

Consumer Information Drives Willingness to Pay for Low Emissions Milk and Beef

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ABSTRACT

*An emerging innovation in the sustainable food space is low methane emissions in beef and dairy products. A leader in this space is Symbrosia,¹ an innovative aquaculture company based in Hawai'i. They produce SeaGraze™, a feed additive derived from the red algae *Asparagopsis taxiformis*, which is designed for ruminant² livestock producers to reduce the methane emissions of their livestock by more than 80%. However, the feed additive SeaGraze™ represents an additional cost for livestock producers, and the consumer demand for low methane emissions beef and dairy products is relatively unknown. This study explores consumer demand and the willingness to pay for low emissions beef and dairy products. It reports on a survey of 495 participants, which found product-informed consumers are willing to pay between 51.7% and 72.3% more for low emissions milk and between 0.6% and 8.6% more for low emissions beef. A regression analysis found the most notable driver of consumer preference and willingness to pay more for these products was product information. This suggests that effective advertising of low methane emissions products is necessary for their financial success. These results should encourage producers in other countries to expand the production and consumption of these kinds of products to curb methane emissions.*

Keywords: Willingness to pay, green products, low methane emissions, *Asparagopsis taxiformis*

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***Asparagopsis taxiformis* (Limu Kohu) and the Reduction of Methane in Hawaii**

Hawaiian land and marine management have been the driving force behind sustainable stewardship in the archipelago since the first Polynesians landed in Hawai'i over 1,000 years ago (Beamer et al., 2021). The ocean provided many staples to the Hawaiian diet and still does; Fish and limu (seaweed) have been cultivated meticulously throughout the islands. Limu, the Hawaiian word for seaweed, was a crucial component not only in fishponds but also in the coastline ecosystems. An estimated 578 marine algae species are present in Hawaii as of 2,003, 80 of which are endemic to the area (Sherwood & Guiry, 2023). Limu has many uses in Hawaiian culture and is a fundamental component of many marine ecosystems. While many species of limu were eaten and used as a flavoring, limu was also an important trade item between different areas of the ahupua`a³ and a crucial component in many medicinal practices (McDermid et al., 2019). Today, the applications of limu are expanding into the aquaculture and sustainability industry.

Asparagopsis taxiformis, a red globalized macroalgae native to the Pacific, is a staple of the Hawaiian diet and has the potential to radically change the agricultural industry (Sherwood, 2008). *A. taxiformis*, known as limu kohu, produces secondary metabolites, most notably bromoform, which have been shown to impede the methanogenesis⁴ process by inhibiting the reduction of carbon dioxide and hydrogen into methane in ruminant animals (Wasson et al., 2022). Recent trials have shown over 80% enteric methane output reduction from cattle when fed with feed supplemented with *A. taxiformis* (Roque et al., 2021). Given this discovery, the race to produce *A. taxiformis* on a large scale has exploded with new companies popping up in Hawai'i, Australia, and beyond.

One company at the forefront of innovation is Symbrosia, a startup based in Kailua-Kona, Hawai'i. Pioneered by Alexia Akbay, the startup has garnered attention globally. The company was founded in 2018 with a vision to create a product that could solve unsustainable livestock agriculture practices. Their *A. taxiformis*-based feed additive is given in low doses to ruminants to reduce their methane emissions and in turn, gives producers new green products to offer consumers, including low-methane milk and beef.

While feeding *A. taxiformis* has positive environmental implications due to its greenhouse gas (GHG) reduction capacity, farmers must

consider how to address the elevated costs of doing so. The generation of carbon credits poses a potential solution. Some argue that carbon neutrality is necessary for food brands to remain successful in a period of increased demand for sustainable products (Reichheld et al., 2023). The creation of premium low methane product lines stands as another attractive but relatively unexplored avenue to absorb the costs of feeding *A. taxiformis*. This raises the question of whether consumers will pay a premium price for sustainable, low emissions (LE) products. To answer this question, Symbrosia partnered with survey distributor SightX and a Claremont McKenna College research institute to conduct a contingent valuation survey evaluating the potential profitability and target markets for low emissions products, helping to answer the question of whether the initial investment in feeding *A. taxiformis* would be financially feasible.

