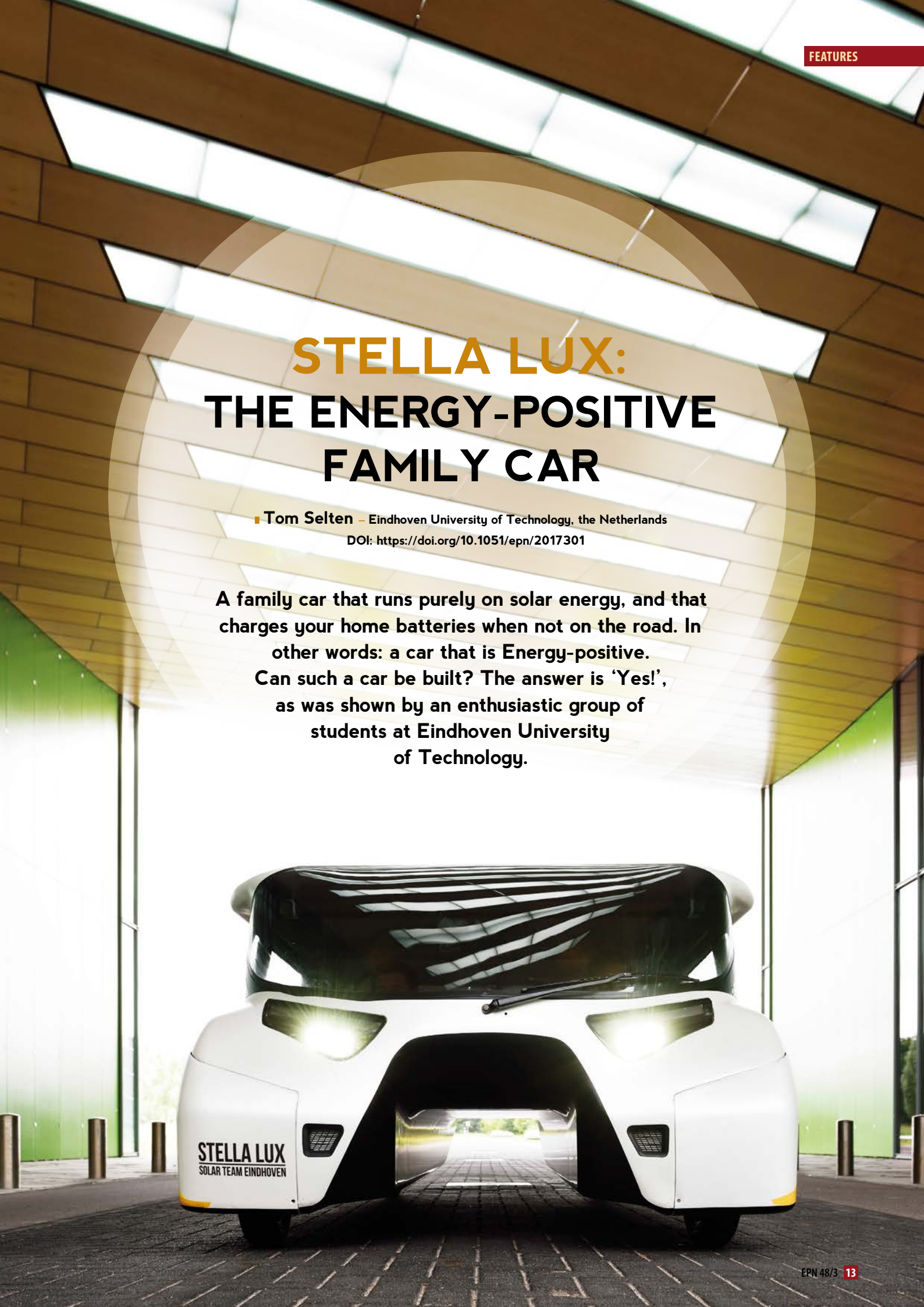
STELLA LUX: THE ENERGY-POSITIVE FAMILY CAR

Tom Selten – Eindhoven University of Technology, the Netherlands
DOI: https://doi.org/10.1051/epn/2017301

A family car that runs purely on solar energy, and that charges your home batteries when not on the road. In other words: a car that is Energy-positive. Can such a car be built? The answer is 'Yes!', as was shown by an enthusiastic group of students at Eindhoven University of Technology.



