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International Energy Agency
Photovoltaic Power Systems Programme

Task 17 PV & Transport

PVPS

Challenges Associated With the Market Entry of Vehicle Integrated PV (VIPV)

2025

Report IEA-PVPS T17-6:2025

What is IEA PVPS TCP?

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The Technology Collaboration Programme (TCP) was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of 6.000 experts across government, academia, and industry dedicated to advancing common research and the application of specific energy technologies.

One of the IEA TCPs is the "Photovoltaic Power Systems Programme" (IEA TCP PVPS). It was established in 1993, and its mission is to "enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems." To achieve this, the Programme's participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct 'Tasks' that may be research projects or activity areas.

The 27 IEA PVPS participating countries are Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, India, Israel, Italy, Japan, Korea, Malaysia, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkiye, the United Kingdom and the United States of America. The European Commission, Solar Power Europe and the Solar Energy Research Institute of Singapore are also members.

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What is IEA PVPS Task 17?

The objective of Task 17 of the IEA Photovoltaic Power Systems Programme is to deploy PV in the transport sector, which will contribute to reducing CO_2 emissions of the sector and enhance PV market expansions. The results contribute to clarifying the potential of utilization of PV in transport and to propose on how to proceed toward realizing the concepts.

Task 17's scope includes PV-powered vehicles such as PLDVs (passenger light duty vehicles), LCVs (light commercial vehicles), HDVs (heavy duty vehicles) and other vehicles, as well as PV applications for electric systems and infrastructures, such as charging infrastructure with PV, battery and other power management systems.

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COVER PICTURE

SOLARSTRATOS experimental solar plane designed by solar pioneer Raphaël Domjan and his crew, constructed for a flight into the stratosphere in Payerne (Switzerland) at the "PV in Motion Conference" in 2024 (Photo: Muntwyler).

INTERNATIONAL ENERGY AGENCY

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Challenges associated with the market entry of Vehicle Integrated PV (VIPV)

IEA PVPS

Task 17

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Special Acknowledgements

We thank the solar pioneers contributing to the Tour de Sol Switzerland, to the World Solar Challenge in Australia and to Sunrayce (USA). They initiated the idea of power production with PV and clean transport. Most pioneers in the 1980ies were successful in a non-traditional way and paved the way for what we now increasingly see in the streets and on the roofs around the world. Engineers today discover many opportunities to make EVs lighter and more efficient. This will promote the VIPV vision, albeit the energy system is still not 100% renewable. VIPVs and niche market applications will be part of this transition.

LIST OF ABBREVIATIONS

a-ha	Norwegian pop band
BFH	Bern University of Applied Sciences
CCA	Comparative Customer Advantage
DOE	Departement of Energy (US)
EV	Electric Vehicles
EVS	Electric Vehicle Symposium
FAI	Féderation Aéronautique Internationale
GM	General Motors
ICE	Internal Combustion Engine
IEA	International Energy Agency
IR	International Rectifier (company)
MEV	Migros Electric Vehicle (Migros = Swiss retailer)
NASA	National Aeronautics and Space Administration
PV	Photovoltaics
PVPS	Photovoltaic Power Systems
kWh	Kilowatt hours (energy)
SFOE	Swiss Federal Office of Energy
SI	Schweizer Illustrierte (Swiss magazine)
SOFA	Solar Fahrrad (solar bike)
TdS	Tour de Sol
TCP HEV	Technical Collaboration Programme (TCP) “Hybrid-, Electric- and Fuel-Cell Vehicle” (HEV)
VIPV	Vehicle Integrated PV
Wp	Watt peak (PV power)
ZEV	Zero Emission Mandate

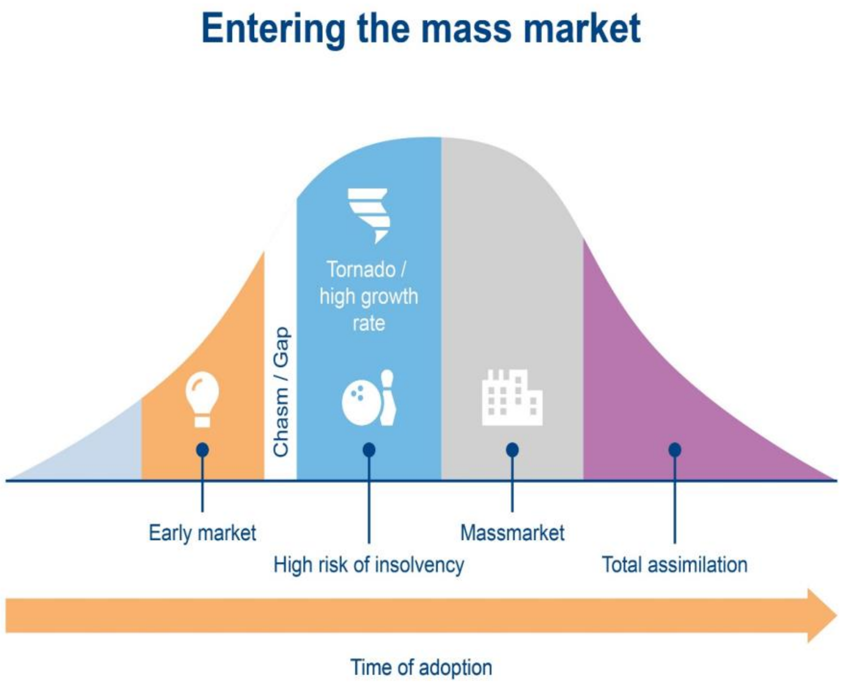
EXECUTIVE SUMMARY

Vehicle integrated photovoltaics (VIPV) or “solar cars” is a topic that has attracted engineers and pioneers for several decades. Their applications are manyfold - on cars, boats and even planes. All VIPV applications had their “ups and downs” over the last 50 years. In this time, we have seen a dramatic improvement in the efficiency of the solar cells and an even more dramatic fall of the price of PV. Not only is PV now one of the cheapest new sources of electricity. But the powerful Li-batteries totally changed the vehicle market. The electric car equally experienced its breakthrough during this time. Using "solar", users can now drive an EV charged by the PV installation on their house. VIPV has thus lost its unique selling proposition USP, and PV on the surface of cars, boats or planes has other advantages today.

The Swiss Tour de Sol in 1985, the first solar car race in the world, at EPFL (École Polytechnique Fédérale, Lausanne, Switzerland), in front of the LESO-PB research building. Solar cars or vehicle integrated PV (VIPV) has made big efforts since 1985 (Source: Prof. Dr. Scartazzini, former director of the LESO Laboratory at EPFL)

In this report, VIPV is nested into the developments past last 50 years. Background information on EVs and PV and on "solar cars" 30-40 years ago is provided, and reasons underlying their disappearance from the market are explored. Based on the “diffusion of innovation" and "crossing the chasm" concepts as published in the open literature, and our own marketing knowledge, we examine the governing factors needed to bring the combination of PV and EVs (VIPV) to the market. Both the above concepts and knowledge are applied to state-of-the-art examples of VIPVs and EVs. It is demonstrated that - while some new VIPV products have struggled in the context of market entry - some commercial vehicles like buses and especially trucks could be positioned in profitable niches.

VIPV is an innovation. The diffusion process of an innovation has well been investigated in the past. We can thus learn from these past insights. We can also integrate the lessons learned from the solar pioneers of the Tour de Sol Switzerland, the World Solar Challenge through Australia and the GM and DOE Sunrayces in the US in the 1980ies and 1990ies. The research results on innovation diffusion, own knowlege on marketing, and hands-on practical experiences of the early solar pioneers all merge to outline possible avenues forward in this report. Some serious problems of the past, like expensive solar cells and heavy batteries, are now solved. This offers new opportunities, but also poses new challenges. “Driving with solar” - the dream of the early solar car pioneers - can now be realised with a cheap, powerful PV installation and an electric car. But the heavy electric cars are still far away from the efficiency of the pioneering era in the 1980ies and 1990ies.



Entering the mass market by “crossing the chasm” (re-drawn based on Moore, 2002) is a tricky undertaking - especially when new technologies are combined, and in an emotional surrounding like the individual mobility

The combination of EVs and PV (e.g., a PV installation on the house or on solar carports) is yet another increasingly important development affecting the market entry of VIPV. However, the VIPV concept remains attractive for the PV technology, as it is a market for very high efficiency solar cells. This market can afford a surplus price for a very high efficiency, way beyond 30%. This will be the next part of the VIPV story and is not written yet.

Although the market entry process of VIPVs like the Sion of Sono Motors, the Lightyear 1 and the X-bus displays some similarities to market entry attempts of VIPV in the 1980ies and the 1990ies, VIPV still offers a high potential:

- Today, electric cars are too heavy and not very efficient - this offers room for a broad range of improvements.
- The powerful batteries trigger light and efficient electric vehicles.
- VIPV is a chance for the PV industry to bring high efficiency solar cells above 30% to the market.
- Bi-directional EVs and PV installations offer hugh possibilities for a decarbonized and cost-effective mobility.
- The combination of PV and EV is ready for the mass market. Owner of PV installations have a preference to use EVs. They feel they drive with “solar”.

1 INTRODUCTION

IEA PVPS Task 17 focuses on electric vehicles with integrated photovoltaics (PV), i.e., "vehicle integrated photovoltaics" (VIPV) for using the PV electricity in the car. The technical system is similar to an off-grid PV system[1] and is composed of:

- the PV generator, which produces the energy;
- the PV controller, which controls the charge and discharge of the battery;
- a battery, mainly lead acid or now mainly Li-battery technology.

VIPV was popular already in the 1980ies. Solar car races such as the Tour de Sol in Switzerland (starting in 1985, the first solar car race in the world), the "World Solar Challenge" in Australia (starting in 1987) and the "GM and DOE Sunrayces" in the US (starting in 1990) promoted vehicle integrated photovoltaics (VIPV), i.e., PV installations on vehicles, all around the world.

The organiser of the Tour de Sol races in Switzerland was Urs Muntwyler[2] who also acted as a steward in the first World Solar Challenge in 1987 (Australia) and in the DOE Sunrayce in 1993 (USA). In 1992, Urs Muntwyler became the leader of the Swiss Pilot- and Demonstration programme "Light-weight electric vehicles" of the Swiss Federal Office of Energy SFOE, and (in 1992) a founding member of the Technical Collaboration Programme (TCP) "Hybrid-, electric- and fuel-cell vehicle" (HEV) of the International Energy Agency (IEA). In this IEA TCP HEV, Urs Muntwyler served as the elected chair from 1998 to 2018.

"Solar cars for everyday use" - which was the title of the first technical conference (in 1986) of the Tour de Sol organization - were first seen in the streets in Switzerland and Germany. Their numbers were small, and the vehicles were mainly light-weight constructions below 600 kg for a two seater. The energy consumption was generally below 10 kWh/100 km. Vehicles with fibre glas construction went below 5 kWh/100 km. A PV panel of 200 Wp (10% efficiency) could produce sufficient energy for a 20-30 km trip.

Most solar cars constructed in the 1980ies and 1990ies never entered the market. One of the underlying factors was the heavy lead-acid battery that limited the range of the electric vehicles (EVs) back in these times. Today, i.e., 30-40 years later, the interest for VIPV gains new momentum both from society and given the many promising changes in technology. New technologies like the light Li-batteries and the cheap high efficient solar modules with over 20% efficiency allowed a dramatic step forward. Yet, success is not only an issue of technology, and market entry of VIPV remains a challenge.

By analysing past VIPV successes and failures on the market, this report (i) aims at illustrating which obstacles may hinder a possible market introduction of VIPVs, and (ii) seeks to outline potential avenues forward.

How innovations need to be designed and communicated to enter the first market has been investigated by Everett Rogers, published in 2003 ("Diffusion of Innovations"). The challenges associated with entering the mass market have been investigated by Geoffrey Moore, published in 2002 ("Crossing the Chasm"). Alongside these two concepts, the theory of Klaus Backhaus ("Competitive Customer Advantages", CCA, 1992) is applied in this report. The CCA help to identify customer benefits, i.e., what needs to be done to convince a customer to buy a product. Together with our own knowledge in marketing, the above concepts and theories will offer a toolbox to the reader to assess own VIPV projects with regard to successful market entry in the future.

2 UNDERLYING RATIONALE

The underlying rationale for the work in this project is the theory on the “diffusion of innovation” as described by Professor Dr. Everett M. Rogers in the book “Diffusion of Innovation”[3]. Our analyses on VIPV transition into the mass market are based on Geoffrey A. Moore and his book “Crossing the Chasm”[4]. As the customers are at the core of attention when selling a product (like VIPV), they need to be convinced that the product is worth buying. Factors governing the processes of a buying decision are nicely described by Prof. Dr. Klaus Backhaus in his book “Investitionsgütermarketing” [5] and in the written material on an “Industry- and investmentmarketing” module offered by the University of Bern, Switzerland where Prof. Dr. Backhaus was one of the teachers.

In Switzerland, the concepts by Rogers and Backhaus were successfully applied (in 1993) in a project on training courses called “Verkaufserfolg mit erneuerbaren Energien” (sales success with renewable energies), financed by the Swiss Ministry of Economics. The concepts were taught to hundreds of participants in follow-up training courses and were also applied in the company “Solarcenter Muntwyler AG”, the market leader in the private PV customer sector in Switzerland in 2010. Similarly was the “diffusion of innovation” concept by Rogers (1962) applied in the “Solarcenter Muntwyler AG” for the expansion of solar and PV installations in Switzerland in the 1990ies. This company was sold (in 2010), only months before the Swiss energy policy changed due to the Fukushima nuclear disaster in Japan, and after Urs Muntwyler became a Professor for Photovoltaics and renewable energies at Bern University of Applied Sciences BFH, and the leader of the PV research laboratory at BFH in Burgdorf, Switzerland. For more than 11 years, efforts on how to successfully use and apply renewable energy and especially PV and electric mobility, were pursued by Professor Urs Muntwyler and PD Dr. Eva Schüpbach in the University context. Many of the trained several hundred engineering students now work in the renewable energy sector, in PV and electric mobility. Some former students even carry on the success story of renewable energy in their own company. As an example, the small-to-medium-sized company on “PV - heat pump - EV infrastructure” of a former student (Helion Solar AG) today employs more than 500 people, a considerable business size in a small country like Switzerland. Together, these next generation engineers achieve the transition to a “100% renewable energy system” in Switzerland. The PV market in Switzerland is now 150 times bigger than in 2010. VIPVs is part of this success story.

