Roads2HyCom

www.roads2hy.com

DELIVERABLE 8.5

DEVELOPMENT OF EDUCATION AND TRAINING AGENDA

Jan Macek, Czech Technical University in Prague
Raimund Bleischwitz, College of Europe
Phil Doran, Core Technology Ventures
Bruno Gnörich, ika RWTH Aachen

Document Number: R2H8022PU.2 Date: 26 January 2009

The European Commission is supporting the Coordination Action "HyLights" and the Integrated Project "Roads2HyCom" in the field of Hydrogen and Fuel Cells. The two projects support the Commission in the monitoring and coordination of ongoing activities of the HFP, and provide input to the HFP for the planning and preparation of future research and demonstration activities within an integrated EU strategy.

The two projects are complementary and are working in close coordination. HyLights focuses on the preparation of the large scale demonstration for transport applications, while Roads2HyCom focuses on identifying opportunities for research activities relative to the needs of industrial stakeholders and Hydrogen Communities that could contribute to the early adoption of hydrogen as a universal energy vector.

Further information on the projects and their partners is available on the project web-sites www.roads2hy.com and www.hylights.org

DEVELOPMENT OF EDUCATION AND TRAINING AGENDA

Abstract

This report contains proposed educational programmes for higher and life-long education of mechanical engineers in the field of fuel cell and hydrogen technologies, used in vehicles or power engineering. Five educational programmes have been proposed:

- Masters in Science (MSc) in R&D for Hydrogen Engineering
- Bachelor course on Hydrogen Technology Implementation
- Life-Long Education – full size version
- Life-Long Education – short version
- Summer School

The proposed education programmes have been divided into a series of subjects. These subjects could be used individually as part of the syllabus for other courses.

This report should be used in conjunction with the Excel spreadsheet “Roads2HyCom R2H8025PU – Education Agenda.xls”, which provides further details on the structure and content of each course.

The Roads2HyCom Education and Training Agenda is a deliverable of the Roads2HyCom project, a partnership of 29 stakeholder organisations supported by the European Commission Framework Six Programme. The project is studying technical and socio-economic issues associated with the use of Fuel Cells and Hydrogen in a sustainable energy economy. More information about the project can be found on the project website www.roads2hy.com.

DEVELOPMENT OF EDUCATION AND TRAINING AGENDA

TABLE OF CONTENTS

1. Introduction

The Roads2HyCom project is studying technical and socio-economic issues associated with the use of Fuel Cells and Hydrogen in a sustainable energy economy. Roads2HyCom Work Task 8.5 is about forming an Education Agenda. This work task will extract relevant information and compile a report with high-level recommendations for the academic agenda. It is intended that this work should reinforce existing activity in the European Hydrogen & Fuel Cell Technology Platform.

The main target group of the academic agenda is the mechanical engineering community. The reasons for it are the following:

- The change to hydrogen economics poses new paradigms for mechanical and process engineering especially, whereas electric and control engineering or standard chemical engineering has already been equipped by suitable methods and technologies.
- Mechanical engineers will play a decisive role in the implementation, realization and operation of new systems.

The modules of proposed programmes may be used for much broader education of civil engineers (concerning infrastructure construction) or chemical and electric engineers. The general information on energy business economics and financing provides valuable information for anybody involved in this expected huge change of a power supplying system.

WT8.5 is lead by the Josef Božek Research Centre at the Czech Technical University in Prague (CTU), with support from ika, Institut für Kraftfahrwesen at RWTH University Aachen (RWTH), College of Europe (CoE) and Core Technology Ventures (CoreTec).

The high-level training (bachelor or master degree) mentioned in the following text considers mechanical engineering experts, educated for hydrogen technologies implementation and/or R&D. Specific minimized subject is proposed for fast updating of knowledge for life-long training of graduated engineers at master level. A smaller module is suggested for more general courses. After all, it should be emphasized that teaching future energy systems requires massive efforts from all academic levels, as described in the full education programme (curriculum).

This Education Agenda utilises the long-time experience of the Czech Technical University in educating vehicle (automotive) oriented engineers and power engineering experts. Currently, an international master called the European Master in Automotive Engineering (EMAE) is taught beside Czech optional curricula for automotive/ICE engineers or railway vehicle engineers, (including the Siemens AG supported curriculum). In the power engineering domain, the optional curricula cover heat-and-powerplant operation or R&D and nuclear powerplant operation or design of mechanical parts.

This background enables the authors to propose a flexible curriculum suitable for both vehicle/transport and power engineering domains using a modular structure with multiple use of newly developed or tailored current subjects. At the other side, this approach offers a complex view on the issues of alternative energy sources and energy vectors.

The mechanical and electrical engineering topics are proposed by CTU in collaboration with RWTH. RWTH has elaborated the issues of intellectual property rights. The College of Europe has covering topics related to socio-economic issues, which must not be separated from purely technical ones. Core Technology Ventures has delivered topics related to financial issues.

This proposal starts with the review of the main goals of the education curriculum. It lists the general goals, main topics of subjects and contents of proposed individual subjects. It gives a base for proposal of the first approximation of possible curricula, from which the level and duration of courses is deduced. The report should be read in conjunction with the Excel spreadsheet "Roads2HyCom R2H8025PU – Education Agenda.xls", which provides further details on the structure and content of each course.

More information about Roads2HyCom, including other reports completed by the project, can be found on the project website www.roads2hy.com.

Requests for further information on the Roads2HyCom Education Agenda should be addressed to:

Josef Božek Research Centre, Czech Technical University in Prague (CTU)

Contact: Jan Macek

Email: Jan.Macek@fs.cvut.cz

Website: http://bozek.cvut.cz

ika, Institut für Kraftfahrwesen RWTH University Aachen (RWTH)

Contact: Bruno Gnörich

Email: gnoerich@ika.rwth-aachen.de

Webiste: www.ika.rwth-aachen.de

The College of Europe (CoE)

Contact: Raimund Bleischwitz

Email: rbleischwitz@coleurop.be

Website: www.coleurop.be

Core Technology Ventures (Coretec Ventures)

Contact: Phillip Doran

Email: phil@coretecventures.com

Website: www.coretecventures.com

2. Overview of Education Agenda on Hydrogen Technology Implementation

The implementation of fuel cell and hydrogen technologies – after they have been developed – is the role of **mechanical engineers in the domains of power engineering and vehicle engineering**.

