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"Mayi", Ultralight Personal Four-Wheel EV

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Summary

"Mayi" aims to bypass the limits to automobile traffic from limited road space and climate change. The solution requires a holistic approach, including our lifestyle and global political guidance. The paradigm change will disrupt the past evolution of the automobile and affect technology, society, politics and the economy. Three requirements form the basis for the vehicle concept: as light, as compact and as simple as possible. This includes lean logistics, local assembly and easy repair, which are needed for the transition to circular economy.

Keywords: light vehicles, city traffic, sustainability, maintenance, business model.

1 Prospective Overview

During the past century, the technology of the automobile developed and matured along an evolutionary trajectory. It started by the transition from the steam engine to the internal combustion engine, with the replacement of coal by oil. It was so successful, that the resulting exponential growth has reached its limits: from congestion and breakdown of road transport to exhaustion of material resources, but most important from climate change. The awareness of the limits to growth emerged half a century ago with the publication by the Club of Rome [1].

A successful transition from fossil fuel engines to electric drive requires a holistic (German: ganzheitlich) approach, which will include the transition to a sustainable lifestyle [2] by civil society, assisted by political guidance and global cooperation. From a holistic perspective, simply exchanging the power train of present cars is not sufficient. The solution must include all aspects of the transportation system [3]. Since half of the world population lives in cities, this will require the development of light and compact electric vehicles with 3 or 4 wheels, supplementing two-wheel EVs. The electric bicycle (Ebike) forms the benchmark for the weight, the dimension and the speed of such a new class of urban EVs. The electric drive is ideally suited for this revolutionary transition to ultralight vehicles, because their batteries are about a factor of 100 smaller than the batteries of electric cars [4]. The electricity for trains, trams and trolleybusses is supplied directly by wires.

1.1 Personal versus Shared Vehicles

Urban mobility is predominantly for commuting between home (A), work (B) and shopping (C). This includes always more or less walking. A personal Ebike or light EV is ideally suited for medium distances. When public transport is needed for larger distance, walking is needed at A and B. Here, a personal light EV is suited from A to public transport (Fig. 1), in contrast to a shared EV from public transport to B. This also allows shopping between public transport and A on the way home. However, it does not make sense the use of an EV to replace 5 minutes of walking or 10 minutes of cycling on flat roads. A personal compact EV with four wheels has more load capacity than two-wheel vehicles, so that it is better suited for shopping or bringing a child to school. These aspects show the importance of a holistic approach for overcoming the growing limits to personal urban mobility.

Fig. 1a Capacity for cargo

Fig. 1b Combined with vertical parking

Fig. 2 Mayi, the 10^{th} Prototype after 10'000 km

1.2 Disruptive versus Evolutionary Technology

Cargo-Ebikes are a typical example of evolutionary design, which became possible when the human powered bicycle was equipped with electric assistance, allowing to increase its weight and carry additional load. However, this eliminated the two unique advantages of the original bicycle: its light weight and compactness.

In contrast to the frame made of tubes for the load carrying structure of Ebikes, the unique design of Mayi shown in Fig. 2 uses a thin-walled aluminium box, filled with polystyrene foam, with a weight of only 3 kg. The absence of pedals allows to save weight and gain space for an additional seat and cargo. This ultralight EV is 1.2 m long, 0.85 m wide and weighs 24 kg with battery. The seat box is custom made from plates of expanded polypropylene (EPP) foam, which is vibration absorbing and has a density of 30 kg/m^3.

For comparison, cargo-Ebikes are longer and heavier than Ebikes. Such human-electric hybrids with cargo capacity are so heavy that often the relatively small contribution of human power cannot compensate the corresponding increase of weight. The resulting rebound effect is that they consume more electricity than a lighter version without pedals.

1.3 The Influence of Weight, Speed and Aerodynamic Drag

The weight of a bicycle is typically about 20 % of the person riding it, increasing to about 35 % for Ebikes. The rolling resistance is independent of speed, while the aerodynamic drag increases with the square of the speed. For bicycles, the two components become equal at a speed of about 20 km/h, so that above this the air drag becomes quickly larger. For cars, which are much heavier and have better aerodynamics, this occurs at about three times higher speed. As a consequence, the air drag of ultralight vehicles, compared to the rolling drag, becomes excessive already above about 25 km/h. This rapidly reduces the advantage of their low weight. As a consequence, a protective canopy for ultralight EVs requires a stronger power train already for low speed urban traffic. An example is the two-seat prototype with a helmet type canopy above the platform shown in Fig. 3 and described in [5]. This explains why bicycles have no fixed rain protection, so that cyclists wear rain clothes, but only when needed.

