1 Petroleum Microbiology's Metamorphosis
Expert Insights on the Energy Transition

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In the dynamic landscape of today's energy sector, the shift from fossil fuels to sustainable energy sources has become a focal point of exploration and innovation. Yet, microorganisms continue to be a dominant player amid this transition period. In a series of enlightening interviews, we engage with experts who stand at the forefront of this research, offering valuable perspectives on the pivotal role of microorganisms in the ongoing energy transition. These conversations provide a unique window into the intricate relationships between microbiology and the energy transition, shedding light on how these tiny organisms hold the potential to drive significant change in our quest for a more sustainable energy future.

Please tell us a bit about your professional background and current line of work.

I am an environmental microbiologist with expertise in the microbiology of subsurface and engineered environments. I am particularly interested in industrial issues associated with microbial activity (e.g., souring, MIC), microbial control, and applications such as biogas production.

From your experience, how has the field of petroleum microbiology research changed over the past 10 years?

The use of molecular microbiology and easy access to DNA sequencing have certainly opened many doors to understanding the complex microbial community associated with petroleum microbiology questions. This has led to many answers and, interestingly, to further questions as well. I believe we have become more aware of the need for interdisciplinary collaboration as well.

In recent years, we have seen a massive shift within the energy landscape. To what extent do you think microbiology would play a role during this transition phase?

It should play an important role if we want to avoid expensive issues in the future. We already know of the importance of subsurface microbial communities and their potential to cause significant changes in engineered environments. By regularly monitoring from "time zero", well-informed mitigating decisions can be made in a timely manner.

Dr. Julia R. de Rezende
Assistant professor
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What are some research topics you believe are important to transfer from the oil and gas industry to the renewable sector?

Microbial ecology of subsurface environments, souring, and MIC. This should be supported by interdisciplinary research with (geo)chemists, engineers, modelers, and materials scientists, and should involve field monitoring and lab experiments. Genomics and metagenomics have a huge potential to unravel knowledge that can lead to groundbreaking solutions, and ecophysiological experiments will help test hypotheses generated by omics techniques and simulate scenarios applicable to the field.

With your expert opinions, how can microbial populations positively and negatively impact green energy as the energy landscape is quickly changing?

As seen for decades in the oil industry, microbial activity can have a detrimental effect on operations with the production of unwanted gases that can contaminate gas reserves, contribute to climate change, and put workers at risk. Biocorrosion can also lead to increased costs in infrastructure maintenance. However, we could also harness the activity of microbes for the production of energy-rich gases or other compounds that can themselves be energy sources with a lower impact on the environment.

Would microbial control remain an important aspect of renewables, and why?

For sure. Microbes are incredibly resilient and can make a living in unexpected environments and surfaces, reducing the lifespan of materials, infrastructure, or operations. Monitoring and early, strategic control are essential.

What would you like to see in the next 10 years in the field of petroleum/energy microbiology?

Interdisciplinary collaboration to tackle these complex, real-life industrial issues, as well as support for research that leads to significant understanding of underlying mechanisms and microbial interactions, which can really lead to meaningful, effective solutions and field-applicable technological advancement.

Please tell us a bit about your professional background and current line of work.

My background is in environmental microbiology with a special focus on subsurface and anaerobic microbiology. I am currently focusing on the effects of microbes in energy systems.

Dr. Nicole Dopffel
Senior Researcher
Norwegian Research Centre (NORCE), Norway

From your experience, how has the field of petroleum microbiology research changed over the past 10 years?

I have not been active for 10 years in this field (so I guess I am still young), but I have already experienced the changes of several oil price crises and now the energy crisis. Prices for energy are either in the sky or at the bottom. The effects on research are always strong. When I started, enhanced oil recovery (EOR) was a very active topic including microbially enhanced oil recovery (MEOR). This is now over, and EOR is not attractive from a research standpoint. I also see that MIC got more and more attention over the past few years. I noticed a strong change when Dennis Enning's paper on EMIC was published. I had the feeling that suddenly the research exploded. Now real petroleum microbiology is difficult and as mentioned oil-related research is not very interesting. But I am not sad about this.