Imagine yourself driving an electric vehicle from your home to work. The morning sun is shining vaguely, and hundreds of cars are entering the highway. It's business as usual, and a traffic jam is beginning to form. You decide to evaluate your car's battery status while slowly progressing through the heavy traffic. Right now, you can see the battery is charging.

During the night the car has been standing in front of the house, and in the morning sun it has been wirelessly transferring energy to your house to meet your energy demand. At the same time, the car has been keeping track of your daily routines to make sure the batteries are sufficiently charged to drive wherever you want to go to.

The era of energy-independent vehicles has begun.

Why did they build this car?

Four years ago, a group of enthusiastic students decided to do something different. Normally you would expect a student to finish his or her studies by following the curriculum, especially in times where the Dutch government has decided to penalize students who take too long to graduate. But, something much more important has caused some students to rebel. They were triggered by a devastating fact: a recent study has shown that 4 billion people will reach the same level of prosperity as the people living in today's Western world. It seems like an impossible challenge to provide them with the high-quality individual transport which we enjoy today while still taking care of our lovely planet. Now, the trick is to let the car take care of its own energy needs. And that's what the students decided to devote 2 years of their lives to; against the status quo but with an unbelievable motivation.

"Stella Lux is the result of an optimized aerodynamic shape combined with the precision science of designing a highly efficient solar energy source."

