Title

In-Foam-Us: Combatting Climate Change Through Development of Signature Products Using Algal Biotechnology

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Publication Date
2016-04-01

Capstone Advisory Committee Final Capstone Project Signature Form

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MAS Marine Biodiversity and Conservation

Capstone Project

Capstone Advisory Committee

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Introduction:

Over the past century, since the advent of the industrial revolution and mass production of consumer products, the footprint of human activity has directly imbalanced the planet's natural carbon cycle. A leading cause of this issue is the increased burning of fossil fuels and the processing of petrochemicals for material products. Oil, coal, and natural gas currently supply around 85% of global energy use and 12% of a barrel of crude oil is devoted to the production of petrochemicals. Crude oil cannot be manufactured and is a diminishable resource. As consumers of petroleum and petrochemical products have become more aware of the negative environmental impacts, a demand has risen for alternative fuel sources and eco-friendly products.

Hypothesis:

If consumers understand the true externalities of petroleum-derived products, then it is possible to influence them to pay a premium price for products that are sustainably sourced.

Objectives:

The objective of this capstone project is to determine the economic feasibility and environmental impact of developing signature sustainable high value products – such as surfboards – using materials derived from algae versus petroleum. This report will incorporate what has been done before, current knowledge, and future pressing conservation issues as they relate to this emerging horizon of biotechnology. Federal government funding supported biofuel research in order to develop gasoline gallon equivalents derived from renewable resources, at first from terrestrial crops such as corn and soybeans, and more recently from algae as a viable resource. This research can now be leveraged to make many petroleum replacement products, but these need to be both economic, as well as environmentally desirable, and this report is intended to identify the feasibility of developing such products.

The development of petroleum replacement products using algae is scientifically proven; issues have arisen economically- the technology infrastructure does not yet support industrialized production that could economically compete with petroleum processing. An incentive to bring down the costs of manufacturing is the development of “coproducts” that would produce marketable materials. If the science and technology exists to replace petroleum as a fuel, it also exists to replace petrochemicals in the synthesis of products such as polyurethane foams used in everything from shoes to car seats to surfboards.

Most surfboards are manufactured out of polyurethane foam- a non-degradable material that is derived from petrochemicals. Scientists at UC-San Diego, in concert with the U.S. Department of Energy and Arctic Foam, a manufacturer of surfboard blanks, have already demonstrated that polyurethane foam can be produced with a significant amount of its chemical composition made with algal-derived oil.

The aim of this capstone project is to understand what percentage of the surfboard will be derived from algal oil, the cost of scaled up production, and whether or not consumers would be willing to pay a premium price for a product that is more environmentally conscious. This paper is meant to speculate the market for maintaining a continuity of production for algal biofuels. The fact that oil is a diminishing resource, it would be wise investment and good business practice to understand the potential of a renewable energy resource for food, fuel, and in this case material goods.

The Craft

Surfboard manufacturing is both an artisanal craft and a disposable industry. Surfing is an ancient Polynesian ritual performed on space-age equipment. The surfboard is essentially a hydrofoil design that planes and accelerates over water and requires balance and coordination of the rider to stay afloat and navigate the surface of a wave.