Fig. 3 Large initial prototype with helmet-type canopy

Fig. 4 Seating with right foot on roller brake

1.4 Safety in Comparison with Bicycle and Car

Four wheels provide better stability than two wheels, so that Mayi is inherently safer than Ebikes. In addition, the control of motor power by the pedal force of Ebikes can lead to risky situations. Several characteristics of Mayi increase the safety additionally: 1) The centre of gravity is lower than for bikes. 2) The legs extend forward to the footrest with roller brake (Fig. 4), which is an advantage in a collision compared to cycling. 3) The left hand is not needed for steering, so that the left arm is always free for giving signs, or even holding safely a transparent umbrella. 4) In a collision, the arms are available for protection, whereas when riding a bicycle, the hands remain on the handlebar. As a consequence, the cyclist is ejected, while the bike remains intact. The opposite occurs with Mayi, which absorbs collision energy while the driver remains seated with the legs pointing forward. With cars the situation is different in two respects: At high speeds, the arms and legs of the persons on board are much too weak for the collision force, requiring protection by airbags. In contrast, cyclists and the driver of Mayi are exposed to high risk on roads with cars, buses and trucks, which is an extremely unsocial asymmetry of safety.

2 Box-Sandwich Platform

The load carrying platform has an ultralight structure, which is found mostly in airplane wings. It carries the supports for attaching the four wheels at its corners and the seat box made from light EPP foam. This concept is more disruptive than the replacement of the automobile chassis by a self-supporting body, because it affects directly the ergonomics of the driver. The load is transferred from the seat to the thin aluminium walls of a closed box, reinforced from the inside to avoid buckling. In contrast to airplanes, the stiffening of the walls is obtained through a 100 mm thick sandwich core of polystyrene with a density of 15 kg/m^3 (Fig. 5), adhesively bonded to the aluminium. The wall thickness of the top layer is 0.5 mm and only 0.25 mm on the bottom. When standing on the platform, the aluminium skin deflects slightly, so that most of the load is transferred to the foam, compressing it elastically. This is similar to an airplane rolling on the concrete plate of a runway. The plate distributes the point load of each wheel over a larger surface.

The 100 mm high rear wall is formed by edging of the top layer, forming one piece, the front wall by edging of the bottom layer. This reduces the number of parts for the six surfaces of the box to four. And the two integral edges reduce the number of rivets, while increasing stiffness.

