

Conference Report

Swiss Stakeholder Workshop for the SUNRISE H2020 FET-Flagship Project

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Abstract: On 27 September 2019, a workshop for the Swiss stakeholders for the SUNRISE flagship project was held at Empa in Dübendorf. The workshop had the aim of community building and was attended by over 30 participants from Switzerland, France, and South Africa. The secondary purpose of the workshop was the inclusion of the previously competing ENERGY-X flagship project into a future joint project from SUNRISE and ENERGY-X. The workshop program had 20 technical presentations including posters, a panel discussion and an interactive session.

Keywords: Circular Economy · Climate Change · Flagship · Paris Agreement · SUNRISE

The SUNRISE project was shortlisted as a future FET Flagship, within the area of Energy, Environment and Climate Change for the 2018 call FETFLAG-01-2018.^[1] EU flagships have a funding volume of 1 billion Euro for 10 years, and the consortia have typically around 100 research groups. However, in early 2019, after the shortlisted Flagship candidates were announced, the European Commission announced that it would abandon the flagship funding platform.^[2] The SUNRISE consortium continues to try to secure funding from the European Union's remaining large-scale funding schemes, such as Partnerships and Missions.

Climate change as a pressing topic has recently come to heightened public awareness.^[3] According to the Paris Agreement^[4] (and protocols from Kyoto^[5,6] and Earth Summit in Rio de Janeiro, 1992^[7]), global warming is attributed to the CO₂ emissions by human civilization, and strict measures are expected from the industrialized countries to meet the goals of cooling the Earth temperatures by 1.5 Kelvin.^[8] The aim of the SUNRISE initiative is to put the brakes on global warming by using renewable energy as the motor to drive a sustainable circular economy. The direct conversion of solar energy into fuels and chemicals is the objective of the initiative, which started its coordinated activities following an AMPEA^[9] Workshop on artificial photosynthesis at the Max Planck Institute für Kohleforschung in Mülheim an der Ruhr in 2012.

The Swiss Federal Laboratories for Materials Science and Technology (Empa), the École Polytechnique Fédérale de Lausanne (EPFL) and Casale SA organized a Swiss Stakeholder Workshop for the SUNRISE large-scale research initiative, which was held at Empa in Dübendorf on September 27, 2019. Since 2009, Empa has organized and co-organized workshops with the scope of renewable energy and artificial photosynthesis.^[10–17] Corresponding national stakeholder workshops have recently taken place in Italy (Bologna), Poland (Warsaw), Turkey (Mersin^[18]), South Africa (Pretoria), and France (Paris).

The 30+ workshop attendees were representatives from universities, government laboratories and industry. The scope of the

workshop was to inform the Swiss stakeholders about the status of the SUNRISE project and to provide a tentative opportunity to share ideas, network, and discuss the Swiss role, ways for supporting the initiative, and opportunities and challenges for a large-scale research initiative.

In his opening remarks, Artur Braun (Empa) timelined Empa's 10+ years history in the field of active artificial photosynthesis research. He also presented the other two organizing institutes' relevance to the SUNRISE initiative. Finally, he showed how the idea of the initiative evolved over the years and briefly sketched the SUNRISE structure.

Frederic Chandezon, SUNRISE governance board member from CEA Grenoble, France, explained the SUNRISE motivation, project and mission in detail. He started with the background information why the initiative is needed, touching on climate change, the public awareness and showing "THE BIG EUROPEAN PARADOX: We enjoy the best quality of life on Earth BUT our enviable prosperity is based on energy and mineral resources coming FROM OTHER CONTINENTS". This led to the conclusion that an independent Europe needs its own sustainable energy sources and the best candidate is solar energy. Then he introduced the SUNRISE initiative to the participants.

SUNRISE and ENERGY-X are the two out of six winning Coordination and Support Action (CSA) projects, which were shortlisted for the 2018 call FETFLAG-01-2018 for future FET Flagships,^[1,19] within the area of Energy, Environment and Climate Change.^[6] The SUNRISE project aims at developing innovative technologies and sustainable approaches for the capture and subsequent storage of renewable energy (solar and wind) through its conversion to fuels and commodity chemicals using abundant molecules (CO₂, H₂O, N₂) and with an overarching circular economy approach. The SUNRISE consortium brings together 20 top universities, research organisations, and companies, backed by a supporting community of currently 200 stakeholders from academia, industry, and society worldwide. SUNRISE has connections with various research and science networks: national (e.g. energy research alliances), European (e.g. EERA, the European Energy Research Alliance is member of both consortia) and international networks such as Mission Innovation. At the end of the two CSAs in March 2019, SUNRISE and ENERGY-X will join efforts and merge into one single initiative, with the tentative name SUN-ERGY.^[7]

