sccer mobility

Swiss Competence Center for Energy Research

Efficient Technologies and Systems for Mobility

Contents

Introduction

Facts & figures

- 16 patent applications
- 8 spin-offs
- 42 new product processes & services
- 70 models & data collections
- 193 researchers
- 38 prototypes, pilots & demos
- 90 industrial partners
- 190 projects

Gloria Romera Guereca, Managing Director of the SCCER Mobility

My first weeks as Managing Director of the SCCER Mobility in May 2014 were a mix between déjà vu about being back at ETH Zurich and a completely new adventure. There I was, sitting in an office at an institution that I was only too familiar with from my time as a doctoral student, but the tasks that awaited me were entirely new to me. As an engineer, I was used to technical tasks rather than dealing with network management, community building, establishing governance, and communication, dissemination, and monitoring processes.

The scientists involved in the SCCER Mobility, meanwhile, were rather familiar. Most of them shared my technical background. I could relate to what they were doing in their laboratories and to how many hours of hard work and dedication each point in a chart represented. It was wonderful to see how passionate they were about their work. And, I could also identify with the industry partners since immediately prior to joining the SCCER I had worked in the R&D department of a company developing sensors. So I knew both, academic and industrial research.

What's more, I fully identified with the vision of the program: developing the knowledge and technologies necessary to reduce the growing carbon dioxide (CO_2) emissions induced by the transportation of people and goods. The task was as critical as it was multi-faceted because a lot needed to be done in several fields, from behavior to efficient conversion technologies and basic infrastructure. Supporting a program that addresses so many different aspects of the transportation system and was composed of members from diverse backgrounds was very enriching. ►

From day one it has been challenging to keep up with the pace of the SCCER. Especially as I was, so to speak, behind schedule from the start. After all, the Management Office was set up in May 2014, four months after the official start of the SCCER Mobility. When I started there were already several tasks that needed addressing. We had to set up the Management Board, finalize the Governance Regulations, organize and hold the very first Annual Conference, organize workshops to discuss our strategic roadmap with representatives of all groups and industry partners, prepare our first monitoring report, and recruit a new team member to establish the MAS|CAS (Master and Certificate of Advanced Studies). Looking back, it seems impossible that we managed all that in such a short time.

One of the major tasks of the Management Office has been to help the almost 200 members of the SCCER to connect with each other and to understand each other's roles on our road to improving the technologies and gaining the knowledge necessary to decarbonize transportation. When trying to summarize the success of the SCCER network, it is easy to reduce it to key figures like the number of joint publications, white papers, and projects—which are, I must admit, impressive. For me, other important parts of that success include that today research groups cite other colleagues from the network, or that doctoral students refer to the SCCER Mobility's vision in their dissertations, and that students find their first jobs in other groups within the SCCER or decide to take a job in the industry to work on implementing mobility solutions. And I hope that younger researchers in particular profited from the Management Office's efforts to create a community.

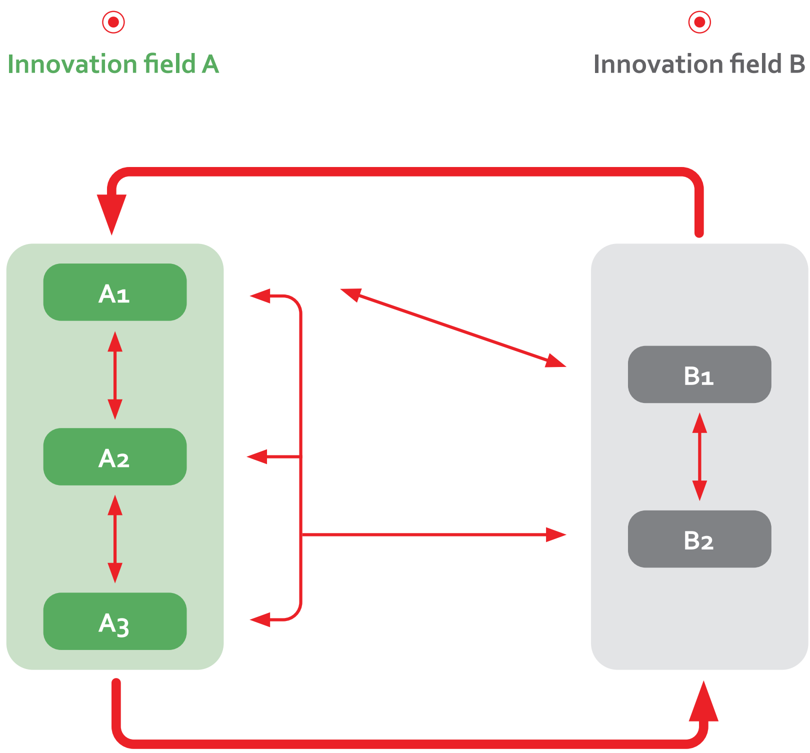
Exchange with the scientists and partners of this community has been the most precious part of my job. Fortunately, we got to meet at several Annual Conferences, or during visits the SCCER's various institutions. Those relationships have been a source of motivation for me with regard to my work in this program.

The past seven years have been a road full of surprises and challenges, and I am very thankful for having had the chance to be part of this big joint effort. I hope that this book will reflect, at least in part, what the SCCER has achieved. The book is not about listing all the milestones and results or quoting all the findings and conclusions. Rather, it focuses on the people involved and on what we have built together.

And I would like to thank this great community. First of all my thanks go to the coordinators of the capacity areas, who invested so much time and energy in helping to build this community. I would also like to thank all the scientists who worked in the program and who supported the Management Office team. And finally, special thanks go to my colleagues at the Management Office, who shared this exciting experience with me.

Structure of the SCCER Mobility

The SCCER consists of two thematic innovation fields, which are each divided into capacity areas that focus on different research topics.



Innovation field A:
Component devices and processes

Capacity Area A1
Systems and components for e-mobility

Capacity Area A2
Chemical energy converters

Capacity Area A3
Minimization of vehicular energy demand

Innovation field B:
System aspects of mobility

Capacity Area B1
Design, demonstration, and dissemination of systems for sustainable mobility

Capacity Area B2
Integrated assessment of mobility systems

Sustainable solutions for Switzerland

Konstantinos Boulouchos, Head of the SCCER Mobility

For seven years, ETH Professor Konstantinos Boulouchos was at the helm of the SCCER Mobility. In addition to new technical and conceptual solutions for sustainable mobility in Switzerland, he helped to build up—together with the Management Office and the boards from science and industry—a large network of researchers and experts. On a personal level, the engineer also gained new insights into the complex socioeconomic aspects of mobility.

What does mobility mean to you personally?
Konstantinos Boulouchos:
A world without mobility is inconceivable. Mobility connects people and enables the exchange of goods.

Mobility tends to have negative connotations in society today because we are primarily focusing on aspects such as air pollution or energy demand and carbon dioxide (CO_2) emissions. Our task—especially as scientists—is therefore to shape the future of mobility in such a way that we reduce the negative impact of mobility as much as possible, while in parallel trying to maximize its positive effects on society.

Was this the objective of the SCCER Mobility?
In essence, yes. The Swiss Competence Center for Energy Research—or, SCCER—along with its focus on mobility was created on the initiative of the Swiss government. Following the 2011 tsunami in Japan and the resulting severe nuclear accident in Fukushima, Switzerland decided to significantly reduce its dependence on nuclear power and fossil fuels and to radically transform its energy sector. This was outlined in the Energy Strategy 2050.

In order to achieve the goals of the Strategy and find solutions to the inherent technical, social, and political challenges, a total of eight energy research competence centers were established, including ours. After all, the mobility sector is very energy-intensive and has so far relied almost exclusively on fossil fuels. These competence centers are financed and managed by Innosuisse, the federal government's innovation promotion agency, with support from the Swiss National Science Foundation (SNSF), while the Swiss Federal Office of Energy (SFOE) has contributed with additional project funding. Essentially, Innosuisse has been mandated with the execution of the "Coordinated Swiss energy research action plan".

The main task of the SCCER Mobility was to develop new mobility concepts and technical solutions in order to improve energy efficiency and to reduce carbon dioxide emissions in particular, while at the same time building up corresponding expertise for science and industry in Switzerland. This competence and capacity building was, and still is, intended to contribute to providing Switzerland with the know-how and human resources necessary for the development of sustainable mobility for the future.

How did you get involved in the project?
Before the intention to establish the SCCER was announced, I served as founding director of the Energy Science Center of ETH Zurich for six years and was therefore part of the delegation from the ETH domain, which was seeking efficient ways of organizing related research activities in collaboration with other institutions. The challenges posed by the mobility sector attracted the interest of ETH Zurich and I was mandated to start organizing a network of researchers and industry experts from across Switzerland.

In order to place the SCCER on the broadest professional foundations possible and to facilitate the transfer of knowledge and technologies from basic research to practical applications, from the outset we wanted to include universities of applied sciences in the network. Having attracted interest from various Swiss research groups, we developed a proposal for Innosuisse in a "bottom-up" way. Andrea Vezzini was instrumental in this process and became the Vice Head of our SCCER. Andrea is Professor of Industrial Electronics at the Bern University of Applied Sciences in Biel and heads the university's Energy Storage Research Centre. Together, we were able to establish a large network of all the major partners from science and industry throughout Switzerland in a short space of time.

Originally the intention of the coordinated action plan was to initiate competition between the various proposals for each SCCER. Quite soon, however, Innosuisse realized that for a small country like Switzerland it would be very difficult to find many quality consortia for the same topic. There was no competing proposal and our SCCER submission was approved by Innosuisse after a thorough assessment. ETH Zurich has served as Leading House of our SCCER from the very beginning. And with the establishment of the Management Office—which has been instrumental to our success—in June 2014, the SCCER could finally start its work (the formal launch had taken place in April 2014).

How did you identify the key issues you have addressed over the past seven years?
As mentioned earlier, in addition to developing innovative technical and socio-economic solutions for the mobility sector our main focus was on capacity building. One of our core objectives was to grow the next generation

"In the end, it all comes down to people."

Konstantinos Boulouchos

of scientists, who will—in the future—contribute to science and industry alike.

"You have to cross the river by feeling the stones."

Deng Xiaoping

Within our SCCER, we therefore decided from the outset to define capacity areas instead of developing work packages or modules. Two coordinators per capacity area constituted, together with the Center's Head, Vice-Head, and Managing Director, the Executive Committee. Due to the high complexity of mobility, three capacity areas dealt with technical aspects and components, such as e-mobility, optimization of fuel cells, combustion, and hybrid engines, as well as the minimization of vehicular energy demands, while two others focused on the mobility system as a whole. Their aim was an integrated assessment of pathways toward a sustainable mobility future. These two capacity areas dealt, for example, with the question of which means of transport are best suited for which kinds of trips, or of how to influence users in their transport choices and how each decision will impact the development of mobility and also the environment and climate in Switzerland. After seven years of work, these assessments will serve as a basis for future decisions.

In addition to the capacity areas, we have developed cross-cutting activities such as the MAS|CAS program and the Learning Lab. Our SCCER was the only one to establish a Master of Advanced Studies (MAS) and three Certificates of Advanced Studies (CAS) on Future Transport Systems. The program was designed first as an instrument for transferring knowledge from academia to industry, but also as an interaction and cross-learning instrument that could incorporate "real-world" problems into the research agendas of the academic institutions concerned. The Learning Lab, meanwhile, was established as a facilitation space for cross-collaboration among research teams from within the research community, and with companies, in new projects with a highly interdisciplinary character.

A very useful view from the outside world was provided by our Advisory Board, consisting of several industrial partners and of prominent academics from abroad. Furthermore, advice from the academic institutions represented on the Board has proven crucial.

Regular webinars and annual conferences rounded off the whole thing, so that there were many opportunities to get to know each other and network. Because, as important as the professional know-how of all those involved is, in the end it all comes down to people.

Are you satisfied with the outcome?
On the whole, yes, very much. But I must admit that the mobility sector is so complex that significant change simply takes decades. On top of this there is also the decentralized structure in Switzerland. Many decisions in public transportation are taken at the cantonal or local level. This makes it more difficult to bring about rapid changes in the highly interconnected transport sector, but has the advantage of ensuring wide participation and bottom-up acceptance.

Significant progress has been made for example in the development of new types of fuel cells, in the integration of renewable fuels, in the design of regional mobility systems using digital technologies in interaction with human behavior, and in the development of integrated assessment tools. We were also very successful with some niche products, such as battery-powered construction machinery. Because there are mainly suppliers to the automotive industry in this country but no car manufacturers, we made a conscious decision to concentrate on selected niches.

For me, the legacy does not so much consist of successful individual projects but mainly of the network of people we built. They will continue our work in the coming years and beyond.

What do you personally take away from these seven years?
Well, you know, as an engineer I am used to searching for technical solutions. Mobility, however, has a major socioeconomic dimension that must be taken into account alongside every technology innovation. Thanks to my time at the SCCER Mobility, I have learned much more about these complexities. Today, I consider these aspects to be as important as technological breakthroughs. Another lesson I learned was that we need a degree of certainty if we are to develop a coherent strategy for reaching our ultimate energy and climate-related targets. At the same time, we must remain flexible enough to adapt to unforeseeable developments that occur along that road to transformation. Or to quote Chinese reformer Deng Xiaoping: "You have to cross the river by feeling the stones". ⦿

Milestones

2013

- Proposal I submitted

2014

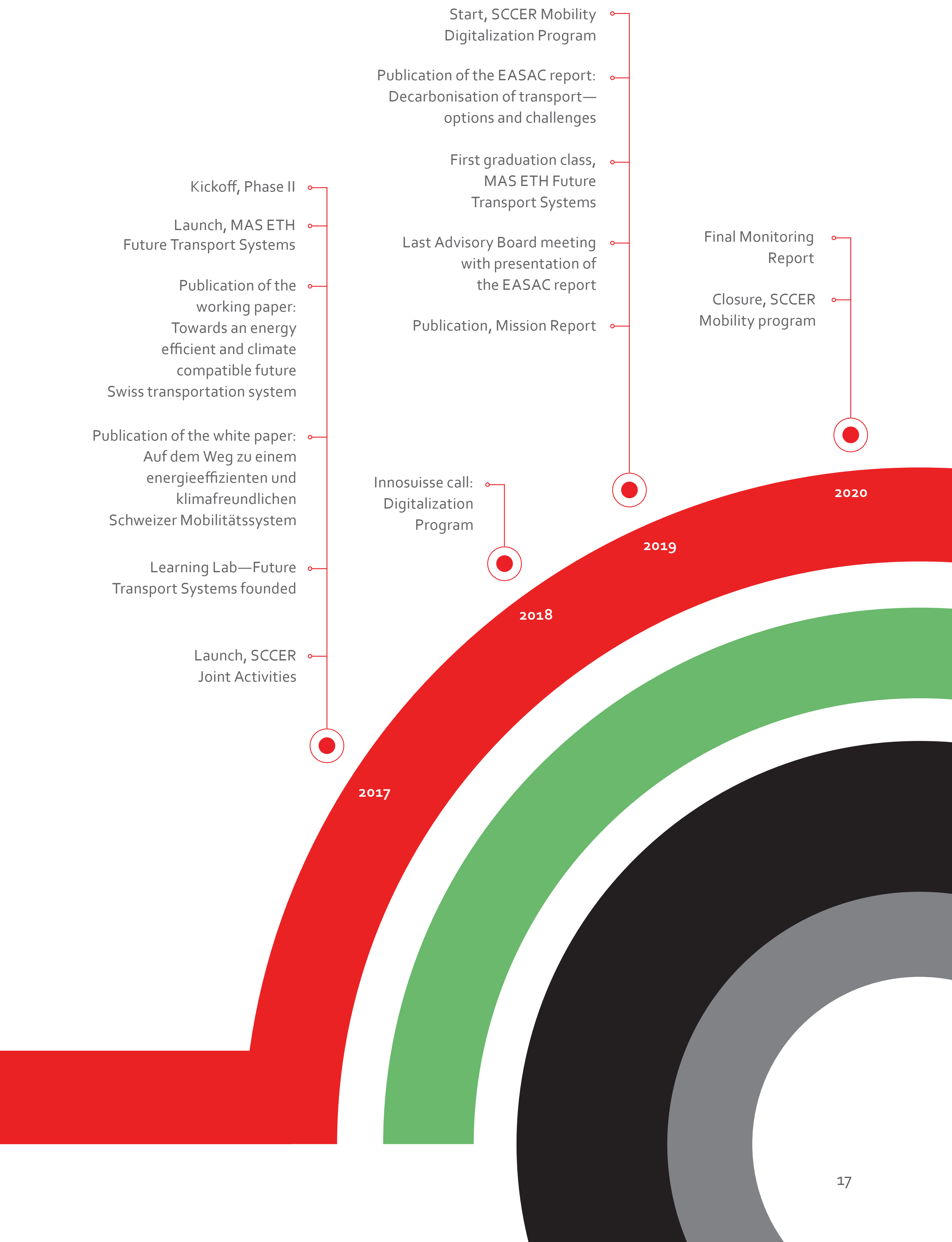
- SCCER Mobility founded
- First SCCER Heads meeting
- Management Office opens
- Launch, SCCER Mobility website
- Formation of SCCER Mobility Board
- First Advisory Board meeting
- Roadmap workshop
- First SCCER Mobility Annual Conference
- Strategic Guidance Project:
  Evaluation of the maximum impact
  potential of various research directions

2015

- Conceptual phase of MAS
  ETH Future Transport Systems begins

2016

- Proposal II submitted


Kickoff, Phase II
Launch, MAS ETH Future Transport Systems
Publication of the working paper: Towards an energy efficient and climate compatible future Swiss transportation system
Publication of the white paper: Auf dem Weg zu einem energieeffizienten und klimafreundlichen Schweizer Mobilitätssystem
Learning Lab—Future Transport Systems founded
Launch, SCCER Joint Activities
2017
Innosuisse call: Digitalization Program
2018
Start, SCCER Mobility Digitalization Program
Publication of the EASAC report: Decarbonisation of transport—options and challenges
First graduation class, MAS ETH Future Transport Systems
Last Advisory Board meeting with presentation of the EASAC report
Publication, Mission Report
2019
Final Monitoring Report
Closure, SCCER Mobility program
2020

1

The five capacity areas

1.1 Innovation field A

Component devices and processes

A1 Systems and components for e-mobility

How can electrical energy be efficiently stored? This was the main question examined by Capacity Area A1 (CA A1). Electric cars can only be successful if the performance, reliability, charging time, lifetime, and costs of batteries are up to the mark. The researchers of CA A1 explored, in particular, battery solutions for niche e-vehicles. And to investigate batteries further they also established the Swiss Battery Research Platform.

The future drives electric

Seven years ago, the storage of electrical energy was considered the biggest obstacle to the introduction of electrically powered vehicles. Capacity Area A1 (CA A1) has not only conducted intensive research to solve this technical challenge, it has also been instrumental in establishing e-vehicles in Switzerland for public transport as well as in niche fields such as agriculture or construction sites.

Our goal was to address the biggest challenge of electromobility: the storage of electrical energy. So far, storage has been the main obstacle to the introduction of electric propulsion and auxiliary units to automotive applications. Consequently, we focused our research on battery performance, reliability, charging time and technology, lifetime, and cost.

As market conditions and infrastructure vary strongly from country to country, we decided early on to limit our research on storage solutions to Switzerland. Within the CA A1, we worked in particular on electric storage solutions for rail and buses, and for construction, agricultural, or municipal utility vehicles. At the core of our research was the newly founded Swiss Battery Research Platform, with battery test facilities at the Bern University of Applied Sciences (BFH), ETH Zurich, Empa, and the University of Applied Sciences Buchs (NTB Buchs)*. In this platform, we have an impressive infrastructure for testing and characterizing battery cells and systems, distributed across various universities, providing the necessary research infrastructure for the development of battery systems for special vehicles.

In addition, competencies and guidelines for testing as well as novel algorithms for the management of the electrical and thermal behavior of battery systems have been built and developed. ETH Zurich and NTB Buchs also investigated the power electronics required for the integration of battery systems in applications and for the charging infrastructure. They were able to demonstrate efficient and compact systems for connecting batteries to the high-voltage systems of locomotives and wireless charging systems.

Close collaboration from the beginning

From the start we had a multidisciplinary and inter-institutional team with partners from several universities of applied sciences (BFH, NTB Buchs, HSLU (Lucerne University of Applied Sciences and Arts)) and the ETH domain (ETH Zurich, Empa). We also worked with other Swiss competence centers, mainly the SCCER Heat & Electricity Storage and the SCCER Future Swiss Electrical Infrastructure. Many of the researchers involved knew each other before the start of the SCCER Mobility, which made collaboration easier and helped us to coordinate our goals from the outset.

One of the best results of this close collaboration is the "eDumper" (see pages 24/25), the largest electric dump truck in the world. Virtually all groups from CA A1 contributed to the development of the battery for this truck, and jointly coordinated publications and press coverage.

To further improve exchange between the partners, CA A1 organized regular events and conferences. Together with Inspire AG, a strategic partner of ETH Zurich, we organized a conference on batteries in automotive applications, and with the Ökozentrum a conference on the second life of batteries. Both were excellent platforms for presenting the work of our individual groups. Some partners within the capacity area co-coordinated

** NTB Buchs was integrated into the Eastern Switzerland University of Applied Sciences (OST) on 1 September 2020.*

their student projects and shared their infrastructure, which benefited research and education, thus helping to support the SCCER's goal of capacity building.

During the SCCER Mobility, e-mobility has made quite some progress. Battery electric vehicles (BEV) have become increasingly accepted as the most promising way to decarbonize individual personal mobility. This is mainly due to a better understanding of the technical potential of the battery technology.

Improving battery technology
In the past, the biggest problem was the low density of lithium-ion batteries. Meaning that they took up much more space in an e-vehicle than they do in a conventional, fossil fuel-based engine. The energy density of lithium-ion battery technology has tripled in the last 10 years. As a result, the prices of battery systems have been falling by 15 percent per year. It is predicted that purchase price parity between a BEV and a car with a diesel engine will be achieved between 2023 and 2025. SCCER Mobility researchers contributed to a better understanding of aging, safety, and thermal behavior by providing our industrial partners with knowledge of how to use battery electric powertrains for their products. For example, we developed a tool to predict the lifetime of batteries, which enabled HESS Carrosserie AG, a bus manufacturer, to provide warranty for their product.

With HESS, we also developed the most successful product of CA A1, the SwissTrolley plus (see page 28). It demonstrates how an innovation driven by battery-based storage can improve public transportation. Today, the progress made in the electrification of articulated buses is relatively visible in public transport in several Swiss cities (Biel, Bern, Zurich, Lucerne) and a recent study carried out on behalf of the Swiss Federal Office of Energy (SFOE) has revealed a CO_2 reduction potential of 87 percent for electric trolleys compared to diesel buses, based on 12 years of operation.

The "evolaris" electric aerobatic aircraft is another special project of CA A1. To date, conventional aerobatic aircraft have been so noisy that they often draw complaints from residents. An electronically operated aerobatic plane could remedy this. The development of an aircraft is, however, a complex affair. Within the SCCER, we have already managed to successfully test 80 percent of the critical functions of the complete electrical drivetrain. Further stress tests need to be carried out before a maiden flight can take place.

Another project we are particularly proud of is the e-tractor of Rigitrac Traktorenbau AG (see page 26), with which we demonstrated how electric propulsion can provide agricultural vehicles with additional power and enable auxiliary equipment to be operated with greater efficiency. The non-road sector accounts for about 8 percent of CO_2 emissions in Switzerland; in terms of pollutant emissions, however, it accounts for between 20 percent (hydrocarbons (HC) and nitrogen oxides (NO_X)) and 32 percent (particulate matter (PM)), depending on pollutant emissions considered. ►

Elsewhere, large batteries were integrated into the drive system of locomotives with Bombardier AG to enable dual-mode operation and increase the efficiency of diesel-hybrid locomotives.

In summary, most of our projects were determined by the needs and requirements of our industrial partners. The advantage of this is that we could apply the outcomes of most of our research directly to the development of actual products. SwissTrolley plus, for example, is now in use in an increasing number of Swiss cities.

Another impressive example of such directly applied research is the eDumper. The Komatsu eDumper of Kuhn Schweiz AG is being used to transport lime and marl from an elevated mining area to a permanently installed transport system. The use of the eDumper saves around 50,000 liters of diesel per year.

Main goals achieved

Looking back, we have achieved our main goals. We established a research platform for battery systems, and built a large network encompassing partners from the academic and industrial sectors. In addition to solid scientific results, we also proved their validity with successful pilot projects and demonstrators. Concentrating our efforts on a relatively constrained topic allowed us to make faster progress along the innovation timeline and to generate valuable input for product development.

We're convinced that the outcomes of the past seven years will become even more visible thanks to several products that will be launched in the coming years, among them an electric tractor for agriculture, electric buses, electric trains, electric aircraft, and large electric construction vehicles. What once seemed like a farfetched idea has become reality, and will soon be mainstream.

Prof. Dr. Andrea Vezzini
Capacity Area Coordinator
Electrochemical Storage and Converter Group,
Energy Storage Research Center (ESReC),
BFH

Project highlight

Electric giant for heavy work

Since January 2018, a gigantic dump truck has been in use in a quarry in the Canton of Bern: the "eDumper", which was converted from a diesel vehicle into the world's largest electric vehicle in just 18 months.