In recent years, we have seen a massive shift within the energy landscape. To what extent do you think microbiology would play a role during this transition phase?

Everything in the subsurface is affected by microbes. So, microbiology will play a vital role also in the future energy systems. Even a more important role as CO_2 and H_2 storage will be key pillars of the energy system and they need to work. Here there are still big question marks when it comes to microbiology. Also, corrosion of wind pillars and wind turbines is a major research area which has been ignored up until now.

What are some research topics you believe are important to transfer from the oil and gas industry to the renewable sector?

- Effects on H_2 underground storage
- Effects on CO_2 storage
- Biomethanation processes
- Biohydrogen processes
- Geothermal installations and microbial problems

What are some key technological advances you see that are important to transfer from petroleum to renewable energy?

I would say all of them. Reservoir microbiology is not specifically linked to oil but to everything which is inside a reservoir.

Would microbial control remain an important aspect of renewables and why?

Sure! Just speaking of hydrogen storage, the question of how to protect the tasty hydrogen from microbial consumption will probably be a research topic for many years. It has not even started yet.

What would you like to see in the next 10 years in the field of petroleum/energy microbiology?

I would love to have a stronger focus on microbial communities and not only single strains. Communities are the drivers in the subsurface but so very hard to research. I also would love if old-school cultivation work will still be done. With the new DNA methods, sometimes it is forgotten that you actually need enrichments and strains growing in the lab to understand your genomic data. Here I see a lot of cool developments in culturing difficult microbes and communities.

Please tell us a bit about your professional background and current line of work.

I am a reservoir engineer with more than 10 years of experience in storage of different gases in the subsurface. This includes, but is not limited to, the storage of hydrogen in porous depleted oil and gas reservoirs. Within my company RAG Austria AG, I am currently charged with supporting research on the subsurface aspects of hydrogen storage and the identification and development of future hydrogen storage projects.

Markus Pichler
Reservoir Engineer Subsurface Storage Development
RAG Austria AG, Austria

From your experience, how has the field of petroleum microbiology research changed over the past 10 years?

There is definitely a change from "those beasts are annoying" to how they can be utilized. It is still a fact that the industry needs to control and deal with microbial life in the subsurface in order to prevent negative effects on our operation. However, projects like Bio-EOR and Underground Sun Conversion are good initiatives in not only worrying about, but also utilizing microbes for the benefit of the industry.

In recent years, we have seen a massive shift within the energy landscape. To what extent do you think microbiology would play a role during this transition phase?

The most important topics are microbial fouling and microbial-induced corrosion, which will stay with the industry as long as we are injecting foreign fluids into the subsurface. Not only in hydrogen storage but also in geothermal applications do microbial-induced changes play an important role when developing a future monitoring and incident-preventing system. The growing awareness for these topics is not only reflected by numerous publications that have been produced in the past years but also by the fact that many oil and gas companies are now establishing their own microbial divisions and are actively spending money on research.

What are some research topics you believe are important to transfer from the oil and gas industry to the renewable sector?

I do not really see that big a shift, to be honest. We are and will still be an energy industry generating and distributing energy to our customers. So, our basic know-how will go in full into this new field of application. It is my understanding that all disciplines that have been supporting the energy industry for the past decades have their role to play in a future energy system and their know-how will be needed. In detail there are changes that need to be addressed, but to give a technical answer, the basic equations stay the same.

With your expert opinions, how can microbial populations positively and negatively impact green energy as the energy landscape is quickly changing?

If we only focus on how microbes can harm and prevent new technologies from arising, the perception will grow that change is impossible and companies as well as investors will no longer be interested. Don't get me wrong. It is important to list all the possible ways in which microbes could prevent a project from happening; however, it depends if this list is presented with an alarmist attitude or one where researchers actually can contribute to a solution. As I see it, the communication that should be done is rather simple. The aim must be to understand the processes that might happen for example in hydrogen storage. If the understanding is there, it can be verified by field tests and solutions can and will be found that will lead toward a positive outcome. Finally, with technologies like renewable methane, and microbial remediation of contaminated sites, there are already examples of how microbes can support a renewable energy future and who knows if there isn't a bug out there that can bind CO_2 in huge quantities.