As the Swiss partner in the ENERGY-X consortium, ETH Professor Javier Pérez-Ramírez was invited to the workshop to represent his flagship candidate. ENERGY-X went through the same process as SUNRISE being a Coordination and Support Action (CSA) project selected for the 2018 call FETFLAG-01-2018 for future FET Flagships, within the area of Energy, Environment and Climate Change. ENERGY-X's vision is very similar to SUNRISE's but their focus is molecular and interfacial catalysis. In his technical talk, Perez-Ramirez presented also the Swiss National Competence Research Centre 'Sustainable Chemical Processes through Catalysis (suchcat)', of which he is the Director.

Brigitte Buchmann, Member of the Empa Board of Directors and Head of the Department for Mobility, Energy & Environment, delivered the official Empa welcome address (Fig. 1). She showed Empa's national roles in Mobility, Energy and Environment. She

also introduced the *move* to the workshop participants – Empa's Future Mobility Demonstrator. *move* provides examples to show the entire pathway of using and converting surplus renewable electricity for mobility – in the form of hydrogen and, in later stages, in the form of synthetic methane and network batteries. She also mentioned NEST (Next Evolution in Sustainable Building Technologies), Empa's research and innovation building, where new advancements can be tested, adjusted and demonstrated under realistic conditions.



Fig. 1. Empa Director Brigitte Buchmann during her welcome address, showing the competences and new energy technology platforms developed and operated at Empa.

The workshop had a Question and Answer (Q&A) session with panel speakers: Michael Grätzel (EPFL, SUNRISE Advisory Board), Artur Braun (Empa, SUNRISE founding member), Frederic Chandezon (CEA, SUNRISE Governance Board), Sophia Haussener (EPFL, SUNRISE Supporter and former member of JCAP^[20]), and Pierdomenico Biasi (Casale SA, SUNRISE Supporter from industry), moderated by Rita Toth (Empa, SUNRISE project coordination).

The audience had the opportunity to express their questions about the SUNRISE project in the Q&A session, the first of which went to Michael Grätzel and related to the provocative question set by the organizers, which mistakes should be avoided on the way to the Holy Grail of direct conversion. This question should be seen in the historic context and evolution of hydrogen economy and solar energy conversion, Braun pointed out. The social and environmental impacts of the SUNRISE initiative's goals were extensively discussed. In addition, the importance of the life cycle assessment of solar energy was emphasized and debated at this session. Sophia Haussener pointed out that all level of communities should be approached to obtain support for a future technology proposed by SUNRISE. The roles of the partners/supporters/advisors in the project were not clear for many participants, therefore this topic was debated as well. The panel members and the audience exchanged views on the acquisition and distribution of the potential future funding during the 1 h long session. Not every question was answered to the satisfaction of the audience.

Greta R. Patzke from Universität Zürich (UZH) introduced a University Research Priority Program (URPP), the 'Solar Light

to Chemical Energy Conversion' (LightChEC; www.lightchec.uzh.ch), which unifies nine research groups from the areas of water reduction/oxidation catalysis, computational and physical chemistry as well as surface science with ties to researchers from Empa. In the technical part of her presentation, she stressed the importance of the attachment of functional molecules to substrates. Abolfazl Ziarati from Université de Genève presented two posters on the use of metal oxide photocatalysts for the conversion of CO₂ to CH₄ with solar light.^[21]

With the invention of the ammonia synthesis in the Haber-Bosch process 100 years ago,^[22] the technological foundations were laid for the production of synthetic nitrate fertilizers from water, air, and fossil fuels. Since, the world population was able to grow over 7 billion people due to food primary production by photosynthesis. One per cent of world energy use, mostly from fossil fuels, goes into fertilizer production, with a huge amount of produced CO₂. The ammonia industry also transitions towards decarbonization. Raffaele Ostuni showed us how CASALE SA, a Swiss technology leader of the ammonia and nitrogen fertilizer production technologies, is at the forefront of this transition. With Voltiana®, Casale owns also its own electrolyzer technology.^[23] CASALE envisions the 'transition' of the industrial production *via* a step-wise decarbonization of the fossil-based process, and at the same time fosters the opportunities to deploy and scale-up the renewable-based ammonia production.

