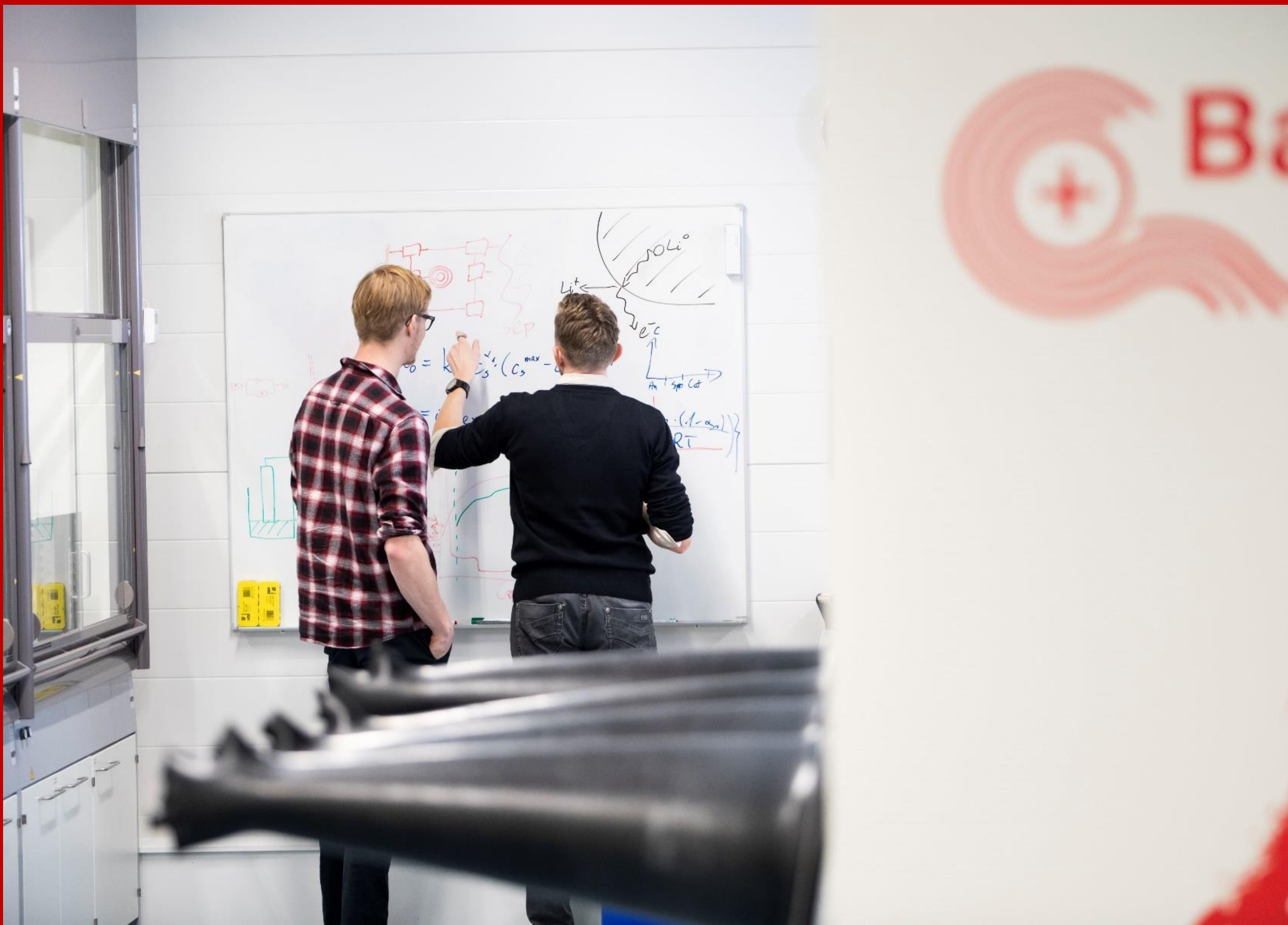
Battery Education

Renewable Energy – Specialization: Battery Technology



UiA University of Agder

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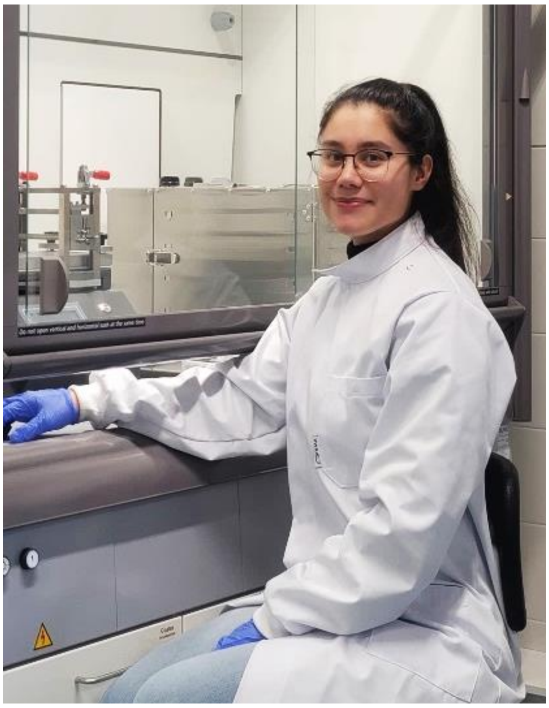
Introduction

Battery energy storage is a key aspect in the transition from fossil fuel-based energy to renewable energy. In the last decade, Norway has positioned itself as a global leader in the electrification of the automotive sector, which showcases the public interest and support for environmentally friendly mobility. However, the production of rechargeable batteries including lithium-ion batteries, and the processing of the necessary raw materials present challenging engineering problems as well as requiring large amounts of energy. Sustainable hydroelectricity in Norway lays the foundation for a battery production industry with a small carbon footprint. Additionally, the Agder region and the south of Norway more broadly have a long tradition of industrial activity and access to many key materials to produce lithium-ion batteries. Established local industry players as well as newcomers have recognized the potential of the region and are investing in a green battery value chain in the south of Norway, the Battery Coast.

Already, local industry in the Battery Coast creates job opportunities for engineers and scientists from diverse educational backgrounds, a trend that will continue for years to come. In Grimstad, the Department of Engineering Sciences at the University of Agder is implementing a new battery education programme to complement the growing industry in the region. Existing battery expertise at UiA is broadened within the university's Battery Coast strategy: the foundation for the new interdisciplinary education on *Battery Technology*.



Cecilie Chakram-Nybru
Bachelor Student (Battery Technology Specialization)