With an empty weight of 58 tons and a payload of 65 tons, the eDumper is good for three world records. Firstly, it is the largest and most powerful battery-powered, electric, wheeled vehicle in the world; secondly, it contains the largest battery ever produced for an electric vehicle; and thirdly, no similar vehicle has ever been able to avoid emitting such a quantity of CO_2 during work. Over the next 10 years, the eDumper is expected to produce around 1,300 tons less CO_2 annually than the diesel version, while transporting 300,000 tons of rock.

The eDumper is a battery-powered conversion of the Komatsu HD 605-7 diesel truck. It is equipped with a high-performance lithium-based storage system, which can be charged and discharged several thousand times. The onboard energy supply was the biggest challenge since sufficient energy had to be squeezed into a limited installation space. In addition, the battery technology had to be safe and reliable, have the highest possible energy density, and offer the longest possible service life. After all, liquid fuels such as diesel or gasoline have around ten times the energy content per unit of weight compared with electrical storage chemistry.

To ensure a sufficient service life, the temperature also needed to be kept around standard room temperature (20 to 25°C), which is quite a challenge—especially with such a large lithium-ion battery. A special air-cooling

Industrial partner statement ——

Close cooperation

Sepp Knüsel

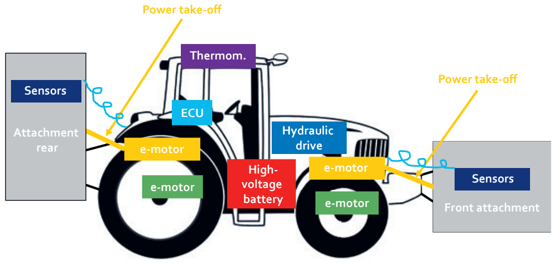
“Thanks to excellent close cooperation with the University of Applied Sciences Buchs, we were able to build up our know-how in the field of e-mobility for our agricultural machinery very quickly. Our purely electrically driven prototype E-Rigitrac SKE 50 has generated great demand from our customers. Visitors to Agrama honored our efforts with the Swiss Innovation Award 2018.”

Sepp Knüsel, CEO and owner of Rigitrac Traktorenbau AG

The world’s largest electric vehicle: the eDumper.

system was therefore installed. Also, worst-case scenarios, like battery failure, were defined and aspects of occupational safety examined. Finally, the charging and discharging infrastructure had to be set up in the mining area where the eDumper is now used. The charger must also be capable of feeding excess energy back into the operating network so that the eDumper can again store braking energy when it is next driven.

Today, the green eDumper is fully integrated into the quarry’s dumper family. Thanks to its electric drive, it is not only much more energy-efficient, but also very fast and drives almost like a limousine. The infrastructure has already been prepared for its giant colleague.



Rigitrac's electric tractor was awarded the Swiss Innovation Award 2018 by the Swiss Agricultural Engineering Association.

Project highlight ——

The emission-free agricultural hand

The Swiss tractor manufacturer Rigitrac Traktorenbau AG builds only 30 agricultural machines per year. From 2017 until 2019, researchers from the University of Applied Sciences Buchs (NTB Buchs) worked with Rigitrac to develop an electrified tractor that can use three kinds of auxiliary equipment. Unlike conventional tractors with diesel engines, the electric Rigitrac tractor is not only emission-free, but also extremely quiet. And all it takes to charge it is a conventional mains socket.

At the heart of this e-tractor is an intelligent control system that minimizes the energy requirements of both tractor and its equipment. In addition, both axles and the attachments are driven separately by e-motors. This means that the attachments can be supplied with power as required, resulting in decisive energy savings.

All sensor values of the prototype are monitored and evaluated via the cloud. In this way, various operating parameters were optimized, and the energy requirements of the overall system minimized. Field tests showed that considerable energy savings could be achieved in mowing operation. When mowing, the energy requirement per area could be reduced by a factor of six compared to a comparable diesel tractor.

And the e-tractor has even more advantages. If charged via a photovoltaic system on the roof of a barn, farmers can massively reduce their energy consumption. On an average Swiss farm of about 18 hectares, the electric tractor powered by photovoltaic electricity saves the additional grey energy needed for the auxiliary electrical equipment within 1.9 months. This means an electric tractor emits approximately 12 t of CO_2 less per year.

NTB Buchs documented its work and development in the form of design guidelines. For its part, during the project Rigitrac hired an electrical engineer who supported the work of NTB Buchs and is still with company today. The project is just one example of knowledge transfer within the SCCER framework, in this case from NTB Buchs to Rigitrac.

Portrait: researchers ——

Developing better batteries

Ueli Kramer, Christian Vögtli

For years, Christian Vögtli und Ueli Kramer worked together at the SCCER Mobility. At the BFH Energy Storage Research Centre, they built—among other things—a customer-specific test facility for batteries and battery management systems. Today, Ueli Kramer is head of SBB's Competence Center for Energy Storage, while Christian Vögtli is working as an engineer at the BFH Energy Storage Research Centre.

How would you describe your professional vision?
Ueli Kramer:
I would like to develop sustainable solutions and use my network of experts to do so. Because to change things today, technical skills and an understanding of corporate policy are more important than ever before.

Christian Vögtli:
Sustainability is also a priority for me. Working on the details of energy systems for construction sites, my goal is to improve existing (motorized building) tools, increasing their energy efficiency.

Why did you choose electrical engineering as your field of study?
Kramer: When I chose my studies, I already knew that I wanted to have something to do with sustainability. By studying electrical engineering I gained the technical knowledge and certain project leading capabilities that I need in my job today.

Vögtli: I came into contact with the topic of sustainability at an early stage. Already in 1996, my parents built a house with low-tech, energy-saving features, rainwater system, and a thermal and later an electrical solar power system. After my training as an automation engineer, I decided to deepen my knowledge. Electrical engineering solutions will increase efficiency and thus contribute to sustainability because electricity can be transformed into light or mechanical power highly efficiently.

What interests you most in your field of research?
Kramer: Combining energy storage and mobility interests me most. Solutions in this area could contribute to a zero-emissions economy.

Vögtli: Change in this area is already discernable. At the system level, for example, more powerful converters and modular battery systems are appearing, making decarbonization solutions increasingly affordable.

What projects are you currently working on?
Kramer: As head of the SBB Competence Center for Energy Storage, I am working directly on the sustainable transformation from fossil fuel-powered systems to renewable solutions. Our projects range from studies and technical support for the upcoming procurement of emission-free shunting locomotives, through the active eco-conversion of our existing diesel-engine fleet, to the decarbonization of our road-based vehicles and special machinery on railway construction sites. It is about building and coordinating a growing team of engineers with different skills, while working within the SBB on different projects and topics as well as supporting other public transport sectors via our experience and know-how.

Vögtli: In the team of Ueli Kramer, I mainly work on solutions to decarbonize railway construction sites. For example, replacing diesel generators with electrical batteries. I also assist with the procurement of battery- or cable-electric working tools, which will replace gasoline-driven ones in the coming decade. ►

A high-performance battery lets the SwissTrolley plus operate even without a catenary.

Project highlight ——

The trolleybus that just keeps going

For over 75 years, the trolley bus has been one of the most popular means of transportation in Zurich. With "SwissTrolley plus", researchers from the Capacity Areas A1 and A2, in collaboration with the Zurich Public Transport authority (VBZ), have managed to transform the traditional trolleybus into a sustainable electric mobility vehicle in line with the energy goals for 2050.

Previously, trolleybuses had only been able to operate over short distances without their catenary, using an onboard diesel generator to supply the power required. For SwissTrolley plus, proven catenary technology was combined with up-to-the-minute battery technology. The novel, high-performance traction battery allows emission-free journeys without a catenary. This makes it easier to extend lines and also to dispense with complex catenary technology at traffic hubs. The battery is designed in such a way that in addition to driving in battery mode the current peaks of the overhead contact line are flattened. Thus, SwissTrolley plus relieves the power supply system considerably and reduces transmission losses.

Conventional trolleybuses can recover braking energy and convert it into electrical energy, feeding it back into the supply lines. As they lack an intermediate storage unit only some of that braking energy can be recovered by other busses on the same supply grid, any excess energy being wasted. The traction battery of SwissTrolley plus, however, allows the trolleybus to capture and reuse almost all regenerative braking energy. As a result, SwissTrolley plus requires up to 15 percent less energy than a conventional catenary bus.

SwissTrolley plus is also equipped with sophisticated software to plan and control the battery charge level with foresight and efficiency. A self-learning, optimized energy management system has been developed that takes a combined view of the energy flows of the drive system and the passenger compartment air conditioning, thus enabling maximum energy efficiency.

Currently, researchers from the Energy Storage Research Centre at Bern University of Applied Sciences (BFH) are still investigating prediction models and methods to maximize battery life. The reason: most catenary buses are in service for up to 30 years. And even with the most modern batteries, such a long service life is still unthinkable. At the Institute for Dynamic Systems and Control at ETH Zurich, further testing and development of the adaptive control system are expected to bring further reductions in energy demand.

For the team of Andrea Vezzini at the BFH Energy Storage Research Centre, I was involved in creating test settings for batteries or battery management systems, and participated in engineering specific battery systems for various customers.

When did you join the SCCER Mobility? Can you give us an insight into your project there?
Vögtli: Thanks to my work at the BFH Energy Storage Research Centre I was involved in the SCCER Mobility from the very beginning.

Kramer: I joined the SCCER after my studies, while working for Solar Impulse.

Why did you decide to join the SCCER Mobility?
Vögtli: I wanted to participate because the meetings, presentations, and webinars were an excellent platform for exchange between research and industry.

Kramer: Right. It was this very exchange that was most important to me too.

Are there any highlights or groundbreaking achievements you would like to share with us?
Kramer: It was exciting to see how completely new solutions and products could be created by combining existing products.

Vögtli: I was very impressed by the launch of the eDumper.

What was the toughest challenge?
Kramer: To get the commitment of policy makers for our decarbonization projects and to move ideas from theory into reality. It's not just a matter of finding the technical solution; a lot of communication is needed to inform and motivate everyone and to keep everyone abreast of the latest developments.

Vögtli: That's true. Another problem is that, especially for people from industry, the readiness level of the latest research is often too far away from market entry. In order to create understanding between industry and research, it helped to understand both sides.

Which interdisciplinary approaches and exchanges with colleagues helped you to find solutions?
Kramer: The direct exchange possible during breaks at the SCCER events or at other meetings helped most.

Vögtli: Yes, indeed. It is very important that researchers, engineers, and practitioners sit down together at one table to find a robust solution.

What will you remember most about the SCCER Mobility?
Vögtli: The annual conferences.

Kramer: True; I agree. And I also liked the SCCER's approach to research, which was along the lines of never forgetting reality and going quickly into practical testing. They also told us that if there were things that we were not good at, there would always be someone else to help us out.

What do you do when you need to "recharge your batteries"?
Kramer: I like outdoor activities best. I go mountaineering, biking, skiing, and trekking, with my wife and son.

Vögtli: I love mountain biking—sometimes with Ueli—and triathlon sports. When I want to take it easy, I go hiking or take my stand-up paddle out, which is very relaxing. ⦿

Short profiles —

Ueli Kramer

2017–today Head of the SBB Competence Center for Energy Storage
2012–2015 MSc in Electrical Engineering, BFH

Qualifications and awards

- UIC Award for renewable innovation

Christian Vögtli

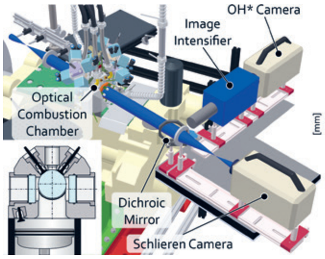
2015–today Engineer MSc at the BFH Energy Storage Research Centre
2012–2015 MSc in Electrical Engineering, HSLU & BFH

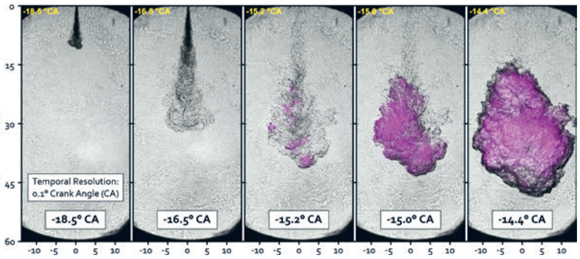
Qualifications and awards

- Styner Award for an Innovative Master Thesis

A2 Chemical energy converters

E-mobility is not a solution in all areas. For example, heavy-duty vehicles need high energy density and ranges and hence will probably not be able to run on electricity in the near future. The researchers from Capacity Area A2 (CA A2) therefore focused on adapting conventional fossil fuel-operated powertrains to more efficient internal combustion engines, and on renewable fuels and fuel cell technologies. Their objective being to increase energy efficiency and to reduce greenhouse gas emissions and other pollutants.





Left: Test setup with cameras.

Right: High-speed sequence to examine spray penetration/evaporation, ignition, and flame propagation.

Project highlight ——

Observing ignition and combustion

Internal combustion engines (ICE) will continue to play a role in global energy strategies during a transitional phase, especially in heavy-duty/marine applications or for decentralized power generation. It is therefore important to make ICEs more environmentally friendly. Lean-burn gas as well as dual-fuel or other multimode combustion processes offer attractive ways of complying with emission standards. These concepts allow us to reduce CO_2 emissions while also contributing to significantly lower particulate and NO_X pollution—all with efficiency comparable to diesel combustion. So far, however, ignition and combustion processes are still posing considerable challenges to the reliable operation of these new types of engines.

To investigate and improve ignition and combustion processes, researchers from the Aerothermochemistry and Combustion Systems Laboratory (LAV) at ETH Zurich and from the Institute of Thermal and Fluid Engineering (ITFE) at the University of Applied Sciences and Arts Northwestern Switzerland (FHNW) developed a unique optical engine test rig called Flex-OeCoS (short for Flexibility regarding Optical engine Combustion diagnostics and/or development of corresponding Sensing devices and applications). This facility enables the investigation of fundamental in-cylinder processes such as mixing, ignition, combustion, and emission formation. Flex-OeCoS also allows the researchers to achieve engine-relevant compression/combustion pressures (max. 130/240 bar), temperatures, and turbulence conditions. The unique optically accessible combustion chamber enables the application of various optical (high-speed) techniques together with the time-resolved acquisition of operation conditions. Depending on the configuration, both compression ignition and various dual-fuel combustion concepts, such as pilot spray or pre-chamber, jet-fired low- or high-pressure gas injection, can be investigated in the optical combustion chamber.

The researchers used the Flex-OeCoS to investigate different dual-fuel concepts and the influence of various parameters, such as charge composition/pilot fuel, temperature/pressure, flow/turbulence, and injection properties. The experiments have yielded extensive insights into the thermochemical processes of dual-fuel combustion and this data is also being used to enhance numerical methods, both contributions further improving engine development. Moreover, the novel test facility allows extended investigation of renewable (e.g., biomass, power-to-gas, or power-to-liquid) or hydrogen-containing fuels, with the aim of further reducing CO_2 and pollutant emissions.

Chemical energy converters ——

On the road to fossil-free transport

Long-distance road transportation is over-proportionally relevant for carbon dioxide (CO_2) emissions. To reduce CO_2 from road traffic, the use of renewable chemical energy "carriers" such as hydrogen and synthetic gaseous or liquid fuels is indispensable. The vision of Capacity Area A2 (CA A2) is fossil-free and energy-efficient long-distance road transport. During the SCCER Mobility time frame, CA A2 and its industrial partners significantly contributed to this target with several new technical solutions.

CA A2 of the SCCER Mobility focused on the efficient and economic conversion of renewable chemical energy into electrical or mechanical power for the propulsion of a vehicle, with the aim of creating efficient and fossil-free road traffic. With their various projects, researchers from CA A2 worked on two subtopics: fuel cell systems and combustion-based systems.

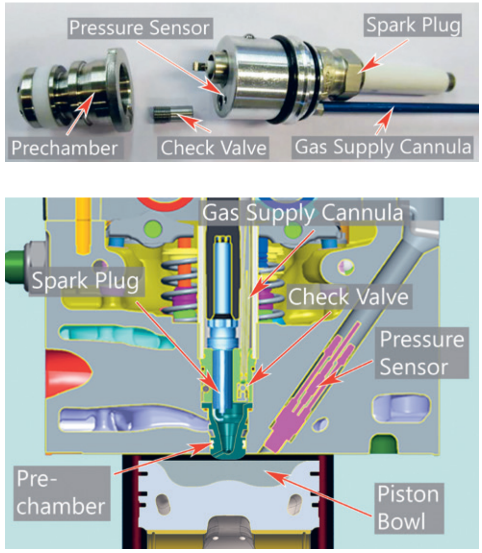
Within these projects, there were also overlaps with various projects from other capacity areas—namely, with A1 for hybrid-electric powertrains (SwissTrolley plus), with A3 for the investigation of real-world vehicle operation (ESMOBIL-RED), and with B2 for life cycle assessment questions. CA A2 was also involved in Joint Activities with other SCCERs, such as the white paper *Perspectives of Power-to-X technologies in Switzerland*, which describes the transformation of the Swiss energy system, or other activities in the field of energy storage demonstrators (Coherent Energy Demonstrator Assessment (CEDA)).

Fuel cell research projects

Hydrogen is a promising energy carrier for the carbon-free or carbon-reduced mobility system of the future. When produced from renewable sources such as wind or solar, the CO_2 emissions of so-called green hydrogen (H_2) will even be below 2 kg CO_2/kg H_2. Aside from being an energy source, hydrogen can also be used to store the fluctuating electric power from renewables, which otherwise might be lost. It thus allows valuable sector coupling between the electric grid, the gas grid, and the mobility sector.

For mobility, hydrogen offers the prospect of fast refueling (less than five minutes for a passenger vehicle) and long ranges due to its high energy density. Hydrogen is therefore also suitable for heavy transport applications such as trucks, buses, and trains. To use it in vehicles, hydrogen is usually converted back to electricity using fuel cell technology, in most cases low-temperature polymer electrolyte fuel cells (PEFC). But despite its environmental and technical advantages, PEFCs present major challenges, one of the most important being cost competitiveness. Three research groups from the Paul Scherrer Institute (PSI) and one from the Zurich University of Applied Sciences (ZHAW) thus worked primarily on more cost-effective solutions for fuel cell systems.

One of the promising approaches they explored is the development of an evaporation cooling system for fuel cells. This solution uses the phase transition of water, injected directly into electrochemical cells, as a cooling principle. They pursued a material-based concept in which modified porous materials allow the evaporation of the coolant water directly in the electrochemical cell. The project began in 2013 with the development of these modified porous structures. In the course of the project, fundamental work on the evaporation process in porous materials was elaborated by PSI researchers together with a group at the Swiss Federal Institute of Technology in Lausanne (EPFL). The ZHAW, meanwhile, contributed cell-level modeling, a principle that was proven to work experimentally at PSI. By the end of the SCCER Mobility, the project aims to show a demonstrator in cells on a technically relevant scale (see page 36). ►



Concept of the novel turbocharged pre-chamber gas engine.

Project highlight ——

Promising gas engine

Gaseous fuels are established and well suited for the transport sector. Vehicles powered by pre-processed biogas or synthetic methane ("e-gas") have very low CO_2 emissions. Pre-processed biogas and synthetic methane can also be mixed, and—with up to 130 octane—have a significantly higher knock resistance than petrol, making them ideal fuels for internal combustion engines. For high loads, such as freeway driving, gas-powered vehicles already achieve higher efficiencies than gasoline-powered engines.

Within the EU Horizon 2020 project "GasOn", which started in 2015, around 20 partners—including Empa and ETH Zurich, as well as four European automobile manufacturers and well-known automotive suppliers—explored the potential of natural gas-dedicated vehicles.

In the work package led by Volkswagen Group Research, a novel turbocharged pre-chamber gas engine concept with a high compression ratio optimized for lean operation was developed. While researchers from Empa and the Institute for Dynamic Systems and Control (IDSC) at ETH Zurich were responsible for the setup, operation, and control of the engine, scientists at ETH's Aerothermochemistry and Combustion Systems Laboratory (LAV) focused on the pre-chamber design using experimental equipment and numerical simulations. LAV findings were then incorporated into the experimental validation of the engine combustion concept.

A flexible motor-control system developed by IDSC allowed the new combustion process to be implemented in the test engine. Tests at Empa's engine test site resulted in a record-breaking 45 percent peak efficiency. By way of comparison, petrol engines for cars typically achieve figures of 35 to 40 percent.

Despite the promising results of the GasOn project, the exhaust gas aftertreatment still needs further research due to the lean combustion process. The project has, however, shown that gas engines can achieve similar efficiencies as (significantly larger) diesel engines.

The subtopic "combustion-based systems" was explored by four research groups—two from ETH Zurich and one each from Empa and the University of Applied Sciences and Arts Northwestern Switzerland (FHNW). These groups bring together competences in the fields of experimental optical and spectroscopic ignition and combustion diagnostics, detailed numeric simulation, and model-based engine control, as well as engine technologies.

The starting points for research in this subtopic were highly optimized fossil-diesel and fossil-gasoline operated internal combustion engine technologies. Today, conventional gasoline or diesel engines are often simply "converted" to run on renewable fuels such as biogas or biodiesel, without the engine having originally been designed for the properties of these fuels. This often leads to a loss of efficiency, and means that efficiency-enhancing properties of renewable fuels, such as higher anti-knock properties or a higher cetane number, do not even come into play.

Improving internal combustion engines

The researchers identified the optimization of gas engines as a major research path. Not least because of the significant biogas potential in many countries worldwide and the comparatively easy synthetization of methane by the catalytic conversion of hydrogen and CO_2.

Currently, the main limiting factor for the efficient use of methane is its low reactivity. To better understand this process, the researchers decided to first improve ignition diagnostics. To this end, an existing combustion investigation system with optical access at the Aerothermochemistry and Combustion Systems Laboratory (LAV) at ETH Zurich was adapted for basic investigations, for both experimental and numeric research. At Empa, meanwhile, a constant-volume combustion chamber with optical access for spectroscopic analytics was installed. And a diesel pilot fuel injection concept was developed together with a combustion control concept by the Institute for Dynamic Systems and Control (IDSC) at ETH Zurich.

The three research institutes' project was expanded in 2015, becoming part of the European Horizon 2020 project "GasOn" when Volkswagen Group Research selected the Swiss institutes as scientific partners. The aim of GasOn was to develop a novel pre-chamber-based combustion concept for passenger car engines (see page 34). This EU project started with fundamental research questions regarding the design of the pre-chamber and its combustion control over technological intermediate steps and ended with an entire engine demonstrator. Finally, an efficiency record of 45 percent for passenger car engines was achieved.

Since exhaust gas pollutants' compliance with current European legislation was not part of GasOn, a follow-up project was initiated with support from the Swiss Federal Office of Energy (SFOE), involving a shift from air-diluted to stoichiometric exhaust (inert) gas-diluted combustion, which allows the application ►

Figure 1

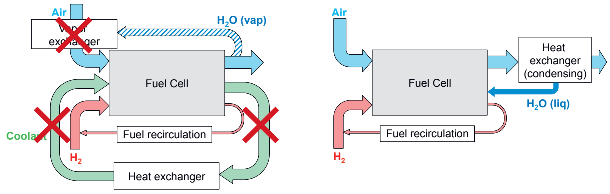


Figure 2

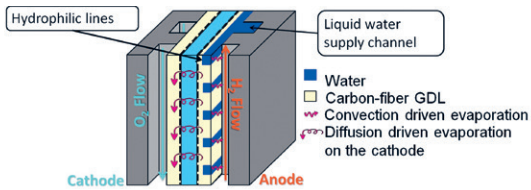


Figure 1: Left: Simplified scheme of a conventionally cooled fuel cell system with humidification of the process air; Right: The novel evaporative cooled system with direct injection of water.
Figure 2: Schematic representation of the evaporatively cooled PEFC concept.

Project highlight ——

Cool fuel cells

Even though state-of-the-art polymer electrolyte fuel cells (PEFCs) reach system efficiencies above 60 percent, a substantial amount of heat has to be "rejected" into the environment. Conventional approaches to cooling transfer waste heat to a liquid coolant that flows through dedicated cooling channels in the cell. This yields high heat fluxes from the cell to the coolant and ensures well-controlled temperature distribution, but requires a complex and thick design of bipolar plates.

To find a better approach two research groups from the Electrochemistry Laboratory (ECL) at the Paul Scherrer Institute (PSI) and the Institute for Computational Physics (ICP) at Zurich University of Applied Sciences (ZHAW) developed, within CA A2, a novel cooling concept based on the evaporation of water. The concept uses modified gas diffusion layer materials including hydrophilic lines, part of the hydrophobic porous structure, filled with water. The advantage of this solution is that it does not require separate cooling channels, thus reducing the volume, complexity, and cost of the fuel cell system by up to 30 percent. The water also evaporates near the membrane, which contributes to better humidification and thus to higher ionic conductivity. This allows higher operating temperatures without the need for external humidification (as a result, only a smaller heat exchanger/condenser is required).

The project started in 2013. During the first phase of the SCCER Mobility, ideas for material development were collected and basic investigations of the evaporation process from porous materials and modelling at the cell level were carried out. In the second phase, from 2017 to 2020, demonstration in small single cells and upscaling to cells on a technically relevant scale were performed.

of a three-way catalytic converter system. This, however, increases the challenge posed by ignition. A novel nanosecond-pulsed ignition technology will therefore be used instead of a conventional coil-based system. The main achievements are the availability of a numeric approach to the design of pre-chamber ignition systems and the knowledge necessary for their technical realization.

