Which are the main goals of SUNRISE?

SUNRISE has three main goals that will be further defined in a Scientific and Technological (S&T) roadmap at the end of the Coordination and Support Action (CSA):

(1) the provision of sustainable fuels from renewable energy (solar fuels);

(2) the synthesis of commodity chemicals from renewable energy (solar chemicals);

(3) the development of efficient methods to recycle CO_2 from the atmosphere.

What is a CSA?

CSA stands for Coordination and Support Action. Sunrise CSA is a collaborative project under Horizon 2020 (the European Framework Programme) that gathers several European institutions to coordinate, support and analyse strategic research actions.

Unlike other Collaborative Projects, CSAs do not finance research and development.

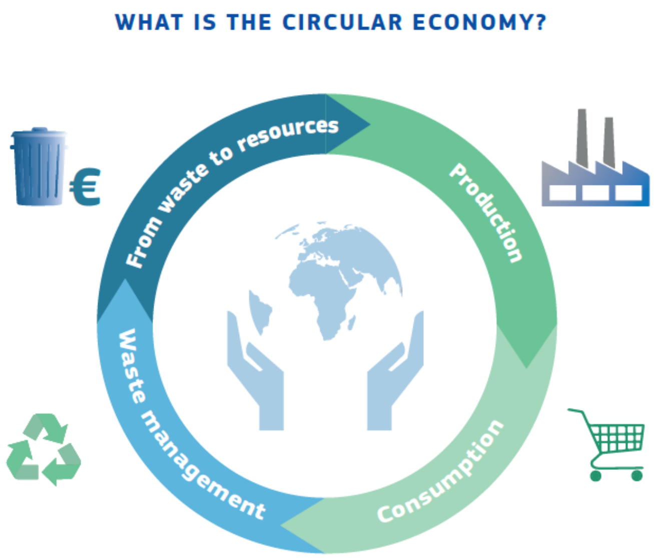
SUNRISE CSA has been selected to provide a roadmap and an implementation strategy for the next European large scale research initiative in the Energy area.

What is 'circular economy'?

Circular economy is an ambitious and sustainable economic model **aimed at minimising waste and making the most of resources**. It focuses on **design thinking, systems thinking, product life extension, recycling and upcycling**.

Circular economy keeps materials and resources in the economic cycle through the separation and recovery of components at the end of a product's life and their use in new applications, reducing waste generation.

In 2015, the European Commission adopted an ambitious Circular Economy Action Plan and has just published a report for accelerating the transition to the circular economy.



Source: ec.europa.eu. Circular economy factsheet_general

How will SUNRISE contribute to a circular economy?

SUNRISE aims at using carbon dioxide (CO_2) from industrial waste gases as a starting material to produce solar fuels and chemicals (from waste to product).

For instance, industrial CO_2 emissions could be captured and transformed into a fuel or an added-value new product reducing the greenhouse gases in the atmosphere. This approach will create a closed carbon cycle, providing huge benefits for society, the environment, the European economy and the ongoing efforts to mitigate climate change.

What are solar fuels?

Solar fuels are synthetic chemical fuels generated directly from sunlight. The solar energy is harvested and converted to chemical energy, which can be stored and transported for later use. Water is the raw material of choice for this process, in which sunlight is used to split water (H_2O) into its components: hydrogen and oxygen. Hydrogen would be an example of a solar fuel. Besides, the hydrogen (or protons) produced in water splitting can react with carbon dioxide (CO_2) to generate carbon-based solar fuels, such as synthesis gas (mixture of hydrogen (H_2) and carbon monoxide (CO)), alcohols (methanol, ethanol, etc.) or methane (CH_4).

What are the advantages of using solar fuels instead of fossil fuels?

Solar fuels use the sun: a free, widely available and infinite source of energy. Solar fuels are produced through sustainable processes and when used they do not contaminate, as they only produce water and CO_2 that can be recycled in the so-called carbon closed cycle.

How will SUNRISE tackle the problem of energy storage?