“UiA's Renewable Energy and Battery Technology programme offers hands-on learning with competent professors, practical lab work, and valuable internship opportunities. This high-quality program enabled me to secure an internship at Morrow Batteries, gaining experience in cell testing and data analysis. For future battery innovators, UiA is the answer!”

Educational Approach

Battery technology is a multidisciplinary field; a successful battery engineer must simultaneously be a chemist, an electrical engineer, a physicist, a data scientist, a mechanical engineer, and an entrepreneur. Studying *Battery Technology* at the University of Agder combines these fields into an interdisciplinary programme where every student can develop individual strengths according to their interests. In addition to a strong technical education, the study programme can be complemented with critical examinations of the ethics of battery production and economic considerations.

Engineering education at the University of Agder has a strong emphasis on application. In the *Battery Technology* programme, theory is combined with laboratory-based courses, giving students practical hands-on experience. In the new battery laboratories at campus Grimstad, students will be able to assemble and investigate their own battery cells in similar environment to an industrial research and development laboratory.

The emerging industry in the Battery Coast brings the possibility for student projects with local companies, including thesis projects and industrial internships. Here, students will tackle real research and development questions. The proximity to companies across the battery value chain allows students to interact with possible future employers during their studies. By including experts and professionals in industry insights lectures and topic-specific guest lectures, battery knowledge that goes beyond the textbook will be accessible. This allows students to establish connections and learn about working in the battery industry.

Trond Erik Aagestad
Alumni (Battery Technology Specialization)

"During my master's project with Battery Coast and Vianode, I explored carbonization in sodium-ion batteries, gaining hands-on lab skills and research experience. Now, at Vianode, I am enhancing graphite fast-charge capabilities for lithium-ion cells. This journey has fuelled my passion for advancing battery technology and practical, impactful innovation"

BSc and MSc Curricula

Becoming a Renewable Energy Battery Technology Expert

Battery Technology is one possible specialization within the Renewable Energy programme at the University of Agder. The first two semesters at the bachelor's level are common courses for all Renewable Energy Students that provides the basis for the various specializations: (I) Electrical Engineering, (II) Energy Technology, and (III) *Battery Technology* (see Table 1). Focused battery content starts in the third semester and is fortified in in-depth laboratory courses in the fourth semester. Semester five gives the students the possibility to personalize their education, either within UiA by choosing their curriculum from a broad variety of elective courses, or through national or international exchange programmes. Graduating bachelor's students will have gained the fundamental skillset of a renewable energy engineer as well as experience in explaining, building, and analysing batteries. The bachelor's education covers the entire battery value chain from material characterization to battery cell testing and analysis to recycling and sustainability.

At the master's level, the specialization in *Battery Technology* extends foundational battery knowledge to understand fundamental electrochemical processes and physics-based simulations of batteries. Students learn how battery cells are built into full systems and how these are safely operated. A highlight of the Master's program is the project-based simulation laboratory in which students will design a virtual battery that is optimized for a specific use-case (e.g., boat, drone, smartphone). At the end of their *Battery Technology* master's study the students will have a detailed understanding of the underlying electrochemical processes in batteries and their implications on battery design and control in practical applications.

Table 1. The curriculum of the Renewable Energy programme with the specialization in *Battery Technology* at bachelor's and master's levels. Click on the individual courses for more information and find details on the novel courses (in bold letters) in the section Course Description.

Bachelor	1	Mathematics 1	Programming and ICT Security	Circuit Analysis	Energy Laboratory	Tech. Environment and Sustainability
	2	Mathematics 2	Physics	Electronic Circuits	Renewable Energy	Thermodynamics
	3	Mathematics 3	Statistics	**Batteries**	**Battery Industry Insights**	Elective Course
	4	Modern System Instrumentation	Technical Drawing	**Battery Laboratory**	Materials and Corrosion	
	5	Elective Courses				
	6	Bachelor's Thesis				
Master	1	**Battery Systems**	Power Electronics for Renewable Energy	Elective Courses		
	2	**Introduction to Battery Simulation**	**Electrochemistry of Batteries**	Data Analysis and Modelling in Renewable Energy	Smart Grid Systems	
	3	**Physics-based battery models**	Energy Research Project	Elective Courses		
	4	Master's Thesis				

Basic Sciences	*Electronics*	*Renewables*	*Chemistry*	*Batteries*	*Economy*

Customize your Curriculum

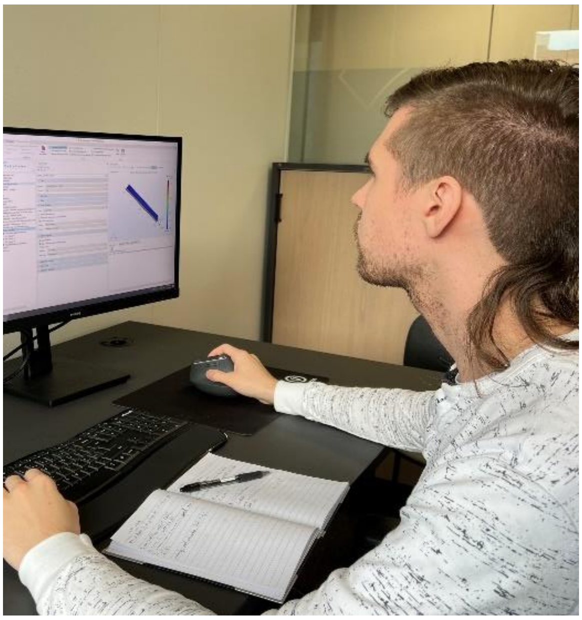
Out of the total 180 credits for the bachelor's degree, 65 can be elected or actively shaped by the students. By offering elective courses the entire 5th semester this is the ideal timespan for students to broaden their horizon, internally or at another international university. Gaining international experience can be an ideal preparation for working in an internationally oriented battery industry and many universities offer highly relevant courses for the aspiring battery engineer:

- RWTH Aachen, Germany
- University of California at Berkley, USA
- University of Oxford, United Kingdom
- Technical University of Munich, Germany
- Massachusetts Institute of Techn., USA
- University of Michigan, USA
- Pennsylvania State University, USA

Students may feel their education is too academic. Elective Research and Development projects allow them to establish connections with the battery industry and work on small, well-defined real-life problems, which may even lead to a thesis project. At the master's level more than half of the credits can be customized to match every student's preferences, strengths, and interests. This allows them to develop their personal path to becoming a battery engineer, but of course we have great course suggestions should one be unsure.

Maybe a student wants to extend the curriculum with a specific lecture from another university but does not want to spend an entire semester abroad? Select courses from Norwegian Universities which are taught virtually can be part of the elective courses as well.

An overview of the elective courses can be found on the following page and can be used to assemble one's own personal curriculum.



Svenas Burba
Master Student (Battery Technology Specialization)

"Optimize battery performance with proven expertise! At UiA's Battery Technology education programme, I developed advanced modeling skills that streamline battery manufacturing processes. Now, as a Morrow intern, I apply my hands-on experience to create thermal and electrochemical models that replace costly experiments with efficient simulations—accelerating battery manufacturing and innovation."

Elective Courses

B,M - Recommended BSc and MSc courses.

Interdisciplinary

5 sp	7,5 sp	10 sp
3D Design M	Mathematics 4 B	General Chemistry B
Material Technology		Mechanics
Microcontrollers		Research and Development Project B,M
		Object-oriented programming
		Programming Project

Electronics

7,5 sp	10 sp
Power Electronics	Low Voltage and High Voltage Technology
Feedback Control Systems B	

Renewable Energy

5 sp	7,5 sp	10 sp
Solar Energy Systems	Solar Cell Technology and Applications	Mathematical Modelling of Batteries (UiS)
Wind Power	Wind Energy	
Hydro Power	Fluid Dynamics and Hydro Power	
Fuel Cells and Redox Flow	Hydrogen, Battery, and Thermoelectric Technologies M	
Bioenergy	Bioenergy	
	Combined Heat and Power Systems	

Economy

7,5 sp	10 sp
Corporate Finance and Economics	Practical Entrepreneurship
	Co-creation – Theory and Practice
	MyMachine – Project Management from Idea to Prototype

Customize your Curriculum

Bachelor – 35 sp Elective Courses
5. Semester

Master – 22,5 sp Elective Courses
1. and 3. Semester

UiA Battery Coast Professors

Faculty members at the Battery Coast combine diverse research backgrounds and world-class expertise in many aspects of battery research and development. At the new Battery Research Centre at Campus Grimstad, Battery Coast members are working on research projects to answer important questions in the field of batteries and contributing to growing the educational competence at UiA.

Johannes Landesfeind
Associate Professor,
Materials and Electrochemistry
Group Leader, Battery Technology

Johannes has experience in lithium-ion battery research from the Technical University of Munich and the Tokyo University of Science. As a battery researcher at Hilti he worked on the development and optimization of next-generation high-power battery cells.

At the University of Agder he combines his experience from academia and industry to create and shape strong competencies in battery education, development, and research at the Battery Coast.

Williams Appiah
Associate Professor,
Battery Simulation

Williams has experience in battery modelling and simulation research from DGIST, South Korea (PhD) and Technical University of Denmark (Postdoc). His research activities focus on merging fundamental science and engineering applications of electrochemical devices such as lithium ion and next-generation batteries. At the University of Agder, he combines his research and teaching experience to educate and inspire the next generation in battery technology, conducts battery research and design modelling tools to accelerate battery development at the Battery Coast.

Eric Logan
Associate Professor,
Commercial cell design

Eric researches the aging and degradation of rechargeable batteries using both established and novel methods. He completed a PhD in Physics at Dalhousie University, Canada, and worked as a cell materials engineer at Tesla in Berlin, Germany qualifying anode electrode materials for mass production. At the University of Agder, Eric conducts research that aims to deconvolute complex processes in battery cell operation and aging.

Gunstein Skomedal
Associate Professor (20%)
Materials

Gunstein researches a range of materials that convert energy from one form to another and which are the backbone of a future fully electrified society. He is concerned with sustainable production and use of materials to work towards a more resource- and energy-efficient future. In addition to his position at UiA, Gunstein is a Research Manager at Vianode, based in Kristiansand, Norway.

Johannes Wandt
Associate Professor (20%)
Degradation

Johannes is interested in Lithium/Sodium-ion cell technology with focus on cell ageing, development of novel characterisation techniques, and the interplay of cell design, mechanics and material chemistry. In addition to his position at UiA, he is a Battery Specialist focusing on Fast Energy, Lifetime, and Power for BMW Group in Munich, Germany.

Course Descriptions

Batteries

Bachelor Semester 3

Autumn | 7,5 cr

Learning The course objective is to equip students with an in-depth understanding of common types of batteries. After passing this course students will be able to explain what happens inside a battery during operation, what its key components are, and how different active materials affect the function of batteries. Participants can calculate the key properties of battery materials and battery cells and know how they can be characterized experimentally. They will be able to review which battery technologies are suitable for which application and what dominates their degradation in the intended use case. Furthermore, students will be able to assess the safety risks of lithium-ion battery materials and cells and know how to handle them safely.

Contents

1. Battery history
2. Galvanic cells and electrochemical series
3. NiMH and lead-acid batteries
4. Setup of a lithium-ion battery
5. Active materials for lithium-ion batteries
6. Cell designs and balancing
7. Degradation and side reactions
8. Battery testing
9. Safety aspects and mitigation strategies
10. Next-generation batteries

Methods 3 h lectures 3 h exercise

Evaluation (graded A-F) Portfolio evaluation

Teachers Johannes Landesfeind

Language English

Battery Industry Insights

Bachelor Semester 3

Autumn — 5 cr

Learning	Firstly, use-case specific application scenarios for lithium-ion batteries are examined and students will learn the implications the intended application has on the selection of battery materials and cell designs. Second in a small mini-series the students will be introduced to current industrial aspects of the battery value chain. This will allow them to better envision what it takes to become a successful battery engineer. Lastly the participants of the course will take a tour with local battery industry partners to see their operation in action.
Contents	1. Lithium-ion batteries in application a. Maritime b. Electric vehicles c. Medical applications d. Mobile devices e. Tools and drones 2. Insights from the battery industry, e.g. a. Raw material production for batteries b. Lithium-ion batteries in electric vehicles c. Challenges in the production of batteries d. Industrial viewpoint on next generation cells 3. Battery industry tour
Methods	5x workshop days — exercises included
Evaluation (graded A-F)	Portfolio evaluation
Teachers	Gunstein Skomedal, Johannes Wandt, guest lecturers
Language	English

Battery Laboratory

Bachelor Semester 4

Spring

10 cr

Learning	In this practical course, the students will benefit from hands-on work in UiA's top-class electrochemical laboratories and will gain first-hand experience handling and operating battery research equipment. Students will learn how to perform and analyze experimental results critically and report their findings in a concise report. This includes the ability to properly depict their results in tables and figures as well as the assessment of equipment and measurement uncertainties in the interpretation of their results. Practically, the students will be able to assemble their own battery, apply previously learned safety procedures and analyze their own data. Working on the experiments in groups makes this course a lively experience teaching not only science but also project management and team communication. The course will be supervised by PhD students from the battery research group, allowing students to establish close relationships with the battery research team and learn from experienced battery researchers.
Contents	The course consists of six experiments to be conducted in the battery laboratories at UiA in small student groups in a rotation scheme. A brief oral examination before the groups start each experiment increases safety awareness. Each experimental procedure and result are summarized in a written laboratory report. 1. Measuring a rod with in-depth error analysis 2. Effects of microstructure on ionic transport 3. Lithium-ion battery electrode preparation 4. Laboratory cell preparation and testing 5. Analysis of a commercial cell 6. Commercial cell testing
Methods	6 laboratory experiments/group work
Evaluation (graded A-F)	Laboratory reports
Teachers	Eric Logan, PhD students
Language	English

Battery Systems

Master Semester 1

Autumn | 7,5 cr

Learning In this course, students will learn about the integration of single battery cells into larger systems and how to control these safely and optimally in the intended application. After successful completion, the participants of the course will know the requirements for a safe operation of interconnected battery cells in modules or on a system level. This includes the physical setup as well as electronic safety measures and online measurements. Control algorithms for specific use-cases, such as fast charging in electric vehicles, or system-level optimizations for, e.g., peak shaving applications are critically analyzed in lectures and exercises. After this course, students will have the skills to design battery systems for specific applications, and evaluate design choices on the basis of cost, performance, and safety. Lecture material will be supplemented by computational exercises to simulate the performance of connected battery systems and demonstrate various control algorithms.

Contents

1. Battery cell design
2. Integration of cells into battery packs/modules
3. Thermal management systems
4. State estimation (state of charge, state of health, temperature)
5. Cell balancing
6. Charging routines
7. Safety measures
8. Battery applications (EV, maritime, home storage, wearables etc.)

Methods 3 h Lectures | 3 h exercises

Evaluation (graded A-F) Portfolio Evaluation

Teachers Eric Logan, guest lecturers from industry

Language English

Electrochemistry of Batteries

Master Semester 2

Spring

7,5 cr

Learning

Electrochemical of Batteries extend the knowledge-based understanding of batteries from the bachelor's level courses to a more fundamental understanding of underlying processes in electrochemical devices. This is essential to follow and interpret the parallel running course on *Battery Simulation* and the subsequent practical simulation course. After course completion, the students will understand the details of ionic transport and potentials in electrochemical devices. They can calculate the properties of electrolyte systems and know how their properties limit practically the operation of batteries or other electrochemical storage devices. Due to practical examples in the exercises, the students can apply their knowledge when characterizing battery components electrochemically. Participants are expected to have a solid understanding of mathematical calculus.

Contents

1. Impedance spectroscopy
2. Electrochemical potential
3. Activity coefficients
4. Reference electrodes
5. Liquid junction potentials
6. Electric double-layer
7. Electrode kinetics
8. Dilute solutions
9. Concentrated solutions
10. Mass transfer in electrochemical systems
11. Limiting current and microelectrodes
12. Concentration overpotential
13. Porous electrodes

Methods 4 h lectures 2 h exercise

Evaluation (graded A-F) Portfolio evaluation

Teachers Johannes Landesfeind

Language English

Introduction to Battery Simulation

Master Semester 2

Spring | 7,5 cr

Learning In close alignment with the parallel running course *Electrochemistry of Batteries*, the module *Introduction to Battery Simulation* condenses physical principles into functioning battery models. Students will benefit from a brief introduction to utilized computational environments (Matlab, Comsol, Python) and gain their first experience in working with these tools in the exercises. This course provides students with understanding and necessary toolsets to be able to understand and model the physical effects in batteries by themselves. The approach from simplified model systems to detailed, physically based simulations give the students a broad basis and an in-depth understanding of possibilities as well as limitations of the different types of modelling approaches.

Contents

1. Overview of battery simulations – from DFT to ECMs
2. Equivalent circuit modelling (Theory)
3. Equivalent circuit modeling (Application)
4. Single particle model (Theory)
5. Single particle model (Application)

Methods 3 h lectures 3 h computational exercise

Evaluation (graded A-F) Portfolio evaluation and oral exam

Teachers Williams Appiah

Language English

Physics-based battery models

Master Semester 3

Autumn 7,5 cr

Learning	In this application-oriented module, the students will learn how to design and model a battery for an exemplary use case (e.g., electric vehicle, boat, mobile phone). The model tasks are executed in groups and are based on previously gained knowledge about battery components and working principles of electrochemical devices and advanced battery simulation models. After course completion, the students will be able to develop a battery for a specific application (choice of materials and cell designs) and can design a physics-based model for isothermal and thermal processes in batteries. The students will be able to explain and visualize bottlenecking processes in batteries during operation based on physics-based simulation models and understand how cell design adoptions impact the operation of the virtual battery.
Contents	The course is structured into five model tasks. For each task, the student groups have 2-3 weeks which includes the preparation of a brief report and the documentation of their model results. 1. Porous electrode model (Theory) 2. Porous electrode model (Application) 3. Thermal modeling and application to cylindrical and prismatic cells 4. Development of cell design for an application
Methods	3 h lectures 3 h computational exercise
Evaluation (graded A-F)	Portfolio evaluation and oral exam
Teachers	Williams Appiah
Language	English

Battery Coast

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