Renewable Energy and PtX-Technologies in Education

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Abstract

To achieve the global targets opposing climate change, it is necessary to reduce CO2 emissions from fossil sources to negligible levels until 2050 at the latest. Thus, the energy demand of the industry, for mobility and for power supply must be covered predominantly by inherently volatile renewable sources. To ensure sufficient grid stability, various storage and reconversion technologies are needed. Power-to-X (PtX) technologies will play a central role in this effort and become an essential basis of our energy supply. The first step of the process is power-to-hydrogen, for which electrolysers in the gigawatt (GW) range are currently being planned or have already been realized. Designed as highly dynamic loads, they take over essential functions for balancing smart grids and supplementing the secondary and minute reserve that can be represented by intelligent power converters and battery storage. Our university has been engaged in the development and operation of Power to Gas (PtG) for more than twenty-five years through various industrial research, regional development projects, as well as practical study programs. We combine laboratory training at industrial plants with various student projects, such as the ThaiGer-H2-Racing Team who built the currently most efficient hydrogen prototype with a consumption of only 8,04 grams of hydrogen per 100 km. The multiple use of these systems for research and educational purposes combined with the motivation and experience of the staff allow a very instructive, hands-on and cost-effective education in the field of PtX technologies and their contribution to grid stability.

Keywords: Education, renewable energy, PtX technologies, PtGas, Power-to-Hydrogen, energy storage, fuel cell applications, smart grids, ThaiGer - light weight race car

1. Introduction

In the future, we will be confronted with enormous challenges converting the generation of energy to rely on renewable sources, the supply of energy via smart grids, and new mobility concepts. The grid infrastructure, built over a period of more than a century to support conventional centralized power generation, must now meet the challenges created using renewable energy. With the help of modern IT applications as well as the integration of modern storage solutions and technologies for sector coupling, intelligent energy supply networks can be created that will secure transnational and local energy supply in the future. This demanding goal requires networking of the protagonists in industrial realization, research and education regarding the mandatory fundamental changes in society. These topics have to be reflected in a practical student education, so that the demand for specialists for these enormous challenges can be met. At the focus of all activities there is the vital question of how we can foster the students' intrinsic motivation to continue working in this innovative field and to develop a sustainable power supply and mobility solutions for various applications.

2. Ptx technologies and Sector coupling

On the one hand, future smart grids will have to automatically activate storage facilities or switch off suitable consumers in the rare case of a supply deficit of regenerative energy. On the other hand, when there is a surplus of renewable energy, the power grid will have to be managed in such a way that the energy requirements of the heating sector, mobility, and the demand for materials in industrial production can be met without carbon dioxide emissions and at minimum cost. This is referred to as sector coupling. Concerning energy consumption, efficient conversion technologies will be necessary in various areas such as the production of electricity, heat supply, mobility, and the chemical industry, as there is a need to decarbonize almost all processes which are still based on fossil raw materials. This requires suitable storage capacities in the form of hydrogen, methane, and liquids such as methanol or ethanol since gases and liquids can be stored easier than electricity. Highly efficient

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and cost-effective conversion processes are to be preferred to avoid a future surge of energy costs. In this respect, existing infrastructures must undergo testing for their use and energetic system short circuits must be avoided.

Therefore, power-to-heat (compare (1) in Fig. 1) with direct heat generation such as the electric heating of heat storages for district heating systems possibly advanced heat pumps with a coefficient of performance (COP) of up to 4 using heat from the environment or the direct power supply of electric railroads and the charging of battery vehicles often involves smaller conversion losses than PtG technology. However, PtG ((2) in Fig. 1) can solve the storage problem very advantageously with the first step (PtH = Power to Hydrogen) producing hydrogen using electrolysers as a storable energy rich gas. Hydrogen can be used in a variety of direct and highly efficient ways in fuel cell vehicles such as cars, trains, ships as well as for decentralized power supply. Power-to-power refers to short-term electrical battery storage for primary control of power grids in the hourly range but also in the minute range using intelligent power electronics. Since power-to-power in the long-term range is only possible with a maximum efficiency of 30%, this technology must be kept to a minimum by the intelligence of the grid control in smart grids [Gamallo, 2007]. Chemical long-term storage with hydrogen (PtH + HtP) or synthetic methane amend the technological spectrum. The use of bioenergy completes this overview. Bioenergy provides biofuels for mobility and biomethane for CHP plants. However, the economically exploitable potential of bioenergy in Germany is only about 25 % of the total energy demand. [FNR e.V.]

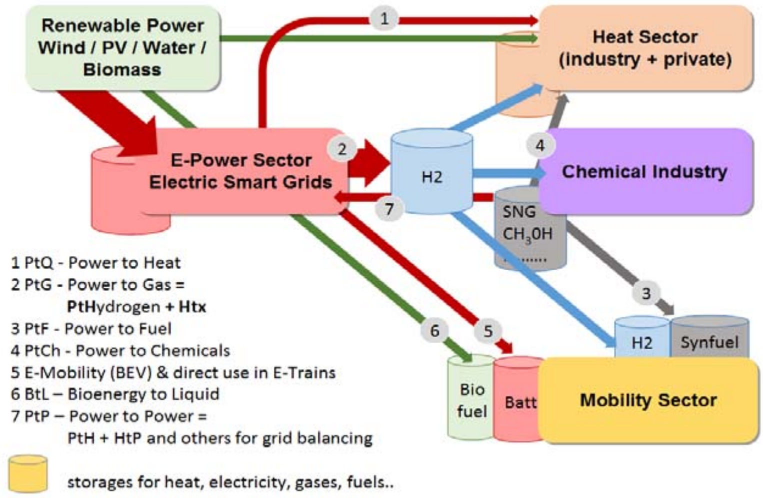

Figure 1: Ptx technologies for sector coupling and some storage options [Steffenhagen et al. 2018]