SUNRISE has the vision that for the next 25 years, the CO₂ to be collected will predominantly originate from concentrated CO₂ sources like cement factories, carbon power plants, ammonia factories, and the like (the non-adiabatic way). Once these concentrated sources are diminished, CO₂ will be captured from the ambient environment, which has a low CO₂ concentration (adiabatic way).

Climeworks AG, an ETH Zürich spin-off company from 2009, develops and markets technology for direct air capture (DAC) of CO₂ (see for example refs ^[24] and ^[25]). Daniel Sutter from Climeworks presented the application of DAC to generate sustainable jet fuel out of atmospheric CO₂ and renewable energy with a fully closed carbon cycle.

SUNRISE uses CO₂ as one essential component in its circular economy by reducing it chemically to CO or other compounds and converting it to fuels and base chemicals. The necessary power for this chemical conversion is supposed to come from renewable sources such as solar energy, wind power or hydropower. One method for electrocatalytic reduction of gaseous CO₂ to CO was suggested by Corsin Battaglia (Empa) using earth-abundant Sn/Cu-nanofiber-based gas diffusion electrodes. They developed a process to fabricate the Sn/Cu-coated polymer nanofiber networks to enhance CO₂ mass transport.^[26,27]

While the SUNRISE project implies that solar energy is a key player, it turned out that catalysis researchers in the workshop outnumbered those scientists who were mainly active in solar energy conversion. A fundamental challenge in chemical engineering is the availability of suitable catalysts, which lower the activation barriers for the targeted chemical reactions. Solutions to this problem have a huge impact on costs and environmentally benign operation of factories.

One specific challenge in catalysis research is the development of catalysts that selectively target certain chemical reactions so that only particular molecules or chemical products are made in the reactors. Important for SUNRISE are the hydrogenation reactions for CO₂. Selective CO₂ hydrogenation and propane dehydrogenation catalysts were presented by Christophe Copéret from ETH Zürich. They use Surface Organometallic Chemistry (SOMC) for the development of this catalytic system.^[8]

Artificial photosynthesis pioneer Michael Grätzel showed recent progress in the electrochemical reduction of CO₂ to liquid fuels of his own research group at EPFL.^[9] CuZn bimetal-



Fig. 2. Artificial photosynthesis pioneer Michael Grätzel shows recent progress in CO₂ reduction of his own group at EPFL, and forwards the message of Belenos and Bill Gates about billion dollar funding for artificial photosynthesis.

lic catalysts are synthesized by *in situ* electrochemical reduction of ZnO-shell/CuO-core bi-metal-oxide. He also forwarded the message of Belenos and Bill Gates^[28,29] about the necessity of billion-dollar funding for artificial photosynthesis (Fig. 2; for a provocative response see the debate article^[30]) and the willingness of investors such as Breakthrough Energy Ventures, to invest. Grätzel re-iterated the role and importance of Breakthrough Energy Ventures for the artificial photosynthesis community.

The electrochemical reduction of CO₂ from the gas phase to produce carbon-based energy carriers, such as carbon monoxide, was a reoccurring topic at the workshop. Alexandra Patru (PSI) showed their newly developed co-electrolyser cell configuration using bipolar-like membrane configurations at PSI for this purpose.^[31] In parallel, they explore electrochemical separation and compression of CO₂ using cells with alkaline membrane and bipolar-like membrane configurations.

While the SUNRISE project is centered in Europe, it does have a trans-European dimension because of its supporters in Australia, Turkey, South-Africa, Israel, India (all Horizon 2020 associated countries), China and the United States. Emil Roduner represented University of Pretoria (UP), South Africa with a talk on how they convert indium oxide, the currently most successful heterogeneous catalyst for thermal methanol production from CO₂, into an electrocatalyst recycling CO₂ to methanol or higher alcohols. The University of Pretoria is one of the South African SUNRISE supporters. One idea is that South Africa could become an exporter of renewable fuels, as Chemistry Professor Egmont Rohwer had speculated recently at the SUNRISE Workshop in South Africa.^[32]

Shipping fuels and chemicals over large distances, for example from South Africa to Europe, is not in the scope of SUNRISE, which is supposed to be a decentralized industry technology. Therefore SUNRISE does not follow explicitly the philosophy of trans-European networks.^[33–41] However, South Africa is a prime example of a country with extensively decentralized communities. For the resilience of communities, SUNRISE would be a viable solution.^[42]

Andreas Borgschulte from Empa illustrated how solar fuels could be produced in a maritime ocean setting, specifically on small artificial islands of 10 km² and from there the fuels could be shipped to the locations where the fuel would be needed.^[43] Noteworthy is that this approach needs no further materials de-

velopment. The only necessary steps are to deploy the factories on the ocean.