Fig. 5 Platform sandwich and side walls

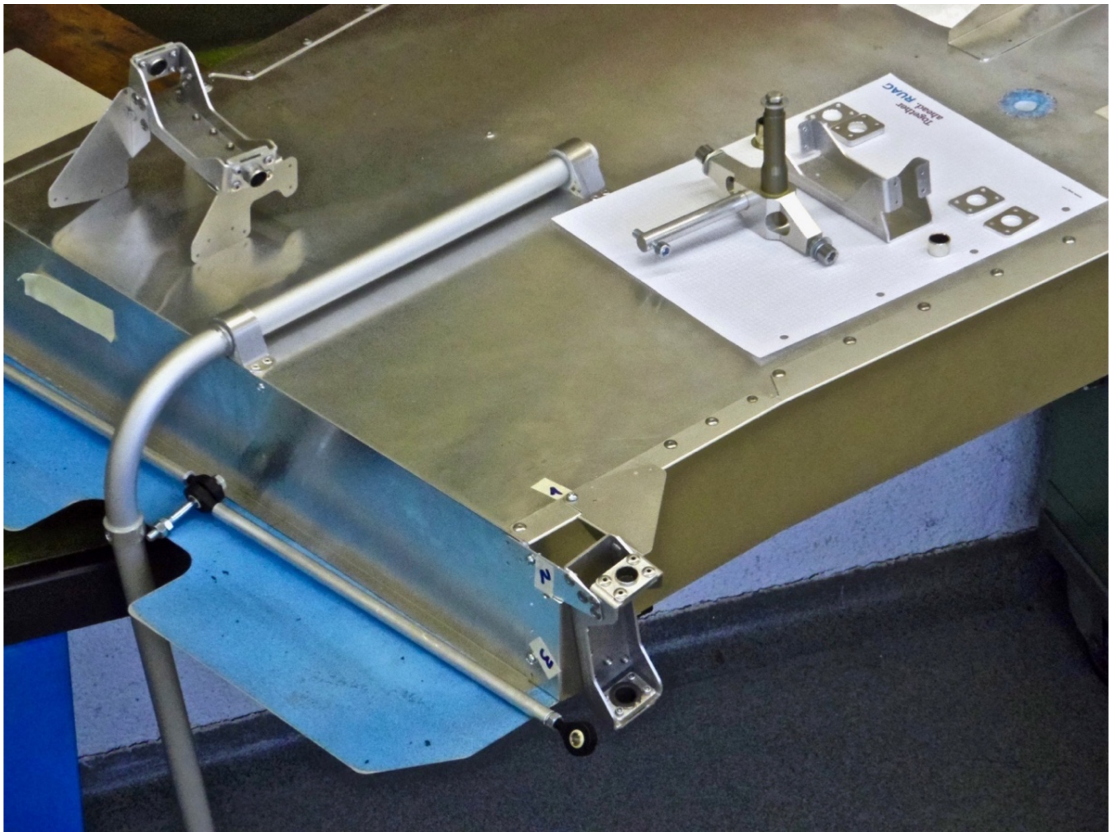
Fig. 6 Platform with attached supports

The two side walls with mirror image are formed by a 1 mm thick U-profile, which partly overlaps the top and bottom skins for the connection with blind rivets (Fig. 6). The side profiles act as longitudinal beams and allow to attach the supports of the wheel axles, also by riveting (Fig. 7). The supports for the joystick and the power train are riveted to the bottom sheet (Figs. 7a and 7c). The aluminium parts are laser cut, including the rivet holes in the upper layer, providing the template for drilling the holes in the layer below. The precise relative position of the two parts to be joined is initially fixed with sheet metal screws (Figs. 7), subsequently replaced by rivets.

Fig, 9 shows the final assembly, with the 20 mm diameter joystick tube, drive train and motor controller, which must be air cooled. The battery is inside the seat box. The details on different photos can differ from each other, since 12 prototypes were built during the course of 7 years.

3 Supports for Wheel Axles and Drive Train

When a bicycle collides with an obstacle, the cyclist falls but the bicycle suffers only minor damage. The opposite occurs with Mayi: the driver remains seated, pushing with the legs against the footrests, so that he is exposed to a smaller risk than the cyclist. The four-wheel vehicle however absorbs a much larger kinetic energy than the Ebike. Therefore, its structure includes deformable parts between the platform and the wheels, which absorb the a)



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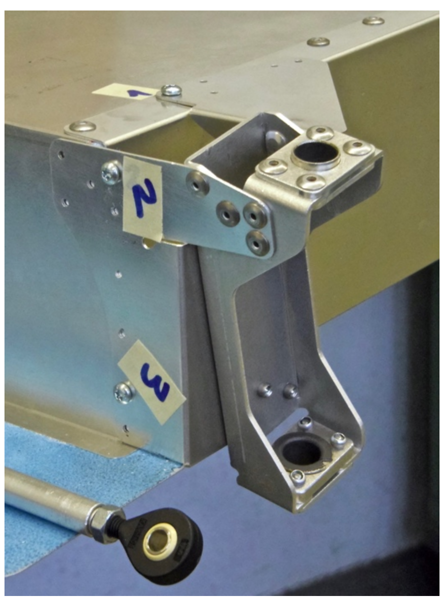

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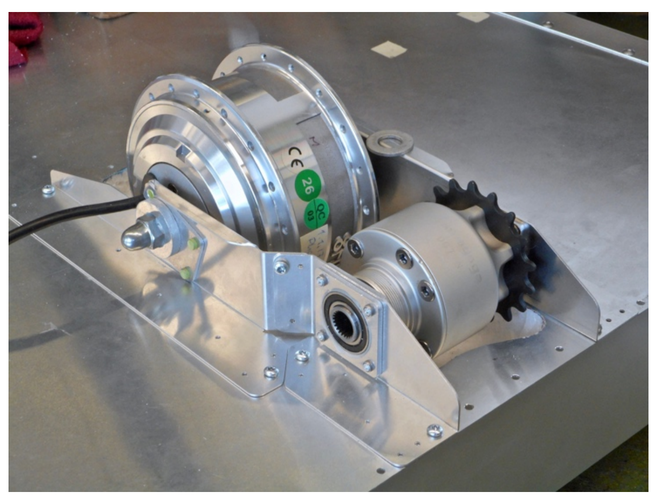

