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D8.6 Teaching Materials

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Version History

Version	Date	Author	Organisation	Description
1.0	29-05-2019	RSW	UBHAM	first draft
2.1	29-04-2020	RSW	UBHAM	final amendments and edits
2.2	01-07-2020	JH	PNO Consultants	Addition of statements below in response to EC request for revision: Copyright Disclaimer & Acknowledgement As provided by UBHAM
3.0	24-08-2020	RSW	UBHAM	Sample slides and references to UBHAM educational pages and MOOCs added References added to other educational projects UBHAM participates in

Statement of originality:

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Glossary

CDT	Centre for Doctoral Training, UK-specific funding scheme for PhD training
credits	UK system of credits, generally 2 credits = 1 ECTS
ECTS	European Credit Transfer System
EPSRC	Engineering and Physical Sciences Research Council (UK)
JESS	Joint European Summer School on Fuel Cell, Electrolyser, and Battery Technologies, annual event evolving from the TrainHy project (2010-2012)
module	Set of lectures gaining a student a specific number of credits, e.g. 5 ECTS
MOOC	Massive Open Online Course
MRes	Master of Research
MSc	Master of Science
PhD	Doctor of Philosophy (also 'Dr.')
Programme	Study programme earning a student a degree
SOC	Solid Oxide Cell
SOFC	Solid Oxide Fuel Cell
Supergen	UK strategic research programme: SUsustainable Power GENeration
UKRI	UK Research & Innovation

1 Introduction

In the course of the HEATSTACK project UBHAM has used output from the project for purposes of education, training, and knowledge exchange.

UBHAM is and has been involved in a number of educational activities, starting with the FCH JU funded projects TrainHy (2010-2012) and KnowHy (2014-2018), the current TeachHy (2017-2020), up to the UKRI (EPSRC) funded Supergen H2FC Hub network. UBHAM has developed a full curriculum for all topics relevant to Fuel Cell and Hydrogen (FCH) teaching within TrainHy that has been further used to set up the syllabus within TeachHy, a project aiming at establishing a transferrable educational programme for an MSc course across Europe. KnowHy was aimed at professional training for technicians, using, amongst others, 'Serious Games' concepts, that have now been integrated into the TeachHy programme and expanded to virtual laboratory access. Within the H2FC Hub project, UBAHM has been developing an educational portal that will allow visitors to access the results and services of the various educational projects mentioned previously, as well as the programmes (PhD/CDT, MRes, MSC etc.) the university itself offers.

This deliverable gives an overview of the various elements that have been developed. Part of the activities have already been reported in Deliverable 8.5 (Bruges Workshop report) or are available online as educational material (MOOC's on the UBHAM web site educational portal).

2 Teaching Materials Development

2.1 Integration of HEATSTACK results into university teaching material

UBHAM runs a comprehensive educational programme covering the topics of Fuel Cell and Hydrogen technologies. This includes

- the Centre for Doctoral Training in Fuel Cells and their Fuels (funded by the UK ESPRC under contract no. EP/L015749/1),
- MSc course in Fuel Cell and Hydrogen Technologies (TeachHy project funded by the EU via the FCH 2 JU under contract no. 779730),

In addition, there are a large number of modules taught in 2nd, 3rd, and 4th Year of the general Chemical Engineering programme that refer to Fuel Cell and Hydrogen technologies. As they touch upon issues of energy storage and electrochemical conversion, these will include information derived from the UBAHM work in HEATSTACK in the modules

- Sustainable Process Engineering (2nd Year ChemEng students),
- Advanced Energy Technologies (MSc in Global Energy Technology & Systems, and 4th Year ChemEng students).

The Centre for Doctoral Training in Fuel Cells and their Fuels (CDT) at the University of Birmingham (UoB) runs several modules related to high temperature fuel cells (SOFC, SOE, SOC, and rSOC), covering aspects of materials design and characterisation, degradation/corrosion, and systems design. The syllabus of the introductory module is attached as Annex 1. This module is also offered for 4th Year Chemical Engineering students, and as a TeachHy module 'Fuel Cell Technologies' (potentially also for online delivery).

Results from HEATSTACK have been incorporated in the following lectures:

- High Temperature Fuel Cells
- Reversible Fuel Cells
- Fuel Cell Systems
- Degradation and Lifetime Issues.