Stephan Hiltbrand (Empa) further elaborated on the – readily existing - Future Mobility Demonstrator: *move* at Empa.^[44] The demonstrator building has photovoltaic panels on the roof and on its façade, an electrolyser (max. 30 Nm²/h), a H₂ compressor (30–65 Nm²/h), a H₂ storage capacity of 3 MP/40 MPa and a H₂ filling station, ‘a gas station’ for fuel cell vehicles, which is readily used by the fuel cell car community in Switzerland.^[45] Empa plans to scale up its sorption-based methanation lab-reactor to a semi-automatic 50 kW chemical plant in combination with direct air capture as a CO₂ source. “Such demonstrators, even on a larger scale, are also planned as part of the Sunrise project. Demonstrators pave the way for the realization of a fully automatic and finally industrial plant.”

Empa’s *move* demonstrator gas station delivers H₂ for cars and trucks, and also methane and mixtures of methane and hydrogen.

Fridolin Holdener observed the workshop as a representative of hydropole, the Swiss Hydrogen Association and presented a poster on the H₂ mobility of the future truck fleet of Hyundai in Switzerland.

Avenegy Suisse (previously under the name of Schweizerische Erdöl-Vereinigung, Swiss Petroleum Association) anticipates that renewable fuels will become increasingly present in the fossil fuel dominated transportation fuel market. Fabian Bilger from Avenegy Suisse showed the requirements for an alternative fuel to make it on the general fuel market for mobility in Switzerland from the fuel industry’s perspective. He explained that it would be integrated mainly by blending with existing products, since the new fuel has to be in agreement with the normative framework for fuels, which can take years to change. Bilger also exercised which of the manifold of geographical, technical, societal, political and economic factors determined the price of fuels at the filling station.

The Paul Scherrer Institut (PSI) in Villigen has a long tradition in energy technology research. In addition to the many aspects of energy basic science, PSI operates an Energy Systems Integration Platform (ESI Platform), which was introduced by Peter Jansohn. At this platform, the power-to-gas concept is realized by converting excess renewable electricity into an energy-rich gas, such as hydrogen or methane (synthetic natural gas). This enables surplus electrical energy to be stored in the form of chemical energy.

The Paul Scherrer Institut operates also large-scale user lab facilities such as the Swiss Spallation Neutron Source SINQ,^[46–48] the Swiss Lightsource SLS,^[49,50] SINQ and the Swiss X-ray Free Electron Laser Swiss-FEL,^[51] all of which have been used for energy materials and photosynthesis research. Maarten Nachtegaal and Davide Ferri presented a poster, which showcased the capability of the SLS for *in situ* studies.

From the beginning of its creation, it was the conviction of the SUNRISE consortium that ecological and societal aspects should be considered as an integral component of the SUNRISE solution to the energy transition. SUNRISE is, therefore, a true multi-scale project, which is reflected by the topical diversity of its partners and supporters.

Astrid Björnsen (Swiss Federal Institute for Forest, Snow and Landscape Research, WSL) delivered the keynote talk titled ‘SUNRISE: Impacts on Society, Environment and Landscape’, in which she showed the complexity of the problem to be addressed by SUNRISE, and which aspects of human-environment would be affected by the projected decentralization of energy capture and production of solar fuels, chemicals and ammonia. She emphasized that “when planning the transformation towards a low-emission society, sound information about the environmental and landscape risks entailed and the societal acceptance of new solar energy systems is needed to identify potential areas of conflicts”.