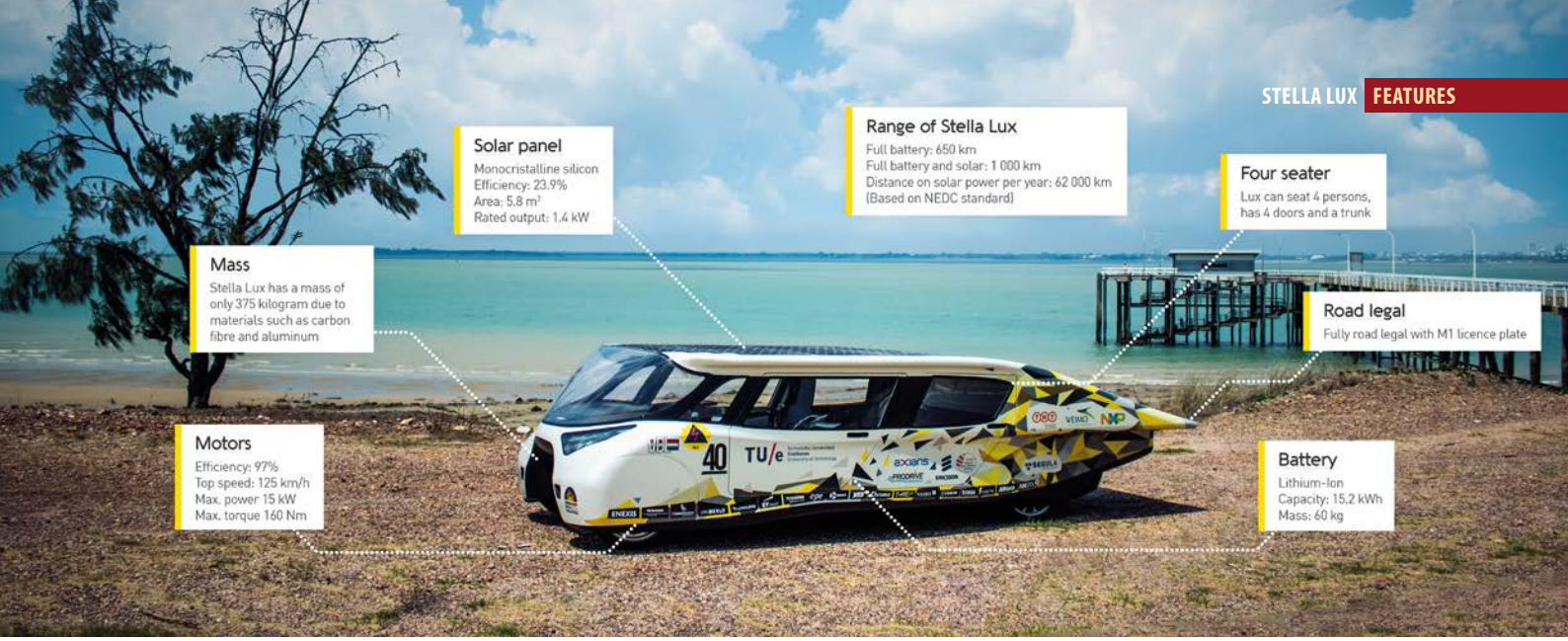
Current Situation

Today's cars rely on external resources, be it nature (oil, biogas) or space used by renewable sources elsewhere (solar panels, wind). When cars harvest the energy themselves, we unlock the freedom of mobility without feeling guilty about using it at the expense of others. With today's technology, it is possible to cut the line between the car and its energy source, and make it fully independent. Since it combines production, buffering, distribution and charging in one car, it is the most efficient family car in the world. A car that is always ready for a trip: an energy-independent vehicle. It can seat 4 persons and has a pretty large trunk for suitcases, so it is a true family car (see Fig. 1).

Designing an energy-efficient car

The principle of an energy-independent vehicle is very easy to understand. You minimize the energy consumed by the car while at the same time maximizing the energy yield. This is sometimes a trade-off which becomes self-evident when looking at Stella Lux. In order to increase the yield we extended the roof a little bit as can be seen in the pictures. By protruding the roof, two extra arrays of solar cells can be placed, which increases the energy yield (see Fig. 2).

The energy use at constant speed is completely determined by the resistance, in newtons, which the car has to overcome to maintain that speed; remember that 1 N = 1 J/m or, more conveniently, 1 kJ/km.



▲ **FIG. 2:** Stella Lux in Australia, where it became the winner in the Cruiser Class of the World Solar Challenge.

There are two types of resistance to be considered:

1) Air resistance or aerodynamic drag F_d. Since the flow profile around the car is turbulent, the aerodynamic drag is given by (*cf.* Bernoulli's law):

$$F_d = \tfrac{1}{2}\,\rho V^2 C_d\, A \qquad (1)$$

where ρ is the air density, V the speed, C_d the drag coefficient and A the frontal area.

2) Rolling resistance or mechanical drag. This is primarily caused by the tires and can be written as

$$F_r = C_r N_f \approx C_r\,[1 + V/Q]\, mg \qquad (2)$$

where C_r is the rolling resistance coefficient, N_f is the normal force, $Q \approx 161$ km/h is a practical parameter to account for the (small) speed dependence of the rolling resistance, m the mass and g the acceleration due to gravity.

Note that the power, given by $P = F*V$, is proportional to V^3 for the aerodynamic drag (eq. (1)). Since this is the dominant resistance at high speed, it is very important to design an aerodynamic shape by decreasing the frontal area and the drag coefficient if one wants the vehicle to reach high speeds. Obviously, this also serves to decrease the energy use.

So the first concern in the design is to have a small aerodynamic drag. Secondly, the mass of the vehicle should be minimized (see eq. (2)). In every design decision, the mass of the car should be considered. And finally, low-rolling-resistance tires are very important to minimize the mechanical drag.

Not surprisingly, these three aspects were of major concern during the design phase of Stella Lux. The car is optimized based on these three aspects.

◂ **FIG. 1:** The Stella Lux is a true family car: it can seat four people and has a trunk for luggage. It is licensed for driving on the public highway. Photos: TU Eindhoven, Bart van Overbeeke.

Materials: How did they build it?

The most crucial parts for Stella Lux to be an energy-independent vehicle are the solar roof, the batteries, the lightweight design and the use of very energy efficient motors and low-friction tires.

a) Solar roof

The solar cells are the most crucial component in powering the vehicle. A total of 381 monocrystalline silicon cells are combined to form a highly efficient (1.5 kW peak) solar array with a total surface of 5.84 square meters (see Factsheet).

Even when it is cloudy, the sunlight capture is maximized by using a non-reflective surface, made up of tiny prisms, which have been layered over the array. These prisms bend the diffracted light to ensure that it arrives perpendicular to the solar cells, increasing the solar yield under all conditions. The solar array has demonstrated a maximum efficiency up to 23.9%, which is very high in comparison with standard solar panels.

b) Battery

The *custom-designed battery pack* contains *1224 Lithium-Ion 3450 mAh battery cells*, giving a total storage capacity of 15.2 kWh. The battery pack stores the energy produced by Stella Lux' solar array. To keep Stella Lux suitable for driving at night, it is possible to charge from the grid as well.