Contingent Valuation Method and Approaches

The contingent valuation method is an economic research method that evaluates willingness to pay for hypothetical goods. In the contingent valuation method, a survey is distributed to respondents who self-report their preferences and willingness to pay for goods. The method is often used to understand the value buyers place on sustainable attributes in consumer products. Sustainable or green products encompass goods and services that are more environmentally friendly than their conventional counterparts. Examples of green product attributes include reduced GHG emissions, limited depletion of natural resources, minimal plastic packaging, and recyclability (Chen & Chai, 2010). SeaGraze™-fed products fall under the sustainable category and have yet to hit the market, making the contingent valuation method an effective tool to evaluate consumer willingness to pay (Palomo-Vélez et al., 2018).

Consumer demographics and environmentalist traits are a major influence on willingness to pay. For example, Li and Kallas (2021) found gender and region influence average willingness to pay for sustainable food products. Additionally, Gomes et al. (2023) explored the influence of age on willingness to pay for green products. The study found four main findings. First, younger generations, such as Generation Z, exhibit a particularly high preference and willingness to pay for sustainable products. Second, younger generations are more likely to prioritize more sustainable products and expect companies to adopt green practices. Third, Gen Z consumers with higher incomes had a higher willingness to pay for green products. Finally, it determined the primary drivers of willingness to pay

among Gen Z. The first driver was environmental concerns, defined as consumers' level of awareness regarding environmental issues and their eagerness to contribute toward their resolution. The second and third drivers were green future estimation, defined as expectations of future demand for green products, and green perceived quality.

In past contingent valuation method research, information has also impacted willingness to pay. Tkac (1998) found that relevant information significantly changed people's allocation of a fixed budget to preserve three animal species. Our study tested this hypothesis with two separate surveys, one with an introduction to low emissions milk and one without.

Generally, contingent valuation method research proves consumers prefer and are willing to pay premiums for sustainable food products. Similarly, Li and Kallas (2021) analysed 80 studies, and found consumers were willing to pay 29.5% more for sustainable products on average. Specifically, the authors noted that organic products elicited the highest percent premium willingness to pay—the percentage consumers are willing to spend on a premium product above the regular price. Given the history of the contingent valuation method in determining consumer willingness to pay for sustainable products, it was determined to be the best research method for this study.

Hypotheses

Based on the above literature, Symbrosia's study aimed to address multiple hypotheses:

1. Consumers will exhibit a positive willingness to pay for low emissions milk and beef.
2. Consumers will not be willing to pay more for low emissions milk and beef than organic milk and beef.
3. Product information that increases consumer understanding will increase consumer preference and willingness to pay for low emissions products.
4. Demographic traits will have a significant effect on preference and willingness to pay for low emissions products. Age may have a particularly strong impact on both, and income may have a particularly strong positive impact on willingness to pay.
5. Environmentalism will have a positive impact on preference and willingness to pay for low emissions products.

Methods: Sample and Measures

The survey was distributed using the SightX platform. The survey was distributed to prescreened, preconstructed panel respondents of the general United States population of consumers. Low-quality responses* were eliminated and automatically replaced.

The contingent valuation survey was designed to include:

1. A screening question, making the survey available only to monthly consumers of beef and dairy products.
2. A treatment control model in which half of the survey's respondents (informed) received educational information on climate change, methane in animal agriculture, and Symbrosia's product, while half (uninformed) received only basic definitions of terms such as "conventional" and "low emissions."⁵
3. A detailed scenario asking respondents to picture themselves shopping in a grocery store followed by a rating of how well they could imagine the scenario on a 5-point scale.
4. Multiple choice questions on respondents' preferred choice among conventional, organic, and low emissions milk and boneless top sirloin steak (beef)⁶ if all were priced the same, including a no-preference option.
5. Open response questions on respondents' dollar willingness to pay for organic and low emissions milk and beef, with an anchor. The anchor was the average price of their conventional counterparts in the respondents' region.⁷
6. Demographic and personal questions, including the self-reported level of ecological consciousness and belief that individual behavior can help to fight climate change on a 10-point scale.
7. Choice and willingness to pay questions including product photos to improve accuracy. Willingness to pay questions included a qualifier that respondents should report a price that they were 80%–100% certain they would be willing to pay at checkout.

*There were three different kinds of low-quality responses: (a) outliers, who provided willingness to pay responses three standard deviations above or two standard deviations below the mean; (b) "down-the-liners," who provided the same response for each open response question; and (c) "speeders," who completed the uninformed survey in under

2.5 minutes, completed the informed survey in under 3.5 minutes, or failed the attention check question.