Fig. 7 Supports for: a) Joy stick assembly and king pin with front wheel axle; b) holder for king pin with riveting sequence; c) in-wheel motor from Ebike and differential.

collision energy by deforming. These parts should be easy to repair or replace. The solution for the front wheels can be seen in Figs. 7a and b. The U-shaped holder made from 2 mm thick sheet, carries the two bearings for the king pin in Fig. 7a (on the paper), carrying the axle for the wheel. The connection of the holder with the platform is provided by a 1 mm thick intermediate support marked with numbers 2 and 3 (Fig. 7b). It is designed as a deformable part for easy repair. Fig. 7 c) shows the support for the drive train, directly riveted to the platform. The non-rotating motor axle is fixed in a slot, for adjustment to the chain length. The differential cannot be removed. The photos in Fig. 7 where taken before riveting the connections and show the screws that fix the positions. The numbers 1 to 3 indicate the sequence for correct positioning of the parts, which is required for the steering geometry and the axle. Fig. 8 shows the plate that holds the rear wheel bearing and to which the disc brake is attached. The right and left disc brakes are symmetrical, with mirror images. The plate is made from three layers with identical shapes, connected by riveting. The mirror image of the right and left plates is obtained by inverting the three components before riveting them together. Collision protection is not necessary here, because the structure is stronger than in the front. In a collision from behind, caused by a similar vehicle, this one will deform first. The four bearings of the half axles are adhesively bondet into to the aluminium plates (Figs. 7c and 8), which is possible because the bearings are over-dimensioned for this ultralight application.

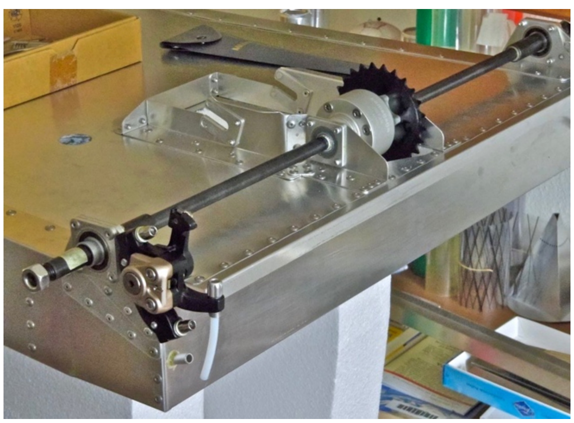

Fig. 8 Half-axles of rear wheels with differential

Fig. 9 Final assembly with drive train and controller

4 Steering, Braking and Power Train

The steering wheel of automobiles was needed to overcome the resistance from the large weight. Power steering has eliminated this need but the wheel has remained. In Airbus planes, an electronic “sidestick” replaces the control column. The force needed for steering the ultralight Mayi is so small that this allows to use a simple and light mechanical joystick, held by the right hand (Figs. 4 and 10). It is made from a 20 mm diameter aluminium tube with 1 mm thickness and has a horizontal axis under the platform (Figs. 6, 7a and 9). Its strength is more than sufficient for steering, but for safety allows easy deformation in a collision. Fig. 7a shows the thin push bars that connect the joystick with the lever extending forward from the king pin. The upper section of the joystick can swing vertically (Figs. 10 and 11), which allows to raise it over the driver’s knee in narrow curves. The handle is provided with a thumb throttle for controlling the motor speed. In the future the throttle will have a linear stroke and be ergonomically similar to a ballpoint pen.

Front brakes are not needed for the 20 km/h speed limit of the motor, which has two advantages: 1) The support for the front wheels can be simpler and lighter; 2) when the disk brakes block the rear wheels, the vehicle remains on a stable linear trajectory. Two independent brakes are required for safety, also because the freewheel of the motor does not allow regenerative braking. This is attained with two independent mechanical disk brakes, each with a separate cable to the foot brake, in tubes through the platform. The unique design of the foot brake (Figs. 11 and 12) consists of a plate with a rough surface, connected to a belt underneath, which goes half way around a roller and is fastened to the platform. This "rolling belt brake" serves also as foot rest, with the advantage of permanent braking readiness.