SUNRISE wants to establish and coordinate large-scale research cooperation across Europe to enable, in the long term, the production of renewable fuels and chemicals from water, carbon dioxide, nitrogen, oxygen and sunlight, as the sole energy source, at industrial scale. The solar energy will be stored in chemical bonds and released at will when needed.

Which technologies will be used?

- **In the short-term:** renewable energies (photovoltaics and wind power) will generate electricity to split water (electrochemical process) and produce hydrogen and other solar fuels.
- **In a medium to long term**: artificial photosynthetic systems will be developed for the **direct conversion of solar energy** through water splitting, following two different approaches**:**
  - **(i)** **photoelectrochemical approach:** development of human-made devices that combine solar energy harvesting and conversion. The photoexcited states of light harvesting materials will drive the catalytic processes for the synthesis of fuels and chemicals in integrated systems.
  - **(ii)** **biological and biohybrid approach:** use of microorganisms equipped with biosynthetic pathways to directly produce a wide range of fuels and chemicals directly from sunlight and CO_2.

When will the new technologies be ready?

SUNRISE large scale research initiative aims to accomplish the following goals by 2030:

- The use of CO_2, H_2O, N_2 and O_2, as feedstock to deploy solar energy converters that produce fuels (e.g. synthesis gas, CH_4, methanol, ethanol) and high-value chemicals (e.g. ethylene, ammonia) at over 100 ton/ha per year.
- The conversion of up to 2500 ton/ha per year of CO_2 into the cyclic economic system.
- Enabling the reduction of CO_2 in the atmosphere by underpinning direct solar energy converters with a 300% energy gain over the current industrial practice on the terawatt (TW) scale for a negative-emission Earth system, to be finally achieved beyond 2050.

What is artificial photosynthesis?

Natural photosynthesis is the process by which plants and other photosynthetic organisms (algae and bacteria) convert solar energy, water and carbon dioxide in carbohydrates (the energy of plants). Artificial photosynthetic systems mimic this natural process aiming to outperform it by developing more efficient and simplified systems.

What are biohybrid systems?

Both biological and biohybrid systems involve the use of living microorganisms and are capable of directly transforming solar energy and storing it. SUNRISE will engineer enzymes and microorganisms to produce biofuel and biohydrogen from sunlight. Biohybrid methodologies combine living systems with artificial made components or materials, such as devices for solar energy conversion.

Which chemicals would be produced?

The target fuels and chemicals will be discussed during the project and included in the S&T roadmap. SUNRISE preliminary targets include: **H_2, CH_4, synthesis gas** or **ethanol**.

More complex solar fuels (**alcohols**) and chemicals (i.e. formic acid, ethylene), including commodities and high-value products, will be obtained from more advanced artificial photosynthetic systems. **Fertilizers** will also be targeted by the activation of nitrogen.

Which are the main challenges to face?

Main challenges include scaling up technologies to the **terawatt level** and **reducing the production costs**, so the produced solar fuels are competitive against fossil fuels (*i.e* < 0.4€/L), as well as developing more efficient materials, based on abundant and low-cost elements.

SUNRISE targets artificial photosynthetic systems with unprecedented efficiencies: 90% photon absorption efficiency and 80% chemical conversion efficiency. Pushing overall for a conversion yield of 70% of the thermodynamic limit.

For the large-scale production of chemicals, where does the energy required come from?

The main idea behind SUNRISE is to convert solar energy into storable and transportable forms of energy: fuels and chemicals from ubiquitous molecules in the atmosphere. Solar fuels can be stored and transported to provide the required energy when sunlight is not available, as an alternative to fossil fuels (carbon, oil, gas), which currently represent around 80% of the primary energy sources.

What about the up-scaling of the short-term approaches (since the upscaling of electrolysers is limited)?

