evostyle
furniture • joinery • turning

David Trubridge

AMERICAN HARDWOOD EXPORT COUNCIL

Seed to Seat

Environmental Life Cycle Assessment

SUMMARY

The latest U.S. forest inventory data confirms that the hardwoods used to manufacture the Seed to Seat designs are an expanding resource and that harvesting of these species is not threatening biodiversity or forest carbon storage. It takes less than three seconds for the five cubic meters of hardwood logs harvested to manufacture all Seed to Seat designs to be replaced by new growth in the U.S. forest.

On a cradle-to-factory-gate basis, the total GWP or "carbon footprint" of all the Seed to Seat designs is 0.54 tonnes of CO_2 equivalent. That's about the same as a 2850 km drive[1] and equal to the carbon emissions of the average Australian over a nine day period[2].

The carbon footprint of the American hardwood lumber delivered to the factory in Australia and New Zealand is better than carbon neutral. This means that other less visible materials have a disproportionately large impact on the carbon footprint. Although metals, glues and coatings accounted for only 6% of the total mass of the finished designs, they are responsible for 23% of the total carbon footprint.

A relatively large share of carbon emissions and other environmental impacts of the finished designs occurred during the manufacturing stage in Australia and New Zealand. Manufacturing emissions were particularly high in Australia due to the lengthy time required on CNC machines with a high power rating, combined with heavy dependence on fossil fuels for power generation in Australia[3].

Overall the results highlight that, from an environmental perspective, the issue of "product miles" – sometimes used to justify preference for local materials over imported products – is much less relevant when procuring wood products than the relative efficiency of processing operations and waste management and variations in the energy mix in the processing locations.

The Seed to Seat products are well designed for longevity - a tribute to the skills of the designers and manufacturers and to the beauty and durability of U.S. hardwoods. Long life in use would significantly mitigate the environmental effects of the designs. The less need for replacement, the less repetition of impacts. There is the additional benefit that long-lived wood products supplement the carbon store in the forest and help to keep CO_2 out of the atmosphere. The six designs together store the equivalent of 0.41 tonnes of CO_2.

1. Australian average carbon emissions from new passenger and light commercial vehicles were 192 g/km in 2013 according to 'Carbon Dioxide Emissions from New Australian Vehicles 2013' by Australian National Transport Commission, May 2014

2. Based on OECD showing Australian carbon emissions (excluding land use change) of 522.4 million tonnes and population of 23.5 million in 2014 (stats.oecd.org)

3. 94% of primary energy consumption in Australia derived from fossil fuel in 2013-14 - based on Australian National Energy Statistics (www.industry.gov.au/Office-of-the-Chief-Economist/Pages/default.aspx)

Seed to Seat designs & designers (from left): Ben Percy, Anne-Claire Petre, Adam Goodrum, Todd Hammond, Greg Natale

Report client: Roderick Wiles, AHEC Oceania, tel: +65 6641 2486, email: rod@americanhardwood.org
Prepared by: Rupert Oliver, Forest Industries Intelligence, tel: +44 7553 346410, email: rupert@forestindustries.info

INTRODUCTION

The Life Cycle Assessment (LCA) covers the series of six Seed to Seat designs, including five manufactured by Evostyle in Australia, respectively by Anne-Claire Petre, Ben Percy, Greg Natale, Adam Goodrum and Todd Hammond, and the Aleni bench designed and manufactured by David Trubridge in New Zealand. Figure 1 summarises the environmental impact of all six designs on a cradle-to-factory-gate basis. The LCA of each individual design is provided separately on pages 6 through to 11. Quantitative assessment is provided against six environmental impact categories of particular relevance to wood products and for which there is broad scientific agreement on methodology (Figure 2). There is also qualitative assessment of impact on forest condition drawing on the LCA of U.S. sawn hardwood prepared by PE International (now Thinkstep) in July 2012 and latest data from the U.S. Forest Service Forest Inventory and Analysis (FIA) Program.

BIODIVERSITY AND LAND USE

The LCA of U.S. hardwood undertaken by PE International concludes that *'in the system under investigation the main material – wood – comes from naturally re-grown forests. The harvested areas had undergone several iterations of harvesting and re-growth. After harvesting, the land is returned to forest so there is no direct land use change to account for in the timeline of few hundred years.'*

On biodiversity impacts, PE International concludes: '*conversion of any other commercial land into the hardwood forest would most probably have a positive impact on the land quality including biodiversity and associated ecosystem services.*'

U.S. Forest Service inventory data shows that the total area of hardwood and mixed hardwood-softwood forest types in the U.S. increased from 99 million hectares in 1953 to 111 million hectares in 2012. Area increased consistently throughout the 60-year period and continued at a rate of 401,000 hectares per year between 2007 and 2012. Between 2007 and 2012, the volume of hardwood standing in the U.S. increased at a rate of 124 million m^3 a year.

Drawing on this data, and adjusting for the differing growth rates of the species used (cherry, red oak and tulipwood), it is estimated that it takes less than three seconds for the five cubic meters of hardwood logs harvested to manufacture all Seed to Seat designs to be replaced by new growth in the U.S. forest.

U.S. forest inventory data confirms that hardwood harvesting is not threatening biodiversity by replacing older more diverse forests with plantations. In 2012, natural forests accounted for 97% of the area of hardwood and mixed hardwood-softwood forest types in the U.S. and only 3% were plantations. U.S. hardwood forests are also aging and more trees are being allowed to grow to size before being harvested. The volume of hardwood trees with diameters 48 cm or greater increased nearly four-fold from 0.73 billion m^3 in 1953 to 2.7 billion m^3 in 2012.

GLOBAL WARMING POTENTIAL (GWP)

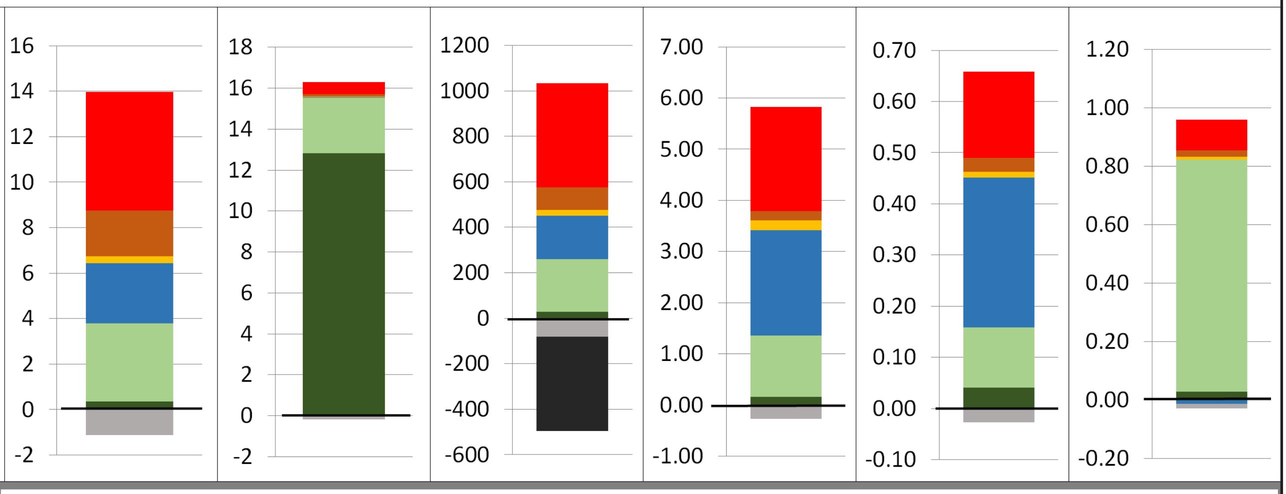
On a cradle-to-factory-gate basis, the total GWP or "carbon footprint" of all the Seed to Seat designs is 0.54 tonnes of CO_2 equivalent. That's equal to the carbon emissions of the average Australian over a nine day period.