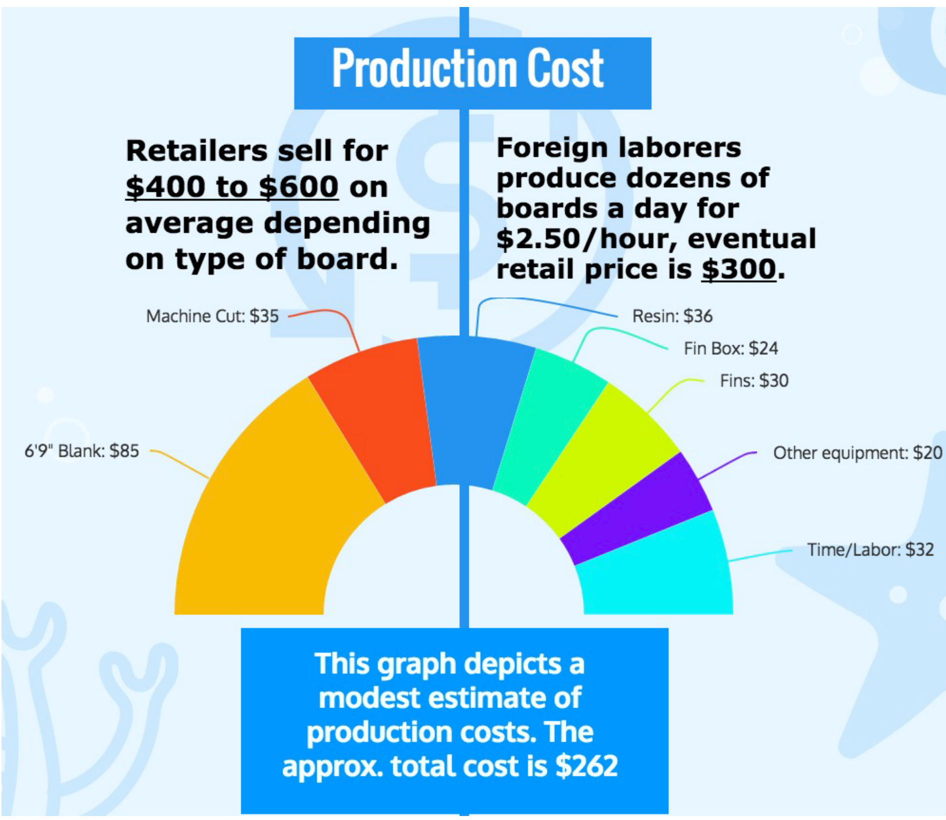
Surfing first gained influence in the continental United States when Duke Kahanamoku, a legendary Hawaiian lifeguard and 1912 Stockholm Summer Olympic gold medalist swimmer, first put on surfing demonstrations in front of large crowds on both the east and west coasts of the United States. Original Hawaiian heavy, solid balsa wood designs were improved upon by Tom Blake in the 1930s, who developed the first hollow paddleboards for lifeguards and ocean rescue personnel. Up until around the 1950s, surfing was practiced by a small enclave of coastal inhabitants. It hit the mainstream vein of American culture with the production of "Gidget," a Malibu surfer girl who entered the homes of Americans through film and then the ubiquitous, newly developed mass median of television.

Surfboard design and shaping has always been a "garage industry," meaning the production process has largely been controlled by individual "shapers" who design and produce surfboards to certain dimensions depending on the size and skill level of the surfer as well as the speculative wave conditions they are riding on. The more volume of the surfboard, the greater the buoyancy, the less maneuverability. Typically longboards, at an average of nine feet, have an elliptical shape and contain around 60-100 liters of material[1], are used by beginners in smaller waves. Shorter boards with "sharper" features and less volume allow greater maneuverability on waves. Most surfboards are made from a polyurethane foam blank, covered in epoxy resin,

[1] http://www.swaylocks.com/forums/board-production-costs

fiberglass cloth, and a glassing resin. Almost every component of a surfboard is derived from petrochemicals.

An average surfboard takes around 16 days to go from blank to finished product, including shaping, fiberglassing, sanding, and painting, and costs around $400 to $600, depending on the type of board. Outsourced foreign labor from third world countries can produce dozens of boards a day for approximately $2.50 an hour.[2] It takes several hours to produce a finished board and the eventual cost at a surf shop or major retailer is around $300.[3] The retail price difference between the custom crafted polyurethane blank and the cheaper, mass-produced import, has serious ramifications in the surfboard market.



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[2] http://fortune.com/2015/10/29/costco-surfboard-wavestorm/
[3] http://www.nbcnews.com/id/38472495/ns/business-us_business/t/us-surfboard-makers-thrive-choppy-waters/#.V0UirpMrKYU
[4] http://www.swaylocks.com/forums/board-production-costs

The Surf Industry

Whether one considers surfing a sport, a hobby, or a spiritual refuge, the activity of riding waves is a cultural phenomenon and a significant business. Over the last decade, the number of people in America who surf at least once a year has increased by nearly half to 2.6 million, with the number of surfers growing by 1.7% each year.[5] More than a million Americans surf at least eight times annually. The median surfer earns $75,000 a year, and in 2010 some $6.3 billion was spent on surfboards, wetsuits, sunglasses, and other surf-related clothing and accessories. Surfing has recently swelled in emerging markets such as Europe, China, and Korea as well. Analysts predict that by 2017, the global surf industry will generate more than $13 billion, not including luxury surf travel industries that charge $12,000 a person for surf trips to destinations such as Peru, Indonesia, and Fiji.[6] Currently women make up 36% of the American surfing population.[7]

The actual economic value of surfing is not something that is easy to quantify. A form of economic analysis dubbed "surfonomics" was born on the northwest coast of Puerto Rico in 2002, when a proposed beachfront condo development threatened the hydraulics of a renown surf break in the town of Rincon. In order to save the wave sanctuary, a trio of environmental groups commissioned a study showing that mostly surf-related tourism generated at least $52 million a year for Rincon. The project was successfully blocked and the event marked a milestone in the valuation of surfing, expanding the economic impact of surfing from merchandise and travel costs to real estate.[8] Value was demonstrated through travel cost studies, measuring things like distance surfers and spectators travel to a surf break, the number of times