3. Local and international research projects and infrastructure of the Stralsund University of Applied Sciences

3.1. Research activities in the field of renewable energies and Ptx technologies

The educational opportunities of the Stralsund University of Applied Sciences have developed since 1994 in close connection with the establishment of the interdepartmental complex laboratory Alternative Energies. It constitutes the central scientific institution of the Stralsund University of Applied Sciences, the Institute for Renewable Energies (IRES) and the Institute for Environment e. V. The Institute for Regenerative Energy Systems (IRES) is focused on research in the fields of conversion, generation, storage and utilization of renewable energies and hydrogen as well as the automation of the associated systems. The question of how to utilize wind and solar power (solar thermal and photovoltaics) bioenergy as well as hydrogen including the associated manufacturing technologies, materials research and system integration, are the subject of applied research. Which is usually carried out in cooperation with companies and research institutes in the state. This particularly includes the work on PEM and SOFC fuel cell systems, e.g. for the maritime sector. The analysis and design of infrastructure scenarios regarding hydrogen/ methane storage and distribution have been and continue to be the basis of research work on hybrid power plants, modular energy container solutions, storage concepts and the grid integration of renewable energies.

Some of the latest research projects will be briefly explained below. The project MethaCycle for example investigated the possibilities to produce methanol from renewable hydrogen and carbon dioxide. [Gulden et al. 2021] The methanol was supposed to be handled in a cycle so that the carbon dioxide could be used with hydrogen again.

In the project ELMAR the Institute for Renewable Energy Systems was looking at the different possibilities to use electric propulsion for maritime applications, specifically in the southern Baltic region, and the missing links in the supply chain of small and medium-sized local enterprises were analyzed. [Voss et al. 2020] HyStarter had the goal to create a network of the necessary key players regarding a hydrogen infrastructure in the region Stralsund/Rügen, which led to the funding of the HyExperts project, which now investigates the needed steps to implement the infrastructure in the region. Led by the INP in Greifswald the CAMPFIRE project explores the prospects of ammonia as a hydrogen storage medium. The contribution of the IRES is the analysis of the needed components for an ammonia-propelled ship. To generate these huge amounts of green hydrogen offshore wind farms are a viable option. In the project PowerH2 we investigate methods to transport the generated energy ashore from water. In this respect a hydrogen pipeline seems feasible. [Hayduk et al. 2022]

The focus of the research network "Netz-Stabil", consisting of research groups from the University of Rostock, Stralsund and Greifswald, was on solving problems related to energy transition as part of the excellence research program of the federal state of Mecklenburg-West Pomerania. One of the challenges was the volatility of renewable energy sources. These fluctuations cause instability in the electrical power grid and therefore threaten the balance between generated and consumed energy. Another problem is the increasing use of drives coupled with inverters. As a consequence, grid frequency and power consumption are decoupled which leads to a decreased self-regulating effect of the grid. In this context, the project group at Stralsund University of Applied Sciences conducted research on suitable storage technologies as well as storage management and built a hybrid energy storage system (HESS), including the necessary power electronics and control algorithms. [Bierhoff et al.] Combining lithium-ion batteries with double-layer capacitors, the focus of this storage system is on short-term volatility due to renewable energy sources in the range of milliseconds to hours. The HESS was combined with a test bed to simulate volatile energy sources such as wind and solar power plants. This then allowed studies to be conducted on the design of individual storage components and to find optimal operating strategies for real wind and solar farms. [Soliman, Bierhoff, 2022,a,b]. Figure 2 shows the basic setup of a possible application in which the HESS is combined with a wind turbine to compensate for power fluctuations. The prototype has a capacity of about 25 kWh and a peak power of about 150 kW.

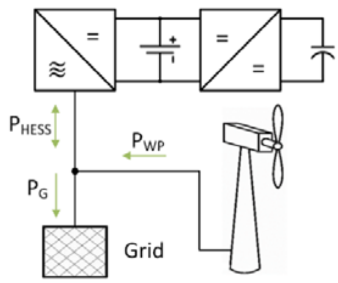

Fig. 2: Hybrid Energy Storage System [Steffenhagen et al. 2018]

The aforementioned topics of applied research are not only comprehensively conveyed in teaching, but they also pose challenging topics for student projects as well as bachelor's and master's theses as a prerequisite for a subsequent career. The equipment developed or acquired in these research projects serves as the basis for student laboratory practicals on state-of-the-art technology.

