Mission Innovation Challenge “Converting Sunlight”

Action Plan Details

Cambridge Report

Mission Innovation Challenge 5 "Sunlight Conversion": Suggestion for Actions

Background

Current energy demand is primarily met through burning fossil fuels such as coal, crude oil and natural gas. In contrast, over 1000 times more energy strikes the earth in the form of sunlight than what would be required to fulfill all of mankind's energy needs. But to replace fossil fuels we need to store that energy on a large scale and for a long time. This can be done by harnessing sunlight to drive the synthesis of 'solar fuels'. However, the transition from fossil based fuels to cleaner solar fuels has been hindered by the low maturity and high cost of conversion technologies. Research and innovation is needed to bring these approaches from infancy to maturity.

In order to deploy solar fuel technologies at large scale, performance breakthroughs and cost reductions are a must, considering the role of high-density fuels and chemicals for long-haul transport and aviation, seasonal storage of sustainable energy and as feedstock to (chemical) industries. For this to happen, the Converting Sunlight Innovation Challenge (IC5) invites governments and the private sector to focus their research and innovation efforts in this direction.

Producing carbon-neutral clean fuels and developing breakthrough energy storage chemicals will not only contribute to mitigating climate change, they will also serve to enhance energy security and will provide opportunities for economic development across the globe.

IC5 'Sunlight Conversion' targets the solar driven synthesis of energy rich molecular fuels or chemicals, a broad challenge often referred to as the synthesis of 'solar fuels'. The six focus areas of IC5 are:

1. Catalyst development for water splitting, CO_2 reduction and other key reactions;
2. Improved solar light-harvesting, charge separation and coupling to catalysts
3. Cyanobacteria and micro-algae that excrete fuels or chemicals into a surrounding medium;
4. Photoelectrochemical, photocatalytic and hybrid bio / inorganic devices
5. Thermochemical pathways using concentrated sunlight
6. Design, engineering and demonstration of devices and systems

To accelerate the Research and Development of Sunlight Conversion, a number of goals must be reached and challenges must be addressed. A range of Actions is proposed within the collaboration of MI and IC5 that target solutions and that will accelerate R&I in solar fuels.

Mission Innovation builds on the idea of international collaboration to tackle the Innovation Challenges. This should be reflected in the Actions proposed below, where the projects will be conducted in collaboration between Mission Innovation member countries.

1. Structural Actions

The large-scale production of fuels and energy rich chemicals from sunlight addresses multiple challenges. It is addressing the intermittency of solar energy through storing solar energy in chemical bonds, enabling the transportation of sustainable energy from sunny regions to regions of high energy demand. It is providing a CO_2 neutral route to the synthesis of molecular fuels and chemical feedstocks, thereby providing a sustainable pathway for CO_2 utilisation. Research and development needs to cover many areas of science and technology, and to include environmental, societal, economic, political and legislative factors. Structural actions are needed to set a Roadmap for the efforts, and to promote collaboration between academia and industry as well as international collaboration between MI countries.

1.1 Organization of workshops, conferences to mobilize the capacities in the MI partner countries and bring experts from different Focus Areas, countries and sectors together.

The necessary work in IC5 has to cover a very wide range of perspectives and competencies. The different Focus Areas of IC5 are at different TRL levels but have many common research and technology goals. This includes e.g. materials for catalysis and light-harvesting, and reactor design. Communication and exchange of experience and perspectives should include all Focus Areas as well as complimentary competences in photovoltaic, electrolyzers and (photo)bioreactors.

Goal/Anticipated outcome: Formation of new networks and collaborative projects between different sectors, competencies and countries, which are able to take on R&D tasks within IC5, enable personnel exchange and undertake training in global state of the art and best practice. Knowledge transfer, resulting in e.g. published reports.

1.2 Development of a global Solar Fuels Roadmap.

There is currently no global Roadmap for solar fuels. A Roadmap will support strategic and long-range planning, and match IC5 short-term and long-term goals with the ultimate solar fuels technology. Road mapping will build on the broad alliance of competencies from point 1.1. An international committee will be established and supported by MI, with the Commission as IC5 lead, to prepare a Roadmap.

Goal/Anticipated outcome: A global Roadmap for solar fuels.

1.3 Defining best practice for standardized comparison of results.

Clear comparison of experimental data from different laboratories will allow for better evaluation of results, and for more informed choices of components, materials and experimental designs. Establishing common best practices for what data must be included, and how it should be reported, may allow for standardized comparison of results. An international committee will be established and supported by MI, with the commission to establish such practices, building on experiences and practices both in the field of solar fuels and related areas such as solar cells and catalysis.

Goal/Anticipated outcome: Best practices will be defined and shared, required for publication and followed by laboratories.

1.4 Co-ordination with other Mission Innovation challenges and global initiatives

Mission Innovation IC5 'Sunlight Conversion' has close complementarities and synergies with several other MI innovation challenges, including IC3 Carbon Capture, IC6 Clean Energy Materials and IC8 Renewable and Clean Hydrogen, as well as other national and international initiatives. Actions of IC5 should be aligned with these initiatives through the organization of joint or co-sponsored workshops, reports and projects.

Goal/Anticipated outcome: Greater co-operation between challenge areas and internationally. Alignment of IC5 roadmap with other MI Innovation Challenge roadmaps.

2. Discovery Actions.

While several complete devices for solar fuels formation have been reported, the field is still on a low-to-medium TRL level. Important challenges remain in all Focus Areas before a large-scale technology can be developed. Therefore, a large amount of fundamental research is needed into novel materials, methods and concepts.

