AN ENVIRONMENTAL COMPARISON OF FOAM-CORE AND HOLLOW WOOD SURFBOARDS:
CARBON EMISSIONS AND OTHER TOXIC CHEMICALS

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Abstract

Surfers in general are viewed as environmentally conscious individuals; however the boards that almost all of them ride are not considered green. In the past few years there has been a movement in the industry to find alternatives to the foam/fibreglass construction of surfboards. This movement was sparked by the closing of Clark Foam in 2005, the largest producer and supplier in the U.S. of polyurethane foam surfboard blanks. The plant was forced to shut down because of increasing environmental regulations. In 2008 a life-cycle analysis of the most common types of surfboards was performed to find out how this product was effecting the environment. There has been extensive research into new foam technology for boards since 2005, however, I believe that wood is a good alternative for surfboard construction. This paper includes a life-cycle assessment (LCA) to determine the emissions from wood board production and compares them to that of classic foam boards. The results show that wood surfboard production produces far less emissions of CO_2, CO, SO_2, NO_x, VOC, and PM10 than foam surfboard production does. The LCA of wood boards included raw material production as well as production and assembly of the board itself. It can be concluded that from an environmental standpoint wood surfboards are a much better choice than the foam boards in use now.

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1.0 Introduction

Surfing is a rapidly growing sport in North America and around the world. The surfing community is seen as an environmentally conscious group; however the large majority of surfboards are not green at all. They are made of foam, mainly polyurethane (PU) (Schultz, Surfboard Contruction, 2011), fibreglass and resin in a process that produces emissions of carbon volatile organic compounds (VOC's) and other pollutants (Schultz, The Surfboard Cradle to Grave, 2009). The boards are also non bio-degradable and cannot be recycled when they are no longer useable. In the past ten years or so surfers have become more aware of the environmental impacts the surf industry had. This was especially evident after Clark Foam, the largest producer of foam blanks, shut down in 2005 (Admin, 2005). Since then a variety of different types of foam have been tested and some are in use today. The main alternative is extruded polystyrene (EPS). It is lighter and produces lower VOC emissions than PU. Some companies are producing EPS boards, however PU is still the main core material on the market today at about 85% of all boards produced (Schultz, Surfboard Contruction, 2011). The limitation on EPS is the health effects it has on shapers (Surf Science, 2011). Surfboards are often hand shaped, exposing the shaper to fine foam particles as they shape the blank. EPS also has a bad reputation for water absorption and stiffness. It is because of these aspects that PU blanks have maintained a large majority share of the market. While there is some experimentation with new foams for surfboard cores such as EPS mentioned above, there is little talk about alternative core materials other than foam. This paper will look at the viability of wood as a construction material for surfboards. Originally surfboards were made from wood, and I believe moving back to wood is an option. Wood is a renewable, recyclable and biodegradable material. The main goal of this paper is to show the differences in the environmental impact of wood surfboards and foam core surfboards. This will be done by comparing life cycle analyses (LCA) of each. A LCA of foam-core surfboards has been done by Tobias Shultz, a grad student at Berkeley in 2008. I will create a LCA for a wood surfboard and compare the results. The basic construction methods of each board will also be outlined to aid understanding of the LCA's. Because of its dominant market share I will only compare PU foam-core surfboards to wood surfboards.

2.0 Construction

It is important to first define the construction methods for both foam boards and wood boards. This will make the LCA easier to understand. To try and simplify the comparison, the construction methods and materials of a board of dimensions 6’ x 20 5/8” x 2 1/4” (1.83m x 0.52m x 0.057m) will be examined. This is a popular size for a surfboard used in most areas where surfing is prevalent. There are many options for fins and fin systems that could be applicable to both boards so for the purpose of this paper fins will not be analyzed.