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[5] http://business.transworld.net/
[6] http://fortune.com/2013/06/05/surfonomics-101/
[7] http://fortune.com/2013/06/05/surfonomics-101/
[8] http://fortune.com/2013/06/05/surfonomics-101/

the visit a year, the amount of time they take off from work, the amount they spend on fuel, and other related expenditures. A 2007 study Mundaka on coast of southern Spain generated $4.5 million annually for local economy. A 2010 study determined that Maverick's, located in Half Moon Bay, CA, generated $23.9 million in revenue, with 420,000 visits each year, who spent an average of $56.70 per visit. A 2012 study on Trestles in San Diego County concluded that 300,00 visitors spent an average of $80 a visit for a total valuation of $24 million.[9]

Blank Monday: The Closing of Clark Foam

On December 5, 2005, the largest polyurethane surfboard blank producing factory in the world shuttered its doors and the owner, a precarious individual named Gordon "Grubby" Clark, destroyed all of his foam making equipment so it could not be replicated by former competitors in the industry. This sent major shockwaves through an industry that depended on Clark to provide polyurethane blanks to surfboard shapers all over the world.

Hobie Alter, a renown creator of fiberglass hull sailboats, began experimenting with surfboard designs with Clark as his apprentice. They began using polyurethane core "blanks" coated with fiberglass to improve flexibility and decrease the weight of surfboards. Clark broke off and started Clark Foam in Laguna Niguel, CA, a surfboard blank manufacturing facility that accounted for 80% of the world's surfboard inventory. Around 400-600,000 polyurethane surfboard blanks were produced a year and sold for a minimum of $50 each, resulting in a $20-30 million market.

This monumental event in the surfing world was known as "Blank Monday," in reference to the 1929 stock market crash that initiated The Great Depression. What this also signified was an opening of the doors to innovative, new, and up and coming blank makers trying to find a

[9] http://fortune.com/2013/06/05/surfonomics-101/

niche and fill a massive market void left by the closing of Clark Foam. Surfboard manufacturing reached a fork in the road that could go one of two ways– polyurethane or other sustainably sourced materials shaped by individual craftsman, or mass-produced and environmentally boorish pop-out boards.[10]

Costco Wavestorm

The Wavestorm is the $99.99 “everyman” surfboard sold exclusively at Costco. It is manufactured in Taiwan and shipped to the U.S. in bulk. It consists of polystyrene foam, rubber fins, a stock plastic leash, and a pre-installed traction pad. It is essentially the “corporate fast-food chain of the surfboard industry.”[11] The board is commercially and mass-produced in every sense. Costco also maintains an iron-clad return policy where if you break a Wavestorm, you can return it for a complete replacement free of charge, drawing customers into the tremendous value of the deal. Since the Wavestorm’s inception in 2007, Costco has sold over 500,000 units and they are expected to sell 100,000 units in 2016. Costco sells five times more Wavestorm boards annually than any other leading surfboard brands. The Costco Wavestorm represents the antithesis of the sustainably sourced surfboard.[12]

The Environment

Considering environmental implications, this study set out to determine if there is a sustainable source that can give surfboard shapers, retailers, and surfers a more environmentally conscious option.

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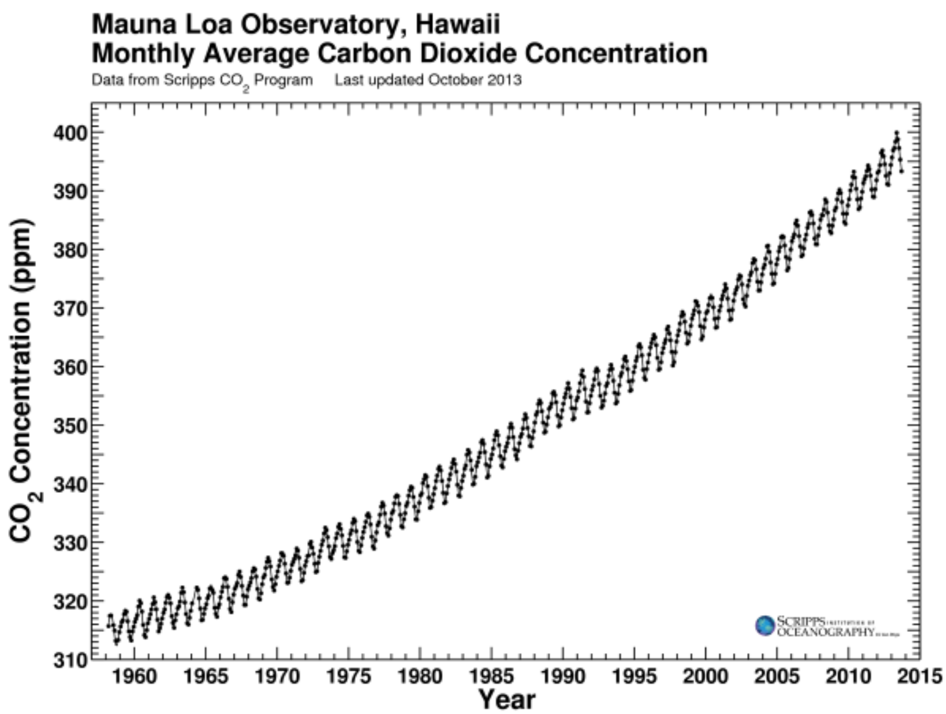
[10] http://www.newyorker.com/magazine/2006/08/21/blank-monday
[11] http://www.theinertia.com/business-media/costcos-wavestorm-becomes-the-most-popular-surfboard-in-america/
[12] http://www.bloomberg.com/news/articles/2015-10-29/wavestorm-s-99-99-surfboard-upends-the-industry