Data Analysis

Various analyses were conducted in Excel and R to help address the above hypotheses. These analyses included descriptive statistics, two-dimensional analysis, and multidimensional analysis with regressions.

Results: Descriptive Statistics

The final sample for data analysis comprised 248 informed and 247 uninformed participants from the 48 contiguous states. The demographic makeup of both samples was comparable, but not identical, to the population of the United States. In Table 1, values with asterixis are 5% or more away from the United States population composition (national information on area type was unavailable). Nontrivial differences in the makeup of the two groups are essential to note, with a higher proportion of females and a higher estimated average income among informed respondents.

Hypothesis 1 and 3

Table 2 summarizes consumer preferences and willingness to pay for low emissions products. The numbers in brackets represent 95% confidence intervals. Table 2 presents two hypotheses: (a) consumers would exhibit a positive willingness to pay for the low emissions attribute (b) informed consumers will be more likely to prefer and be willing to pay more for low emissions products compared to uninformed consumers.

In summary, proportions of both groups preferred low emissions milk and beef to their conventional counterparts. While both groups would pay more for low emissions milk, only the informed group would for beef. In fact, many individual responses offered less than the anchor price. This could be explained by: the refusal to state true willingness to pay, rather than devaluing low emissions beef; the high price of beef compared to milk; and a higher valuation for low emissions milk than low emissions beef (Pennington et al., 2017). Notably, the informed group had higher values across the board compared to the uninformed group, underscoring the need for further analysis of the information effect.

Regression analysis was used to test the information effect. This analysis found that with all else equal, an informed individual's likelihood of

Table 1.
Summary Statistics for Informed and Uninformed Respondents.

		Informed	Uninformed
Average Age (years)		46.6	45.2
Gender	Male	43.6%	52.6%
	Female	55.6%	47.4%
	Other	0.8%	0%
<i>Race</i> ¹	White	81.9%	77.3%
	Black	16.1%	16.6%
	Asian	0.8%*	3.2%
	Native American	1.6%	3.2%
Ethnicity	Hispanic/Latino	12.9%*	9.7%*
	Not Hispanic/Latino	87.1%	92.3%
Average Income (\$1,000s)		55.2	65.7
Region	Northeast	14.9%	16.6%
	Southeast	32.3%*	27.5%*
	Midwest	22.6%*	22.7%*
	South Central	19.4%	16.2%
	Southwest	9.3%*	13.4%
	Northwest	1.2%	3.6%
<i>Area Type</i> ²	Metropolitan	82.7%	85.4%
	Micropolitan	8.9%	8.9%
	Small Town	3.6%	3.2%
	Rural	4.8%	2.4%
Average environmental consciousness (10-point scale)		5.9	6.1
Average belief in individual behavior (10-point scale) ³		6.5	6.2
Average clarity rating of imagined scenario (5-point scale)		4.4	4.1

Notes: 1. Percentages may sum to over 100% because multiselect was allowed. 2. Determined based on respondent-reported ZIP codes and corresponding USDA Rural–Urban Commuting Area (RUCA) code classifications. 3. Referred to as “Belief in individual behavior.” This is the belief that individual behavior can improve climate change.

Table 2.
Estimated Preferred Market and Average Percent Premium Willingness to Pay for Low Emissions Products*.

	Informed	Uninformed
Preference for low emissions milk	33.5%	16.2%
	[27.6%, 39.3%]	[11.6%, 20.8%]
Preference for low emissions beef	29.0%	16.6%
	[23.4%, 34.7%]	[12.0%, 21.2%]
Premium willingness to pay for low emissions milk	62.0%	49.5%
	[51.7%, 72.3%]	[41.4%, 57.5%]
Premium willingness to pay for low emissions beef	4.6%	–2.5%
	[0.6%, 8.6%]	[–6.6%, 1.7%]

*Sample values are reported with 95% confidence intervals in brackets above.

preferring low emissions milk is greater than an uninformed individual's likelihood of preferring low emissions products. If an uninformed individual had a 50% chance of preferring low emissions milk, an otherwise identical informed individual would have a 70.2% chance of preferring low emissions milk. If an uninformed individual had a 50% chance of preferring low emissions beef, an otherwise identical unprimed individual would have a 64.1% chance of preferring low emissions beef. It also found that with all else equal, an informed individual's percent premium willingness to pay for low emissions products is higher than an uninformed individual's percent premium willingness to pay for low emissions products. With all else equal, an informed individual's percent premium willingness to pay for low emissions milk is 13.5% higher than an uninformed individual's on average. With all else equal, an informed individual's percent premium WTP for low emissions beef is 7.3% higher than an uninformed individual's on average.