This important link, implementation of fuel cell and hydrogen technologies, is missing from current Education Agendas and this document aims to deliver a potential agenda for Hydrogen and Fuel Cell education, together with basic information for the other hydrogen technologies stakeholders-.

When planning a new curriculum for the implementation of fuel cell and hydrogen technologies, the fuzzy specification of future needs and comparatively long time delay between the start of curriculum development and the first graduates should be taken into account. Therefore, the contents should be proposed in a flexible modular structure and should also include information on other possibilities for covering future energy demands.

The general demand is **to understand the comprehensive (holistic) approach to the issues of alternative energy sources and energy vectors, with a focus on fuel cell and hydrogen technologies** in comparison to other solutions, i.e.

- To keep the knowledge to the current standard solutions;
- To stress the logical consequences of basic laws of nature instead of pure factography;
- To take into account the yet uncertain future solutions;
- To educate to understanding of needs using comparison with the current "State of the Art" (SOTA).

Analysis of missing issues in the current mechanical engineering curricula detected the following possible gaps in knowledge that would be necessary for future hydrogen-oriented engineers:

- General theoretical background
- Energy and environmental requirements of world in the future
- SOTA in vehicle and power engineering
- Fuel cell and hydrogen technology tools
  - Hydrogen production,
  - Storage and distribution networks,

   – Transformation of chemical energy to electrical or mechanical energy (FC, ICE)

   – Safety issues

- Energy economics, distribution infrastructure features, energy business

- Financing of emerging technologies

- Intellectual property issues

The transformation of current paradigms used in vehicle engineering or power engineering should cover both life-long learning for existing engineers and operators as well as the education of new young specialists.

Simultaneously, both R&D oriented staff and operators should be prepared at different levels and at different education costs and efforts. For those reasons, a hierarchy of curricula has been created, as presented in the following scheme:

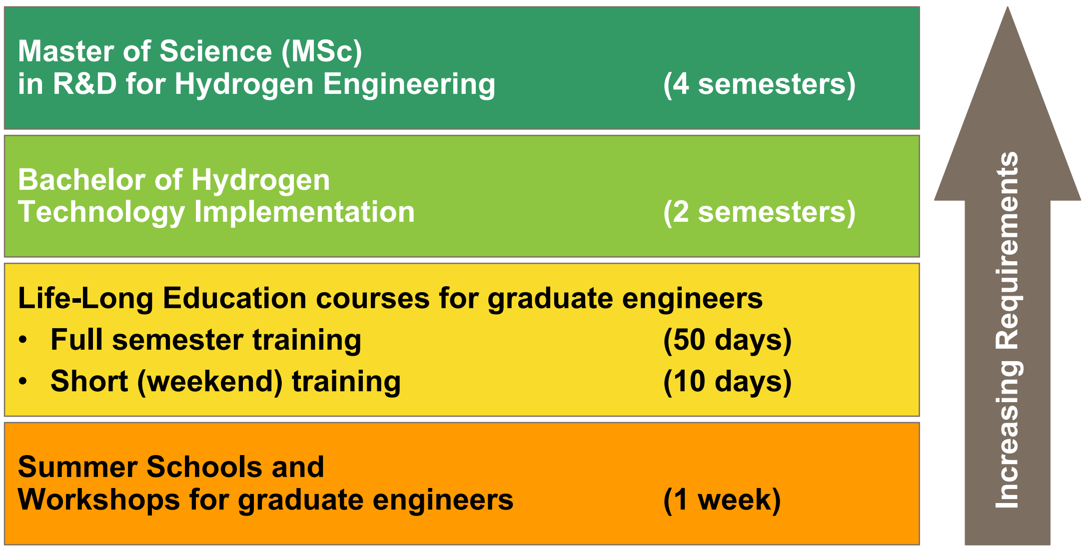

Figure 1: Hierarchy of curricula for educating graduate engineers on implementing hydrogen technologies

These requirements would pose high demands on the number of subjects and courses, which might be ineffective for universities. Therefore, the study programme (curriculum) should be structured for the rationalistic use of teaching material prepared for the highest level of education, simplifying it for the use at lower level or for life-long learning (LLL), summer schools, etc.

The suitable pattern developed during the work on WT8.5 is presented in the following picture, enabling the university to use a modular system.