Hybrid solutions

Parallel to the ignition research, Empa and ETH Zurich developed an electrohydraulic-actuated, fully variable valve train. In conventional Otto-cycled engines, power control is carried out by throttling the intake air, which results in significant losses in efficiency, especially at low and part load. The newly developed valve train prevents those losses by varying the lift and opening duration of the gas exchange valves. Having succeeded with a demonstrator system, integration into a full passenger car engine began. One main research question dealt with the use of such a system in hybrid-electric propulsion systems. First results indicate that an electric engine and battery can be designed to be smaller (and cheaper) if the internal combustion system is operated with a variable valve actuation system.

Another main research field of CA A2 was the use of new oxygen-containing liquid fuels such as dimethyl ether (DME) or polyoxymethylene dimethyl ethers (OMEs). These form less or almost no particles during combustion and therefore allow new and more efficient combustion concepts for diesel engines. DME and OMEs can be produced in a catalytic process from hydrogen and CO_2 by forming methanol, the educt (physical mixture) for either catalytic DME production or its oxidation to formaldehyde, the other educt for OME formation.

The starting point for research in this field was to initiate a novel basic research instrument allowing a better understanding of the injection, inflammation, and combustion of these new fuels. The head of one cylinder of a multi-cylinder engine was therefore separated from the other cylinders and equipped with optical access, by researchers from FHNW and ETH Zurich. Besides OMEs' use as a direct diesel substitute, they can also be used in dual-fuel engines (gas–diesel engines), a concept that is becoming increasingly popular for ship propulsion.

Another engine project was realized in collaboration with FPT Motorenforschung in Arbon. FPT Motorenforschung is part of CNH Industrial and specializes in powertrain research. It produces powertrains for commercial applications for several brands, including Iveco, Fiat, Magirus, Case, and New Holland. In the first step, the efficiency of a heavy-duty diesel engine was increased to almost 50 percent by implementing a new exhaust gas recirculation (EGR) concept. In the next step, the engine was converted for DME operation.

These kinds of research projects are important for Switzerland as they complement the corresponding development activities taking place with regard to low CO_2 powertrains at FPT Industries in Arbon (TG), WinGD in Winterthur (ZH), Liebherr in Bulle (FR), and several Swiss automotive suppliers. The optical engine allows a simulation algorithm for the combustion of such fuels to be developed—a prerequisite for optimized engines. Moreover, FHNW researchers have examined specific sensor instrumentation in cooperation with their industrial partner Kistler Instruments regarding pressure, temperature, or heat flux measurement for combustion research-based applications.

All these CA A2 projects will, in the long run, contribute to CO_2 reduction, especially in long-distance road vehicles, and will pave the way to a fossil-free future.

Christian Bach
Capacity Area Coordinator
Automotive Powertrain Technologies (APTL), Empa

How autonomous vehicles perceive the world

Miriam Elser

Since January 2020, Miriam Elser has headed the Vehicle Systems Group at Empa. The 31-year-old Swiss, born and raised in Spain, participated throughout 2020 in the SCCER Mobility. Her team worked on a digitalization project to assess the real-world behavior of sensors for automated vehicles.

You joined the SCCER Mobility in January 2020. Why?
Miriam Elser:
The work of this SCCER is very exciting because it connects the most important technology research areas in the mobility sector. I think these links are crucial to enabling sustainable mobility. In addition, the annual conferences, webinars, and other events gave a good overview of the activities of the entire SCCER and were also a great platform for networking and establishing valuable cooperation.

What projects are you currently working on?
The main goal of our group is to assess the impact of road mobility on air pollution and climate change and to evaluate the potential of new technologies, such as new propulsion systems and autonomous vehicles, to reduce these negative effects in real-world applications. With this, we want to support technological development with regard to a move to net-zero CO_2 road mobility.

We focus in particular on the measurement and modeling of vehicular pollutants and greenhouse gas emissions, real-world vehicle fuel consumption, and in-vehicle segmentation and operation analysis. Our goal is to contribute to the development of a "digital twin" of road mobility. Our latest field of activity is autonomous and automated vehicles and how they perceive the world.

Can you give us more insight into your project?
Our team at Empa lead the digitalization project Automated Driving Sensor Testing Vehicle, in collaboration with the Institute for Dynamic Systems and Control (IDSC) at ETH Zurich, the Swiss Federal Institute of Metrology (METAS), and the Swiss Federal Roads Office (FEDRO). Within this project, we have designed and realized a vehicle platform and a test track on the Empa campus, and developed testing procedures for the real-world evaluation of autonomous vehicle sensors and systems. For example, we compared the sensor signals for clear and foggy weather, day and night, or in clean and dirty conditions. These findings were used to investigate the surroundings' effects on the performance of the main vehicle sensors for autonomous or automated driving.

Which experiences from the SCCER Mobility are still relevant for your job?
The Automated Driving Sensor Testing Vehicle project constituted the beginning of research into the field of automated driving in our group. The infrastructure and knowledge gained from this project, as well as the connections with other research groups of the SCCER Mobility, have opened up numerous opportunities for us to continue our research in this field.

What will you remember most about the SCCER Mobility?
Although I joined the SCCER Mobility only during its last year, I very much enjoyed the events, especially the annual conference, where the organizers connected the different topics, projects, and researchers in an outstanding way. I gained a more comprehensive understanding of mobility, a very complex and interesting field due to its combination of technical and social issues.

Short Profile

Dr. Miriam Elser

2020–today	Head of the Vehicle Systems Group, Automotive Powertrain Technologies, Empa
2019	Scientist, Automotive Powertrain Technologies, Empa
2016–2018	Postdoc, Advanced Analytical Technologies, Empa
2013–2016	Doctoral student in Atmospheric Chemistry, PSI/ETH Zurich
2011–2012	MSc in Physics, University of Milan, Italy
2006–2010	BSc in Physics, University of the Balearic Islands, Spain/ University of Milan, Italy

Portrait: researcher ——

Working together on real-life projects

Andreas Ritter

During his doctoral studies at ETH Zurich, Andreas Ritter helped develop the "SwissTrolley plus" prototype. His research focused, in particular, on the energy management strategy that controls the hybrid powertrain's battery, with the aim of reducing the vehicle's overall energy consumption.

What vision drives your career?
Andreas Ritter:
I want to contribute to a reduction in energy consumption in the transport sector and thus mitigate the sector's impact on the environment.

Since beginning your dissertation in 2015, you have been part of the SCCER Mobility. Why did you join?
I liked the fact that a range of Swiss industry and research partners are working together on the SwissTrolley plus project. The project is a good example of how research can be applied, since the trolleybus is widespread in public transport in Switzerland. The bus and our project have thus even generated interest from the general public. For me, this project is ideal for the SCCER.

Tell us more about SwissTrolley plus.
The goal was to develop a novel type of trolleybus, equipped with a high-performance traction battery, to travel without recourse to overhead wires. We needed an energy management system that ensures high system efficiency to allow the trolleybus to operate in this way. Together with our project partners—Carrosserie HESS AG, Bern University of Applied Sciences (BFH), and Zurich Public Transport (VBZ)—we developed and tested control algorithms that met these requirements.

How does this algorithm work?
In public transportation, vehicles adhere to repetitive driving patterns. We used this predictability to develop a universal algorithm that can be applied to a wide variety of public transportation vehicles. The algorithm is designed to learn typical driving behavior so that this can later serve as the basis for the energy management system. A prototype trolleybus is already equipped with a computer on which the algorithm is running. During operation, it continuously calculates the best energy management strategy, mainly deciding how much the battery should be used at a particular moment. The system runs completely autonomously and doesn't need an external computer or data source. We use a web interface, but only to download measurements or for software updates.

Which experiences from your time at the SCCER Mobility are still relevant to your current research?
The SCCER offered us very uncomplicated access to a network of open-minded researchers who are all application-oriented. I would argue that we all still benefit greatly from this, on both a scientific and a personal level.

When you think about the SCCER Mobility, what do you remember most?
I remember fondly our annual meetings, where members of the network presented their exciting latest findings. These events were also an opportunity to meet interesting people from both research and industry in a relaxed atmosphere. It felt good to be part of this community, and to work together on the challenges of future mobility. ⦿

Short profile ——

Andreas Ritter

2015–today	Doctoral student in Mechanical Engineering, ETH Zurich
2012–2014	MSc in Mechanical Engineering, ETH Zurich
2007–2012	BSc in Mechanical Engineering, ETH Zurich

Awards

- Watt d'or 2015 for the project "AHEAD—Advanced Hybrid Electric Autobus Design"

Patents

- A. H. Ritter, P. V. Elbert, C. H. Onder, A. Naef, M. Widmer, H.-J. Gisler: "Verfahren zur Vorhersage zukünftiger Fahrbedingungen für ein Fahrzeug", EP-Patent Europa, Anmelde-Nr.: 17 151 441.7.

A3 Minimization of vehicular energy demand

Zero-emission fuels and more efficient engines can reduce energy consumption and emissions. But non-propulsive energy demand can also be reduced. Capacity Area A3 (CA A3) investigated technologies and strategies for developing lighter materials, including exploring new means of processing for the high-volume production of lightweight thermoplastic and bio-inspired composites with outstanding mechanical properties.

Reducing the energy demand of vehicles

Emission-free technologies can get to the root of mobility's sustainability problem. Their introduction, however, takes time and depends on consumer acceptance. Capacity Area A3 (CA A3) has therefore focused on complementary approaches for reducing the energy intensity of road travel, regardless of the propulsion system. This has included a framework for analyzing the effects of and the technology necessary for the introduction of novel lightweight materials into mass-automotive production.

Zero-emission drive technologies target the root of the sustainability challenge facing our current transportation system: its dependence on fossil fuels. But new vehicle technologies will only be able to establish themselves as quickly as they are adopted by markets, with buyers choosing emission-free cars over conventionally propelled vehicles. Since change takes time, it could be decades before net-zero emissions are reached.

For this period, until mobility is completely transformed, it makes sense to explore additional ways to reduce vehicular energy demands—regardless of the propulsion system involved. After all, vehicles with zero-emission technologies would also benefit from such innovations. Lower overall energy demand could, for example, improve acceleration ability or increase the autonomy range, particularly on winter days, when the energy needed to heat the interior of the vehicle outweighs that needed to drive it. For electric cars, smaller batteries could also favor a reduction in vehicular weight, and reduce the life cycle impact of production, thus leading to cost reductions for consumers.

The scientists of CA A3 pursued a two-pronged approach in their research: On the one hand, they created semi-empirical models to determine the energy demands of any car using any common powertrain under real-world road conditions. On the other, they explored novel materials for car construction.

With their models, scientists from the Aerothermochemistry and Combustion Systems Laboratory (LAV) at ETH Zurich can map practically all currently relevant propulsion technologies and quantify the effects of technological changes on virtually every vehicle under a range of road conditions. In combination with cohort models of the fleet (i.e., all cars currently registered and in operation on the road) and scenarios for market and technology development, these models allow extrapolation, meaning that the future energy demands of the fleet can be predicted. These models can also be used to estimate the effects of the use of lightweight composites, which may be more significant at the manufacturing stage but will also allow energy savings and reduced environmental impact during the operation of the vehicle.

The impact of weight reduction

Lowering the effective mass of a vehicle by using different construction materials also reduces vehicular energy demand. Although this does not eliminate the carbon dioxide (CO_2) emissions of a vehicle powered by fossil fuels, it does reduce them: as a rule of thumb, a 10 percent reduction in weight results in a 6–7 percent reduction in CO_2 emissions per kilometer during operation. New materials pose two key challenges however: (1) the environmental impact of their production could cancel out the operational savings, and (2) they must be producible in sufficient quantity and quality and fast enough to allow their integration into mass-automotive production.

Researchers from several Swiss universities worked on developing lightweight vehicular components based on recyclable thermoplastic composite technologies for mass production processing schemes, new material systems for complex-shaped parts, and bioinspired materials with high resistance to fracturing and breaking. Emphasis was also placed on the circularity and life cycle assessment (LCA) of the new processing approaches to sustainable production. Moreover, for the duration of their activities the scientists of CA A3 built a strong network with industry to enhance the framework necessary for moving from laboratory-scale processing to real automotive applications.

To develop practical components for vehicles, processing strategies using recyclable thermoplastic composites were pursued. To successfully employ thermoplastics in the automotive market, fast production processes that are competitive with existing market solutions had to be developed. To achieve this goal, researchers at the Institute of Polymer Engineering (IKT) of the University of Applied Sciences and Arts Northwestern Switzerland (FHNW) concentrated on expanding the manufacturing and mechanical possibilities of thermoplastic composites by improving impregnation, fiber-matrix adhesion, and compatibility with several polymeric matrix materials. To date, compression resin transfer molding (RTM) has emerged as one of the most promising approaches.

Meanwhile, a research group at the Swiss Federal Institute of Technology in Lausanne (EPFL) focused mainly on polyamide, a high-fluidity thermoplastic polymer developed by Solvay, an industry partner of the SCCER Mobility. The scientists used molten polyamide to impregnate a dry textile fabric, using an in-plane RTM process to create a scalable alternative to the classical production of thermoplastic composites, which uses compression molding of pre-impregnated textiles.

Two strategies were validated: (1) a very-high-permeability, non-crimp textile fabric, and (2) more conventional glass or carbon textiles, whereby large flow channels were created by permanent or collapsible polymer grid spacers. The second strategy, for which a patent was filed, offers improved flexural stiffness of the final part. In the summer of 2020, scaling up with industrial partners was underway, as was a cost/LCA analysis to evaluate potential production scenarios. This method is complementary to the compression RTM technique as it allows the production of more complex, hollow-shaped parts.

New manufacturing strategies

Today, manufacturers use hybrid preforms to reduce the long consolidation times caused by the high viscosities of thermoplastic melts. To simplify the development of complex parts, new manufacturing strategies in the form of hybrid bicomponent fibers (BCFs)—e-glass monofilaments clad in polycarbonate sheaths—have been developed within CA A3. The benefits of BCF preforms are that they remain flexible in ambient conditions and can be processed using stamp-forming methodologies without pre-consolidation. The consolidation behavior of BCFs successfully demonstrates that preforms made from them can be directly stamp-formed, thus appreciably reducing the processing time associated with thermoplastic composite processing. This fast processing in the development of fully impregnated products, coupled with the flexibility of unconsolidated preforms, renders thermoplastic composites significantly more attractive to high-volume production markets, including those for automotive parts and for the development of complex parts.

To evaluate the potential of the three newly developed thermoplastic production processes—compression RTM, in-plane RTM with flow channels, and BCFs—each underwent a thorough LCA and was compared with the conventional production of a metal bonnet/hood. In addition, researchers at FHNW analyzed the use of energy and resources as well as the impact on human health, ecosystem quality, and climate change. A typical product LCA is composed of four phases: raw materials acquisition, manufacture, use, and end-of-life treatment. Preliminary results show great potential for the new processes developed within CA A3. The energy required to replace the metal bonnet/hood of a car with a plastic one is balanced out after around 100,000 kilometers, and energy savings start. The outcome ►

of the analysis can, however, differ depending on the metal (recycled or not) used. The choice of fibers also has an impact. Carbon fibers, for example, consume much more energy during production than glass fibers. In addition, their influence on climate change and materials consumption is significantly greater. Besides the selection of the materials for the bonnet/hood, it is important to take a closer look at potential energy losses during production, and in particular at any heating-cooling cycles involved.

The Complex Materials Group at ETH Zurich, meanwhile, explored the potential of nacre—so, mother-of-pearl—as a novel material for increasing vehicular crash resistance. This biological composite displays an exceptional combination of strength and non-catastrophic fracture behavior, which is surprising considering that its main constituent is brittle calcium carbonate. It has the potential to provide powerful guidelines for the design of lightweight composite materials with enhanced fracture resistance using naturally abundant building blocks. ETH researchers managed to reveal some of the "design principles" of nacre, and investigated the structure–property relationships of model, nacre-inspired composites. These currently hold the record for the combination of high stiffness, strength, and toughness for this class of materials, with properties rivalling traditional, energy-intensive carbon fiber composite materials. Since these remarkable properties arise primarily from the material's multiscale structure and not from chemistry, this work opens up an enticing pathway toward the manufacture of high-performance composites using more sustainable and environmentally friendly building blocks.

On the whole, the researchers from CA A3 advanced the technology readiness level of future-oriented, recyclable, and sustainable thermoplastic composite technologies for the transportation sector. The SCCER Mobility provided a unique platform for discussion and the exchange of ideas and research outcomes, extending the scope of the research carried out within the individual teams. Although the readiness levels of the technologies investigated are not homogenous, as the SCCER draws to a close its results are already finding practical applications, including at the company Bcomp (see page 47), or in the form of start-ups such as 9T Labs, NematX, or CompPair (see pages 45, 46 and 50). Another start-up is planned for the near future (see page 50).

The start-ups in particular were guided and inspired by the capacity area's industry partners, which also provided technical expertise to the research projects. This pioneering collaboration with industry also revealed that it is challenging for research to meet the short-term needs of the original equipment manufacturer (OEM) and supplier network in Switzerland. If, however, we are to meet the demands of future mobility, this collaboration is needed to ensure that successful investments are made and that we promote a circular materials economy, and the movement toward zero-emission mobility.

Prof. Dr. Paolo Ermanni
Capacity Area Coordinator
Laboratory of Composite Materials and Adaptive Structures (IDMS-CMAS),
ETH Zurich

Automated production equipment.

Project highlight ——

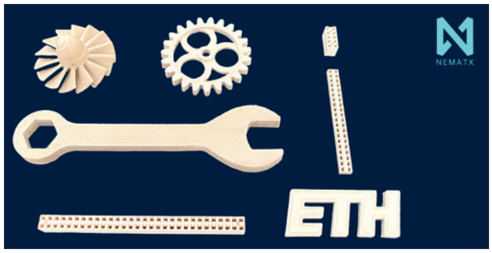
Next-generation composite series production

9T Labs, an ETH spin-off founded in 2018, is working to make carbon fiber composite materials widely accessible. Their industrial 3D printing solution is based on Martin Eichenhofer's research into the continuous lattice fabrication (CLF) technology developed at the Laboratory of Composite Materials and Adaptive Structures at ETH Zurich. The goal is the mass production of high-performance composites that should be as easily manufactured as metals.

9T Labs' technology is based on the automated, additive deposition of material according to a digital blueprint to build fiber reinforced thermoplastic (FRTP) composite components. This approach makes new lightweight constructions possible.

A software suite powered by integrated finite elements analysis (FEA) simulation tools enables rapid differentiation of the most optimal designs. State-of-the-art additive manufacturing equipment combined with advanced post-processing technology enables series production of structural composite parts. The future of composite manufacturing inherently depends on the automation and digitalization of the production process. 9T Labs therefore offers its customers an all-in-one solution to accelerate the mass production of composite materials, with rapid turnaround times.

www.9tlabs.com



Fully functional LCP objects fabricated with the nematic 3D printing technology.

Project highlight ——

Inspired by wood and silk

As part of CA A3, researchers at ETH Zurich have developed a printing technique that combines bottom-up self-assembly with top-down shaping from a 3D printer to produce scalable bioinspired hierarchical materials from thermotropic liquid crystal polymers (LCP). The 3D-printed high-performance polymer objects are lightweight and show mechanical properties typically only found in fiber-reinforced polymers or metals, while being fully recyclable and less energy intensive. Further advantages of the team's nematic 3D printing technology include high-temperature resistance up to 300°C, flame retardancy, and high material inertness. Because their 3D-printed parts clearly exceed current benchmarks in high-performance polymer 3D printing, the ETH spin-off NematX AG, founded in April 2020, is currently developing this technology to market maturity.

The 3D printing materials and processes developed by NematX were inspired by two natural materials —spider silk and wood. The unrivalled mechanical properties of spider silk result from the high degree of molecular alignment of silk proteins along the fiber directions. What is special about wood, in its turn, is that it arranges all its fibers along the stress lines as it grows and adapts to its environment.

A patent application for this NematX technology has already been filed. Besides space and aircraft manufacturers, transportation and medical companies are interested in using this development to print complex-shaped lightweight parts for harsh-application environments. In addition, close collaborations with chemical companies for developing enhanced 3D-printable LCP formulations have been established, which enables NematX to offer prototyping services and small series production of end-use parts.

www.nematx.com

Industrial partner statement ——

Access to expertise and equipment

Julien Rion

Bcomp, based in Fribourg, specializes in the development of natural fiber composites. In the course of the SCCER Mobility, Bcomp and the Institute of Polymer Engineering (IKT) at the University of Applied Sciences and Arts Northwestern Switzerland (FHNW) worked together to optimize the matrix system for Bcomp's powerRibs. Their objective was to increase the degree of impregnation and thus to improve the overall performance of the composites. Julien Rion, CTO of Bcomp, describes the collaboration and outcome of the project.

How did this collaboration come about?
Julien Rion:
We had collaborated before and mentioned, during one of our meetings, our problems getting a good impregnation of our powerRibs' reinforcements. We decided to look for a solution together.

How, concretely, did you work together?
FHNW had the machines for conducting the impregnation trials and Bcomp the testing machines for getting real, direct feedback and allowing for constant optimization. The tasks and missions were thus clearly defined, and the project advanced smoothly.

What results were achieved thanks to this collaboration?
A new generation of powerRibs with better impregnation was born. It was the beginning of two more years of development work at Bcomp, leading to the final industrial product being achieved in Spring 2020.

How are you still benefitting today from the collaboration with researchers from the SCCER Mobility?
Our product has been improved, and large-scale production is currently being set up.

Would you recommend collaboration with a research cluster?
Yes. It means access to competent people with new ideas and technical equipment, and makes possible research that wouldn't be feasible for small or medium-sized enterprises (SME).

Addressing real-world problems

Kunal Masania

Kunal Masania draws inspiration from the rich variety of shapes found in nature in order to create new materials. In 2020, the 37-year-old Brit was appointed Associate Professor at Delft University of Technology, where he develops algorithms for the printing of complex objects and for determining their mechanical behavior. In this new role, he still benefits from his experiences at the SCCER Mobility. Above all, he has learned to always quantify the impact research has on society.

What is your professional vision?
Kunal Masania:
Man-made materials are stiff and strong but require considerable energy to produce. In stark contrast, nature has developed strategies to build structures even in mild ambient conditions through hierarchical structuring. Living organisms use readily available materials to structure objects into exquisite three-dimensional shapes. I am inspired by the rich library of designs we find in the natural world and motivated to replicate these with engineering materials.

Why did you originally decide to study engineering?
I grew up in London, and from as early as I can remember I was playing with tools and building things. My dad was a high-voltage electrical engineer in India, and my mum is the daughter of a plumber, so I guess it was in my DNA. I could think of nothing else I would rather do, and excelled at sciences at school, only heightening my curiosity about the world around me.

What interests you most in your field of research?
I'm really inspired and motivated by trying to address real-world problems. Nothing is more satisfying than when curiosity-driven science can be applied to the societal challenges we are facing today. One example is biologically inspired composites that can adapt to stresses, repair themselves, or even generate energy. These could have applications in many fields, from aerospace to biomedical.

What projects are you currently working on?
Whilst at ETH Zurich working with Professor André Studart and his Complex Materials Group, I became fascinated by using additive manufacturing to structure new materials into geometries or functions that are not possible in any other way. We developed a new process to 3D print bioinspired liquid crystal polymer composites that are fully recyclable. When we print, the materials align in the nanoscale to the direction in which the printer moves. This means they can rival state-of-the-art composite materials in terms of lightweight performance. Think about laying spider silk down in patterns that you see in natural wood. Now, at Delft University of Technology (TU Delft), we are developing complex algorithms to predict how fiber paths might look in three dimensions, realizing the printing of complex objects, and developing "digital twins" of the manufacturing process so we can precisely predict mechanical behavior. Several of my new projects relate to sustainable aviation and the adoption of hydrogen as a clean source of fuel in future transportation.

From 2014 until 2019 you were part of the SCCER Mobility. Can you give us a deeper insight into your projects there?
In 2014, I began working on technology problems while at the University of Applied Sciences and Arts Northwestern Switzerland (FHNW). I moved to ETH Zurich in 2015. Through working at FHNW before moving to ETH Zurich I learnt how technologies can

progress in Switzerland and had already had a chance to hone my technology skills thanks to several successful Innosuisse projects. With this mindset, I could attract other students to join me on my journey.

The core of my work during my time with the SCCER focused on simplifying the fabrication of complex geometries from high-performance materials at length scales ranging from nanoparticles to large structures. Initially, at FHNW, for me this meant trying to manufacture faster, with higher quality, and cheaper, with industrial high-performance materials. Later, at ETH Zurich, the focus turned to manufacturing materials that had never been dreamed of before. I would like to highlight three examples that were made possible by the SCCER Mobility.

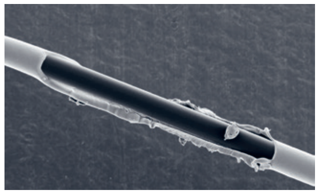
During my PhD at Imperial College London, I investigated silica-modified epoxy polymers in bulk and as the matrix of carbon and glass fiber-reinforced composites. We proved, for the first time, the presence of a "nano-effect" with respect to increasing toughness with decreasing particle size, making my early research pivotal in the area of the "nano-toughening" of polymers. At ETH Zurich, inspired by the micro-structure of seashells—also made of nanoparticles—we developed powerful guidelines for the design of lightweight composite materials with enhanced fracture resistance across three size scales by combining nanoparticle assembly with advanced fabrication techniques.

I am proud to say that ETH Zurich currently holds the record for the combination of high stiffness, strength, and toughness for this class of materials. Their properties even rival industrial carbon fiber composite materials. These remarkable properties arise primarily from the multiscale structure, and not from chemistries, and open an enticing pathway toward the manufacturing of high-performance composites using more sustainable and environmentally friendly building blocks in the future.