The EU project TeachHy, coordinated by UBHAM is developing an online MSc course in Fuel Cells and Hydrogen Technologies which includes lectures and modules from the above programme and on SOC and Fuel Cell and Electrolyser Systems where input from HEATSTACK is being integrated.

Sample slides can be found in Annex 2.

2.2 Knowledge exchange activities

Within the annual Bruges Workshop on Fuel Cell Systems on 21/22 May 2019, a special session was held on the outcomes of the HEATSTACK project with presentations given by SunFire, Senior Flexonics, ICI Caldaei, and University of Birmingham. The programme is attached here as Annex 3.

Copies of the HEATSTACK presentations to the workshop will be published on the HEATSTACK website and have been compiled in Deliverable D8.5.

UBHAM runs an educational portal on Fuel Cell and Hydrogen Technologies that links to the above projects (funded by the UK EPSRC under contract no. EP/P024807/1, [1]) currently being established under

<https://www.birmingham.ac.uk/research/activity/chemical-engineering/energy-chemical/fuel-cells/education-training/education-and-training.aspx>

This page links to the various activities UBHAM is conducting, mostly also mentioned in this deliverable. Fig. 1 shows the page layout and the links to the various educational offerings.


One of the items is the section facing the public and offering Massive Open Online Courses (MOOCs), small 'video' type lectures that explain topics and issues around fuel cell and hydrogen technology. They are made for the more or less technically savvy or interested public. Three MOOCs related to HEATSTACK project output have been developed


- Fuel Cell Systems explained
- Heat exchangers in High Temperature Fuel Cell systems
- Issues of heat exchangers in High Temperature Fuel Cell systems

Sample slides have been included in Annex 4. The actual MOOCs can be found under the above link in the MOOC section.

In a next step these MOOCs will be staged into a set of lectures that can be taken in order to receive a 'mini degree' (upon a to-be-defined assessment), an activity undertaken together with the T.I.M.E. network of worldwide universities sharing into energy education.

UBAHM is also part of a professional training activity continuing from the now completed KnowHy project (funded by the EU via the FCH 2 JU under contract no. 314685). KnowHy offers several short courses aimed at Technicians in order to inform and instruct them on fuel cell (system) details. The courses consist of a basic module that is combined with more specialised material on Fuel Cell Systems, Fuel Cell Vehicles, Fuel Cell CHP etc. The novelty of this approach was the blended learning structure and the integration of 'serious games' elements for laboratory experience building. The final day of the course is taken face-to-face as a real world laboratory training and exam day. HEATSTACK information has been integrated into the fuel cell system topics.


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Fig. 1: UBHAM page offering access to the various educational programmes, including material developed from HEATSTACK work.



2.3 Integration of HEATSTACK results into non-university education and training

The Joint European Summer School in Fuel Cell, Electrolyser, and Battery Technologies (JESS, originating from the EU project TrainHy [2], funded by the EU via the FCH JU under contract no. 256703) is an annual event organised by UBHAM in cooperation with Forschungszentrum Jülich (DE), The Danish National Technical university (DTU), and University of Ulster (UK).

Within the JESS programme, HEATSTACK input has been integrated into the lectures on high temperature system components. Lectures H.07 and H.11, given by a member of the SunFire management, include first-hand results from materials characterisation and the application of heat exchangers in SOC systems. The title page from the programme brochure acknowledging the HEATSTACK contributions and the syllabus for the SOC module is attached as Annex 5 and 6.

3 References

- [1] C.Stockford, N.Brandon, I.Metcalf, J.Irvine, T.Mays, D.Book, V.Molkov, A.Kucernak, N.Shah, R.Steinberger-Wilckens, P.Dodds, A.Dueso, S.Samsatli, C.Thompson: H₂FC SUPERGEN: An Overview of the Hydrogen and Fuel Cell Research Across the UK. IJHE 40 (2015) 5534-5543. Scopus EID: 2-s2.0-84937232544.
- [2] R.Steinberger-Wilckens, S.Linderoth, A.Dahoe, J.Mertens, S.Reiners: European Curriculum in Fuel Cells and Hydrogen. European Fuel Cell Forum, Lucerne, 2-5 July 2013.