3 DIFFUSION OF INNOVATION, MASS MARKET AND CUSTOMER SEGMENTS

Here, we describe aspects of innovation diffusion, mass market and customer segments that may open the doors to avenues leading to a possible introduction of VIPV to the mass market.

3.1 Diffusion of Innovation: Customer Segments and Target-Oriented Marketing

How an innovation enters the mass market has been of interest for a long time. The oldest and most famous study was carried out in the 1940ies at Iowa State University. The study followed the diffusion of a hybrid crop by the farmers in 1943[6]. Similar studies were conducted in the 1920ies and the 1930ies. Based on these studies Prof. Dr. Everett Rogers wrote the first edition of his book “Diffusion of Innovations” (Rogers, 1962). The book of Rogers (1962) has several editions, which always included new research results. The book describes that, if a product (or technology, like VIPV) doesn’t offer enough customer advantages, it will not enter the market segment it is aiming at. Even if the product (or technology) enters the specific market segment it may dissapear after the market entry, as other solutions offer more customer advantages. Social change is fundamental for every change process and hence, new technologies need time to enter the mass market. This is especially the case if the associated infrastructure needs to be prepared. High prices slow down the market introduction.

When the findings of Rogers (1962) are applied to VIPV, the obstacles listed below need to be overcome:

- Solar cells and PV modules with a certain flexibility are needed;
- solar cells with an acceptable low price level are needed;
- designers have to learn how to integrate the solar cells into their design concepts (-> architecture of the cars). This is not an easy task and can be compared with the challenge posed by the (much more simple) approach of building-integrated PV (BIPV) that architects struggle with;
- the car shouldn’t be parked inside a building, but outside most of the time (to attract sunlight);
- there must be a certain amount of sunlight (mid-European conditions and better);
- the electric consumption of the car shouldn’t be too high, otherwise the percentage of the energy produced by the solar cells will not be sufficiently relevant.

Rogers (1962) developed a graph illustrating the innovation diffusion over time (Figure 3.1-1). Customer groups are on the X-axis and the market share is on the Y-axis. Each customer group and its position in the market is shown. In the first market are the “innovators” (2,5 % market share) and the customer group “opinion leaders” (market share of 13,5 %). These are followed by the “early majority” and the “late majority”, each of which represent 34 % of the market share. Finally, there are the “laggards” (or “late adopters”) with about 16 % market share.

An analysis based on this graph offers us hints on the target audience[7] like, e.g., the education, income, or preferred location of living of the "innovators" and "opinion leaders". This graph hence demonstrates how target-oriented marketing works.

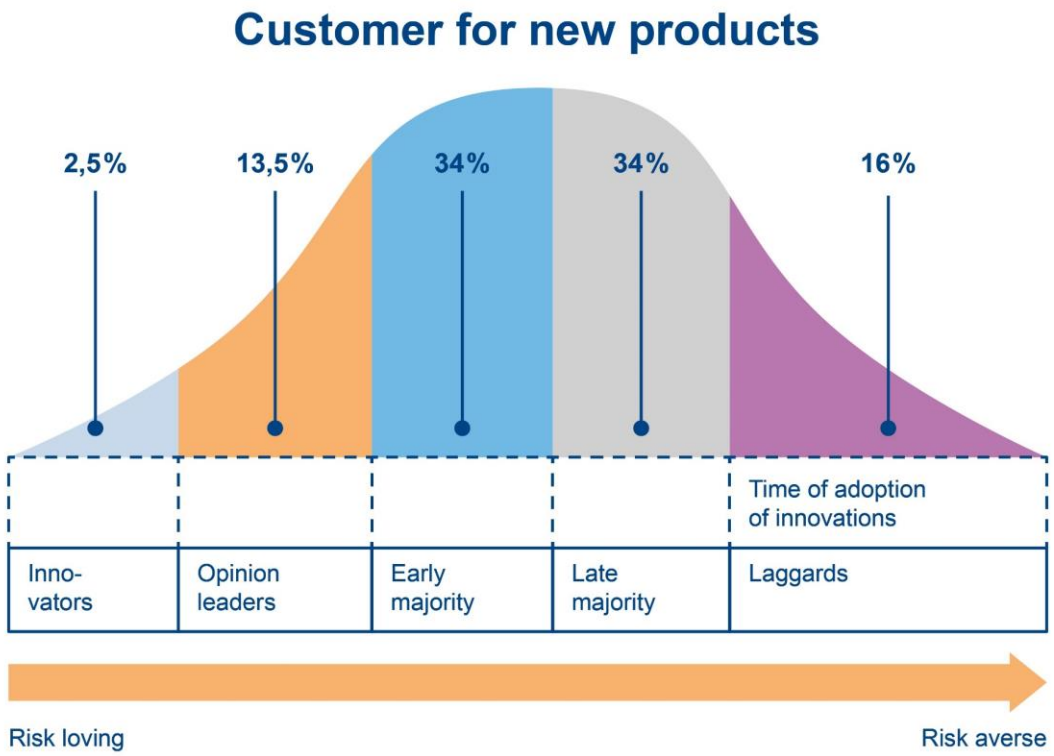


Fig. 3.1-1 Diffusion of innovation (re-drawn based on Rogers, 1962)

3.2 The Process of Accepting a Novelty[8]

If the innovation demonstrates clear characteristics of a "novelty", and if these characteristics are perceived as a novelty by potential customers, then the acceptance of the innovation is higher[9]. These characteristics can be used in the selling process, and clever marketing will reflect on how the product to be sold can be positioned in the context of the "novelty" aspect.

The characteristics of a novelty are:

- **Relative advantage:** The novelty must have a relative advantage (as will be discussed later in this report; see "Competitive Customer Advantage, CCA)"
- **Compatibility:** The innovation must be compatible with already existing values, experiences and the wishes of the customer
- **Complexity:** If the innovation is too difficult to understand and use, it's acceptance will decrease

- **Triability:** The new aspects of the novelty must be clearly visible, and prospective customers must be able to test them
- **Observability:** The novelty must be perceived by others as a “novelty”

3.3 Entering the Mass Market by Crossing the Chasm

Even when the customer groups “innovators” and “opinion leaders” perceive the novelty of a product, the novelty cannot stay for a long time, and the market segment “innovators” and “opinion leaders” hence have a short lifetime. This is especially a challenge if a company doesn’t earn enough money with these first two customer groups. The danger of running out of cash is serious when the ultimate goal is the mass market. The transition from the “innovators” and “opinion leaders” to the mass market is described by Geoffrey Moore (2022) in his book “Crossing the Chasm”[10].

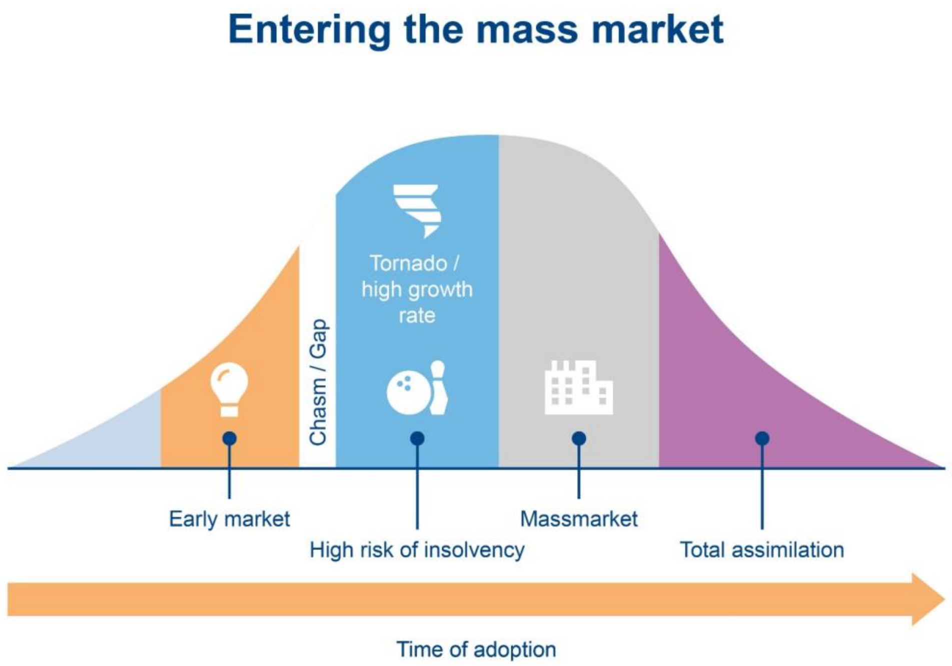


Fig. 3.2-1 From early market to the mass market (re-drawn based on Moore, 2002)

According to Moore (2002), most products fail (“bowling alley”) when attempting to enter the mass market, either because a lack of money, or because the product is too special (see, e.g., TWIKE, City-el or Sinclair C5 in Chapter 6).The key obstacles to “crossing the chasm” are hence (i) investments and (ii) efforts to satisfy the new customer group “early majority”.

3.4 Customer Benefit is Fundamental for Success or Failure

3.4.1 Marketing Tools for Companies: The 4 P's

Marketing draws on instruments with which prospective customers can be influenced. The 4 P's in marketing are[11]:

- **Product:** The product with all its features
- **Place:** The place where the product can be bought (physical or in the internet)
- **Price:** The price of the product for which the customer will be charged
- **Promotion:** How the customer can be influenced to buy the product

These marketing instruments also work for VIPVs, solar carports and electric vehicles and offer a company many possibilities to differentiate itself from other companies.

Now these are instruments for companies to sell their product. But what about the customers?

3.4.2 Customer 4 P's (plus 5th P)

The equivalent of 4 P's for the customers are[12]:

- **Profit:** The customer wants to get a "good deal". The purchase of a VIPV should be a bargain for the customer. This is tricky as a purchase depends on the initial investment, the costs for the energy, service costs, cost for taxes, insurance, etc.
- **Pride:** The product to be purchased is expected to make the customer happy (use, ownership of the product, etc.)
- **Pleasure:** The product and its use should give the customer some pleasure
- **Peace:** The use of the product should be trouble-free, no hassle, simple service, etc.

In the context of purchasing a VIPV by an "innovator" or an "opinion leader", we believe a 5th P is important in addition to the 4 P's. We call it "responsibility for the world of tomorrow"[13].

3.4.3 Convincing a Customer: The Competitive Customer Advantage (CCA)

Customers have to be convinced that the product, in our case a VIPV, is the "superior" choice; this perception of superiority also includes the company offering the VIPV. Customers are not convinced at the beginning of the buying process and seek to compare the VIPV with other solutions first (e.g., hybrid car, one of the electric cars with or without PV installation, e-bikes, etc.). The choices offered to a prospective customers by the competing products are not a simple issue for a VIPV sales person. There is much work associated towards establishing a purchase decision during which the customer still compares the VIPV with competing products. At this stage, no real disadvantage of the VIPV should emerge. If, as an example, the VIPV costs 100 000 USD, most of the prospective customers will leave the purchasing process, as the high price will be too strong a disadvantage. Rather, there should be 2-3 strong convincing advantages for the VIPV and no real disadvantage (such as the price). When this is the case, the "Competitive Customer Advantage" (CCA)[14] will be in favour of the "VIPV purchasing decision". As will be elaborated on VIPV buying decisions in Chapter 9, this is a difficult issue as the advantage of a VIPV, in most cases, is not so strong. However, things look differently when a niche market is considered, like e.g., a "car with an continuous power supply". But this is not the mass market of today. If the VIPV option, i.e., an EV with a PV coverage, were in the same price range as an EV, this could attract mass market EV buyers (which is not a reality today and difficult to achieve in practice).

Fig. 3.4-1 Competitive Customer Advantage, CCA (re-drawn based on Backhaus, 1992)

3.4.4 Finding Customers[15]

Before customers can be convinced, they need to be found and identified. The concept on the “diffusion of innovation” by Rogers (1962) in Figure 3.1-1 offers us some ideas on how customers in the “innovator” and “opinion leader” segment can be identified, namely by, e.g., analysing potential customers with regard to their habits, believe systems, buying power, etc.

4 SOLAR CARS, PLANES AND BOATS: A HISTORICAL PERSPECTIVE

4.1 IR Solar Car 1960

The first EV with solar cells was presented by the American semiconductor company International Rectifier IR in 1960. They retrofitted a 1912 Baker Electric car with a solar panel by Charles Escoffery from International Rectifier Corp. The panel cost 20 000 USD at this time, which today would be around 161 700 USD. With the panel and the lead-acid batteries, the Baker could run for three whole hours at a whopping 20 mph (32 kph). This showcase vehicle was too expensive and not very practical, but it brought the idea of "PV in transport" into the newspapers for the first time ever.

Impact on the diffusion of VIPVs: Strange curiosity -> small impact on "innovators".

Fig. 4.1-1 International Rectifier IR solar car 1960 (Source: SI / TdS 1985)

4.2 Solar Car Pioneer Alan T. Freeman (UK) - 1977-1983

In the 1970ies and the 1980ies, the UK inventor Alan T. Freeman built several solar cars and boats. The model in Figure 4.2-1 had 585 Wp and a 24 V battery with 35 Ah. The range was 50 miles at 15 mph. Alan T. Freeman described his activities in a brochure "Solar Energy for motive power" in 1983[16]. Freeman was the first person who used solar-powered vehicles and boats for mobile applications. Freemans brochure was an inspiration for the Tour de Sol racing rules in 1984 (see Section 5.2.).

Impact on the diffusion of VIPVs: Technical curiosity - some impact on "innovators".