3.2. Modernization of the complex laboratory to the SMART-GRID-LAB

As early as 1993, the Integrated Energy System Laboratory (Complex Laboratory) was established as a multidisciplinary laboratory with state-of-the-art industrial equipment for the research area of renewable energies, it was continuously expanded and modernized to become a Smart Grid Laboratory last year. With its new switchgear, it enables the intelligent and open networking of energy generators, storage facilities and consumers, realistic upscaling in the simulation area as well as studies on sector coupling. The complex laboratory was constantly extended by new equipment. Starting in 1996, a wind-PV-hydrogen chain with grid-connected reconversion (the first plant worldwide with components from 10 - 100 kW) was installed. It served as a research, experience and teaching platform for hybrid energy and storage solutions. Furthermore, it is used to operate our CHP in natural gas-hydrogen mixed gas operation in addition to testing and developing PEM and SOFC fuel cell systems including their components. The laboratory itself consists of the following individual systems(Fig. 3): A Stirling engine [50 kWth and 10 kWel], a catalytic hydrogen boiler [21 kW], a biomass boiler [50 kWth], an adsorption refrigeration system [10 kW] with a solar thermal system [40 kW], and fuel cell systems [20 W ... 2 kW]. Since 2020, a lithium-ion battery storage component [10 kWh] complements the whole system, which is important in terms of grid stability. Thus, the complex laboratory is equipped with sophisticated devices and systems from all areas of renewable energies and storage technologies.

The switchgear technology of the Complex Laboratory was put into operation in 1995 with the establishment of the laboratory. Although the system was repeatedly optimized and adapted to the requirements of laboratory operation and for teaching purposes, and the individual systems including the associated measurement and safety technology of the laboratory were adapted as well as expanded to the corresponding state of development, it no longer met the requirements of a future energy supply to intelligently link consumers and generators. Therefore, the idea was born to equip the IRES research and training laboratory, which consists of various renewable energy generator and storage technologies as well as different consumers, with SMART-GRID functionality. The SMART-GRID-LAB at Stralsund University of Applied Sciences could then be put into operation in 2021. The intelligent and open linking of generators, storage units and consumers now enables realistic upscaling in the simulation area. With the new switchgear technology, the interaction of renewable energy suppliers with storage facilities and energy consumers can now also be investigated during a comprehensive sector coupling. This makes it possible to accompany the introduction of regional smart-grid solutions directly and soundly by grid operators, but also to map research and training in the field of PtX technologies in a smart-grid environment. The University of Stralsund is furthermore planning to connect other specialist laboratories of the university in the energy and automation sector with the SMART-GRID-LAB to form a cross-functional platform, so that they can communicate and exchange data via the platform. The students are thereby able to directly access the Complex Laboratories plant technology via the communication interfaces. This includes the configuration of hybrid power supply solutions, their parameterization, experiment planning/ sequencing and the associated data evaluation.

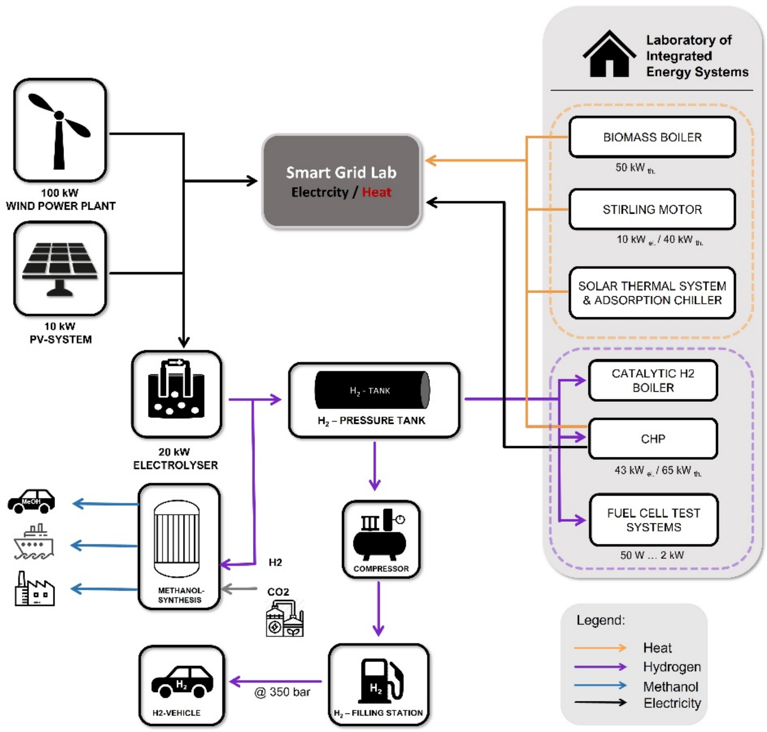

Figure 3: Structure of the IRES-Laboratory of Integrated Energy Systems (KAE) at Hochschule Stralsund

The authors plan to expand the SMART GRID LAB later to make data interfaces available to the cooperating energy suppliers and thus to significantly increase the consistency in the processing of highly particular tasks of the industrial partners. An outstanding performance in controlling and logging the process is critical for the analysis of the interaction between individual system components and consumers within a SMART-GRID. The system offers update times of 1 µs per I/O module at local bus level. With the higher-level PROFINET bus system, the processes can be run and analyzed in real time. Modbus TCP and Modbus RTU are used to communicate with the devices and systems (see Fig. 4). Thus, the automation system of the research laboratory is state of the art. It now provides the basis for implementing the intended functionality of the SMART-GRID as a laboratory platform. The components interacting within the SMART-GRID-LAB network can be configured, adapted, controlled and evaluated with regard to their operating behavior by remote access via the network with the aid of the implemented control technology and the visualization system in accordance with the experimental tasks. New components can be added at any time due to the modular design.

The system configuration complies with the following specifications:

- Performance on local bus level with update times of 1 µs per I/O module (transmission of fast samples according to standard part IEC 61850-9-2)
- Real-time capability according to IEC 61850
- PROFINET at the programmable logic controller level according to IEC 61850
- Modbus TCP and Modbus RTU on the communication level between the devices and systems of the lab
- Use of industry standard components to ensure reliability considering the high loads which are to be expected, compatibility of individual components with each other.