The carbon footprint of the American hardwood lumber delivered to the factory in Australia and New Zealand is better than carbon neutral – in the sense that the carbon stored in the wood during growth (0.79 tonnes of CO_2 equivalent) exceeds the carbon emissions during all stages of material extraction, processing and

FIGURE 1: CRADLE TO FACTORY GATE ENVIRONMENTAL IMPACT OF SIX SEED TO SEAT DESIGNS

Impact category	Primary energy demand (non-renewable)	Primary energy demand (renewable)	Global Warming Potential	Acidification Potential	Eutrophication Potential	Photochemical Ozone Creation Potential
Unit	GJ	GJ	kg CO2-Equiv.	kg SO2-Equiv.	kg Phosphate-Equiv.	kg Ethene-Equiv.
Total	12.86	16.10	539	5.55	0.63	0.93

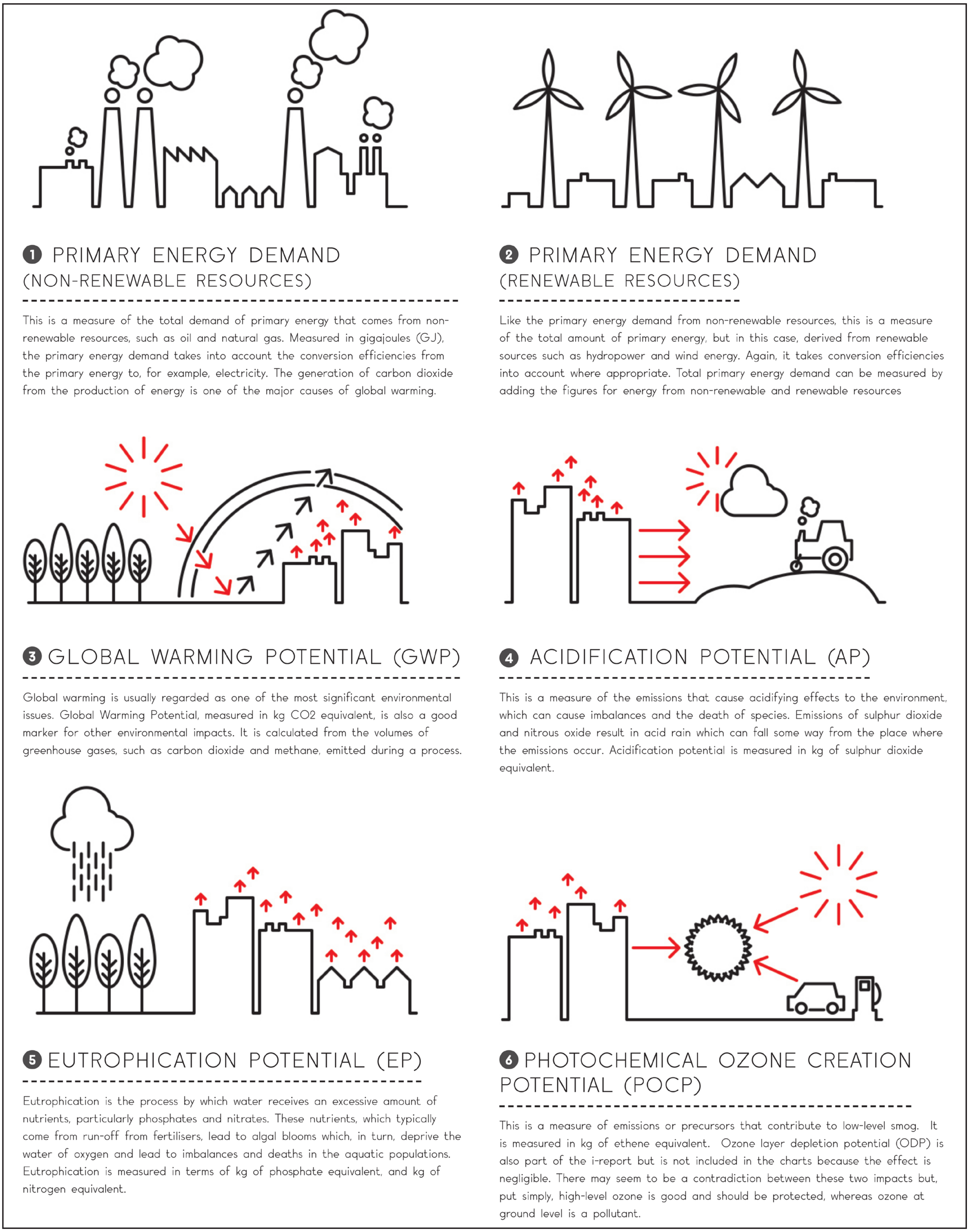
Data by process steps



Impact Category	Unit	Hardwood forestry	Hardwood processing	Hardwood transport	Metal fixings & strips	Glues & coatings	Manuf-acturing	Process waste	Biogenic carbon	Total
Primary energy demand (non-renewable)	GJ	0.37	3.42	2.65	0.30	2.02	5.23	-1.12	0.00	12.86
Primary energy demand (renewable)	GJ	12.81	2.72	0.03	0.04	0.11	0.59	-0.20	0.00	16.10
Global Warming Potential	kg CO2-Equiv.	27.03	233.28	191.30	23.30	100.08	459.35	-80.49	-414.74	539.11
Acidification Potential	kg SO2-Equiv.	0.163	1.192	2.065	0.183	0.186	2.034	-0.271	0.000	5.552
Eutrophication Potential	kg Phosphate-Equiv.	0.04	0.12	0.29	0.01	0.03	0.17	-0.03	0.00	0.63
Photochemical Ozone Creation Potential	kg Ethene-Equiv.	0.03	0.79	-0.01	0.01	0.02	0.11	-0.01	0.00	0.93

transport from the U.S. (0.45 tonnes of CO_2 equivalent). Of these emissions, those associated with processing (52% - mostly kiln drying) exceed those due to transport (42%) despite the extremely long shipping distances involved. Only 6% of carbon emissions to deliver the American lumber occurred during forestry operations. A large share of carbon emissions of the finished designs occurred during the manufacturing stage in Australia and New Zealand. Emissions due to use of grid electricity during manufacturing were 0.46 tonnes of carbon dioxide equivalent. Emissions were particularly high in Australia due to the lengthy time required on CNC machines with a high power rating, combined with heavy dependence on fossil fuels for power generation in Australia. 94.1% of

FIGURE 2: ENVIRONMENTAL IMPACT CATEGORIES



primary energy consumption in Australia derived from fossil fuel in 2013-14. This contrasts with New Zealand where 39% of primary energy consumption in 2014 derived from renewables and only 37.8% from oil and coal.

Wood's dual role as a material for product fabrication and as biomass for energy production has implications for the carbon footprint. Carbon emissions are partially offset by 0.08 tonnes of CO_2 equivalent resulting from substitution of fossil fuels through incineration of the wood waste created during manufacturing.

Because the American hardwood used for the designs is better than carbon neutral, other less visible materials have a disproportionately large impact on the carbon footprint. Although metals, glues and coatings accounted for only 6% of the total mass of the finished designs, they are responsible for 0.12 tonnes of CO_2 equivalent, 23% of the total carbon footprint.