This Action targets laboratory scale break-through research in all Focus Areas. It will address novel concepts, materials and methods to enhance the performance and technological potential of sunlight conversion, addressing issues of efficiency, stability, environmental impact, cost and scalability. The proposed research must explain how it may lead to results that are significantly beyond current state-of-the-art.

Research areas for Discovery Actions include:

2.1 Light Harvesting

Novel concepts, materials, devices and organisms to absorb sunlight, and use the resultant electronic / thermal excitations to drive the synthesis of solar fuels. This action will have parallels and synergies with photovoltaic solar conversion.

2.2 Catalysis

Novel catalysts for the synthesis of solar fuels and chemicals, including for water oxidation and reduction, CO_2 and N_2 reduction, in particular catalysts avoiding rare earth metals. This action will have parallels and synergies with electrocatalytic processes, e.g.: ‘Power to X’.

2.3 Device integration and in operando analysis.

Integration of light harvesting and catalytic components, in particular in configurations which could enable low cost fabrication combined with efficient and stable performance. Component and *in operando* analyses and modelling to guide further optimization.

2.4 Engineered metabolic pathways.

Photosynthetic microorganisms with engineered metabolic pathways for efficient and selective production of the desired fuel.

Goal/Anticipated outcome (for 2.1 - 2.4): New materials, organisms, methods and concepts that result in better properties and performance for solar fuels production. Production of solar fuels that cannot be made today by these methods (ammonia, drop-in fuels, jet fuels). Success will be measured by the number and quality of break-through results and patents published.

3. Development Actions

The progress from research to technology needs to be facilitated. The situation is different for the different Focus Areas: for example thermochemical water splitting have been demonstrated in plants with up to 750 kW_{th} thermal input, and photobioreactors are running for commercial production of high-value products, but fuel production is not yet commercially competitive. However, both Areas require a higher energy conversion efficiency for large scale commercial application. The required work in these Focus Areas is foreseen to mainly be performed in Actions 2 and 4, although work in Action 3 is not excluded.

Photocatalytic and photoelectrochemical devices have been typically shown only at relatively small lab scale. Although small devices have shown high energy conversion yields, over 15% STH for non-concentrated sunlight, there is very little data showing a combination of high energy conversion yield and long-term stability, with scalable, low cost and commercially viable solutions. These is also little data on large area devices. Testing of materials and processes in larger devices will give more understanding of processes and performance bottlenecks, and stimulate work on engineering design and multi-scale modeling. Testing and reporting will follow the best practices and protocols defined in Action 1.3 above.

3.1 Development and testing of devices with at least 1 cm^2 active area.

Similar to the field of solar cells, testing of photo(electro)chemical devices with an active area of at least 1 cm^2 will show the performance of the materials and device design under conditions more relevant for a large plant. Work in this Action will lead to new data and identification of bottlenecks.

Goal/Anticipated outcome: A greatly expanded data base of device performance, combining data on energy conversion efficiency and stability using standardized test protocols, with new materials and designs. Combinations of performance numbers that greatly exceed those reported so far. These include e.g. solar-to-fuel efficiencies of at least 15%, stability tests over 1000 h and avoidance of precious metals. Other combinations of performance metrics which exceed current state-of-the-art and target specific market applications would also be relevant. The possibility of recycling and/or use of low cost materials and processes should be taken in account as well.

3.2 Development of devices with an active area of at least 100 cm^2

Success of the final technology depends on the combination of (at least) the following factors: efficiency, robustness/lifetime and scalability (materials and processes, social and environmental effects, economic and energy ROI). Device/systems modelling as well as techno-economic analysis should/must be part of the project. Comparisons with and lessons from solutions based on photovoltaics and electrolysis must be made.

Goal/Anticipated outcome: Development of device design and analysis, with performance data for several systems following standardized protocols. Bottlenecks will have been identified and solved.

4. Demonstration Actions

As indicated in Action 3, the different technologies involved in IC5 are at different TRL levels, and differ in the challenges that need to be addressed to achieve large scale, commercially viable sunlight conversion. Specific milestones for each technology will be identified in Action 1.2 above.

Large-scale demonstrations of solar thermochemical fuel generation, on a scale of 1 MW_{th} or more, are of immediate interest to industry (energy, chemical, aluminum, steel …). Such actions need large investments and, consequently, the set-up of such demonstrations will have to be carried out by industry-led consortia from a number of MI partner countries.

Photobioreactors with engineered microorganisms (green algae, cyanobacteria) are able to produce complex fuels with multiple carbon-carbon bonds. Demonstration Actions are of interest to show the ability to scale up production in long-term continuous operation, and with high energy conversion efficiency.

Development of autonomous photoelectrochemical and photocatalytic systems is of interest for decentralized applications, as the best lab cells have relatively high solar-to-fuel conversion efficiencies. A Demonstration Action would have to scale up this technology to a complete system on a demonstration scale, managing feedstock supply and harvesting the resulting fuel. Synergies with the European Commission Horizon Price “Fuel from the sun: artificial photosynthesis” are expected.

Comparisons with and lessons from solutions based on photovoltaics and electrolysis must be made.

Goal/Anticipated outcome:
Demonstration of one or more sunlight conversion technologies at sufficient scale to show a clear pathway to commercially viable synthesis of fuels and / or high energy chemicals driven by sunlight. A minimum of 10% solar to fuel efficiency, 10 year stability and low cost are likely requirements for large-scale commercial viability, depending upon legislative and tax environment. The expected metrics and year of fulfilment will be defined in the solar fuels Roadmap of Action 1.2.