2.1 Foam Surfboard

The large majority of surfboards sold today are constructed with foam and fibreglass. After many years of experimenting and trying to improve board design this has taken over as the main method because it is relatively cheap and easy to produce in large quantities. Boards are normally produced first as blanks and then later sold to shapers who finish the job by hand. There is a variety of foam/fibreglass/resin boards sold today. The most common one is polyurethane (PU) foam core with unsaturated polyester resin (UPS) and fibreglass. This construction method can be seen in figure 1. As stated above about 85% of boards today are made with this type of construction (Schultz, Surfboard Contruction, 2011). This paper will only look at this type of foam board construction.

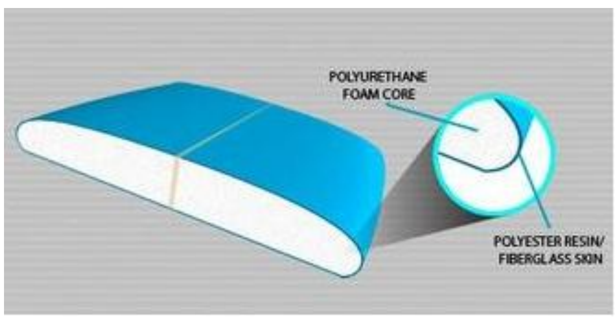

Figure 1. Polyurethane Surfboard Construction (Schultz, Surfboard Contruction, 2011)

2.1.1 Materials

The materials used in the construction of a P/U and UPS surfboard are as follows (Schultz, The Surfboard Cradle to Grave, 2009):

- Foam core: 6’2”x20 5/8”x2 1/2” with wood stringer.
- Fibreglass: 3.64m²
- UPS Resin: 2.37L
- Catalyst/Resin Hardener: 50mL

- Surfacing agent: 100mL

(Converted to metric units)

2.1.2 Method

Foam core surfboards are made in two stages. First the foam “blank” is made by a company that produces blanks in a variety of shapes and sizes. Then the blanks are bought by shapers who hand shape the boards.

The production of the blank involves first producing the foam. Polyurethane foam is made by an addition polymerization reaction. Some amounts of diol or polyol, diisocyanate, and water are mixed together. The diisocyanate reacts with the diol/polyol to form urethane, and reacts with water which gives off CO_2 gas to create bubbles. Using different additives PU foam can be made for a variety of different uses (Wang, 2006). Once the foam is set, the blank is cut in half and the wood stringer is placed in the middle and glued into place.
The blanks are then sold to surfboard shapers. Shaping is generally done by hand, although some do it mechanically using CNC machines. The shape of the board depends on what performance characteristics the shaper is looking for. Once the board has been made into the desired shape it goes on to the glassing stage.

The fibreglass is laid over the board and resin is applied and left to harden. Once the board has been glassed and the resin has hardened on both sides the board is sanded to create a smooth even surface.

2.2 Wood Surfboard

The first surfboards ever used were made out of solid wood and could be up to 14 feet long (COTW, 2011). Board design and construction has come a long way since then and this paper does not suggest taking any steps backwards. The board construction method that will be looked at in this paper is a hollow board with a plywood rib system for vertical support, solid wood rails and sawn solid wood top and bottom sheets with fibreglass and epoxy resin (Gallagher, Classic Wood Surfboards, 2010). This type of board is not new, however it is not produced in large quantities. There is a variety of methods used today for building a hollow wood surfboard. I will analyze the method used by Gallagher surfboards as it is fairly standard.

These boards are custom made by hand and therefore cannot be directly compared to foam board production. In order to make a better comparison I will assume the wood boards are produced in larger quantities in a more automated production process.

2.2.1 Materials

The materials needed for hollow wood surfboard construction are as follows:

- Plywood
- Solid wood for top/bottom sheets and rails
- Fibreglass
- Resin

2.2.2 Method

The method for constructing a hollow wood surfboard is very different from the method to build a conventional foam board. There are more raw materials involved and more components that need to be fabricated. Wood boards are not produced as blanks the way foam boards are. They are produced in one shop and the finished product is ready for use.