Fig. 4.2-1 One of the solar cars of Alan T. Freeman (Source: Wikipedia)

4.3 Swiss Radio Pioneer Matthias Lauterburg 1982

In 1982, the radio pioneer Matthias Lauterburg started a private radio station in the capital of Switzerland (Bern). Matthias Lauterburg drove a Zele Zagato EV with 4 solar panels from Arco Solar. He parked this small car in the public streets of Bern and was always eager for the PV modules to face the sun. The solar panels Arco Solar 16-2000 (33 Wp), the most popular PV panel of that time, cost about 1 200 EUR each. Lauterburg was the first Swiss in a solar car and probably one of the first in the world.

Impact on the diffusion of VIPVs: Interesting curiosity - impact on "innovators" and "opinion leaders" interested in solar energy - the car helped to promote the Tour de Sol in Switzerland.

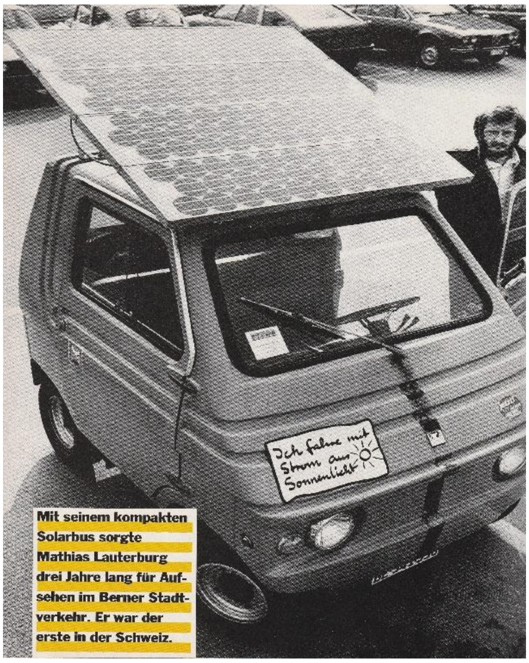


Fig. 4.3-1 Swiss radio pioneer Matthias Lauterburg with his solar car in the streets of Bern 1982 (Source: SI / TdS 1985)

4.4 Solar Bikes SOFA I-III

The Swiss engineer Gernot Schneider tried to use solar energy to drive on the hilly streets of his region in Switzerland. In 1983, he developed a first “Solar-Fahrrad SOFA I” (Solarbike 1). Together with colleagues, he developed further models, including the 3-wheeler SOFA 3. SOFA 3 was produced by a cooperative, in small numbers, which started to sell it around 1985 and thus, it was the first VIPV on the market. SOFA 3 was a racing member on the Swiss Tour de Sol in 1985. One of the engineers involved in the development of SOFA was Josef Brusa who started his own company Brusa AG for drive trains of EVs. In the 1980ies, the drive trains and charging systems were the backbone of many EVs up to today’s Porsche Taycan. Brusa AG now is a leading international group of companies in electric drive trains and similar fields.

Impact on the diffusion of VIPVs: SOFA3 attracted even opinion leaders - the SOFA3 was used to promote the Tour de Sol - Brusa products paved the way for the EV in the mass market.

Fig. 4.4-1 Swiss engineer Gernot Schneider on the SOFA 1 (Source: SI / TdS 1985)

4.5 Model Airplanes and Solar Powered Planes

The first electric flight was on 21 October 1973 in a HB 3 called MB-E1 constructed by Fred Militky. The short flight quickly was forgotten by the public, and the used Varta NiCd-batteries were heavy and weak. But Militky produced airplane models for the company "Graupner" who built a solar powered kit, which was sold to the public. These models solved the problem of the expensive, weak and heavy batteries with the power production of the also expensive but relative light solar cells. Electric drive trains and the flavour of direct solar powered planes raised interest in the model community. Books on solar planes helped to understand the technical aspects.

The first PV powered airplane model was Solaris I/ II founded by DARPA (US) and built by Astro Flight. Solaris I had nearly 10 m span, 12 kg weight and 450 Wp solar cells. The first flight was in 1974. Solaris II was an improved model with 570 Wp.

Fig. 4.5-1 Solar models (Source: Internet)

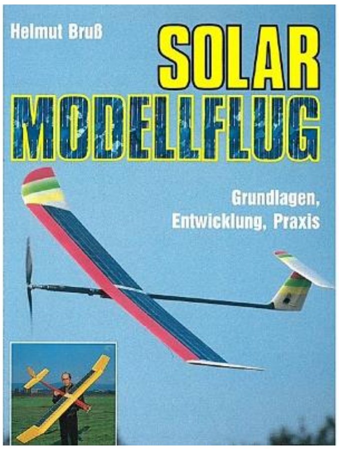


Fig. 4.5-2 Popular book on solar powered models in the 1980ies (Source: Muntwyler)

It is interesting to note what happened with the solar powered models; they nearly disappeared, the underlying reason being the light and powerful Li-batteries. These batteries can endure huge discharge rates of C_{50} (50 A from a 1 Ah battery) and more. This allows massive applications from models of all types up to small and big drones. This is an interesting illustration and the first example how a solar powered applications disappeared as soon as another technology offered a better and cheaper solution. This process can easily be explained by the concept of the Competitive Customer Advantage CCA. The recharge of the batteries can be done by the grid or "power boxes". Sometimes, the aeromodellers have several batteries ready that can be recharged at home.

Impact on the diffusion of VIPVs: Raised the interest of "innovators" and "opinion leaders", but disappeared when the cheaper and more powerful Li-batteries entered the market.

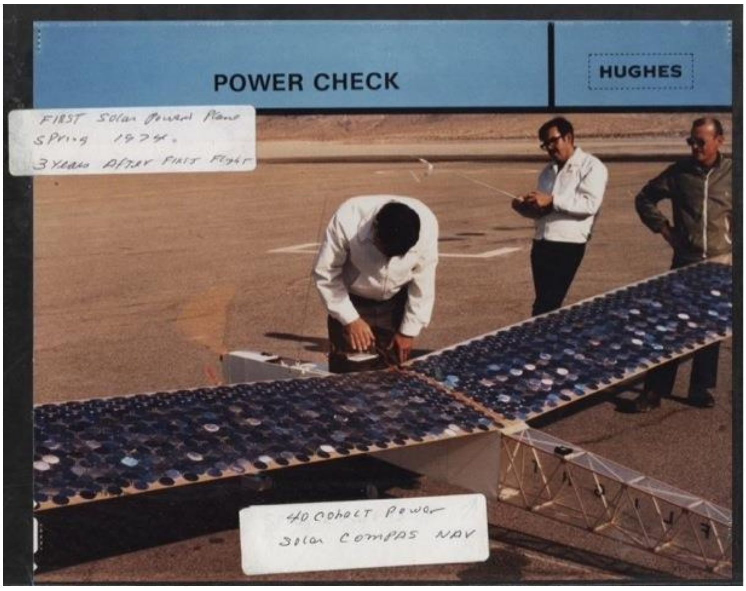


Fig. 4.5-3 Solaris prepared for flight - some companies such as Hughes later participated in the first World Solar Challenge race in 1987 (Source: Hughes)

4.6 Solar Powered Planes from Paul McCready (Aeronvironment/ USA)

The aeronautical engineer and glider world champion in 1956, Paul McCready, built human powered planes. He also built several PV powered planes. The first PV powered plane was the Gossamer Penguin, a transformed human powered plane. The more advanced "Solar Challenger" crossed the Channel between Paris and London in 1979.

Impact on the diffusion of VIPVs: The crossing of the Channel with the Solar Challenger in 1979 created a huge media impact. "Solar" was seen as a new promising technology. It got a flower of the airplane pioneers in the first decades of the last century. This attracted "innovators" and "opinion leaders" and even created attention among the "early majority".

Fig. 4.6-1 Gossamer Penguin (Source: Aeronvironment)

Fig. 4.6-2 Solar Challenger 1979 (Source: Aeronvironment)

Later, McCready's company Aeronvironment built big long-distance and high-altitude solar wings for NASA like, for example, the «Helios» with 75,3 m span (below). Helios reached 30 km altitude in 2003.

Impact on the diffusion of VIPVs: Hugh media impact due to the size of the plane. Strenghtened the image of "solar" as a new, promising technology - pushed the image of solar technology to the "early majority".

Fig. 4.6-3 The huge "Helios" solar plane of NASA (Source: Aeronvironment)

The PV-powered air planes disappeared when the powerful Li-batteries entered the market. One of the few exeptions is the "SOLARSTRATOS" solarplane from Raphaël Domjan (Switzerland) and his team. This experimental solar plane aimed at reaching the stratosphere (see cover).

5 SOLAR CAR RACES

5.1 First pioneers crossing Australia and the USA with solar cars

Solar cars mainly runing on solar energy collected on the car surface have already become popular in the 1980ies with solar pioneers in the US, the UK, Continental Europe, and in Australia. The two adventurers Hans Tholstrup and Larry Perkins crossed Australia in 1983 from the west to the east (i.e., from Perth to Sydney) in the so-called “Quiet Achiever”, a solar-driven car. They needed 20 days for the distance of 4’130 km. Their solar car had a PV surface of 8 m^2. The solar cells had an efficiency of about 8% and 500-640 Wp. The batteries had 24 VDC/ 80 Ah. The vehicle had 4 wheels and a weight of only 125 kg[17]. The solar car trip was succesful and got massive media coverage worldwide.

The first crossing of the USA started on 16 July 1984 in San Diego. The solar car had a weight of 280 kg and 640 Wp solar cells from Solarex. The size of the car was 1,8x6,6 m, the motor had a power of 0,5 PS[18].

Impact on the diffusion of VIPVs: Spectacular novelty - high coverage in the mass media - impact on “innovators” (young entrepreneurs and technicians).

Fig. 5.1-1 “Quiet achiever” on the trip from Perth to Sydney in 1982 (Source: BP)

5.2 Tour de Sol 1985 solar car race in Switzerland

In autumn 1984, three engineers from the local branch of the Swiss Solar Association of the states Bern / Solothurn / Fribourg (BEFRISO) decided to organise a solar car race through Switzerland as a PR tour for the use of solar energy. Subsequently, PV engineer Urs Muntwyler quit his job in the end of 1984 to organize the first race conducted in 1985. The technical rules were developed alongside the sport code of the Fédération Aéronautique Internationale FAI for Aeromodels.

The race had two categories:

- Racing cars with a maximum surface of 6 m^2 and a solar generator of 120 Wp - 480 Wp. The battery could be 10 h x of the solar power, therefore, a maximum of 4’800 Wh with C_{10} discharge.
- Racing cars with additional human driven propulsion, mainly pedals; same conditions for the solar generator and the battery.

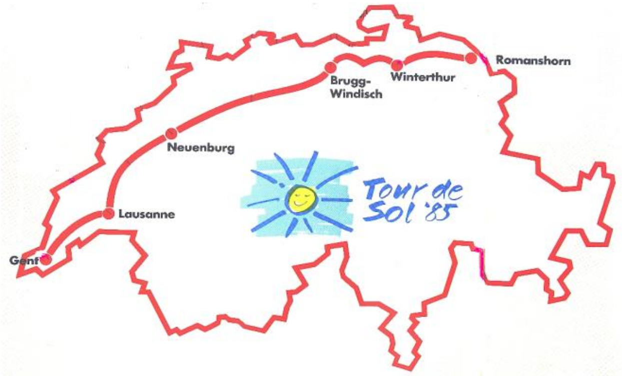


Fig. 5.2-1 Route of the Tour de Sol 1985 (Source: TdS)

Fig. 5.2-2 Esoro car on Tour de Sol race in the 1990ies (Source: TdS)

The Tour de Sol Switzerland generated a huge interest among the mass media. This was multiplied by the sponsorship of the popular magazine “Schweizer Illustrierte”, daily coverage and broadcasts on the race on the Swiss Television and the new private radio stations mainly concentrating on the local race participants. Solar energy not only turned into a widely discussed topic, but the Swiss National Solar Energy Association also gained thousands of new members and became the biggest solar organization in the world[19].

Urs Muntwyler and his team organised the Tour de Sol solar car races in Switzerland from 1985-1992, which became the biggest solar car races of the world in the 1980ies. With the technical regulations defined by the Tour de Sol team, technical progress was fostered on a year by year basis. The result were light-weight EVs like the SOFA IV, TWIKE, Horlacher vehicles and even the SMART car. With the exception of the SMART car, the vehicles mainly were not able to enter the mass market. Most vehicles vanished when the wave of electric vehicles in the mid 1990ies, fostered by the Californian ZEV regulation, disappeared. On the PV side, the effects were more sustainable. Decentralized grid-connected installations were established, which are, today, a major market for PV production.

Impact on the diffusion of VIPVs: Spectacular novelty - very high coverage in the mass media - big interest from the public - impact on “innovators” (young entrepreneurs, engineers and students, who wanted to be part of this new application). Some start-ups used the Tour de Sol momentum for the start of solar companies of all kinds.

Fig. 5.2-3 SOFA IV "solar car with additional pedals" on Tour de Sol 1985 (left) - Winner TdS 85 "racing solar car" Mercedes-Benz powered by Alpha Real (middle) - Esoro: Multi TdS winner in the category "series car with grid connected PV " (right) (Source: TdS)

5.3 Tour de Sol Switzerland - races 1986-1992 / European Alpine Solarcar Championship 1988-1992 / Tour de Sol Alpine 1990-1993

After the success of the Tour de Sol 1985, Tour de Sol races were held each year. The number of participants reached 120 in the solar car categories, and up to 30 in the solar boat category (1988 and 1989).

The main sponsor was the Swiss furniture company "Möbel Pfister", which helped to reach a broad audience and the general public. Other main sponsors were "Schweizer Illustrierte", a popular weekly magazine, the insurance companies "SCHWEIZ Versicherung" and "Elvia". The race was able to attract sponsoring in the order of 1 million CHF each year.

The highlight of each leg of the solar race was a public event with various attractions such as music concerts. Often, the location of the public event was in a centre of a town and attracted a big number of spectators similar to popular bicycle races. Each Tour de Sol race had its own song. In 1988, the Tour de Sol song reached top 10 of the weekly hit chart in Switzerland.

With 7 legs and later on an additional stage at noon, thousands of spectators could be reached every day. Many radio stations made a daily contribution on the race, and the Tour de Sol race was in the Swiss TV daily news. From each Tour de Sol race, a TV emission in the Sunday programme broadcasted the entire race. This emission could also be purchased as a video tape.