With this new modular automation concept, extensive data acquisition is possible and thus constitutes the basis for innovative research and training.

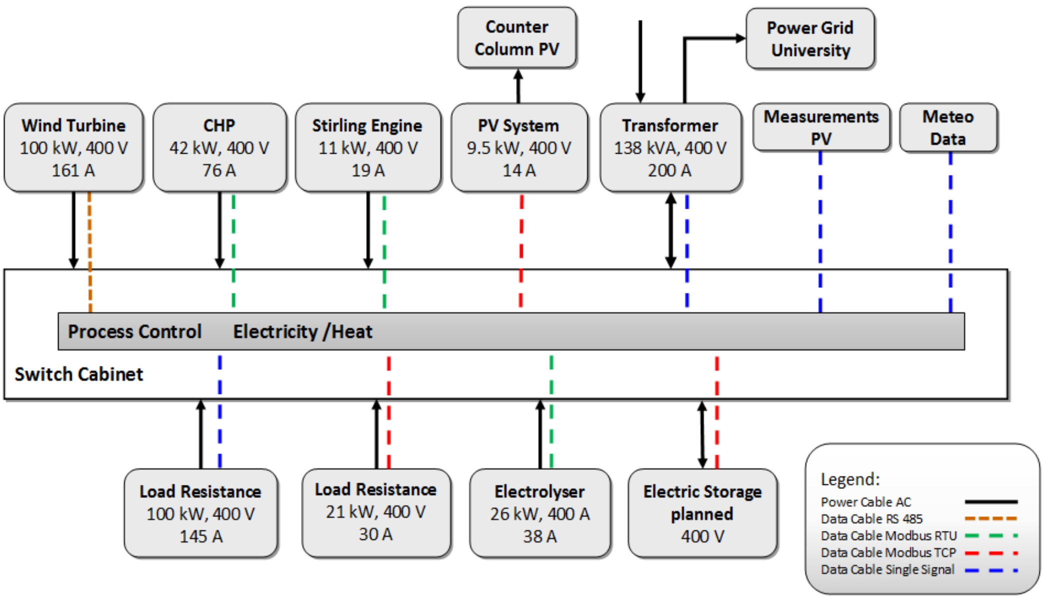

Figure 4: Overview Integrated Energy System Laboratory - Electricity [Steffenhagen et al. 2018]

4. Education in Renewable Energy, Ptx technologies and E-Mobility

4.1. Development and overview of various education programs

To meet the growing demand for specialized personnel, our university has a long tradition of research and education in renewable energy and hybrid energy systems management. Various educational formats have been developed. These include a German-language bachelor's program in renewable energy since 2009 and a German-language master's program in electrical engineering with a specialization in renewable energy since 2007, as well as an English-language master's program in renewable energy and E-Mobility since 2018. This master's program also promotes international cooperation with our partners in Europe, Thailand and South America. For shorter study visits of international students, we have a postgraduate program in renewable energy and hydrogen technology since 1997 (offered in English language, five months in winter semester) and a two-week international spring school in English for students from our partner countries.

A high level of practical relevance and the associated motivation of the students play a very important role in the training. By means of interdisciplinary student projects, such as the ThaiGer-H2 Racing Team, a practical education had to be ensured. The fact that said team is able to participate in international competitions achieving excellent results provides a boost to motivation. Since 2008, our team has been competing in the Shell Eco-Marathon. In the "Hydrogen Fuel Cell Prototype" category we obtained first place four times in a row between 2018 and 2022. The goal of this competition is to achieve minimal fuel consumption during a race lasting 39 minutes at a speed of approximately 25 km/h. Building and driving the race car encourages interdisciplinary teamwork and multicultural thinking. The race car project is also covered during spring school and team members work as tutors during lab experiments. In this way, both the spring school participants and the team members can gather experience and the students' motivation to deal with new technologies is promoted.

In order to raise pupils' interest in renewable energies and related technologies as well as new mobility concepts, we have long maintained close contacts with local schools. We started with a hydrogen truck model built by pupils and students. We also organize project days on a regular basis where pupils can access this new technology in practical experiments. Since 2017, a school team named "GreenDrive" has also been participating in the Shell Eco-Marathon with a battery-powered race car in the category "Prototype Battery Electric". In 2022 their efforts were rewarded with a fourth place in Nogaro (France). Another accomplishment of this engagement is that the first student members of this team have started their studies at our university.

4.2. Bachelor Programms

At the same time as the Complex Laboratory was being constructed and the research focus on renewable energies and hydrogen technology was being established, teaching concepts were being developed. Initially, modules from the field of renewable energies and hydrogen technologies were included in the diploma program and later in the bachelor's program in electrical engineering. In 2009, we started a standalone cross-faculty bachelor-study-program "renewable energies" with two specializations: electrical and thermal energy systems. It contains additional scientific and mechanical engineering fundamentals and offers more scope for regenerative energy converters and systems, energy storage, hydrogen technology and fuel cells as well as the associated plant engineering. Furthermore, energy efficiency issues are considered. The program has a duration of seven semesters and is graduated with a Bachelor of Science (B.Sc.) degree. It was successfully reaccredited in 2019 by the Accreditation Council until September 30, 2027. It is a practical degree program, which is accompanied by extensive laboratory training, student projects and a twelve-week practical phase in the seventh semester. This ensures optimal starting conditions in the industry. The curriculum is structured as follows:

1. **Natural science basics**
   mathematics I and II, physics, thermodynamics and fluid mechanics, modeling and simulation
2. **Technical basics**
   electrical engineering I, II and III, electronics, mechanics, construction and materials, PLC programming and actuator technology, measurement and sensor technology, control engineering, process engineering
3. **Specialization renewable energy**
   fundamentals of energy conversion, hydrogen technology, fundamentals of solar systems, energy efficiency, energy management (plant design, energy economics, energy storage), regenerative energy converters I (geothermal, wind, hydropower), regenerative energy systems.
4. **Interdisciplinary qualifications**
   scientific work, technical English, presentation and rhetoric, business administration, integrative elective module 1 out of 3 (project management, environmental management/environmental law, environmental engineering)
5. **Specialization**
   Electrical energy systems: electrical machines, power electronics, electrical power generation, electrical power supply, low voltage systems, high voltage systems, elective module.
   Thermal energy systems: electrical machines and power electronics, thermal energy systems I and II, regenerative energy converters II, fluid machinery, two elective modules.
6. **Finishing study work:** Project work, practical phase in a company, bachelor's thesis with colloquium

4.3. SpringSchool and Postgraduate Course in Renewable Energy

For study visits of international students, we established a one-semester postgraduate course in renewable energy and hydrogen technology as well as a two-week international SpringSchool in English. We started the SpringSchool as early as 1992. 30 years ago, the use of hydrogen as an energy storage medium in combination with renewable energy sources was a rather fictional idea, still far away from functional applications. Therefore, we invited scientists from Sweden, Argentina, Poland, and Norway and some of their most enthusiastic students to come and collaborate with us. This scientific fiction has become a reality. Participants from various countries look forward a varied program with practice-related experiments and interesting excursions every year.

The Spring School was funded by the Erasmus Program of the European Union from 1992 to 2014 and received the European Award for SpringSchool in 2008. This placed us among the top ten ERASMUS intensive programs out of more than 200 in Europe, and at that time we were the only program dealing with renewable energy and hydrogen technology [Bauch 2011]. After that, we were able to secure financing from the university and continue this successful tradition. Participants only have to pay a small contribution for room and board. Over the years, we have adapted the content of the SpringSchool to the current state of knowledge and incorporated the work of researchers and lecturers from our partner universities. The current title, FUSES+ (FUture Sustainable Energy Supply) based on renewable energy and hydrogen technology, is a combination of an in-depth introduction to hydrogen, fuel cells and system automation, extended by current developments in renewable energy sources, power quality and electric mobility. In April 2022, the 29th SpringSchool was held with lecturers and students from Finland, Norway, Brazil, Lithuania, and Poland to share our knowledge with an international community.

As we aimed at deepening the cooperation with our international partners and enabling the students to prolong their stay at our university, e.g. within the European Erasmus exchange program or with the help of our partners from Thailand, we established an international Postgraduate Study Course in 1997. This one-semester intensive course between September and February is designed to deal with future issues of ecological relevance, which allows students from Spring School to come back to our university and deepen their knowledge. Initially, we were not yet able to offer a full master's program and thus this intensive course could help to meet the growing demand for engineers in the field of renewable energy. This program still exists today. It is suitable for final year students as well as PhD students of technical fields from Germany and abroad [Luschtinetz et al]. Since this study course promotes international cooperation students have arrived from the European Erasmus exchange program, from South America sponsored by the DAAD, and from partner universities with which the University of Stralsund made bilateral agreements. Moreover, even postgraduates and company workers attend this study course. Some participants then stayed for another semester and did research at our IRES institute or completed special trainee programs in their own countries up to the PhD degree. The course program is constantly adapted to current developments and currently includes the following topics: environmental energy management, hydrogen technology, fuel cells, hydrogen laboratory, bioenergy, wind power plants, solar energy (photovoltaics, solarthermal energy), power systems technology and electrical power quality, a Small Project and an Energy Excursion Program. An examination completes the course and students, if they pass, can obtain a maximum of 30 ECTS credits, which are then accepted at the home university.

4.4. Master’s Programmes

Motivated by the great interest of the students in the previous international programs, we established a new specialization in renewable energy in our German-language master's program in Electrical Engineering in 2007. Initially, we focused on the field of renewable energy and hydrogen technology and started with modules such as Solar Systems, Wind Power, Electrochemistry, Fuel Cell Systems, Hydrogen Technology, CHP Systems and Bioenergy, and renewable energy Systems. Later, modules were added from the field of drive technology and alternative emission-free drive concepts. Most of the modules include laboratory training or the students work on their own projects, so that the training is very practical. Although this requires a great deal of supervision, it helps to motivate students, promotes independent work as well as group work, and optimally prepares students for a later career in science and applying their knowledge.

The program is addressed to students with a bachelor's degree in electrical engineering or related courses of at least 180 ECTS. The duration of the program is three semesters and yields 90 ECTS credits. Students graduate with the academic degree of Master of Science (M.Sc.) which generally qualifies for admission to a doctoral program at a university. The lectures are delivered in German and English. The Master's program was successfully accredited by the Accreditation Council in 2022 until September 30, 2030. In the first semester, which is usually the summer semester, mainly basic knowledge on a theoretical level is taught. However, it also includes an elective module with a practical background in addition to an integrative elective module called "Project Management". The winter semester is used for specialization in areas such as hydrogen technology, fuel cells, bioenergy, solar systems, wind turbines, electromobility, alternative non-fossil mobility, vehicle management systems, power electronics, special problems of drive technology, modern methods of control engineering and automation technology. The winter semester consists mainly of application-oriented elective modules where the lecture language is usually English. The winter semester is often used as a sandwich semester in Master's/PhD study programs by foreign students. Students can enroll in either the summer or winter semester. The study schedule starting in the summer semester can be seen in Figure 6. When enrolling in the winter semester, the first two semesters are reversed. Based on the postgraduate course "Renewable Energy and Hydrogen Technology" several f international cooperations with different countries like Thailand, Russia, Poland, Brazil, Norway and Finland have developed. Following that path, a desire to deepen the cooperation arose and to enable double degrees as well. To accomplish this, however, we needed not just a single semester in English, but an English-language master's program in renewable energy. In the development of this new English-language master's program, our many years of international experience with English-language events with our international partners on site, were eminently useful. Additionally, the master's program of "Electrical Engineering" with a focus on renewable energies as well as the postgraduate course "Renewable Energy and Hydrogen Technology" have been incorporated. In addition to modules dealing with the use of renewable energy sources and hydrogen technology such as solar radiation in PV and solar thermal systems, biomass, wind and hydropower as well as the use of hydrogen as a storage medium, we established a new focus on electro mobility, a highly innovative, fast-growing and future-oriented sector in Germany and abroad.

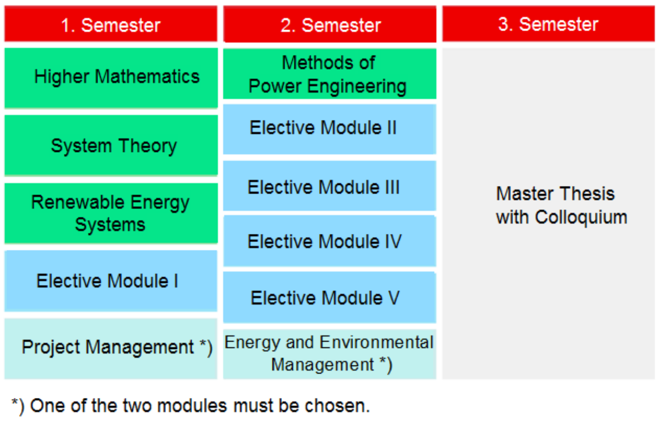

Figure 5: Curriculum Master Electrical Engineering, specialization renewable energy

The electrification of the automobile in combination with hydrogen as a storage medium can be an important step toward making mobility more environmentally friendly in the coming decades and maintaining the competitiveness of our automotive industry. The new study program, in which the first students enrolled in 2018, addresses these future topics and helps to meet the growing demand for engineers. There is no equivalent range of courses in northern Germany. The master's program "Renewable Energy and E-Mobility" is aimed at students with a bachelor's degree in electrical engineering, mechanical engineering or related courses or physics. It is offered in a three- and four-semester option, as foreign students often come to us with a bachelor's degree of 180 ECTS. The four-semester option includes either additional practical or study semesters. Enrollment for the previously mentioned course starts only in the summer semester, the course with a duration of three semesters can be begun in summer and winter semesters. In addition to compulsory modules based on mathematical-technical fundamentals as well as interdisciplinary qualifications, such as energy and environmental management or quality management in the automotive industry, application-specific knowledge is taught in both compulsory and elective modules in the two focus areas. The student can choose from elective modules in the areas of renewable energies or e-mobility as well as independent elective modules to also acquire inter-disciplinary or in-depth electrotechnical expertise. In the final semester, students work on their master's thesis.

Since the range of courses we offer is not limited to students with a degree in electrical engineering, we thought it is crucial to give students with a mechanical engineering degree, for example, the opportunity to acquire any specialist knowledge they might lack, especially in the field of electromobility. At first, we left it up to the students to compensate for any technical deficits through independent elective modules. However, the students did not make sufficient use of this option, which led to problems in the more advanced modules. For this reason, we have adapted the modules in the first semester to match the underlying bachelor's degree. Thus, the module "Power Electronics" does not have to be taken by students who have already completed the module in the bachelor's degree. These students can then choose a different elective module. In addition, students who come to us with a bachelor's degree in mechanical engineering must take the module electrical energy transmission and conversion as a first elective module. This decision was made by the admissions committee. Since the level of proficiency and the knowledge imparted to foreign applicants vary significantly, we have introduced the following admission requirements step-by-step:

- **Bachelor's degree** in electrical engineering, power engineering, renewable energies, mechanical engineering, physics or related subjects
- **Proof of knowledge in the following fields** with a minimum of:
  - Measurement technology at least 4 SWS or 5 ECTS- Control engineering at least 4 SWH or 5 ECTS
  - Fundamentals of electrical engineering at least 4 SWH or 5 ECTS
  - Electrical machines at least 2 SWH or 3 ECTS
- **Proof of English language skills at B2 level**
- Grade point average of at least 1.8 in the first degree
  (With a grade point average of 1.9 to 2.3, a case-by-case assessment is made based on a letter of motivation and other documents)

The master's program is in very high demand. We have between 400 and 700 applicants for the four-semester version in the summer semester. This master's program enables us to deepen existing international collaborations and to find new cooperation partners, e.g. in Brazil. The curriculum of the master's program "Renewable Energy and E-Mobility" in the three-semester-option is structured as follows:

1. **Mathematical-scientific basics:** modelling of physical systems, system theory
2. **Specialized technical bases of renewable energy technology**:
   renewable energy systems, methods of power engineering, power electronics
3. **Application-oriented knowledge**: (elective modules, min. four modules must be chosen)
   current topics of renewable energy, solar systems, wind power plants, hydrogen technology, fuel cell systems, control of electrical drives, sustainable non-fossil mobility, advanced power electronics, project seminar e-mobility, vehicle management systems, vehicle simulation & test drive
4. **Interdisciplinary qualifications:** quality in automotive industry or energy and environmental management
5. **Master's thesis**

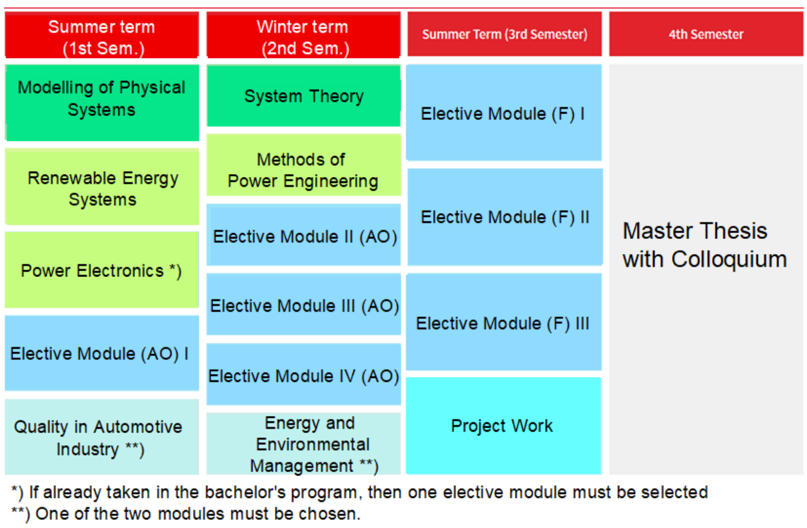

Figure 6: Curriculum Master Renewable Energy and E-Mobility, 4 semesters without internship semester

In the four-semester version, students can choose to complete an internship semester in the third semester or choose three independent elective modules and complete a project thesis.

The following modules are available as independent electives: selected topics of control engineering, electrical energy Conversion und Transmission, International Accounting, Human Resources Management, German as a foreign language I and II (A1 or A2 level) and all application-oriented modules. The students are involved in various student projects such as the ThaiGer and also in current research projects, which enhances motivation and independent work. The practical semester, which is chosen by many students, makes the education particularly hands-on and the students are well-prepared for their careers to come in this field of future relevance.

5. Light weight race car projects

5.1. ThaiGer - a student project

The ThaiGer-H2-Racing Team is a student team at the Stralsund University of Applied Sciences, which has been developing and building hydrogen-powered prototype vehicles for over 14 years. With this international team our university managed to acquire a lot of experience motivating young students to develop and implement new technologies. This successful project started in 2008 with students from Thailand, Spain, Poland and Germany in Stralsund, hence the name ThaiGer (Thailand + Germany). Students from the international postgraduate course and later also from the Renewable Energy and E-Mobility (REEM) master's course have worked in this team and participated in competitions across Europe. The cross-faculty and interdisciplinary collaboration promotes the multicultural and interdisciplinary idea of the study program. Currently, the team includes about 30 students from the Stralsund University of Applied Sciences, coming from all faculties and different study programs. However, the students are united by one thing - the goal of building the most efficient hydrogen-powered vehicle for the Shell Eco-marathon in the "Hydrogen Fuel Cell Prototype“ category. Annually, the ThaiGer team competes in the largest efficiency competition, the Shell Eco-marathon Europe, and has won first place in the "Hydrogen Fuel Cell Prototype“ category in 2017, 2018, 2019 and 2022. All vehicles compete in their respective categories, on a racecourse of approximately 16 km to determine the most efficient vehicle. The course must be completed at an average speed of 25 km/h in a given time. The vehicle with the lowest fuel consumption wins the race.

Our team improved gradually each year and in 2016 took second place with the result of 2029 km with one litre of gasoline equivalent. In 2017, with the new very light ThaiGer VI race car (23 kg), the team improved again and took first place ahead of the team from Turin, which is sponsored by Ferrari. A significant weight reduction was achieved by a new monocoque frame made of carbon fibre and the power train was revised, too. In the first victory in 2017, hydrogen consumption was 17.8 litres, which corresponds to 880.5 km with one cubic meter of hydrogen or a range of over 2600 km with one litre of gasoline equivalent. The ThaiGer VI also competed in the following two years, 2018 and 2019, and again performed exceptionally well in 2019 with 1083 km/m^3 of hydrogen, comparable to a range of 3295 km with one litre of gasoline equivalent.

After the Corona break, the ThaiGer team returned to Nogaro (France) as defending champions in 2022. The goal of becoming European champion for the fourth time in a row was achieved with an excellent result. For the 2022 Shell Eco-marathon in Nogaro, the team developed a new vehicle the ThaiGer 7. The monocoque frame was made completely of carbon prepreg. Compared to its predecessor it was now 25 cm shorter, its weight was reduced, and the aerodynamic behaviour was improved. The new design of the ThaiGer 7 vehicle is striking, reflecting the function of the fuel cell. The front part of the vehicle features hydrogen and oxygen molecules, which are torn into individual atoms by the blue lightning bolts. After releasing energy, the atoms then connect to form water at the rear of the vehicle.