There are four major components that have to be produced and then assembled together. These components are as follows (Gallagher, 2010):

1. Spine and Ribs
2. Rails
3. top and bottom sheet
4. Fibreglass and resin

The spine and rib components are the main structural component in the board. They are made out of plywood and will be cut out 2440x1440mm (4'x8') sheets. Once the ribs and spine are cut to size they will be assembled by hand. The ribs and the spine are produced with a half lap joint for ease of assembly. A small amount of glue is placed in each rib-spine joint. The top and bottom sheets are made of solid wood cut to about 19mm thick and edge glued together. The assembled spine and ribs are then glued onto the bottom sheet of the board. The rails are then built onto the board by bending multiple small strips over the edge of the ribs from the nose to the tail. The strips are all glued together to form the rail. After the glue has set the rails are shaped. Next the top sheet is glued on and the board is cut to its final shape and sanded smooth. After this fibreglass and resin are applied using the same procedure as in foam board production.

Machines used in production include (Gallagher, 2010):

- Table Saw
- Band Saw
- Planer
- Jointer
- Chop Saw
- Belt Sander

3.0 Environmental Comparisons

The purpose of the LCA for each board type is to try and determine the difference in the environmental impact from each. The most important part of the LCA for both types is the cores of the surfboards. The cores consist of the board minus the fibreglass and resin. Although PU boards usually use UPS resin, which has larger environmental impacts, epoxy resin can be used as well. Both boards use fibreglass to seal the board and give it its final strength characteristics. Since the glassing process is the same for both boards, emissions for both will be assumed the same and therefore not analyzed. The emissions for fibreglass and resin and other chemicals used in the glassing/finishing process have been removed from the final numbers. There are some different options such as a bamboo fibreglass substitute however it could be used for either construction method so it will not be analyzed. While some repairs will be necessary they will be far fewer and will require less material. Transportation from the production facility to the retailer or customer is not analyzed in this report because this is necessary for both board types. LCA's will be done for one surfboard of the dimensions mentioned in the construction section.

3.1 List of Assumptions

1) The US power generation spread is an accurate representation of that used by surf manufacturers and will produce relevant emission values. The U.S. emission averages from

electricity generation are relevant values to the emissions from energy use of a wood surfboard manufacturer.

2) LCA studies for foam surfboards, plywood and solid wood are accurate and relevant. The average emissions from the mills tested are a relatively accurate representation of the emissions of the mills that would supply the raw materials for wood surfboards.
3) Emissions from production can be separated down to a per surfboard basis and that this is an accurate representation of the entire process.

3.2 Life Cycle Analysis (foam-core surfboard)

3.2.1 Production

As stated in the introduction, the LCA for a foam board has already been done in the Surfboard Cradle-to-Grave Project by Tobias Shultz at the University of California, Berkeley. The necessary results will be restated below. All values have been converted from imperial to metric.

The carbon emissions from the blank production and shaping processes are 60kg of CO_2 gas per board. The majority of the carbon emissions come from blank production and resin application. Table 1 shows the amounts of materials per surfboard for the glassing process.

There is also an assortment of toxic by-products released in surfboard production. The table below gives the values in kilograms per surfboard.

Table 1 Other pollutant emissions from foam surfboard construction (Schultz, The Surfboard Cradle to Grave, 2009)

all units in kg	CO2	CO	SO2	NOX	VOC	PM10
UPR	60	0.27	0.076	0.076	0.085	0.014

These emission values include blank production and shaping, fibreglass and resin are not included.

3.2.2 Useful life

During the useful life of the surfboard there is little environmental impact. The board is used until the owner either breaks it or decides it is no longer useful to them.

3.2.3 End of Life

After the user is finished with the board there are two possible scenarios; sale and reuse; and disposal. If the board is sold and reused it returns to the useful life stage. If it is disposed of the board will likely go to a landfill. The foam is not biodegradable and it may leach some toxic chemicals after some time (Schultz, The Surfboard Cradle to Grave, 2009).

3.3 Life Cycle Analysis (Wood Board)

In order to properly do a life-cycle analysis (LCA) of a wood surfboard all of the individual materials have to be taken into consideration. These materials include solid wood, plywood, glue, fibreglass and resin. The processes to make each material and the emissions from those processes will have a large effect on the overall lifecycle of the board. Quantities for each wood material are shown in the table below. The ribs are assumed to be rectangular for ease of calculations; there are 12 ribs in total in the board. The top and bottom sheets are also assumed to be rectangles as they are produced as a rectangular sheet then cut to shape (Gallagher, 2010). The rails are also square as they are rounded after assembly. Glue will not be assessed in this LCA because little glue is needed and it has little effect on the total emissions.

Table 2 Amounts of materials for wood surfboard components

	Component		
Material	**Ribs (m^2)**	**Top/bottom (m^3)**	**Rails (m^3)**
Solid Wood	-	0.02	0.01
Plywood	0.38	-	-

Quantities for fibreglass and resin materials are the same as for foam-core surfboards and can be found in Table 1 in the previous section.

3.3.1 Production

Solid Wood

Information on emissions from solid wood production taken from "LCI of Softwood Lumber Production" by Milota, West and Hartley; and "Environmental Impact of Producing Hardwood Lumber Using Life-Cycle Inventory" by Bergman and Bowe. All values converted to a per surfboard basis.

Below is an outline of the basic process of producing lumber. Various emissions are associated with this process. Each different process uses energy, some of the energy is electric and comes from the power grid, and some is created by burning wood waste from the mill.

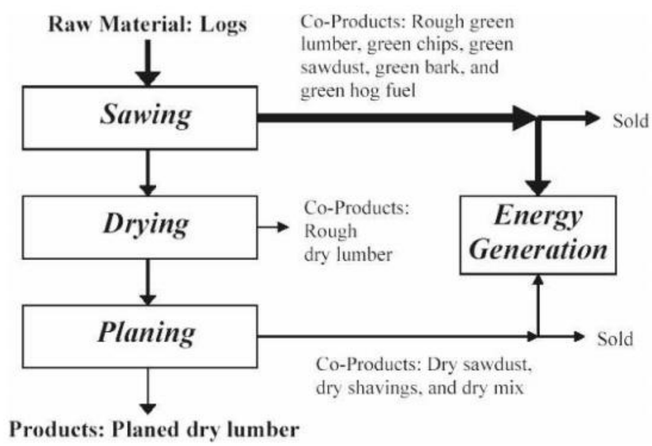

Figure 2 Life cycle of hardwood lumber (Bowe & Bergman, 2008)

Hollow wood surfboards can be made with many different species to achieve an appearance that appeals to each individual. For this reason I will look at both softwood and hardwood lumber production for the wood used to produce the top and bottom sheets and the rails. This will give a range of possible emissions depending on the species used in each specific board. The table below shows the emissions from both softwood and hardwood lumber production.

Table 3 Emissions from solid wood lumber production per surfboard.
(Milota, West, & Hartley, 2005), (Bowe & Bergman, 2008)

Emissions (kg/surfboard)	**CO2**	**CO**	**SO2**	**NOX**	**VOC**	**PM10**
Softwood	15.5	0.0370	0.0296	0.0129	0.00240	0.0499
Hardwood	17.0	0.0939	0.0345	0.0306	0.0360	0.00221

Plywood

Information on the life cycle and emissions from plywood wood production was taken from "Gate to Gate Life-Cycle Inventory of Softwood Plywood Production" by Wilson and Sakamoto. Units have been converted to amounts per surfboard.

The basic process of producing plywood is outlined in figure 6. All of the processes require energy which creates emissions. There are also some emissions from the resin used in the plywood.

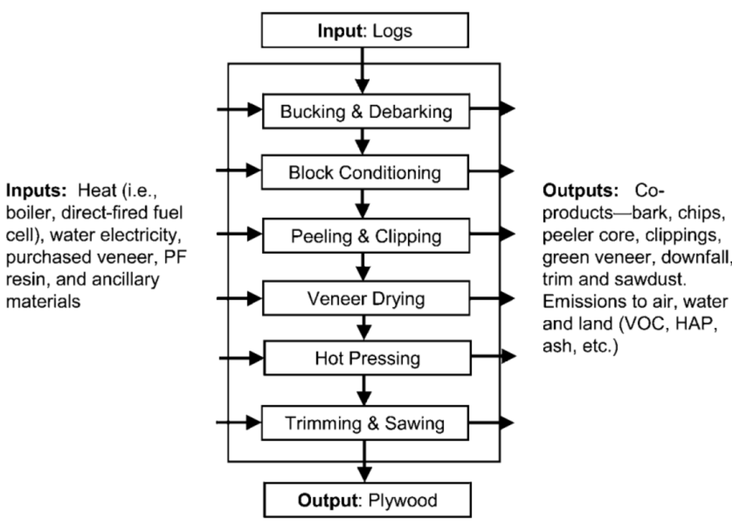

Figure 3 Plywood production process (Wilson & Sakimoto, 2005)

Emissions from plywood production are shown in the table below. They are for a plywood plant in the Pacific Northwest.

Table 4 Emissions from Plywood Production per surfboard (Wilson & Sakimoto, 2005)

Kg/surfboard	**CO2**	**CO**	**SO2**	**NOX**	**VOC**	**PM10**
Emissions	0.89	0.0051	0.0026	0.0016	0.0016	0.00055

These values include emissions from energy use, both electric and other sources such as wood fuel boilers used in the production process as well as emissions from the plant itself.

Surfboard Production

This production process is outlined above in the construction section. It involves producing each of the components of the surfboard and assembling the board. The main contributor to emissions from the production of the surfboard is going to be power consumption from the machines. The table below shows the power consumption for the machines used in production. The values are averages from a number of similar machines. The power consumption has been converted to per surfboard units.

Table 5 Energy consumption per surfboard from surfboard production process

(kWh)/surfboard	**Table Saw**	**Planer**	**Jointer**	**Bandsaw**	**Belt Sander**	**Chop Saw**	**Total**
Power Consumption	4.0	2.5	2.5	0.5	0.2	0.4	10.1

Since most surfboards are produced in the US the emissions from electrical power generation will be taken from the average in the US. The average amount of CO_2 emissions in the US in 1.341 lb/kWh or 0.610 kg/kWh (US Department of Energy, 2000). Converted to a per surfboard unit it becomes 6.160 kg CO_2 emissions per surfboard.

Table 6 Emissions from energy use per surfboard

(Miller & Van Atten, 2004) (US Department of Energy, 2000)

Power Generation (kg/surfboard)	**CO2**	**CO**	**SO2**	**NOX**	**VOC**	**PM10**
Emissions	6.16	-	0.038	0.017	-	-

Sufficient data could not be found on the emissions from power generation for carbon monoxide, VOC's and PM10.

3.3.2 Useful Life

Similar to foam-core surfboards, wood boards have little emissions in their useful life. They may also require the odd repair but overall there is little to no environmental impacts from the board during use.

3.3.3 End of life

After its useful life the same two scenarios are likely, resale and reuse, and disposal. The difference is that wood is biodegradable and recyclable. If the board is thrown out, the majority of it is biodegradable. Unlike the foam-core boards, wood surfboards can be recycled. The fibreglass can be stripped off and the wood can either be reused in another application or recycled somewhere else.

3.4 Uncertainty

There is some uncertainty involved with this LCA. The main cause of uncertainty is the different time periods that the data comes from. The LCA's for plywood and solid wood are from 2005 and 2008 while the power generation data for the U.S. is from 2000 and the surfboard cradle to grave report was completed in 2009. This may cause some discrepancies in the final numbers for emissions from each process.

There is also uncertainty in the data for some of the emissions from energy consumption as I could not locate data on VOC, carbon monoxide and PM10 emissions from U.S. power generation. This will probably cause the wood board emission values for these chemicals to be lower than they actually are.

The final uncertainty issue is with the raw materials data for the wood board construction. The LCA's for plywood and solid wood are taken as average values from a number of mills. The raw materials used for the wood board will likely come from only a few mills and therefore will probably be different than the average. The same can be said for power consumption. Depending on the area where the boards are manufactured the power generation will be from a different source and could have different emissions.

4.0 Discussion

After looking at the emissions from production of foam core and hollow core wood surfboards it is obvious that the emissions from production of wood boards are much lower. Table 8 below shows the results clearly. Throughout the entire process of producing a wood board, including the production of raw materials and the production of the board itself wood boards produce lower emissions in all categories analyzed. Solid wood values were taken as an average of hardwood and softwood emissions. This means that emissions could fluctuate if different quantities of hardwoods or softwoods are used; however this fluctuation will be minimal and will have little effect on the total emissions.

Table 7 Total Emissions, kg/surfboard for foam and wood boards

Total emissions kg/surfboard	**CO2**	**CO**	**SO2**	**NOX**	**VOC**	**PM10**
Wood	23.30	0.071	0.073	0.040	0.021	0.0017
Foam (PU core)	60	0.27	0.076	0.076	0.085	0.014

It is important to note, as mentioned above that the wood boards are not mass produced and there for the emissions values for the actual board production may not be directly comparable to foam board production. The majority of the emissions for wood surfboards, however, come from raw material production. If the raw material production (plywood and solid wood) is viewed as the equivalent to foam blank production and the board production is viewed as equivalent to the shaping process this comparison makes more sense. If the production of wood boards was increased and a larger shop producing large quantities of boards was in operation the emission values would of course be different. Wood board emissions are significantly lower than that of foam boards giving a lot of room to change the process and still produce less emissions.

Another issue with foam boards is with its after use characteristics. Once the board is finished being used or no longer usable there is not much that can be done with it. Often times the board just sits outside or gets sent to a landfill. Toxic chemicals present in the board can leach into the ground (Schultz, The Surfboard Cradle to Grave, 2009). The foam is not biodegradable and it cannot be easily recycled. Wood on the other hand is biodegradable and can be recycled with relative ease. It also holds large amounts of carbon within its structure limiting carbon releases into the atmosphere.

The major limitation on wood surfboards today is the cost. Grain Surfboards is a producer of hollow wood surfboards and they generally sell their boards for $1500-$2000. This is roughly three times the average surfboard price which is $600 (Surfboard Industry Sags, 2008). However, like Gallagher surfboards Grain produces their boards in smaller quantities mainly by hand. This price could be significantly lowered by producing more boards in a more high-tech shop.

4.1 Uncertainty Discussion

While the possible uncertainties outlined earlier will likely cause some differences in the emission values, the difference between wood and foam board emissions from production is quite large. This gives a lot of room for changes without changing the results. There is also the chance that this uncertainty will actually lower the emissions depending on which suppliers are used and what type of power generation is prevalent in the area where the surfboards are produced.

5.0 Conclusion

Wood surfboards have much lower carbon emissions as well as other toxic emissions making it a good option for a “greener” alternative to the traditional foam core surfboards. While in mass production it may be harder to create personally shaped boards to the rider’s specifications, it is a good product for the majority of surfers. If this change were to take place the emissions from surfboard manufacturing would decrease dramatically. This shift would also remove the issue of non-recyclable, non biodegradable waste from old foam boards that are either broken or finished being used. A new process will have to be developed to produce wood boards at more competitive prices in order to gain enough market share to have any environmental impact. The technology needed is there so it is likely possible to design a process to do this.

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