FIGURE 3: MATERIAL AND CARBON BALANCE: U.S. HARDWOOD DELIVERED TO FACTORY GATE

	American hardwood quantity (1)		Replace-ment time (2)	Carbon footprint		
				Emissions (3)	Biogenic carbon (4)	Total footprint (5)
	m3	kg	seconds	Kg CO_2 eq		
Emi pods by Anne-Claire Petre						
Red oak	0.104	71.7	0.12	102	-111	-9
O.C.S. bench by Ben Percy						
Tulipwood	0.269	127.3	0.52	97	-193	-95
Stripped bench by Greg Natale						
Red oak	*0.063*	*43.3*	*0.07*	*47*	*-67*	*-20*
Tulipwood	*0.105*	*49.5*	*0.20*	*38*	*-75*	*-37*
Total	0.167	92.8	0.28	85	-142	-57
3 Don chairs by Adam Goodrum						
Cherry	*0.030*	*17.0*	*0.16*	*12*	*-26*	*-14*
Tulipwood	*0.034*	*15.9*	*0.07*	*12*	*-24*	*-12*
Total	0.064	32.9	0.23	24	-50	-26
3 J.A.C armchairs by Todd Hammond						
Cherry	0.098	55.3	0.52	37	-84	-47
Aleni bench by David Trubridge						
Cambia ash	0.203	137.1	1.06	107	-208	-101
All products	0.90	517.04	2.73	451.30	-786.31	-335.00

1) Volume of boards delivered to the furniture factory in Australia/New Zealand actually used for manufacture of the prototype - excludes unused sections of boards diverted to other product streams. Where necessary mass is calculated from volume using density of boards measured on site (for designs manufactured by Evostyle in Australia) and standard destiny of Cambia Ash taken from Cambia website (for bench manufactured by David Trubridge in New Zealand)

2) Replacement time is time in seconds it takes for new growth in the U.S. hardwood forest of the specific species to replace that required to be harvested to supply wood for the project. It is assumed that log volume required to be harvested is double volume of delivered boards (i.e. 50% conversion efficiency from logs to boards). Hardwood forest growth data is derived from the USDA Forest Inventory and Analysis (FIA) Program.

3) Data for carbon emissions is taken from updated LCA model developed by Thinkstep (formerly PE International) as part of the US hardwood LCA study commissioned by AHEC and includes all emissions from point of extraction in the U.S. through all processing stages and transport to factory gate in Australia and New Zealand. Based on density of boards on site and standard industry drying practices, it is assumed that red oak is dried to 10% moisture content and all other species to 12% moisture content.

4) Biogenic carbon is the carbon stored in wood material during growth and is treated as a negative emission. Due to difficulties of tracing carbon flows at every stage of the life cycle, carbon storage is calculated directly from the mass of the delivered hardwood assuming that 46% of dry mass consists of carbon (where 1 kg of carbon is equivalent to 44/12 kg - i.e. 3.666 kg - of carbon dioxide).

5) Carbon footprint is calculated as the balance between emissions and biogenic (stored) carbon. A negative figure indicates carbon storage in the wood exceeds all emissions associated with delivery of the boards to the factory gate.

PHOTO CREDIT: DAVID TRUBRIDGE

ACIDIFICATION POTENTIAL

The total acidification potential of all the Seed to Seat designs is 5.6 kg of SO_2 (sulphur dioxide) equivalent. Acidification is caused mainly by the burning of fossil fuels and the scale of impact is directly related to their sulphur content.

37% of the acidification potential is due to emissions during generation of the electricity used at the manufacturing stage and is due to the high proportion of fossil fuels, particularly coal, in the Australian energy mix.

27% of the acidification potential is due to emissions during hardwood processing in the United States. A significant proportion is due to use of grid electricity, mainly to power fans during the lengthy kiln drying cycles. Two thirds of energy for electricity generation in the U.S. derives from fossil fuel, half of which is coal. Some acidification potential is also due to biomass combustion to provide the thermal energy for kiln drying.

A further 37% of the acidification potential of the Seed to Seat designs is due to emissions during shipping of hardwoods from the U.S. to Australia and New Zealand and partly reflects the assumptions made about sulphur content of marine fuels. The LCA assumes an average sulphur content of 2.7% for the fuel used on the ships transporting the wood from the U.S. This may well be an over-estimate. It exceeds the global average figure of 2.4% estimated for 2010 by the International Maritime Organisation, an average already skewed by relatively high figures for shipping in the Middle East and Asia. Progress is also being made to further reduce the sulphur content of these fuels under the International Convention for the Prevention of Pollution from Ships (MARPOL) which sets a global target of only 0.5% from 2020 onwards.

PHOTOCHEMICAL OZONE CREATION POTENTIAL (POCP)

The Seed to Seat designs have a combined POCP of 0.93 kg of ethene equivalent. Around 85% occurs at the hardwood processing stage in the U.S. and is due to emissions of terpenes, volatile organic compounds (VOCs) released from wood resins. Terpenes are released naturally as trees grow, but processes in which wood is heated (such as a kiln drying) result in more significant emissions. In practice there is substantial variation in the level of VOC emissions between species and they also depend on drying times and on other factors such as the mix of heartwood and sapwood.

Most U.S. hardwood processing happens in rural areas with the implication that terpene emissions are less likely to contribute to urban smog. Terpenes have a short atmospheric lifespan and the highest photo-oxidant concentrations are expected within five hours after the emission takes place, and within a distance of 50 km. The environmental impact of terpenes also varies widely depending on the local presence of other pollutants, notably nitrogen oxides. For the general public, the smell around wood-processing units is likely to be the most noticeable environmental effect. Nevertheless, the photo-oxidants created due to terpene emissions can cause forest and crop damage, and they are harmful to humans as they cause irritation in the respiratory tract and in sensitive

FIGURE 4: MATERIAL AND CARBON BALANCE: FINISHED DESIGN LEAVING THE FACTORY

	Quantity in product (1)			Sawdust & shavings (2)	Waste wood to		Carbon footprint			
	Hardwood	Other material	Total		Quantity	Energy generated	Emissions (4)	Biogenic carbon (5)	Process waste offset (6)	Total footprint (7)
	kg			kg	kg	MJ	Kg CO_2 eq			
Emi pods by Anne-Claire Petre	35.9	0.9	36.8	22.6	13.3	104.0	222.4	-55.4	-12.5	154.6
O.C.S. bench by Ben Percy	80.6	3.4	84.0	26.1	21.2	165.6	233.7	-122.2	-19.9	91.6
Stripped bench by Greg Natale	55.7	9.0	64.7	26.5	11.2	87.6	180.8	-85.1	-10.5	85.3
3 Don chairs by Adam Goodrum	14.1	2.0	16.1	11.5	7.5	58.6	127.3	-21.4	-7.0	98.8
3 J.A.C armchairs by Todd Hammond	22.4	0.7	23.1	24.7	8.3	64.8	146.3	-33.9	-7.8	104.6
Aleni bench by David Trubridge	63.9	1.1	65.0	24.5	48.7	380.0	123.8	-96.8	-22.8	4.1
All products	272.7	17.0	289.7	135.9	110.2	860.6	1034.3	-414.7	-80.5	539.1

1) Mass of finished design in kg and quantities of non-wood materials in various units as provided by Evostyle in Australia and David Trubridge in New Zealand. With the exception of the Stripped bench by Greg Natale which has a brass component of estimated 5.1 kg, non-wood materials are exclusively steel screws and other fixings, glues and coatings. Wood content is calculated as the difference between mass of finished design and the estimated mass of non-wood components. Dry mass of coatings and glues is estimated to be 60% of wet mass.
2) Due to lack of detailed data on follow-on usage and disposal, impacts of saw dust and shavings are not modelled and all impacts associated with production of these materials allocated to the Seed to Seat design. In the case of Evostyle in Australia, saw dust and shavings are not wasted but sent to commercial poultry farms to be used in bedding and then used again in gardening mix for plants.
3) It is assumed that waste recorded by Evostyle in Australia and larger offcuts identified by David Trubridge in New Zealand are incinerated for energy production.
4) Includes all emissions during extraction, processing, and transport of wood and non-wood materials to the factory gate and with manufacturing in Australia and New Zealand. Due to lack of detailed LCA data on non-wood materials sourced in Australia and New Zealand (including steel screws, glues, coatings, and brass), data is used for the closest surrogates available in the thinkstep GABI database and transport in each case is assumed to be 10000 km by ship and 1000 km by truck (sufficient to deliver products to the factory from China for example). The analysis excludes onward delivery of the products. Due to lack of data it also excludes the small volumes of sandpaper and polish used during finishing.
5) Carbon storage is calculated directly from the mass of the hardwood contained in the finished design and assumes that 46% of dry mass consists of carbon. This carbon will remain stored for the life-time of the design, an additional benefit of durability in hardwood products (alongside reduced need for replacement).
6) The offset due to production of energy from incineration of wood offcuts which replaces for use of fossil fuels.
7) Carbon footprint is calculated as the balance between emissions on the one hand, and the process waste offset and biogenic (stored) carbon on the other.

parts of the lungs. This finding highlights the need for more work to understand the specific impacts of terpene emissions within the context of US hardwood kilning facilities and the actions required to mitigate these impacts.

