Grant agreement number: 779730

WP9 Administration and Project Management

D9.2 Industry advisory board training needs document

Due date: 28/02/2018

Lead participant name: UBHAM

List of contributors: Industrial Advisory Board

Status: F (Final, updated)

Dissemination level: PU (Public)

Last updated:

30/07/2018

(revision 30/11/2019)

Document History

Issue Date	Version	Changes Made/Comments
30/07/2018	1.0	MoM of meeting in Lucerne
30/06/2019	2.0	edits and re-formatting
30/11/2019	3.0	Revision following mid-term review Report on KIC Innoenergy interaction
20/07/2021	3.1	EU funding statement update as per review request

Disclaimer and Acknowledgment:

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 779730. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe research.

Any opinions expressed in this report are solely those of the authors and neither of the FCH 2 JU, nor the European Commission or its representatives.

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About TeacHy

As the FCHT industry gradually emerges into the markets, the need for trained staff becomes more pressing. TeacHy2020, or short TeacHy, specifically addresses the supply of undergraduate and graduate education (BEng/BSc, MEng/MSc, PhD etc.) in fuel cell and hydrogen technologies (FCHT) across Europe.

TeacHy2020 will take a lead in building a repository of university grade educational material, and design and run an MSc course in FCHT, accessible to students from all parts of Europe. To achieve this, the project has assembled a core group of highly experienced institutions working with a network of associate partners (universities, vocational training bodies, industry, and networks). TeacHy offers these partners access to its educational material and the use of the MSc course modules available on the TeacHy site. Any university being able to offer 20 to 30% of the course content locally, can draw on the other 80 to 70% to be supplied by the project (and its successor entity that will support the platform post-project).

This will allow any institution to participate in this European initiative with a minimised local investment. TeacHy will be developing solutions to accreditation and quality control of courses, and support student and industry staff mobility by giving access to placements. Schemes of Continuous Professional Development (CPD) will be integrated into the project activities. We expect a considerable leverage effect which will specifically enable countries with a notable lack of expertise, not only in Eastern Europe, to quickly be able to form a national body of experts.

TeacHy will offer some educational material for the general public (e.g. MOOC's), build a business model to continue operations post-project, and as such act as a single-stop shop and representative for all matters of European university and vocational training in FCHT. The project partnership covers the prevalent languages and educational systems in Europe. The associated network has over 70 partners, including two IPHE countries, and a strong link to IPHE activities in education.

Deliverables Abstract

This deliverable summarises the discussions that took place between the TeacHy project and the Industrial Advisory Board between Nov. 2017 and July 2018. They were targeted at defining education and training goals as seen by the Advisory Board and aligning them with the project developments.

Outcomes of these discussions were used to focus and refine the project activities in WP 1, 2, and 3.

In the revision details have been updated and the interaction with the KIC Innoenergy included.

1 Questionnaire

1.1 Data gathering procedure

In order to align the project activities, mostly based on an academic view of student education, with the outside view of industry and various stakeholders, the Advisory Board was created in TeacHy to gather feedback on results and have a sounding board for key and critical project developments.

In early 2018 a questionnaire was therefore developed and distributed to the Advisory Board members for feedback. The results were then discussed at a face-to-face meeting in the context of the 2018 Lucerne SOFC Forum conference and further evidence collected.

1.2 Questionaire content

The questionnaire had a total of 4 questions and a subsequent area for general feedback.

The questionnaire is documented in Annex 2.

It centred around four main topics:

1. Assessment of Training Needs
2. Assessment of Training Format
3. Assessment of Training Content
4. Assessment of overall project

to which the responding members of the Advisory Board offered feedback and commentary.

Responses were received from

- Prof Jürgen Garche, IPHE topical lead for Education,
- Dr Laurent Antoni, Chair Hydrogen Europe Research,
- Dr Birgit Thoben, Global Innovation Manager, Bosch,
- Dr Michael Spirig, Director European Fuel Cell Forum,
- Dr Bernard Frois, CNRS, Member of the FCH JU State Representative Group.

In the following the responses have been summarised, also including any diverging opinions, and an attempt been made to draw unambiguous conclusions for project progress.

Responses have been recorded without revealing the sources in order to retain a level of privacy.