4 Annex

4.1 Syllabus of the module Fuel Cell Technology within the CDT and TeachHy programmes at University of Birmingham

Module	26222	Fuel Cell Technologies	
	coordinator	Prof Robert Steinberger-Wilckens	Autumn Term 2019/20
Monday	21-Oct		
09:00	09:30	Welcome and General Introduction	Robert Steinberger-Wilckens
09:30	11:00	Sustainable and Renewable Energy Future	Robert Steinberger-Wilckens
11:00	11:30	break	
11:30	13:00	Introduction to Coursework	Robert Steinberger-Wilckens
13:00	14:00	lunch break	
14:00	16:00	A basic introduction to Electrochemistry and Thermodynamics	Neil Rees
Tuesday	22-Oct		
09:00	11:00	Low Temperature Fuel Cells	Yousif Al-Sagheer
11:00	11:30	break	
11:30	13:00	High Temperature Fuel Cells	Artur Majewski
13:00	14:00	lunch break	
14:00	16:00	Reversible Fuel Cells	Artur Majewski
Wednes.	23-Oct		
09:00	11:00	Fuel Cell Systems	Robert Steinberger-Wilckens
11:00	11:30	break	
11:30	13:00	Fuel Cell Applications	Robert Steinberger-Wilckens
13:00	14:00	lunch break	
14:00	16:00	Lab Tour (Meet in front of G6: fuel cell lab)	Yang Li
Thursday	24-Oct		
09:00	11:00	Fuels for Fuel Cells	Robert Steinberger-Wilckens
11:00	11:30	break	
11:30	13:00	Tutorial	Peter Mardle
13:00	14:00	lunch break	
14:00	16:00	Degradation and Lifetime Issues	Robert Steinberger-Wilckens
Friday	25-Oct		
09:00	11:00	Marketing Fuel Cells	Robert Steinberger-Wilckens
11:00	11:30	break	
11:30	13:00	Outlook and Closing Remarks	Robert Steinberger-Wilckens
13:00	14:00	lunch break	
14:00		end of module	


4.2 Sample Slides of the Fuel Cell Technology module of UBHAM and TeachHy

Module 26222
Fuel Cell Technologies

Autumn term 2019/20


Fuel Cell Systems
23 Oct. 2019

Prof Dr Robert Steinberger-Wilckens
Centre for Fuel Cell & Hydrogen Research
University of Birmingham




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TeachHy



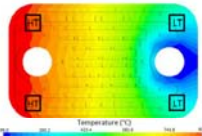

Impact of HX Operating Conditions

- temperature gradients induce mechanical stress on heat exchanger components
- differences in temperature lead to differences in oxide scale evolution
- this will impact both on the longevity of the heat exchangers, as well as the volatile chromium compounds transferring into the SOC stack



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TeachHy

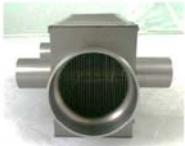
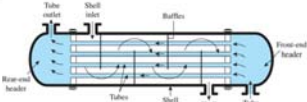



High Temperature Heat Exchangers

Due to higher temperatures often designed as


- 'tube in tube'
- 'shell in tube' exchangers.

More compact design and transfer are very forming

Sources: www.thomas.net, senior flexionics

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TeachHy

Thanks for your Attention!

Any Questions?



Acknowledgments go to the various sources of images and figures and to the partners in the HEATSTACK project for provision of materials. HEATSTACK was supported by the European Union's H2020 programme through the Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement no. 700564