The battery pack uses intelligent load balancing technologies to ensure extremely efficient conversion of the stored energy. The battery monitoring system continuously checks the state of charge.

With the combination of direct solar energy and the battery pack, the maximum daily range of the car is up to 1000 km in summer but varies with the time of the year (see Fig. 3).

c) Lightweight design

A carbon fibre monocoque was used to build the car body. These really thin fibres are woven together much like textile threads. They are very strong, stiff yet lightweight. The monocoque has been designed to carry most of the body weight. It has an integrated roll cage for increased safety, meeting all the stringent safety requirements. The total body-mass is *75 kg*.

A car's energy consumption is closely linked to its shape, so it is of key importance to minimize air resistance (*cf.* eq. (1)). Stella Lux is the result of an optimized aerodynamic shape combined with the precision science of designing a highly efficient solar energy source.

Special features of the shape include the converging tail at the base of the car – for optimum aerodynamics – and the protruded roof – to accommodate additional solar cells. A tunnel under the vehicle further reduces air resistance (see Fig. 1).

d) In-wheel motors and low-friction tires

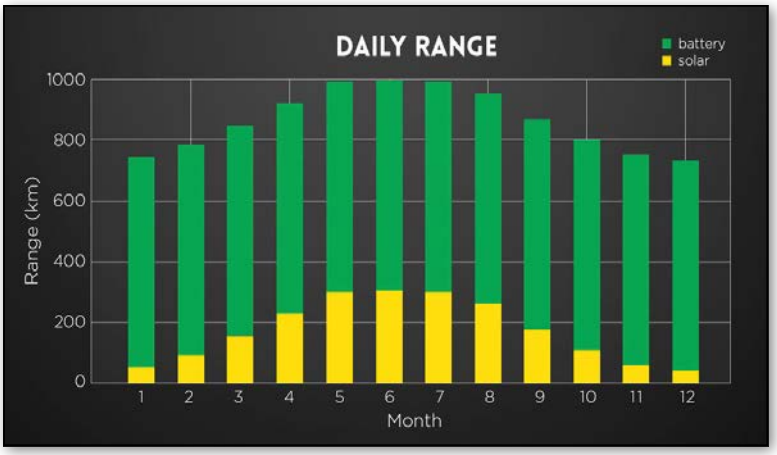
The *in-wheel motors* convert the supplied electrical energy into forward motion. Placing the motors directly in the wheels means that no transmission or gearbox is needed, resulting in an energy efficiency of 96%. The total powertrain – consisting of the battery and motor – has a measured efficiency of 92%.

In-wheel motors allow for *regenerative braking*. In conventional cars, the kinetic energy absorbed by the brakes is converted into waste heat. Instead, Stella Lux can capture a large part of this braking energy. By providing torque in the opposite direction, the motors become generators and recharge the batteries.

Stella Lux' special *low-friction* tires also contribute to minimizing energy consumption. The coefficient of rolling resistance for the tires on Stella Lux is around *4 times lower* than that of conventional tires.

Conclusion

The Stella Lux proves that an energy-positive family car offers a viable future scenario. One has to keep in mind that the performance of solar cells and batteries are bound to improve in the future. If costumers are willing to sacrifice some comfort and are satisfied with moderate speeds, sustainable personal transportation is within reach. ■



▲ FIG. 3: Maximum daily range of the Stella Lux car throughout the year in The Netherlands.

About the Author

Tom Selten is affiliated with the University of Technology Eindhoven. As a student Industrial Engineering, he decided to join Solar Team Eindhoven. Meanwhile, Tom Selten retired from his team and is currently a master student Innovation Management at the UT Eindhoven.

FACTSHEET STELLA LUX		
Seats	4	
Doors	5	
Length	4523	(mm)
Width	1756	(mm)
Height	1122	(mm)
Mass	375	(kg)
Battery capacity	15	(kWh)
Equivalent usage	390	(km/l)
Motor efficiency	97	(%)
Range sunny day in the Netherlands according to NEDC*	1000	(km)
Range sunny day in Australia according to NEDC*	1100	(km)
Range by night	plus/minus 650	(km)
Top speed	125	(km/h)
Amount of solar cells	381	cells
Type of solar cells	Monocrystalline Silicon	
Solar array	5,8	m^2
Number of battery cells	1224	cells
Type of battery cells	Lithium Ion	

* New European Driving Cycle