The Keeling Curve is a graph that depicts the concentration of atmospheric carbon dioxide, a greenhouse gas (GHG). David Charles Keeling, a professor from the Scripps Institution of Oceanography, UCSD, began measuring atmospheric CO_2 concentrations in 1958 from the Mauna Loa Observatory in Hawaii. The data gathered from the peak of a Hawaiian volcano first alerted the public to the fact that carbon dioxide was accumulating in the atmosphere faster than the oceans or other carbon sinks, such as plants, algae, and vegetation, could absorb it. This proved that human emissions of CO_2 were substantially enhancing the greenhouse effect.[13]

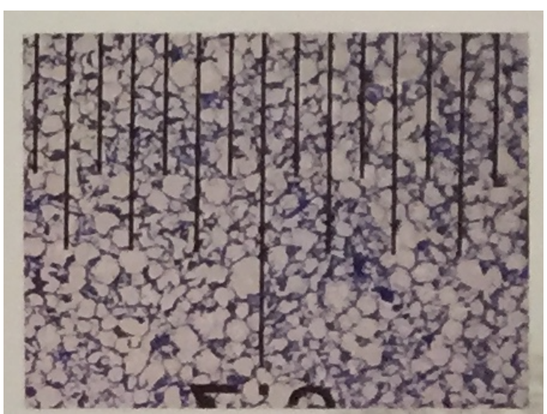


[13] Johansen, 2002

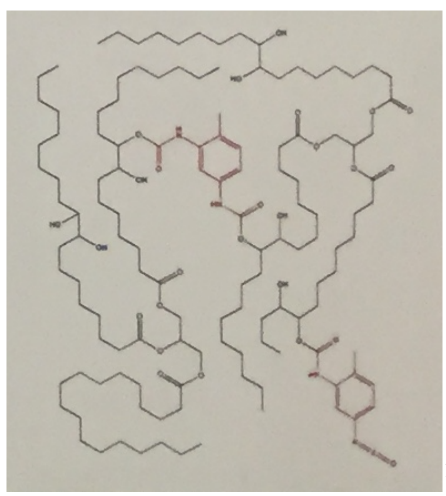
Polymer Foams

Polyurethane was invented by German industrial chemist Dr. Otto Bayer at the dawn of World War II. The foam was first used as a replacement for rubber as well as a coating to protect common material such as metal and wood. Flexible polyurethane soon made its way into furniture cushioning and the automotive industry. Polymer foams are a ubiquitous building material used in everything from disposable packaging for fast food to surfboards. Their omnipresent nature is due to the fact that they have a lot of advantageous properties. Their density is low, making them light and flexible. Some foams have very low heat transfer, making them excellent insulators. Many are flexible and soft, meaning they provide comfort when used for furniture and bedding.

Polymer foams are made up of a solid and gas phase mixed together to form a foam. This happens by combining two phases too fast for the system to respond in a smooth fashion. The resulting foam has a polymer matrix with either bubbles or air tunnels incorporated into it, which is known as either a closed or open-celled structure. Closed-cell foams are generally more rigid while open-cell foams are usually flexible.