Hypothesis 2

t-testing⁸ was used in order to test the second hypothesis that the percent premium willingness to pay would be higher for organic than low emissions products. The results found that both the informed and uninformed groups had statistically similar percent premium willingness to pay for low emissions beef and organic beef (see Table 3). Although the uninformed group had a significantly lower premium for low emissions milk than organic milk, the informed group had statistically similar percent premium willingness to pay for low emissions and organic milk. These results indicated that especially when educated on their environmental benefits, consumers may value low emissions products similarly to organic, a classification with an established sustainability premium (Carlson, 2016). The difference in results for milk between the informed and uninformed population again signaled the potential of an information effect. Essentially, survey respondents who received information on SeaGraze™ and its benefits were willing to pay more for milk than respondents who did not receive information.

Hypothesis 4

To address hypothesis 4 ordinary least-squares modeling was used (see Tables 4 and 5). Hypothesis 4 postulated that demographic traits would have a significant effect on preference and willingness to pay for low emissions products. The analysis found that with all else equal, for a

Table 3.
Summary of Results of *t*-Tests for Differences in Mean Percent Premium Willingness to Pay Between Low Emissions and Organic Products.

	Estimated Difference in Means	<i>t</i> Value	<i>p</i> Value (Two-tailed)
Milk— <i>informed</i>	-0.002	-0.06	.952
Beef— <i>informed</i>	-0.004	-0.16	.873
Milk— <i>uninformed</i>	-0.093	-3.28	1.20e-3**
Beef— <i>uninformed</i>	-0.018	-0.73	.465

one year increase in age, the percent premium willingness to pay for low emissions milk will decrease by 0.6% on average. With all else equal, a Black individual’s percent premium willingness to pay for low emissions milk is 24.8% higher than a white individual’s on average. With all else equal, an individual in a micropolitan area or a small town’s percent premium willingness to pay for low emissions milk is 50.3% higher than an individual in a rural area’s on average. With all else equal, for a \$10,000 increase in income, the percent premium willingness to pay for low emissions beef will increase by 0.6%.⁹ Relatedly, ordinary least-squares modeling found that with all else equal, for a one dollar increase in anchor price (the price of conventional beef), the percent premium willingness to pay for low emissions beef will decrease by 5.3% on average.

Hypothesis 5

To address hypothesis 5, regression analysis was used. Hypothesis 5 postulated that ecological consciousness would have a positive impact on preference and willingness to pay for low emissions products. The analysis found those with a higher belief in individual behavior (those who believe individual behavior can improve climate change) are more likely to prefer low emissions milk and beef. If an individual with zero belief in individual behavior on the 10-point scale had a 50% chance of preferring low emissions milk, an otherwise identical individual with five belief in individual behavior on the 10-point scale would have a 66.6% chance of preferring low emissions milk and a 72.2% chance of preferring low emissions beef. Environmentalism was not found to have a significant effect on the percent premium willingness to pay for low emissions milk and beef.

Table 4.
Summary of Multiple Regression Predicting Percent Premium Willingness to Pay for Low Emissions Milk.

	Estimated Regression Coefficient	<i>t</i> Value	<i>p</i> Value (Two-tailed)
Age (years)	-0.006	-3.13	1.85e-3**
Black	0.248	2.74	6.38e-3**
Micropolitan	0.503	2.48	.013*
Small town	0.503	2.04	.042*
Information	0.135	2.06	.040*

Table 5.
Summary of Multiple Regression Predicting Percent Premium Willingness to Pay for Low Emissions Beef.

	Estimated Regression Coefficient	<i>t</i> Value	<i>p</i> Value (Two-tailed)
Anchor price	-0.053	-3.492	5.23e-4*
Income (\$10,000s)	0.006	2.17	.031*
Information	0.073	2.506	.013*

Analysis: Discussion of Regression Analysis

This section will focus on hypotheses 1, 3, and 4 to expand on aspects of the data analysis that require further discussion.