A major breakthrough was the realization of a printing technique that combines bottom-up self-assembly with top-down shaping from a 3D printer to achieve scalable bioinspired hierarchical materials from liquid crystal polymers. These 3D-printed polymers are fracture resistant, fully recyclable, and do not require labor- and energy-intensive manufacturing. I believe this to be a game changer in several structural applications as it enhances the longevity and sustainability of structural components. A patent was filed with the support of ETH transfer and several industries approached ►

"I joined the SCCER because I wanted to see the societal impact of my research."

Kunal Masania



Open coating bicomponent fiber.

Project highlight ——

Simpler and faster

Antefil Composite Tech, a pioneer project at ETH Zurich, aims to accelerate the transition of the global composites industry toward a more cost- and energy-efficient future. The technology is based on developing preform materials made from glass fibers, which are individually clad in a meltable, recyclable thermoplastic material. The result is flexible preforms that behave like dry textiles but already contain all the polymer required for part production. The novel architecture of the hybrid bicomponent fiber technology has the potential to reduce the cycle time of large-scale part production while improving material quality through a guaranteed uniform distribution of fibers and matrix material. Antefil also provides recyclable material preforms for processes currently bound to thermosets, thus opening up the possibility of a circular materials economy. These novel preform materials will allow composites to be readily utilized in untapped markets for advanced lightweight materials technology. After establishing the technology, in 2020 Antefil started to prepare the scaled production of its innovative new preform, with the support of an ETH Pioneer Fellowship and a BRIDGE Proof of Concept grant.

www.antefil.com

Left: Products made from various fibers.
Right: Standard pre-impregnated textiles.

Project highlight ——

Smart textiles

CompPair Technologies SA, a spin-off from the Swiss Federal Institute of Technology in Lausanne (EPFL) founded in 2020, is the result of research carried out at the Laboratory for Processing of Advanced Composites (LPAC) related to efficient light-weighting solutions, in line with the objectives of the SCCER Mobility. CompPair specializes in new healable composite solutions in the form of "prepregs", textiles pre-impregnated with an innovative resin. CompPair's novel technology provides in situ repair solutions that lengthen the lifespan of composite structures, thereby increasing durability and reducing the need for maintenance and repair events in composite parts. In April 2020, the company received the Solar Impulse Efficient Solution Label, which seeks to bridge the gap between ecology and the economy, combining the protection of the environment with financial viability and thereby demonstrating affordable solutions and opportunities for clean economic growth.

www.comppair.ch

us. Given the excitement and interest, an ETH spin-off, NematX AG, was founded in 2020.

Lastly, I have been developing strategies to structure sustainable materials. Cellulose-based natural materials such as wood and flax are hierarchically structured and capture carbon during their growth, and thus can result in a lower carbon footprint. We can exploit their low material density and high mechanical performance if we can preserve and utilize their hierarchical structure for our needs. Having extensively studied the underlying hierarchical architecture, my research is implemented in materials and advanced fabrication techniques now used to produce sustainable structural materials with the company Bcomp. We have worked together since 2011 and I have had the opportunity to use science for societally relevant technology. We are proud to say that we have developed the stiffest, toughest natural fiber composite and achieved several noteworthy applications, ranging from skiing and sports to space to several new structures in automotive.

Why did you decide to join the SCCER Mobility?
I joined the SCCER because I wanted to see the societal impact of my research. Interacting with teams from ETH Zurich, the Swiss Federal Institute of Technology in Lausanne (EPFL), and FHNW, I had the opportunity to learn about topics ranging from permeability to energy scenario modelling for different transport configurations. I was lucky enough to move from FHNW to ETH Zurich in pursuit of the research problems that really fascinated me. The SCCER's openness to interdisciplinary exchange also gave me the opportunity to work with Professor André Studart.

Early in 2020 you were appointed Associate Professor at Delft University of Technology. Which experiences from the SCCER Mobility are relevant for your current position?
Much of the research I began at ETH Zurich during the SCCER is being followed up on in my current role. The need to drastically reduce energy consumption and carbon dioxide (CO_2) emissions is most definitely a challenge that we face globally. To that end, we are exploring how additive manufacturing and the digital fabrication of new materials can help us make more efficient use of resources. Being based in the Department of Aerospace Engineering places me in a wonderful hotbed because of the stringent requirements on materials and process for applications in aviation. If we can develop some of these materials and processes to the point where they're "aerospace ready", then I think we can create broad acceptance in many structural applications. A second compelling case is manufacturing in space, because resources are desperately limited. Developing strategies to manufacture whilst being frugal with materials and energy will certainly help us reach our sustainability goals on Earth.

Will you be able to continue to research scientific findings from your time at the SCCER?
Yes, very much so! Despite my moving and the SCCER soon coming to an end, our ambition has not waivered. I would say that, if anything, the COVID-19-pandemic has only highlighted the sense of urgency humanity feels regarding the stress it is subjecting the planet to. I feel more motivated than ever to try to create societal impact through my scientific work.

When you think about the SCCER Mobility, what do you remember most?
I really value the difficult questions from the evaluation panel and how they challenged us to understand and quantify the impact our research has on society. I believe I will continue to express this mindset in my research. Attending the annual conferences was particularly eye-opening as we could see all the amazing work going on around us to reduce Swiss mobility's energy and CO_2 demands. This ranged from components, energy convertors, and lightweight structures all the way to a systems-level understanding of vehicles and transportation networks. ⦿

Short profile —

Kunal Masania

2020–today	Associate Professor, TU Delft, Netherlands
2015–2019	Senior Scientist, ETH Zurich
2011–2015	Postdoc group leader, FHNW
2006–2011	Doctoral student in fracture mechanics of multiscale composites, Imperial College London, UK

Awards

- Shortlisted for the Spark Award 2020, best invention at ETH Zurich
- Top research team 3D Printing Industry Awards shortlist, 2019
- Best poster presentation of student at the SCCER Mobility Annual conference, ETH Zurich, 2018
- Best presentation of student at the British Society of Strain Measurements, Experimental Mechanics Conference at Imperial College London, UK, 2018
- JEC Innovation Award for an automated production system for fully recyclable, complex bicycle components, 2016
- MaP Career Seed Grant, ETH Foundation, 2015
- School of Engineering award for research excellence, 2014

1.2 Innovation field B

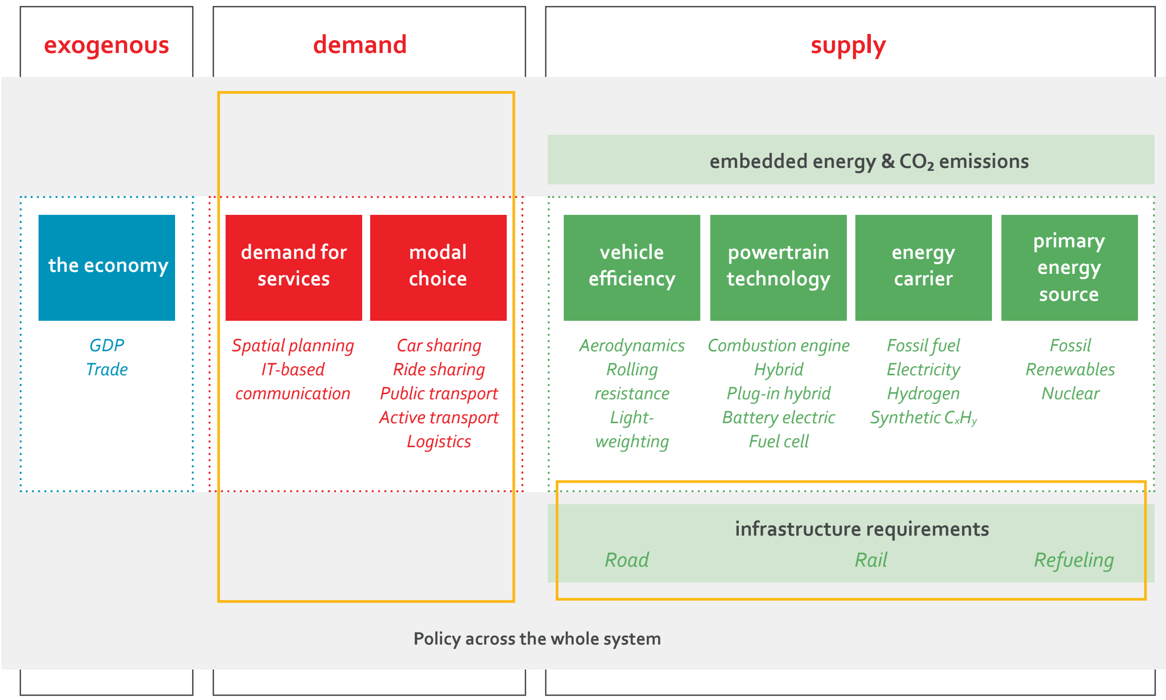
System aspects of mobility

B1 Design, demonstration, and dissemination of systems for sustainable mobility

In our modern world everything is connected. When creating mobility solutions, it is therefore important to take into account the complex interaction between users, technology, and infrastructure. Capacity Area B1 (CA B1) interrelated all aspects of mobility in order to develop tools for consumers, municipalities, and policy makers, to encourage decisions that lead to a reduction in energy demand.

Everything is connected

Traditionally, mobility research is divided into two areas: firstly, technical research for the development of components; secondly, the planning of mobility and traffic flows. Capacity Area B1 (CA B1) investigated system aspects and analyzed the interaction between users, technology, and infrastructure to increase energy efficiency in the mobility sector. Only in this way can the reduction of energy consumption and carbon dioxide (CO_2) emissions in cities and transportation, and the commuter problem, be addressed successfully.



Areas of influence & impact.

CA B1 looked from a systemic perspective for solutions that increase energy efficiency in the mobility sector. In doing so, the interactions of users, technology, and infrastructure were analyzed. A particular challenge for our capacity area was the fact that we needed to address not only technical but also social issues. The technical challenges included software compatibility between different devices. On the social level, meanwhile, we wanted to achieve the adoption of sustainable thinking and associated changes in behavior.

Our research results mainly consist of newly developed methods and models, and the implementation of prototypes. The methods and models are mature in the sense that they can be employed and utilized by stakeholders in the mobility–energy field. They have also been applied and tested in real-world case studies, with encouraging results.

Our software prototypes work, but still remain to be implemented (and commercialized) by industry. We see this as a challenge because money needs to be invested to do so (see page 62).

During the past seven years, CA B1 has focused mainly on three research areas: infrastructure, information and communication technology (ICT), and urban planning. In the first phase, from 2014 until 2017, we concentrated on the analysis of mobility behavior to establish the basis for improvements to energy efficiency. The spatiotemporal behavior of humans was simulated and monitored. These so-called mobility patterns were then linked to urban planning and environmental data to optimize the mobility system and consequently increase its efficiency. In the second phase (2017–2020) we also included the impact of renewable energy in our analysis. Throughout both phases, ICT played a major role.

Understanding mobility choices

One of our research highlights that made use of ICT is the personalized energy mobility application GoEco! For this app, in a first step algorithms for spatiotemporal data analysis were developed. These were then used for a mobile application that was implemented in the format of a "living lab". The objective of GoEco! was to monitor and—later on—influence and change mobility patterns, which are currently still dominated by car traffic (see pages 60/61). The data from GoEco! also facilitated a better understanding of why individuals choose certain travel modes and helped to elaborate reasonable alternatives to the private vehicle.

For the development of the GoEco! app our capacity area worked together with CA B2. It contributed expertise in the field of the design and large-scale testing of smartphone applications.

In the second research phase, CA B1 again collaborated with CA B2. For the project "Grid impact assessment of e-mobility" we explored the impact of e-mobility ►

on network stability. We wanted to find out how to integrate electric vehicles (EV) into the distribution grid using intelligent charging strategies. The interaction between the power grid and electric vehicles was investigated under three different scenarios to cover the mobility needs of a broad population.

A project we are very proud of is “Mobility behavior in Switzerland” (MOBIS). It is a mobility pricing experiment that uses GPS tracking and online surveys (see page 63).

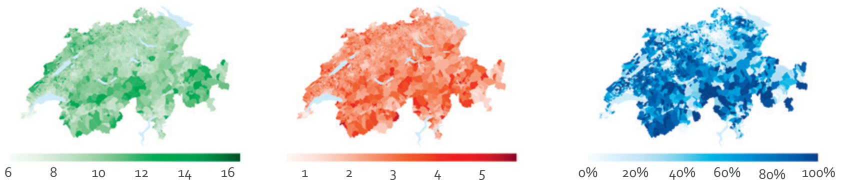
Another impressive example of the work of B1 is the “Large-scale regionalized household model that investigates environmental impacts in the context of total household consumption”. The model predicts realistic consumption and environmental profiles for individual households in Switzerland (see page 59).

Our research has clearly shown that for the transition to sustainable mobility it is necessary to consider all systemic aspects of the mobility system: Although technology will have to continue to improve, people will also need to change their behavior. Only by a joint effort can we solve the most challenging problems regarding supply and demand in the mobility sector.

In my opinion, MaaS (mobility-as-a-service) is the keyword for future developments. GoEco!—an innovative concept that offers mobility-as-a-service (MaaS) by combining public and private transport services—is just one of the possible scenarios. Car, ride, and bike sharing are MaaS concepts that are currently initiating a paradigm shift. A single app provides the user with the complete package: planning, booking, and payment work together for all selected means of transport—regardless of where the journey takes place and who is offering the means of transport.

I think MaaS could turn the entire mobility sector on its head. By 2050, not only will MaaS be implemented, it will be sustainable and fully powered by renewable energy to meet individual mobility needs. Sustainable mobility behavior will only become established in society with technologies such as mobility tracking applications acting as a supporting framework.

Prof. Dr. Martin Raubal
Capacity Area Coordinator
Institute of Cartography and Geoinformation (IKG), ETH Zurich



Maps of Switzerland showing the carbon footprints of households.

Project highlight ——

The environmental impact of households

Household consumption is the driving force behind most economic activity worldwide. Private households need goods and services and thus indirectly also need housing, nutrition, and the production and disposal of goods, as well as transport. As a result, households are responsible for a large part of global pollution.

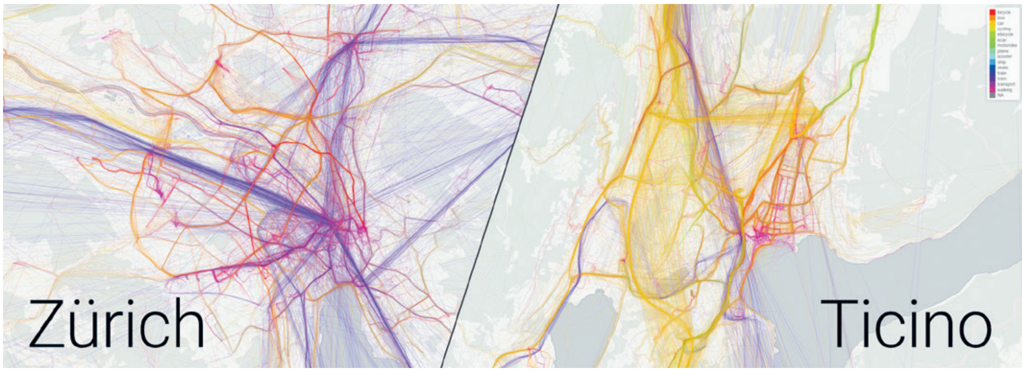
In Switzerland, the largest share of the total carbon footprint of household consumption is due to mobility requirements. These are especially influenced by place of residence, and thus by distance traveled to both the workplace and service infrastructure, which in turn influences both mobility needs and the consumption of services. To explore this connection more closely, researchers from ETH Zurich further developed their household consumption model within the framework of the SCCER Mobility. The aim: to investigate how the mobility-induced environmental impact of households can be measured and to capture regional differences. They also wanted to find out more about the relationships and trade-offs between mobility and other consumption areas.

The researchers developed a regionalized, large-scale, bottom-up model that predicts realistic consumption and environmental profiles for individual households in Switzerland. The model was designed to provide detailed information on prevailing local consumption patterns, and to help policy makers to better understand these patterns in their region, enabling them to derive environmental strategies tailored to their population.

Three existing bottom-up models were combined within a new probability-based classification framework: an energy model for the building stock, an agent-based traffic simulation, and a consumption model for households. The resulting model forecasts the demand in about 400 different consumption areas for each Swiss household and provides a realistic picture of the variability of households' environmental footprint.

As a result, in 2018 certain general macro trends could be observed. It was found, for example, that higher incomes lead to higher mobility emissions, that smaller households use cars more often than larger households, and that mobility effects decrease with the age of household members. Rural households tend to travel further by car than urban households but use air travel and taxis less. Leisure activities have a significant impact on mobility behavior, and "mobile" households tend to use all modes of transport rather than focusing on a single option.

At the municipal level, the project showed that per capita income, population density, building age, household structure, and the accessibility of public transport services are potential drivers for the municipal carbon footprint. While the municipalities with higher emissions are located in rural areas and have a higher proportion of old buildings and/or higher shares of people living in areas with poor access to public transport, those with lower emissions have a larger proportion of family households and tend to be located in densely populated regions.



Travel behavior of living lab participants in the city of Zurich and the Canton of Ticino.

Project highlight ——

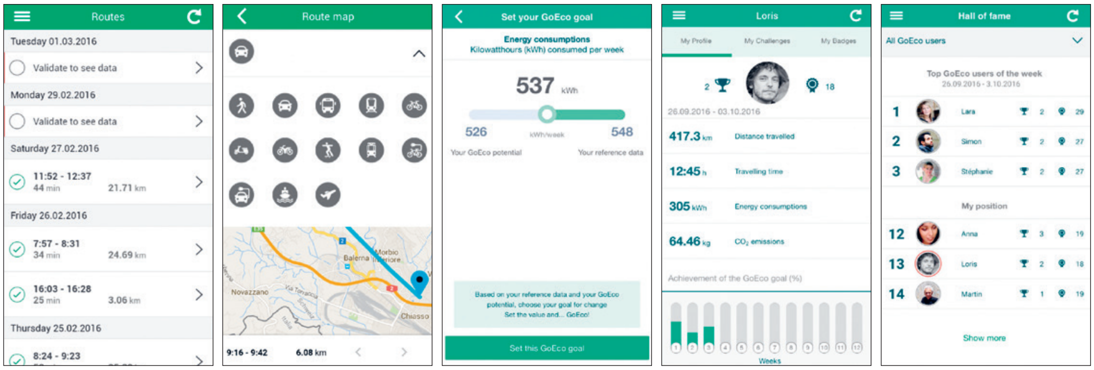
Bike instead of car

How can we encourage people to cycle or walk to reduce energy consumption and CO_2 emissions? How can we motivate them to use the public transportation system, or to rely on emerging alternatives such as car-sharing and carpooling systems?

To change people's mobility behavior, in 2016 researchers from the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) and ETH Zurich created the smartphone application GoEco! They hoped that in particular the wide acceptance of smartphones and tablets would contribute positively to people rethinking and changing their mobility behaviors.

The aim of GoEco! was to investigate if and how information feedback and social interactions can be effective in fostering changes in personal mobility choices. Research in social and environmental psychology has shown that one of the most powerful triggers for sustainability transitions lies in providing bottom-up personal feedback and comparison with the behaviors and performance of other members of one's community. Individual feedback and social comparison activate competition and the urge to stand out among one's peers.

To test these theories in the mobility sector, the researchers created a so-called living lab—a field study involving real-life users in real-world settings. Between 2016 and 2017, about 400 users tested the GoEco! smartphone application, which tracked their trips and used game elements to challenge them to modify their mobility behavior.



400 users tested the GoEco! smartphone application.

To get a broader understanding of the complex phenomenon of behavior change, the living lab was run both in the Canton of Ticino and in the city of Zurich. The two regions differ significantly with respect to mobility options and to the sociocultural attitude of the population with regard to mobility. To gain insight into the users' perceptions and attitudes, a survey was carried out at the end of the experiment. Furthermore, selected users were interviewed individually.

Comparing the data collected between the first and the last monitoring period, overall, GoEco! did indeed bring about a change in individual mobility patterns, reducing both average energy consumption and average CO_2 emissions per kilometer. These behavioral changes were, however, only recorded for "systematic" routes in Ticino—namely, those taken regularly, such as home–work routes.

The explanation for this seems quite straightforward. Firstly, in a city like Zurich, use of public transport is widespread. The car is mainly used when no other options are available and it was thus harder for Zurich-based participants to change their behaviors in a positive sense because the prevalence of public transport use is already high. At the same time, it is easy to understand the benefit of changing our habits with regard to routes we take regularly, as such changes create a greater overall effect.

www.goeco-project.ch

Industrial partner statement ——

Optimizing distribution networks

Andreas Ulbig

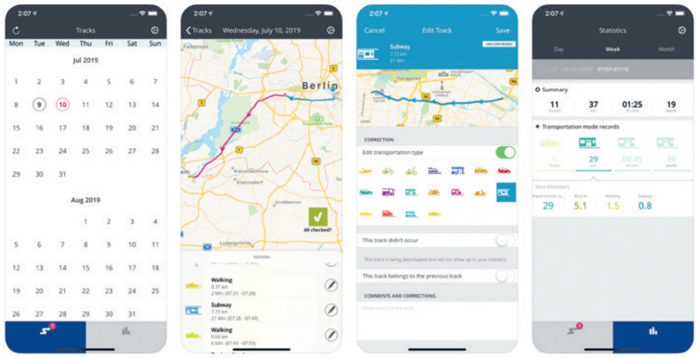
In December 2017, ETH Zurich spin-off Adaptricity launched its new software platform Adaptricity.Sim. This platform helps energy suppliers to reduce the costs of planning and operating electricity networks and at the same time increase transparency in the network.

Adaptricity was founded in 2014 as a spin-off of the Power Systems Laboratory (PSL) of ETH Zurich. "We specialize in the planning and optimization of distribution networks—a topic that is becoming increasingly important against the background of the energy revolution," explains Adaptricity's COO Dr. Andreas Ulbig. "In this context, we develop highly innovative software for possible applications in network planning, network operation, and asset management."

"Our research results mainly consist of newly developed methods and models such as network monitoring with smart meter data or asset management based on effective load data, but also of prototypical implementations. The models have already been applied in case studies and show encouraging results.

Adaptricity has gained significant expertise in the field of e-mobility—in particular in the challenges associated with distribution network operations—and has expanded its consulting services to network operators in Switzerland, Europe, and beyond. Improved grid simulation and analysis functions are found in the core software product Adaptricity.Sim."

www.adaptricity.com



State-of-the-art analyses of mobility behavior to gain new insights for optimizing traffic planning in urban areas.

Project highlight ——

What climate and health are worth to us

How can mobility in Switzerland become more efficient? What expectations do people have when they choose a particular transport mode? What should transport look like in the future? The project "Mobility behavior in Switzerland" (MOBIS) addresses these questions, aiming to understand how best to improve the transportation system in urban agglomerations.

For the project, researchers from ETH Zurich, the University of Basel, and the Zurich University of Applied Sciences (ZHAW) conducted a nationwide survey on mobility pricing from September 2019 to January 2020. Mobility pricing is widely regarded as a promising policy measure for the near future, both to combat congestion and to offset for falling fuel tax revenues. At the technical level, traditional survey methods were combined with the smartphone application "Catch my day", an app-based GPS tracking system.

The aim was to understand to what extent information—for example, about effects on health or CO_2 emissions—and mobility pricing influences mobility behavior. If information has a comparable impact to mobility pricing, it could offer an interesting tool for policy makers.

For two months, the researchers tracked the participants, who were divided into a control group and two treatment groups: one group only received information on the external impact of their mobility behavior on climate, health, and congestion, while the second group also received any money saved during the treatment phase as a result of changes in their mobility behavior. The initial results show that both information and mobility pricing led to a reduction in the total external costs incurred in comparison with the control group.

In March 2020 the original project was modified, and continued as MOBIS:COVID-19 under the guidance of ETH Zurich and the University of Basel. With this new project, the researchers want to gain a better understanding of how the pandemic is affecting mobility and everyday life in Switzerland, including how the partial lockdown measures impacted people's daily mobility. First results indicate a dramatic decrease in the total distance and number of trips traveled per day when compared to the period covered by the original MOBIS study. Public transport experienced the greatest decrease in usage, whereas cycling saw a large increase.

Original MOBIS project: www.ivtmobis.ethz.ch/mobis/
MOBIS:COVID-19 project: www.ivtmobis.ethz.ch/mobis/covid19/

Strengthening skills

David Jonietz

Dr. David Jonietz joined the SCCER Mobility in 2016 when he became a postdoctoral researcher at the Chair of Geoinformation Engineering at ETH Zurich and took the lead of the Mobility Information Engineering (MIE) Lab. Until 2018 he primarily worked on the projects SBB Green Class and GoEco! Today, he leads a research group at HERE Technologies, focusing on the development of novel machine learning algorithms for modeling and predicting urban traffic. He is also a Scientific Advisor at the Institute of Advanced Research in Artificial Intelligence (IARAI).

What is your professional vision?
David Jonietz:
In my opinion, technological developments can be a game changer for tackling both the local and the global environmental challenges of today and tomorrow. Ever-growing quantities of sensor data provide a highly detailed and multi-faceted representation of our environment. But they require quasi-autonomous learning systems if actionable insights are to be extracted. I aim to contribute to developing such systems.

