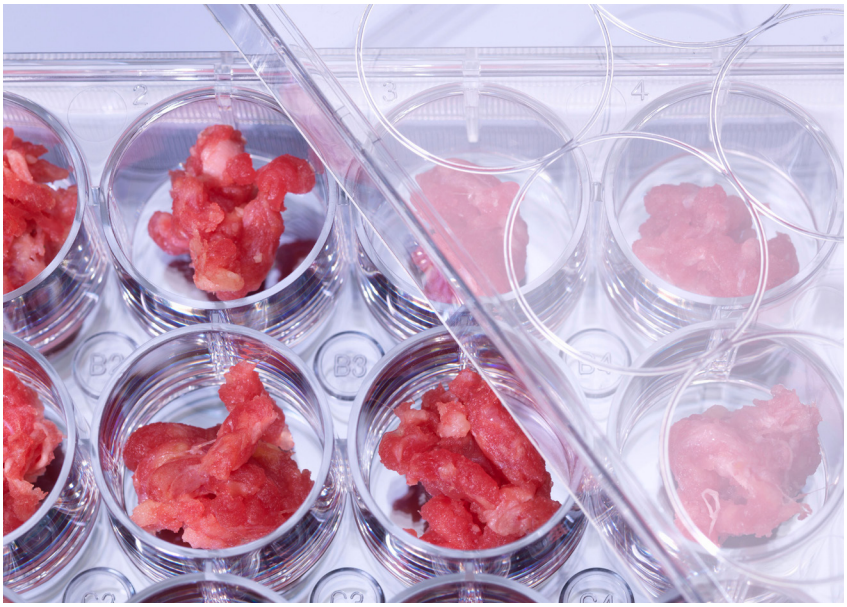
THE GOOD FOOD INSTITUTE

GROWING MEAT SUSTAINABLY: THE CULTIVATED MEAT REVOLUTION

Feeding the world's growing population with finite land and water resources will be one of the greatest challenges of the 21st century. United Nations scientists state that animal agriculture is one of the major causes of the world's most pressing environmental problems, including land degradation, loss of biodiversity, global warming, and air and water pollution (FAO 2006). Cultivated meat could address these challenges by conserving land and water, preserving habitat, reducing greenhouse gas emissions, and preventing manure pollution and antibiotic overuse.

CULTIVATED MEAT IS MUCH BETTER FOR THE ENVIRONMENT

Like conventional meat, cultivated meat is made of animal cells. In a conventional system, meat comes from animals that must be fed, housed, and slaughtered. Cultivated meat comes from cells grown in cultivators to produce various cuts or varieties of meat. A cultivated meat supply chain will have some commonalities with conventional meat, like growing feed crops, operating farm equipment and buildings, and transporting products to supermarkets. But there are some crucial differences. Cultivated meat can be produced more quickly and efficiently, with little waste and no animals to slaughter. In the seven weeks it takes a farmer to raise a flock of 20,000 chickens, a meat cultivation facility could theoretically produce a million times as much meat from a starter culture the size of a single egg.[1]



Meat production is responsible for most of agriculture's environmental impacts. More than three-quarters of agricultural land is used to support cows, pigs, and chickens, but animal products provide only 18% of global food calories and 25% of protein (Mottet et al. 2017). The impacts of conventional meat are difficult to reduce because they come from many different sources: fertilizer and feed crop production, transportation of grain and animals, manure, and the animals themselves. In its 2017 Sustainability Report, the U.S. Farmers & Ranchers Alliance reports a mere 2% improvement in energy use and greenhouse gas emissions across the beef supply chain between 2005 and 2011 (USFRA 2017). In contrast, simply running on clean energy would reduce the life cycle emissions of a meat cultivation facility by 40% to 80%. So cultivated meat can provide a way to satisfy consumer demand for meat while easing pressure on the environment.

CULTIVATED MEAT CONSERVES LAND & WATER RESOURCES

Meat cultivation promises to be faster and less wasteful than raising animals. As a result, it will conserve soil, water, habitat, and other critical resources. Industrial animal agriculture requires massive quantities of feed crops. Most of those crops end up as manure, not meat. Studies show that cultivated meat would use land 60 to 300 percent more efficiently than poultry and 2000 to 4000 percent more efficiently than beef

[1] Based on a starter cell culture density of $4x10^7$ per ml and production values from Mattick et al. 2015, compared with chicken production data in Putman et al. 2017 and an edible weight to live weight ratio of 0.52.