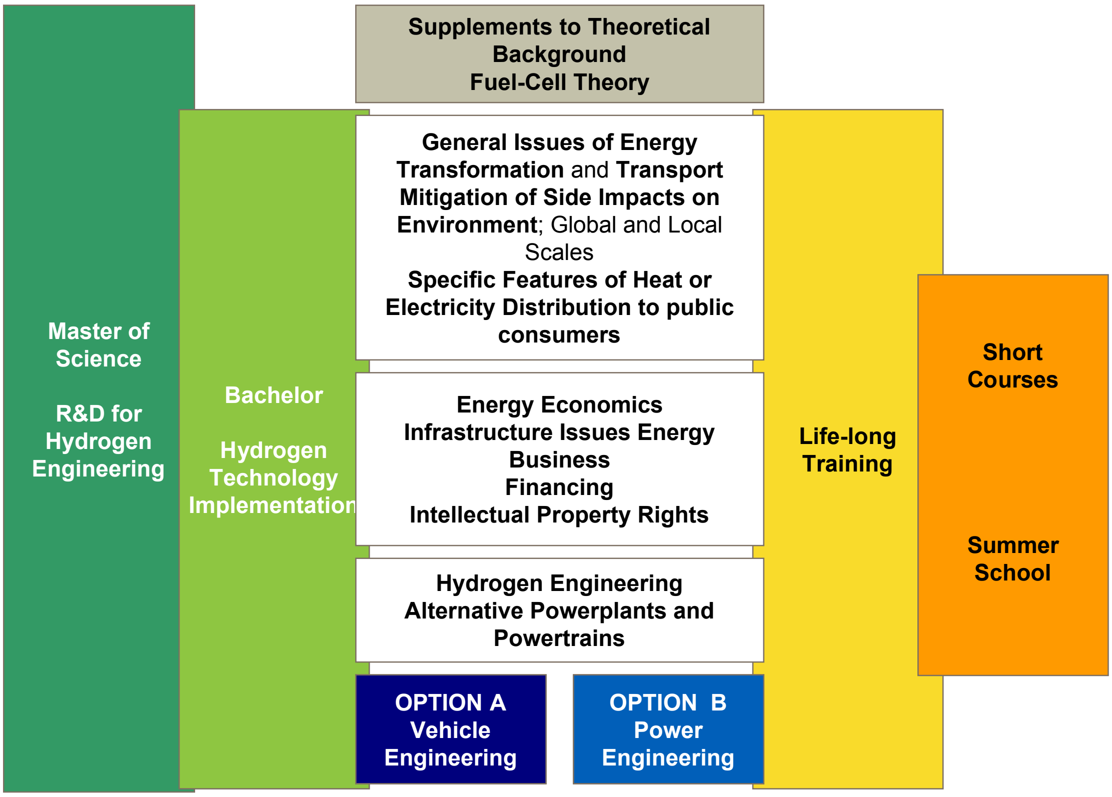

Figure 2: Pattern of course development for the four curricula levels

The details of different curricula levels, including goals and specific subjects, are described Sections 3 to 6 below. The interactive list of courses and subjects with detailed description of their contents, time range, student efforts and duration is enclosed in the appendix Excel spreadsheet R2H8025PU.

In all cases, the most experienced trainers in Europe, directly involved in major developments, should be preferred as lecturers.

Note about other educational activities in Europe

Within Europe there are already several H2&FC education activities in operation. Some of these are listed below.

The **University of Ulster** is running annual Summer Schools on Hydrogen Safety as part of the European HyCourse project (2006-2010) (Contact: v.molkov@ulster.ac.uk, www.engj.ulst.ac.uk/esshs/hycourse)

The University of Ulster also offer a PgCert / PgDip / MSc in Hydrogen Safety Engineering, as part of the European HySafe project

The **Danish Hydrogen and Fuel Cell Academy (HyFC)** offers a PhD programme in Hydrogen, covering the entire chain from production to end use. HyFC also organise Summer Schools on Hydrogen and Fuel Cell technology, in connection with the Grove Conference. The courses are aimed at PhD students (www.hyfc.aau.dk)

The **Polish Hydrogen and Fuel Cell Association** run a Summer School in Fuel Cell and Hydrogen Technology (www.hydrogen.edu.pl)

H2-Training, a European project within the framework of the Leonardo da Vinci Programme (www.h2training.eu)

3. Master of Science in R&D for Hydrogen Engineering

3.1 Pre-requisite

The MSc in R&D for Hydrogen Engineering requires students to have at least 3 years of general engineering education at bachelor level, focused on theory of natural science.

3.2 Specific Goals

The graduates from the MSc in R&D for Hydrogen Engineering should know and understand:

- **The physical and chemical base** of energy transformation and transport by suitable vectors (thermodynamics, physical chemistry, transport phenomena, electrochemistry, electromagnetism);
- The **energy requirements of mankind**; the issues of sources of energy at the Earth, those of global warming (basic atmospheric science, IPCC state of the art) and local pollution issues;
- The general principles of **energy transformation and transfer by suitable carriers**, including synthetic fuels, especially hydrogen;
- Principles and examples of Well-to-Wheels (WTW) approach (generally, Well-to-User approach);
- **Pollution mitigation principles and assessment** - testing of environment friendliness; TW/User approach to local pollutants and global warming issues;
- The principles and solutions of **current vehicle design and/or** the principles and solutions of **current heat-and-powerplant design** (according to **options**);
- **Alternative powerplants and powertrains** – principles and design of fuel cells, especially hydrogen based;
- **Fuel-cell engineering and FC powerplants**
- **Energy economics**, focus on hydrogen
- **Energy infrastructure development** – economic and financing aspects
- **Energy and business economics, financing and intellectual property issues;**
- **Specific issues of hydrogen engineering** (production, storage, distribution and safety/security; for every issue principles, design of facilities, assessment of effects, suitability for vehicles/stationary use, future prospects).

3.3 Course Duration

The MSc in R&D for Hydrogen Engineering is a two year course (4 semesters), designed to enhance basic general mathematics, physics, chemistry and engineering education from a “theory oriented” 3-year bachelor curriculum.

3.4 Subject Contents

The MSc in R&D for Hydrogen Engineering contains the following subjects:

1. **Advanced Thermodynamics and Physical Chemistry** (appendices to thermochemistry, phase and chemical equilibrium; chemical kinetics, electrochemistry) **[CTU]**

2. **Transport Phenomena** (appendices to heat and momentum transfer; diffusion, liquid solutions, transport under electric forces, membranes) **[CTU]**

3. **Appendices to Electrical Engineering** (electric circuits; basics of electrodynamics; magnets and permanent magnets; theory and efficiency of electrical machines (motors, alternators); principles and efficiency of accumulation of electric energy (batteries, supercapacitors); principles of power semiconductor elements; power semiconductor systems (frequency converters, etc.) and their control and efficiency) **[CTU]**

4. **The General Issues of Energy Transformation and Transport by Suitable Vectors [CTU]**
   - The energy requirements of mankind
     - Main goals – heat, light, power for manufacturing, construction and agriculture, mobility, air conditioning, cooling, informatics and communication machines
     - Mitigation of side-effects – environment issues, sustainability
     - The knowledge base on energy,
   - The sources of energy at the Earth and their transformation
     - Fossil and renewable energy sources, i.e., hydrocarbon fossil fuels and biomass, geothermal, nuclear, wind, water and solar
     - Principles of transformation, transport and storage
       - Conversion to heat (chemical - combustion, nuclear reactions, solar energy capturing, geothermal energy)
       - Thermal engines (reciprocating engines with internal or external combustion; turbines – water, steam, gas, wind)
       - Electric energy production, transport and storage - rotating or reciprocating electric generators, electric mains, batteries, super capacitors, superconductivity issues;
     - Synthetic fuels including hydrogen
     - Scenario analysis.