Combining geography with computer science, geoinformatics is at the heart of efforts to develop technological solutions to current and future environmental challenges. To be successful in the long run, however, the discipline needs to preserve its interdisciplinary approach and remain open to new developments in related fields, such as machine learning. At the same time, we need to critically evaluate and, if needed, adapt novel methods and algorithms to the particularities of the geo-spatial domain to build up a rich and robust set of tools and benchmarks for geo-spatial data science.

Why did you first decide to study geoinformatics?
I first learned about geoinformatics during my undergraduate studies in Geography at the University of Augsburg. I was fascinated by the scientific variety and practical relevance of the field. In particular, I was interested in developing computer science methods for analyzing, modeling, and simulating human behavior in the real world, a topic I further explored in my doctoral thesis in geoinformatics.

What interests you most in your field of research?
I am curious to see the potentially disruptive effects that recent developments in machine learning will have on our field. With this in mind, in recent years I focused on the opportunities and challenges that accompany the use of neural networks for analyzing geo-spatial data related to traffic and mobility.

What projects are you currently working on?
In collaboration with IARAI, our team at HERE Technologies recently launched the second iteration of our Traffic4Cast competition for the NeurIPS 2020 conference. Building on the success of last year's competition, we're again encouraging innovative traffic prediction methods that can help address problems related to motorized traffic and sustainability. To do so, we publish an unprecedented amount of data related to traffic, weather, points of interest, and other elements for more than 10 cities and for over an entire year.

From 2016 to 2018 you were part of the SCCER Mobility. Can you give us a deeper insight into your projects there?
As a postdoctoral researcher at the Chair of Geoinformation Engineering at ETH Zurich I mainly worked on the SBB Green Class and GoEco! projects.

In SBB Green Class, we collaborated with SBB on a one-year experiment in which 150 participants received a comprehensive multimodal mobility offer. With a smartphone application, we tracked and analyzed the mobility patterns and behavioral changes of the participants.

The evaluation of the experiment showed significantly lower average CO_2 emissions.

For GoEco!, our team collaborated with University of Applied Sciences and Arts of Southern Switzerland (SUPSI) to develop an application that aimed to support a sustainable mobility lifestyle by automated tracking, analysis, and modification of behavior using gamification elements. In a study with 200 participants from the Canton of Ticino and the city of Zurich, we demonstrated positive effects on their mobility behaviors.

Why did you decide to join the SCCER Mobility?
In my view, the transition toward sustainable mobility is a highly relevant and complex topic and therefore requires an interdisciplinary approach. This clear aim of the SCCER Mobility, together with its technological focus, interested me the most.

Today you work at HERE Technologies. Which experiences from the SCCER Mobility are relevant to your current job?
During my time at the SCCER Mobility, I acquired and strengthened skills that are still highly relevant for my work at HERE Technologies. They range from the hands-on development and application of machine learning methods and handling large GPS data sets to strategic project planning and team management.

Can you point out a few differences between academia and industry?
Although I am still in a research position, at HERE Technologies we place a comparatively greater focus on the actual productization potential of our results. While the scalability of developed methods is much more important in industry, data availability is typically not as problematic as in academia.

When you think about the SCCER Mobility, what do you remember most?
I especially enjoyed the exchanges with colleagues from diverse fields during the annual SCCER Mobility conferences.

Short profile —

Dr. David Jonietz

2019–today	Principal ML & AI Engineer, HERE Technologies, Zurich Scientific Advisor at the Institute of Advanced Research in Artificial Intelligence (IARAI), Vienna, Austria
2018–2019	Lead ML & AI Engineer, HERE Technologies, Zurich
2016–2018	Postdoctoral Researcher and Group Leader, Chair of Geoinformation Engineering, ETH Zurich
2016	Doctoral degree in Geoinformatics, University of Augsburg, Germany
2015–2016	Researcher, GIScience Research Group, University of Heidelberg, Germany
2011–2015	Research and teaching, Professorship for Geoinformatics, University of Augsburg, Germany

Awards

- Best Short Paper Award, AGILE, Wageningen, Netherlands (2017)
- Best Poster Award, mobil.TUM International Scientific Conference on Mobility and Transport, Munich, Germany (2012)

B2 Integrated assessment of mobility systems

Which changes in the Swiss mobility sector are needed if we are to achieve efficiency and climate targets? What are the associated implications for the sustainability of the mobility system? Capacity Area B2 (CA B2) evaluated the performance of the alternatives for the future Swiss transport sector with respect to various economic, environmental, and social criteria. The goal of the scientists was to explore technology options and behavioral aspects that might contribute to Switzerland achieving the objectives of its energy strategy, and thus to support decision-making relevant to the transformation of the Swiss mobility system.

Holistic analysis

In order to inform and support the sustainable transformation of the Swiss mobility system, Capacity Area B2 (CA B2) analyzed how the future mobility system would look depending on different ambition levels with regard to climate change mitigation. One of the central questions focused on the choice of drivetrains and associated fuels that would satisfy the demand for mobility services while complying with the objectives of the Swiss energy policy.

The overall goal of CA B2 was to provide a comprehensive, primarily quantitative, long-term assessment of the Swiss transport sector as part of the wider energy system embedded in the socioeconomic environment. To achieve this objective, CA B2 brought together a highly interdisciplinary team of researchers. Due to this diversity, it initially took some time to develop a common understanding of the topics. At the same time, this led to stimulating discussions and new insights.

CA B2 measured the performance of mobility technologies and the Swiss transport system based on derived indicators covering environmental, economic, and social dimensions of sustainability as well as selected utility aspects important for the consumers. In this context, the impacts of prospective technological developments and energy policies were accounted for. Social scientists also addressed socioeconomic aspects, with focus on mobility behavior, consumer preferences, and changes in lifestyle. A central question concerned the composition of the future mobility system in terms of drivetrains and associated fuels, since they need to satisfy demand while meeting the goals of the Swiss energy policy.

Exploring highly complex models

The various projects were carried out at different universities and institutes. The Laboratory for Energy Systems Analysis (LEA) at the Paul Scherrer Institute (PSI) pursued a holistic assessment of current and future mobility technologies (see pages 78/79). The assessment is based on state-of-the-art modeling approaches such as life cycle assessment (LCA), the impact pathway approach (IPA), risk assessment, internal cost assessment (ICA), external cost assessment (ECA), total cost assessment (TCA), and multi-criteria decision analysis (MCDA). Databases that provided input to the models were updated and extended to assess the performance of a wide spectrum of drivetrains and fuels with regard to environmental, economic, and social dimensions of sustainability. The results demonstrate the strengths and weaknesses of the various options and their potential to contribute to policy goals.

Furthermore, the researchers expanded the Swiss energy model by implementing a much more detailed representation of mobility technologies, and also extended other demand sectors and added a number of supply and storage technologies that will play an increasing role in a more decentralized energy system. The system model generated cost-optimal solutions with and without constraints, based on more or less ambitious climate protection policies. Using a global model, PSI researchers were also able to account for environmental burdens within energy supply chains outside Switzerland.

PSI's Technology Assessment group also released the webtool "Carculator" (see page 77). It allows us to quantify the life cycle environmental burdens of passenger vehicles registered between 2000 and 2050 in more than 80 countries. The reference application projects the expected evolution of greenhouse gas (GHG) emissions per kilometer for gasoline-powered and battery electric vehicles, for each member state of the European Union, plus the United Kingdom, Switzerland, and Norway. Results show that, already in 2020, battery electric vehicles perform better than gasoline-powered vehicles in 28 out of the 30 countries.

Meanwhile, researchers at the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) developed and tested smartphone applications aimed at tracking mobility patterns and nudging behavioral change (see page 71). In cooperation with CA B1 the functions of the GoEco! app (see page 58) were extended.

To promote the concept of mobility-as-a-service (MaaS), researchers from the Institute of Sustainable Development (INE) at Zurich University of Applied Sciences (ZHAW) analyzed which factors would increase acceptance. To get a better understanding, they explored what makes people use MaaS for commuting, weekday leisure, and weekend trips, with a survey.

As a further project of the capacity area the Institute for Economy and the Environment (IWOe) at the University of St. Gallen (HSG) examined the interplay of rational and affective factors in the decision process to buy an electric vehicle (EV). The objective was to find "touchpoints" that would allow EVs to be promoted more effectively in the future.

Positive feedback on research results

CA B2 managed to achieve state-of-the-art results attracting major international attention. So, the scientific effort was worthwhile although challenging at times. The complexity and the extraordinarily high data intensity posed a particular challenge. Also, the search for a practicable solution for a scenario with net-zero carbon dioxide (CO_2) emissions was extremely difficult; but in the end we succeeded.

Our LCA tool is widely used and we receive very positive feedback on it. Socioeconomic activities are carried out in close cooperation with local and regional stakeholders and may contribute to changes in mobility behavior in the future.

I personally hope that decision-makers will familiarize themselves with the results and insights from our work. In particular, the results strongly suggest that electric mobility should be actively promoted. This does not mean that electric mobility does not have its weaknesses. Among other factors, the availability of high amounts of additional, nearly carbon-free electricity is necessary if we are to reach a high level of penetration with electric cars.

To further address the growing demand for electricity, the overall efficiency of the energy system needs to improve. Rebound effects are a potential threat to such an improvement. Hopefully, some changes in mobility behavior toward a shift to public transport will contribute to energy savings.

While the proportion of electric battery vehicles will increase, hydrogen, bio-, and synthetic fuels will also contribute significantly, particularly in the net-zero emissions climate scenario and in the transport of goods. Developments in international aviation are troublesome, because if the trend in demand growth continues, any gains from land-based transport could be largely canceled out. This seems to be the most difficult challenge for mobility.

Dr. Stefan Hirschberg
Capacity Area Coordinator
Laboratory for Energy Systems Analysis (LEA), PSI

Research partner statement ——

Reality check

Christian Bauer

Collaborating with industry provides a means to verify whether the assessments of scientists reflect the real world. A good example of such collaboration is the life cycle assessment (LCA) of passenger cars carried out as part of a project commissioned by the Volkswagen Sustainability Council.

The project partners were MCC Berlin, PIK Potsdam, and Volkswagen AG. Alongside the additional funding, data exchange and mutual learning were also beneficial:

- The future car performance data required for the LCA were exchanged by the Paul Scherrer Institute (PSI) and Volkswagen.
- PSI learned about Volkswagen's internal priorities and strategies for electrification and also gained deeper insights into European decarbonization policies in the mobility sector.

The health benefits of specific policy measures, such as driving bans for older vehicles in German cities, were also investigated, and the findings can be at least partly transferred to Switzerland.

Christian Bauer, Technology Assessment group, PSI, was part of the project from the very beginning: "The cooperation with Volkswagen was especially helpful as it allowed us to compare our data and assumptions with practice—for example in the calculation of life cycle assessments. Despite us working together closely, it was always clear that we were conducting independent research."

Project highlight ——

Key factors of mobility behavior

Capacity Area B2 projects to transform mobility in Switzerland
To reduce greenhouse gas emissions and the consumption of fossil fuels, major efforts are being made toward the electrification and optimization of drivetrain technologies. Further gains can be achieved by optimizing the entire mobility system including the behavior of its users—an aspect particularly determined by daily routines and cultural values. Already today there are alternatives to currently dominant mobility patterns, based on alternative modes of transportation, new technologies, and new business models.

The socioeconomic part of Capacity Area B2 focused on three different approaches to changing the present mobility paradigm. For example, researchers from the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) investigated opportunities for transition to energy friendly and environmentally friendly mobility behavior. Meanwhile, scientists at the University of St. Gallen (HSG) analyzed consumer preferences for electric vehicles' and these vehicles integration into the electric grid, while their colleagues at the Zurich University of Applied Sciences (ZHAW) explored the potential of mobility-as-a-service (MaaS).

All three projects underline the ongoing changes in the mobility sector with regard to electrification, the use of digitalization and alternative mobility concepts, and the importance of renewable energies. These three aspects together define a new mobility paradigm, and business models capable of significantly reducing energy consumption and negative impact on global climate change.

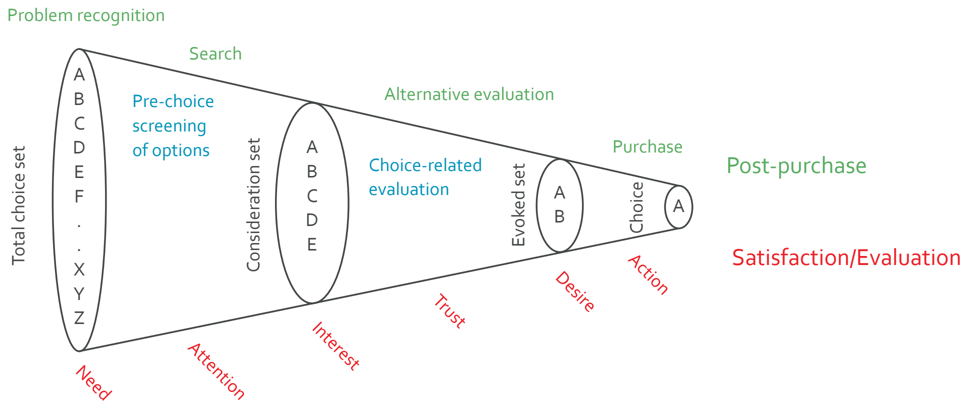
Citizens discussing Bellidea features during a co-creation activity in the Bellidea living lab.

1. SUPSI: App facilitates behavioral change
To change people's behavior and to encourage the use of public transport instead of cars, cities worldwide are launching app-based programs. Whether such apps are effective or not is, however, controversial, partly because their use is voluntary. Analyses of field trials revealed that users only use these apps temporarily before dropping out, and that they are often used by people who already prefer to use public transport and the bicycle.

To overcome these limitations, researchers from the Institute for Applied Sustainability to the Built Environment (ISAAC) at SUPSI invited approximately 40 citizens from Bellinzona to co-design a smartphone app, constituting a so-called living lab. The resulting app, Bellidea, aimed at promoting a more sustainable form of mobility.

The results are encouraging. The app has even managed to convert "mainstream car drivers". Besides, the development process has strengthened mutual trust between citizens and policy makers. The project has thus opened up opportunities for participatory governance practices to be applied to future decision-making processes.

www.bellidea.ch



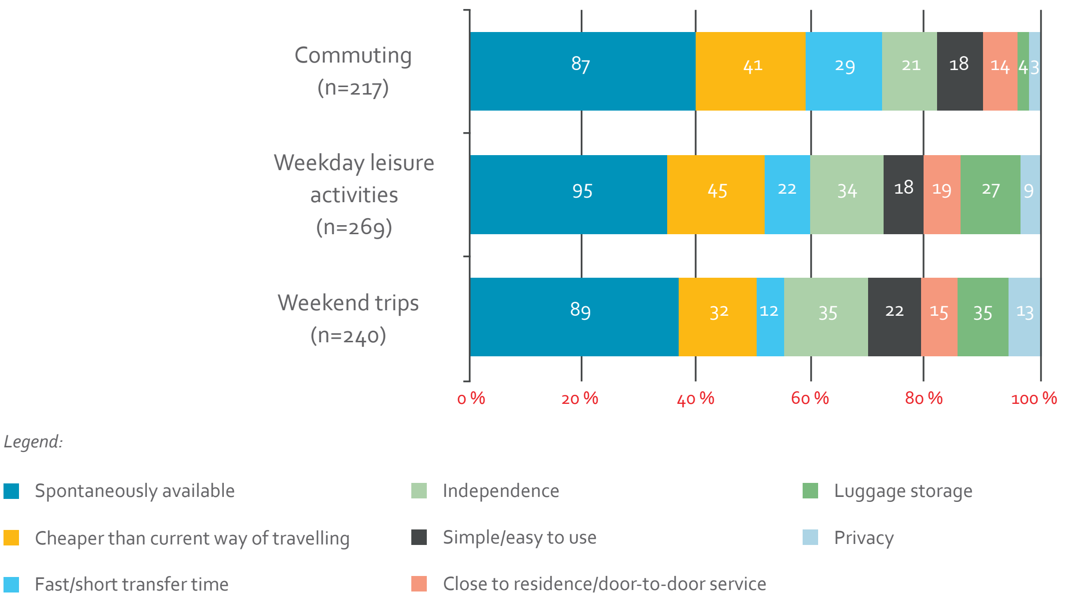
Conceptual framework of the vehicle purchase process.

Project highlight ——

2. University of St. Gallen: Influencing car buyers

A fundamental shift to electric vehicles could substantially contribute to the reduction of fossil fuel consumption and greenhouse gas emissions, thus helping to achieve the goals of the Swiss energy strategy. In Switzerland, however, despite people's positive attitudes toward electric mobility and the increasing growth rate of electric vehicles, the market share of such vehicles is currently only very modest. It is therefore uncertain whether the Swiss government's target of 15 percent market share by 2022 will be reached.

A study conducted by the Institute for Economy and the Environment at HSG shows that the final stages of the complex process of purchasing a car are strongly influenced by external factors such as car dealers, who are often still reluctant to recommend electric vehicles. This is a serious obstacle to the diffusion of electric mobility. Policy measures such as training programs on electric mobility for car dealers and encouraging car buyers to consult a variety of information sources could lower barriers present in the current buying process. The results of the study will be published by 2020.



Characteristics that would motivate the use of MaaS for commuting, weekday leisure, and weekend leisure trips, respectively.

3. ZHAW: Mobility-as-a-service

Researchers from the Institute for Sustainable Development at ZHAW explored how to reduce private passenger car use and ownership with the concept MaaS. MaaS encompasses mobility solutions such as sharing offers and public transport.

In order to better understand the needs and factors affecting MaaS in Switzerland, the researchers conducted a comprehensive online survey. The results show that people are generally more open to using MaaS for commuting than for leisure trips. If MaaS is actually to be used in everyday commuting, it must meet three key needs: spontaneity, lower costs, and short transfer times. For leisure trips (both weekdays and weekends), independence and luggage storage facilities are relevant factors. Overall, the provision of information and low barriers to practical experience are the key to fostering such combined mobility services.

Committed to change

Francesca Cellina

Merla Kubli

Romain Sacchi

They want to deliver tangible results and thus create a sustainable society. Researchers Francesca Cellina, Merla Kubli, and Romain Sacchi are either still working on or have worked in the past on various projects within the framework of Capacity Area B2, striving for this common goal. They talk about their research, and how behavior change can ensure a climate-friendly future.

What is your professional vision?
Merla Kubli:
The vision that motivates my work is a future energy and mobility system that is powered by renewables, uses resources in a sustainable manner, and satisfies consumers' needs.

Romain Sacchi:
What drives me personally is to be able to simplify the complexity of reality in order to present clear and tangible facts to decision-makers. I believe providing robust information increases the odds that they will pick the solutions with the best outcomes for our environment and society.

Francesca Cellina:
I hope my activities can contribute to fostering a societal transition and to shaping a more sustainable and climate-resilient society, for the sake of future generations. Specifically, my work addresses the "automobility" regime and automobile dependency currently dominating our society. Since I work at a university of applied sciences, my research activities aim at developing practical solutions for problems affecting our society and economic system.

Francesca Cellina, you studied urban mobility. Why did you choose that field?
Cellina: I've always had a strongly pro-environmental attitude and I've been a supporter of cycling since I was young. Tackling the challenge of reducing car use in urban areas was a natural choice.

Merla Kubli, Romain Sacchi, what motivated your choice of field of study?
Sacchi: Although I was concerned by the various environmental issues reported on by the media when I was a young student, I didn't really have the background to become an ecologist and to go out into the field. Given my background in economics, I decided to specialize in industrial ecology to get to the root of our environmental issues. In my field, I analyze how industrial systems interact with the environment.

Kubli: Coming from research that looked at flexibility business models based on solar-battery systems, I was particularly interested in understanding what role electric vehicles can play in contributing to balancing supply and demand in energy markets and how this impacts mobility systems. I'm fascinated by emerging solutions that connect electric vehicle (EV) drivers, "prosumers" (who are, at the same time, producers and consumers), and providers. From my perspective, a business model that actively engages consumers and makes them part of value co-creation will revolutionize mobility and energy systems.

When did you join the SCCER Mobility? And can you give us a deeper insight into your projects?
Cellina: I've been part of the SCCER Mobility since the very beginning—so, since 2014—and have collaborated with a number of different researchers over the years. Through pilot interventions in the field, I examined the effectiveness of smartphone apps in changing individual mobility patterns by reducing car use and by rethinking overall mobility demand.

Kubli: I joined in April 2018 as a postdoctoral researcher. I looked at the interconnection between investor and consumer acceptance of electric mobility. Joining the SCCER Mobility was a great opportunity for me to expand my research after completing my doctorate.

Sacchi: I only joined in June 2019 to work on quantifying the environmental impact of various means of transportation. It's important to find out more about the environmental and societal benefits and drawbacks of all these emerging technologies. Especially since significant changes—notably electrification—are taking place in the transport sector.

What was the toughest challenge and what the highlight of your time with the SCCER?
Kubli: Communication across disciplines can often be challenging, but at the same time it's also very rewarding. My personal highlight was gaining empirical insights about EV drivers' preferences for smart EV charging. We now know how we can tailor these offers to consumers' needs.

Sacchi: Data acquisition is always a challenge. Still, we recently managed to streamline the production of forward-looking databases used in environmental analyses, making prospective analyses of transport technologies easier. We also developed a public interface for quantifying the environmental impacts of different means of transport.

Cellina: For me, field interventions were the toughest challenge. For one of our projects, for example, we wanted to observe the mobility behavior of around 600 individuals for one entire year.

And your highlight?
Cellina: Well, in one of our projects we achieved a positive result in an area where we didn't expect one. Although it turned out to be difficult to achieve tangible changes in mobility behavior by using smart phone apps, we found that by involving the citizens of Bellinzona in the co-design of their app's features, city government officials discovered the positive aspects of participatory decision-making. So, the municipality might adopt this "living lab" approach for future projects of its own.

Since the SCCER is coming to a close, where are you currently working and on what?
Kubli: I'm continuing my research as a postdoctoral researcher at the University of St. Gallen (HSG). Starting in August 2021, I will be Assistant Professor for Managing Climate Solutions, working for the EU-funded Horizon 2020 project E-LAND, where we develop business models and a toolbox for energy communities.

Cellina: I'm still working at the University of Applied Sciences and Arts of Southern Switzerland (SUPSI), and am currently examining the effect of air travel on climate change. ►

Sacchi: I work as a postdoctoral researcher at the Laboratory for Energy Systems Analysis (LEA) at the Paul Scherrer Institute (PSI). I currently still dedicate most of my time to the SCCER Mobility's CA B2, specifically dealing with the life cycle assessment of mobility technologies.

Walk, cycle, take the train, or buy an electric car—what do you, personally, do to reduce greenhouse gas emissions?

Kubli: In my everyday life, my modal split consists of cycling and taking the train. I don't own a car, but through my membership of a vehicle-sharing scheme I have access to more than 2,800 cars in Switzerland should I need one. I also discovered bicycle touring as an exciting means of long-distance travel. In fall 2018, my partner and I cycled 3,600 kilometers, all the way to Marrakesh.

Cellina: I often use my folding bicycle, which I also take with me on the train. My family also owns an electric hybrid car we use on weekends if our destinations have poor public transport connections.

Technology or behavior change or both—what will save the planet?

Sacchi: In many cases, behavior change could already today put us on a much better path. For example, if we stopped eating meat we could already cut global greenhouse gas emission by 18 percent.

Cellina: I also see behavior change and policies as valuable levers for building individual and collective commitment to change.

Kubli: The technology is already relatively well developed. What we really need now is action from companies and consumers, who need to adopt these low-carbon innovations. For this to happen, we need functioning business models and consumer engagement.

Short profile —

Francesca Cellina

2020–today	Enrolled in a doctoral program on the "Analysis of Social and Economic processes", University of Milano Bicocca, Italy
2014–2020	Senior Researcher, Institute for Applied Sustainability to the Built Environment (ISAAC), SUPSI
2009–2014	Researcher, ISAAC, SUPSI
2001	MSc in Environmental Engineering, Politecnico di Milano, Italy

Short profile —

Dr. Merla Kubli

Starting 2021	Assistant Professor for Managing Climate Solutions, University of St. Gallen
2018–2021	Postdoctoral Researcher, University of St. Gallen
2018	Doctoral degree in Management, University of St. Gallen and ZHAW
2014	MSc in System Dynamics, University of Bergen, Norway/ New University of Lisbon, Portugal/ Radboud University Nijmegen, Netherlands

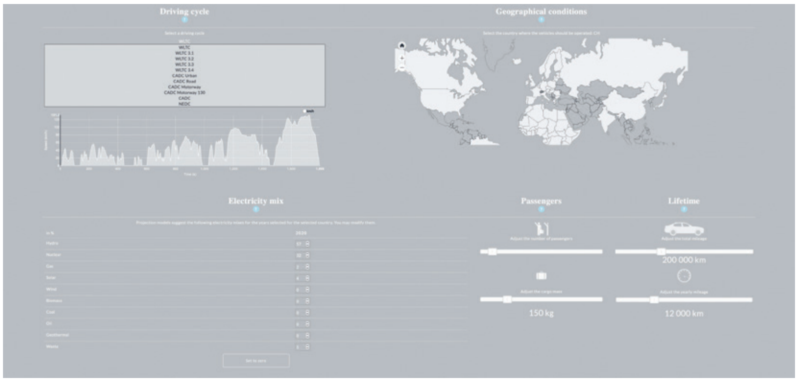
Awards

- Best paper award at the IAEE conference
- Best poster award at the SCCER Mobility annual conference
- Scholarship of excellence by the European Commission for the Erasmus Mundus European Master in System Dynamics

Short profile —

Dr. Romain Sacchi

2019–today	Postdoctoral Researcher at PSI
2015–2018	Doctoral degree in Industrial Ecology, Aalborg University, Denmark
2010–2012	MSc in Environmental Sciences, Aalborg University, Denmark



Graphical user interface of "Carculator", showing some of the user options.