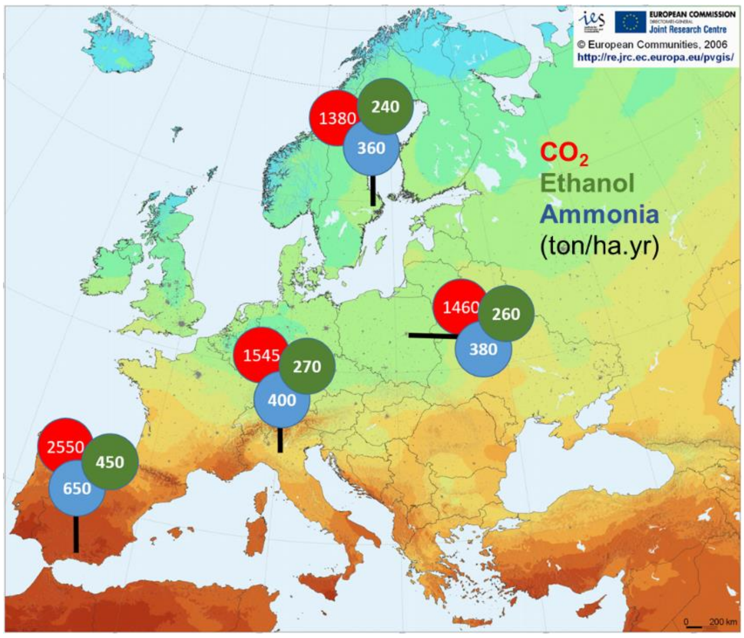
Electrolysis is the process of using electricity to split water into its components hydrogen and oxygen. This reaction takes place in a unit called an electrolyser, which can vary in size from small to large-scale MW-sized stack and modular systems.

Current up-scaling challenges include industrial electrocatalytic conversion of CO_2 and production of flexible cost-competitive systems adapted to intermittent and fluctuating power supply.

How will the SUNRISE technologies benefit different European regions?

SUNRISE aims to convert up to 2500 ton/ha per year of CO_2 into products, depending on latitude and climate. SUNRISE benefits from Europe's diversity and proposes a portfolio of solutions for each region, depending on the renewable energy sources available and on the economic environment. In regions with abundant renewable electricity (wind, solar, hydro) and available concentrated CO_2 sources, electrolysis could provide a sustainable source of chemicals and fuels. In other regions with high solar irradiation, direct conversion approaches represent an ambitious, long-term option.

According to the average annual solar irradiation different estimations for CO_2 conversion potential are possible. In the following map, you can see the calculated maximum potential for CO_2 conversion for Malaga, Piacenza, Warsaw, Stockholm (red circles). The map also shows production estimations (per hectare and year) of a sustainable fuel (ethanol: green circles) or chemical (ammonia: blue circles).



Notes: A two-electron process is assumed, consuming two photons per excited electron, 90% photon absorption efficiency and 80% chemical conversion efficiency. The realization of such targets on the hectare scale requires radical new concepts and tandem devices that operate in the laboratory with a photochemical current of 16 mA/cm^2 under AM 1.5 irradiation, the universal laboratory reference standard for solar power conversion.

Calculations take into account half reactions for the conversion of CO_2 and H^+ into ethanol and N_2 and H^+ into ammonia (the conversion rate at AM1.5 is 0.014 μmol cm^{-2}s^{-1} for ethanol and 0.029 μmol cm^{-2}s^{-1} for ammonia).

Radiation data for individual cities are taken from http://wrdc.mgo.rssi.ru.

What about the land use? Do you need a lot of space to produce significant amounts of chemicals?

Primary average power consumption per capita is remarkably constant at ~6 kW for European citizens. Assuming a 30% efficiency of an artificial photosynthetic system this would translate into ~100 m^2 per capita of surface required, which corresponds to ~1% of the European surface, a much lower estimation than for current biomass practice (0.5% energy efficiency, ~10,000 m^2 per capita).

Europe beyond 2050:
700 million people - 2 TW SUNRISE Power

Efficiency of solar conversion	Surface per capita	Total area needed
100 %	30 m^2	0.3 %
10 %	300 m^2	3 %
1 %	3000 m^2	30 %
0.1 %	30000 m^2	300 %

Artificial Photosynthesis (10 % – 1 %)

Biomass (0.1 %)

Notes: assuming 50% of the 6 Kw/capita coming from solar fuel; European population of 700 million; average insolation of ~100 W/m^2; 30% energy efficiency with an external quantum yield of 70%.