What would you like to see in the next 10 years in the field of petroleum/energy microbiology?

Pilots and commercial projects but also a huge increase in public engagement. The transformation we are seeing is still a niche of our industry and although there is one press release after another common people are not yet really informed nor engaged. Lab experiments are great and dearly needed to explain the basics that we are seeing in the field. But nothing beats a long-term field experiment. Only by verifying lab experiments in the field can we really build confidence in emerging technologies. Also, in a public engagement it is something completely different if you show lab experiments compared to the actual application of the technology. Especially if you deliver this technology to the public so they can experience it and see the benefit they are gaining for themselves. If we manage the step from lab to field together with the public, then in my opinion the biggest showstopper for a future renewable energy system is out of our way.

Please tell us a bit about your professional background and current line of work.

I have a PhD in chemical engineering with a focus on microbiology. During my PhD, I studied the physiology of co-culture biofilms, particularly the ones implicated in

microbial corrosion. I also investigated the metagenome and metabolome associated with microbial corrosion from oilfield-produced water. After my PhD, I started working at DNV (an independent, energy-consulting company) managing microbiology projects covering topics like microbial corrosion, biofilms, bioremediation, biofouling, etc. We work with oil and gas companies needing technical support in microbiology.

Dr. Susmitha Purnima Kotu
Senior Engineer
DNV, USA

From your experience, how has the field of petroleum microbiology research changed over the past 10 years?

It was 10 years ago that I started my PhD and was exposed to the field of petroleum microbiology for the first time. The biggest shift has been the widespread adoption of molecular microbiological methods for understanding the microbial community and the role of microorganisms. I see more professionals aware of the appropriate methods for sampling and preservation when conducting corrosion failure analysis. The most interesting of all these is the focus in research shifting from solely trying to solve microbial challenges in petroleum microbiology to also investigating the uses of microorganisms to help with energy transition. A couple of examples include a) using microorganisms for carbon capture and conversion to useful products such as jet fuel and beverage bottles (work done by LanzaTech) and b) using depleted oil and gas reservoirs to make hydrogen (work done by Cemvita Factory).

In recent years, we have seen a massive shift within the energy landscape, to what extent do you think microbiology would play a role during this transition phase?

Many energy companies have pledged net-zero emissions by 2050. This involves efficient, safe, and sustainable use of oil and gas assets ensuring no leaks or failures. Hence, the biggest role of microbiology in this energy transition is to reliably diagnose the microbial threats and optimize the mitigation treatments.

What are some research topics you believe are important to transfer from the oil and gas industry to the renewable sector?

I think the concepts of microbial communities, microbial metabolism, appropriate sampling and preservation, and reliable understanding of microbial threats are critical.

An integration in the innovation of digital technologies and molecular biology is important during this transition. This can be particularly useful for identifying microbial biomarkers and applying the knowledge of these to microbial threats in oil and

gas systems. This can also be helpful for meta-analysis of microbiological metabolic processes and identifying specific metabolic pathways of interest and tweaking these metabolic pathways to produce low-carbon products.

With your expert opinions, how can microbial populations positively and negatively impact green energy as the energy landscape is quickly changing?

Despite the increase in the use of renewables, fossil fuels will still contribute to 49% of the global energy mix (per DNV Energy Outlook 2022). This means that the negative impacts of microbiological populations in existing oil and gas operations cannot be ignored and should be accounted for appropriately. The most interesting aspect of energy transition is the emerging field of using microbiology and synthetic biology for energy transition to produce biofuels and bioproducts that have lower carbon emissions than the traditionally used methods.

Would microbial control remain an important aspect of renewables, and why?

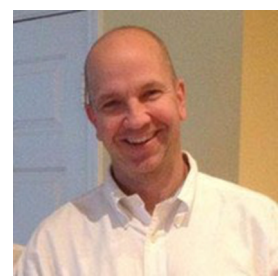
Microbial control for renewables is an emerging field with a lot of unknown unknowns. The widespread adoption of renewables may highlight these microbial challenges soon. Being aware of some of these microbial challenges and implementing effective microbial control is important.

