Renewable fuels for sustainable electricity production

Dr Andre Heel is the leader of a joint project that is developing more sustainable solutions for electricity and heat production. Here, he discusses some of the challenges his team has overcome and the potential business opportunities this new technology offers

First, how did you get involved with researching renewable fuels, and where does your expertise lie?

I live with an awareness of environmental issues, so the consumption of resources matters to me. On top of that, I have been working for over 15 years in the field of materials for energy applications.

The focus of my research has been solid oxide fuel cells (SOFC), which can produce electricity and heat from fossil fuels like natural gas, including methane. Within this research project, we explored new materials and concepts with the aim of utilising waste carbon dioxide from cement plants, through long-term storage of hydrogen by carbon dioxide methanation.

How great an opportunity do cement plants provide for the harvesting of carbon dioxide for later use in energy-generating processes, such as the methanation process you propose?

Although carbon dioxide emissions from cement plants in developed countries have been substantially reduced in the last decade, there are still large quantities of emissions from the calcination of limestone for the production of lime for use in industrial processes.
The advantage is, there are only a few big plants per country and they provide highly concentrated carbon dioxide. I feel this is a great business opportunity.

Does this mechanism offer advantages over other carbon dioxide sequestration methods?

Yes, a carbon dioxide sequestration method such as the carbon capture and storage (CCS) technology needs additional energy to collect and separate the carbon dioxide and finally to store it in caverns or underground. The gas is also not frequently emitted close to storage sites and there is often no infrastructure available to transport it. Therefore, the most important drawback of other carbon dioxide methods is that they do not reduce emissions; they are just convenient technologies to prevent its emissions into the environment.
The advantage of carbon dioxide methanation is that we already have a possibility to transport and store the produced renewable methane in the existing natural gas grid.
In this way, there is both an economic and environmental advantage.

What challenges have you encountered in the project so far?

New and innovative technologies, such as ours, often face the challenge of competing with highly industrialised or mass production technologies. Did you know that in the early 20th Century more electric powered cars were on roads than cars with combustion engines? However, the subsequent decline in fossil oil prices led to a worldwide decline of electric powered cars.

Nowadays, this technology is back in the limelight, but we have to catch up with nearly 100 years of technological improvement. The same is valid for fuel cells. The principle of a fuel cell, that is, electrochemical conversion of a fuel, has been known for over 150 years. But it has only been in the last 10-15 years that enough knowledge has been gained to bring them onto the market and make them affordable. But the problem remains – for us and for every other new energy technology – that you still have to compete with cheap fossil resources, especially now that fossil oil has hit a historically low price level.

How can the challenge of competing against cheap fossil oil prices be overcome?

The only chance we have is to make the process more efficient, or have a better quality product that can compensate for the initially higher costs. This is exactly what the individual subproject teams within our joint project group are working on. Governments will also have to provide legal regulations that allow renewable energy technologies to fully develop, and private consumers will have to reconsider their consumption behaviour.

Can you anticipate what the next few years hold for the renewable fuels project and your research within it?

Within the next two to three years, we have to show that the technologies we are developing can provide the benefits we are working towards. The next step is to convince established energy providers or new key players on the energy market to implement our ideas. For example, the cement industry could act as a provider for renewable energy carriers and get paid for synthetic natural gas instead of paying for carbon dioxide allowances – why not? I feel very optimistic about the potential for a breakthrough of renewable energy technologies in Switzerland, as it has an excellent climate of innovation.

Reducing greenhouse gas emissions

Scientists involved in the National Research Programme's **Reduction and Reuse of CO_2: Renewable Fuels for Electricity Production** joint project in Switzerland are testing innovative ways to reutilise waste resources of carbon dioxide, harness energy from the Sun and produce electricity with zero carbon emissions

BURNING FOSSIL FUELS and the release of greenhouse gases such as carbon dioxide into the atmosphere are creating an ever more present and widespread issue. The need to reduce environmentally harmful emissions has also taken centre stage on nationwide agendas. In Switzerland, a 2050 Energy Strategy has been developed, setting ambitious goals for cutting energy consumption in order to transition the nation towards a low-carbon economy. To meet these goals, there is a clear need for the development of carbon-free or carbon-neutral alternatives to fossil fuels.

A joint project led by Dr Andre Heel from Zurich University of Applied Sciences, is working towards achieving this by producing alternative renewable fuels for electricity production. The joint project, entitled Reduction and Reuse of CO_2: Renewable Fuels for Efficient Electricity Production is made up of five partner projects and is being carried out as part of a national research programme in Switzerland. The project investigates the production and utilisation of renewable energy carriers, which involves the development of new smart materials, using waste carbon dioxide from cement plants and solar energy.