EUTROPHICATION POTENTIAL

The total eutrophication potential of all the Seed to Seat designs is 0.63 kg of phosphate equivalent – about the same as that caused each year by conventional farming of 300 square meters of land for wheat in the UK. So while not negligible, the eutrophication potential is not as significant an issue for the Seed to Seat designs as the acidification potential or POCP.
Perhaps surprisingly, hardly any of the eutrophication associated with the Seed to Seat designs is linked to the growth of U.S. hardwood. Fertilisers are very rarely needed to encourage growth of American hardwoods since they thrive under natural conditions. Instead, nearly all eutrophication potential of the Seed to Seat designs is due to nitrate emissions during burning of fuels for transport and processing of materials.

PRIMARY ENERGY DEMAND

12.86 GJ of non-renewable (fossil fuel) energy is required during all life cycle stages to finish the designs, mainly grid electricity in the U.S. and Australia and during the transport phases.
The 16.1 GJ input of renewable energy is due partly to the high proportion of thermal energy from burning of wood waste during hardwood kiln drying. At least 90% of all thermal energy used for kiln drying in the U.S. hardwood sector is derived from biomass.
The high proportion of renewable energy attributed to the forestry stage is a feature of life cycle inventory rules for wood designs and has nothing to do with the energy for forestry operations. It is the solar energy absorbed by the tree during growth and converted into chemical energy within the wood itself. In other words, it is the energy that would have been released if the wood were burnt immediately after harvest.

VALUE OF A LONG LIFE

This is not a cradle-to-grave assessment due to lack of data on product life and disposal. However, qualitative analysis suggests the Seed to Seat products are well designed for longevity - a tribute to the skills of the designers and manufacturers and to the beauty and durability of U.S. hardwoods. Long-lived wood products supplement the carbon store in the forest and help to keep CO_2 out of the atmosphere. The six designs together store the equivalent of 0.41 tonnes of CO_2.
At end of life, since 95% of the mass of the Seed to Seat designs comprise wood which can be readily separated from non-wood components, the waste material may be incinerated and thereby offset use of fossil fuels (if these are still widely used at that time). These designs will therefore go a long way to fulfilling the requirements for "extended producer responsibility" whereby the manufacturer takes responsibility for the entire life cycle of the product, especially the recycling and final disposal.


PHOTO CREDIT: TOM FERGUSON

STRIPPED BENCH BY GREG NATALE

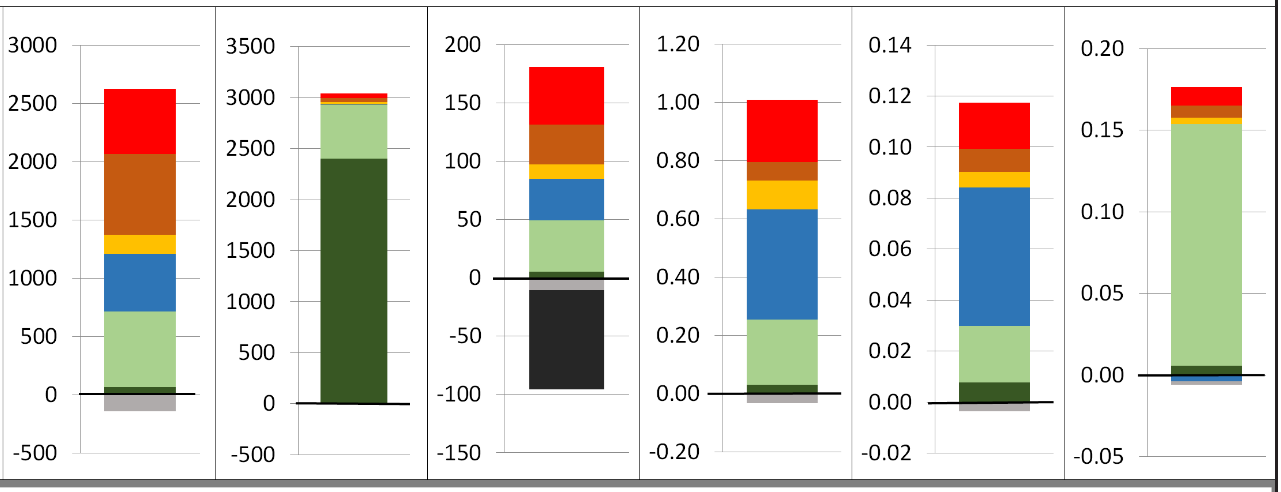
The environmental profile of the Stripped bench differs in some notable respects from the other Seed to Seat designs. Despite being one of the larger pieces, the bench has the second lowest carbon footprint – at 85 kg CO_2 equivalent, about the same as a 450 km drive and equal to the carbon emissions of the average Australian over a 40-hour period. Emissions of 181 kg CO_2 eq. are offset by 11 kg CO_2 eq. due to burning of wood offcuts at the factory in Australia (which substituted for fossil fuel) and 85 kg CO_2 eq. of carbon stored in the wood.
The electrical energy required to manufacture the bench in Australia is around half that required for the other Australian Seed to Seat designs – mainly because, unlike the other designs, the bench requires very little time on the CNC machine. This means that environmental impacts at other stages of the life cycle – such as hardwood processing and transport - are relatively more important.
The bench also utilises more non-wood materials than the other Seed to Seat designs, including a brass strip of five kilograms and a larger number of screw fixings. However, American hardwood is still very dominant and the major determinant of environmental profile.
86% of the mass of the bench comprises a mix of red oak and tulipwood, two of the most abundant American hardwood species. It takes less than one third of a second for forest growth to replace the hardwoods used to manufacture the bench.
Conversion efficiency is relatively high for a high-quality bespoke furniture design, with 60% of the lumber delivered to the Australian factory to fabricate the bench ending up in the finished design, 12% being utilised for energy generation, and 28% wastage as sawdust and shavings.

PHOTO CREDIT: TOM FERGUSON

CRADLE TO FACTORY GATE ENVIRONMENTAL IMPACT OF STRIPPED BENCH

Impact category	Primary energy demand (non-renewable)	Primary energy demand (renewable)	Global Warming Potential	Acidification Potential	Eutrophication Potential	Photochemical Ozone Creation Potential
Unit	MJ	MJ	kg CO2-Equiv.	kg SO2-Equiv.	kg Phosphate-Equiv.	kg Ethene-Equiv.
Total	2483	3033	85.29	0.97	0.11	0.17

Data by process steps



Key: Hardwood forestry, Hardwood processing, Hardwood transport, Metal fixings & strips, Glues & coatings, Manufacturing, Process waste, Biogenic carbon

Impact Category	Unit	Hardwood forestry	Hardwood processing	Hardwood transport	Metal fixings & strips	Glues & coatings	Manuf-acturing	Process waste	Biogenic carbon	Total
Primary energy demand (non-renewable)	GJ	69	645	496	163	690	560	-142	0	2483
Primary energy demand (renewable)	GJ	2400	526	6	24	38	44	-5	0	3033
Global Warming Potential	kg CO2-Equiv.	5.07	44.08	35.80	12.29	34.27	49.33	-10.50	-85.06	85.29
Acidification Potential	kg SO2-Equiv.	0.031	0.224	0.378	0.098	0.064	0.214	-0.033	0.000	0.974
Eutrophication Potential	kg Phosphate-Equiv.	0.008	0.022	0.054	0.006	0.009	0.018	-0.004	0.000	0.114
Photochemical Ozone Creation Potential	kg Ethene-Equiv.	0.006	0.148	-0.004	0.004	0.007	0.011	-0.002	0.000	0.171

J.A.C. ARMCHAIRS BY TODD HAMMOND

Use of American cherry in a simple elegant design contributes to a strong environmental profile. With forest volume of around 400 million cubic meters, cherry accounts for 3% of the U.S. hardwood resource. Every year, the volume of cherry in U.S. forests grows on average by 11.7 million cubic meters, of which only 4.3 million is harvested. This means the volume standing in U.S. hardwood forests expands by 7.4 million cubic meters every year. It takes around half a second for forest growth to replace the cherry used to manufacture the three armchairs.