2 Questionnaire Outcome

2.1 Section 1: Training Needs

2.1.1 Question 1: Order of magnitude of HR market

The following main responses were given to the human resources estimates in the table provided:

> I think it's idle to find more accurate numbers. Surely you can improve the numbers from today's perspective (2018), e.g. number of FCEVs in 2030 is not 0.5 M but maybe 2 M (according to IEA) - but the important message from 2012 remains, that we need a lot more workers, technicians and engineers in the H2&FC area, and in the order of magnitude as estimated. In that sense, I would not necessarily want to change the numbers, because the 2012 message still remains.
>
> The number of FCV for 2020 (in 2 years) seems rather high - 30'000 estimated, for 2030 (in 12 years) rather low – 2 Mio estimated (10-15% market share after break through); the values for the other technologies would appear similarly skewed.
>
> The numbers in the first table give an impression of overestimation. The general development might be a good estimation. I would partly assume higher numbers, but keep in mind electrical vehicle are easier to build than combustion engine vehicles. And a lot of jobs will be taken over by robots 2030 ff. These numbers should be updated taking into account the last Mc Kinsey report for the Hydrogen Council. An estimation for the employment could be to use the ratio
> - 1 Full Time Employee per 150 k€ of Turnover
> - 20% engineers, 30% technicians, 50% workers.
>
> The technical and cost advances i.e. market success/political push of the HybridV and BEV will have an impact on the FCV launch - it is a remaining uncertainty for the breakthrough.
>
> The number of SMEs in 2030 seems rather too low - I do not believe that all R&D and manufacturing will occur in large companies.

Conclusion:

The numbers are more or less accepted as a first estimate with the full market entry (again) pushed back slightly, though with more ambitious goals in 2030.

As a result the number of trainees will appear to be in the ball park given by the table provided from the SET-Plan Education. This development will require substantial training and educational initiatives with a specific emphasis of in-job training for scientists, engineers and worker already in work.

2.1.2 Question 2: Comprehensiveness of the TeacHy offering

Did participants think that above MSc course, modules for CPD use, and single modules integrated into various educational programmes anything was missed?

> I think the MSc course level as "master" is fine. For lower level courses the teacher can use the MSc "master" material by individual extractions. For higher level courses (PhD) additional material the teacher has individual to extend the basic MSc material.
>
> A system should be found that allows to upload all individual variations (lower and higher level) from the MSc "master". Other lecturers can then use this pool freely. Maybe based on the pool later additional lower and higher level educational programmes could be elaborated.
>
> The modules could also be sold on training platforms or at online universities. An APP, e.g. like „busuu", combined with online-exams should be considered.
>
> The aspect of practical training (in-lab) is absolutely necessary.
>
> why only focus on uni - e.g. also middle scool etc (ok when reading the next question)?
>
> - CPD will be very important - due to grow of new jobs (replacing old job profiles)
>
> persons have to further educate

Conclusion:

The laboratory work will need to be an essential part of the curriculum. Ways have to be found to make this possible in the blended learning format (e.g. work by POLITO).

Modules should be easily adaptable to other training needs than MSc or be suitable for various levels with specialisation elements added where needed.

Whether or not to adapt to smart phone technology is questionable due to the additional effort and risk introduced by changing technologies and platforms, and the reduced format (screen space available). Could maybe introduce an App format for overall course management by the students.

2.1.3 Question 3: Could there be other (better) ways of supplying FCH training than an MSc course?

For instance by supplying lower level training or more MOOC-type material:

> I agree with the MSc course concept.
>
> But please keep the scientific level high and combined practical experience. This is necessary to support the technology. In my point of view a BSc will in general be too low a qualification.
>
> Include evening course format with lower level than MSc?

Conclusion:

Continue with MSc level material with the option of downgrading or developing elements that can be combined to satisfy different levels (additive elements for higher levels of education/ degree). The MOOC format will also satisfy general public use.

Again, place considerable emphasis on delivering the practical element of training.

An intensive discussion was held with Torsten Fransson, retired professor from KTH who is involved in the KIC Innoenergy. He is part of establishing a ‘micromaster’ within the KIC which in essence consists of freely available short MOOCs that as a whole could be assessed and lead to some sort of certificate.

It was not immediately clear

- how this approach would match the stringent quality requirements of an MSc degree and/or
- how the quality assurance in the context of a university granting a degree based on such elements would be realised;
- who and how a degree would be awarded and by whom and how the assessment would be arranged;
- how a long-term sustainable operation could be achieved without a financial contribution from either universities, or other educational (e.g. involved in Continuous Professional Development, CPD, schemes), or governmental bodies, or via industry sponsorships.