In addition, the fuel cell system was particularly optimized to achieve higher efficiency. The fuel cell itself is constructed from bipolar plates and membranes that were purchased externally. The end plates for the FC stack were developed by the team and are made of carbon. The fuel cell is the main energy supplier in the vehicle and is supported by a small supercap battery. Furthermore, the membrane pumps for the air supply were replaced by a self-developed, more efficient side channel blower. Moreover, a two-phase cooling system for the fuel cell was developed and manufactured as part of a bachelor’s thesis. In contrast to the old water cooling system, the new cooling system does not require a circulating pump, which has made it possible to reduce self-consumption and weight. The race car is propelled by a highly efficient permanent magnet axial BLDC motor (brushless DC motor) which was developed and manufactured as part of the team's project and a final thesis. The motor is integrated into the rear wheel, which is made of carbon. Due to the construction method and the renouncement of iron package, an efficiency of over 95% could be obtained.

Figure 7: ThaiGer-Team with ThaiGer 7 in 2022

A new pressure reducer (see fig. 8) was also designed for the race, which won the Technical Innovation Award. The Technical Innovation Award is presented as an off-track award alongside the main race. The device reduces the pressure of hydrogen from a gas cylinder with 200 bar to the 0.3 bar which constitutes the pressure required for the fuel cell. The two-stage pressure reducer is equipped with two pressure relief valves as well as a solenoid valve and pressure display. Weighing roughly 300 grams, the pressure reducer is much lighter and more compact than conventional fittings.

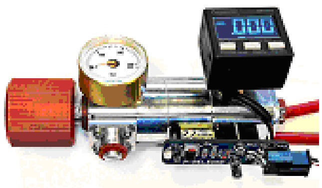

Figure 8: New pressure reducer (own development) of the ThaiGer 7

This development certainly contributed to the victory. But just as important in the end, however, was the team spirit and its close cooperation. With 1118 km/m³ of hydrogen, the ThaiGer-H2-Racing team won the European championship title for Stralsund and was far ahead of the second-place team, H2politO from Italy's Politecnico Di Torino, which achieved 899 km/m³ of hydrogen. The hydrogen category is considered the supreme discipline of the competition and requires a great deal of skill and know-how. Thus, out of the twelve teams that competed in this category, only five teams managed at least one valid scoring run.

5.2. GreenDrive

Collaboration with local schools has long been proven to motivate pupils to get involved in green technology and new mobility concepts, as well as to study at our university later on. For example, since 2016, students from the ThaiGer team have been supporting the "Greendrive" school team from the secondary school "Schulzentrum am Sund". Their goal was to compete in the Shell Eco-marathon with a battery electric vehicle in the "Prototype Battery Electric" category. The pupils who developed the car in collaboration with Stralsund University of Applied Sciences were delighted to come in fourth this year with a result of 682.9km/kWh.

The ten pupils normally come to the university once a week for two hours with a supervising teacher. Just before the Shell Eco-marathon, they were present more often, naturally, including Saturdays. The student team was founded in 2016 and first converted the old vehicle, the ThaiGer V, to an all-electric drive. Putting it into practice, the team participated in its first race at the Challenge Event in Le Mans, France in 2017. The Challenge Event is a small-scale Shell Eco-marathon for new teams and is also organized by Shell. The Greendrive team was able to qualify for the big Shell Eco-marathon the following year in 2018. The school team was able to repeat that success in 2019 and 2022. In 2022, the pupils competed with the same monocoque frame as the ThaiGer7 but with green flashes and wheels. The vehicle is powered by a small lithium polymer (LiPo) battery. The weight of the entire vehicle is 18 kg. This made it the lightest vehicle competing in the Shell Eco-marathon by far. It is even 4 kg lighter than ThaiGer 7 because the fuel cell system, hydrogen bottle, supercap battery etc. were replaced by one small battery. Furthermore, the same wheel hub motor was used as in ThaiGer 7. The motor, which is already in its third generation, was largely manufactured by the pupils themselves as part of a MINT project. The precision of the manufacturing process was improved compared to the old motor, which made it possible to reduce the air gap between the magnets and the winding and increase efficiency. Compared to 2019 in London, the result was improved by 10 km/kWh on a much more challenging racetrack in Nogaro. A total of 25 teams registered in this category and 17 teams managed at least one scoring run. [Greendrive, 2022]

6. Summary

Various factors play a role in the education of students in the use of renewable energy sources, PtX technologies, smart grids, and electric mobility. On the one hand, this includes the acquisition of suitable teaching staff, sufficient laboratory equipment as well as practical research and cooperation with regional industry. Nonetheless, the interaction of all stakeholders involved to enhance the motivation of the students is an equally significant aspect. The education of students, research, industrial cooperation with regional partners and public commitment should be developed at the same time in a sustainable way, as all aspects involved mutually benefit each other. By using equipment created or acquired through research projects in teaching, from publicly funded research equipment to self-made prototypes and small test beds, costs can be minimized and additional experience can be gained for the next steps in the process of research. Students being responsible for their own projects as well as laboratory training on all available equipment embedded in all educational programs, enable practical training and promote student and lecturer motivation. Due to the early entry into PtH and PtP technology in research and teaching 30 years ago, the Stralsund University of Applied Sciences was able to provide many impulses for industrial use and the training of engineers in the field of PtX technologies.

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