Cherry has been out of fashion now for several years, reducing incentives for sustainable forest management in those areas where it predominates, notably the Allegheny Plateau of Pennsylvania, Ohio, Michigan, New York, and West Virginia.

The conversion efficiency of the armchairs is slightly lower than some of the other Seed to Seat designs – a consequence of the fine curved cherry wood elements introduced into the design. 40% of the lumber delivered to the Australian factory to fabricate the armchairs is incorporated into the finished design, 15% is utilised for energy generation, and 45% is waste sawdust and shavings.

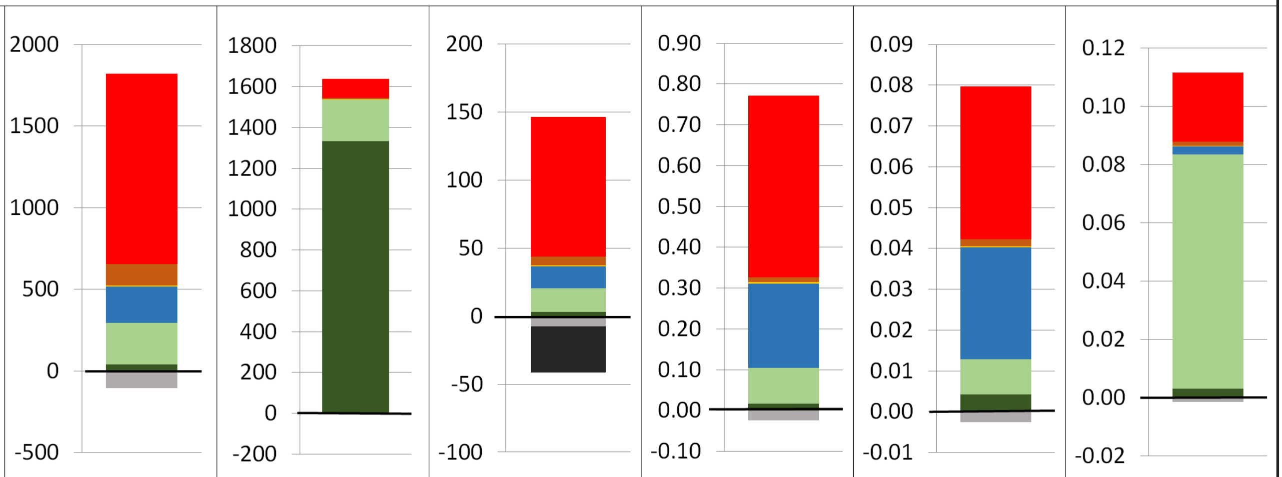
The design also requires fairly heavy use of electricity for machines, particularly the CNC machine, moulder and various saws, and a significant proportion of environmental impact is therefore attributed to the manufacturing stage in Australia.

Nevertheless, the carbon footprint is modest for such high quality bespoke furniture, at 105 kg CO_2 eq. for the three J.A.C armchairs manufactured for the Seed to Seat project, about the same as a 550 km drive and equal to the carbon emissions of the average Australian over a 2-day period. Emissions of 146 kg CO_2 eq are offset by 8 kg CO_2 due to burning of wood offcuts at the factory in Australia (which substituted for fossil fuel) and 34 kg CO_2 eq. of carbon stored in the wood of the finished design. A product with such timeless appeal should store carbon for many decades.

CRADLE TO FACTORY GATE ENVIRONMENTAL IMPACT OF THREE J.A.C ARMCHAIRS

Impact category	Primary energy demand (non-renewable)	Primary energy demand (renewable)	Global Warming Potential	Acidification Potential	Eutrophication Potential	Photochemical Ozone Creation Potential
Unit	MJ	MJ	kg CO2-Equiv.	kg SO2-Equiv.	kg Phosphate-Equiv.	kg Ethene-Equiv.
Total	1716	1634	104.64	0.75	0.08	0.11

Data by process steps



Key

- Hardwood forestry
- Hardwood processing
- Hardwood transport
- Steel fixings
- Glues & coatings
- Manufacturing
- Process waste
- Biogenic carbon

Impact Category	Unit	Hardwood forestry	Hardwood processing	Hardwood transport	Metal fixings & strips	Glues & coatings	Manuf-acturing	Process waste	Biogenic carbon	Total
Primary energy demand (non-renewable)	GJ	38	254	225	7	130	1167	-105	0	1716
Primary energy demand (renewable)	GJ	1332	203	3	1	7	92	-4	0	1634
Global Warming Potential	kg CO2-Equiv.	2.81	17.40	16.40	0.55	6.43	102.72	-7.78	-33.90	104.64
Acidification Potential	kg SO2-Equiv.	0.017	0.087	0.206	0.004	0.012	0.445	-0.025	0.000	0.747
Eutrophication Potential	kg Phosphate-Equiv.	0.004	0.009	0.027	0.000	0.002	0.037	-0.003	0.000	0.077
Photochemical Ozone Creation Potential	kg Ethene-Equiv.	0.003	0.080	0.003	0.000	0.001	0.024	-0.001	0.000	0.110