CARBON DIOXIDE INTO STORABLE METHANE

Renewable energy, such as wind or solar energy, is imperative to curbing carbon dioxide emissions. However, these sources of renewable energy are highly subject to daily and seasonal variation in levels of production, often leading to an imbalance between supply and demand. There is therefore a need to store any surplus energy for later use.

Converting non-storable sources of energy into other forms of storable energy, known as 'energy carriers', is an effective way to address issues surrounding energy management.

In the first of the five partner projects, Heel and his colleagues are working on developing this concept by employing methane and hydrogen as the vital energy carriers. To produce methane, the research group is developing a novel catalyst to convert the vast amounts of carbon dioxide produced from cement plants into storable methane through methanation with hydrogen. This means that carbon dioxide is not emitted into the environment and this synthetic methane can replace imported fossil methane.

However, the process of methanation is not without its difficulties: "We face the problem that carbon dioxide from cement factories contains sulphur impurities, which poisons common catalysts. As catalysts age with operation time, or get contaminated from reactants like sulphur, their performance declines," Heel explains. To get around this, the third subproject team has developed solid oxide fuel cells (SOFC) anodes for use in catalysts that can regenerate themselves, making these materials more tolerant against such poisons. Alongside this, they are also currently investigating the possibility of bio-inspired sulphur resistant catalysts.

THE POWER OF HYDROGEN

Hydrogen, as another energy carrier, is a vital component for the conversion of carbon dioxide to methane. Therefore, in the second subproject, researchers are working on producing hydrogen using solar energy. The sunlight that reaches the Earth provides vast quantities of energy, however, the problem remains that this form of energy is unreliable. The team is therefore harnessing the solar energy and converting it into a form of chemical energy that can be stored, in this case: hydrogen. This is accomplished through a conversion process called photoelectrochemical (PEC) water splitting, which splits water into hydrogen and oxygen upon reaction with sunlight. The hydrogen can then be stored, transported and used both for the conversion of carbon dioxide to methane as well as in other processes, such as operating fuel cell cars.

SMART MATERIALS

In order to convert the renewable methane and hydrogen into something useful, you need fuel cells. Unlike conventional boiler or oil-fired heating, fuel cells work on the principle of electrochemical conversion, providing both electricity and heat, which means they can achieve much higher energy efficiency rates of over 90 per cent.

However, in a similar way to how impurities eventually reduce the efficiency of catalysts involved in the methanation process, the same thing happens in most conventional nickel-catalyst fuel cells. "Redox cycles can cause severe degradation of the nickel catalyst. With every redox cycle, the nickel is coarsening and growing, while the performance gets worse. Additionally, the nickel metal is oxidised, which finally leads to cell rupture by mechanical stress," elucidates Heel.

The novel materials developed in the third subproject contain only about 10 per cent of the nickel in conventional catalysts. To add to this, the material is provided via a perovskite, which acts as a sponge, taking up and releasing the nickel during a redox cycle. "The benefit is, a formerly detrimental redox cycle is now purposely used for a self-regeneration to extend operation time and performance. This is what we call a 'smart material'," explains Heel.