What would you like to see in the next 10 years in the field of petroleum/energy microbiology?

I would like to see a deeper understanding of microbiological challenges in the solar, wind, and hydrogen industries. To be more specific, an understanding of the impact of soil microbiology and any microbial threats associated with solar farms, the impact of microorganisms and potential for microbial corrosion in the flooded wind turbine foundations and offshore wind, and the unintended microbial consequences of underground hydrogen storage.

Please tell us a bit about your professional background and current line of work.

I have a Ph.D. in Environmental Microbiology with a Post-Doc on bioremediation of the Exxon Valdez spill in Alaska. I had a brief tenure in Academia before being recruited into the oil and gas industry and working with an operator (BP), service company (Baker Hughes) and now a manufacturer (Lanxess). Currently, I hold the position of Energy Technology Fellow at Lanxess Microbial Control in Houston responsible for business development, technology transfer, and shaping the innovation pipeline and strategy for global oil and gas applications.



Dr. Kenneth Wunch
Energy Technology Fellow
Lanxess, USA

From your experience, how has the field of petroleum microbiology research changed over the past 10 years?

The most dramatic change has been the application of molecular tools in the industry. A decade ago, evaluating the microbial contamination in a system involved serial dilution culturing with "bug bottles" to quantify sulfate-reducers, acid-producers, or general heterotrophic bacteria present. Clearly, this left gaping holes in understanding population dynamics. Application of qPCR, metagenomics, and bioinformatics now allows us to thoroughly investigate oil and gas systems to determine what organisms are present; what is their involvement in corrosion, souring, or biofouling; and how they are being introduced into the system. Ironically, the chemistries developed to control these populations have changed little over the past 10 years mainly due to regulatory costs. However, their application has evolved due to the adoption of modern molecular techniques.

In recent years, we have seen a massive shift within the energy landscape. To what extent do you think microbiology would play a role during this transition phase?

I think we are on the precipice of a shift in the energy landscape away from fossil fuels but have not yet reached it. Europe is leading the way, but it will take years before North America and Australia adopt this transition and decades before countries like India, Russia, and China do so. In the renewable technologies that are becoming commercially viable (solar, wind, geothermal, hydro, tidal), microbiology is more problematic than beneficial. However, economically harnessing the biomass potential of algae to produce biofuels and the development of microbial fuel cells will most likely lead the way in beneficial contributions from microbes.

What are some research topics you believe are important to transfer from the oil and gas industry to the renewable sector?

The continued advancement of how microbial communities contaminate energy systems and their potential impacts, including corrosion, souring, biofouling, and other biogeochemical transformations.

Also, the energy industry has made huge strides in understanding how and where microbial communities "infect" systems. I think it is imperative to take these learnings into account when designing and developing new assets for renewable energy.

With your expert opinions, how can microbial populations positively and negatively impact green energy as the energy landscape is quickly changing? Would microbial control remain an important aspect of renewables, and why?

I don't have practical experience in how microbial populations positively influence green energy so I will combine the subsequent question about microbial control into my answer. Outside of solar, microbial processes have the potential to negatively impact the efficiency of current commercial green energy technologies. Equipment in aquatic environments is susceptible to macro biofouling, which is initiated by

the attachment of biofilms to the infrastructure surface. This biofouling can have deleterious effects on hydrodynamics in tidal and hydro technologies along with impacting mooring lines or power cables in offshore wind turbines. Biofouling also impacts geothermal processes as microbial contamination can reduce the efficiency of heat exchange. However, the green energy technology that has the potential to be most impacted by microbial populations is hydrogen storage. As green hydrogen is generated from low-carbon power often found in remote locations, it must be stored and transported to population centers. Current solutions for storage are focused on depleted salt caverns and oil and gas reservoirs. These environments may be convenient for geologically storing large quantities of hydrogen but are also ideal for the growth of halophilic, hydrogenotrophs that metabolize hydrogen as a source of energy. The resultant problems are ones very familiar to oil and gas energy, including souring (production of sulfide), corrosion, and biofouling.