Project highlight ——

Assessing the life cycle of cars

Decision support for car buyers and decision-makers: Researchers at the Paul Scherrer Institute (PSI) have developed a web tool called "Carculator". It can be used for detailed comparison of the environmental performance of passenger cars over their entire life cycle.

Since 2014, researchers from PSI's Technology Assessment group have been developing Carculator, a life cycle assessment (LCA) tool that estimates the environmental burden of current and future vehicles. The user can select various parameters, including the type of powertrain, vehicle size, and emission standards, and choose from a large number of fuels. Even bio- and synthetic fuels are accounted for, as are future technologies such as CO_2 capture and storage in hydrogen production. Users can also choose from more than 80 countries, since they determine the electricity mix for battery electric cars and hydrogen production by electrolysis, and can select the year of registration (2000 to 2050). In the future, users will also be able to enter the electricity mix, to test the effect of different scenarios. Carculator even allows advanced users to model their own vehicles. Or they can—before purchasing a new vehicle—find out more about the environmental performance of different options.

The tool also shows not only greenhouse gas emissions, but also the release of particulates, harmful nitrogen oxide emissions, and the usual environmental assessment indicators such as pollution of water bodies and resource demand. To make comparison easier, Carculator presents these values graphically for all selected vehicles in parallel. Furthermore, the data and the results of the ongoing studies are accessible to both end users and the research community.

Comprehensive comparison

Carculator also gives professionals a look behind the scenes: besides its online interface, it can be installed and used as a Python library, where the source code and all the underlying calculations can be viewed, and even modified. This feature is primarily intended for the research community, who will want to know how the work was performed and might want to use calculations for further studies of their own. This transparency should prove helpful regarding the public debate and serve as best practice in the scientific community.

In Carculator, PSI researchers have provided a unique tool. But it's not finished yet—upcoming versions will also include other means of transport, such as buses, two-wheelers, trains, aircraft, and trucks.

Carculator is available at https://carculator.psi.ch

Legend:

- Internal combustion engine (ICE)
- Hybrid ICE
- Plug-in hybrid electric
- Fuel cell electric
- Battery-electric
- Fossil fuels
- Electricity
- Hydrogen
- Bio- & synthetic fuels
- ○ Tailpipe emissions (CO_2)
- — Supply chain (CH)
- × Total GHG emissions

Project highlight ——

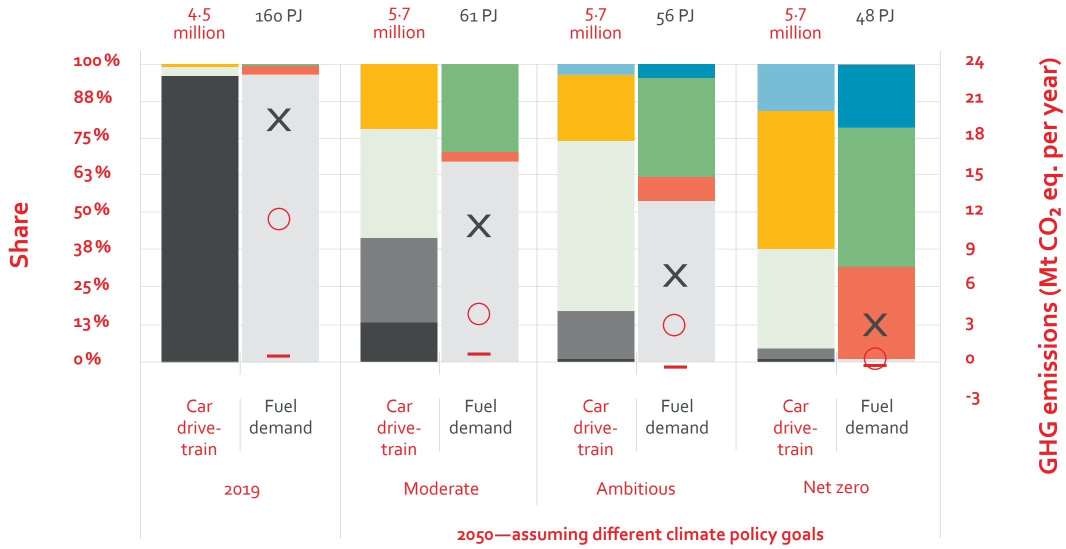
The best way to reduce CO_2 emissions

Exploring scenarios for climate-friendly and efficient mobility

The SCCER Mobility and its associated Joint Activities generated a variety of scenarios for the future evolution of the Swiss transport sector. The sector has been modelled as a part of the Swiss energy system and the scenarios cover different ambition levels with regard to climate change mitigation. In addition to a reference scenario based on moderate climate objectives reflecting current trends, an ambitious carbon dioxide (CO_2) emission reduction scenario of 80 percent by 2050 compared to 1990 and a scenario aiming at net-zero CO_2 emissions by 2050 were analyzed (excluding emissions from international aviation, land use, and forestry). The scenarios were assessed with the Swiss TIMES Energy Systems Model (STEM) of the Paul Scherrer Institute (PSI), which generates cost-optimal solutions and takes into account the multiple interdependencies between different technologies and actors. Some of the key findings are summarized below.

From fossil fuels to electric cars

The path to an extensive electrification of cars will lead to the widespread use of hybrid vehicles in the medium term. If we succeed in further reducing purchase cost and charging time while increasing range, the number of battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) will increase—especially if fossil fuel prices continue to rise. In an ambitious climate target scenario, in 2050 at least 80 percent of cars will be based on battery and fuel cell drives. Achieving net-zero CO_2 emissions by 2050 also requires that the remaining PHEVs use biofuels or synthetic fuels produced with carbon capture and storage (CCS). Depending on the climate target, the new car fleet alone will require around 5–9 TWh of electricity, which in 2050 would be dominated by renewable energy sources.



The figure shows the composition of the Swiss car fleet by drivetrain and corresponding fuel in year 2019 and for three scenarios for the year 2050. Greenhouse Gas (GHG) emissions from the fleet are provided based on coupling the STEM model with life cycle assessment (LCA) and the global system model REMIND. The bars indicate the share of number of cars having specific drivetrains and the car fleet's fuel shares. The markers show the GHG emissions from different sources—so from the tailpipe and from the supply chains in Switzerland, which together with related emissions abroad add up to the total GHG emissions. In this way, not only the direct emissions from the car but also the indirect emissions from the fuel supply chain, car manufacturing, maintenance, and disposal as well as infrastructure are accounted for.

Trucks and buses of the future

The electrification of trucks beyond hybridization is very expensive due to the high energy densities needed for batteries and the high annual mileage involved. Large-scale use of electric trucks can therefore only be achieved in connection with ambitious climate policy measures, such as strict emission targets or high taxes on fossil fuels. Under such conditions, light-duty vehicles (LDV) and urban buses would become extensively electrified. To achieve a net-zero emissions scenario, a portion of medium-sized trucks would become battery electric. For heavy-duty road-transport segments where direct electrification is limited or impracticable, trucks using hydrogen fuel cells and hybrid internal combustion trucks powered by biofuels and imported synthetic fuels (power to liquid) are core technology options.

Increase in hydrogen fuels

Transport is a major driver for the deployment of hydrogen in the energy sector since it consumes more than three-quarters of hydrogen totals across the different climate scenarios in the year 2050. To meet the goal of net-zero CO_2 emissions by 2050, the hydrogen share of the transport sector will need to reach 20 percent. This increase would also promote the production of biomass-based hydrogen.

Importance of a holistic assessment

The holistic assessment of national long-term climate goals shows clear interdependencies between climate change mitigation actions within the different sectors of the economy. To achieve the national climate goals, cross-sectoral coordination is necessary. Sectoral potentials and costs of emission mitigation strongly affect the design of sectoral policies. For example, the use of mature mitigation options (e.g., electric passenger cars, heat pumps) and disruptive end-user innovations (e.g., car sharing, smart homes) should be prioritized and supported, followed by appropriate incentives to increase the technology readiness of CCS technologies in electricity and hydrogen production, in order to achieve net-zero emissions cost-efficiently by 2050.

2

Overarching activities

2.1
Learning Lab— Future Transport Systems

Systemic evaluation

Bringing together the ideas of researchers and commercial partners can be a challenging task. To map experts' "mental model" of the future transport system in Switzerland a participatory method was used. This model-based approach was able to capture the complexity of socio-technical transition in the Swiss mobility sector.

The Learning Lab—Future Transport Systems (L^2-FTS) was established to integrate research activities across the SCCER Mobility network and to define new projects with various commercial partners. Its main objective is to provide insights into current challenges and potential solutions with regard to a sustainable transport system in Switzerland. These insights will inform future political decisions, which in turn will influence future technological developments. Within the SCCER Mobility network, L^2-FTS supports the Management Office of the SCCER by analyzing the relevance of the network's research activities. In collaboration with industrial partners, it analyzes the main technological challenges facing future mobility. L^2-FTS uses a variety of methods to analyze the Swiss transport system, with a special focus on complex socio-technical transitions—where both social and technological factors are vital for system transformation. In its search for solutions, it gathers information from different stakeholders to gain a better understanding of their main challenges and the impact of new technologies. The core goal of the Learning Lab is to transform this understanding into an analytical and quantifiable model by mapping the mental models of experts. This systemic approach is necessary to understand how different social and technological innovations are relevant to a sustainable Swiss mobility system.

In this respect, L^2-FTS conducts research on the impact of emerging technologies on the future state of both road and rail transportation systems, especially in the freight sector. From among its range of methods, qualitative data analysis, Vester's sensitivity model, and social network analysis are used to gather ideas on emerging technologies. Different data sources are used to analyze the technology potentials of the future freight system in a quantitative way. Simulation models complement these methods by analyzing interdependencies, feedback loops, and emerging clusters.

Within this framework, L^2-FTS is collaborating with SBB Cargo on the research project "Future environmental performance of Swiss freight transport". For this project, it is investigating competition and collaboration between rail and road freight systems in Switzerland. To be able to analyze the main challenges and opportunities of the freight transport system, L^2-FTS developed a method to map expert opinion into dynamic models of specific technologies and technological solutions. This dynamic modeling allows us to look at how selected interventions—including road electrification, strategic decisions regarding rail, and policy changes—impact the dynamics of road–rail freight collaboration and competition.

Around 30 experts representing all groupings in the Swiss freight market have participated in the SBB Cargo project, including operators, shippers, technology providers, policy makers, and academics.

The main result so far is a systemic understanding of the main challenges, solutions, and potentials in the Swiss mobility system. The impact of new technologies and strategies will be simulated by system dynamics modeling. The results will help SBB Cargo and other companies to better understand the existing challenges and potential solutions in the freight transport market.

Another major project is looking into the key performance indicators (KPI) of the Swiss mobility system. This project evaluates the impact of the SCCER Mobility's research activities on the KPIs of a sustainable mobility system in Switzerland. Around 30 experts representing all the research groups from the SCCER Mobility have been involved. In particular, this project has tried to find out whether the research activities within the capacity areas are connected and build on each other. The KPI project analyzes how different activities are related, and how they can be grouped into different clusters.

The results of the KPI project can be used to organize similar research programs in the future. This will also help decision-makers to better understand the relevance of research activities to the goals they have set, and how to initiate further research projects. The SCCER's Management Office will also be able to use the results of the project when reporting to the evaluation panel and reflecting on the lessons learnt.

Currently, L^2-FTS still has visibility thanks to the SCCER Mobility, including its website, newsletter, and network. Unfortunately, overall reach is limited since part of the SBB Cargo project is confidential and the KPI project is primarily focused on the activities of research teams within the SCCER Mobility network. In the future, however, the activities and results of L^2-FTS could be used by companies and policy makers when developing strategies and making technological decisions. Furthermore, the Learning Lab will hopefully endure—if in a new format, pursuing the main findings of the current phase, along with new research tracks. ⦿

Dr. Amin Dehdarian
Postdoctoral Researcher
ETH Zurich

Dr. Albert Mancera Sugrañes
Postdoctoral Researcher
ETH Zurich

Dr. Mireia Roca-Riu
Postdoctoral Researcher
ETH Zurich

Interview: researcher ——

The social dimension of mobility

Since April 2018 Dr. Amin Dehdarian has been a postdoctoral researcher in the Learning Lab—Future Transport Systems (L^2-FTS). He holds a doctoral degree from the Swiss Federal Institute of Technology in Lausanne (EPFL) and specializes in the application of complex systems theory to understand technological changes in the energy and transport sectors. He talks here about the challenges faced by L^2-FTS and about his vision of the mobility of the future.

What were the biggest challenges you had to overcome?
Amin Dehdarian:
The two projects "Key Performance Indicators (KPI) of the Swiss mobility system" and the SBB Cargo were very interactive. We had to interview more than 60 experts. Getting to talk to all these busy people was quite a challenge, and delayed the data-collection process. Accessing quantitative data is also quite difficult, and for modeling and data-driven methods we needed our partners to commit to providing us with data.

The implementation of the results is no easy matter either. They're primarily related to strategic decision-making. And those decisions are made at a very high level of management, which needs to take into account lots of other factors outside the scope of our research, including political issues, organizational change, and demographic factors.

What were the highlights of your research?
What surprised some of the experts was that road and rail freight systems are considered as complementary rather than as competitors. Secondly, road freight electrification and rail digitalization are the primary technologies of the future in the freight system.

What will happen once the SCCER Mobility winds down?
Hopefully it will continue in a new format. Which means that we would be able to use the main findings of the SCCER to define new research tasks.

Based on your current research, what is your personal vision for the future?

In my opinion, a decarbonized freight transport system in Switzerland is feasible for 2050, based on recent technological developments and the political support now behind it. Battery technologies and fuel cells are the most likely solutions for road electrification. In the coming decades, the focus will be on collaborations that contribute to joint business cases, economies of scale, and standardization, especially for urban logistics. Rapid urban growth and changing market expectations remain, however, critical challenges for the future.

What are the main recommendations for decision-makers—from policy makers to industry and consumers—that result from your research?

More focus on business cases, economic aspects of new technologies, and collaboration is required for the development of new technological solutions. At the moment, there's a focus on technological advances. But this should be complemented by involving research partners focused on the institutional and social aspects of technological developments.

Short profile ——

Dr. Amin Dehdarian

2018–today	Postdoctoral Researcher, L^2-FTS, SCCER Mobility
2013–2017	Doctoral degree in Management of Technology, Swiss Federal Institute of Technology in Lausanne (EPFL)
2009–2013	MBA, Sharif University of Technology, Tehran, Iran
2011–2013	Change management consultant, MAPNA Locomotive Engineering and Manufacturing Company, Tehran, Iran
2008–2009	Internship, the Electrical Research Center, Sharif University of Technology, Tehran, Iran
2004–2008	BSc in Petroleum, Sharif University of Technology, Tehran, Iran

Key project

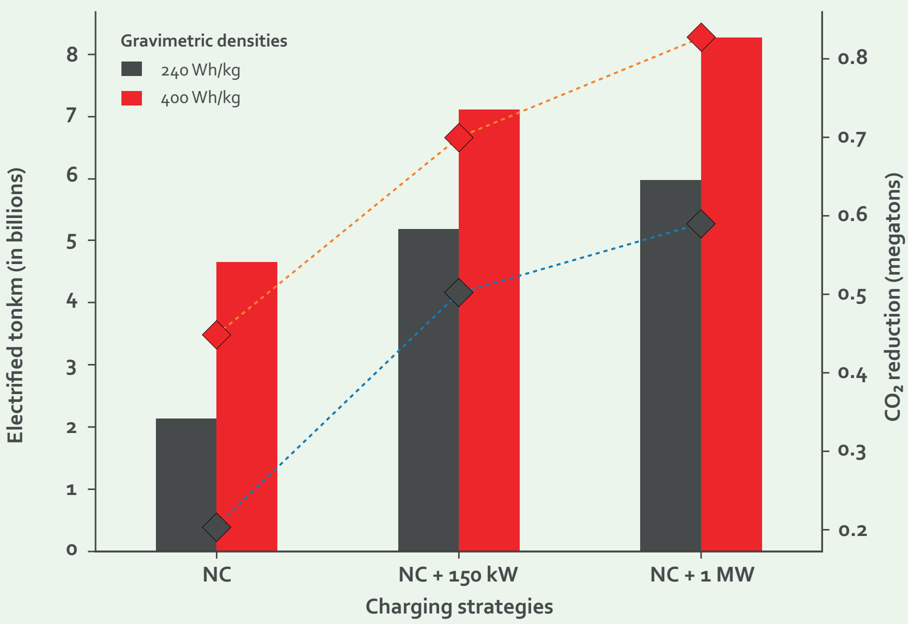
Rethinking freight transport

Analysis of the Swiss freight market and future scenarios

The objective of the project "Future environmental performance of Swiss freight transport" is to gain insight into potential environmentally friendly scenarios for the freight sector. It focuses on road and rail transport—in particular on heavy-duty road freight vehicles (over 3.5 tons) and freight trains—and on upcoming technological and business models and their role as competitors and/or cooperators in the national freight market.

Electrifying road freight

The main focus of the project with regard to the road freight future scenario was to explore road freight's potential for electrification. Thus far, electrification has been considered a promising method of reducing CO_2 emissions. Two technologies stand out: electric batteries and hydrogen fuel cells. The project focuses on the potential that battery electric heavy-duty trucks have to replace combustion engine heavy-duty trucks in Switzerland, given the particularities of Swiss road transport and the combined transport of freight.



Number of ton kilometers (tonkm) that could be covered by battery electric trucks given different energy densities of batteries and charging strategies, along with CO_2 emissions avoided.

With big data tools, the performance of the entire Swiss truck fleet was replicated to determine its energy demand. Based on this data and considering two types of gravimetric densities (240 Wh/kg and 400 Wh/kg), the approximate size of electric batteries for trucks was calculated, and it was also estimated which parts of the fleet could be electrified.

Scenarios for charging—including night charging (NC) versus night-plus-day charging (150 kW and 1 MW) during logistic operations such as loading and unloading—were also designed and their costs assessed. To calculate economic viability, the total cost of ownership (TCO), including vehicle-based capital and operating expenditures, was estimated for the existing trucks and for their electric counterparts. Further, infrastructure costs, such as the installation and maintenance of charging stations and the enhancement of the electric grid for the different Swiss cantons, were evaluated in a separate analysis. A study was conducted to evaluate another battery electric based solution for road freight transportation—overhead catenary systems—identifying which segments of the Swiss highway system could potentially be adapted to this new system.

Main findings show that it is possible to replicate up to 75 percent of today's road freight system using battery electric vehicles (2 to 8 billion tonkm/year). Big savings (56 percent) on CO_2 during operation are possible (0.2 to 0.8 megatons of CO_2/year). Economic investment will be necessary to adapt the electric grid to the new levels of demand and chargers need to be installed in the right locations. This investment could reduce externalities of the sector drastically, providing a greener transportation system in Switzerland. ⦿

Short profile ——

Dr. Albert Mancera Sugrañes

2019–today	Postdoctoral Researcher, L2-FTS, SCCER Mobility
2011–2017	Doctoral degree at the Institute for Transport Planning and Systems, ETH Zurich
2010–2011	Strategic consultant in engineering issues at CETMO (Centre for Transportation Studies for the Western Mediterranean), Barcelona, Spain
2008–2009	MSc exchange program in Transportation and Urban Planning, University of Liège, Belgium
2003–2010	BSc and MSc in Civil engineering, Polytechnic University of Catalonia, Barcelona, Spain

Digitalization in the mobility sector

The latest additions to the SCCER Mobility were research projects in the field of digitalization, since information and communication technologies are rapidly growing in importance. Five new projects were identified and will be funded until the end of 2020.

Research in the field of digitalization is one of the latest projects of the SCCER Mobility. Five projects—embedded in the different capacity areas—are being funded until the end of 2020.

In late 2018, Innosuisse invited the SCCER Mobility to expand the scope of its program to also address research issues at the interface between digitalization and mobility. The main reason for Innosuisse's decision was that information and communication technologies have developed significantly since the SCCER was launched in 2013, opening up opportunities that were unthinkable seven years ago. The newly proposed research projects were approved and initiated in May 2019. As the projects were embedded in different capacity areas and were barely connected, it was deemed critical to dedicate a special project to exploiting potential synergies between the projects and to ensure coherence within the SCCER Mobility program. Therefore, a final, umbrella project bringing together all digitalization activities was also established as an overarching activity within the Learning Lab—Future Transports Systems (L²-FTS).

Within the digitalization program of the SCCER Mobility, researchers from a range of institutions working on various projects of the SCCER Mobility tackled different challenges.

- The "Smart Mobility Data Platform" project plans to create a platform to analyze the performance of vehicles, batteries, and other mobility devices during both demonstrators and long-term projects.

- The "Automated Driving Sensor Testing Vehicle" project evaluates the behavior of vehicle sensors in the real world—combining that behavior with advanced data management strategies for automated driving (AD) decision-making in order to support the development of an AD field test strategy and regulations for Switzerland.

- The "Decision Support System (DSS) for Personalized Ride-sharing Services" project aims to create a prototype to enable and promote carpooling, with personalized, short-term, real-time trip recommendations for travelers.

- The "Optimizing the Potential Impact of Electric Mobility on Grid Stability" project investigates how to prevent a negative impact of electromobility on grid stability. It uses detailed personalized mobility predictions and precise grid network modelling and is connected with different mobility scenarios in the Canton of Ticino.

In November 2019, Mireia Roca-Riu joined L²-FTS to focus on and lead the overarching, umbrella project. The project investigates the links between the four other projects. The aim is to monitor all four projects and to develop a framework for cooperation and knowledge exchange. It also provides an assessment of how these digitalization projects contribute to the overall strategy of the SCCER Mobility.

Common elements Block I	1. open data set	2. decision-making problems	3. solving approaches	4. scenario generation
Smart Mobility Data Platform P. Affolter & A. Laube	Clear	In progress	In progress	Clear
AD Sensor Testing Vehicle C. Bach & E. Frazzoli	Clear	Clear	Clear	Clear
DSS for Personalized Ride-Sharing Services M. Raubal	In progress	Clear	Clear	Clear
EV on Grid Stability M. Raubal, R. Rudel & L.M. Gambardella	In progress	Clear	Clear	Clear

● Clear ● In progress

Connecting elements among all the SCCER Mobility digitalization projects.

Key project ——

Connecting elements

The "umbrella" project

The role of the overarching, umbrella project is to identify potential links between the four other digitalization projects. The project was developed at the Learning Lab—Future Transports Systems (L^2-FTS) and is run in collaboration with all the SCCER's academic research partners. In addition to managing and monitoring all the other digitalization projects, this activity serves as a platform for cooperation in order to strengthen the network between the different institutions concerned and to encourage the exchange of ideas and methodologies. Another objective is to assess the overall impact of the digitalization projects on the development of the mobility sector—compared to other projects, which focus, for example, on new technological solutions.

Additionally, L^2-FTS has proposed a framework to classify and define "digitalization" in order to create common ground for communication between the project groups. The exchange of ideas and methodologies is based on connecting elements, which are common to all the digitalization projects. The creation of an open data set, the definition of decision-making approaches, and their solving approaches, and the generation of scenarios are part of a first block of connecting elements, which were discussed at the beginning of the project.

A second block of connecting elements brings together the results of the SCCER's various projects. The most important is the value of data, which differentiates the digitalization projects from all other projects in the SCCER. The idea is that the digitalization projects highlight the value of data for their various project decisions, thus enabling them to quantify how different those decisions would have been had the data not been available. So, they can quantify if the decisions would be different if the data were not available. Another connecting element is the profiling of different project prototypes, which—brought together and compared—allow the researchers to learn from one another. The final connecting element is the assessment of the overall impact of the SCCER's digitalization projects on the development of the mobility sector compared to other projects, which focus, for example, on new technological solutions.

Short profile ——

Dr. Mireia Roca-Riu

2019–today	Postdoctoral Researcher, Learning Lab – Future Transport Systems (L^2-FTS), SCCER Mobility
2016–2019	Postdoctoral Researcher, Institute for Transport Planning and Systems (IVT), ETH Zurich
2011–2015	Doctoral degree in Statistics and Operations Research, Polytechnic University of Catalonia, Barcelona, Spain
2007–2008	MSc in Statistics and Operations Research, Polytechnic University of Catalonia, Barcelona, Spain
2002–2007	BSc in Mathematics, Polytechnic University of Catalonia, Barcelona, Spain

2.2 MAS|CAS program

Transferring research into practice

To shape future mobility, transport company professionals, government institutions, and the mobility and energy industry must be familiar with the newest technology and trends as well as changing needs and policy frameworks. With this requirement firmly in mind, the SCCER Mobility designed a continuing education program for professionals. Since 2017, ETH Zurich has been offering the MAS ETH in Future Transport Systems, developed by the SCCER.

The mobility sector is changing at a rapid pace. Multimodal services, car sharing, e-mobility, and autonomous driving are among the trends that will shape the mobility of the future. To contribute to and drive these changes, the various players in the mobility sector must be familiar with innovations, new technologies, individual mobility needs, and changing conditions, and must understand the complexity of the mobility system.

With its Master of Advanced Studies (MAS) ETH in Future Transport Systems and three Certificates of Advanced Studies (CAS) degrees, ETH Zurich offers practice-oriented continuing education for the sector's professionals. The program was devised within the SCCER Mobility network and certain network members play key roles in the academic management and teaching of the courses. The program provides participants with the necessary technical foundations to better predict the impact of specific changes and interventions on the overall system. This enables them to develop integrated, sustainable, and climate-friendly mobility solutions that they can implement in their own working environment.