In summary, the Tour de Sol, solar cars and the use of solar energy was enormously popular in Switzerland in the late 1980ies and early 1990ies.

Additional solar car races, like the "European Alpine Solarcar European Championship" in fall 1989, were organised in the state of Graubünden, and a winter race, the Tour de Sol Alpine, was held on the frozen lakes of the state of Graubünden (Lenzerheide and Arosa). These activities allowed some of the pioneers to participate in solar car races on a regular basis, gave their sponsors a broad visibility and attracted media coverage the whole year. Some Tour de Sol teams were hence semi-professionals with budgets of several hundred thousands of Swiss francs per year.

Impact on the diffusion of VIPVs and solar applications: The massiv media presence provided a new positive image for solar technologies in Switzerland. The installation and use of solar thermal and grid-connected PV installations increased. Several start-ups tried to bring solar cars and light-weight electric vehicles the market. Many solar companies had their start in the Tour de Sol races. Some later reached a considerable size, the biggest had over a billion EUR turnover and is listed on the stock market. Some electric cars like the SMART are still on the market (https://ch.smart.com/de/).

5.4 Swiss Solar Salon 1986-1998 and technical conferences «Solarcar in everyday use»

The Tour de Sol organization set up an annual technical conference; each conference presented new technical and organisational issues of the race and the technology. The main contributions were provided by the racing teams who presented their successful concepts and technologies. Starting in 1988, an exhibition with components and solar cars was also organised; this exhibition was expanded to solar technologies, solar boats and - in the last exhibition in 1998 - to solar planes. This was probably the worldwide first exhibition with solar planes. Both, the conferences and the exhibitions were held in the big exhibition centers at Bern, Zürich and Basel in Switzerland, and were financially supported by sponsors. Visitors had to pay an entry fee.

The exhibitions were very popular and were appreciated by both specialists and the public. They were by far the biggest events of their kind, and brought the sales for all kind of electric vehicles - from e-bike to electric cars - to a peak. Vehicles of Swiss companies like Fridez AG (“Pinguin” models), Horlacher AG, Solec AG, Larag AG, Hotzenblitz (Germany), etc. were displayed and could be bought. In later years, the first fast speed e-bike “Dolphin” from Markus Kutter was also on display and could be purchased. Sales for solar hot water installations and, above all, PV installations, were high, too. This was important, as the market for both solar thermal and PV was in the “innovator” stage then. Massiv PR and media support pushed the topic into the mass media, and it was not unusual that - in the prime time of the Swiss TV - the exhibition was a topic.

It must be noted that the Swiss Federal Office of Energy SFOE back then also contributed to this growth of solar, by e.g., launching initiatives like a “Pilot- and Demonstration” programme for “light-weight electric vehicles” in Switzerland. The objective of this programme was to replace 8% of all combustion engine vehicles by EVs and to study the impact of such a change. The SFOE P+D programme “light-weight electric vehicles” in Switzerland started in 1995 and had a great impact for many years[20] insofar as it financed more than 100 projects in the era of light-weight EVs and first fast e-bikes. The biggest project was a fleet test with electric vehicles in a small Swiss city. Mendrisio, a city with 10’000 inhabitants in the Italian speaking region of Switzerland, did win the competition for participation, and hence the fleet test was conducted in Mendrisio.

5.5. World Solar Challenge in Australia and GM/DoE Sunrayces USA

Solar racing became popular worldwide when the Australian adventurer Hans Tholstrup developed a racing formula for a “long-distance solar car race” from Darwin to Adelaide, called the “World Solar Challenge”. The rules for this race included a request for 8 m^2 solar cells to be mounted on the surface of a car. This request pushed up the efficiency of solar cells. In the first race, a combination of GaAs solar cells and high-efficient solar cells from satellite applications were seen on the solar car from General Motors. The daily racing time was from 8 AM to 5 PM and the teams had to stop along the racing route.

Fig. 5.5-1 Engineering School Biel (now Bern Universitiy of Applied Sciences BFH) was 3rd in the first World Solar Challenge and the winner in 1990 (Source: BFH / ISB)

Twenty-two cars competed in the first race in 1987. The winner was a solar car of GM. This car was built by light-weight specialist and airplane constructor Paul McCready, a former glider world champion, and his company Aeronvironment in California (see Section 4.6.). Second was Ford Australia, and third the Engineering School Biel from Switzerland (Figure 5.5-1).

The race received worldwide media coverage and today, is held every second years, the last one being in 2023, when the racing category “category with passenger vehicles” was added. The fact that many student teams participate in this race today is especially promising.

Back in the 1980ies and 1990ies, the race in Australia stimulated a lot of University employees and car companies like GM, Ford, Honda, Toyota, etc. Some companies like, e.g., Honda in 1990 devoted huge budgets (in the range of 50 million USD) to the race.

In the US, a first long-distance solar car race (with fixed stages) was organised by General Motors (GM) in 1990. The regulations were similar to the “World Solar Challenge”. The first “GM Sunrayce” started in Orlando (Florida) and ended in Detroit. After successful completion of a pre-proposal phase, thirty-two pre-qualified Universities from the US could take part in the race. The first winner was the University of Michigan. In 1993, the race was taken over by the Department of Energy (DoE). Thirty-four Universities were competing in the race, which started in Fort Worth (Texas) and ended in St-Paul-Minneapolis. Again, the winner was the University of Michigan, which was a huge motivation for the next generation. This generation now works in the industry worldwide and brings the e-mobility to the mass market.

5.6. Prices and Components of VIPVs in the 1980ies and 1990ies

Most light-weight electric vehicles and solar cars in the 1980ies used lead-acid batteries. These batteries were heavy, about 20Wh/ kg and some up to 30Wh/ kg. A 48 V/ 100 Ah battery pack had, therefore, a weight of nearly 200 kg. With a consumption of 5-10 kWh/ 100 km, the range was only about 50-100 km. But a consumption of 5 kWh/ 100km needed a very aerodynamic and light car made of plastic. Such vehicles were the three-wheelers Horlacher “Eggs” and cars like the “Esoro” (Figure 5.2-3). Producing electricity from PV was, therefore, an interesting option, provided the design of the vehicles allowed it (e.g., round shapes like the Horlacher “Eggs” were not favourable).

Fig. 5.7-1 Light-weight EVs in the 1990ies, from left to right: Solec (Switzerland), KEWET (Norway), Think (USA), Stromboli (Switzerland) (Source: Internet)

The solar cars and light-weight electric cars obviously used PV panels of the 1980ies/1990ies for their mobile and stationary applications. Between 1985 and 1990, a popular 55 Wp solar panels such as the mono-cristalline M55 from Arco Solar cost about CHF 1 100 (about 1 100 USD), therefore 20 USD/ Wp. The module had a rugged aluminium frame and a glass cover. The efficiency was about 10%, and the weight was about 7 kg. In summer conditions, ca. 6 h of the nominal power could be earned in mid-European conditions, which is about 330 Wh per day. Over the year, the yield was less than 50 kWh or 100 kWh/ m^2. Special light-weight PV panels such as the often used poly-cristalline MSX30L from Solarex had 30 Wp, with an efficiency of 10%. The solar cells were glued on an aluminium backplate and had a plastic encapsulation. The price was below 600 USD (end user price). This module was often fixed on small light-weight electric vehicles such as the City-el's or the four-wheel "Pinguin" models of Fridez Solar AG.

Later in the 1990ies, and until the year 2000 and beyond, PV prices went down a little bit. A popular PV panel like the MSX 64 from Solarex cost about 1 200 USD (single number), which is still about 20 USD/ Wp, and about 8 USD/ Wp for bigger quantities (like for grid-connected PV installations on private houses).

The energy production of about 330 Wh on a summer day is not a lot for a vehicle that uses 5 kWh/ 100 km. This gives a range extension of 6 km per summer day, but only 3 km as an annual mean value for the 55 Wp PV module with a surface of about 0,5 m^2. This, and the popularity of grid-connected private PV installations of 3 kWp with an annual yield of 3 000 kWh and a price of about 36 000 USD for the whole installation, made PV panels on a vehicle a rare exeption. With this price for a private PV installation, the customer groups were the "innovators" and "opinion leaders", i.e., the same customer groups as for the light-weight electric cars. This explains the limited success of the combination of EV+PV in the late 1980ies and mainly in the early 1990ies.

In Switzerland, the leading country for EV+PV in these two decades, the most popular vehicles were the "Mini-el" with nearly 1 000 vehicles and the more expensive, but also more powerful "TWIKE". The price for a "Mini-el" was between 6 000-9 000 USD and the price for a "TWIKE" was about 26 000 USD. A light-weight four wheeler such as the "Solec" was about 20 000 USD. This was, at this time, a popular way to use a small ICE as a conversion to an EV. Unfortunately the lead acid batteries didn't last very long and the exchange was costly. After the production stop of these cars, the number of these light-weight e-vehicles decreased over the following years.

Impact on the diffusion of VIPVs: Due to the heavy lead-acid batteries of the four wheel light-weight electric vehicles and the possibility of a PV roof with something like 60-120 Wp PV power, a certain range extension was reached. Probably more important than the range extension was that the PV roof transported the "innovator" and "opinion leader" message. Due to the short-lived lead acid battery and the sometimes low quality of the vehicles, the small four wheelers disappeared, and the more powerful TWIKE's controlled the niche market.

5.7. Conclusions on Solar Cars / Light-weight Electric Vehicles (1980ies and 1990ies)

While the solar cars and light-weight electric vehicles in the 1980ies and 1990ies attracted a considerable amount of customers, dozens of projects failed and companies went bankrupt. The underlying reason is that the products did not “cross the chasm” (Moore, 2002), i.e., were not able to enter the mass market sufficiently fast. Production and distribution costs were too high in the early market, and - because of regulations - expensive tests and changes would have been necessary to enter the mass market.

Only new car concepts like the efficient ICE 3L Lupo / A2 from VW / Audi and hybrid cars from Toyota offered alternatives to the less powerful (yet attractive and similarly expensive) solar cars and light-weight electric vehicles. For commuters, fast e-bikes were an alternative to the light-weight EVs.

Fig. 5.9-1 Prototypes from Horlacher AG; for Thailand (2nd left) and for the USA (right) (Source: 2x TdS / 2x Horlacher AG)

Only few companies were able to switch to other markets, e.g., as a producer of automotive components. Examples are companies like Brusa AG (Switzerland), Esoro (Switzerland) or Akasol (Germany). Other companies (like Horlacher AG or Bucher Leichtbau, both Switzerland) stopped and returned to their core business.

Fig. 5.9-2 Vehicles with Brusa electronics and powertrains (Source: Brusa AG)

Among the “surviving” companies are businesses in solar energy. In this field, dozens of companies were set up during the Tour de Sol era, because the use of PV modules as a source of decentralized off-grid power supply entered several market segments. These include the use in mobile applications such as recreational vans (RVs), boats and in small airplanes. Especially gliders are still a successful niche application, like the off-grid applications of PV in telecommunication or the PV for application at home. The number of these applications is still huge and growing. The customer benefits of a small PV power source for light, mobile phones and communication in hundreds of millions homes are very strong. This is not new, e.g., the main author of this report installed such PV applications for “dispensaires” (local hospitals) and private homes in Rwanda 40 years ago.

In summary, worldwide solar car races in the 1980ies and 1990ies offered many people a lifelong learning experience in energy efficiency, solar technology, solar architecture, photovoltaics and electric cars. Many of the participants in these early solar car races now work in all kind of industry and/or are involved in all kind of business, and some even moved into politics.

5.8. Lessons Learned for PV in Transport

With regard to PV in transport, some new projects like the Aptera (USA), Sion from Sono Motors (Germany), Lightyear (The Netherlands), and a version of the Hyundai Ioniq 5 (South Korea) appeared on stage in the last years. They all want to enter the VIPV market. As this is a difficult task, the traditional transport sector could offer a smoother alternative. In trucks and transport vehicles of all kind, the efficiency of electric production with a diesel motor for the delivery of electricity is very low. A decentralized PV power production system would be much cheaper and offers a better financial reward. This is even the case for applications that don’t live as long as a PV module. The short lifetime of cars (as compared to the relatively long lifetime of a PV module) was already a big concern 40 years ago. Today, given the “super low prices” of PV modules, this concern has disappeared, and PV modules pay off even during short-time applications that do not live longer than 10 years.

6. TOUR DE SOL SWITZERLAND AND SUCCESS STORIES ON MARKET ENTRY

6.1. Success story 1: Fast-speed e-bikes

First e-bikes went on the market in the mid 1980ies. They were expensive, had heavy lead acid batteries, and the range was short. Top speed was limited to 20 km/h for the electric drive. The result were poor sales and consequently, these bikes disappeared rather quickly (example: Elfa Geiger, Switzerland).

Almost a decade later, the Swiss inventor Michael Kutter developed a fast-speed bike with NiCd-batteries. The bike added the much more powerful electric motor to the power of the pedals. This e-bike called “Dolphin” was fast with up to 40 km/h and was sold in small numbers. The heart of the “Dolphin” was a special gear.

Fig. 6.1-1 Markus Kutter (left) with his revolutionary drive train of the fast speed e-bike “Dolphin” (Photo: Kutter). First “Flyer” model (right) with an illustration on how much gasoline is used for a commuter with 2x10 km per day as compared to the PV surface needed for the same range in 8 years (Source: Muntwyler)

Some months later, three young folks, in their company BKTech in Burgdorf (region of Emmental, Switzerland), worked on a similar bike and called it “Flyer”. A Flyer hat 2 x 12 V lead acid batteries in a robust bike frame. This, and the electronics including a 230 AC charger, filled the space between the horizontal tube and the central pedals below. Both forces were added on the pedal wheel. The bike had several gears and could easily reach 40 km/ h. It was sold for about 7 000 EUR, and a reasonable number of these bikes was sold after 1996. BKTech also attracted some investors. An improved version of this fast-speed bike (with quite a complicated motor design) also had a certain success on the market. But then, BKTech went bankrupt, the founders left the company and a new CEO joined the company. He changed the drive system and brought a new version of the e-bike (called “Flyer”) on the market. The main version was still a fast-speed bike. In parallel, the new CEO improved the marketing with “e-bike tourisme drives” in the hilly regions of the Emmental and was able to attract financial support from the Swiss Federal Office of Energy SFOE. Due to a campaign called “New Ride”, e-bike trails were organized throughout the country. Finally, the Flyer became so successful that the market became stable without the “New Ride” programme. The e-bikes were also promoted to help elderly people moving around in a powerful manner by the e-support. As a consequence, the selling numbers of the “Flyer” bikes went up and e-bikes sales in Switzerland are today nearly equal to all other bike sales. This process was also aided by new city programmes promoting more bikes in the streets.