What would you like to see in the next 10 years in the field of petroleum/energy microbiology?

A more structured and comprehensive strategy for risk management in traditional and novel energy development. This would include:

- **Modeling** – determine operational risk of microbial contamination.
- **Preventive Barriers** – development of primary barriers (chemical, operational, mechanical, etc.) to mitigate the risks modeled.
- **Barrier Assurance** – confirmation that preventive barriers are working as intended by developing and routinely measuring KPIs (key performance indicators). Failure of preventive barriers requires an immediate operational response.
- **Reactive Barriers** – manage preventive barrier failure by operational design or other chemical or physical barriers.

Please tell us a bit about your professional background and current line of work.

I have a background in environmental engineering, specializing in computational methods and modeling of multiphase flow in porous media. My research is centered around solving engineering challenges within subsurface energy resources, in particular for geological CO_2 storage applications. I currently lead a research group of computational geoscientists who develop new models and simulation tools that can be used for a variety of energy applications within petroleum, CCS, subsurface energy storage, and wind. I also head up several large research initiatives, including one of the three national centers for petroleum research, Centre for Sustainable Subsurface Resources (CSSR). Among the many things we research in CSSR is the influence of microbiological activity on underground hydrogen storage.

As an applied researcher within geosciences, I interact with many different specialists in geology, geochemistry, petrophysics, and geomicrobiology. My professional interest is to build so-called multi-physics models that accurately reflect the complex

interplay of multiple physical-chemical-biological-thermal processes in deep geological systems. The purpose of these models is to help practitioners understand and manage the energy resources in their portfolio. The multidisciplinary nature of developing complicated models is as challenging as it is rewarding.

Dr. Sarah E. Gasda
Research Director,
Energy & Technology Division,
NORCE, Norway

From your experience, how has the field of petroleum microbiology research changed over the past 10 years?

I have only been peripherally involved in petroleum microbiology research. About five years ago, I had a small part in a research project on MEOR where laboratory and modeling studies tried to understand how microbes preferentially clog flow paths, thus encouraging better reservoir sweep. That was the last such project in our project portfolio. Industry interest dried up due to shifting priorities. It costs a lot to perform experiments to screen and characterize microbes for use in MEOR. The money is not there anymore to support this line of research.

In recent years, we have seen a massive shift within the energy landscape. To what extent do you think microbiology would play a role during this transition phase?

I think microbiology will play a role, even if it doesn't always seem that way now. I will give an example from my experience with CO_2 storage research. During my PhD coursework, I was connected to the Princeton Environmental Institute where I was exposed to the existence and complexity of microorganisms in the subsurface. But for the first 10 years of my research career within CO_2 storage (prior to 2010), microbiology was not a topic that anyone talked about. One reason for this was a single study by a well-respected microbiologist at Princeton that concluded there were no environmental impacts of CO_2 storage on microbiological communities living thousands of meters underground. Since that time, microbiology has become popular again in CCS, this time to understand how we can use microbes to remediate leakage.

What are some research topics you believe are important to transfer from the oil and gas industry to the renewable sector?

The laboratory and experimental capabilities that have been built up over the past decades to study petroleum resources are extremely sophisticated. The image resolution we can achieve now allows us to see fluid interfaces moving from pore to pore

in almost real time, which is really exciting. Analysis of these data has dramatically improved our understanding of the fundamental nature of fluid flow in porous media, including how fluids are trapped, remobilized, transferred to new phases, and react with minerals. We have achieved many key insights that are applicable to other types of porous media well beyond oil and gas. It is important to continue this direction of research in porous media science as we move into the renewable sector.

What are some key technological advances you see that are important to transfer from petroleum to renewable energy?

There are many. I think the most important is digitalization. The oil and gas industry has been driver of many important advancements in digital technology. For example, the push toward remote operations and automation of platforms helps increase safety and reduce costs. These advancements can have wide-reaching repercussions in other sectors, which is positive. Another example is simulation technology, where the size of reservoirs, increasing complexity of thermal-mechanical-hydraulic-chemical processes (and microbiology), and the level of geological uncertainty have the danger of pushing CPU time through the roof. Simulation experts have to be very smart in finding ways to simplify models without sacrificing accuracy. There's good progress, but more needs to be done.

What would you like to see in the next 10 years in the field of petroleum/energy microbiology?

In our underground hydrogen storage projects, we see a clear need for more interdisciplinary research at the intersection between fluid flow and transport in porous media and microbiology. I want to see more experiments where the microbes are not so well fed and where the conditions are more realistic, even varying in time and space. I also want to see models developed that really detail the close coupling between the microbial-chemical processes and the flow and transport of fluids in porous rocks. These are very challenging topics, but the most important thing is to work together to design good experiments, and even invent new ways of studying and modeling these complex systems. I also want more field pilots to test our understanding, acquire data, and reveal the gaps so we can fine-tune our research moving forward.

Please tell us a bit about your professional background and current line of work.

I'm currently Docent and Project Manager at VIA University College in the Research Center for Built Environment, Energy, Water, and Climate (Horsens, Denmark). I graduated from Aarhus University, Denmark (2002), with a master's degree (cand. scient.) in biology. In 2005, I earned a PhD from the Department of Microbiology, Aarhus University. The same year I was employed at the Danish Technological Institute (DTI) in the Centre for Chemistry and Water Technology, where I was responsible for the consultancy activities for the oil and gas industry around the North Sea and later also worldwide. While heading DTI Microbiology Laboratory I was also developing several consultancy and business activities with the oil and

gas industry. I founded DTI Oil and Gas in both Denmark and Norway, where I was the team and business development leader for five years. Thereafter, I worked as a project manager at DNV (Det Norske Veritas) in the field of corrosion management in both Bergen and Esbjerg.

I'm the current chair of AMPP SC-22 on Biodeterioration and ISMOS TSC, an organization I co-founded in 2006 with Dr. Corinne Whitby. I'm an international scientific reviewer and the author of 150+ technical and scientific papers and book chapters related to industrial microbiology, applied biotechnology, corrosion management, oilfield microbiology, water treatment and safety, reservoir souring, and biocorrosion. I spent quite some time editing and reviewing book proposals in my field of expertise and I have co-edited the books *Applied Microbiology and Molecular Biology in Oilfield Systems* (Springer, 2011); *3rd International Symposium on Applied Microbiology and Molecular Biology in Oil Systems* (Elsevier, 2013); *Applications of Molecular Microbiological Methods* (Caister Academic Press, 2014); *Microbiologically Influenced Corrosion in the Upstream Oil and Gas Industry* (CRC Press, 2017); *Microbiological Sensors for the Drinking Water Industry* (IWA Publishing, 2018); *Oilfield Microbiology* (CRC Press, 2019); and *Failure Analysis of Microbiologically Influenced Corrosion* (CRC Press, 2021). And also, the current book you are sitting with right now. While I remember: I was honored with the NACE Technical Achievement Award in 2020 for outstanding research on MIC in the energy sector. That was a great endorsement of my current work. I think I'll leave it with this and tell the story of the origin and development of EuroMIC for another time.

Dr. Torben Lund Skovhus
Docent and Project Manager
VIA University College, Denmark

From your experience, how has the field of petroleum microbiology research changed over the past 10 years?

I took a quick look at the book Dr. Corinne Whitby and I edited and published in 2011 with Springer called *Applied Microbiology and Molecular Biology in Oilfield Systems* to get inspired. In fact, the problem in the industry remains the same (MIC, souring, and biofouling), but our toolbox has increased with more sophisticated molecular methods that are now also reaching the commercial market (e.g., long-read nanopore DNA sequencing). In the ISMOS community, we have published numerous books and special journal issues from the beginning, enriching knowledge for industry professionals and academics alike. One major accomplishment I want to highlight is our effort to transform all the excellent scientific work from the ISMOS events (and from other communities) into industry-relevant recommended practices, guidelines, and standard documents. Just to mention a few milestones are the following: DNVGL-RP-G101, NACE-TM0212, NACE-TM0106, ASTM-D8412-21, and the recently published Energy Institute document *Selection, Applicability, and Use of Molecular Microbiological Methods (MMM) in the Oil and Gas Industry*.

Further standard documents are on the way from AMPP SC-22 and ISO, which is very encouraging for implementing the correct use and applicability of the latest methods to investigate petroleum microbiology and MIC.

In recent years, we have seen a massive shift within the energy landscape. To what extent do you think microbiology would play a role during this transition phase?

For clarification, it might be worth splitting this question into two parts: 1) the positive role microorganisms could play in the energy transition away from coal, oil, and gas to a more sustainable energy landscape, and 2) the negative impact microorganisms will have on the new infrastructure that comes with the energy transition.

For the first part, I'm rather optimistic as we will find great use of microorganisms in large-scale fermentation plants for e-fuel production based partly on genetic engineering and synthetic biology. This is already ongoing as we speak and will increase in focus over the coming decade. For the second part, the learning from the current research is that microorganisms will always find a way to assist degrading (man made) materials in the environment, if they get something out of the effort – so our new energy infrastructures will also suffer from MIC, biofouling, etc. Here we need to transform our current knowledge from primarily the oil and gas industry to the new industries and their materials. An example of this knowledge transition is the ongoing Euro-MIC (euro-mic.org) project where training of the coming generation of researchers and industry professionals is a key element via training programs, conferences, developing standards, and hosting industry workshops.

What are some research topics you believe are important to transfer from the oil and gas industry to the renewable sector?

I'll highlight three areas where I see an important transfer of knowledge and skills. 1) production chemistry testing, 2) monitoring and testing via a multiple lines of evidence (MLOE) approach, and 3) the future use of AI in monitoring the threat of corrosion in general and MIC in particular.

First, we need to transfer all the existing knowledge on how to prevent corrosion by the use of production chemistry. Several good standards and guidance documents have been produced in this field recently. Second, a MLOE approach for diagnosing MIC is required and is now being implemented worldwide in operating companies based on solid work over the past decades. Finally, we see an increase in the application of AI in material selection, prediction of corrosion failures, and optimization of mitigation approaches. Procedures and algorithms will be important to transfer to the new energy landscape for building a more sustainable future.

Would microbial control remain an important aspect of renewables and why?

Sure. Wherever we have water, nutrients, favorable growth conditions for microorganisms, and a surface to colonize, we will find the potential for MIC to happen. Not that it always will – but often it is the case. This will eventually lead to material degradation. Take for example the Power-to-X (PtX) revolution. PtX covers technologies that produce fuels, chemicals, and materials based on green hydrogen made

by electrolysis. Electrolysis is a process where electrical energy from, for example, wind turbines and solar cells is used to split water into hydrogen and oxygen. The hydrogen can then be used directly as an energy source. It can also be refined into methanol and e-jet fuels using CO_2, just as it can be refined into ammonia using nitrogen. During the PtX process, a vast amount of ultra-clean water is needed. When water is part of the process – so are the microorganisms and the threat of MIC will be present.

What would you like to see in the next 10 years in the field of petroleum/energy microbiology?

In my opinion, we have most of the tools and technologies we need to assess, mitigate, and monitor corrosion and MIC. The task is to use it wisely and come up with smarter and more updated ways of regulating the industry, so we avoid leaks, spills, and other disasters. Standardization is picking up slowly – but there is still a good way to go. For many operating companies, production chemicals are applied as insurance. We have done something – we hope it works. Few invest the effort in establishing robust corrosion management systems to ensure that the treatment effectively accomplishes its intended purpose of corrosion control, which should be a focus area over the next decade. Finally, we need much more updated training courses for industry professionals, students, and established academics. Today, they have very limited access to the latest knowledge through MIC training courses worldwide, and there is a great demand for such courses. This is the main reason we recently established the MIC E-learning Academy (www.mic-learning.com), which features free tutorials, an online expert community, and certified online training material. What I'll very much like to see is more students and industry professionals getting upgraded on their knowledge in the field of petroleum microbiology and MIC in the decades to come.