The program structure

Development of the MAS and CAS programs began in 2015. Ruth Förster was the first program manager, and with her strong background in didactics, continuing education, and alternative teaching methods she coordinated the program's conception and the content development for the three CASs. In doing so, it was particularly important to take into account the limited time available for classroom instruction. The major challenge was to find the right combination of conventional classroom teaching to convey the basics and modern teaching methods such as blended learning, flipped classroom for further discussion, and in-depth study.

Another challenge was to have the program bring together the expertise of different institutions. In 2015, that expertise in the various aspects of mobility was spread across different Swiss universities. For the first time, through the MAS and CASs, the SCCER Mobility helped bundle this know-how into a single interdisciplinary program. Today, researchers and lecturers from institutions throughout Switzerland, from ETH Zurich to the Paul Scherrer Institute (PSI), and from Empa to the Swiss Federal Institute of Technology in Lausanne (EPFL), as well as several universities of applied sciences, contribute to the MAS and CASs.

The program covers freight and passenger transport as well as public and private transport. The focus is on rail and road, although other aspects of mobility may also be addressed. In addition to standard engineering know-how regarding energy conversion, fuel consumption, and emissions, the lecturers impart knowledge on topics such as geographical information systems, scenario development and forecasting, economic feasibility, and life cycle assessment, as well as business model design. The objective is to enable participants to evaluate, develop, and implement integrated and sustainable mobility solutions. ►

"The design of sustainable mobility that also meets the needs of society poses major challenges. Systems thinking and the targeted use of new technologies are indispensable. The MAS ETH in Future Transport Systems provides the theoretical and practical knowledge necessary for well-founded discussion and to successfully tackle the implementation of new forms of mobility."

Rita Nenniger, Head of Innovation, PostBus

"Thanks to the MAS program, I was able to systematically learn about the mobility of the future and get a holistic picture of current developments and future challenges. Combining cases from my own professional experience with state-of-the-art science as well as the expertise of external lecturers and my fellow students led to promising ideas, new insights, and fruitful discussions. In sum, the up-to-the-minute nature of the topic, the dynamism of the group, and the ambitious atmosphere allowed me to take home knowledge and skills that I can apply to my work at Verkehrsbetriebe Zürich."

Silvan Weber, Project Manager Market Development, Verkehrsbetriebe Zürich

The program has been very well received. Participants particularly appreciate the interaction with researchers during lectures and laboratory visits, as well as the wide variety of teaching methods. Further plus points include opportunities to network with fellow students and experts from different companies and institutions.

Target groups and requirements

The main target group for the two-year MAS program and the CAS courses are professionals in a strategic or operational role, and project managers and executives from the private sector and governmental institutions. Participants from all industries are welcome. People who want to change career paths and are aiming to work in the mobility sector can also apply.

Applicants should be proficient in German and English. Academic requirements for participants include a Master's degree from ETH Zurich or a Master's level qualification in the engineering sciences. Interested individuals with a degree in information and communication sciences, industrial engineering, natural sciences, or geography are also welcome to apply. Depending on further qualifications and professional experience, applicants with a background in economics, social sciences, or humanities may also be admitted. Two years of experience in the field of mobility or related areas are required.

So far, most participants have been professionals based in Switzerland working at public transport companies, for public authorities, or in the private sector including for mobility/energy solution providers, consultancies, or insurance companies.

The future of the program

The program was launched in the spring semester of 2017. In fall 2018, the first five students graduated with a MAS ETH in Future Transport Systems. Current students will begin writing their Master's theses in fall 2020, and

"Insights into future mobility indicate the direction in which the automotive industry will develop. Suppliers need to understand and evaluate these emerging ecosystems and dependencies to determine their business strategies. The CAS System Aspects provides students with the scientific background, trends, and drivers. The course also fosters exchange with fellow students, and encourages discussions about various aspects of mobility. All things considered, the CAS provides the tools needed to help shape the mobility of tomorrow."

Thomas Maissen, Division Management, Jansen AG are expected to graduate early in 2021. To ensure that the MAS and CAS program continues once the SCCER Mobility phases out at the end of 2020, it was integrated from the beginning into the ETH Department of Mechanical and Process Engineering and the ETH School for Continuing Education. The third round of the program is scheduled to begin in the spring semester of 2021.

During its conceptual and early stages, the program received funding from Innosuisse and ETH Zurich. From 2021 onward, all financial support will cease and the program will have to be self-sufficient. In order to attract enough participants, the program's management team plans to continuously adjust course content to incorporate the trends and suit the needs of the mobility sector, and intends to partner with companies as sponsors.

The benefits for research

The benefits of the program for science and research are tremendous. Not only do the lecturers transfer their knowledge to program participants, in return they also gain unique insights into the industry and the workings of governmental processes. They learn which questions are vital for the mobility sector and can thus integrate them into their research. In addition, participants have to write term papers, which are often related to research projects. And the close cooperation with the mobility industry fosters new partnerships and collaborations, which in turn further contribute to mobility's transition to sustainability.

Prof. Dr. Christopher Onder
Academic Director, MAS|CAS ETH
Institute for Dynamic Systems and Control (IDSC), ETH Zurich

Dr. Kirsten Oswald
Program Manager, MAS|CAS ETH
in Future Transport Systems,
ETH Zurich

Graduates are able to

- understand the physics of the systems involved
- identify dynamics in the complex system of mobility
- understand the effects of measures and apply them to concrete problems
- discover potential for sustainable and integrated mobility solutions
- develop innovative, marketable products or services and implement new business models
- recognize and optimize economic, ecological, and social aspects of existing mobility services or systems
- help shape transformation processes

MAS|CAS in numbers

2017/2018 participant numbers

- MAS—5 students
- CAS System Aspects—6 students
- CAS Technology Potentials—4 students
- CAS New Business Models—10 students

Total number of graduates

5 MAS; 20 CAS

2019/2020 participant numbers

- MAS—5 transfers from CAS to MAS; 3 new students
- CAS System Aspects—8 students
- CAS Technology Potentials—7 students
- CAS New Business Models—5 students

Total number of graduates

8 MAS; 20 CAS

Lecturers

- 45 academic lecturers
- 15 external lecturers

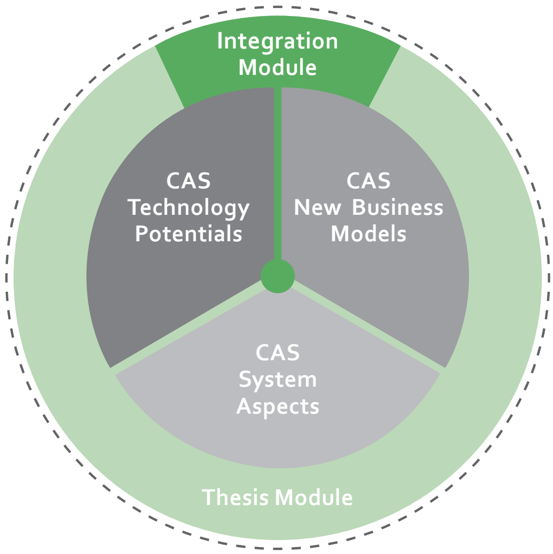
Modularity MAS

MAS ETH in Future Transport Systems

The Master of Advanced Studies (MAS) ETH in Future Transport Systems consists of three interdisciplinary Certificates of Advanced Studies (CAS): System Aspects, Technology Potentials, and New Business Models. Upon successful completion of the three CAS courses, students can opt to obtain their MAS degree by completing a Module Integration and Master's thesis. Total study time is usually two years part-time.

Certificates of Advanced Studies

The three CASs (System Aspects, Technology Potentials, and New Business Models) can be taken individually. The total study time for each is usually half a year part-time.



Time-line

	Spring Semester	Fall Semester
Year 1	CAS System Aspects	CAS Technology Potentials
Year 2	CAS New Business Models	Master's Thesis Integration Module

Portrait: alumnus ——

A broader perspective

Wolfgang Kling

In May 2019, the first students completed their Master of Advanced Studies (MAS) ETH in Future Transport Systems, marking a successful conclusion to the first round of a program developed within the framework of the SCCER Mobility. Among the graduates was Wolfgang Kling, Fleet and System Manager at BLS AG, one of Switzerland's largest transport companies.

Why did you decide to sign up for the MAS?
Wolfgang Kling:
To be honest, I initially only wanted to sign up for the Certificate of Advanced Studies (CAS) System Aspects, and out of pure curiosity. But as the CAS gave me completely new insights and the mood in the class was great, I decided to continue.

How did the program go? What did you like best?
Looking back, it was a very inspiring time and meant a heavy workload, but the effort was worth it. The lecturers and my fellow students helped to create a stimulating atmosphere and we were able to establish a network that will remain beyond the MAS.

I particularly liked the interdisciplinary group work. We learned a lot from each other and to look at things from completely different perspectives. From the MAS, I gained a lot of new insights and they have given me a realistic and concise view of current challenges in the mobility sector. I can now present my point of view in an even more scientifically sound manner. Thanks to the program, I have learned how important it is not to think in terms of individual categories and closed systems when it comes to the mobility and energy sectors.

What do you think about the structure of the program?
The MAS provides a broad overview of the diverse aspects of the mobility system and of technological potentials and teaches basic methods for developing business models. The CAS modules are ideal for deepening the knowledge acquired and for determining which topic one would like to focus on in the MAS thesis. The concluding integration module expands the expertise you have developed until it reaches across disciplines, while the MAS thesis allows you to explore one aspect in greater detail.

What did you investigate in your thesis?
I looked at how an "e-highway" could help reduce carbon dioxide (CO_2) emissions from road freight transport in Switzerland. Currently, road freight transport contributes 4 percent of national emissions, and at the moment there is no applicable solution to reducing them that won't require restrictions.

One possible future solution could be the electrification of national roads, tiered according to traffic load and energy demand. Depending on the number of electric trucks powered by overhead lines, Switzerland could cut its CO_2 emissions per year by up to 1.4 million tons. The investment in these trucks could be amortized by their lower energy costs.

Do you expect e-highways to become a reality soon?
There are tests ongoing in Germany and Sweden on different highway stretches and in mines. But they cover only short sections of 4 to 5 km in length, intended to test the system itself as well as the transition to and integration into standard roads. The infrastructure —with all its overhead gear and power supply—is, and will remain, as expensive as it currently is for rail or trolleybus systems. So, I doubt it will be rolled out broadly soon.

You graduated a while back; do you still benefit from the course today?
I do, and in many different ways. For example, a short time ago I applied my knowledge of mobility systems and technical solutions to reduce emissions in a recently launched BLS project that aims to reduce the use of fossil fuels as much as possible for all the projects we carry out in the field of infrastructure maintenance.

3

Outreach & outlook

3.1
Research achievements and outlook for the mobility sector

Shaping the future

Andrea Vezzini, Deputy Head of the SCCER Mobility

Deputy Head Professor Andrea Vezzini from Bern University of Applied Sciences was on board from the outset. He gives an overview of the achievements of the SCCER Mobility and comments on the future of the mobility sector.

"The many facets—that's the exciting thing."

Andrea Vezzini

What were the main objectives of the SCCER Mobility? Were they achieved?
Andrea Vezzini:
The SCCER Mobility had two objectives: Firstly, to find solutions to reduce carbon dioxide (CO_2) emissions in Switzerland. Second, to develop young talent and to institutionalize new research positions for the mobility of the future. After all, we need researchers if we are to achieve the energy transformation we're aiming for by 2050. By broadening the base of researchers at the various institutions, new jobs and facilities have been created. We were able to identify ways of reducing CO_2 emissions, which we made publicly available as a basis for decision-making in two white papers. In particular, the paper "Towards an Energy Efficient and Climate Compatible Future Swiss Transportation System" was very well received by the public.

In retrospect, it can be said that we achieved both goals and were able to clarify the energy transformation and the further development of the mobility sector.

The capacity areas have played a major role in you achieving the main objectives. What are the key achievements in each?
In principle, we have two major axes—the technology axis and the socioeconomic research. Accordingly, achievements must be divided into technological aspects (Capacity Areas A1, A2, and A3), on the one hand, and socioeconomic or systemic aspects (B1 and B2), on the other. During phase 2 of the SCCER program in particular we encouraged so-called cross-cutting projects involving several capacity areas across the two axes.

Could you summarize for us the most important aspects of each capacity area?
Concerning the technological achievements, as coordinator of CA A1 I can look back with great satisfaction. In CA A1, e-mobility, in particular there has been an enormous change—from a niche application to front-runner technology. While the fundamental challenge of electromobility over the past seven years has been the onboard energy storage system or vehicle battery, this problem has now essentially been solved.

At the SCCER, we had to decide where to start our research. Should we tackle major projects with international car manufacturers or concentrate on Switzerland? We decided on Switzerland and mainly developed battery systems for niche vehicles, such as buses or construction vehicles. We were actually able to trigger a lasting trend here: In the next five to ten years, possibly every transport company in Switzerland will switch to electrified buses, or like Bern and Zurich to hybrid buses. And in the eDumper we created the world's largest electrified dump truck.

The time horizon was also well chosen. We set ourselves realistic goals. It would, for example, have been much more difficult to build an aircraft. We would probably still be working on that.

Were the other capacity areas as successful as A1?
Capacity Area A2 was mainly about chemical energy converters. It is, after all, simply not enough to say that the future is electric—there will be a long transition phase. There are areas of application where we will continue to depend on the energy density of chemical energy sources in the future, such as long-distance transport, ships, and aircraft. They will use either fuel cells or synthetic fuel-powered combustion engines.

In addition to optimizing combustion engines for synthetic fuel and the development of hybrid solutions —incidentally, this is an example of the successful collaboration between Capacity Areas A1 and A2— the researchers focused on two other approaches in particular: fuel cells and gas engines.

In contrast to A1, there was a lot of basic research, which is why even after seven years no marketable solution was expected. As already mentioned, we had two routes here—fuel cell activity and combustion engines. We have, however, made significant progress: We have managed to develop fuel cells that are more efficient and much cheaper. And we have built new engines based on natural gas, which can also be fed with renewable gas.

As gas engines are in a difficult position due to the current political framework conditions, while we were able to make progress unfortunately these research approaches are currently are not being applied.

In Capacity Area A3, the aim was to reduce vehicles' energy requirements. There are two possible approaches here. Firstly, energy efficiency can be improved by increasing the efficiency of drive systems. Secondly, one can reduce vehicle weight by lightweight construction, so that vehicles require less energy.

We found interesting new approaches in lightweight construction, replacing aluminium and steel with thermoplastic and bioinspired composites. In this area we also sought to collaborate with industry at a very early stage.

And the other two capacity areas, B1 and B2?
Here it was a matter of embedding new technologies into the complete mobility system. Capacity Area B1 dealt with increasing mobility's energy efficiency from a systemic perspective. This approach takes all aspects of mobility into account—so, mobility technology, infrastructure, and users—and relates them to mobility patterns, urban planning, and environmental data. One focus lies on designing and optimizing the infrastructure for renewable energy carriers (supply of charging stations, hydrogen filling stations, and logistics). On the user level, research deals with assessing new IT and information service technologies to foster energy-saving mobility choices. Capacity Area B1 interlinks mobility choices and patterns with environmental and spatial planning to develop a decision support tool for consumers, municipalities, and policy makers, leading to reductions in demand for energy.

Finally, Capacity Area B2 was about evaluating a future scenario for the Swiss mobility system and how it could be made sustainable. The consequences of environmental influences were also included: this, in turn, serves as a basis for decisions regarding future strategies.

For example, we were able to determine what it would mean if Switzerland were to convert individual passenger transport completely to an electrified basis. In fact, contrary to our expectations, energy demand would only increase by 15 to 20 percent—that is, by 14–16 terawatt hours. This fact has greatly contributed to substantiating the discussion.

Within the framework of this project, the GoEco! tracker app was developed, enabling researchers to study people's mobility behavior. At the same time, the app automatically provided participants with feedback and advice regarding their own, individual mobility behavior.

What are the key achievements when it comes to scientific knowledge and collaboration?
The collaboration between the universities of applied sciences, on the one hand, and the universities and ETH domain, on the other, on such a large scale was new territory for us. Creating a network and working together in an interdisciplinary manner was very enriching. It was clearly shown that the universities can work well with the universities of applied sciences, on all academic levels.

One of the results is the creation of a center for battery technologies, the Energy Storage Research Centre (ESReC) at the Bern University of Applied Sciences (BFH), where I work.

How can you be sure that the SCCER has brought about a lasting change?
The Master of Advanced Studies (MAS) and the Learning Lab, the latter a virtual network for exchange between researchers, are certainly part of the SCCER's legacy. The MAS is an ideal instrument for providing future decision-makers in the field of mobility with new data from research. This will have a significant impact on how the future of mobility will look.

"The large network is breaking down into slightly smaller dynamic networks, but the connections remain."

Andrea Vezzini

Your personal highlights of the past seven years?
It was very satisfying to be part of the project from the beginning and to be involved in ►

shaping everything as the SCCER's Deputy Head.

The many facets—that's the exciting thing. And to see how much can be achieved with a little coordination between the different areas involved. Also, the exchange within the network was something very enriching. One example is the "Young Talent Development" platform, where young scientists present their projects. Personally, I very much enjoyed the SCCER's annual conference, where academic and industrial partners met to exchange ideas.

"The exchange within the network was something very enriching."

Andrea Vezzini

What is your conclusion with regard to the SCCER Mobility: Is now the right time to stop?
The SCCER Mobility has become very complex and at some point we will run out of steam. Maybe we can say "hit reset" now. The large network is breaking down into slightly smaller dynamic networks, but the connections remain. New projects are already emerging: the federal funding program SWEET (SWiss Energy research for the Energy Transition) and the Innosuisse NTN–Innovation Booster, to name but two. And this will work because people now know and trust each other.

What will the biggest challenges be in the next 30 years?
For mobility, these are certainly the decarbonization of the mobility system while at the same time providing a CO_2-free energy supply without the option—at least in Switzerland—of resorting to nuclear energy. But there are also a lot of infrastructure challenges, such as public chargers for e-mobility. We are also only at the beginning of autonomous mobility. In addition to the technology, there are still some regulatory hurdles to be overcome. And then there is the discussion of whether we need to let mobility grow unchecked at all.

Where do we stand now?
Overall, we're not there yet, but we're on the way. Imagine a typical S-curve, where it takes a long time for something to get going and then it goes very quickly. We are now at the bottom bend of that S-curve. Over the next 10 to 20 years change will accelerate massively. A lot of things are going to happen when it comes to mobility.

How did you, personally, come to the topic?
It was almost a lifelong dream: I started my doctoral degree at ETH Zurich in 1991 and finished in 1996. At that time I was already writing my dissertation on hybrid vehicles and have been working on the topic of mobility ever since.

Admittedly, 30 years is a long time to be working on the same theme. But to see all the things I hoped for become reality, that is the greatest satisfaction for me personally.

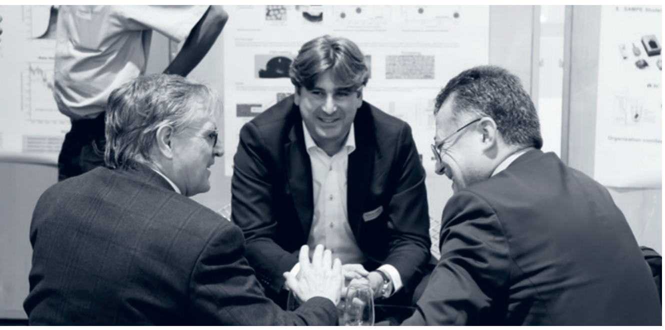
A small example may help. In 2001, I developed an electric bicycle at BFH, with which we cycled 3,000 km through Australia with a team. In five days. Even then we were convinced that e-bikes were the best. And now they outsell standard bikes!

Every engineer is satisfied when what he or she is working on finds a practical application. And this particular dream has come true. ⦿

Annual Conferences

A successful networking and exchange platform

The annual conferences are the SCCER Mobility's largest networking events, where the SCCER's researchers meet scientific and industrial partners, representatives of public bodies, and other interested parties. All come together to discuss selected research results, the overall goals, and the future direction of the program. The conferences are also an opportunity to meet and exchange ideas and information with potential collaboration partners.



2014

2015

2016

The very first SCCER Mobility Annual Conference took place in 2014, with 75 participants. In the following years the SCCER welcomed well over 120 participants each year; in 2019 the figure was 150.

The program of the conference usually spans an entire day, with keynote lectures from international speakers, presentations including research highlights from the various capacity areas and other activities, talks by invited speakers from industry, and panel discussions covering current topics in mobility research. The program also features a poster session, where young scientists and junior researchers can present their work. And during coffee breaks, lunch, and the aperitif that rounds off the session, these same scientists and researchers have opportunities to engage in discussions with other participants. In sum, a chance to receive fresh input and new insights into their projects.

Since 2017, poster authors have also been invited to submit their poster for the Best Poster Award. An external review committee evaluates candidate posters; the six best authors present their work with short pitches in the plenary session. A jury of experts then chooses the Best Poster, and at the end of the day the winner is announced and the Award presented. The entire poster session not only gives authors more visibility, it also allows them to practice presenting their research in a very concise manner.


2017


2018


2019

Dissemination of expertise & young talent development

Phase I

- 1st Annual Conference
- Life cycle assessment workshop
- 2nd Annual Conference
- Academia–Industry Dialogue: Energy storage on locomotives and the railway system
- Seminar: Need for and patterns of the adoption of disruptive transportation technologies
- Seminar: The electric vehicle is here (again)—and why it might stay this time!
- Summer School: Energy storage in batteries—materials, systems, and manufacturing
- 3rd Annual Conference

Phase II

- Autonomous Driving event (co-organizer)
- Start-up and entrepreneurship workshop
- 4th Annual Conference
- ETSAP Workshop: Special session on decarbonizing the transport sector
- Seminar: Challenges of energy-saving automatic train operation by maximal usage of regenerating brakes in Japanese urban railways
- Batteries for E-Mobility event (co-organizer)
- Presentation skills course
- ETH eDays Symposium (co-organizer)
- 5th Annual Conference
- Launch, recurring webinar series
- Academia–Industry Dialogue: Decarbonizing the freight sector in Switzerland
- Public event: Environmental impacts of new mobility technologies
- Second-Life of Batteries conference (co-organizer)
- 6th Annual Conference
- ETH Week—Rethinking Mobility (co-organizer)
- Final Annual Conference


2014
2015
2016
2017
2018
2019
2020
11 Sept 2014
June 2015
26 Aug 2015
1 Oct 2015
17 Nov 2015
4 May 2016
11–15 July 2016
16 Sept 2016
31 Jan 2017
8 June 2017
15 Sept 2017
12 Dec 2017
7 Dec 2017
1 Feb 2018
12 & 19 June 2018
10 June 2018
11 Sept 2018
25 Oct 2018
29 Nov 2018
2 May 2019
Sept 2019
6 Sept 2019
8–12 Sept 2019
23 Nov 2020

3.2 SCCER Mobility working papers, white papers, and mission statement 2020+

Publications

SCCER Mobility

Important topics for transport research in Switzerland post 2020 (2019)

SCCER Mobility mission report

Swiss Competence Center for Energy Research—Efficient technologies and systems for mobility (2018)

SCCER Mobility flyer

Auf dem Weg zu einem energie-effizienten und klimafreundlichen Schweizer Mobilitätssystem (2017)

SCCER Mobility white paper

Towards an energy efficient and climate compatible future Swiss transportation system (2017)

SCCER Mobility working paper

Capacity areas

Umweltauswirkungen von Personenwagen: heute und morgen (2020)

Capacity Area B2, Laboratory for Energy Systems Analysis (LEA) at the Paul Scherrer Institute (PSI), EnergieSchweiz

Fact sheet update

The environmental burdens of passenger cars: Today and tomorrow (2018)

Capacity Area B2, Laboratory for Energy Systems Analysis (LEA) at the Paul Scherrer Institute (PSI), EnergieSchweiz

Fact sheet and background report

Learning Lab—Future Transport Systems

The key performance indicators (KPI) of the Swiss mobility system—
A systemic approach to research activities within the SCCER Mobility network (2020)
KPI project report

Joint Activities

Perspectives of Power-to-X technologies in Switzerland (2019)
Joint Activity white paper on the perspectives of power-to-product (P2X) technology in Switzerland
P2X white paper and supplementary report

Associated

Decarbonisation of transport: Options and challenges (2019)
European Academies' Science Advisory Council (EASAC)—with contributions from SCCER Mobility members
EASAC Report

Participants

Acknowledgement ——

Our special thanks go to all participants in this research program, without whom work on this scale would never have been possible.

Board Members

Prof. Dr. Konstantinos Boulouchos
Head of the SCCER Mobility
Head, Aerothermochemistry and Combustion Systems Laboratory (LAV),
Professor at Institute of Energy Technology,
ETH Zurich

Prof. Dr. Andrea Vezzini
Deputy Head of the SCCER Mobility
Head, Energy Storage Research Centre (ESReC),
Professor for Industrial Electronics,
BFH

Prof. Dr. Detlef Günther
Delegate of Leading House (ETH Zurich)
Vice President for Research and Corporate Relations,
ETH Zurich

Academic institutions

Dr. Brigitte Buchmann
Head, Department Mobility,
Energy and Environment,
Empa

Prof. Jürg Christener
Director, School of Engineering,
FHNW

Prof. Dr. Christian Rüegg
Director,
PSI

Prof. Dr. Jürg Meier
Head, Department Mechanical
Engineering, Energy Technology and
Aviation,
ZHAW

Industry partners

Karin Biffiger
Head of Technology and Innovation,
SBB AG

Dr. Christian Fischer
CEO, Bcomp Ltd.