Cultivated meat would allow producers to meet the growing demand for animal protein while eliminating the pressure to clear wild land for feed crops worldwide.

(Hanna L. Tuomisto, Ellis, and Haastrup 2014; Mattick et al. 2015). For example, an acre of Iowa cropland can support the production of 1,000 pounds of chicken meat each year. That same acre would support 1,700 to 3,500 pounds of cultivated meat, freeing up cropland to produce grains, vegetables, or fruits for people.

Due to its efficiency, cultivated meat would also prevent and counteract one of humanity's most destructive actions: clearing forests and grasslands for animal feed. Cultivated meat would allow producers to meet the growing demand for animal protein while eliminating the pressure to clear wild land for feed crops worldwide. This more innovative approach will also reduce the unsustainable use of synthetic fertilizers and help to prevent the "biological annihilation" of habitat for feed and pasture (Ceballos, Ehrlich, and Dirzo 2017). Losing critical habitat would not only cause a mass extinction, but also destabilize the water cycle, climate, and other global systems on which humanity depends (Steffen et al. 2015).

CULTIVATED MEAT FIGHTS CLIMATE CHANGE

Cultivated meat also has the potential to help governments and businesses meet climate goals without dramatic shifts in consumption patterns. One study found that out of 10 scenarios for reducing food-related emissions, replacing a fraction of conventional meat with cultivated meat was the third-most effective option even without including the added benefits related to dramatically lower land requirements (Mohareb, Heller, and Guthrie 2018).

For example:

- Improving soil: restoring native prairie on the 10% lowest-yielding cropland used for feed crops could store up to 40 million metric tons of CO_2 in the soil each year.
- Partnering with bioenergy: trees and grasses, farmed on pasture and rangelands not suitable for food production, can provide low-carbon biofuels while improving soil and restoring biodiversity.
- Reducing deforestation: producing more meat on less land with cultivated meat will prevent deforestation for ranching and feed crops around the world, a necessary step toward keeping climate change below 2°C.
- Carbon capture and sequestration: the contained nature of cell cultivation could allow producers to capture carbon dioxide as the cells "exhale," leading to carbon-negative meat.

Because cultivated meat is not yet produced commercially at large scale, estimates about its environmental impact are based on assumptions, which result in different conclusions about its efficiency. All three environmental studies of cultivated meat published so far show very promising results (Hanna L. Tuomisto, Ellis, and Haastrup 2014; H. L. Tuomisto and de Mattos 2011; Mattick et al. 2015). Cultivated chicken will use 35% to 67% less land than current chicken farms do and reduce nutrient pollution by 70%.[2] The impact of cultivated beef is even greater, reducing land use by over 95%, climate change emissions by 74% to 87%, and nutrient pollution by 94%.[3]

CULTIVATED CHICKEN		CULTIVATED BEEF		
35% – 67%	**70%**	**95%+**	**74% – 87%**	**94%**
% less land used	% of nutrient pollution reduction	% less land used	% of climate change emissions reduction	% of nutrient pollution reduction

These figures are the result of comparisons with nine reputable life cycle analyses of conventional U.S. chicken and beef production (Putman et al. 2017; Nathan Pelletier, Pirog, and Rasmussen 2010; N. Pelletier 2008; Kebreab et al. 2016; Lupo et al. 2013; Capper 2012, 2011; Costello, Xue, and Howarth 2015; Gulli 2017). Moreover, these results do not account for the many efficiency-boosting measures that a commercial meat cultivation facility will almost certainly take to improve profitability and thus efficiency. Incorporating heat exchangers, nutrient recycling, and clean energy into meat cultivation facilities would dramatically reduce environmental impacts.

[2] Producing one ton of cultivated meat may require 0.6 acres (Tuomisto et al. 2014) to 1.2 acres (Mattick et al. 2015) of cropland.

[3] Producing one ton of cultivated meat may generate 3 to 4 tons (Tuomisto et al. 2014) to 7.5 tons (Mattick et al. 2015) of CO_2 equivalent greenhouse gas emissions and 7.9 kg PO_4eq eutrophying pollution (Mattick et al. 2015).