5. **Pollution Mitigation Principles and Assessment** (testing of environment friendliness; WTW/User approach) **[CTU]**
   - Current pollutants and exhaust gas aftertreatment
   - Global warming issues and carbon balance of energy transformation

- Anthropogenic global warming mitigation procedures – CO_2 sequestration, nuclear energy, renewable energy;
- Hydrogen technologies assessment
- Principles and examples of WTW approach (generally, Well-to-User approach)
- Scenario analysis.

6. **Energy Economics**, focused on Hydrogen **[CoE]**
   - Characteristics of energy markets (pricing non-renewable natural resources, natural monopoly, investment goods – utilities, pay-back times, least cost planning, demand side management)
   - Regulation of energy markets (economics of regulation, EU internal market for energy, taxation),
   - Environmental economics of energy (externalities of energy production and transformation, economics of global warming, Kyoto commitments, sustainability management)
   - Energy security: international economic and political relations, assessing vulnerability,
   - Economics of energy efficiency, renewable energies and alternative fuels
   - Energy scenario analysis.

7. **Energy Infrastructure Development – Economic Aspects [CoE]**
   - Investment assessment (cost benefit analysis, preference analysis, scenario analysis, discounting)
   - Economics of centralized and decentralised energy structures (smart grids, peak load management, access management, connectivity),
   - Demand side management, cooperation with stakeholders.

8. **Energy and Business Economics [CoE]**
   - Business development: cost models, market analysis, developing products and services for different customers
   - Financing
   - Marketing, raising awareness,
   - Management: running an SME energy company.

9. **Financing of New Technology Implementation Projects [CoreTec]**
   - Selected financial terminology
   - How finance fits into the wider economy
   - How the financial intermediation chain is ‘laid’ out
   - The importance of mapping the stage of technological development to the appropriate ‘link’ in the financial chain
   - The requirements of financial providers
   - Necessary Documentation
     - Business plan
     - Investor presentation
   - Elements of the investment process:
     - Technical, commercial, financial and legal due diligence
     - Interaction with Bankers, Industry specialists, Accountants, Lawyers, Public Relations

- Case studies / examples of successful and unsuccessful interaction between developers and financiers
  - Seed
  - Early-stage
  - Late-stage
    - IPO
    - Trade sale.

10. Issues Relating to Intellectual Property Rights [RWTH]

- General Issues of Intellectual Property Rights
- Patents, Copyrights, Trademarks and Allied Rights
- Intellectual Property Rights in EU Law: Free Movement and Competition Law

11. **Hydrogen Engineering** (for every issue principles, design of facilities, assessment of effects, suitability for vehicles/stationary use, future prospects) **[CTU & RWTH]**

- Production technologies (hydrogen-containing primary materials – NG or water, sources of primary energy – heat from nuclear or chemical sources, electric energy, hydrogen production processes – NG reforming, water electrolysis, water thermal dissociation, biomass thermal decomposition, hydrogen quality, WTT assessment)
- Hydrogen storage and distribution technologies (including knowledge on compressors and liquefaction machinery, deep temperature cooling technologies); mass, volume, energy requirements; re-fuelling stations and use of blown-off hydrogen;
- Hydrogen safety threats, principles of mitigation, regulations, standards;
- Synergy between vehicle and stationary use (distributed hydrogen production from local sources of renewable energy, car FC/ICE as heat-and-power source for house, etc.);
- Scenario analysis.

12. Fuel-Cell Theory and Fuel-Cell Powerplants [RWTH & CTU]

- Electrode, electrolyte and membrane chemistry
- FC stack design and auxiliaries (air/fuel conditioning by supercharging, humidification, etc.),
- FC stack performance issues at different loads, FC maps
- FC operation issues - efficiency in operation, transient response, durability, performance of FC under load
- Specific optimization of powerplants/powertrain using efficiency/power boosters (cogeneration, hybridization, ICE-FC combination).

13. Alternative Powerplants and Powertrains – Principles, Design, Operation Problems [RWTH & CTU]

- FC working principles (PEMFC, Direct Methanol FC (DMFC), Molten Carbonate FC (MFC), Phosphoric Acid FC (PAFC), Solid Oxide FC (SOFC), Alkaline FC (AFC), etc.)
- Fuel cells in powerplants (SOFC) or auxiliary power units
- Fuel cells for vehicles

- Future thermal engines for biomass-based fuels or **hydrogen**
- Photovoltaic cells.

14. Specific Features of Heat or Electricity Distribution to Public Consumers [CTU]

- Thermal cycles of power and heating plants, energy and exergy comparison.
- Choice of capacity and output parameters for different plants, cogeneration ratio. Optimization of the cogeneration factor. Technical and economic evaluation of the operation.
- Possibilities for the connection of heat consumers to DH network and their comparison. Heat storage.
- Environmental impacts of power and heating plants operation.
- Technical and economic aspects of the power generation industry development from the national point of view. Structure of prices within the power generation industry. Importance of economic appreciation for projects and design variants.
- More complex problems of technical and economic optimization solved by computer.
- Economic assessment of the impact of power generation on the environment.