Christian Köbel
formerly Director Product Management,
Bombardier Primove

Dr. Marcus Quasthoff
Patent Officer, Liebherr Machines SA

Former Members

Roland Siegwart	Vice President, Research and Corporate Relations, ETH Zurich
Kurt N. Clausen	Head, Department Research with Neutrons and Muons, PSI
Egon Lang	Deputy Director, School of Engineering and Head, Department Mechanical Engineering, Energy Technology and Aviation, ZHAW
Andrea Weber Marin	Vice Dean, Lucerne School of Engineering and Architecture, HSLU
Daniel Meier	CEO, Verkehrsverbund Luzern

Advisory Board

Cooperation partners

ABB Turbosystems AG, Baden
Adaptricity AG, Zurich
ASTAG, Schweiz. Nutzfahrzeugverband, Bern
AXA Insurance Ltd., Winterthur
Batteriewerk Schweiz AG, Winterthur
Bcomp Ltd., Fribourg
Bombardier Primove, Zurich
Bombardier Transportation Locomotives, Zurich
Bucher Municipal, Niederweningen
Carrosserie HESS AG, Bellach
CSEM (Swiss Center for Electronics and Microtechnology), Neuchâtel
CTI National Network Carbon Composites Switzerland, Windisch
Cyclops AG, Baar
Designwerk GmbH, Fehraltorf
Dow Europe GmbH, Horgen
Embotech AG, Zurich
ESRI Switzerland AG, Zurich
Research Association for Combustion Engines, Frankfurt (Germany)
FPT Motorenforschung AG, Arbon
Municipality of Glarus Süd, Glarus
HERE Technologies, Zurich
Kistler Instruments AG, Winterthur
Kummler & Matter AG, Zurich
Kyburz Switzerland AG, Freienstein
LEM SA, Fribourg
Liebherr Machines SA, Bulle
Marcel Boschung AG, Payerne
myStromer AG, Oberwangen
Protoscar SA, Rovio
SBB AG, Bern
St. Gallisch-Appenzellische Kraftwerke AG, St. Gallen
Stadler Bussnang AG, Bussnang
Swiss Federal Institute of Metrology (METAS), Wabern
Swiss Federal Roads Office (FEDRO), Ittigen
Verkehrsbetriebe Züri ch (VBZ), Zurich
Verkehrsverbund Luzern, Lucerne
Volkswagen AG, Wolfsburg (Germany)

Government institutions

Dr. Nicole Mathys	Head, Fundamentals & Data, Swiss Federal Office for Spatial Development (ARE)
Martin Pulfer	Head, Research Program "Traffic Circulation", Swiss Federal Office of Energy (SFOE)

International scientists

Prof. Dr. Horst Friedrich	Institute Director, Institute of Vehicle Concepts, German Aerospace Center DLR, Frankfurt (Germany)
Dr. Jari Kauppila	Head, Statistics and Modelling, International Transport Forum at the OECD, Paris (France)
Prof. Dr. Andreas W. Schäfer	Professor for Energy and Transport, Energy Institute, University College London (UCL), UK

Management Office

Dr. Gloria Romera Guereca
Managing Director

Dr. Kirsten Oswald
Project Manager

Pascal Sonder
Administration and Finances

Former staff

Michael Bürgi	Co-Managing Director
Fiorella Meyer	Administration and Finances

Capacity Area Coordinators

Members of the Executive Committee

Prof. Dr. Andrea Vezzini
Electrochemical Storage and Converter Group, Energy Storage Research Centre (ESReC),
BFH

Christian Bach
Automotive Powertrain Technologies (APTL),
Empa

Dr. Felix Buechi
Electrochemistry Laboratory (ECL),
PSI

Prof. Dr. Paolo Ermanni
Laboratory of Composite Materials and Adaptive Structures (IDMS-CMAS),
ETH Zurich

Prof. Dr. Véronique Michaud
Laboratory for Processing of Advanced Composites (LPAC),
EPFL

Prof. Dr. Stefanie Hellweg
Institute of Environmental Engineering (IfU),
ETH Zurich

Prof. Dr. Martin Raubal
Institute of Cartography and Geoinformation (IKG),
ETH Zurich

Dr. Stefan Hirschberg
Laboratory for Energy Systems Analysis (LEA),
PSI

Dr. Roman Rudel
Institute for Applied Sustainability to the Built Environment (ISAAC),
SUPSI

Dr. Gil Georges
Aerothermochemistry and Combustion Systems Laboratory (LAV),
ETH Zurich
(Joint Activity Coordinator)

Former Capacity Area Coordinators

Merja Hoppe	Institute of Sustainable Development (INE), ZHAW
Clemens Dransfeld	Institute of Polymer Engineering (IKT), FHNW
Vinzenz V. Härri	Institute of Electrical Engineering (IET), HSLU
Urs Sennhauser	Electronics and Reliability Center (ERC), Empa

Principal Investigators

Prof. Dr. Peter Affolter
Institute for Mobility and Energy Research (IEM),
BFH

Prof. Dr. Kay Axhausen
Institute for Transport Planning and Systems (IVT),
ETH Zurich

Christian Bach
Automotive Powertrain Technologies (APTL),
Empa

Prof. Dr. Jürgen Biela
Laboratory for High Power Electronic System (HPE),
ETH Zurich

Prof. Dr. Konstantinos Boulouchos
Aerothermochemistry and Combustion Systems Laboratory (LAV),
ETH Zurich

Dr. Felix Buechi
Electrochemistry Laboratory (ECL),
PSI

Prof. Dr. Francesco Corman
Institute for Transport Planning and Systems (IVT),
ETH Zurich

Dr. Andrea Del Duce
Institute of Sustainable Development (INE),
ZHAW

Prof. Dr. Paolo Ermanni
Laboratory of Composite Materials and Adaptive Structures (IDMS-CMAS),
ETH Zurich

Prof. Dr. Emilio Frazzoli
Institute for Dynamic Systems and Control (IDSC),
ETH Zurich

Prof. Dr. Markus Grob
Institute of Polymer Engineering (IKT),
FHNW

Prof. Dr. Vinzenz V. Härri
Institute of Electrical Engineering (IET),
HSLU

Marcel Held
Electronics and Reliability Center (ERC),
Empa

Prof. Dr. Stefanie Hellweg
Institute of Environmental Engineering
(IfU),
ETH Zurich

Prof. Dr. Kai Herrmann
Institute of Thermal and Fluid
Engineering (ITFE),
FHNW

Dr. Stefan Hirschberg
Laboratory for Energy Systems
Analysis (LEA),
PSI

Prof. Dr. Joachim Huber
Architecture, Wood and
Civil Engineering (AHB),
BFH

Prof. Dr. Gabriela Hug
Power Systems Laboratory (PSL),
ETH Zurich

Prof. Dr. Annett Laube
Institute for ICT-Based
Management (ICTM),
BFH

PD Dr. Ioannis Mantzaras
Combustion Research Laboratory (CRL),
PSI

Principal Investigators

Prof. Dr. Véronique Michaud
Laboratory of Polymer and
Composite Technology (LPAC),
EPFL

Prof. Dr. Christopher Onder
Institute for Dynamic Systems
and Control (IDSC),
ETH Zurich

Prof. Dr. Martin Raubal
Institute of Cartography and
Geoinformation (IKG),
ETH Zurich

Prof. Dr. Andrea Rizzoli
Dalle Molle Institute for Artificial
Intelligence (IDSIA),
SUPSI

Dr. Roman Rudel
Institute for Applied Sustainability to
the Built Environment (ISAAC),
SUPSI

Prof. Dr. Kurt Schenk
Institute for Energy Systems,
NTB Buchs

Prof. Dr. Jürgen Schumacher
Institute of Computational Physics (ICP),
ZHAW

Prof. Dr. Maximilian Stöck
Institute for the Development
of Mechatronic Systems (EMS),
NTB Buchs

Prof. Dr. André Studart
Laboratory for Complex Materials
(CML),
ETH Zurich

Prof. Dr. Andrea Vezzini
Electrochemical Storage and Converter
Group, Energy Storage Research Centre
(ESReC),
BFH

Prof. Dr. Rolf Wüstenhagen
Institute for Economy and
the Environment (IWOE),
HSG

Former Principal Investigators

Clemens Dransfeld	Institute of Polymer Engineering (IKT), FHNW
Merja Hoppe	Institute of Sustainable Development (INE), ZHAW
Urs Sennhauser	Electronics and Reliability Center (ERC), Empa
Ulrich Weidmann	Institute for Transport Planning and Systems (IVT), ETH Zurich

MAS|CAS ETH

in Future Transport Systems

Konstantinos Boulouchos	Academic Director
Christopher Onder	Deputy Academic Director
Kirsten Oswald	Program Manager
Petra Vetsch	Administration
Pascal Sonder	Finances

Former staff

Martin Raubal	Deputy Academic Director
Ruth Förster	Program Manager
Renate Grau	Program Manager
Maria Youssefzadeh	Program Manager
Laura Gonzalez	Administration
Fiorella Meyer	Finances

Members

A

Marcel Abegglen
Donat Adams
Nicole Aegerter
Daniel Aeppli
Peter Affolter
Paula Andrea Aguirre Marrett
Dominik Allemann
Nicolas Allenspach
Christos Altantzis
Josef Althaus
Lyaysan Amirova
Ayoh Anderegg
Shelly Arreguin
Mathias Aschmann
Yannick Aubry

B

Andreas Marcel Bachmann
Milos Balac
Andrea Baldassari
Urs Bamert
Rolf Bandhauer
Konstantinos Bardis
Christophe Barro
Christian Bauer
Thomas Baumgartner
Henrik Becker
Mattia Beltrametti
Sotirios Benekos
David Bernhardsgrütter
Albedo Bettini
Marco Beyeler
Frédéric Bless
Christopher Blomberg
Fabian Bösch
Patrick Boesch
Manuel Bötschi
Pierre Boillat
Michele Bolla
Axel Bomhauer-Beins
Claudio Bonesana
David Botor
Massimo Botta
Pierre Etienne Bourban
Florian Bouville
Adrian Braun
Christian Brauner
Edgar Brodmann
Stefan Brönnimann
Guillaume Broggi
Dennis Brütsch
Dominik Bucher
Roman Bucher
Jürg Bührer
Thomas Bütler
Simon Buob
Peter Burgherr

C

Urs Cabalzar
Emir Çabukoglu
Baris Caglar
Priscilla Caliandro
Luigino Capone
Davide Carnelli
Julien Carron
Patrick Cartier
Roberta Castri
Alberto Castro Fernandez
Maxime Cattin
Pasqualina Cavadini
Francesca Cellina
Cécile Chariatte
Yen Chun Chen
Daniel Christen

Rouven Christen
Francesco Ciari
Sadik Cinik
Magali Cochet
Mac Corzillius
Brian Cox

D

Sara Dalle Vacche
Mario Danzi
Salvatore De Angelis
Valerio de Martinis
Benjamin Decoopman
Amin Dehdarian
Marc Demierre
Dimitry Demin
Adrien Demongeot
Alexey Denisov
Marco Derboni
Panayotis Dimopoulos
Oliver Döbrich
Clemens Dransfeld
Thibaut Dubernet
Leo Duchène
Jaka Dujc
Steven Dünki
Olivier Duvanel

E

Gerhard Egli
Martin Eichenhofer
Fabian Eichin
Philipp Elbert
Jens Eller
Miriam Elser
Thomas Ewald

F

Alessandro Facchini
Nicolo Frapolli
Andreas Frömelt
William Fuhrer

G

Alfred Gadola
Karoline Gamma
Elisabeth Garcia Mendoza
Gil Georges
Patrick Gerber
Stefan Geringer
George Giannakopoulos
Christoph Giger
Bernhard Girardi
Vincenzo Giuffrida
Thomas Gloor
Dietmar Goericke
Nicolas Gort
Christoph Gossweiler
Erik Graf
Roland Graf
Pasquale Granato
Stefan Grieder
Rabeb Grissa
Markus Grob
Michael Grob
Madeleine Grossman
Sebastian Guzman Ortiz

Members

H

Patrick Habermacher
Oskar Häfeli
Severin Hänggi
Vinzenz V. Härri
Patrick Haldi
Jannik Hamper
Aymane Hassan
Thomas Heck
Meike Heinz
Maximilian Held
Robert Herrendörfer
Thomas Hilfiker
Stefan Hiltbrandt
Christian Hohl
Andreas Holzner
Ye Hong
Sebastian Hörl
Raphael Hörler
Merja Hoppe
Joachim Huber
Mathias Huber
David Humair
Richard Hutter

I/J

Mahmoud Jafargholi
Felix Jauch
Jon Jauregui Cano
David Jonietz
Adrian Joss

K

Ayyoub Kabachi
Evangelos Kalkounis
Thomas Kammermann
Andre Keller
Susanne Keller
Markus Kerellaj
Karri Keskinnen
Neeta Khare
Peter Kiefer
Stefan Klammer
Florian Klunker
Elvira Knam
Tom Kober
Jann Koch
Reto Koenig
Dimitri Kokkinis
Maria Kotzagianni
Nikolett Kovacs
Erich Kramer
Ueli Kramer
Merla Kubli
Lukas Küng
Viktoras Kulionis
Marc Kunz
Mascha Kurpicz
Falk Kyburz
Panagiotis Kyrtatos

L

Ludovic Lauber
Annett Laube-Rosenpflanzer
Hortense Le Ferrand
Yann Lebaupin
Isabelle Lendvai
Yves Leterrier
Rafael A. Libanori
Markus Lindegger
Roman Litscher
Wenmei Liu
Clarissa Livingston
Shannon Long
Daniel Luder
Sandro Luh

M

Seyed Saeed Madani
Pascal Mainini
Albert Mancera Sugrañes
Francesca Mangili
Ioannis Mantzaras
Vittoria Manzi-Orezzoli
Sébastien Mariéthoz
Anastasia Markou
Philip Marmet
Björn Martin
Henry Martin
Dario Marvin
Kunal Masania
Clemens Alois Mathis
Christoph Maurer
Vasco Medici
Thomas Meer
Ronny Meoli
Laura Merotto
Tobias Michl
Dario Milano
Dejan Milojevic
Tobias Minder
Moritz Mittelviefhaus
Joseph Molloy
Alexandre Mordasini
Luca Morici
Vincent Morier
Yoann Moullet
Gael Mourouga
Adrian Mularczyk
Urs Muntwyler
Christian Murkovic
Christopher Mutel

N

Günter Nagel
Sawsane Nakouzi
Lorenzo Nespoli
Regina Neugebauer
Manuel Neumaier
Giovanni Nicoletti
Einar Nielsen
Simon Nigsch

O

Christopher Oberschelp
Peter Obrecht
Christian Peter Ochsenbein
Mikael Oettli
Duvanel Olivier
Andyn Omanovic
Vit Orava
Behrooz Ostadmohamamadi Arani
Kirsten Oswald

P

Luca Pampuri
Sushant Pandurangi
Evangelos Panos
Viola Papetti
Giacomo Pareschi
Matteo Parravicini
Alfons Pascual
Amin Paykani
Dimos Peftitsis
Bénédicte Petitat Flückiger
Cornel Pfister
Halime Philipp
Mathieu Piccand
Jana Plananska
Christopher Plummer
Nikolaos Prasianakis
Filippo Pura

Members

Q

Gianfranca Quadri

R

Miriam Rabacal
Kannan Ramachandran
Jose Pedro Ramalho Veiga Simão
Werner Raupach
Ralph Reust
Emmanuelle Reuter
Daniela Riederer
Michael Rieger
Adrianna Righetti
Andreas Ritter
Johannes Ritzmann
Gerhard Rizzo
Martina Rizzoli
Mireia Roca-Riu
Tobias Rogg
Jakub Rojewski
Gloria Romera Guereca
Federico Rosato
Jorim Rosenberg
Marvin Rüppel
Adrianna Rutkowska
Christian Rytka

S

Mayank Sabharwal
Romain Sacchi
Christian Sailer
David Sakellarakis
Matteo Salani
Gabriel Salkim
Damiano Salvatori
Alejandro Santis
Bima Sanusi
Fabian Schadt
Manuel Schaffner
Christoph Schaller
Simon Scheider
Vanessa Schenker
Warren Schenler
Maike Scherrer
Ueli Scherrer
Dirk Scheuble
Roman Scheuss
Christoph Schneeberger
Timan Schneider
Mathias Schön
Phillipe Schwartz
Michael Schwertner
Omar Seddik
Udo Seifried
Ercan Selcuk
Tanuj Sen
Kyle Seymour
Rhythima Shinde
Peng Shuai
Muriel Siegwart
Jose Simao
Antriksh Singh
Bercan Siyahhan
Emiliano Soldini
Patrik Soltic
Pascal Sonder
Matteo Spada
Jeroen Staal
Richard Stahl
Remo Stauffer
Ioannis Stavropoulos
Roland Steinauer
Maximilian Stöck
Milos Stojadinovic
Boris Stolz
Tibor Stolz
Roger Strässle
Michael Striednig

Julia Studer
Pascal Süess
Wojciech Szmyt

T

Christopher Tchervenkov
Elena Tervoort
Helena Texeido Pedarros
Moritz Thommen
Riccardo Tinivella
Tobias Tischhauser
Ambra Toletti
Uros Tomic
Thomas Trachsel
Karin Treyer
Robin Triguéra
Alessio Trivella
Panagiota Tsotra

U

Andreas Ulbig
Duglas Urena Hunziker

V

Mayeul Van den Broek
Stijn van Dooren
Walter Martin Vera Tudela Fajardo
Nicola Vermes
Petra Vetsch
Roman Vetter
Claudia Visentin
Rafael Vitorino
Sabine Vogt
Christian Vögtli
Maximilian Volk
Cyrill Von Uslar
Gabriel Vonwyl
Pascal Vuichard

W

Daniel Wagner
Michael Walczak
Patrick Wälti
Pengling Wang
Rashid Waraich
Stephanie Wegmann
Paul Weiser
Olga Weiss
Adrian Weitnauer
Joël Wenger
Steffen Wienands
Valérie Willimann
Marianne Wink
Jakub Wlodarczyk
Wilhelm Woigk
Joanna Wong
Yuri Wright
Silas Wüthrich
Dario Wüthrich

X

Hong Xu

Y

Wen Yang
Moullet Yoann
Maria Youssefzadeh

Z

Alessandro Zanardi
Xiaojin Zhang
Pengxiang Zhao
Igor Zhilyaev
Tammo Zobel
Norbert Zsiga
Thierry Zufferey
Benno Züger
Daniel Zürcher
Lucian Zweifel

Abbreviations

Term	Definition
AD	automated driving
AI	artificial intelligence
APTL	Automotive Powertrain Technologies, Empa
ARE	Swiss Federal Office for Spatial Development
BCFs	bicomponent fibers
BEV	battery electric vehicle
BFH	Bern University of Applied Sciences
CA	capacity area (of the SCCER Mobility)
CO_2	Carbon dioxide
CAS	Certificate of Advanced Studies
CCS	carbon capture and storage
CEDA	Coherent Energy Demonstrator Assessment
CETMO	Centre for Transportation Studies for the Western Mediterranean (Barcelona, Spain)
CLF	continuous lattice fabrication
CML	Laboratory for Complex Materials, ETH Zurich
CNG	compressed natural gas
CRL	Combustion Research Laboratory, PSI
DME	dimethyl ether
EASAC	European Academies' Science Advisory Council
ECA	external cost assessment
ECL	Electrochemistry Laboratory, PSI
EGR	exhaust gas recirculation
Empa	Swiss Federal Laboratories for Materials Science and Technology
EMS	Institute for the Development of Mechatronic Systems, NTB Buchs
EPFL	Swiss Federal Institute of Technology in Lausanne
ERC	Electronics and Reliability Center, Empa
ESReC	Energy Storage Research Centre, BFH
ETSAP	Energy Technology Systems Analysis Programme of the International Energy Agency (IEA)
EV	electric vehicle

Term	Definition
FCEV	fuel cell electric vehicle
FDM	fused deposition modeling
FEA	finite elements analysis
FEDRO	Swiss Federal Roads Office
FHNW	University of Applied Sciences and Arts Northwestern Switzerland
Flex-OeCoS	Flexibility regarding optical engine combustion diagnostics and/or development of corresponding sensing devices and applications (project)
FRTP	fiber reinforced thermoplastic
GHG	greenhouse gas
HC	hydrocarbons
HSG	University of St. Gallen
HPE	Laboratory for High Power Electronic Systems, ETH Zurich
HSLU	Lucerne University of Applied Sciences and Arts
IARAI	Institute of Advanced Research in Artificial Intelligence (Vienna, Austria)
ICA	internal cost assessment
ICE	internal combustion engine
ICP	Institute of Computational Physics, ZHAW
ICT	information and communication technology
ICTM	Institute for ICT-Based Management, BFH
IDMS-CMAS	Laboratory of Composite Materials and Adaptive Structures, ETH Zurich
IDSC	Institute for Dynamic Systems and Control, ETH Zurich
IDSIA	Dalle Molle Institute for Artificial Intelligence, SUPSI
IET	Institute of Electrical Engineering, HSLU
IfU	Institute of Environmental Engineering, ETH Zurich
IKG	Institute of Cartography and Geoinformation, ETH Zurich
IKT	Institute of Polymer Engineering, FHNW
INE	Institute of Sustainable Development, ZHAW
IPA	impact pathway approach
ISAAC	Institute for Applied Sustainability to the Built Environment, SUPSI
ITFE	Institute of Thermal and Fluid Engineering, FHNW
IVT	Institute for Transport Planning and Systems, ETH Zurich
IWOe	Institute for Economy and the Environment, University of St. Gallen

Term	Definition
KPI	key performance indicator
L^2-FTS	The Learning Lab—Future Transportation Systems
LAV	Aerothermochemistry and Combustion Systems Laboratory, ETH Zurich
LCA	life cycle assessment
LDV	light-duty vehicle
LEA	Laboratory for Energy Systems Analysis, PSI
LPAC	Laboratory for Processing of Advanced Composites, EPFL
MaaS	mobility-as-a-service
MAS	Master of Advanced Studies
MCDA	multi-criteria decision analysis
METAS	Swiss Federal Institute of Metrology
MIE Lab	Mobility Information Engineering Lab, ETH Zurich
ML	machine learning
MOBIS	Mobility behaviour in Switzerland (project)
NC	night charging
NO_x	nitrogen oxides
NTB Buchs	University of Applied Sciences Buchs (NTB Buchs was integrated into the Eastern Switzerland University of Applied Sciences (OST) on 1 September 2020)
OEM	original equipment manufacturer
OMEs	polyoxymethylene dimethyl ethers
PEFCs	polymer electrolyte fuel cells
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
PSI	Paul Scherrer Institute
PSL	Power Systems Laboratory, ETH Zurich
RTM	resin transfer molding
SFOE	Swiss Federal Office of Energy
SME	small or medium-sized enterprise
SUPSI	University of Applied Sciences and Arts of Southern Switzerland
TCA	total cost assessment
TCO	total cost of ownership
TRL	technology readiness level
VBZ	Zurich Public Transport
ZHAW	Zurich University of Applied Sciences

Imprint

Editor

Swiss Competence Center for Energy Research (SCCER) Mobility
ETH Zurich
Leonhardstrasse 27
CH-8092 Zurich

Dr. Gloria Romera Guereca
Dr. Kirsten Oswald
Pascal Sonder

Editing & layout

federform.ch—Dr. Inken De Wit, Beate Obolensky, Katja Schubert
SCCER Mobility—Dr. Gloria Romera Guereca, Dr. Kirsten Oswald, Pascal Sonder

English language consultancy

elcs.ch—Dave Brooks

Photos

page 23: Andreas Sutter/eMining, Kuhn Schweiz; page 24: Carrosserie HESS AG; Rigitrac Traktorenbau AG; page 26: Carrosserie HESS AG; page 30: ITFE-FHNW; page 32: Empa & ETH Zurich; page 36: figure 1: PSI; figure 2: WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim; page 43: 9thLabs; page 48: Antefil; CompPair; page 56: ETH Zurich; page 59: ETH Zurich; page 60: ETH Zurich, SUPSI; page 61: ETH Zurich; page 63: Catch-a-day/Motion-tag, Berlin; page 71: SUPSI; page 72: J. Plananska (2020). Touchpoints for electric mobility: Investigating the purchase process for promoting sales of electric vehicles in Switzerland. Energy Research & Social Science, 69, 10174.; page 73: R. Hoerler, A. Stünzi, A. Patt, A. Del Duce; page 77: www.carculator.psi.ch; page 79: PSI; page 86: A. Mancera/L²-FTS, ETH Zurich; page 88: L²-FTS/ETH Zurich

Photos Participants: Bcomp Ltd., BFH, Bombardier Primove, Empa, EPFL, ETH Zurich, FHNW, HSG, HSLU, Liebherr Machines SA, NTB Buchs, PSI, SBB AG, SUPSI, ZHAW

Paper

Superset Offset-Preprint, matt, super white, wood-free 300/120 gm²
FSC Mix Paper

Print

Kasimir Meyer AG, Wohlen, CH

Swiss Competence Center for Energy Research

Efficient Technologies and Systems for Mobility

Synthesis book sccer mobility Swiss Competence Center for Energy Research Efficient Technologies and Systems for Mobility