CULTIVATED MEAT CUTS POLLUTION AND SAVES LIVES

By not producing manure, cultivated meat avoids one of the most damaging and deadly impacts of industrial agriculture. Farm animals in the U.S. produce over 1 billion tons of manure each year, polluting the water and air of rural communities and spreading disease (EPA 2013). While cow, pig, and chicken farmers must contend with thousands of individual sources of waste, a cultivated meat system will contain and treat used cell culture media and other waste products at the source. This centralization also offers producers an opportunity and a financial incentive to recycle valuable nutrients. Studies show that cultivated meat could reduce eutrophying pollution (the oversupply of nutrients that causes algae blooms and dead zones in lakes and oceans) by 75% compared to chicken and 98% compared to beef (Mattick et al. 2015; Putman et al. 2017). And because cultivators are contained and carefully controlled systems, cultivated meat production would eliminate toxic air pollution completely.

FOOD SAFETY: ANTIBIOTIC RESISTANCE & BACTERIAL CONTAMINATION

Cultivated meat also eliminates the two biggest dangers to human health from agricultural pollution: foodborne illness and antibiotic resistance. Cultivated meat would eliminate manure from the food system, saving tens of thousands of Americans each year from hospitalizations due to meat and vegetables contaminated by animal wastes. In the United States, most antibiotics are fed to animals on industrial farms at low doses as growth promoters and to keep the animals alive in conditions that would otherwise breed disease (Hakim 2018; Harvey 2018). These low doses allow bacteria to become resistant to the drugs used in human medicine. A report from the UK government found that antibiotic resistance is slated to cost the global economy $100 trillion by 2050 (O'Neill 2016). By not using antibiotics as a routine aspect of production, cultivated meat could avert this threat and save millions of lives a year (O'Neill 2016).

EXAMPLE

Water pollution from industrial agriculture is both a local and a global problem. Manure and fertilizers pollute thousands of miles of waterways in the United States, poisoning drinking water, destroying habitat, and creating vast dead zones in the Gulf of Mexico, the Chesapeake Bay, and other coastal waters. For example, the EPA has set a target of reducing nitrogen pollution to the Chesapeake Bay by 24,000 tons from 2016 levels by 2025. By simply replacing half of the industrial chicken farms in the watershed, cultivated chicken could meet the EPA's nitrogen reduction target by eliminating ammonia emissions from chicken manure.

CONCLUSION

By conserving agricultural resources and eliminating major sources of air and water pollution, cultivated meat will reduce the environmental impacts of food production and contribute to a wide range of sustainability goals. Efficiency improvements in land and water use will contribute to conservation. Cultivated meat provides many opportunities to reduce the carbon emissions of the food system, protecting against climate change. And eliminating manure and antibiotic growth promoters will improve the health of rural communities, restore American waterways, and ensure the effectiveness of lifesaving medicines. Cultivated meat will be a powerful sustainability tool for companies, cities, and nations to create a healthier, more efficient, and more just food system.

REFERENCES:

Dewey-Mattia, Daniel, Karunya Manikonda, Aron J. Hall, Matthew E. Wise, and Samuel J. Crowe. 2018. "Surveillance for Foodborne Disease

Capper, J. L. 2011. "The Environmental Impact of Beef Production in the United States: 1977 Compared with 2007." *Journal of Animal Science* 89 (12): 4249–61.

———. 2012. "Is the Grass Always Greener? Comparing the Environmental Impact of Conventional, Natural and Grass-Fed Beef Production Systems." Animals 2 (2): 127–43.

Ceballos, G., P. R. Ehrlich, and R. Dirzo. 2017. "Biological Annihilation via the Ongoing Sixth Mass Extinction Signaled by Vertebrate Population Losses and Declines." *Proceedings of the National Academy of Sciences of the United States of America* 114 (30): E6089–96.

Costello, Christine, Xiaobo Xue, and Robert W. Howarth. 2015. "Comparison of Production-Phase Environmental Impact Metrics Derived at the Farm- and National-Scale for United States Agricultural Commodities." *Environmental Research Letters* 10 (11): 114004.