15. ICE Theory and Operation [CTU]

- Mixture formation principles in ICE
- Combustion principles in ICE
- Heat transfer in ICE
- Charge exchange and torque control
- Mixture formation devices of ICEs
- Combustion realization in ICEs
- Pollution formation and EG aftertreatment
- Supercharging, turbocharging and downsizing of ICEs
- Engine maps
- Specific features of hydrogen ICE
- Simulation principles and practice

16. Heat Transfer Devices [CTU]

- Heat transfer principles
- Similarity in heat transfer
- Heat exchanger elements
- Typical heat transfer cases
- Elementary heat exchanger theory
- Heat exchanger pressure losses
- Heat exchanger simulation and optimization tools

OPTION A: **Automotive Hydrogen Technologies**

17. Vehicle Dynamics and Specific Features of Vehicle Power Demands [CTU & RWTH]

- Vehicle longitudinal dynamics, inertia and weight forces, resistances and demands on tractive power

- Principles of transmissions, specific features of mechanical, hydraulic and electric transmissions
- Optimization and automization of vehicle transmissions and their control - limits of Tank-to-Wheels (TTW) efficiency and practical tuning of transmission to engine and vehicle needs
- Simulation of vehicle driving - principles, engine representation, road fuel consumption and emissions
- Simulation code practice
- Vehicle vertical and transversal dynamics, advantages of electric active elements
- Possibilities of tractive energy recuperation.

18. ICE theory and operation [CTU]

19. Mechanical and Electrical Transmissions [CTU & RWTH]

- Spur and helical gears – geometry
- Bevel gears - geometry
- Spur and helical gears - strength and durability
- Automotive gearboxes with fixed shafts
- Epicyclic gearboxes
- Differentials and power-split devices

20. Hybrid Vehicle Theory [CTU & RWTH]

- Classification of hybrid vehicles
- Components of vehicles - motors, generators, power split devices, frequency converters, accumulators, super capacitors
- Examples of hybrid vehicle design
- Hybrid vehicle simulation and assessment of hybridization impacts on TTW efficiency

OPTION B: **Hydrogen Power Engineering**

21. Heat Transfer Devices [CTU]

22. Combustors [CTU]

- Principles of boiler combustor design - solid, liquid and gaseous fuels
- Combustor chemistry and pollutants formation
- Combustor aerodynamics
- Advanced combustion systems: Pressure fluidized bed gasification, cleaning of gasification gases. Low temperature vortex coal combustion. Surface combustion of natural gas.
- Combustor performance and control
- Possibility of control of combustion reaction mechanism. Low emission (SO_2, SO_3, NOx, HCl, HF, heavy metals, furanes, dioxins) technologies. Design of incinerators. Selection of technical means for emission reduction.

23. Nuclear Fission Reactors and Prospects of Fusion Devices [CTU]

- Advanced reactors of 3rd and 4th generation

- Use of advanced reactors for hydrogen production by water thermal dissociation
- Basic principles for insurance of nuclear safety. Various levels of defence-in-depth for current and advanced nuclear units.
- Insurance of inherent, passive and active safety. Accidents with reactivity perturbations (reactivity excursion mechanism, standard and prompt power excursions, Černobyl). Accidents with heat removal impairment (loss of flow, loss of heat sink, TMI - 2 accident). Loss of coolant accidents-LOCA (depressurization phase, flooding phase, theoretical analyzes and the results of model experiments). Fuel behaviour during accidents, failure mechanism until melting point.
- Conditions and physical and technological processes in the containment, source term.
- Spreading of radioactivity within the unit and in the environment. Radiological consequences.
- Prospects of nuclear fusion

24. Steam, Gas and Wind Turbines [CTU]

- Principles of turbomachinery
- Thermodynamics of turbine cycles
- Features of airfoils and blade cascades
- Turbine and compressor stage features
- Steam turbine design and features
- Gas turbine design and features
- Turbo compressor features
- Wind turbine design

The practical training is based on homework and several projects using simulations.

According to availability, experiments and laboratory training may be involved into Hydrogen Engineering, Vehicle dynamics, Internal Combustion Engines and other subjects.

Altogether it is planned as 18 subjects for 4 semesters, each semester taking 300 hours (+ projects and labs up to 370 hours). On average this works out as 60 hours for every subject (4 per week).

4. Bachelor Course on Hydrogen Technology Implementation

4.1 Prerequisite

This course is designed to be the final year of a four-year bachelor or master degree in mechanical engineering. Therefore the student is expected to have completed 3 years of general engineering education at bachelor level.

4.2 Specific Goals

The graduates are taught to apply:

- The general issues of **energy transformation and transport by suitable vectors**; the energy requirements of mankind; the issues of sources of energy at the Earth
- **Pollution mitigation principles and assessment** - testing of environment friendliness; TW/User approach to local pollutants and global warming issues;
- **Alternative powerplants and powertrains** – design with FCs or other sources and Well-To-User analysis
- Specific features of heat production and distribution to public consumers
- **Hydrogen engineering** (production, storage, distribution, safety)
- **Energy economics**
- **Energy infrastructure development** – economic aspects
- **Energy business economics**
- **Financing of new technology implementation projects**
- **Issues relating to Intellectual Property Rights**
- **The principles and solutions of current vehicle design** or the principles and **solutions of current heat-and-powerplant design**:

  OPTION A: **Vehicle Technology**

  – Vehicle dynamics and specific features of vehicle power demands
  – Internal Combustion Engine (ICE) theory
  – Mechanical and electrical transmissions
  – Hybrid vehicle fundamentals

OPTION B: **Power Engineering**

- Combustion and combustors
- Heat transfer devices
- Steam, gas and wind turbines

4.3 Course Duration

The Bachelor in Hydrogen Technology Implementation is designed as a one year course (2 semesters) that is part of a four year bachelor or master degree in mechanical engineering. However it could be combined with a standard master automotive or power engineering curriculum as well.