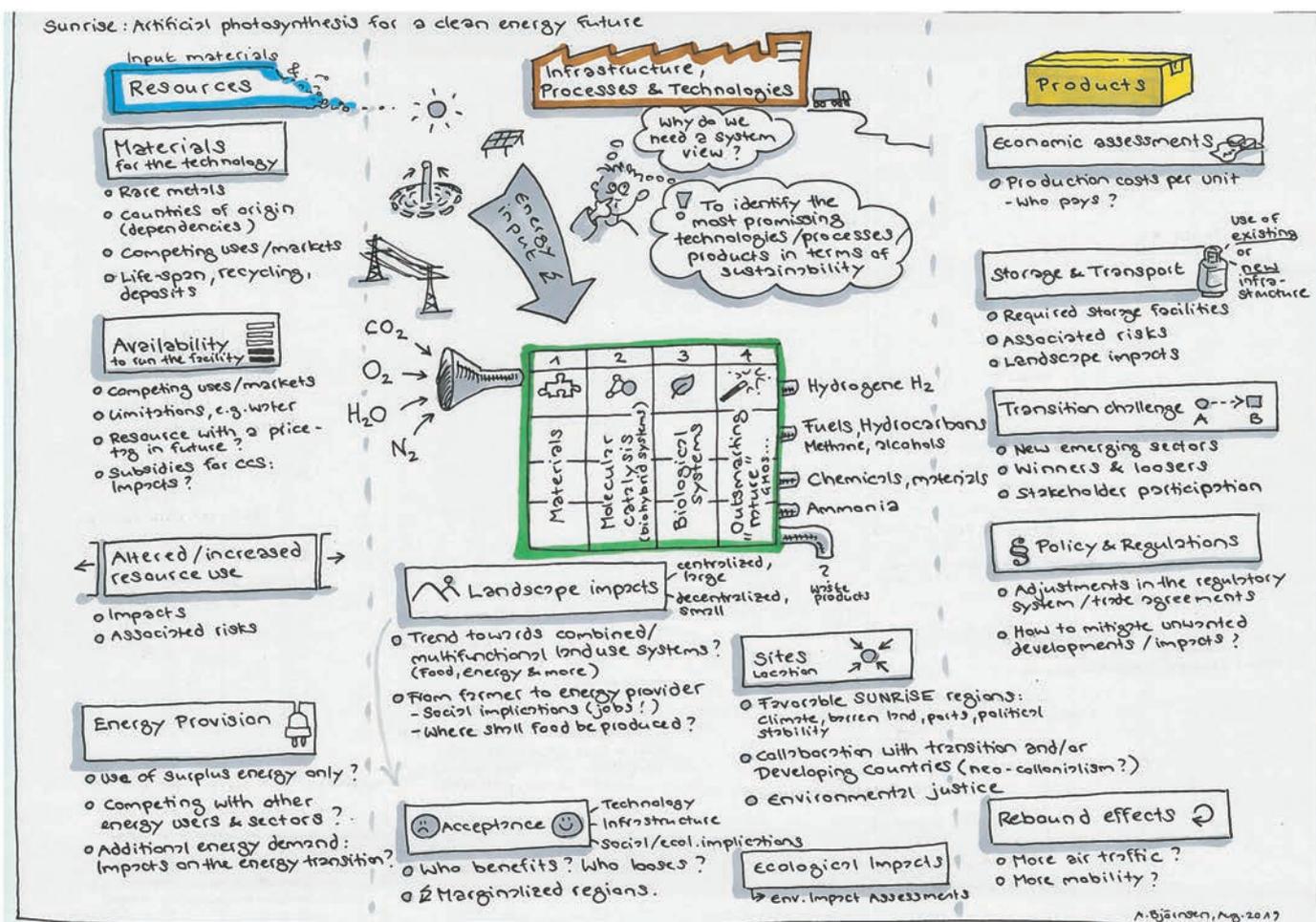


Fig. 3. The best choice of SUNRISE technologies (green box) and related transformation pathways requires a system understanding. This includes information on input materials and resources (blue box), infrastructure, processes and technologies (brown box), and the entailed products (yellow) (Illustration: A. Björnsen Gurung (WSL) 2019).

This includes information on input materials and resources, infrastructure, processes and technologies, and the entailed products, which is schematically illustrated in Fig. 3.

Björnsen’s keynote talk was the opening of an interactive workshop, which was chaperoned by Anna Roschewitz and Cornelia Moser (novatlantis GmbH) and was started by an introduction of the company novatlantis. At the interactive workshop, all participants were requested to give their input in three topics: 1. What could be missing from the proposal from a system point of view and which are the most relevant factors. 2. The target products in Switzerland, the target market and the predicted technological advancement levels. 3. How to receive support from relevant stakeholders and how to do lobbying.

The importance of life cycle assessment (LCA) of solar energy was emphasized by Didier Beloin-Saint-Pierre (Empa, St. Gallen). The result of this assessment can be compared with the LCA of other renewable energy options. Such comparisons then show when solar energy is the more environmentally sustainable option and help to identify potential improvement possibilities to increase the environmental competitiveness of solar energy technologies.

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