From the examples inspected it appeared doubtful that a university would accept the level of expertise for an MSc level course.

Nevertheless, it was agreed to continue the discussion and explore the options to exchange teaching materials, link each others’ pages and explore synergies, e.g. in referencing each other and using each others’ free material in the publicly accessible parts of the web pages.

2.1.4 Question 4: Priorisation of the high-level topics list (see Annex 2).

Advisory Board members were asked to give their opinion on the importance of the topical headlines comprising the syllabus.

The ranking to be used was: 1 = essential, important; 2 = useful; 3 = less important; X = can be deleted.

The results are presented on the following page (ranking in first column).

The following additional comments were received:

> Will electrolyser technology be included in topic 2.2?
> (response: in view of the increasing importance of electrolysers in the clean energy transition and the advent of reversible fuel cell technology, the titles and content of modules have been adapted to place more emphasis on electrolysis and cover fuel cell and electrolyser technology jointly where suitable).
>
> A module with practical work (lab experience) has to be added
> (response: has been done in the current syllabus).
>
> The topics are too focused on Fuel Cells. Specific technical modules have to be integrated on
>
> - Electrolysis (low and high temperature)
> - Hydrogen Storage (compressed, solid, cryo-liquid, liquid (LOHC, NH3…))
> - Transectorial system integration
> - Eco-design may be integrated into LCA chapter
> - Diagnostics/Prognostics may be integrated in the modelling chapter
>
> To interest newcomers in the FCH field, some more contextual lecture may be integrated on
>
> - Role of H2, a flexible energy vector, in the energy transition
> - Supply Chain/value chain description
>
> Topics should be expanded to include projects, markets & programmes not only in the EU, but also US/Canada, Japan, S.Korea, some modules are too EU oriented.

Conclusions:

The ‘history’ element curiously drew very disparate ranking. A similar result was presented for the ‘policy’ element.

‘Modelling’ and technical details of ‘non-PEFC low temperature fuel cell technology’ were assessed as slightly less important.

The consortium sees its choice of headlines in the syllabus confirmed and has made the lower ranking elements optional modules. The exception is the ‘Modelling’ module that has now been combined with the topic of ‘control’ and is generally believed to be of substantial importance.

In order to take the additional topic comments on board, the syllabus headlines were revised to include the above comments.

	1. Fundamental modules	
1/1/2/1/1	1.1.	THERMODYNAMICS AND ELECTROCHEMISTRY
2/1/2/1/1	1.2.	CHARACTERISATION METHODS
2/1/1/1/1	1.3.	BASIC PROPERTIES OF HYDROGEN
1/1/1/1/1	1.4.	TYPES OF FUEL CELLS
2/2/2/1/3	1.5.	MODELLING
3/1/1/3/2	1.6.	Technology History
	2. Applied modules	
1/1/1/1/1	2.1.	APPLICATIONS OF FUEL CELLS AND HYDROGEN
1/1/1/1/1	2.2.	HYDROGEN TECHNOLOGY
2/1/2/2/1	2.3.	OTHER FUELS FOR FUEL CELLS
1/1/1/2/1	2.4.	INTRODUCTION TO LOW TEMPERATURE FUEL CELLS (PEFC, HT-PEFC, AFC, PAFC, DMFC)
1/1/1/2/2	2.5.	POLYMER ELECTROLYTE FUEL CELLS (PEFC)
2/1/2/3/2	2.6.	OTHER LOW TEMPERATURE FUEL CELLS
1/1/1/1/1	2.7.	INTRODUCTION TO HIGH TEMPERATURE FUEL CELLS (SOFC, MCFC)
1/1/1/1/2	2.8.	SOLID OXIDE FUEL CELL (SOFC)
1/1/2/2/2	2.9.	MOLTEN CARBONATE FUEL CELLS (MCFC)
2/1/1/1/1	2.10.	HIGH TEMPERATURE FUEL CELL SYSTEMS AND SYSTEM COMPONENTS
1/1/1/1/2	2.11.	FUEL CELL AND ELECTROLYSER CHARACTERISATION METHODS (Materials characterisation cf. 1.2)
1/1/1/1/1	2.12.	SAFETY OF HYDROGEN
1/1/1/2/1	2.13.	SAFETY IN FUEL CELL TECHNOLOGY
2/1/2/1/1	2.14.	REGULATIONS, CODES & STANDARDS FOR FUEL CELLS AND HYDROGEN APPLICATION
3/1/1/3/3	2.15.	EUROPEAN & INTERNATIONAL FCH POLITICS
2/1/2/1/2	2.16.	LIFE CYCLE ANALYSIS, RECYCLING & ENVIRONMENTAL ISSUES
1/1/2/-/2	2.17.	MARKET AND BUSINESS DEVELOPMENT