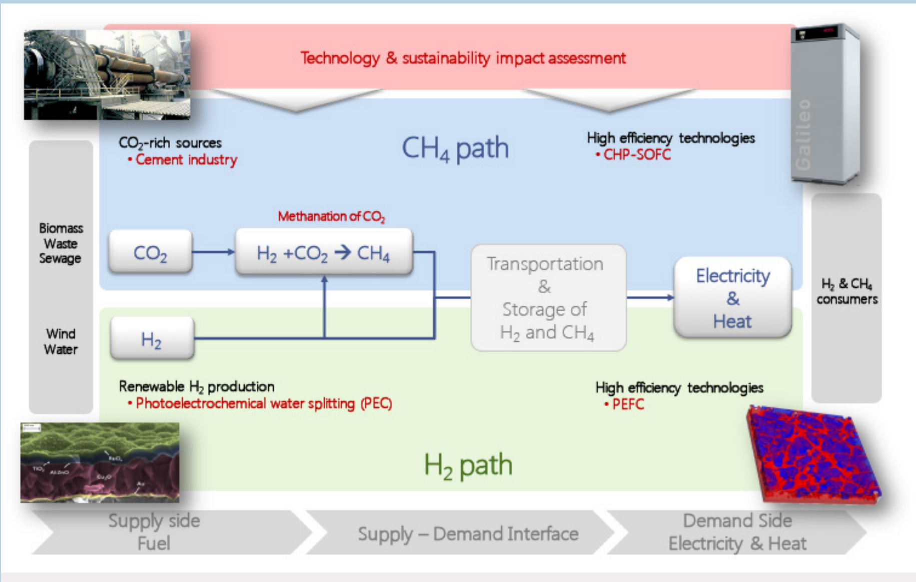
HYDROGEN FOR MOBILITY APPLICATIONS

In their fourth project, the researchers are focusing on proton exchange membrane fuel cells (PEFCs) and the development of low-cost, multifunctional materials to improve cell performance, robustness and durability. Using better optimised processes, they will also reduce the expense of PEFCs per unit of energy produced. The fuel cells are being designed to operate on pure hydrogen, thus releasing zero emissions at the source. With regard to industrial and environmental impact, PEFCs could play a key role in the replacement of conventional combustion engine vehicles, therefore significantly contributing to the reduction of carbon dioxide emissions in the mobility sector.

ENSURING SUSTAINABILITY

As the fifth and final part of the joint project, a sustainability assessment will be carried out in order to evaluate the entire process, taking into account potential impacts to the environment as well as economic and social benefits and drawbacks. Assessments will cover the whole process, right from the methanation of carbon dioxide from the cement industry, through to hydrogen production through PEC water splitting and the use of renewable energy carriers in fuel cells for electricity and heat generation. The information gained from the assessments will be used to judge how well the technology fits within the wider scope of the 2050 Energy Strategy in Switzerland.

It is clear that these nationwide sustainability objectives can only be met by moving towards more carbon neutral alternatives to energy production. Heel and his team's continued research is contributing towards this transition and helping to cut carbon dioxide emissions from other sources.



Key: carbon dioxide (CO_2); methane (CH_4); hydrogen (H_2); proton exchange membrane fuel cells (PEFCs); combined heat and power (CHP); solid oxide fuel cells (SOFCs).

REDUCTION AND REUSE OF CO_2: RENEWABLE FUELS FOR ELECTRICITY PRODUCTION SUBPROJECTS

PROJECT 1: Carbon dioxide (CO_2) methanation

Dr Andreas Borgschulte (Swiss Federal Laboratories for Materials Science and Technology, EMPA)
Dr Andre Heel (Zurich University of Applied Sciences, ZHAW)

PROJECT 2: Hydrogen (H_2) production

Professor Anders Hagfeldt (École Polytechnique Fédérale de Lausanne, EPFL)
Professor Dr Jürgen Schumacher (ZHAW)

PROJECT 3: Solid oxide fuel cells (SOFCs)

Dr Andre Heel (ZHAW)
Dr Lorenz Holzer (ZHAW)

PROJECT 4: Proton exchange membrane fuel cells (PEFCs)

Professor Dr Jürgen Schumacher (ZHAW)
Dr Felix Büchi (Paul Scherrer Institute, PSI)

PROJECT 5: Sustainability assessment

Vicente Carabias-Hütter (ZHAW)
Matthias Stucki (ZHAW)
Adrian Burri (ZHAW)

NATIONAL RESEARCH PROGRAMME: RENEWABLE FUELS JOINT PROJECT

OBJECTIVES

To investigate and elaborate upon the uses of individual technologies, including:

- Utilisation of cement-based carbon dioxide using a methanation process
- Sustainable production of renewable fuels
- Further carbon dioxide reduction by consuming renewable fuels with highly efficient electricity conversion technologies using mobile (PEFC) and stationary fuel cells (SOFC)
- Assessment of the sustainability, economic value and social acceptance of the technologies

KEY COLLABORATORS

See 'Subprojects' boxout

PARTNERS

Zurich University of Applied Sciences (ZHAW)

Swiss Federal Laboratories for Materials Science and Technology (EMPA)

École Polytechnique Fédérale de Lausanne (EPFL)

Paul Scherrer Institute (PSI)

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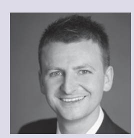

ANDRE HEEL obtained his PhD from the Karlsruhe Institute of Technology (KIT) in Germany. He worked as a postdoc and scientist in the field of nanomaterials for catalysis and energy applications at EMPA in Switzerland. In 2010, he became research coordinator for the fuel cell manufacturer Hexis AG and representative for the Swiss SOFC research activities in Europe. Since 2013, he has been at ZHAW, where he is a lecturer and head of the Laboratory for Process Technology. The main focus of his research activities are materials and processes for renewable energy carriers, power-to-gas and SOFCs.

Zurich University of Applied Sciences
School of Engineering

Energy Turnaround
National Research Programme NRP 70