (by reducing pesticide use by 50 percent, and assuming he can capture 30 percent of the created value while his customer gets 70 percent). His total addressable market (TAM) is the global pesticide spraying market. Global costs of pesticides are over $100 billion. Using the same numbers for efficiency increase and value capture, he could reach annual revenues of $15 billion if the TAM is penetrated. The product will be manufactured in-house and sold as a solution that growers can mix in with their pesticides before spraying. Maher is planning on finding a strategic partner for large-scale deployment. He will be seeking a partner with established distribution channels and an existing customer base of large-scale farmers using immense quantities of chemicals that are in need of this solution.

Maher's secondary invention is already being commercialized through a company Maher formed with his team called Infinite Cooling. Their TAM in the U.S. consists of all power plants that use evaporative cooling, an $8 billion market. His team's threshold market is power plants that have high water costs (higher than $5/1000 gallons), resulting in a beachhead market of $240 million. Their product is priced at 50 percent of the estimated value to their customers, which results in an attractive payback period of two years. The company will also provide operations and maintenance service for $200,000/year. During their current pilot stage, Infinite Cooling plans to start engaging with potential strategic investors who own/operate power plants, Engineering, Procurement, and Construction (EPC) power plant contractors who have relationships with existing power plants, and contractors who can help manufacture and install their systems.