Impact on diffusion of innovation: The success of the fast e-bikes and later of the e-bikes with limited speed was achieved by a classic market introduction process. After the

innovative e-bike "Dolphin" from Michael Kutter and "Flyer" by BKTec", more sophisticated, cheaper and better usable e-bikes were brought onto the market. Today, there exist a lot of e-bikes models on the market with all kind of performance and price tags. E-bikes reached the mass market.

6.2. Success story 2: Decentralized PV installations

In the second Tour de Sol in 1986, the "Öko Center Langenbruck", an NGO with activities in renewable energies such as solar architecture, wind generator and PV, participated with a grid-connected PV installation. This was the third grid-connected PV installation in Switzerland. As this vehicle categorie was not part of the official categories in 1986, the NGO run as "out of competition". The interest in this category was, however, big - and in Tour de Sol 1987, a new category "series solar cars grid-connected" was introduced. The sponsor of this category was the "Swiss Association of Utilities VSE". This was important as, back then, there were no rules for the injection of PV electricity into the grid. It turned out, that this category was a big success and motivated house owners, companies and farmers to start mounting grid-connected PV installations on their properties. For the 3rd Tour de Sol race in 1987, the company Horlacher AG installed a PV installation on the roof of their company building (Figure 6.2-1). They used the energy from their grid-connected PV installation for their electric 2-seaters. The winner of this categorie was the former Formula 1 racingpilot Marc Surer on a Horlacher "Egg".

Fig.6.2-1 "Horlacher Eggs", the vehicles of the Swiss company Horlacher AG in Möhlin (canton of Argau) were Tour de Sol participants from 1987 onwards, in the category "solar cars with grid-connected PV". The vehicles were sold in small numbers to private users in the late 1980ies in Switzerland (Source: Horlacher AG)

The PV installation on the Horlacher AG roof was built by the company of Markus Real, alpha real AG. The engineer Markus Real was, together with Mercedes-Benz, the winner of the first Tour de Sol race in 1985. He promoted the idea of decentralized grid-connected PV installations with his "MEGAWATT" campaign where he attracted 333 owners of a 3 kVA power station and offered a reasonable price for each unit of 48'000 SFR (now equal to 48'000 EUR). He was successful, and the idea of decentralised PV installations on roofs was later introduced to the Sacramento's "Photovoltaic Pioneer Programme", designed by S. David Freeman, who visited Markus Real in Switzerland[21]. Similar roof-top PV programmes started in California, Japan and Germany, and roof-top PV is now a backbone of PV systems worldwide.

Impact on the diffusion of VIPVs: Novelty, which successfully moved along the classic innovation path, starting with "innovators" and "opinion leaders". Due to cheap PV modules and inverter prices since the 2010ies, the mass market could be opened for everybody who owns a house. PV is now the cheapest renewable electricity source. Roof-

top PV is still ahead, as the mounting infrastructure (the roof) still exists and the consumers live underneath the roof.

6.3. Success story 3: The first EV in Norway

On the Tour de Sol exhibition in 1989 (termed “Solarsalon”), the Norwegian pop band a-ha showed up and bought a “Larel” electric car, which was a converted Fiat Panda. The conversion had been done by the Swiss company Larag AG, who sold about 100 of these cars. Back then, it was forbidden to import an EV in Norway, but nevertheless, the popular singer of a-ha, Morten Harket, drove the Larag car in Oslo (which was forbidden, too). The Norwegian police was hence likely under considerable stress as they were obliged to arrest the driver (Morten Harket) who was, however, extremely popular in Norway and all around the world. The Norwegian police finally found a way out of this dilemma and licensed the car as a “recreational vehicle, RV” (as the Larel had two batteries, similar to RVs). Today, a-ha are still in the business (Figure 6.3-1) and just released a new album called “True North” (2022).


Fig. 6.3-1 Norwegian a-ha pop band in 1989 (left) with singer Morten Harket (left), Professor Harald Rostvik (middle) and the Larel (background). Right: a-ha 35 years later in a BBC UK documentary on electric cars in 2022 (Source: Harald Rostvik)

a-ha manager and friend Professor Harald Rostvik explained: “Then we later set up Norway’s first electric vehicle organization “Norstart” in our region that later turned into the national one. In 1994, we in Stavanger had the first electric bus on a fixed route in Scandinavia. Then the “Elcidis” project (electric goods vehicles - EU project with 8 cities), then all the incentives pushed by us with driving the imported car in toll roads without paying” [22].

Norway is now the worldwide leader in the use of EVs.

6.4. Success story 4: Sinclair C5 (UK)

Several light-weight EVs went on the market in the 1980ies, some of the designs being far away from traditional cars and bikes. Among the first was the UK “Sinclair C5” introduced in January 1985. January is probably not the best season for introducing an open electric vehicle, especially not in the UK (rain, cold, fog). Thus, it is no surprise that sales figures of the 400 GBP vehicle were behind the very high expectations, and in August 1985, the production was terminated (after 17 000 vehicles had been sold). The UK Sinclair C5, a small 3-wheeler, had two wheels in the back and one in the front, and pedals that supported the 12 DC Volt lead-acid battery, which fed the 250 W motor. The velocity was 24 km/ h, and the range around 30 km. The steering was a handlebar behind the sitting driver, which was a special arrangement and very simple to learn and to use. However, a disadvantage was that all shocks on the street went directly into the dorsal vertebra. This was the reason why the main author of this report sold his “C5”.

Impact on the diffusion of VIPVs: Given the low price (400 £), the mass market could theoretically be reached. Yet, for such a novelty with unclear user profile and user advantages, this approach was, nonetheless, not sufficiently sustainable. Few C5 were transformed to a VIPV, e.g., during Tour de Sol 1985, two C5 with a solar roof were running in the category "solar with additional power"[23].

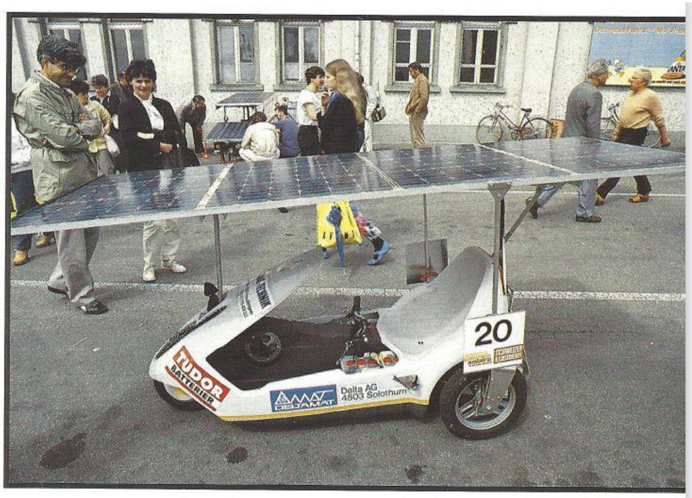


Fig. 6.4-1 Sinclair C5 on the Tour de Sol 1985 (Source: TdS)

6.5. Success story 5: Mini-el from Denmark

In 1986, the Danish inventor Steen V. Jensen developed a one-seater light-weight 3-wheeler called "Mini-el" (later called "City-el"). The wheel concept was two wheels in the back and a steering wheel in the front. Steen V. Jensen studied mobility after the first oil crisis in 1973 and tried to bring a cheap and comfortable vehicle to the market. The vehicle looked like a glider and had a huge canopy, which opened into the height. The vehicle was made with thermoplastic. The voltage of the lead acid batteries was 36 V. The company El-Trans AS in Randers produced about 6'000 vehicles, which made the "Mini-el" one of the best sold EVs at that time. Yet, as production suffered from technical problems right from the beginning, the company went bankrupt. "Mini-el's" were very popular for commuters in cities. Around 1990 in the Swiss capital of Berne several hundred "City-el's" were used. Production stopped in 1995, and the company was sold to Germany, and later, different companies produced small numbers of the "City-el"[24].

Impact on the diffusion of VIPVs: Because of the reasonable price, the City-el attracted "innovators" and "opinion leaders". In the Swiss capital of Bern, several hundred City-el's could be seen in the streets around 1990. But eventually the price was too high, and the company couldn't continue the production and the further development of the concept. Note: With the new Li-batteries, the City-el would, today, still be an interesting vehicle for the "small mobility".

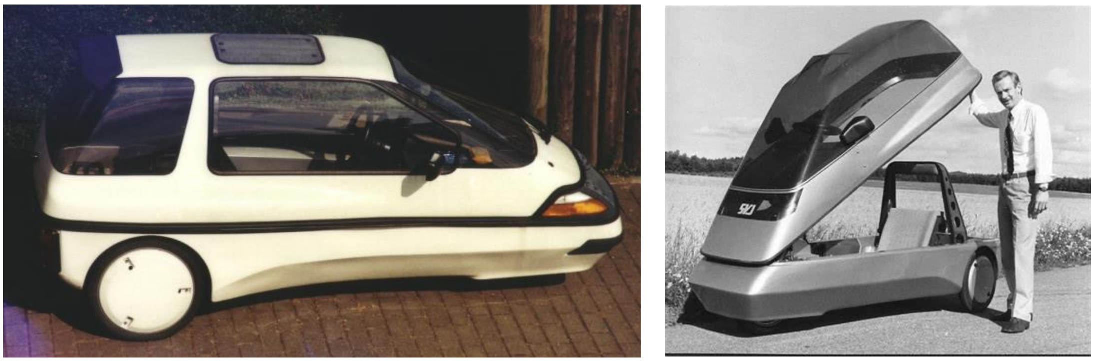


Fig. 6.5-1 "Mini-el" from Denmark (left), with inventor Steen Volmar Jensen (Randers, Denmark) (right) (Source: EL-Trans AS)

6.6. Success story 6: TWIKE 3-wheeler / 2-seater from Switzerland

In the Tour de Sol 85 race, the high school student Ralph Schnyder did win the 2nd place in the category "solar cars with additional drive/ pedals". Jointly with some of his colleagues, he presented, in 1991, an electric two-seater with 3-wheels, called TWIKE II (cost: about 26 000 EUR). The wheel concept was two wheels in the back and a steering wheel in the front. The two persons in the vehicle had pedals in parallel to a high voltage AC-drive. The steering was done with a stick - like in modern planes. The vehicle had NiCd-batteries and later Li-batteries. It was able to reach a speed of 80km/ h, the TWIKE II was eligible for driving on highways.

After 1990, several hundred TWIKEs were sold at a price of about 26 000 CHF and the vehicle was highly attractive to "innovators" and "opinion leaders". Yet, the company suffered from financial problems, and after several attempts to reorganise the company, it was sold to Germany. Today, there is still a company who tries to bring a new TWIKE version on the market.

Fig. 6.6-1 TWIKE in front of the first Swiss 100% solar house (Source: Muntwyler)

The USP of the TWIKE is its appearance and being a 2-seater with pedals. Furthermore, as this vehicle runs with electricity, the energy can be produced with PV. TWIKEs can reach a top speed of about 80 km/h, had a reasonable range of 40-90 km and a support of pedals (which give only a fraction of the energy, but is good for warming the drivers in the winter). Instead of the heavy lead-acid batteries (that was common in the early times), TWIKES had NiCd-batteries. An important fact was also the price in the region of 26 000 EUR, which is high, but acceptable for “opinion leaders” in Switzerland.

Customers who bought/buy this product are technically interested people with a responsibility towards the environment and a high buying power. These may be entrepreneurs or engineers who are convinced of and motivated to buy and use “green” products. TWIKE’s are still in use and can be seen daily in Bern, the capital of Switzerland.

Impact on the diffusion of VIPVs: As a popular light-weight EV with a high performance and at a high price, the TWIKE attracted the customer group “innovators” and especially “opinion leaders”. More than 1 000 TWIKEs were sold.

Fig. 6.6-2 Innovator with "in-roof grid-connected" PV installation, integrated hot water solar thermal installation and a TWIKE (left) in Switzerland before 2010 (Source: Solarcenter Muntwyler AG)

6.7. Success story 7: Kyburz postal service LEVs

The engineer Martin Kyburz became fascinated by VIPVs on the first stop of the Tour de Sol 1985 in Winterthur. He joined the Tour de Sol in 1992 with a three-wheel prototype vehicle and started his own company Kyburz Switzerland AG.

Fig. 6.7-1 Tour de Sol 92 vehicle (left) and postal service vehicle (second left), e-vehicle for elderly people (third left) and 49 e-trolleys (right) for the Austrian postal service, delivered by Kyburz Switzerland AG (Source: Kyburz AG)

The first product successfully introduced into the market by Kyburz Switzerland AG was a 3-wheeler vehicle for elderly people. A similar vehicle for the Swiss postal service revolutionized this postal service due to the simple electric concept. This vehicle is now sold worldwide and in 2024, Kyburz Switzerland AG will be establishing a big factory in Switzerland for the mass production of such light-weight EVs.

6.8. Success story 8: Tour de Sol 1986 winner Migros electric vehicle MEV1

The organiser of the Swiss Tour de Sol races was also responsible for the Swiss booth at the energy exhibition in Geneva in 1986. Switzerland presented the country as a producer of electricity with renewable energies (mainly hydro) and innovative solar cars and electric cars. One of the new electric cars promoted at the Swiss booth in 1986 was the “MEV 1”, the Tour de Sol winner of 1986 in the category “serie solar cars”. The MEV 1 was sponsored by the retail chain “Migros” who, at this time, considered establishing a production line for light-weight electric vehicles in Switzerland together with the electronic company Autophon AG. Some years later, the watch producer SWATCH started to realise this idea, which later became the SMART car (https://ch.smart.com/de/).