EPA. 2013. "Literature Review of Livestock and Poultry Manure and Implications for Water Quality." Washington, DC: Office of Water.

FAO. 2006. "Livestock's Long Shadow."

Gulli, Alexandra. 2017. "A Comparative Analysis of Feed and Environmental Factors on Broiler Growth in the United States." Edited by Greg Thoma. MS, Fayetteville, AR: University of Arkansas, Fayetteville. http://scholarworks.uark.edu/etd/2488.

Hakim, Danny. 2018. "At Hamburger Central, Antibiotics for Cattle That Aren't Sick." *New York Times*, March 23, 2018. https://www.nytimes.com/2018/03/23/business/cattle-antiobiotics.html.

Harvey, Fiona. 2018. "Huge Levels of Antibiotic Use in U.S. Farming Revealed." *Guardian,* February 8, 2018. https://www.theguardian.com/environment/2018/feb/08/huge-levels-of-antibiotic-use-in-us-farming-revealed.

Kebreab, E., A. Liedke, D. Caro, S. Deimling, M. Binder, and M. Finkbeiner. 2016. "Environmental Impact of Using Specialty Feed Ingredients in Swine and Poultry Production: A Life Cycle Assessment." *Journal of Animal Science* 94 (6): 2664–81.

Lupo, C. D., D. E. Clay, J. L. Benning, and J. J. Stone. 2013. "Life-Cycle Assessment of the Beef Cattle Production System for the Northern Great Plains, USA." *Journal of Environmental Quality* 42 (5): 1386–94.

Mattick, C. S., A. E. Landis, B. R. Allenby, and N. J. Genovese. 2015. "Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States." *Environmental Science & Technology* 49 (19): 11941–49.

Mohareb, E. A., M. C. Heller, and P. M. Guthrie. 2018. "Cities' Role in Mitigating United States Food System Greenhouse Gas Emissions." *Environmental Science & Technology.* https://doi.org/10.1021/acs.est.7b02600.

Mottet, Anne, Cees de Haan, Alessandra Falcucci, Giuseppe Tempio, Carolyn Opio, and Pierre Gerber. 2017. "Livestock: On Our Plates or Eating at Our Table? A New Analysis of the Feed/food Debate." *Global Food Security* 14 (September): 1–8.

O'Neill, Jim. 2016. "Tackling Drug-Resistant Infections Globally: Final Report and Recommendations." London, UK: Review on Antimicrobial Resistance. https://amr-review.org/sites/default/files/160518_Final%20paper_with%20cover.pdf.

Pelletier, N. 2008. "Environmental Performance in the US Broiler Poultry Sector: Life Cycle Energy Use and Greenhouse Gas, Ozone Depleting, Acidifying and Eutrophying Emissions." *Agricultural Systems* 98 (2): 67–73.

Pelletier, Nathan, Rich Pirog, and Rebecca Rasmussen. 2010. "Comparative Life Cycle Environmental Impacts of Three Beef Production Strategies in the Upper Midwestern United States." *Agricultural Systems* 103 (6): 380–89.

Putman, Ben, Greg Thoma, Jasmina Burek, and Marty Matlock. 2017. "A Retrospective Analysis of the United States Poultry Industry: 1965 Compared with 2010." *Agricultural Systems* 157: 107–17.

Steffen, Will, Katherine Richardson, Johan Rockström, Sarah E. Cornell, Ingo Fetzer, Elena M. Bennett, Reinette Biggs, et al. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347 (6223): 1259855.

Tuomisto, Hanna L., Marianne J. Ellis, and Palle Haastrup. 2014. *Environmental Impacts of Cultured Meat: Alternative Production Scenarios.* Edited by Rita Schenck and Douglas Huizenga. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector. San Francisco: ACLCA.

Tuomisto, H. L., and M. J. de Mattos. 2011. "Environmental Impacts of Cultured Meat Production." *Environmental Science & Technology* 45 (14): 6117–23.

USFRA. 2017. "Agriculture in America Sustainability Report 2017." Chesterfield, MO: U.S. Farmers and Ranchers Alliance. http://www.fooddialogues.com/wp-content/uploads/2017/06/FR_Sustainability-Report-2017-FNL-v7.pdf.