4.4 Subject Contents

The one-year course covers the following subjects:

1. **The General Issues of Energy Transformation and Transport by Suitable Vectors:** the same as for the MSc (p.11) **[CTU]**

2. **Pollution Mitigation Principles and Assessment** (testing of environment friendliness; WTW/User approach): the same as for the MSc (p.11) **[CTU]**

3. **Specific Features of Heat or Electricity Distribution to Public Consumers**: similar as the MSc (p.14) but reduced **[CTU]**
   - Thermal cycles of power and heating plants, energy and exergy comparison.
   - Choice of capacity and output parameters for different plants, cogeneration ratio. Optimization of the cogeneration factor. Technical and economic evaluation of the operation.
   - Possibilities for the connection of heat consumers to DH network and their comparison. Heat storage.
   - Environmental impacts of power and heating plants operation.
   - Economic assessment of the impact of power generation on the environment.

4. **Alternative Powerplants and Powertrains – Principles, Design, Operation Problems**: the same as for the MSc (p.13) **[CTU]**

5. **Energy Economics, focused on Hydrogen**: the same as for the MSc (p.12) **[CoE]**

6. **Energy Infrastructure Development – Economic Aspects**: the same as for the MSc (p.12) **[CoE]**

7. **Energy and Business Economics**: the same as for the MSc (p.12) **[CoE]**

8. **Financing of New Technology Implementation Projects**: the same as for the MSc (p.12) **[CoreTec]**

9. **Issues Relating to Intellectual Property Rights**: the same topics as for the MSc (p.13) but reduced duration **[RWTH]**

10. **Hydrogen Engineering** (for every issue principles, assessment of effects, operation problems): similar to the MSc (p.13) but very reduced duration, focused on operation and safety issues **[CTU & RWTH]**
    - Production technologies
    - Hydrogen storage and distribution technologies (including knowledge on compressors and liquefaction machinery); operation problems; fuelling stations;
    - Hydrogen safety threats, principles of mitigation, regulations, standards;
    - Synergy between vehicle and stationary use (distributed hydrogen production from local sources of renewable energy, car FC/ICE as heat-and-power source for house, etc.);
    - Scenario analysis (an overview).

OPTION A: **Hydrogen Automotive Engineering**

11. **Vehicle Dynamics and Specific Features of Vehicle Power Demands:** similar to the MSc (p.14) **[CTU & RWTH]**
    - Vehicle longitudinal dynamics, inertia and weight forces, resistances and demands on tractive power
    - Principles of transmissions, specific features of mechanical, hydraulic and electric transmissions
    - Optimization and automation of vehicle transmissions - limits of TTW efficiency and practical tuning of transmission to engine and vehicle needs
    - Simulation of vehicle driving - principles, engine representation, road fuel consumption and emissions
    - Possibilities of tractive energy recuperation.

12. **ICE Theory and Operation:** similar to MSc (p.14) but shortened **[CTU]**
    - Mixture formation principles in ICE
    - Combustion principles in ICE
    - Heat transfer in ICE
    - Charge exchange and torque control
    - Mixture formation devices of ICEs
    - Combustion realization in ICEs
    - Pollution formation and EG aftertreatment
    - Supercharging, turbocharging and downsizing of ICEs
    - Engine maps
    - Specific features of hydrogen ICE

13. **Mechanical and Electrical Transmissions:** similar to MSc (p.15) but reduced duration **[CTU & RWTH]**

14. **Hybrid Vehicle Principles:** similar to MSc (p.15) but shortened **[CTU & RWTH]**
    - Classification of hybrid vehicles

- Components of vehicles - motors, generators, power split devices, frequency converters, accumulators, super capacitors
- Examples of hybrid vehicle design

AND/OR OPTION B: **Hydrogen Power Engineering**

15. Heat Transfer Devices: the same as for the MSc (p.14) **[CTU]**

16. Combustors (p. **Error! Bookmark not defined.**) **[CTU]**

- Principles of boiler combustor design - solid, liquid and gaseous fuels
- Combustor chemistry and pollutants formation
- Combustor aerodynamics
- Advanced combustion systems: Pressure fluidized bed gasification, cleaning of gasification gases. Low temperature vortex coal combustion. Surface combustion of natural gas.
- Combustor performance and control

17. Steam, Gas and Wind Turbines: similar to MSc (p.16) but shortened in duration **[CTU]**

18. Nuclear Fission Reactors (p. **Error! Bookmark not defined.**) [**CTU]**

- Advanced reactors of 3rd and 4th generation.
- Use of advanced reactors for hydrogen production by water thermal dissociation
- Basic principles for insurance of nuclear safety. Various levels of defence-in-depth for current and advanced nuclear units.

According to the availability, experiments can be incorporated into the training.

Altogether 10 subjects for each semester.

5. Life-long Training Courses for Graduated Engineers

5.1 Prerequisites

The student should have a master degree in mechanical or electrical engineering for the full course.

A bachelor or master degree in mechanical or electrical engineering is the prerequisite for the short course.

5.2 Specific Goals

The goals involve mastering knowledge on:

- The sources of energy at the Earth and their transformation including **synthetic fuels, especially hydrogen**
- **Alternative powerplants and powertrains** – principles and design of fuel cells, especially hydrogen based, issues of alternative energy sources,
- **Principles and examples of WTW approach (generally, Well-to-User approach)**
- **Pollution mitigation principles and assessment** / testing of environment friendliness; WTW/User approach, global warming issues
- **Economical, financing, intellectual property and security assessment issues**
- **Hydrogen engineering** (production, storage, distribution and safety/security; for every issue principles, design of facilities, assessment of effects, suitability for vehicles/stationary use, future prospects)

5.3 Course Duration

The full-sized variant of the life-long training course is a one-year course covering 45 days of teaching (1 day per week for 45 weeks). The course could be spread over 2 years with some interruptions.

The short variant of the life-long training course is designed to last 10 weeks with 10 days ot teaching (1 day per week for 10 weeks).

5.4 Subject Contents – Full-Sized Training Course

This course may be based on the one-year bachelor course (p.18) or can be reduced to a single subject according the short version of the Life-Long Training course (p. 23).