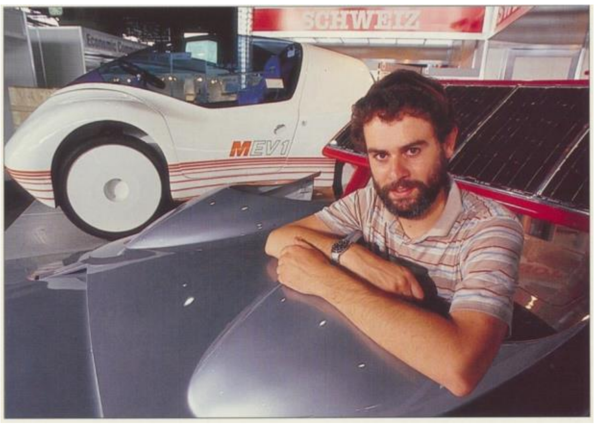


Fig. 6.8-1 Country Swiss exhibition stand on the Energy Fare Palexpo Geneva in 1986 with Tour de Sol 86 winner (series solar cars) MEV 1 (Migros Electric Vehicle 1) in the back and exhibition organizer Urs Muntwyler in an EV from Bucher Leichtbau AG (Source: TdS)

6.9. Conclusions on Success Stories

Despite of all the efforts in technology and dissemination in the 1980ies and 1990ies, the car technology was not ready back then, and the e-vehicles didn’t reach a broader public. One of the reasons being the lead acid batteries that were too heavy, and the big car producers stopped their efforts in the 1990ies. It was the time when Japanese car producers started moving into hybrid technology. It was also the time when German (and other) car producers pushed the diesel engines with (cheated) exhaust systems (with serious consequences for some car managers). This finally contributed to the breakthrough of the EVs around 2020.

The customer groups who bought the first e-vehicles in the 1990ies have used their vehicles for decades. E-vehicles like the “TWIKE”, and, to a lesser extent also the “City-el”, can still be seen on the roads in towns such as Bern (Switzerland). But the big and heavy electric cars are now the best sold models per year.

In summary, some of the goals of the Tour de Sol Switzerland have been achieved. Especially the main goal, to popularize the use of solar energy was reached. EVs and PV made their market breakthrough, and everyone can now propel his/her EV with a PV installation. This is important when considering that 6 TWh electricity produced with decentralized PV, in Switzerland today, contributes 10% towards the overall electricity consumption. The goal of the so-called Swiss

Energy Strategy 2050 is more than 40 TWh way before 2050. Many countries in the world have similar goals to reach 100% energy supply with renewable energies. Such a goal was totally unrealistic 50 years ago.

7. A SHORT HISTORY OF EVS AS A BASE FOR VIPVS

A VIPV is mainly an EV with PV on its surface. Hence, a short history of EVs is provided here.

7.1. Limited market success and niche markets for EVs in the 19th and early 20th century

First electric vehicles (EVs) in the market competed around 1900 with steam and combustion engines. The first car which reached the 100 km/ h speed was the electric “La Jamais Contente” in 1899 by the Belgian constructor and driver Camille Jenatzy. In Switzerland one of the producers was Tribelhorn AG which has built electric vehicles in Switzerland since 1902.

Finally, combustion engine vehicles (ICE) did win the competition. EVs disappeared from the mass market and moved into niches. Some niches like electric trains were very successful, followed by electric tramways and trolley buses. In Switzerland, some companies managed to survive in niches and several thousands of electric vehicles were on the roads in 1939.

Fig. 7.1-1 Tribelhorn truck (left), and SIG EL 300 from 1943 with Zele Zagato and others (right) (Source: Wikipedia)

Other applications were, e.g., milk delivery vehicles (slow speed needed and a lot of “start and stop”), fork lifts (heavy lead-acid battery was counter-weight). In some tourism resorts like Saas Fee or Zermatt, both in Switzerland, only special low-speed EVs have been allowed since the 1950ies, and ICEs are forbidden.

Fig. 7.1-2 Special electric vehicles in the car free tourism resorts at Saas Fee and Zermatt in the Swiss Alps (Source: Wikipedia)

7.2. EV renaissance after 1970 - ZEV in California - international collaboration and European fleet tests

After the oil shock in 1974, the electric drive train had a short comeback. Cars like the 2-seater “Sebring” in the USA and the “Zele Zagato” from Italy were in the spotlight. In the early 1990ies, EVs increasingly got attention due to the “Zero Emission Act” in California, the goal of which was to reduce air pollution and have 2% of “zero emission vehicles ZEV” in 1998. This was mandatory for the five biggest car sellers in California (GM, Ford, Chrysler, Toyota and Nissan). Hence, at the Electric Vehicle Symposium EVS in Anaheim (USA) in December 1994, car producers presented electric cars like the GM EV1 (with a closed lead-acid battery) and a prototype with a NiMh-battery. Ford presented the Ecostar with a high temperature sodium-sulfur - battery. Japanese car producers displayed the Toyota RAV4 and Honda the Honda EV, both with a NiMh-battery.

The GM EV1 was only leased to customers. Yet, the car industry was able to “kill” the ZEV - mandate, and EV1s had to be returned and were scrapped, while the customers complained.

In 1992, the International Energy Agency (IEA) launched a Technical Collaboration Programme (TCP) for “Hybrid-, Electric- and Fuel-Cell Vehicle” (HEV-TCP/ www.ieahev.org), which officially started in 1995. The author of this report has served as the elected Chair of the IEA TCP HEV from 1998 to 2018. The programme is still active and today has around 50 working groups on various EV activities.

In European countries, EV fleet test were started in the 1990ies with Germany, France and Switzerland acting as the pioneers. The fleet test on the Island of Rügen in Germany was expected to assist the German car industry to get into the EV business. Between 1992 and 1996, German car producers sold their electric cars in small numbers on the Island of Rügen. But there were many public complaints on the tests, albeit customers were satisfied. Nevertheless, the tests were accompanied by researchers and attracted interest from other countries.

In France, the French car industry and the politics selected the Atlantic city of La Rochelle for their fleet tests. French cars like the Peugot 106, the Citroen Saxo, and Renault Clio - all as electric versions and with the NiCd-battery from SAFT (F) - have been sold since the beginning of 1994.

In Switzerland, the city of Mendrisio in the southern, Italian-speaking part of the country, did win an official tender of the Swiss Federal Office of Energy SFOE for a fleet test. 8% of all the ICE cars were supposed to be replaced by EVs (e.g., EVs from France, Norway, Germany, Japan, Switzerland etc.) and by some small EVs like the KEWET (Norway). The fleet test started in 1995 and was quite successful.

In all countries, the EV enthusiasm soon faded as EVs were about twice the price as a similar ICE car, and all car producers stopped their production.

Lessons learned from the 1990s

The price for an EVs was about twice as for a ICE car and hence, the car industry was not really interested in bringing this technology to the market. Also, the pressure from politics was not strong enough to maintain the mandates. Rather, the US car industry moved to bigger cars called “Sport Utility Vehicles SUVs”. The profit for such a car is much higher than with an EV and associated with minor risks for the company.

7.3. Developments from 2000-2010 and EV breakthrough after 2010

Between 2000-2010, rumours about hydrogen vehicles with a much bigger range kept the interest in EVs down. In Japan, the car industry moved towards hybrid cars and in Europe, the car industry moved towards diesel engines.

The resurgence of the EV was when an outsider, Elon Musk, took over the “Tesla” project. Musk had noticed a converted Lotus Elise with an electric drive train from Alan Coconi from the Californian tech company AC Propulsion. Coconi was involved in power electronic projects with Cuk-converters for the “Spacelab” satellite in the early 1980ies. He worked on the “Impact”-EV, which was later the EV1 for GM.

Fig. 7.3-1 Tesla Roadstar, Tesla S, Tesla 3 and Tesla Cybertruck (Source: Wikipedia)

Musk built a first EV with round Li-battery packs, the Tesla “Roadstar”, which is very similar to the Lotus Elise. Between 2006-2010, Musk sold 2 450 Roadsters in over 30 countries, at a price of about 100 000 USD. The Tesla “Roadstar” hence was a typical product for “innovators”.

The next car of Tesla was the Tesla S in 2012, a 6-seater with fast acceleration and a range up to 600 km, which was way over what have been seen before. The price was in the range of 80 000 USD. After some years, the Tesla S was the best sold EV in the world, with a total of more than 250 000 vehicles sold. Model S reached both customer groups “innovators” and “opinion leaders”. A similar SUV, the Model X, came into market in 2015. In wealthy customer countries and car markets like Switzerland (medium car price is 55 000 EUR), the two models exceeded the sales of upper class models from Mercedes+BMW+Audi, totalling turnovers of hundreds of millions per year in a small country with only about 250 000 total car sales per year.

The next model of Tesla, the Model 3, a mid-size sedan, was presented in 2016 and got immediately hundreds of thousands of reservations. Since 2017, more than 5 millions Tesla 3 were sold. In 2021, a smaller SUV, the Tesla Y, was introduced to the market. Up to the end of 2023, 2 million cars were sold. Both, the Tesla 3 and Y, are now cars for the “early majority” in wealthy regions of the world. The lately presented Tesla "Cybertruck" relies to niche market customers like "opinion leaders".

This effort from outside the car industry was the breakthrough of the electric vehicle. The competition from Tesla and concerns on global warming built up huge pressure on the car industry to bring EVs once more to the market. The move to EVs is especially interesting for producers in China with higher competences in electric drives and electronics than in combustion engines. There are many Chinese companies that mainly or only offer EVs. Politics in many countries and regions like in China, USA and Europe now support the move to more efficient and clean cars.

Diffusion of Innovation by Tesla: Tesla has followed the classic "Rogers (1962)" curve and has been very successful in doing this. They needed a lot of innovation and entrepreneurship, and created a unique momentum. They had some serious problems to ramp up the production and to bring the new models to the market. An advantage of Tesla was that the owner, Elon Musk, was engaged in his own unique way to move towards his own success. However, a new model is needed for the "late majority", with a price tag of around 20 000 USD.

CCA of Tesla:

Profit: High performance EV at an affordable price (for the target group)

Pride: Nice design and image (no CO_2) - often combined with own house

Pleasure: Modern functions, fast acceleration, high driving comfort

Peace: Proprietary fast charging network, quiet drive

8. A SHORT HISTORY OF PV AS A BASE FOR VIPVS

8.1. Where is the VIPV?

A VIPV has mainly two parts: a vehicle with an electric drive train and some PV, which covers a part - or even better - the entire energy consumption. As demonstrated in the rules for the Tour de Sol solar car races from 1985 to 1987 this can be a parallel development, from PV installed on the car to grid-connected PV charging stations for the car. From the perspective of customer needs, the difference is minor. But the price of the PV power and -energy and the possibilities are much more attractive if a PV system is not installed on the car. This is especially the case when the car producers are not familiar with “this PV stuff”. Therefore, it is important to highlight the PV technology and PV systems.

8.2. PV - a very short summary

PV has been known since the 18th century[25]. The technology as we know it today started in 1954 with the development of the first solar cell based on Silicon. For decades, the application has been limited to niches such as power supplies for satellites. In the 1970s, new companies like Solarex, Arco Solar, etc. tried to develop cheaper solar cells for terrestrial applications. With a worldwide production of 40 kWp in 1975, efficiencies in the range below 10% and prices up to 100 USD fitfty years ago, PV has dramatically improved. Now, a standard PV module has more than 400 Wp, cost less than 0,5 USD/ Wp, the efficiency is over 20% and the market is in the range of 600 GWp (2024). Therefore, we now have cheap and efficient solarcells for a wide range of applications. According to IEA forecasts, PV is now the cheapest source of new electricity infrastructure, together with on-site wind energy.

8.3. The two ingredients for VIPV are both in the mass market

The two basic technologies for VIPV, being EV and PV, are both in the mass market. In terms of flexibility, solar cells are more flexible, while the car industry is less flexible. In addition, the car industry has not much understanding of that “crazy solar”. Old officers still struggle with the replacement of the ICE by the electric drive train. Car companies often have no technical experts on top. As an example, in the 1980ies, the CEO Bob Stempel has been the first engineer and the “engineering CEO” of GM for decades. He was a proponent of electric cars. After a few years, he was replaced and GM went back to the ICE and started SUV factories. Companies like VW cheated on their customers with faked exhaust measures. Japanese car stopped their EV activities from the 1990ies and pushed the hybrid cars. This created room for newcomers like “Tesla” and Chinese car producers.

8.4. Customer advantage can be reached in different ways

What about the customer advantages of a VIPV in the context of these developments? Additional customer satisfaction (4P’s) is reached when the customer wishes below are addressed:

- **Profit:** Cheap affordable energy source with solar and an affordable car
- **Pride:** Own solar energy and a car with high performance
- **Pleasure:** Works fine and looks good
- **Peace:** No problem, low service, etc. and a fast charging network that works

Most of the customer wishes above can be fulfilled with a grid-connected PV installation and an EV. A (grid-connected) PV system can also be much more powerful (10-20-times more powerful) than a VIVP, and has a longer lifetime. A further advantage of a PV installation is that the surplus energy can be used to propel other electric consumers in the house like hot water production or a heat pump (heating). If the electric car can be used as a “house battery”, then this is yet another strong argument for a system like a grid-connected PV installation.

If utility companies offer their customers “PV electricity” EV user don’t need their own PV installation anymore.

8.5. Differentiation for the VIPV is more challenging

The success and breakthrough of electric vehicles is a challenge for and a threat to VIPV. In such a situation, “PV on the car” is more an additional nice feature in a way the most expensive Hyundai “Ionique 5” version has offered it for a short time. But the PV on the car soon disappeared because, according an EV dealer[26], it made the logistics too complicated

A possible way forward might be to differentiate an EV label with “PV on the shelf”. But this first attracts “innovators” and “opinion leaders” and, therefore, will start in a niche market. The move of car companies from the Far East like Japan and South Korea was not along this avenue to enter the European car market some decades ago. Instead, they offered cheap cars with more features, with a good or better quality than the standard market. With this strategy, the “mass market” can be reached in one step, which was the case with the Japanese car producers in the 1960ies and the South Korean car makers in the 1980ies. It seems as though the Chinese car producers currently pursue the same strategy with their EVs.