2.1.5 Question 5: Confirmation of the overall project scope

The consortium wished to receive a final free format comment on the opinion on the overall project content and objectives.

> The project is quite important. I like it. The scope of the project seems to me to go into the right direction. This project is of great importance to ensure highly qualified jobs in Europe and to attract young people in the field of FCH.
>
> The programme seems to me at this stage exhaustive and perhaps too detailed. It would be better to uncover a little than to cover a lot.
>
> The practical work with hydrogen technologies is one of the important educational tasks. Therefore: not too much theory, but more practical work: installing and repairing, security, and manufacturing systems and components. I miss the practical knowledge part. No student will be able to build a fuel cell only based on theoretical background. Additional a certain time frame for work inside a fuel cell lab is necessary or an exchange with industry cooperation combine with a practical part.
>
> I would suggest to describe what the student is supposed to have learned after having followed this course. What practical knowledge will be associated with this course? (response: this is an essential part of the module planning, i.e. defining the learning outcome, and is included in all module preparation forms).
>
> Proposals for additions to the IPHE University Partners:
>
> IPHE 3 – Prof. Yong-Gun Shul, Yonsei University, S. Korea, shulyg@yonsei.ac.kr
>
> IPHE 4 - Prof. Mu PAN, Wuhan University of Technology, China, panmu@whut.edu.cn
>
> Both are willing to work in the project as a kind of associated partner. I have both informed that no money will need to be provided from the project for their project contribution. More partners could be recruited by contacting especially French universities.
>
> Ensure a good complementarity with KnowHy outcomes.
>
> Translation of the documents in many (if not all) European languages is important to ensure a broad audience.

Conclusions:

Overall, the scope, aims, and objectives of the project were confirmed.

The suggestions for an additional Associate Partner network will be followed up.

The project aims at translating into as many languages as feasible.

UBHAM is setting up an e-learning portal that will also allow access to the KnowHy programme, besides TeacHy, the JESS Summer School, a set of MOOCs and possibly some general public information.

This portal is now accessible at:

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

Annex 1: Invitation letter

The TeacHy project:

Teaching Fuel Cell and Hydrogen Science and Engineering Across Europe within Horizon 2020

Dear colleague,

the TeacHy project we contacted you about in March/April 2017 has been awarded a grant by the FCH 2 JU and has started working on 1 Nov 2017.

One of the first tasks is to confirm the membership of the Advisory Board and its preliminary terms of reference. We therefore kindly request you to check on the here attached documents and confirm (or reject) your future involvement in the project. Please respond within the next seven days whether you wish to remain involved in this activity.

TeacHy will establish a European university Masters course in Fuel Cell and Hydrogen technology offering universities that want to cooperate the option to run approx. 30% of the course as face-to-face modules locally and be able to rely on the further 70% delivered by the project through e-learning. In this way we want to empower European universities to teach these subjects even if they are not sufficiently equipped locally. The only further prerequisite – apart from becoming part of the project network – will be the responsibility for the local certification of the course and final examination. The project partnership consists of 12 universities from across the EU and from Ukraine with ample experience in teaching subjects from electrochemistry to fuel cell engineering.

The Advisory Board will help us to introduce an outside, preferably non-academic perspective to our work and especially support us in defining the learning outcome required from the course. The first step in your work with us is therefore a response to the questionnaire you will find attached. We kindly ask you to share your thoughts with us. It should not take more than 30 minutes to fill in the questionnaire.

We will be calling in meetings of the Advisory Board only when necessary and – due to everyone's busy schedules – try to limit face-to-face meetings. Due to the budgetary constraints training initiatives seem to always attract at the level of funding, we will only be able to pay your travel expenses in exceptional circumstances. We would – if possible – rely on your affiliated institutions and companies to support the project by covering your travel costs and working time. If this is not possible we will of course cover expenses or revert to web conference hosting.