The full-sized variant of the Life-Long Training course includes the following subjects:

1. **The General Issues of Energy Transformation and Transport by Suitable Vectors**: the same contents as for the MSc (p.11) but shortened duration **[CTU]**

2. **Pollution Mitigation Principles and Assessment** (testing of environment friendliness; WTW/User approach): the same for the MSc (p.11) **[CTU]**

3. **Specific Features of Heat or Electricity Distribution to Public Consumers:** the same as for the bachelor course (p.18) **[CTU]**

4. **Alternative Powerplants and Powertrains – Principles, Design, Operation Problems:** the same as for the bachelor course (p.18) but reduced duration **[CTU]**

5. **Energy Economics, focused on Hydrogen:** the same as for the MSc (p.12) **[CoE]**

6. **Energy Infrastructure Development – Economic Aspects [CoE]**
   - Economics of centralized and decentralised energy structures (smart grids, peak load management, access management, connectivity),
   - Demand side management, cooperation with stakeholders.

7. **Energy and Business Economics [CoE]**
   - Management: running an SME energy company.

8. **Financing of New Technology Implementation Projects:** the same as for the MSc (p.12) but reduced duration **[CoreTec]**

9. **Issues Relating to Intellectual Property Rights:** the same topics as for the MSc (p.13) but reduced duration **[RWTH]**

10. **Hydrogen Engineering** (for every issue principles, assessment of effects, operation problems) the same as for the bachelor course (p.19) **[CTU & RWTH]**

OPTION A: **Hydrogen Automotive Applications**

11. **Vehicle Dynamics and Specific Features of Vehicle Power Demands –** the same as for the bachelor course (p.19) **[CTU & RWTH]**

12. **ICE Theory and Operation** – similar to the bachelor course (p.19) but shortened **[CTU]**

13. **Mechanical and Electrical Transmissions [CTU & RWTH]**
    - Spur and helical gears – geometry
    - Spur and helical gears - strength and durability
    - Automotive gearboxes with fixed shafts
    - Epicyclic gearboxes

14. **Hybrid Vehicle Principles:** similar to the bachelor course (p.19) but shortened **[CTU & RWTH]**

AND/OR OPTION B: **Hydrogen Power Engineering**

15. **Heat Transfer Devices:** the same as for the bachelor course (p.20) **[CTU]**

16. **Combustors:** similar to the bachelor course (p. 20) but shortened **[CTU]**

17. **Steam, Gas and Wind turbines:** similar to the bachelor course (p.20) but reduced **[CTU]**
    - Principles of turbomachinery
    - Thermodynamics of turbine cycles
    - Features of airfoils and blade cascades
    - Turbine and compressor stage features
    - Wind turbine design

18. **Nuclear Fission Reactors:** similar to the bachelor course (p.20) but shortened **[CTU]**

5.5 Subject Contents – Short Course

The second variant of the Life-Long Training course cumulates the main issues into a single subject as a base for further individual studies. The subject is titled "Introduction to Hydrogen Engineering Issues" and covered both stationary and automotive applications. The main topics have to reflect:

- Earth energy resources, global issues, sustainability, renewable sources.

- Principles of WTW assessment of fuel consumption and emissions. Global warming, IPCC SOTA, carbon balance and methods to improve it, the knowledge base on energy, scenario analysis.

- General problems of energy use for tractive force of vehicles. Electric car components and their performance maps.

- Electricity production, the current problems and stationary heat and power plants for alternative fuels.

- Principles of PEM FC performance, DMFC, FC stack features, auxiliaries (air, hydrogen, water, control). Comparison of FC and ICE cars, gaps and ways to improve it. Hybrid solutions, combinations of prime movers (FC, ICE, etc.).

- Hydrogen production / Natural Gas reforming, electrolysis, thermochemical methods, biomass usage.

- Hydrogen storage / mass, volume, energy requirements.

- Safety, security, standards

- Energy economics, focused on hydrogen and energy business economics

- Energy infrastructure development – economic aspects
- Financing of new technology implementation projects
- Issues relating to Intellectual Property Rights

These demands may be covered by using appropriately shortened parts of the subjects, prepared for the full courses, described above, namely:

1. **The General Issues of Energy Transformation and Transport by Suitable Vectors**: similar to full course variant (p.22) but significantly shortened **[CTU]**

2. **Vehicle Dynamics and Specific Features of Vehicle Power Demands [CTU & RWTH]**
   - Vehicle longitudinal dynamics, inertia and weight forces, resistances and demands on tractive power
   - Principles of transmissions, specific features of mechanical, hydraulic and electric transmissions
   - Optimization and automation of vehicle transmissions - limits of TTW efficiency and practical tuning of transmission to engine and vehicle needs
   - Simulation of vehicle driving - principles, engine representation, road fuel consumption and emissions
   - Simulation code practice

3. **Alternative Powerplants and Powertrains** – principles, design, operation problems: similar to full course variant (p.22) but significantly shortened **[CTU]**

4. **Pollution Mitigation Principles and Assessment:** similar to full course variant (p.22) but significantly shortened **[CTU]**

5. **Hydrogen Engineering:** similar to full course variant (p.22) but significantly shortened **[CTU & RWTH]**

6. **Issues Relating to Intellectual Property Rights**: similar to full course variant (p.22) but significantly shortened **[RWTH]**

7. **Energy Infrastructure Development** – economic aspects: similar to full course variant (p.22) but significantly shortened **[CoE]**

8. **Energy Business Economics:** similar to full course variant (p.22) but shortened **[CoE]**

9. **Energy Economics Focused on Hydrogen**: similar to full course variant (p.22) but significantly shortened **[CoE]**

10. **Financing of New Technology Implementation Projects [CoreTec]**
    - Selected financial terminology
    - Necessary Documentation
    - Business plan

- Investor presentation
- Elements of the investment process:
  - Technical, commercial, financial and legal due diligence
  - Interaction with Bankers, Industry specialists, Accountants, Lawyers,
- Public Relations
- Case studies / examples of successful and unsuccessful interaction between developers and financiers
  - Seed
  - Early-stage
  - Late-stage
    - IPO
    - Trade sale

Altogether this course consists of 14 lectures of approximately 5 hours each.