9. ENERGY PRODUCTION AND SAVINGS OF VIPV'S

9.1. Energy yield of a VIPV

On a VIPV, a nominative power of 1 kWp is quite a high number. How these different surfaces are oriented depends on the size and shape of the car. Earning 600 kWh/ year in mid- European conditions is quite a good value. A standard EV with a consumption of 15 kWh/ 100 km can run 4 000 km with this energy. This is about 1/3 of the standard range of a Swiss car driver with 12 000 km. Most of this energy is produced in the summer season[27].

Fig. 9.1-1 Nissan Leaf for research at the PV Laboratory of Bern University of Applied Sciences BFH in Burgdorf, Switzerland (left). Aerial view of the PV LAB building (right) showing several PV installations and carports (Source: Muntwyler / Internet)

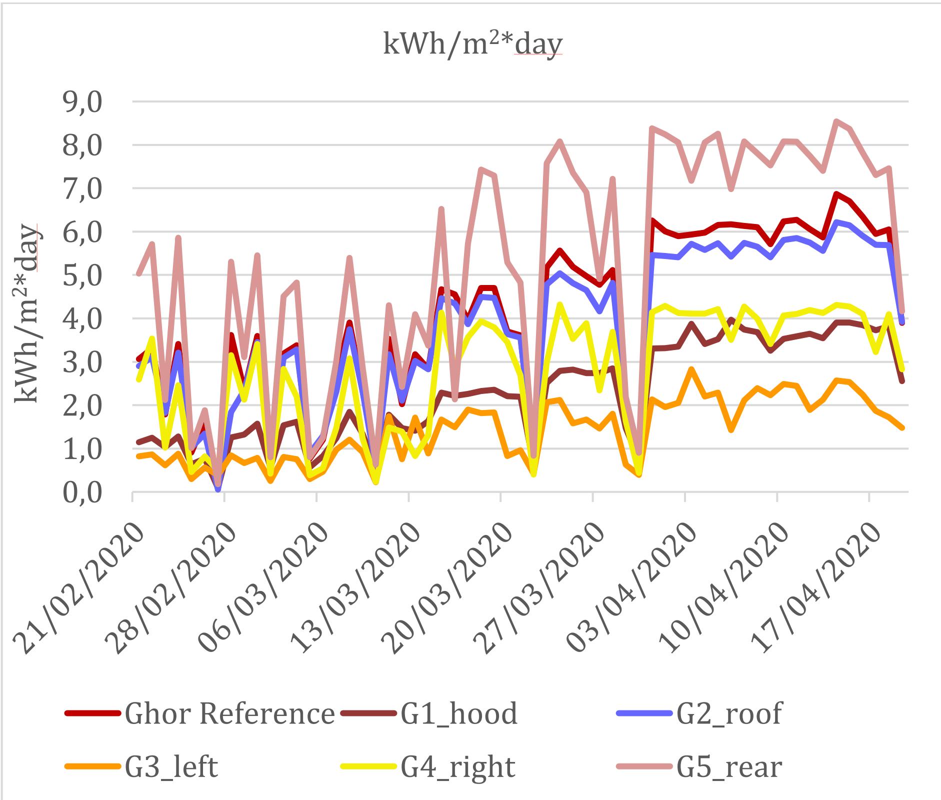


Fig. 9.1-2 Yield of the different surfaces of a 1kWp car on different periods of the year in Burgdorf / Switzerland at PV LAB BFH (Source: Urs Muntwyler/ David Zurflüh)

9.2. Energy yield and range of a VIPV

The optimum size and orientation of PV on a car are not always guaranteed, and hence, the yield is normally smaller in practice. But, for most consumers, this doesn't matter because they need an additional charging possibility anyway. The VIPV function is thus not so relevant as compared to the annual consumption. If the car consumption or the use were smaller, the PV contribution would be bigger. If a 6 kWh/ 100 km vehicle (something like a TWIKE) runs 10'000 km per year (less than the mean value in Switzerland with short distances and a good public transport for the longer distances), it could match the annual consumption. But for the low insolation of the wintertime, the car still would need an external recharge.

9.3. VIPV chances for regions with less infrastructure and more insolation

For regions with higher mean values of the monthly sunshine duration and more insolation, an annual coverage would be possible. These are regions around the equator. These regions sometimes have less infrastructure, and a VIPV would hence have sufficient customer benefits. Unfortunately, we haven't seen such vehicles in these regions yet. But: Might the VIPV market be quite different from what we think today? The world is bigger than the world of industrialised countries and therefore, VIPVs can have uses that differ from traditional cars.

9.3.1. Success story: VIPV in tropical region

Student Emmanuel Alieu Mansaray from Freetown (Sierra Leone) built his solar car with components from trash for 500 USD[28]. The speed is about 15 km/ h.

What is the USP of this car?

- **Price** : Cheap and affordable
- **Peace** : Works well for him
- **Pride** : Makes him a successful inventor - he wants to go into green energy
- **Pleasure** : He has something unique with a value to use

Fig. 9.3-1 Student Emmanuel Alieu Mansaray from Freetown (Source: LinkedIn)

9.3.2. Success potential

Mahindra, the Indian technology company with over 260 000 employees, built 40 000 EVs named “Last Mile Mobility” (mainly 3-wheeler rickshaw) in the months up to February 2024[29]. The total EV sales are 140 000[30].

The leading version, the “Treo” has a range of about 110 km. On the surface of the “box” version, 400 Wp PV power can be installed. With a daily 6 h nominal sunshine, about 2,4 kWh energy could be produced. This daily production is one third of the battery capacity and is enough to drive 20 km daily. This would be an autonomous VIPV. The customer value for such a version seems to be fair. The question is if Mahindra himself sees a potential for such a version.

Fig. 9.3-2 Mahindra’s leading EV version (Treo) in different models[31]

9.4. Current VIPV models

Four VIPV projects that are or were in preparation should also be mentioned here:

Fig. 9.4-1 Aptera/ Sion from Sono Motors / Lightyear 1/ X-Bus (from left to right)[32]

9.4.1. Aptera (USA)[33]

The Aptera project started in 2005 to develop a light-weight high-efficiency 2-seater with 3-wheels with 700 Wp solarcells and a hybrid drive train. They collected 24 million USD for the development and production. But in 2011, they run out of money and had to stop.

The US light-weight electric vehicle project “Aptera” is now in its second life. With the rising interest in VIPV’s and EVs, they started a second attempt in 2019 for a real electric vehicle. Due to the light-weight and sleek design with a cw value of 0,19, the Aptera needs 100 Wh/ km. It accelerates very fast and has a long range of 400 miles. The PV power can bring back 40 miles per day in very good sunshine conditions. The three-wheeler with 2 seats has a price tag of 33 200 USD. This shouldn’t be a problem for “innovators” and “opinion leaders”.

Fig. 9.4-1 The attractive design of the Aptera will thrill “innovators” and “opinion leaders”[34]

In December 2022, Aptera invited reservations for the car and got more than 100 million USD from the reservation of more than 3 000 cars. But the delivery is delayed from the planned date in 2022 and is now scheduled for 2025 (https://aptera.us/aptera-update-july-2024-powertrain-news/).

9.4.2. Sion Sono Motors (Germany)[35]

Sono Motors was founded in 2016 in Germany. They had 10 000 reservations in 2019 for a production start at the end of 2019. The only developed 4-wheeler with five seats called “Sion” had several interesting features that attracted tens of thousands of prospective customers. The Sion had 1 200 Wp PV power and bi-directional charging-, discharging-capabilities.

On the internet site of Sono motors, some arguments in favour of the Sion could be found:

4 good reasons why the world needs the Sion	Customer benefit
1. Cost- and emission-free range thanks to solar energy	Profit/ Peace/ Pride/ Pleasure but: ➔ same can be achieved with a PV installation!
2. 54 kWh battery without cobalt, nickel and manganese	Solves a problem, which most customers are not aware of ➔ creates confusion!
3. Powerbank on wheels thanks to bi-directional charging	V2H or V2G? Profit? Pleasure? Pride? ➔ USP but difficult to explain - some competitors (Hyundai/ VW/ Ford)!
4. Your independent home storage	Customer benefit? Peace? Profit? Pleasure?

Table 9.4-1 Customer benefits of Sion by Sono Motors (compiled by Muntwyler)

Besides all the problems associated with bringing such a project into the production and sale, the customer benefits are not convincing. Even more scary, the customer benefits can be reached much easier with other investments. For “innovators” and “opinion leaders”, the look of the car, the integrated solar cells and some other functionalities made the “Sion” a fascinating package. It attracted several tens of thousands of prospective customers (including the main author of this report) who paid a reservation fee of 500 EUR or even more. Later, up-front payment could be made to obtain the car earlier. But even the ensemble of this did not provide sufficient funding, and the Sion Sono Motors project was abandoned in the end of February 2023. Some of the know-how is now supposed to be fed into the “PV on trucks etc.” market.

9.4.3. Lightyear (The Netherlands)

«Lightyear» started as a participant of the World Solar Challenge in Australia. It was a starter in the category “solar passenger car” and won several times. In 2016, they started the development of the “Lightyear One”. The dream was that solar cars do not need charging stations anymore[36]. In 2022, the car got the name “Lightyear 0”. Five 5 million EUR were raised in a crowdfunding campaign. From 2019 onwards, reservations could be made. The price for one car was around 250 000 EUR. The target was to produce an exclusive number (less than 1 000 cars) by the Finnish car producer Valmet Automotive. In January 2023, this goal was abandoned in favor of the “Lightyear 2” development that cost 40 000 EUR. In January 2023, the operating company Atlas Technologies, however, went bankrupt. The Holding Atlas Technologies is now concentrating its activities towards the development of flexible solar cells for the car industry. The Dutch project “Lightyear 0” had a surface of 5 m^2 and could reach a range of up to 70 km / day. The cw-value was very low (0,175). The car had special light-weight wheels and was relatively light with a 60-kWh battery.

9.4.4. X-Bus Electric Brands (Germany)

The fourth VIPV concept is the light-weight electric bus called X-bus from the German company Electric Brands. The company started in 2019 with the development of the car in the class L7e (light EV) which restricts the passengers to 3. Several versions for different uses are presented on the website. The price should be between 18 000-25 000 EUR. The production should be done by the Dutch VDL Nedcar in 2025. 17’000 customers made a reservation for the X-bus. The electric drive train has 15-56 kW. The battery is between 15-45 kWh. The empty weight is 500-800 kg, and the total weight of the car is 1 600 kg. The top speed reaches 100 km/ h. The surface for the solar cells is up to 6 m^2, which provides up to 1’200 Wp on the roof. Unfortunately, on 29 January 2024, Electric Brands AG, based in Eppertshausen (Germany), filed an application for insolvency in self-administration with the Darmstadt Local Court (based on information on their website, accessed in February 2024).

9.4.5. What is left after these bankrupts?

The Lightyear 0 project, X-bus and Sion of Sono Motors all went bankrupt. This is not a big surprise, as the customer benefits were not sufficiently addressed, and given the difficulties associated with an extensive series production. Sion from Sono Motors and Lightyear 0 thus joined the many challenges that vehicle producers of similar light-weight electric vehicles faced in the 1980ies.

In a survey, «Sion» subscribers communicated what they will do now[37]:

- 75% miss the Sion very much
- 22% wait for a bi-directional EV
- 36% use their old car
- 19% bought another EV
- 14% will buy another EV now
- 5% want to buy a Lightyear or an Aptera

The biggest interest is in a bi-directional Wallbox (50% would buy one) if the EV can use it! This provides some hint towards what the wishes are of the customers and can be termed "**a lesson learned**". Hence, there still seems to be some room for a VIPV, especially for the "innovator" and "opinion leader" customer groups.

9.5. Light electric vehicles with a potential for conversion to a VIPV

Every light-weight electric vehicle can be transferred to a VIPV. In many cases, this makes sense if the e-consumption is low, the daily distances are short, and the surface is still reasonable. In the streets of Bern, an example of a Kyburz 2-seater with a solar roof could be detected. It seems that the user had mounted an own PV roof which is enough for 400 kWh a year. This is an example how a transformation from light-weight EV to VIPV can be achieved.

Fig. 9.5-1 Kyburz 3-wheeler with PV (Source: Muntwyler)

Fig. 9.5-2 SQUAD (NL) 45 km/ h cheap L 6 (no license) car «pioneer» model[38]

9.6. Others

From time to time, other prototypes and show case cars with PV are presented, especially from Chinese car producers. But mass market producers of known brands have no short-term interest in VIPV as it disturbs their ramp-up of the BEV production[39].

For newcomers in an established market like China or brands in other countries, VIPV would be an interesting differentiation to the established brands. Especially interesting are potential markets without national car productions (like, e.g., Switzerland). But with such a strategy, the newcomers had to start with small numbers for "innovators" and "opinion leaders". In reality, it can be noticed that the Chinese car producers follow the avenue of Japanes car producers of the 1960ies and of South Korean companies in the 1970ies: car with a relatively low price tag and a lot of features aiming at the mass market.

But in the future we will regularly encounter some "unknown brands" with solar cells on it[40]:

Fig. 9.6-1 Hanergy Solar R with thin film solar (2016)[41]

Fig. 9.6-2 Tianjin Solar Chinese Car - VIPV prototype (2022)[42]

Fig. 9.6-3 Alin mach. E5 solar LEV[43]

10 NICHE VIPV MARKETS WITH POTENTIAL

Besides the VIPV applications, there are many mobile "applications with PV on it".

10.1 Recreational vehicles with PV (RVs)

RVs have a second battery for additional consumers in the cabinet of the RV, like light, fridge, communication devices, water pumps, etc. This can't be supplied by the normal car battery. RVs have, therefore, a second battery. The recharge of that battery with PV has been standard over 30 years[44]. This is an established application of "PV in transport".

Diffusion of innovation: This application is standard for more than 30 years and has reached the mass market. But the "mass market" is still a niche market.