23/10/2019

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Slide 76/76



4.3 Programme of the HEATSTACK session at the Bruges Fuel Cell System Workshop 21/22 May 2019

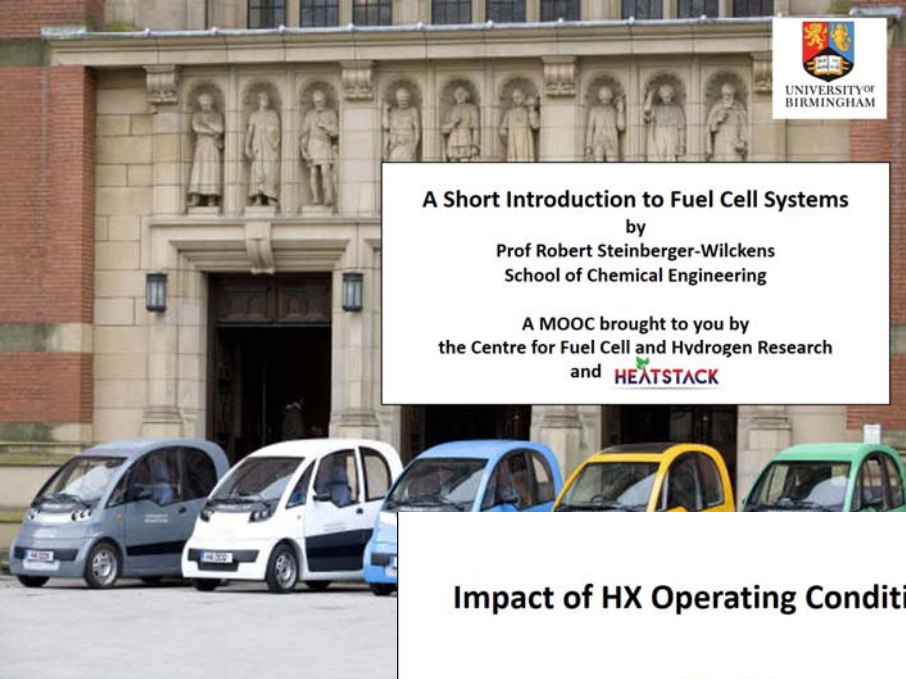
Tuesday , 21 May 2019	
8:30 – 8:55	Registration and uploading of presentations
FC System Technical Details	
9:00 – 9:30	SOC systems for PtX applications: a process engineering perspective – <i>Sanchit Gupta, DLR</i>
9:30 – 10:00	Fuel cells for heavy-duty vehicles in Europe: an insight into both legislative and technical challenges – <i>Marcus Taylor, University of Birmingham</i>
10:00 – 10:30	Cooling with Heat – <i>Bhargav Pandya, University of Birmingham</i>
10:30 – 11:00	Coffee Break
11:00– 11:30	Thermo-sensing of SOFCs – <i>Jung-Sik Kim, University of Loughborough</i>
FC System Components / HEATSTACK results	
11:30 – 12:30	Design and manufacture of Cathode Air Pre-Heaters – <i>Charlie Penny, Senior Flexonics</i>
12:30 – 14:00	Lunch
14:00 – 14:30	Gas/Gas heat exchanger for process intensification – <i>Carlo Tregambe, ICI Caldaie</i>
14:30 – 15:00	Status of the development and manufacturing of Sunfire-Home – <i>Tobias Seidel, Sunfire</i>
15:00 – 15:30	Coffee break
15:30 – 16:00	Chromium release and corrosion on SOFC heat exchangers – <i>Kun Zhang, University of Birmingham</i>

16:30	<i>Historium Museum Tour</i>
18:00	<i>Dinner at restaurant</i>

Wednesday , 22 May 2019	
8:30 – 8:55	<i>Registration and uploading of presentations</i>
Fuels for Fuel Cells: Biogas, syngas, and synthetic fuels	
9:00 – 10:00	Experience with a biogas fuelled SOFC: DEMOSOFC – <i>Massimo Santarelli, Politecnico di Torino</i>
10:00 – 10:30	Operation Experience With a Novel Highly Efficient Mirco-Scale SOFC CHP System Based on Biomass Gasification – <i>Nikolaus Soukup, AVL.</i>
10:30 – 11:00	<i>Coffee break</i>
11:00 - 11:30	Gas processing for Gasifier-SOFC systems - <i>Alessandro Cavalli, TU Delft</i>
11:30 - 12:00	A P2G concept for Indonesia – <i>Artur Majewski, University of Birmingham</i>
12:00 – 13:30	<i>Lunch</i>
13:30	Coffee and End of Meeting

4.4 Sample slides from the MOOCs developed within the HEATSTACK project

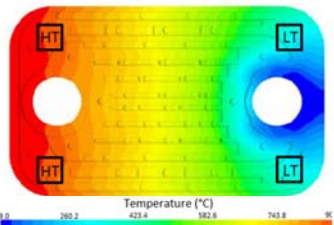
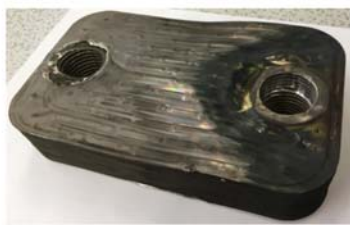


A Short Introduction to Fuel Cell Systems
by
Prof Robert Steinberger-Wilckens
School of Chemical Engineering

A MOOC brought to you by
the Centre for Fuel Cell and Hydrogen Research
and **HEATSTACK**


Impact of HX Operating Conditions

- temperature gradients induce mechanical stress on heat exchanger components
- differences in temperature lead to differences in oxide scale evolution
- this will impact both on the





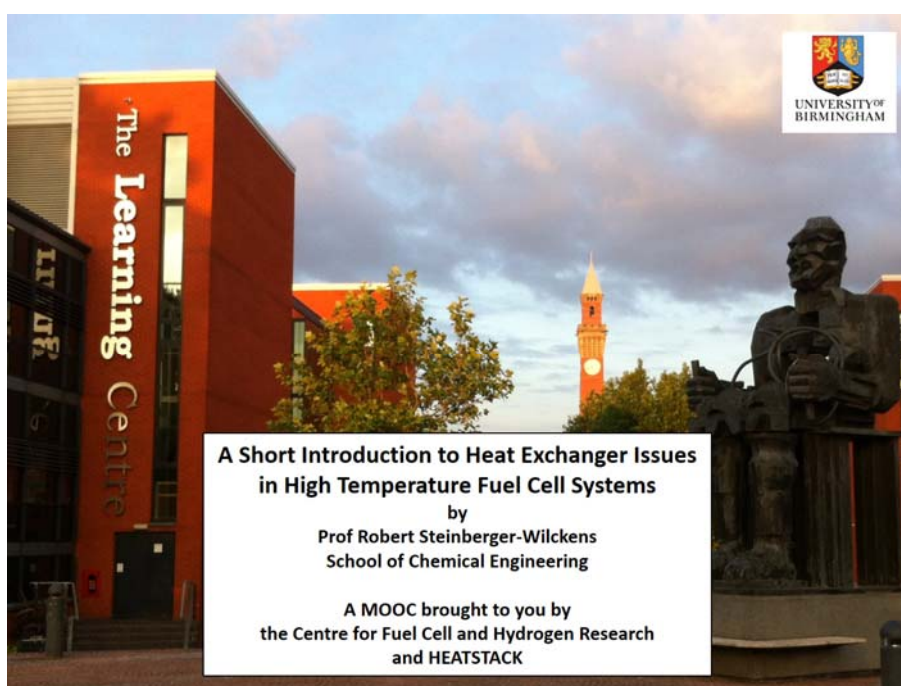
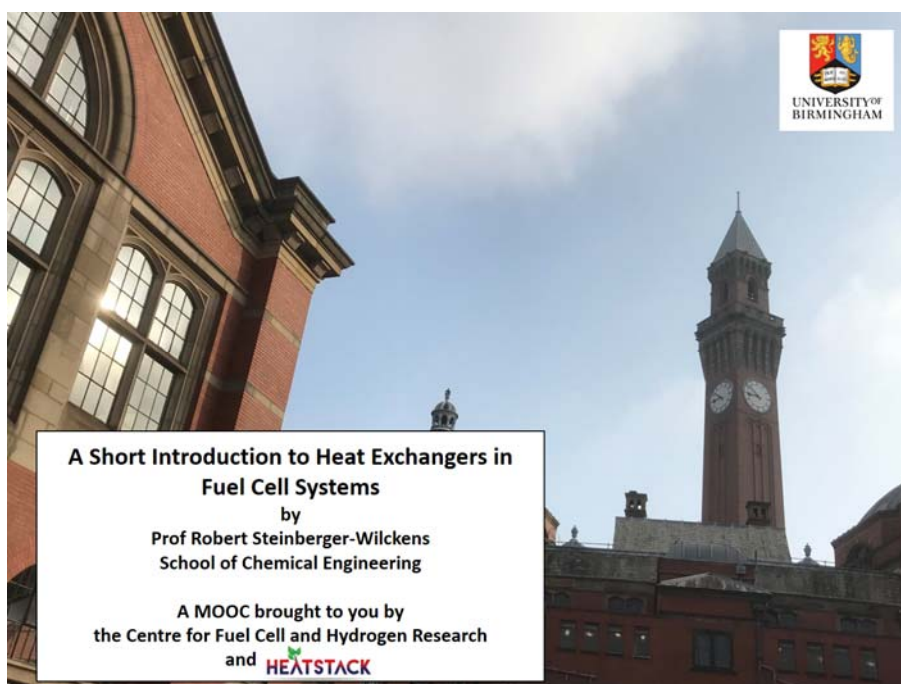
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4.5 JESS programme brochure acknowledgments



*Joint European Summer School on Fuel Cell,
Electrolyser, and Battery Technologies
JESS 2019*

*Week 1 - Introductory Courses
16 – 20 September 2019*

*Hotel Amarilia,
Vouliagmeni, Athens, Greece*



sponsored by



4.6 JESS syllabus on SOC

JESS 2018		High Temperature Fuel Cells and Electrolysers (SOFC and SOE)	final programme last changed 12/09/18
		P ... plenary lectures (all students), St ... student presentations, HT ... specialised lectures, HL ... high & low temperature courses	
Monday	10/09/2018		
P.01	08:30	Welcome and General Introduction	Jens Oluf Jensen (DTU)
	09:00	Sustainable and Renewable Energy Future	Jens Oluf Jensen (DTU)
	09:45	coffee break	
P.02	10:00	Introduction to Fuel Cells and Electrolysis	Shangfeng Du (U Bham)
	11:15	break	
P.03	11:30	Thermodynamics and Efficiency of Electrochemical Cells	Jens Oluf Jensen (DTU)
	13:00	lunch	
P.04	16:00	Introduction to Batteries	Hans Kungl (FZJ)
	17:30	coffee break	
P.05	18:00	Introduction to Solid State Chemistry & Ionics	Ico Vinke (FZJ)
P.06	19:30	Introduction to the Students' Project	Shangfeng Du (U Bham)
	19:45	welcome reception (bar)	
	20:15	dinner	
St.01	21:15	Students' Introductions I	Lars Cleemann (DTU) / Josef Mertens (FZJ)
Tuesday	11/09/2018		
HT.01	08:30	Electrolyte Materials for SOFC / SOEC	Artur Majewski (U Bham)
	09:45	coffee break	
HT.02	10:00	Fuel Electrode Materials for SOFC / SOEC	Artur Majewski (U Bham)
	11:15	break	
HT.03	11:30	Air Electrode and Contact Layer Materials for SOFC / SOEC	Artur Majewski (U Bham)
	13:00	lunch	
P.07	16:00	Characterisation Methods for Fuel Cell, Electrolyser and Battery Materials	Shangfeng Du (U Bham)
	17:15	coffee break	
P.08	17:30	Exercise on Characterisation, Electrochemistry and Thermodynamics	Shangfeng Du (U Bham)
	18:45	break	
St.02	19:00	Students' Introductions II	Lars Cleemann (DTU) / Josef Mertens (FZJ)
	20:30	dinner	
Wednesday	12/09/2018		
HT.04	08:30	Cell and Stack Designs for SOFC / SOEC	Ico Vinke (FZJ)
	09:45	coffee break	
HT.05	10:00	Manufacturing of SOFC / SOEC	Ico Vinke (FZJ)
	11:15	break	
HT.06	11:30	Exercise on Materials / Design	Ico Vinke (FZJ)
	13:00	lunch	
	15:00	excursion	
	21:00	dinner	
Thursday	13/09/2018		
P.09	08:30	Atomistic Modelling in fuel cell, electrolyser and battery research	Ivano Castelli (DTU)
	09:45	coffee break	
HT.07	10:00	System Technology for SOFC	Ico Vinke (FZJ)
	11:15	break	
HT.08	11:30	Degradation in SOFC / SOEC	Anke Hagen (DTU)
	13:00	lunch	
HT.09	16:00	Exercise on Degradation	Anke Hagen (DTU)
	17:00	coffee break	
HT.10	17:15	Exercise on System Technology	Robert Steinberger-Wilckens (U Bham)
	18:30	break	
St.03	18:45	Student project time	n/a
	20:00	dinner	
Friday	14/09/2018		
HT.11	08:30	System Technology for SOEC	Oliver Posdziech (SunFire)
	09:45	coffee break	
HT.12	10:00	New Trends in SOFC / SOEC	Anke Hagen (DTU)
	11:15	break	
HL.01	11:30	Power to Gas, Fuels and Chemicals	Oliver Posdziech (SunFire)
	13:00	lunch	
St.04	16:00	Optional ECTS exams	
	17:00	coffee break	
St.05	17:15	Students' Project Presentations	Robert Steinberger-Wilckens (U Bham)
	18:45	break	
P.10	19:00	Farewell	Robert Steinberger-Wilckens (U Bham)
	20:30	gala dinner	