EMI PODS BY ANNE-CLAIRE PETRE

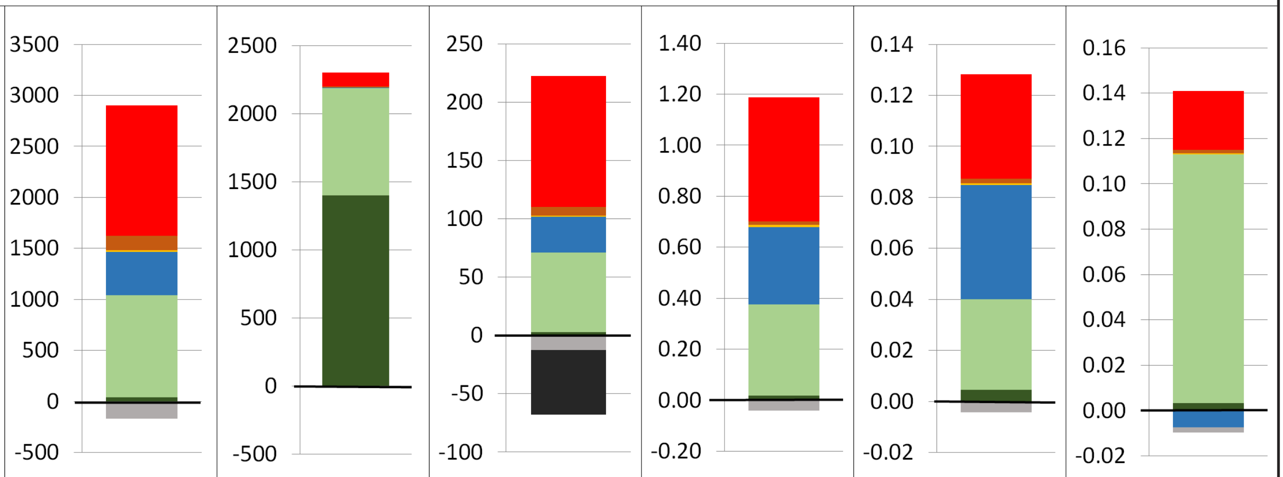
The Emi pods are made in red oak, the most abundant American hardwood with forest volume of around 2,500 million cubic meters, 18% of the total U.S. hardwood resource. Every year, the volume of red oak in U.S. forests grows on average by 55 million cubic meters, of which only 34 million is harvested. This means the volume standing in U.S. hardwood forests expands by 21 million cubic meters per year. It takes little more than one tenth of a second for forest growth to replace the red oak used to manufacture the pods.
The carbon footprint of the finished pods is 155 kg CO_2 equivalent, about the same as an 810 km drive and equal to the carbon emissions of the average Australian over a 3-day period. Emissions of 222 kg CO_2 eq. are offset by 12.5 kg CO_2 eq. due to burning of wood offcuts at the factory in Australia (which substituted for fossil fuel) and 55 kg CO_2 eq. of carbon stored in the wood.
Nearly half of total carbon emissions, and a large share of the acidification and eutrophication potential of the Emi pods, occurred during manufacturing in Australia and are almost entirely due to the long time required (over 8 hours) on a CNC machine powered by electricity from the national grid. This highlights that environmental impacts are heavily dependent on the energy source during manufacturing. Australia's national grid relies mainly on fossil fuels so any manufacturing requiring large inputs of electricity in the country tends to have a high environmental footprint – and major improvements in environmental performance may be achieved by manufacturers shifting to alternative renewable energy sources such as solar.
The LCA of the EMI pods also highlights that the environmental impacts of prototype or bespoke designs, which involve more trial and error, tend to be high relative to individual standardised items from a production line. If the pods were to be produced on a large scale, the manufacturer would invest in tooling to greatly reduce the time required on the CNC machine (perhaps to no more than a quarter of the time required on the prototype). This factor, combined with more efficient utilisation of the wood, could well reduce the carbon footprint by as much as 50%.

PHOTO CREDIT: TOM FERGUSON

CRADLE TO FACTORY GATE ENVIRONMENTAL IMPACT OF TWO EMI PODS

Impact category	Primary energy demand (non-renewable)	Primary energy demand (renewable)	Global Warming Potential	Acidification Potential	Eutrophication Potential	Photochemical Ozone Creation Potential
Unit	MJ	MJ	kg CO2-Equiv.	kg SO2-Equiv.	kg Phosphate-Equiv.	kg Ethene-Equiv.
Total	2734	2297	154.57	1.15	0.12	0.13

Data by process steps



Key: Hardwood forestry, Hardwood processing, Hardwood transport, Steel fixings, Glues & coatings, Manufacturing, Process waste, Biogenic carbon

Impact Category	Unit	Hardwood forestry	Hardwood processing	Hardwood transport	Metal fixings & strips	Glues & coatings	Manuf-acturing	Process waste	Biogenic carbon	Total
Primary energy demand (non-renewable)	GJ	40	999	426	16	145	1276	-168	0	2734
Primary energy demand (renewable)	GJ	1401	786	6	1	8	101	-6	0	2297
Global Warming Potential	kg CO2-Equiv.	2.96	68.08	30.64	1.25	7.19	112.33	-12.47	-55.41	154.57
Acidification Potential	kg SO2-Equiv.	0.018	0.358	0.302	0.010	0.013	0.487	-0.040	0.000	1.149
Eutrophication Potential	kg Phosphate-Equiv.	0.004	0.035	0.045	0.001	0.002	0.041	-0.004	0.000	0.124
Photochemical Ozone Creation Potential	kg Ethene-Equiv.	0.003	0.110	-0.007	0.001	0.002	0.026	-0.002	0.000	0.131

O.C.S. BENCH BY BEN PERCY

The O.C.S bench is made in tulipwood, one of the most abundant American hardwoods with forest volume of over 1000 million cubic meters, 7% of the total U.S. hardwood resource. Every year, the volume of tulipwood in U.S. forests grows on average by 32 million cubic meters, of which only 13 million is harvested. This means the volume standing in U.S. hardwood forests expands by 19 million cubic meters every year. It takes just over half a second for forest growth to replace the tulipwood used to manufacture the bench.

Tulipwood is under-utilised – in the sense that far more grows in the U.S. forest than can be used for commercial applications which undermines investment in sustainable forest management. The bench highlights that tulipwood is a beautiful, easily worked, and environmentally-friendly material with potential for use in a wide range of applications.

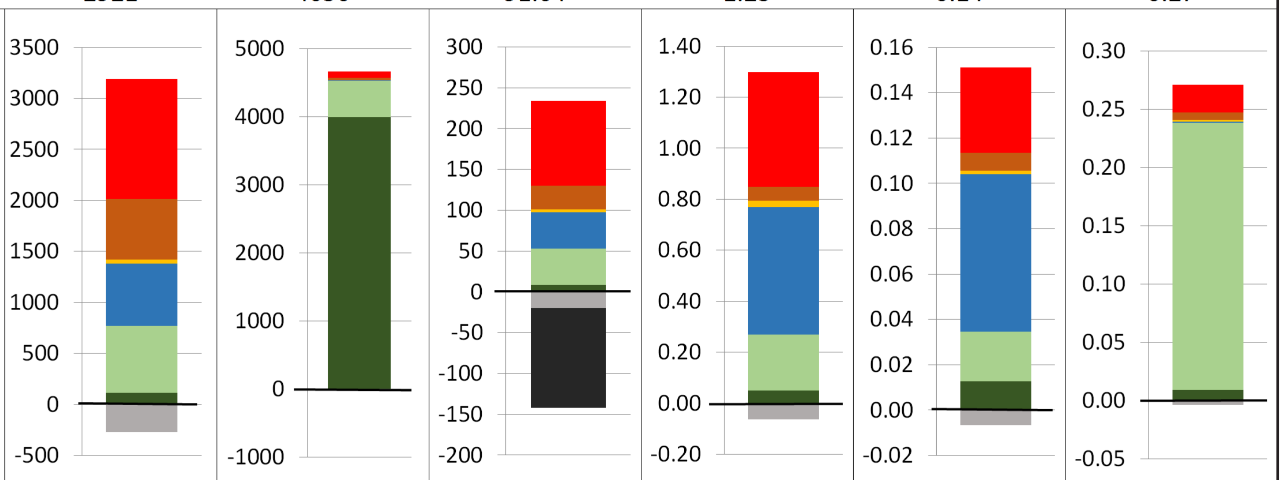
Although carbon emissions associated with manufacturing the O.C.S. bench are high relative to the other Seed to Seat designs, these are offset by the high wood content (and therefore carbon stored) in the finished design. Wood wastage was lower than for the other Seed to Seat designs with 63% of the lumber delivered ending up in the final design.

The carbon footprint of the O.C.S. bench is 92 kg CO_2 equivalent, about the same as a 480 km drive and equal to the carbon emissions of the average Australian over a 42-hour period. Emissions of 234 kg CO_2 eq. are offset by 20 kg CO_2 eq. due to burning of wood offcuts at the factory in Australia (which substituted for fossil fuel) and 122 kg CO_2 eq. of carbon stored in the wood of the finished design.

CRADLE TO FACTORY GATE ENVIRONMENTAL IMPACT OF O.C.S. BENCH

Impact category	Primary energy demand (non-renewable)	Primary energy demand (renewable)	Global Warming Potential	Acidification Potential	Eutrophication Potential	Photochemical Ozone Creation Potential
Unit	MJ	MJ	kg CO2-Equiv.	kg SO2-Equiv.	kg Phosphate-Equiv.	kg Ethene-Equiv.
Total	2921	4656	91.64	1.23	0.14	0.27

Data by process steps



Key: Hardwood forestry, Hardwood processing, Hardwood transport, Steel fixings, Glues & coatings, Manufacturing, Process waste, Biogenic carbon

Impact Category	Unit	Hardwood forestry	Hardwood processing	Hardwood transport	Metal fixings & strips	Glues & coatings	Manuf-acturing	Process waste	Biogenic carbon	Total
Primary energy demand (non-renewable)	GJ	114	653	612	41	591	1177	-268	0	2921
Primary energy demand (renewable)	GJ	3994	534	8	3	33	93	-10	0	4656
Global Warming Potential	kg CO2-Equiv.	8.43	44.69	44.28	3.29	29.38	103.61	-19.87	-122.16	91.64
Acidification Potential	kg SO2-Equiv.	0.051	0.220	0.498	0.026	0.054	0.449	-0.063	0.000	1.234
Eutrophication Potential	kg Phosphate-Equiv.	0.013	0.022	0.069	0.002	0.008	0.038	-0.007	0.000	0.144
Photochemical Ozone Creation Potential	kg Ethene-Equiv.	0.009	0.229	0.001	0.001	0.006	0.024	-0.004	0.000	0.267

DON CHAIRS BY ADAM GOODRUM

The wood content of the Don chairs is the major determinant of environmental impact. Very few non-wood materials are used and the relative simplicity of the designs allows the wood to speak for itself and avoids the need for elaborate processing and finishing.

The chairs are manufactured in cherry and tulipwood, both of which are widely available and under-utilised American hardwood species. It takes less than a quarter of a second for forest growth to replace the hardwoods used to manufacture the set of three Don chairs manufactured for the Seed to Seat project.

The carbon footprint is quite low, particularly for a prototype, at 99 kg CO_2 equivalent for the three chairs. That's about the same as a 520 km drive and equal to the carbon emissions of the average Australian over a 45-hour period. Emissions of 127 kg CO_2 eq. are offset by 7 kg CO_2 eq. due to burning of wood offcuts at the factory in Australia (which substituted for fossil fuel) and 21 kg CO_2 eq. of carbon stored in the wood of the finished design.

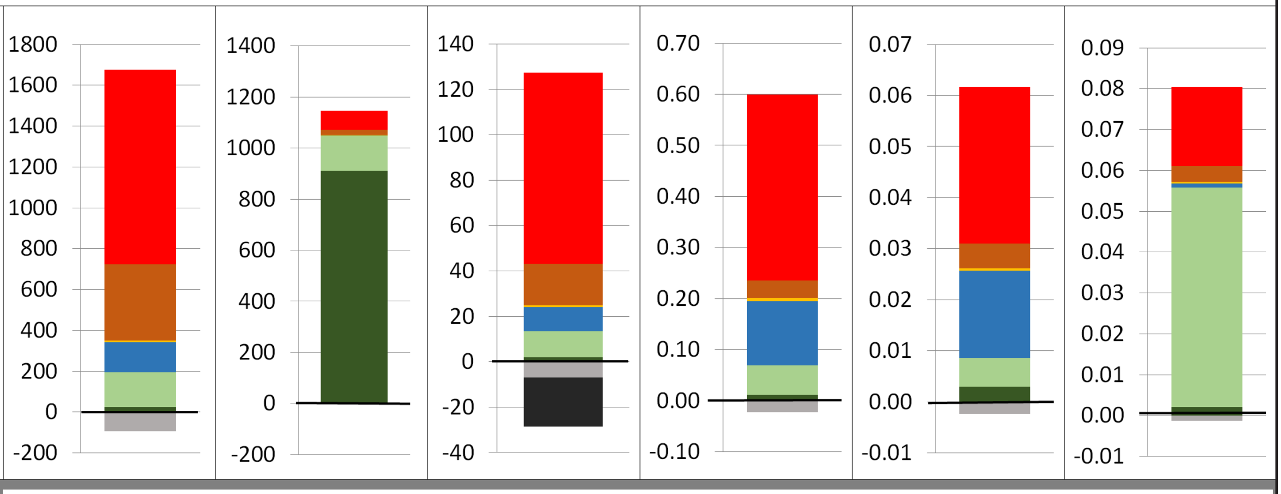
A large proportion of carbon emissions and other environmental impacts occur at the manufacturing stage in Australia, primarily due to nearly four hours spent on the CNC machine. Emissions during the manufacturing stage could be significantly reduced for mass-production through investment in product-specific tooling.

PHOTO CREDIT: TOM FERGUSON

CRADLE TO FACTORY GATE ENVIRONMENTAL IMPACT OF THREE DON CHAIRS

Impact category	Primary energy demand (non-renewable)	Primary energy demand (renewable)	Global Warming Potential	Acidification Potential	Eutrophication Potential	Photochemical Ozone Creation Potential
Unit	MJ	MJ	kg CO2-Equiv.	kg SO2-Equiv.	kg Phosphate-Equiv.	kg Ethene-Equiv.
Total	1582	1142	98.82	0.58	0.06	0.08

Data by process steps



Key: Hardwood forestry, Hardwood processing, Hardwood transport, Steel fixings, Glues & coatings, Manufacturing, Process waste, Biogenic carbon

Impact Category	Unit	Hardwood forestry	Hardwood processing	Hardwood transport	Metal fixings & strips	Glues & coatings	Manuf-acturing	Process waste	Biogenic carbon	Total
Primary energy demand (non-renewable)	GJ	26	169	146	10	372	954	-95	0	1582
Primary energy demand (renewable)	GJ	910	138	2	1	20	75	-4	0	1142
Global Warming Potential	kg CO2-Equiv.	1.92	11.53	10.61	0.78	18.42	84.01	-7.03	-21.42	98.82
Acidification Potential	kg SO2-Equiv.	0.012	0.057	0.126	0.006	0.035	0.364	-0.022	0.000	0.577
Eutrophication Potential	kg Phosphate-Equiv.	0.003	0.006	0.017	0.000	0.005	0.031	-0.002	0.000	0.059
Photochemical Ozone Creation Potential	kg Ethene-Equiv.	0.002	0.054	0.001	0.000	0.004	0.019	-0.001	0.000	0.079

ALENI BENCH BY DAVID TRUBRIDGE

PHOTO CREDIT:
DAVID TRUBRIDGE

The Aleni bench is manufactured in New Zealand using American ash, a species with forest volume of 670 million cubic meters, around 5% of the U.S. hardwood resource. Every year, the volume of ash in U.S. forests grows on average by 12 million cubic meters, of which only 6 million is harvested. This means the volume standing in U.S. hardwood forests expands by 6.0 million cubic meters every year. It takes little more than one second for forest growth to replace the ash used to manufacture the bench.

The ash is thermally modified, a process which while consuming relatively little energy, considerably enhances the durability of the hardwood. This combines with high quality design to ensure that the bench will remain in use for many years, providing a long-term carbon store and reducing the need for regular replacement – a particularly relevant issue for outdoor furniture which often has a short lifetime in use. Another benefit of thermal modification is that it avoids use of chemical preservatives and thereby facilitates disposal, either by incineration or in land-fill, at end of life.

The carbon footprint of the bench is extremely low, only 4.1 kg CO_2 equivalent, about the same as a 22 km drive and equal to the carbon emissions of the average Australian over a 2-hour period. Emissions of 123.8 kg CO_2 eq. are offset by 22.8 kg CO_2 eq. due to burning of wood offcuts at the factory in New Zealand (which substituted for fossil fuel) and 96.8 kg CO_2 eq. of carbon stored in the wood in the finished design.