Fig. 10 Seat position, weight distribution and joystick steering

Figs 7c shows the electric motor with the differential and Fig. 9 their arrangement under the rear of the platform, together with the motor controller. It is a standard wheel hub motor for Ebikes, with planetary gear and freewheel, which saves energy but does not allow regenerative braking. The 250 W version has 24 V and the 350 W version 36 V. The LiFePo batteries have a capacity of 10 Ah in both cases, providing a range of 30 km with a top speed of 16 km/h and 40 km with 20 km/h respectively. The battery with a weight of 3 or 4.5 kg is located in the box under the seat and does not need a protective case. In future series production, a dedicated powertrain will integrate motor and differential. It will have regenerative braking and the option of two gears, for cruising on flat roads and climbing.

Because the Mayi concept is dedicated to a sustainable future lifestyle with no need of personal automobiles, its limited range is not a problem. For long-distance excursions, a small on-board charger can be plugged into standard sockets, available everywhere. One hour of charging extends the range by 10 km.

5 Design for decentralized Assembly and Repair

Today, mass production of cars and Ebikes includes final assembly, which requires intercontinental logistics and subsequent regional transport of the entire vehicles. During the past decades, the repair of damaged components and subassemblies shifted towards replacing them, causing waist and reducing the vehicle life. Assuring repairability must start at the stage of the initial mechanical design (German: Konstruktion), allowing simple assembly in local workshops (Fig. 13). The skills acquired during assembly are subsequently needed for repair.

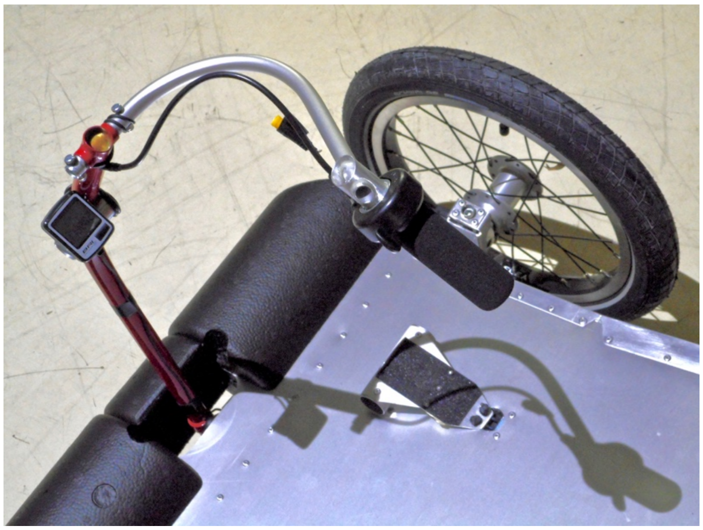

Fig. 11 Upper section of joystick with thumb throttle and height adjustment
Fig. 12 Foot brake with cables for the two mechanical disk brakes on the rear wheels, with a rolling belt

Fig. 13 Riveting instruction
Fig. 14 Permanent connection between half axle and hub of the rear wheel by adhesive bonding

For high volume mass production, laser cutting of the aluminium parts will be replaced by stamping. For the seat box made from EPP foam there are two alternatives: Industrial production with molding tools for a standard shape, or hand made from EPP plates with hot-wire cutting of the contour, assembled by adhesive bonding, for customized individual solutions.

Simplicity was a primary requirement, starting from the original design of Mayi, which evolved during a decade by building and testing a dozen prototypes. The underlying principle for simplicity is “More for less”. Fig. 14 shoes an example: The rear half axle is permanently connected to the wheel hub by adhesive bonding. This is possible with Mayi because the wheels remain fastened to the vehicle during repair or replacement of a tire (Fig. 15), which is a simpler operation than with a bike. High strength adhesive bonding is an industrial process, which is not suitable for local workshops. However, the entire wheel connected to its half axle complicates logistics. As a consequence, the entire wheel with its spokes must be assembled locally. This is possible with simple tools and easy to learn. The example shows that a transition from mass-production of complete vehicles to a more sustainable system with autonomous local assembly, separated from the industrial fabrication of components, requires a holistic (German: ganzheitlich) approach, starting with the design process.

An example for the repairability of the load carrying structure can be seen in Fig. 16. The added reinforcements are riveted on top of the parts damaged by a collision or by a local fatigue crack. In contrast, a cracked bicycle frame made from welded aluminium tubes is not repairable.