10.2. PV on buses and trucks - a big market

Similar to RVs, all standard vehicles with an ICE have a certain need for electricity. Normally, the electricity is produced by a combustion engine and a generator. This is extremely inefficient. In most cases, users neglect this inefficiency and the surplus costs for the gasoline consumption. But in big vehicles like buses, trucks, etc. it is a relevant amount of energy and costly, therefore money is an issue. In most of these applications "PV on the roof of the vehicle" could be a solution.

This is not new: Duty vehicles like the Piaggo 3 wheeler were already transformed in 1985 (for the Tour de Sol race). But the solar cells were too expensive and the lead acid batteries too heavy. Hence, these transformed duty vehicles disappeared. Yet, with the cheap and efficient PV panels of today, things have changed. This is the market that the survivor of Sono Motors and some other companies may be looking for. The potential seems big. Producers and consumers are mostly not aware of this cost saving potential.

Diffusion of innovation: This application is in the "opinion leader" stage.

Fig. 10.2-1 Modern buses and e-trucks can use solar cells to replace «diesel» and save costs. Are they "innovators" or "opinion leaders"?[/45]

10.3 Boats with PV

Similar to the RVs, boats have the same need for electricity. Here, some small wind generators from specialized companies like Marlec (UK)[46] compete with the PV. In some boat types like sailing boats, the PV application is a little tricky as the surface of the boat must be entered to handle the sailing devices. Therefore, the PV industry developed especially slim modules with plastic surface, like the MSX-lite products from Solarex (US)[47].



Fig. 10.3-1 Left: «Korona» from the Technical University of Konstanz (is now in the Deutsche Museum Berlin), designed by Professor Schaffrin, winner of the first solar boat race in the world at the Tour de Sol 1988. Middle: «Planet solar» boat for the trip around the world in 2010 with Swiss Raphaël Domjan (Switzerland) and his team. Photos: Tour de Sol/Planet solar/BKW. Right: «MobyCat» from BKW (Switzerland) for passenger trips, built and in commercial use in 1991 (Source: Muntwyler)

Diffusion of innovation: This application has been standard for more than 40 years and has reached the mass market. But the "mass market" is still a niche market. Some boats like the "Korona" in the 1980ies and especially the "Planet solar" in 2010 created a huge worldwide media impact. The "MobyCat" reaches mass market for passengers on a boat trip on the lakes of Biel-, Murten- and Neuenburg (Switzerland).

10.4 Solar-powered planes - mainly gliders

The solar model airplane and solar powered planes moved to the focus of constructors more than 30 years ago. The US pilot Eric Diamond built the "Sunseeker" and crossed the US in 1990. He used thin film solar cells from Sanyo. The "Icaré II" solar plane was built by Professor Nitschmann from the University of Stuttgart and flew more than 350 km in 1996. Several solar planes were on display as early as on the Solar Salon in Zürich in February 1998. Unfortunately, most of the applications disappeared, together with all projects we have seen around the world. One of the underlying reasons is that it is very difficult to integrate solar cells in the bending and sleek structure of big wings.

Another reason is that Li-batteries now offer a real alternative. Gliders with an electric retractable motor have been on the market for more than 10 years. The first product is the "Antares" of the company Lange Flugzeugbau (Germany), developed by the Power Electronics Laboratory Biel at Bern University of Applied Sciences BFH (i.e., the same people who developed the successful racing solar cars from the mid 1980ies). There are two Antares-models on sale; they are "open class gliders" with 21,5 or 23 m span. The glider ratio is 1:58 for the 21E and 1:60 for the bigger model 23E. The gliders have a retractable motor system. It climbs with 4m/s and more. The planes can now climb up to 5 400 m with one charge.

The Antares E21/ 23E are some of the most powerful gliders in the world. Increasingly, gliders now have retractable electric motor systems. This seems to be a game changer and offers many advantages as compared to the expensive and unreliable ICE with Rotax and Solo Motors. In high performance gliders, the additional weight of the batteries is less severe. On the contrary: To make the gliders faster, pilots load additional weight (water tanks in the wings of the gliders) for long fast distance flights. The battery weight gives more speed due to the higher weight. Some world class pilots in search for new records use Antares gliders.

Fig. 10.4-1 Sunseeker 1990 Eric Diamond[48]

Fig. 10.4-2 Icaré II University of Stuttgart[49]

Fig. 10.4-3 Antares E21 Lange Flugzeugbau (Source: Muntwyler)

Fig. 10.4-4 FES motor system of a Ventus racing class glider from Schempp-Hirth[50]

A new trend, and cheaper than the retractable motor system, is the “Front Electric Sustainer FES System” like on the Ventus from Schempp-Hirth. Most of these planes cannot start by themselves. The first launch is done by a winch or with a towplane.

In April 2024, Schempp-Hirth announced the maiden flight of a Ventus-3E with a retractable electric system. We will see in the future both motors systems as their applications are different. The retractable motors systems have more performance, can start by themselves, but are more difficult to handle than the FES motor system. FES systems are more adapted to clubs where many pilots fly the plane. But overall, we talk about production numbers of hundreds in total. Glider production is a niche market, and the planes are in the price range of several hundred thousand Euro.

Fig. 10.4-5 The DG 808 of the author with PV integrated in the fuselage (Source: Muntwyler)

Integrated PV on the fuselage of high-performance gliders like in DG 808C prolong the autonomy of the bord batteries. For long-distance flights, gliders often have special solar modules supporting the board battery, as these flights can take up to 10 hours and more. The electronics like telecommunication, transponder, navigational aids and “anti-collision devices” consume a lot of electricity. The retractable motors system, if integrated in this DG 808C, needs some electricity to move out the motor of the fuselage and to start the combustion motors. Therefore, sufficient electric power is crucial. The PV modules used for this application are specially fabricated for this purpose[51].

Diffusion of innovation: This application was purchased by “innovaters” twenty years ago and has probably now arrived in the “opinion leader” customer group. But the “mass market" is a tiny niche market. Production numbers for gliders are normally below 1 000 per model.

11 PV ON TRANSPORT INFRASTRUCTURE

11.1 History of solar carports and PV on transport infrastructure

The idea to propel the EVs via an externally-placed PV surface first came up before the 2nd Tour de Sol race in 1986. Two mobile PV power stations from the PV companies “Fabrimex AG” (Switzerland) and “AEG” (Germany) could charge the vehicles of the participants with DC power.

Fig. 11.1-1 Solar charging stations at Tour de Sol 1986 (Source: TdS / Muntwyler)

The step to an AC solar carport was made in 1989 by the “Allgemeine Dezentrale Energieversorgung (ADEV)” company in Burgdorf, Switzerland by installing a solar charging station at the railway station of the city of Liestal. The launch and opening ceremony were part of the 5th Tour de Sol race in Switzerland in 1989 from the south to the north over the Alps.

In 1990, the former Tour de Sol organization member and PV entrepeneur Thomas Nordmann installed a 100 kWp PV plant supported by the Swiss Federal Office of Energy SFOE on the sound barriers of the A12 highway near Chur in the Swiss Alps. With this installation, he defined “PV in transport” as “PV on transport infrastructure”. PV on transport infrastructure has, since then, been one of the PV markets with a high potential in Switzerland. This development was pushed by the Swiss government by launching public tenders for 450 PV installations along the Swiss highways and on parking places[52].

Fig. 11.1-2 PV sound barrier installation 100 kWp A13 (1989)[53]

11.2 Future of solar carports and PV on transport infrastructure

In France, since 2023, parking spots with a certain size must be equipped with PV panels. This mandatory law is a good example how the solar carports can bring their full potential to the grid. The conjunction with slow and fast charging facilities for EVs offers a good synergy for "PV in transport". Depending on the needs of the local grid, a battery or fast charging process and grid support may make sense.

Diffusion of innovation: With a mandate, the solar carports can quickly jump into the mass market.

11.3 Synergies of VIPV and PVSC?

The controlled charge of EVs at PVSC (PV solar charging stations) is an interesting way to manage "PV overproduction". For single users of PV and EV, this is a reality and brings profit from their PV installation. The results are dramatic low energy costs for the driving energy of the car, especially if compared to combustion engine cars.

The controlled charge of EVs is a way to use the grid infrastructure much better and to avoid some reinforcement.

Diffusion of innovation: There is a market for solar carports and infrastructure. It will reach the mass market in the next years.

11.4 Bi-directional EVs offer unique opportunities for PV & EV

The next step are bi-directional EVs. This offers even more benefits for the EVs. The technical hurdles on the hardware side are minimal as the rejection power must not be too big; 11 kVA would be enough. The hardware must be part of the EV itself. Software to optimize the use of the EVs such as the storage system is not "space rocking technology". More complicated are attractive business models, especially as the utility companies are involved, and they are not always very innovative. Bi-directional EVs will eliminate a big part of the private home storage systems for PV owners.

Diffusion of innovation: The expensive external bi-directional charging stations for a few EVs have only been a "bridge technology" for "innovators". As this technology offers additional functionalities and customer advantages with low costs, the integrated bi-directional functionality of EVs is now ready for the mass market. The obstacles to overcome are (i) the car producers need to be sufficiently fast (and innovative) and (ii) utilities need to offer attractive conditions for the users.

Fig. 11.4-1 Bi-directional EV at the PV Laboratory of Bern University of Applied Sciences BFH in Burgdorf, Switzerland[54] (Source: Muntwyler)

12 OUTLOOK & PERSPECTIVES

While the long-distance solar car racings in the 1980ies and 1990ies were successful, VIPV as “PV power on the shelf of a car”, which can propel the car, has not developed in a way what would have been expected back then. But this does not mean that VIPV doesn’t work. This will be outlined below.

12.1 VIPV from a customer perspective still exists

From a customer perspective, “solar cars” are alive and very successful. The customer wants to “drive with solar”. In countries with a good electric infrastructure, this is possible with a stationary grid-connected PV installation and a traditional EV. A PV installation is now cheap, has a long lifetime and can feed much more than an EV. The EVs are less mature, they are still too heavy and not very efficient in terms of energy. But this can be improved by standard engineering processes.

Below is a summary on the customer perspective:

- **Profit:** Cheap PV electricity and an affordable car; both are available for at least the “early majority”.
- **Pride:** Own solar energy and a car with high performance; this is available for at least the “early majority”.
- **Pleasure:** Works fine and looks good; has fully succeeded for the “majority”.
- **Peace:** No problems, low service, etc. and a fast charging network that works; most points are fulfilled. Minor points like the fast charging network have some room for improvement but are fulfilled at least for the “early majority”.

12.2 VIPV can have different shapes and “appearances”

What is probably disturbing is that the “real VIPV” hasn’t made the market breakthrough yet. For “innovators” this might happen with concepts like the “Aptera”. The fundamental requirement is a very efficient light-weight EV and highly efficient PV. Both is within reach of the technical state of the art. But for the mass market, customers want to see much more car versions in terms of size, features and possibilities. This would create a real niche market for “real VIPVs” and swiftly open the doors to the mass market.

12.3 VIPV as a “UPS in motion”

In the mass market, PV on EVs will be introduced as a “car feature”. But this is only needed after the innovations in the car and EV market are saturated. This is by far not the case yet. I expect that such features will emerge around 2030.

EVs and VIPVs can be much more than a standard car. They can act as a “mobile power station” or “uninterruptable power supply”. This is a feature, which can be offered by the producers without big efforts and will differentiate this car from ICE and standard EVs. The VIPV capability will support this functionality.

12.4 Perspectives

The difficulties encountered by the four VIPV projects Aptera, Sono Motors, Lightyear and e-Box remind us of projects in the past. As elaborated above, the customer benefits are not strong enough and the needed financial ressources are very high, in fact, too high.

Additionally:

- The car industry struggles to bring the needed number of BEVs into the showroom. They will wait with VIPV as VIPV complicates everything for them, especially the communication of the customer benefits of EVs.
- PV on boats/ trucks/ buses is still a business case and **this is the first market for VIPVs.**
- Always observe the Chinese car market, many new entries look out for a differentiation in the marketing.

Conclusion: The VIPV is first a niche market.

For the PV industry, VIPVs offers the chance for a first market with high efficient solar cells up to and beyound 30% efficiency. The price can be much higher than for standard solar cells. A VIPV will have about 1-2 kWp on a car for around 50’000 EUR. The lifetime of the solar cell can be lower as for standard solar cells as the car will not last longer than 15 years.

Short-term benefits of VIPVs:

- The advantage of an EV with PV is much better if the EV is light and very efficient. Actually, the EVs are not very efficient (>>10 kWh/ 100km).
  - ➔ A **key performance indicator KPI** describing the ratio of self driven daily distances would improve the efficiency of EVs and would prepare the way for VIPVs.
- PV charging stations are popular among private EV users. It is cheap electricity for the EV and less surplus PV electricity from the own PV installation.
  - ➔ This helps the PV electricity production for EVs and the EV market penetration.
- Public parking places need to be equiped with PV; this should be mandatory and should be introduced in many countries.
  - ➔ This increases the PV electricity production for EVs and pushes the EV market penetration.
  - ➔ There is a chance for low speed, light weight EVs with very low energy consumption. Here is the “solar fraction” much higher and the additional price for the “solar feature” will be moderate. This “solar feature” can be offered as an additional feature.

The own PV installation and electricity from PV helps the market penetration of EVs but lowers the pressure for VIPVs. From a standard point of view of VIPV, the last years have been disappointing. Instead of making progress and enter the market, projects have struggled and quit the vehicle production. At the same time, decentral PV installations are growing faster every year. PV is now the cheapest electric source together with on-site wind generators. The EVs on the market are better and the prices decrease. The EVs will be improved in the near future and will have more functionalities like, e.g., “bidirectional charging”. For customers, such VIPVs will be available in different forms and appearances.

VIPV applications on buses, trucks, etc. will increase as the PV market will differentiate in the future. Lighter EVs will preprare the way for the next stage of VIPVs. “PV in transport” is possible for customers up to the “early majority”.

For regions with (today) a weak electric and road infrastructure, VIPVs offers exciting functionalities. This aspect of “PV in transport” (maybe combined with “PV on transport infra-structures”) is an open field for research, development and application!

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