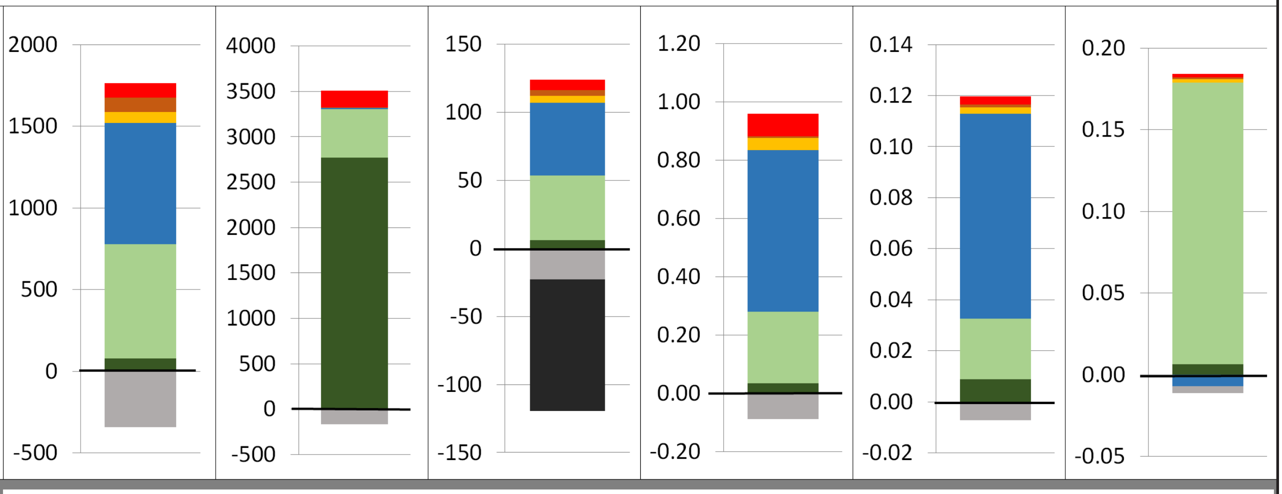
Relatively low carbon footprint and other environmental impacts compared to the other Seed to Seat designs is largely explained by much lower impacts during the manufacturing stage. Less time is required on energy-intensive equipment like the CNC machine. Use of electricity also tends to be less environmentally costly in New Zealand, where a large proportion is hydro power, than in Australia which depends more on fossil fuels. David Trubridge Ltd further reduces the impact by purchasing power through Meridian Energy which generates electricity from 100% renewable energy sources (hydro and wind).

The Aleni bench vividly illustrates how, if measures are taken to reduce environmental impacts during manufacturing, furniture products made in American hardwood can be close to, or even better than carbon neutral. This applies even when the American hardwood is shipped over a long distance, in this case from the Eastern United States to New Zealand.

CRADLE TO FACTORY GATE ENVIRONMENTAL IMPACT OF ALENI BENCH

Impact category	Primary energy demand (non-renewable)	Primary energy demand (renewable)	Global Warming Potential	Acidification Potential	Eutrophication Potential	Photochemical Ozone Creation Potential
Unit	MJ	MJ	kg CO2-Equiv.	kg SO2-Equiv.	kg Phosphate-Equiv.	kg Ethene-Equiv.
Total	1420.6	3342.8	4.148	0.9	0.11	0.17

Data by process steps



Key: Hardwood forestry, Hardwood processing, Hardwood transport, Steel fixings, Glues & coatings, Manufacturing, Process waste, Biogenic carbon

Impact Category	Unit	Hardwood forestry	Hardwood processing	Hardwood transport	Metal fixings & strips	Glues & coatings	Manuf-acturing	Process waste	Biogenic carbon	Total
Primary energy demand (non-renewable)	GJ	79	698	744	65	88	91	-344	0	1421
Primary energy demand (renewable)	GJ	2770	535	10	5	5	183	-166	0	3343
Global Warming Potential	kg CO2-Equiv.	5.85	47.50	53.58	5.13	4.39	7.34	-22.84	-96.80	4.15
Acidification Potential	kg SO2-Equiv.	0.035	0.245	0.554	0.040	0.008	0.076	-0.087	0.000	0.872
Eutrophication Potential	kg Phosphate-Equiv.	0.009	0.024	0.080	0.002	0.001	0.003	-0.007	0.000	0.113
Photochemical Ozone Creation Potential	kg Ethene-Equiv.	0.006	0.172	-0.007	0.002	0.001	0.002	-0.004	0.000	0.173

WHAT IS LCA?

Life-cycle environmental assessment (LCA) involves the collection and evaluation of quantitative data on all the inputs and outputs of material, energy and waste flows associated with a product over its entire life cycle so that the environmental impacts can be determined. LCA quantifies environmental effects against a range of impact categories. LCA may also provide qualitative assessment of other environmental impacts, such as on biodiversity and land-use, that are less easy to quantify.

WHAT IS INCLUDED IN THE LCA?

The LCA of the Seed to Seat designs covers all processes from extraction of wood and other raw materials, transport of these materials to processing location, all processing steps (notably sawing and kilning in the case of wood), transport of processed products to the factory in Australia or New Zealand, and manufacture of the finished design. Due to lack of information on durability, maintenance and disposal at end-of-life, the LCA is not a full "cradle-to-grave" assessment, and instead determines the environmental impact of the design when delivered to the customer.

WHO PREPARED THE LCA?

The LCA is commissioned by the American Hardwood Export Council (AHEC) and prepared by Rupert Oliver, Director of Forest Industries Intelligence Ltd, a U.K. based consultant with over 25 years experience of sustainability issues in the forest products sector.

HOW IS THE LCA CARRIED OUT?

The LCA draws on a two-year study, commissioned by AHEC and undertaken by PE International (now Thinkstep), to assess environmental impacts linked to delivery of U.S. hardwood into world markets[a]. This involved a wide-ranging independent assessment of hardwood forestry practices and a survey of the hundreds of U.S. companies engaged in the processing and export of hardwood products. Information from the LCA of U.S. hardwoods is combined with the latest U.S. government forest inventory data[b] and data gathered during manufacturing at Evostyle in Australia and by David Trubridge in New Zealand. It is also combined with Thinkstep's existing life-cycle inventory database which covers an expanding range of non-wood materials and products.

WHAT ASSUMPTIONS ARE MADE?

In any LCA there will be data gaps and various assumptions have to be made. The analysis errs on the side of caution and aims to over-estimate rather than to under-estimate environmental impact, for example:

- U.S. hardwood is assumed to be delivered to Australia and New Zealand by a particularly long and tortuous route: by truck from central harvest point to an East Coast port in the U.S., by container ship through the Suez Canal to Singapore, transfer to another ship for Australia and New Zealand, and then an additional 100 km to the factory gate.
- Other materials such as glues and coatings are assumed to be solvent based and sourced at least as far away as China.
- Wood waste from manufacturing in Australia and New Zealand is assumed to be burnt in a standard municipal waste incinerator with relatively low efficiency. In practice, much higher levels of energy output may be achieved in modern specialised biomass incinerators.
- Sulphur content of marine fuels is assumed to be 2.7% compared to estimated international average of 2.4%.

THESE ARE PROTOTYPES NOT PRODUCTION MODELS - HOW DOES THAT EFFECT THE LCA?

The environmental impacts of prototypes will be relatively high per unit of production. When producing at scale, manufacturers are able to adjust material procurement and production techniques to significantly increase efficiency and reduce waste.

The importance of this factor for the Seed to Seat designs is particularly evident from the large amount of time - and therefore relatively high energy input - required for CNC milling in Australia (over 8 hours in the case of one design). Under normal circumstances, the manufacturer would have tooling made for this specific design, reducing the time on the CNC machine to around a quarter of that required for the prototype.

a. The thinkstep *LCA study of U.S. sawn hardwood is available at http://www.americanhardwood.org/fileadmin/docs/sustainability/Final_LCA_Lumber_report.pdf*

b. Latest U.S. forest inventory data is drawn from the U.S. Forest Service Forest Inventory and Analysis (FIA) database at http://apps.fs.fed.us/fia/fido/index.html (last accessed in January 2016 and using 2014 data for most U.S. states)