It remains to wish you a very Happy and Successful New Year 2018 and express our gratitude to your involvement in our project.

with kind regards from

the whole project consortium and

the project coordinator, Prof Robert Steinberger-Wilckens

Annex 2: Questionaire

The following pages document the questionnaire as it was sent out to the Advisory Board members.

The TeacHy project:

Initial Advisory Board Questionnaire:

Assessment of training needs

(1) In 2012, the SET-Plan Education group on Fuel Cell & Hydrogen technology came up with the following table of trained personnel requirements estimated up to the year 2030. It collects numbers for (trained) workers, technicians, and engineers (including scientists).

Question: would you agree on the numbers mentioned or do you have another opinion?
Is there anything strikingly wrong about the estimates (number of companies in specific sections etc.) that might positively or negatively influence the numbers stated?

2012									
	Est. annual production		**Market value**	**CAGR**	**Number of companies involved**		**Employment**		
Application area	**Unit**		**(M€)**		**SMEs**	**Large companies**	**Workers**	**Technicians**	**Engineers**
Fuel cell electric vehicles	#	100	5	---	10	8	250	750	1500
Hydrogen refuelling stations	#	20	20	---	10	5	133	133	133
Hydrogen Production	ton	895	9	---	15	5	447	447	447
Stationary fuel cells	#	50	2	---	18	5	83	83	83
Early markets - forklifts	#	300	4	---	18	6	25	25	25
Early markets - power generation	#	500	1,2	---	18	5	25	25	25
TOTAL			**41**				**964**	**1464**	**2214**

2020									
	Est. annual production		**Market value**	**CAGR**	**Number of companies involved**		**Employment**		
Application area	**Unit**		**(M€)**	**2012-2020**	**SMEs**	**Large companies**	**Workers**	**Technicians**	**Engineers**
Fuel cell electric vehicles	#	100 000	3 000	45%	5	12	12 500	6 250	6 250
Hydrogen refuelling infrastructure	#	150	135	12%	3	7	750	750	750
Hydrogen Production	ton	145 447	1 164	32%	10	10	4 848	4 800	4 800
Stationary fuel cells	#	50 000	625	45%	10	7	5 000	5 000	5 000
Early markets - forklifts	#	10 000	100	21%	10	8	417	417	417
Early markets - power generation	#	20 000	28	22%	10	7	208	208	208
TOTAL			**5 052**	**30%**			**23 723**	**17 425**	**17 425**

2030									
	Est. annual production		**Market value**	**CAGR**	**Number of companies involved**		**Employment**		
Application area	**Unit**		**(M€)**	**2020-2030**	**SMEs**	**Large companies**	**Workers**	**Technicians**	**Engineers**
Fuel cell electric vehicles	#	500 000	12 500	7%	2	15	62 500	31 250	31 250
Hydrogen refuelling infrastructure	#	300	420	3%	3	7	2 250	1 125	1 125
Hydrogen Production	ton	425 635	3 405	5%	5	10	11 350	11 237	11 237
Stationary fuel cells	#	150 000	1 500	5%	5	8	11 250	5 625	5 625
Early markets - forklifts	#	30 000	240	5%	5	8	1 000	1 000	1 000
Early markets - power generation	#	30 000	42	2%	5	8	500	500	500
TOTAL			**18 107**	**7%**			**88 850**	**50 737**	**50 737**

<u>Assessment of Training Format</u>

(2) TeacHy will be offering an e-learning platform for partner universities to access. The material supplied will be the modules that make up a full MSc course. A 'module' is equivalent to a conventional university 'lecture' – that can be delivered 'long and thin' (i.e. regular lessons every week of term), or 'short and fat' (a full week of lectures) – just to make this more graphical since the timing is of no issue when working with e-learning.
Besides using the full course, partners will be able to access single modules to integrate into other teaching activities (apart from the TeacHy courses). The project will also open up to Continuous Professional Development (CPD) schemes. In this way we also include a 'lower level' participation apart from the full involvement in the MSc course structure.
Is there any other level missing in this concept?