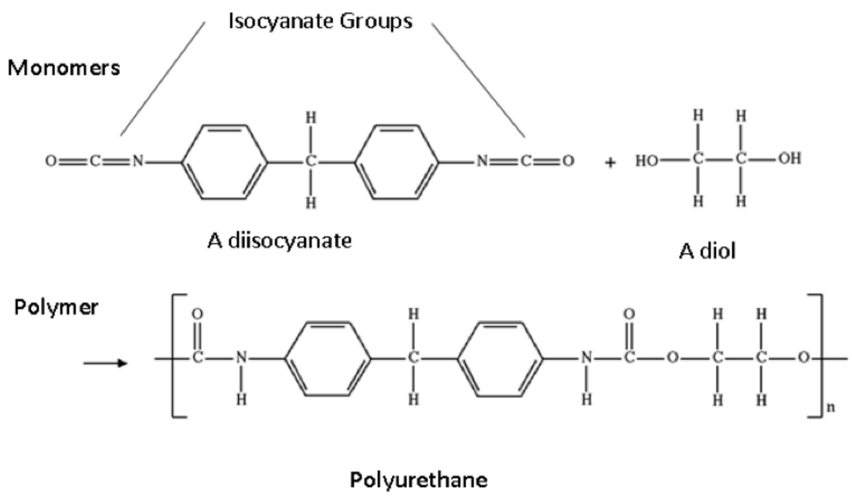


A microscopic view of a slice of our foam. Tiny bubbles form during the reaction which gives the foam its lightness and expansion


[14]

[14] Willet, 2002

Polyurethanes are any type of polymer containing a urethane linkage. The urethane linkage is –NH-CO-O-.[15] Polyurethanes are formed by reacting isocyanates with compounds that have an active hydrogen that contain hydroxyl groups, in the presence of a catalyst. Since there are many compounds containing active hydrogens and many different diisocyanates, the number of polyurethanes that can be synthesized is large. The specific properties of the polyurethane can be tailored to a specific need by combining the appropriate compounds.[16]



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Issues facing the polymer foam industry are that of waste disposal, recyclability, flammability, and the effect of blowing agents on the environment. The restrictions on the use of chlorofluorocarbons (CFCs), has become very important in making polymer foams more environmentally friendly. Advances in biodegradable foam materials are also helping to improve the recyclability and waste disposal.[18] The amount of foam wasted in the surfboard manufacturing process as well as improper disposal of equipment leads to plastic pollution,

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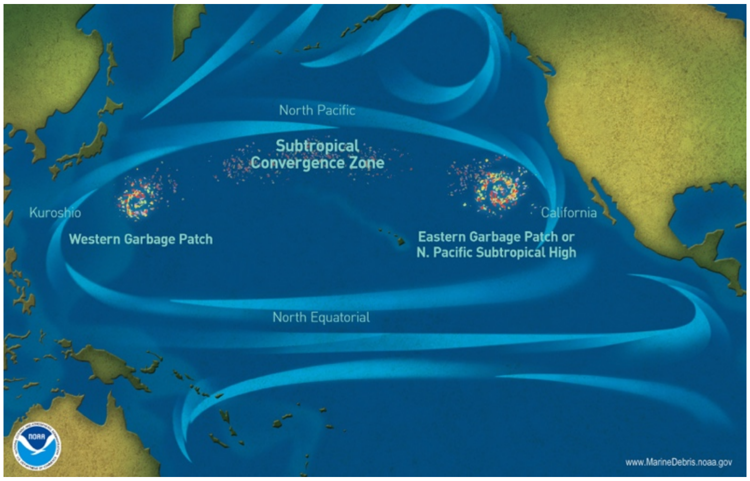
[15] Willet, 2002
[16] Willet, 2002
[17] http://chemistryofmaterials2013.wikidot.com/lisa-hudoba
[18] Willet, 2002

which often finds its way into the ocean and gets trapped by the currents of the North Pacific Gyre and has detrimental environmental effects.



Algae Biofuels

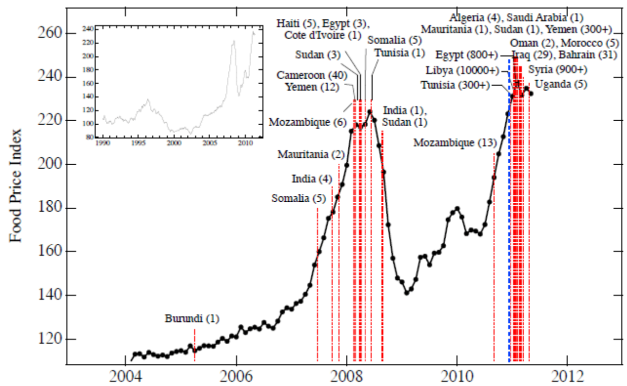
Algae biomass holds great potential as a sustainable alternative to conventional transportation fuel. About 23% of the 99.3 quads of total energy demand in the U.S. in 2008 was used in the transportation sector.[19] Oil is essentially decayed and compressed organic matter found in the Earth. Algae constitutes a vast percentage of that matter, and by extracting lipids from algae cultures, there is the ability to manufacture fuel from a sustainable source that can be controlled. Increasing research and development of lipid extraction from algae biomass can greatly offset the petrochemical industry.

The evolution of biofuels as an alternative resource to fossil fuels has undergone several generational phases. First generation biofuels were derived from edible plants grown on arable land and consisted of ethanol and butanol produced via yeast fermentation. Crops included were wheat, sugarcane, and oily seeds. These processes were attributed as a potential reason for spikes

[19] Sander, 2010

in food prices because their devotion was cutting against the food price index and they were ultimately net energy negative.

Food price index overlaid with significant riots in the Middle East and North Africa



Marco Lagi, Karla Z. Bertrand and Yaneer Bar-Yam of the New England Complex Systems Institute

Second generation biofuels were produced from non-edible crops grown on non-arable land. Sources have high lignocellulosic content, which include wood and organic waste. They have the potential to be net energy positive.

Third generation biofuels are produced from algae and other microorganisms. They are resilient organisms that can be grown from sunlight, CO_2, and brackish water. They do not use arable land, are the fastest growing of all biofuel sources, and are potentially carbon neutral.

Fourth generation biofuels consist of genetically engineered organisms for efficient production of biofuels. These include altering lipid characteristics and introducing lipid excretion pathways. They aim to be carbon negative by creating artificial carbon sinks.[20]

From 1978 to 1996 the US Department of Energy's National Renewable Energy Laboratory ran the Aquatic Species Program (ASP). The objective of the program was the production of

[20] Naik et al, 2010

biodiesel from high lipid-content algae grown in ponds, utilizing waste CO_2 from coal fired power plants. In the early years of the ASP program a collection of over 3,000 oil producing strains of mostly microalgae was amassed. After screening and characterization efforts the collection was reduced to around 300 promising species, mostly green algae and diatoms. At the height of the ASP program, much of the work focused on the physiology and biochemistry of algae as it related to improving oil production in algal organisms. The latter years of the ASP program were mostly focused on molecular biology and genetic engineering techniques for improved oil production in microalgae, and the development of large-scale algae production systems.

The program's basic conclusion was microalgae production of biodiesel was technically feasible but unviable economically. The program concluded the factors effecting cost the most were biological, and not engineering related. Even with favorable assumptions of biological productivity, their projected costs for biodiesel were two times higher than petroleum diesel fuel costs at the time.[21] The price of oil was at approximately $25 per barrel at the time this conclusion was made. The program was closed by the U.S. Department of Energy in 1996, but multiple researchers involved continued to work in the area of energy production through the culture of microorganisms.

Since the closing of the Aquatic Species Program the vast majority of work is narrowly focused on lab-scale research on the characteristics of individual microalgae species, such as lipid profiles, or oil extraction and processing techniques.[22] A minor collection of work has focused on rough calculations of the economics and engineering of utilizing microalgae for

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[21] Sheehan et al, 1998
[22] Laurens et al, 2012

biofuel production as a method to replace large portions of the world's energy needs– such as replacing all petroleum used by the US for transportation.[23]

The fluctuating price of fuel controls the ebb and flow of algal biofuel research. When gas prices are high, such as after the economic meltdown of 2007, government funding and grants flooded into the algal biofuel market, but as the U.S. is poised to become a world oil exporter due to fracking and a global oil supply surplus, the price of fuel drops and the funding of developing an economically viable algal biofuel dries up.

The development of biofuels has risen as a result of the negative impacts of fossil fuel usage, the economic and sociological consequences of a diminishable public resource, and the anthropogenic environmental effects of combustion and greenhouse gas (GHG) release. These impacts can be summarized into four main concerns:

1. High energy prices
2. Increasing energy imports
3. Concerns about petroleum supplies
4. Greater recognition of environmental consequences.[24]

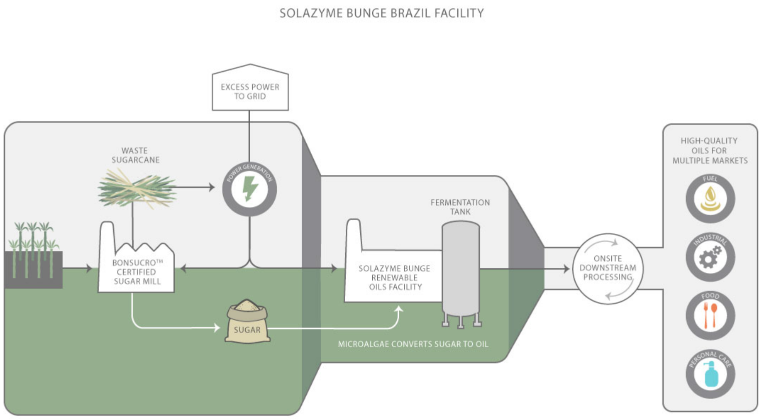
But for industrial scale biofuel manufacturing to make an impact as a viable substitute for conventional fuels and petrochemicals they need to essentially fill these four requirements:

1. Superior environmental benefits
2. Economically competitive
3. Producible in sufficient quantities
4. Net energy gain over production[25]

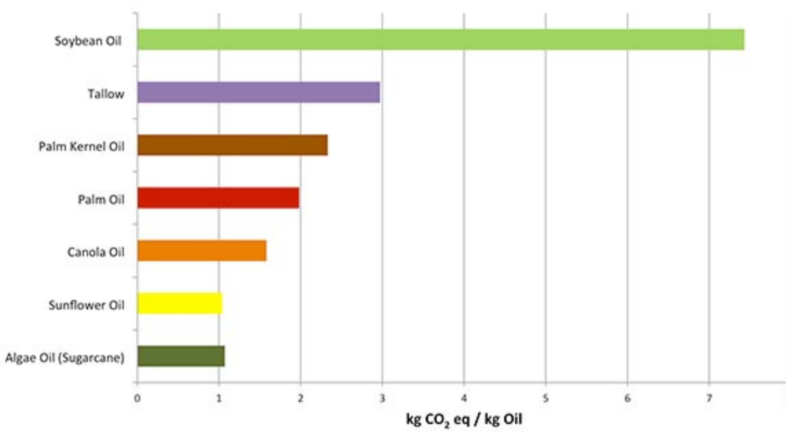
[23] Briggs, 2004
[24] Hill et al, 2008
[25] Hill et al, 2008

Algal Biofuel Life Cycle Assessment

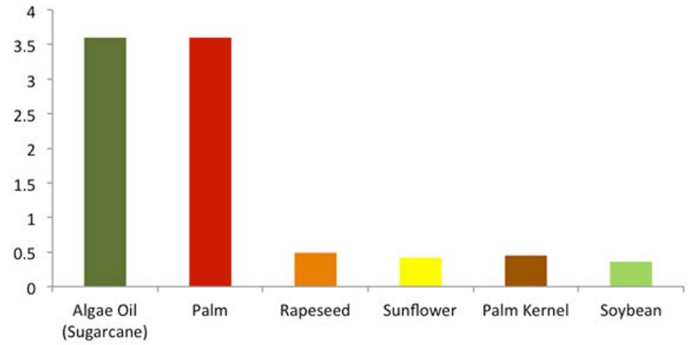
Solazyme Industrials is a biotechnology company that produces food and fuel through the processing of microalgae using sugarcane feedstock.



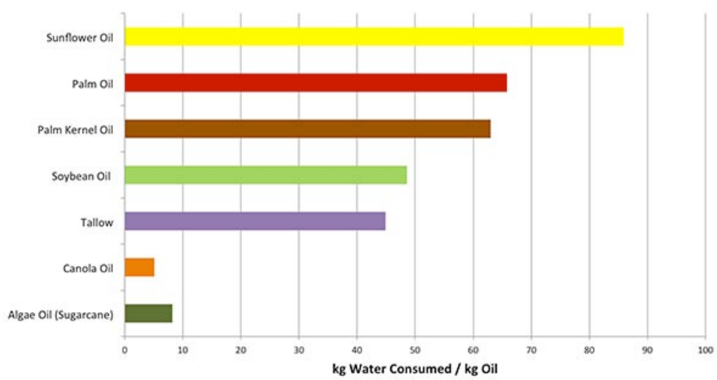
Solazyme commissioned a lifecycle assessment (LCA) of their algae oil production from cradle-to-gate and determined that algae oil production had significantly lesser emissions of CO_2 per amount of algae oil produced versus terrestrial based biofuels:



The production of algae oil also yielded more oil per hectare (approximately 2.471 acres) of land required to grow other crops:



Algae oil also consumed significantly less water than most other terrestrial food crops it was compared to in the production process:

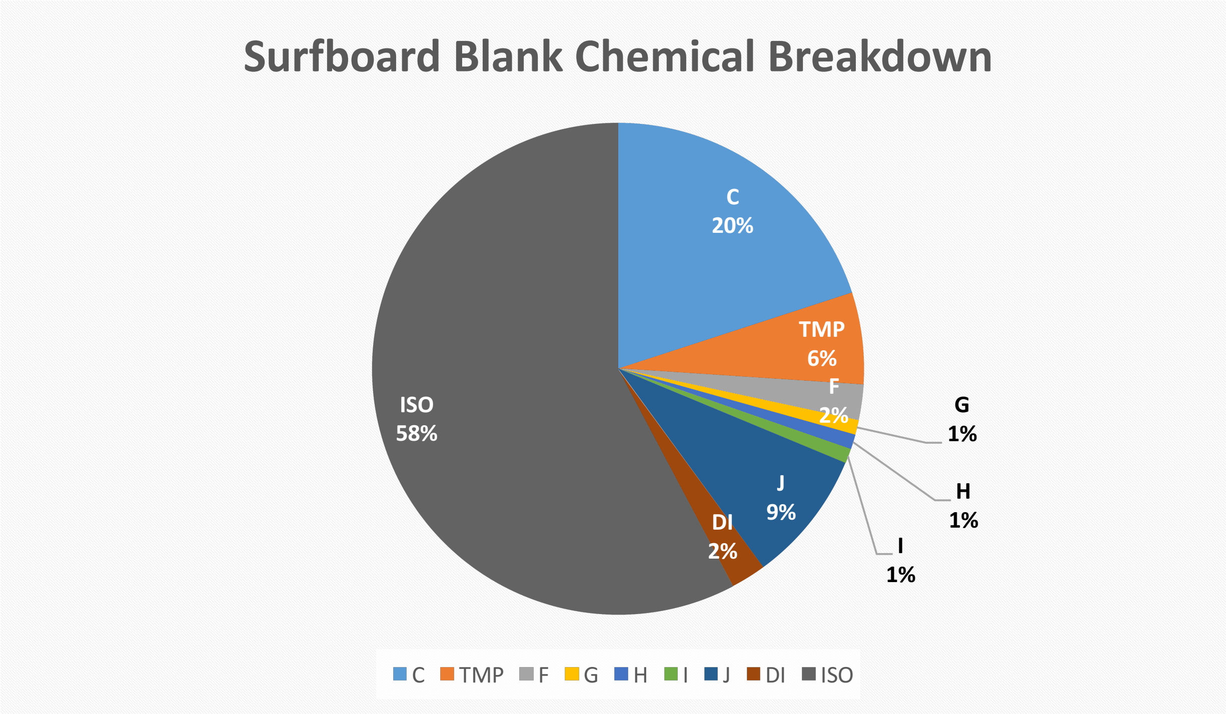


All of these factors contribute to the possibility of deriving food, fuel, and petrochemicals from a sustainable source that also sequesters CO_2 as a photosynthetic organism.[26]

Chemical Component Breakdown of Polyurethane Blank

Algenesis is a material products company that seeks to develop signature products using algal biotechnology to lessen dependence on the petrochemical industry. Their formula for a sustainably-sourced surfboard is broken down in this graph:

[26] http://solazymeindustrials.com/sustainability/our-footprint/#main-content



In this chart, the area depicted by the letter "C" represents polyols derived from algae. From this early stage formula, around 20% of the polyurethane blank is derived from algae oil. There have been significant improvements to the refinement process that have increased this amount to over 30%, with aspirations to replace over 50% in the near future.

Market Study

The purpose of the market study was to determine if the general public would support a sustainable surfboard option through detailed discussions with individuals involved in the surfboard market, focus groups, and randomized sample surveys. One straightforward question was to ask shop owners and proprietors of the surfboard craft what their opinions were on the Costco Wavestorm.

Opinions ranged from the negative: *"They're basically big chunks of trash with a relatively short life span before they end up as junk– we need to figure out a way we can repurpose the materials."*

To the practical:

"If you are looking for an ecologically healthier alternative, you would have to prioritize price right there along with ease of use and distribution."

To the doomed:

> *"Ruined my life, great value for the customer…cycle of the foamie nearing the end."*
>
> *"They are a regular retail surf shops worst nightmare in most ways. Their performance level is bottom of the barrel."*

To the hurt:

> *"It is garbage, but the price is low and they have full warranty. It has hurt the industry…"*

To the hopeless:

> *"It kind of sucks but I'm pretty indifferent."*

When asked to respond with the first word that same to mind when they heard the term "petrochemicals":

Of those surveyed who provided an answer, 33% listed an overwhelmingly negative word, i.e. **bad, damaging, pollution**. There were no overtly positive words listed. The most common answer was **oil** (22%), followed by **gas** (8%). Other commonly repeated answers were **dependency**, **fossil fuels**, and **bad**

<u>Conclusion</u>

The closing of Clark Foam in 2005 marked a significant divergent path for the surfboard manufacturing industry. With the advent of imported, mass-produced pop out boards sold exclusively at wholesale retailer chains, a more environmentally conscious approach to chemical components within material products needs to be taken into account. Through economic analysis of the breadth of the swelling surf industry and market surveys, it can be stated that there does exists a market for high-end, custom made polyurethane surfboards derived from sustainable sourced bio-products such as algae. By continuing research, development, and investment into the algae biofuel industry, biofuel production facilities can maintain relevant technology by committing to producing algae oil for signature products, so that when the time comes for fuel prices to spike, the technology hasn't lost a step. Refinements are needed in order to bring down the cost of biofuels processing, such as maximizing the lipid content profile of specific algae strains, streamlining their growth and processing, and bringing down the cost of industrial-scale facilities. By developing signature products using algal biotechnology, anthropogenic impacts of petrochemical manufacturing will begin to lighten the carbon footprint and reduce the effects of climate change.

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