6. Summer School Course

The Summer School Course is designed as introductory training for graduates with a business or economics degree or for graduates with a mechanical, automotive, power or electrical engineering degree.

The Summer School is designed to typically last for one week.

The schedule and contents may be easily adapted for different training objectives, using the contents of the higher level courses. The pre-requisites is a bachelor level of technical education.

Introductory courses are focused on energy and transportation. They can be used as a part of Summer Schools on sustainability, global change, etc. The overall length is about 5 hours for each module. The modules are:

A. General introduction:

- Global warming and future energy supply,
- Renewable energies, biofuels, energy efficiency, WTW approach,
- Safety of alternative fuel systems (storage, operation).

B. Vehicle powertrain / powerplant issues

- Hydrogen and fuel cells
- Electric power engineering issues

C. Economics of sustainable energy systems, scenario analysis

D. Practical issues of running an SME company; stating group project tasks

E. **Finishing Workshop** for completing group projects elaborated during a week of summer school with ample possibilities to discuss any questions and to exchange opinions.

These issues are taught as a part of the following subjects, transformed from the fast variant of life-long learning (p.23):

1. The General Issues of Energy Transformation and Transport by Suitable Vectors [CTU]

2. Vehicle Dynamics and Specific Features of Vehicle Power Demands [CTU & RWTH]

3. Alternative Powerplants and Powertrains – principles, design, operation problems [CTU]

4. **Pollution Mitigation Principles and Assessment [CTU]**

5. **Hydrogen Engineering [CTU & RWTH]**

6. **Issues Relating to Intellectual Property Rights [RWTH]**

7. **Energy Infrastructure Development – economic aspects [CoE]**

8. **Energy Business Economics [CoE]**

9. **Energy Economics Focused on Hydrogen [CoE]**

10. **Financing of New Technology Implementation Projects [CoreTec]**

7. Individual Use of Proposed Subjects in Other Courses

Any of proposed subjects, described above, can be used separately in other mechanical engineering or similar curricula.

8. Text books and e-learning sources

This section contains a list of recommended text books, papers and e-learning resources. The references in italics are specialist information sources suitable for mechanical engineering students.

8.1 Text books and technical papers

Barbir F., PEM Fuel Cells: Theory and Practice (Sustainable World Series) Elsevier 2005
ISBN: 0-12-078142-5

Bejan, A. Advanced Engineering Thermodynamics. Wiley Int. Ed. 1988

Cornish, W., Llewelyn D., Intellectual Property: Patents, Copyrights, Trademarks and Allied Rights, Sweet & Maxwell Publishers, 2007, ISBN: 978-0-4219-1900-6

Doran Ph., Robeson S. et al: Finance and the fuel cell industry: a review of the current financing climate. International journal of hydrogen energy, 28 (2003) pp. 713-715

Doran Ph.: Hydrogen and fuel cells: a new take on financing. The Fuel Cell review, June/July 2005

Heywood, J. B.: Internal Combustion Engine Fundamentals. Mc Graw Hill 1988 . ISBN 0-07-028637-X

Hoogers G., Fuel Cell Technology Handbook. CRC Press and SAE International 2002
ISBN: 978-0-7680-0706-0

Larminie J., Dicks A., Fuel cell systems explained. 2nd ed. Wiley, 2003 ISBN: 0-470-84857-X

Lomborg, B.: The Skeptical Environmentalist (Verdens Sande Tilstand). Cambridge University Press 2001 (Forlaget Centrum AIS 1998)

Lomborg B.: Cool it. The Sceptical Environmentalist’s Guide to Global Warming. Cyan Copenhagen 2007, Dokořán Prague 2008. ISBN 978-80-7363-188-8

Keeling D. T., Intellectual Property Rights in EU Law: Free Movement and Competition Law: v. 1, Oxford University Press, 2004, ISBN: 978-0-1982-5918-3

Miller J. M., Propulsion Systems for Hybrid Vehicles (Power & Energy). The Institution of Electrical Engineers, London 2004 ISBN: 0-86341-336-6

Stone, R. Introduction to Internal Combustion Engines. SAE 1999. ISBN 0-7680-0495-0

Westbrook M., The Electric and Hybrid Electric Car R-322. SAE International 2001

ISBN: 978-0-7680-0897-5

Winterbone D. E., Advanced Thermodynamics for Engineers.
Arnold 1997 ISBN: 0-340-67699-X; Wiley ISBN: 0-470-23718-X

8.2 Recommended e-learning websites

Roads2HyCom Hydrogen and Fuel Cell Wiki (www.ika.rwth-aachen.de/r2h)

Roads2HyCom Hydrogen and Fuel Cells: Handbook for Communities (www.roads2hy.com/WP7.html)

European Road Transport Research Advisory Council, Strategic Research Agenda, link: http://www.ertrac.org/strategic_research_agenda.htm

9. Conclusions

This report proposes a series of topics related to the implementation of fuel cell and hydrogen technology that could be included in master or bachelor study courses on vehicle or power engineering:

- High level of explanation of current problems and hints to bridge the gaps in future for masters
- **A practice-driven approach** reconstituting real-life professional situations through case studies and practical examples for both masters and bachelors
- Time space for workshops finalizing individual or group projects has to be planned.

Otherwise, summer or weekend courses of life-long education are feasible:

- **Truly tailored compact courses** designed for high-level executives from the private sector and participants of summer schools
- Time space for workshops finalizing individual or group projects has to be planned.

In all cases, the most experienced trainers in Europe, directly involved in major developments, should be preferred as lecturers.

10. Appendix

Excel spreadsheet “Roads2HyCom R2H8025Puv2 – Education Agenda).xls”, which contains a Database of Subject Modules (Document Number R2H8025P.2)