(3) TeacHy in principle addresses the 'academic' training pathways of BEng/BSc/MEng/MSc (also including PhD) but will primarily concentrate on an MSc type course of (finally) 18 months duration. This should target the need in training technicians (depending on national educational system definitions) and engineers (including scientists). The project KnowHy has already built a training programme for non-academic 'technicians' that is part-based on e-learning, part on practical training seminars.
Having 100,000 trained staff available in 2030 means (as an example) 200 universities across Europe have to start training in 2020 with 50 students each enrolled each year (just to indicate the challenge we are potentially facing).
Do you agree that an MSc course will be suitable to specifically spread high-level, specialised FCH2 knowledge or would there be better ways of doing this?

Assessment of Training Content

(4) In the following you will find the major headlines of the TrainHy curriculum – a result of the TrainHy project run from 2010 to 2012. It lists all (?) main topics that could theoretically be taught on any FCH2 course – which would probably be hopelessly overladen. It may well be that partner universities chose to place their emphasis on slightly different specialisations – which might be a welcome development.
What is your view on the priority of the topics listed below? Please indicate your views by a
1 = essential, important
2 = useful
3 = less important
X = can be deleted
in the first column of the table.

This list only comprises of the main headlines to save you work.

You can get an impression of the full detail with an example on the next but one page.

Assessment of Training Content (Table)

	1. Fundamental modules	
	1.1.	THERMODYNAMICS AND ELECTROCHEMISTRY
	1.2.	CHARACTERISATION METHODS
	1.3.	BASIC PROPERTIES OF HYDROGEN
	1.4.	TYPES OF FUEL CELLS
	1.5.	MODELLING
	1.6.	Technology History
	2. Applied modules	
	2.1.	APPLICATIONS OF FUEL CELLS AND HYDROGEN
	2.2.	HYDROGEN TECHNOLOGY
	2.3.	OTHER FUELS FOR FUEL CELLS
	2.4.	INTRODUCTION TO LOW TEMPERATURE FUEL CELLS (PEFC, HT-PEFC, AFC, PAFC, DMFC)
	2.5.	POLYMER ELECTROLYTE FUEL CELLS (PEFC)
	2.6.	OTHER LOW TEMPERATURE FUEL CELLS
	2.7.	INTRODUCTION TO HIGH TEMPERATURE FUEL CELLS (SOFC, MCFC)
	2.8.	SOLID OXIDE FUEL CELL (SOFC)
	2.9.	MOLTEN CARBONATE FUEL CELLS (MCFC)
	2.10.	HIGH TEMPERATURE FUEL CELL SYSTEMS AND SYSTEM COMPONENTS
	2.11.	FUEL CELL AND ELECTROLYSER CHARACTERISATION METHODS (Materials characterisation cf. 1.2)
	2.12.	SAFETY OF HYDROGEN
	2.13.	SAFETY IN FUEL CELL TECHNOLOGY
	2.14.	REGULATIONS, CODES & STANDARDS FOR FUEL CELLS AND HYDROGEN APPLICATION
	2.15.	EUROPEAN & INTERNATIONAL FCH POLITICS
	2.16.	LIFE CYCLE ANALYSIS, RECYCLING & ENVIRONMENTAL ISSUES
	2.17.	MARKET AND BUSINESS DEVELOPMENT

Assessment of Training Content (ctd)

For information: Example of detailed curriculum

The list of topics under a numbered headline can be considered as the titles of a slide set covering this headline area. Level 2 and 3 numbering would then refer to a single lecture or part of a lecture, depending on scope.