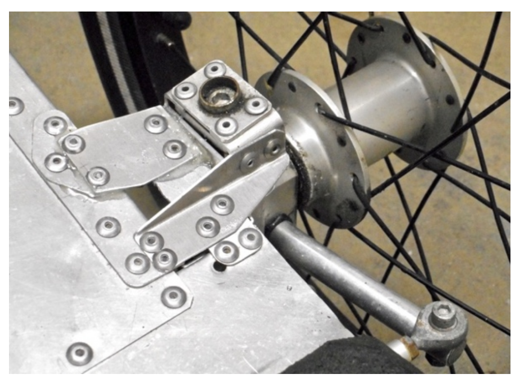

Fig. 15 Repair of a flat tire without removing the wheel
Fig. 16 Simple repair of damage caused by the collision of the left front wheel with an obstacle

Decentralized assembly and repairability require a fundamental rethinking of business models and working environment, away from the conveyor belt and towards individual workshops. This will affect almost everything. We have no choice, because of the increasing pressure and chaos caused by climate change, compounded with the problems of global outsourcing and logistics. These problems are interconnected and can only be overcome by a holistic approach, including the transition to a sustainable future lifestyle.

6 Conclusions and Outlook

The flat surface of the load-carrying platform offers the flexibility for different dedicated designs of the seat box made from expanded polypropylene (EPP) and for loading cargo (Fig. 10). This includes enough space for a child or even an adult passenger for short trips, who sits 15 cm further back for elbow freedom. Luggage or shopping bags are stored in a net suspended from a U-shaped light tube in the rear (Fig. 1a), which serves also as support for vertical parking (Fig. 1b). The two outstanding advantages, compared to Ebikes and cargo bikes, are the lightness and compactness of Mayi. In addition, the four wheels provide more safety than an Ebike, in combination with the legs extending forward.

The components of Mayi are manufactured by standard industrial processes, with one exception: The mass production process for adhesively bonding the aluminium walls to the sandwich core of polystyrene foam must first be developed. The precise shape of this core serves as the jig for positioning the thin walls. The application of adhesive and the subsequent merging of the parts will be automatic, with robots. For long distance transport to decentralized assembly points, the mass-produced raw platforms can easily be stacked on top of each other.

Mass production of the raw platforms will form the core of the future business model. Together with decentralized autonomous local assembly and repair, it is a major step towards circular economy. This will be a commercial disruption besides the technical disruption of the platform, including the joystick and the rolling ribbon brake.

Changing the Paradigm of Automobility

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The automobile represents the most important single factor shaping the lifestile of the majority of people in developed countries. Automobility is consciously or unconsciously immanent in everyday's life, even of people not using a car, because road traffic affects everybody. Therefore it is not surprising that a forceful paradigm has evolved, encompassing how we think, feel, use and are affected by the automobile. Automakers have actively helped to build up this paradigm. They have done this so effectively and in such depth, that they have become captives of their own success. As a consequence they now have great difficulties to rethink the automobile in view of the urgent environmental constraints and the resulting necessities. So far their reactions have been mostly defensive and the resulting solutions are far from sufficient.

The problem we face is: how can the process of rethinking the automobile both from the technical and the emotional side be activated and lead to the implementation of radically new concepts. The paper will analyse the obstacles inherent in the present paradigm of automobility and present ideas for actions to overcome them.

Fig. 17 Critical thinking from 1994

The major obstacle for market development is our current way of thinking (paradigm), which tends to imagine the future along the historical trajectory from the past. An abstract by the author [Fig 17] from 1994 tries to explain this dilemma for the personal automobile and road traffic. The origin of this paradigm goes back to the invention of the steam engine and the subsequent industrialisation, which was powered by coal. The resulting exponential growth, including the massive use of oil and natural gas, is the primary cause of climate chance. The warning from half a century ago by the Club of Rome, with the publication of "The Limits to Growth" [1], marked a window of opportunity for a historical turning point. Now we are too late and not capable to rapidly change our outdated way of thinking, which would be needed to change our life style.

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Walter Janach, born 1939, studied mechanical engineering at Swiss Federal Institute of Technology (ETH) in Zürich, with a doctorate in control engineering. After a decade of industrial research at Swedish multinational Atlas Copco, he became professor of technical thermodynamics and laboratory head of thermal machinery at Luzern University of Applied Sciences. Since his retirement, he is developing a game changing ultralight EV for future personal urban mobility, in collaboration with universities in Switzerland, China and Germany.