Hypothesis 1: Overall, the willingness of consumers to pay premiums for low emissions products, is consistent with prior literature largely suggesting that consumers are willing to pay premiums for sustainability in food products. The estimated average premium for low emissions milk was noticeably higher than the average calculated by Li and Kallas (2021), suggesting that low emissions may be a highly valued sustainable attribute.

Hypothesis 3: In general, regression analysis supported the hypothesis that product information would have a significant positive effect on both preference and willingness to pay for low emissions products. Notably, information is the only variable with a significant positive effect on both preference and percent premium willingness to pay for low emissions beef and dairy. This implies that if environmental advocates and agricultural producers aim to improve the financial feasibility of implementing methane-reducing technologies such as *A. taxiformis*, providing product

information through marketing, press, and word of mouth may be an efficient tactic. Product information may have the power both to expand the preferred market for low emissions goods and increase the potential premium on their prices. This is especially significant because, excluding belief in individual behavior, the other variables that correlate with preference and willingness to pay for low emissions goods are near-impossible to externally affect. Furthermore, increases in consumer education on low emissions products may correlate with increases in belief in individual behavior, producing an even greater expansion of the market for low emissions products.

Hypothesis 4: Regression analysis showed that demographic traits had a significant effect only on willingness to pay and that environmentalism had a significant effect only on preference. Considering the models for low emissions product preference, it is notable that no demographic variables were found to be statistically significant, suggesting that preference for low emissions products can be attributed primarily to product information and beliefs about climate change. Considering the models for percent premium willingness to pay for low emissions products, the differences in the effects of specific variables on milk compared with beef should also be discussed.

First, income has a significantly positive effect only on the percent premium willingness to pay for beef, possibly because beef is much more expensive than milk. Therefore, given the same percent premium for milk and beef, the *dollar premium* for beef is greater and makes up a larger proportion of an individual's budget. Therefore, income-based differences in the feasibility of paying high premiums for low emissions products may be more pronounced for beef than for milk. Furthermore, percent premiums for beef were lower overall, and as the price of conventional beef rose even higher, respondents' willingness to pay a premium decreased. Flores and Carson (1997) came to a similar conclusion when performing a theoretical analysis of the income elasticity of willingness to pay (the percent change in willingness to pay for a given percent change in income), finding that it is dependent on the portion of a consumer's budget that a good takes up, among other variables. These conclusions might suggest that for beef, the income-based ability to afford a premium overpowers the other demographics (such as age, area type, and race) that had a significant effect on the percent premium willingness to pay for milk.

Second, the negative effect of age on willingness to pay for low emission milk supports the hypothesis that age would significantly impact willingness to pay for low emissions products. This finding is aligned with academic expectations that Generation Z will drive sustainable consumption through high willingness to pay, possibly based on beliefs about green products that may not be captured in the “belief in individual behavior” question (Gomes et al., 2023). It is important to note, however, that for low emissions beef, the effect of age was positive, although insignificant at the 95% confidence level. This suggests that the effect of age may be less straightforward than previously suggested.

Limitations of Analysis

It is important to note that the contingent valuation method is limited by the hypothetical bias both in general and when studying willingness to pay for green products; consumers state higher premiums when considering a hypothetical situation than they would be willing to pay in reality (Li & Kallas, 2021). The survey attempted to mitigate this bias by providing a detailed grocery store scenario, an anchoring price, and by asking respondents to provide a response they were 80%–100% certain to pay out at checkout, all of which was included in each willingness to pay question. Furthermore, negative and zero willingness to pay premiums were not excluded, which could have balanced over-reported premiums. This study is also limited in its inability to comprehensively explain the effects of race and area type on percent premium willingness to pay for low emissions milk. Additionally, the difference in effects of demographic variables on willingness to pay for milk compared with beef could also be explained by different demographics’ attitudes toward the two products, which are difficult to measure.

Real-world Applications

Although this survey included respondents only in the 48 contiguous states, its findings may have important implications for Hawai‘i. As mentioned, product information and belief in individual behavior are major drivers of preference for low emissions products, both of which may be elevated in Hawai‘i due to the importance of responsible environmental management in Hawaiian culture. Aloha ‘āina is a belief among Hawaiians that there is a profound connection between humans and the land as strong as a familial tie.

This concept lends to generational knowledge of the relationships between the seasons, moon, tides, and environment to produce schedules for harvesting resources that have ensured the replenishment of valuable food assets creating a sustainable system (Beamer et al., 2021). Such practices encourage individual environmentally friendly behavior more broadly, as well as awareness of environmental innovations such as SeaGraze™ (Zhang & Chabay, 2020). Symbrosia's local presence as a leading *A. taxiformis* producer in Hawai'i may heighten awareness of methane-reducing feed additives, and thus, expand the preferred market for low emissions products. These high levels of product information in Hawai'i could also elicit a higher percent premium willingness to pay for low emissions products.

Further considering the drivers for percent premium willingness to pay, Hawai'i has a smaller Black population than the United States overall, at 2.2% versus 13.6%, which, according to regression analysis, may decrease average percent premium willingness to pay for low emissions milk (U.S. Census Bureau QuickFacts: United States, 2020). Data on the percentage of each population in micropolitan areas and small towns is not available. Relevant to willingness to pay for low emissions beef, Hawai'i has a higher median income than the United States overall, at \$94,814 versus \$75,149 as of 2022 (U.S. Census Bureau QuickFacts: United States, 2020). The state also faces higher prices; for example, for 12/15/2023 through 12/21/2023, the weighted average price of boneless top sirloin steak in Hawai'i was \$12.49, while the national weighted average price was \$7.88 (United States Department of Agriculture, 2023). Based on the results of regression analysis, this implies that with all else equal, the “median” Hawaiian consumer's percent premium willingness to pay for low emissions beef is expected to be 23.2% lower than the “median” US consumer's.¹⁰ Additionally, higher levels of product information in Hawai'i could partially mitigate the effect of elevated prices.

Because regressions model the preferences and percent premium willingness to pay of individuals, their results cannot be perfectly applied to average willingness to pay in regions such as Hawai'i. However, overall trends in the variables that significantly affect preference and willingness to pay suggest, again, that product information may drive the profitability of low emissions products in Hawai'i, while high existing prices may decrease the percent premium willingness to pay—in 2023, Hawaii was identified as having the highest cost of living nationwide (Lau, 2023).

Despite the history of responsible environmental management in Hawai'i, cultural and economic shifts have made sustainable consumption

less accessible through elevated prices and limited industry. Hawaii's top ranking for cost of living in the United States has caused an exodus of Native Hawaiians from the state as they seek a more affordable way of life (Yamaguchi & Breen, 2023). Since Western contact, Hawai'i's main economic activity has shifted rapidly from sandalwood to sugar and most recently to tourism (La Croix, 2021). The global pandemic underscored the imperative to cultivate a more diversified and resilient economy, mitigating overreliance on the tourism sector (Bond-Smith & Fuleky, 2022). In the last decade, many have highlighted aquaculture as a growing sector in Hawai'i, projected to become a \$230 million industry by 2028 (Heaton, 2023). Algae production makes up a large portion of the Hawaiian aquaculture industry and is expected to expand in the coming years. Thus, Symbrosia aims to positively influence the state's economic activity through algae production, as well as improving green product offerings to promote sustainable growth. By introducing products that are better for the planet and locally produced, Symbrosia will contribute to a circular economy model to achieve greater harmony between the environment and society, promoting sustainable growth (Ghisellini et al., 2016). Advocating aquaculture in Hawai'i is imperative for the development of a more sustainable economy, both financially and environmentally, in the coming years.

Contemporary enterprises are also confronted with the imperative of actively contributing to the welfare of their local communities. This typically takes the form of community outreach programs, donations to local charities, and the provision of public education. Symbrosia models sustainable community engagement in many forms. Notably, Symbrosia has committed to restoring fishponds around the islands of Hawai'i, Kauai, and Oahu by providing resilient strains of *A. taxiformis* to Indigenous fishery management community organizations. This project will include an exploration of farming of *A. taxiformis* in land-based ponds with a focus on sustainable monitoring, harvesting, and long-term management efforts. Symbrosia's dedication to restoration, education, and sustainability positions the company as a noteworthy player in corporate and community sustainability.

The main challenge in cultivating *A. taxiformis* is bringing it to scale. Symbrosia is rapidly expanding *A. taxiformis* production in accordance with its goal of serving one million cows by the year 2030. Currently, one cow requires 100 grams of dry feed additive per day to reduce their methane emissions. Current production supports a trial with Parker Ranch on the Big Island of Hawai'i, illustrating Symbrosia's ability to address agricultural

methane emissions on a local scale. The study will also supply beef products to local vendors to promote green consumption in the Islands. However, there were approximately 1.6 billion cows worldwide as of 2022, meaning that *A. taxiformis* production will have to scale significantly to meet the global market (Food and Agriculture Organization of the United Nations, 2022). This invites more nations to cultivate their own algae to meet domestic needs and collectively contribute to a climate change mitigation strategy.

Given *A. taxiformis*'s natural global range in the tropics, it stands that Symbrosia could be an excellent model for new companies in countries that rely heavily on beef and dairy products as a food and income source. Companies in New Zealand, Australia, and Sweden have begun farming *A. taxiformis* in the hopes of lowering their carbon footprints. A similar model may also be attractive in Brazil, a nation that has the second-largest commercial cattle herd at 232 million as of 2018 (Zia et al., 2019). While Brazil has made efforts to reduce deforestation of the Amazon for cattle farming, their beef and dairy industry produced 35.1% (437,226 Gg CO₂-eq) of national emissions as of 2010. In Brazil, endeavors to offset carbon emissions have been implemented through the afforestation of Eucalyptus trees within cattle pastures, aimed at carbon sequestration (Nemitz, 2022). Although this is a creative climate solution, it has cause for concern. Eucalyptus trees are not native to Brazil and pose a fire hazard. *A. taxiformis* could be implemented in conjunction with carbon sink methods in order to reduce the environmental effects of cattle farming. *A. taxiformis* is native to the tropical region of the country, suggesting that its production could be viable. Brazil's aquaculture industry is valued at over one billion USD annually and has an innovative scientific community that could reasonably integrate *A. taxiformis* farming into their production (Valenti et al., 2021). This study's findings on positive willingness to pay for the low emissions attribute suggest incentives for Brazilian food brands to adopt *A. taxiformis* in their supply chains. Symbrosia is participating in early research with stakeholders in Brazil to verify implementation in their tropical grazing systems.

Conclusion

The market for sustainable, low emissions products is rapidly evolving due to the new generation of consumers and readily available information about the climate crisis. This allows opportunities for new companies such as Symbrosia to showcase methane-reducing products and appeal to a

new market. Although the exclusive cultivation of *A. taxiformis* may not constitute a comprehensive solution to address climate change, it represents a progressive stride in fostering public and corporate awareness regarding the environmental impact of consumer products. Symbrosia demonstrates how a company can produce GHG-mitigation products while giving back to its community. This study also highlights a shifting economic climate that values sustainable attributes in consumer goods. Given the study's findings, it is of primary concern to prioritize marketing and education of sustainable products to encourage preference and willingness to pay for food products with sustainable attributes.

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NOTES

1. <https://symbrosia.co/>
2. An herbivorous, even-toed, hooved mammal (suborder Ruminantia and Tylopoda) that has a complex 3- or 4-chambered stomach. Examples include cattle, sheep, goats, and deer.
3. A Hawaiian term for a large traditional socioeconomic, geologic, and climatic piece of land.

4. Methanogenesis is the biological process where certain microorganisms produce methane gas as a byproduct while breaking down organic matter in oxygen-deprived environments.
5. Product information may be referred to as priming from now on. The group with detailed product information will be called “informed,” and the group without will be called “informed.”
6. All questions about beef referred specifically to boneless top sirloin steak, which this study will refer to as beef from now on.
7. Average prices for each region were obtained from the USDA’s National Retail Report for the period of 03/03/2023 through 03/09/2023. Specifically, prices of 2% and whole milk were averaged, and prices of choice and branded boneless top sirloin steak were averaged.
8. A *t*-test is a ratio that quantifies the difference between the “means” of two groups while taking into account the variance.
9. This change may seem particularly small, but it represents multiple cents for a single pound of beef. For a producer processing tens or hundreds of thousands of pounds of beef in a year, this implies an economically significant increase in revenue.
10. It is important to note that of course, Hawaiian incomes and prices are included in US averages, meaning that this comparison is between consumers in Hawai‘i alone and consumers in the US overall, not between consumers in Hawai‘i alone and consumers in the contiguous states.

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