2.5. POLYMER ELECTROLYTE FUEL CELLS (PEFC)
2.5.1. First principles
Electrode reactions, triple phase boundary, ion conduction in electrolyte, operating temperature and regimes, fuel gases
2.5.2. Low-Temperature PEFC
2.5.2.1. Membranes
materials, physical properties, protonic conductivity, water uptake, water transport, water management, gas permeation
2.5.2.2. Electrodes
Catalysis & catalysts, materials, structures, water management
2.5.2.3. MEA availability and performance
Design and performance of commercially available membranes and MEA's
2.5.2.4. MEA degradation mechanisms
Catalyst corrosion/particle growth, support corrosion, loss of hydrophobicity, OCV condition, load cycles, freeze-thaw cycles
2.5.3. High-Temperature PEFC (HT-PEFC)
2.5.3.1. Background and principles
Relative CO tolerance, heat rejection advantages, development background and history, manufacturers
2.5.3.2. Membranes
PBI, PFSA-based, TPS, PEEK, casting, doping, mechanical properties, conductivity, modifications (curing, cross-linking, blends, polymer modifications), phosphoric acid chemistry.
2.5.3.3. Electrodes
Catalysis & catalysts, structure, materials
2.5.3.4. MEA availability and performance
Design and performance of commercially available membranes and MEA's, CO tolerance
2.5.3.5. MEA degradation mechanisms
Acid loss, catalyst corrosion/particle growth, support corrosion, loss of hydrophobicity, OCV condition, catalyst poisoning
2.5.4. MEA's and MEA design
2.5.4.1. Geometries
Maximum cell size, MEA thickness considerations, design targets
2.5.4.2. Manufacturing methods
2.5.4.2.1. Membrane manufacturing
Tape casting, extruding
2.5.4.2.2. MEA manufacturing
Calendaring, spraying, painting, printing of layers
2.5.5. Stack components and design
2.5.5.1. Stack components
2.5.5.1.1. Gas Diffusion Layer
Materials, treatments and coatings, porosity, electrical conductivity, compressibility, permeability
2.5.5.1.2. Bipolar Plates
materials, properties, corrosion and coatings, shape and orientation of flow field, configuration of flow fields(shape, dimensions, and spacing), pressure drop
2.5.5.2. Stack Configuration
Manifolding, uniform distribution of reactants within stack, sealants, clamping
2.5.5.3. Heat Removal from a Fuel Cell Stack
Stack Heat Balance, Heat Conduction, Active Heat Removal, Heat Dissipation from the Stack by Natural Convection and Radiation, Alternative Stack Cooling Options
2.5.5.4. Sizing and layout of a Fuel Cell Stack
2.5.5.5. Manufacturing stacks
2.5.6. Systems and system components

2.5.6.1. Hydrogen supply
Pressure regulation, purity of fuel , impurities, humidification, anode gas recycling, fuel utilisation

2.5.6.2. Hydrocarbon fuel processors for PEFC systems
Basic Processes and Reactions, methane and propane reforming, gas processing and cleanup, water gas shift, fine cleaning, purity requirements

2.5.6.3. Heat management
Cooling (air, cathode air, liquids), useful heat extraction, heat recycling, heat exchangers, afterburners

2.5.6.4. Hydrogen–Oxygen Systems
Oxygen Supply, water and heat management

2.5.6.5. Hydrogen–Air Systems
Air supply, blowers and compressors, passive air supply, water and heat management

2.5.6.6. Electrical Subsystem
DC/DC converters, DC/AC converters, connection to DC systems (e.g. vehicles), connection to AC systems (e.g. grid, UPS etc.)

2.5.6.7. Designing systems
Design targets, system sizing and layout, efficiency, Sankey digrams and system components losses, system integration, simplification vs. high efficiency: mobile and stationary designs, system optimisation

2.5.6.8. Stack and system degradation mechanisms
Deactivation, catalyst poisoning, carbon corrosion, BiP corrosion, load cycling, thermal cycling, rapid start-up, standby, freezing, vibration

2.5.7. Applications and history

2.5.7.1. Brief introduction to PEFC history

2.5.7.2. Vehicles
Passenger (Daimler/NECAR 3+4 and f-cell, Nissan, Toyota, Honda, GM, Ford, VW, Opel, Fiat, etc.), buses (Ballard, Evobus, CUTE project, Van Hool etc.), light utility (GM, Energy Partners, NECAR 1+2), forklift trucks and freight handlers (Linde, etc.), small vehicles (golf carts etc.), concept cars (Toyota, GM HyWire)

2.5.7.3. Space craft

2.5.7.4. Stationary applications: CHP
Ballard 250 kW CHP, CALLUX, Ene.Field, Vaillant, Baxi, Viessmann etc.

2.5.7.5. Stationary applications: UPS
Plug Power, Rittal, Relion

2.5.7.6. Stationary applications: Power generation
NedStack

2.5.7.7. Portable, minature and toys
micro FC, Nexa, heliocentris, Horizon

2.5.7.8. Markets & programmes
EU, US/Canada, Japan, S.Korea, China

2.5.8. Current R&D issues
Improved and alternative water management, lower catalyst loading, non-noble metal catalysts, increased operating temperature, increased CO tolerance, freeze proof MEAs, higher durability and lifetime, reduced costs, simplified and compact systems

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Assessment of overall project

(5) Here you have some space to comment on the overall project and its approach, based on the information you have received and digested to date: