Novel Education and Training Tools based on digital Applications related to Hydrogen and Fuel Cell Technology

Karlsruhe Institute of Technology

Institute of Nuclear- and Energy Technologies (IKET)

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Content

- General Target and Aim
- General Objectives (overview of structure)
- e-Laboratory (e-engineering, e-science)
- Explicit Examples
- e-Learning (LMS)
- e-Learning (more specifics)
- Collaboration
- e-infrastructure (implementation)
- Conclusion

Education

Fuel C… …Technologies

Most Education… …t tackled

Trainers, Lectures, Professors

Scie… …Students, Industrial Employees

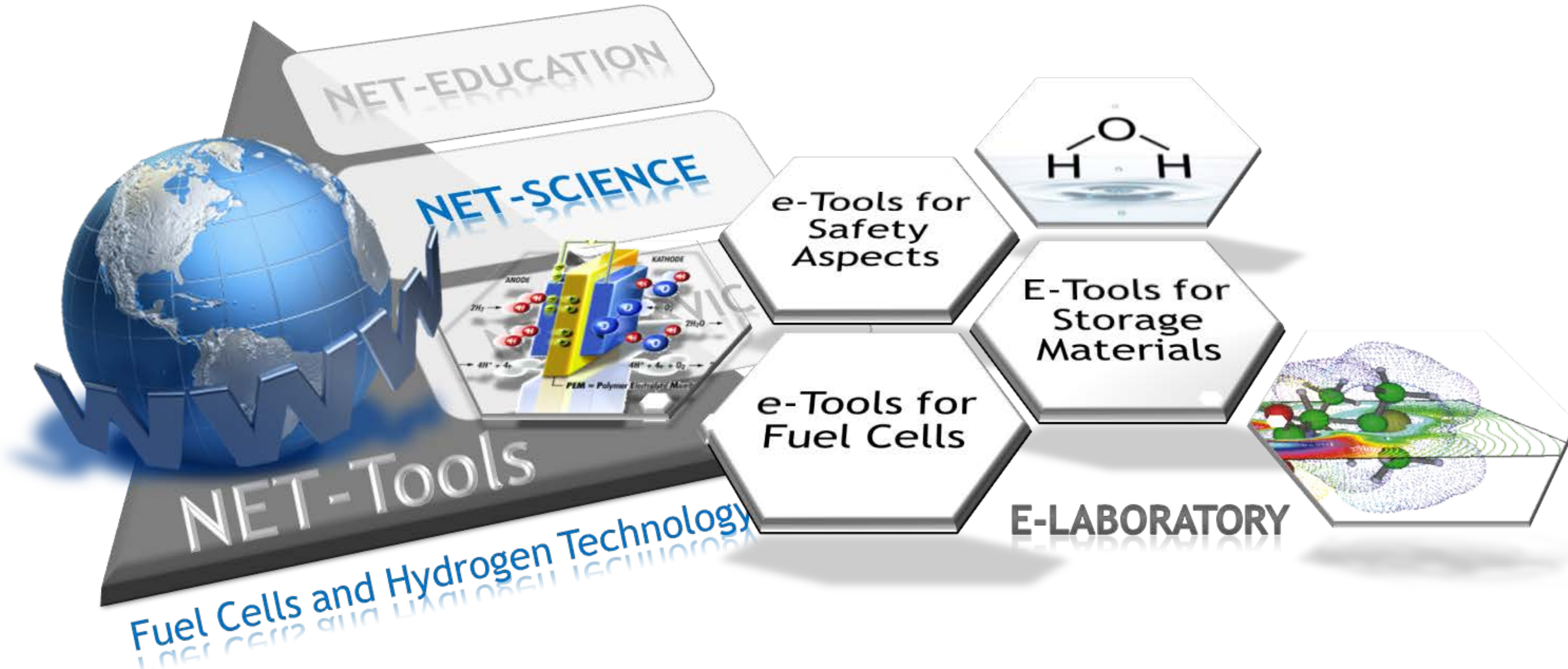
Information f… …e.g. Companies, Investors, Politicians)

……………………Interfaces………………

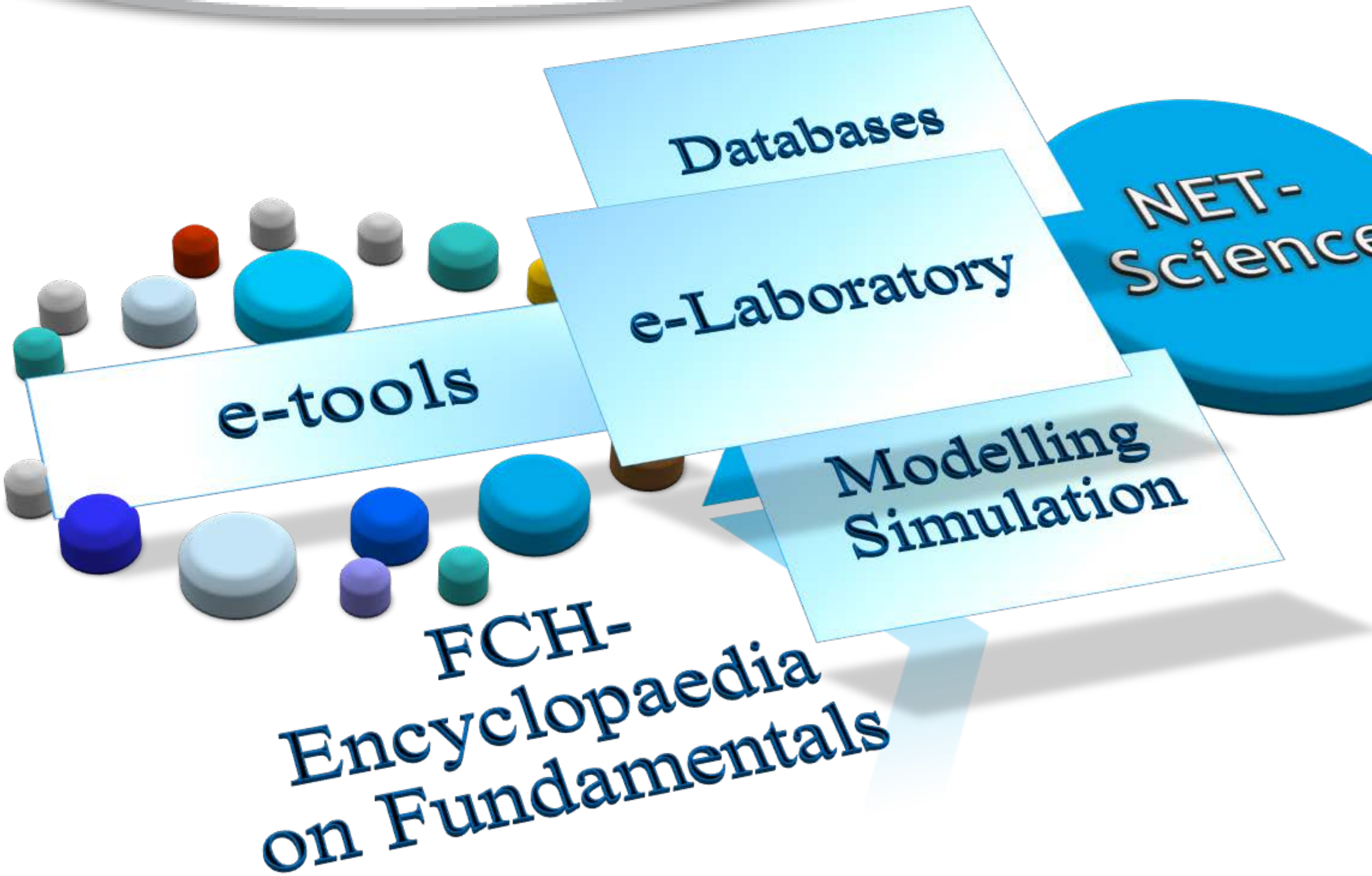
……very different demands……

General Aim (graphical overview)

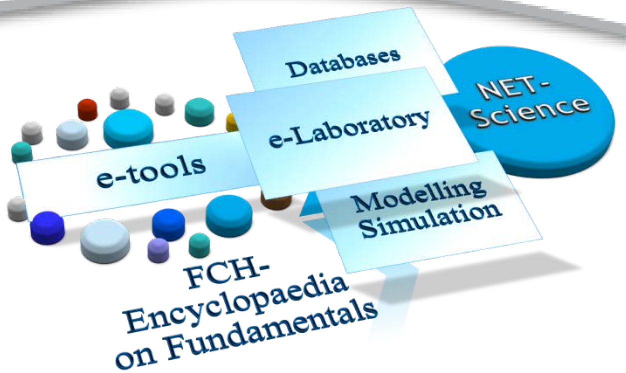
To develop, realize, promote and provide a common e-platform



General Aim (structural overview)



General Objectives



- Development of an e-Laboratory Platform
  subdivided into:
- e-Engineering Toolbox
  - Modelling and simulation of FCH related technical aspects
  - Guidelines and brief handbooks of e-tools
- e-Science Toolbox
  - Modelling and simulation of FCH relevant phenomena
  - Database of results received from done experiments
  - Database related CFD programming (validation and verification of codes)
  - Guidelines
- Database
  - Repository of done experiments and results
  - Guidelines and handbooks

e-Engineering (samples of tools)

NET-Tools

- e-Engineering
  - Renewable energy system (RES) tools
    - 1. Design and optimization of hybrid RES-hydr
  - Fuel cells (FC) tools
    - 1. Simulation of SOFC based on natural gas as fuel
    - 2. Energy balances and hydrogen costs for various electrolysis techniques
    - 3. Cell and stack models for both fuel cells and electrolysis
    - 4. Thermo-mechanical mode
  - Storage tools
    - 1. Storage material propertie
    - 2. gProms thermal design of storage tanks optimization (http://www.psenterprise.com/gproms.html).
  - FC integrated into CHP tools
    - 1. Simulation of FC system integrated into mCHP application, including electrolyser operation
  - Safety engineering tools
    - 1. Under-expanded jet parameters model
    - 2. Adiabatic and isothermal model of blowdown of storage tank dynamics
    - 3. Flame length correlation and three hazard distances for jet fires
    - 6. Passive ventilation in an enclosure with one vent: uniform hydrogen concentration
    - 7. Mitigation of uniform mixture deflagration by venting technique
    - 8. Force
    - 9. Blast
    - 10. Effect of buoyancy on decrease of hazard distance for unignited releases
    - 11. Pressure peaking phenomenon for ignited releases
    - 12. Upper limit of hydrogen inventory in closed space
    - 13. Mitigation of localised non-uniform deflagration by venting
    - 14. Blowdown time as a function of storage pressure, volume, and TPRD diameter
    - 15. Radiation from hydrogen fireball after high-pressure hydrogen tank rupture in a fire
    - 16. Effect of buoyancy on hazard distances for jet fires
    - 17.Calculation of choked flow for stagnation conditions in vapor, liquid or supercritical regimes.

Simulation of SOFC based on natural gas as fuel

Cell and stack models for both fuel cells and electrolysis

Forced ventilation system parameters

Adiabatic and isothermal model blowdown of storage tank dynamics

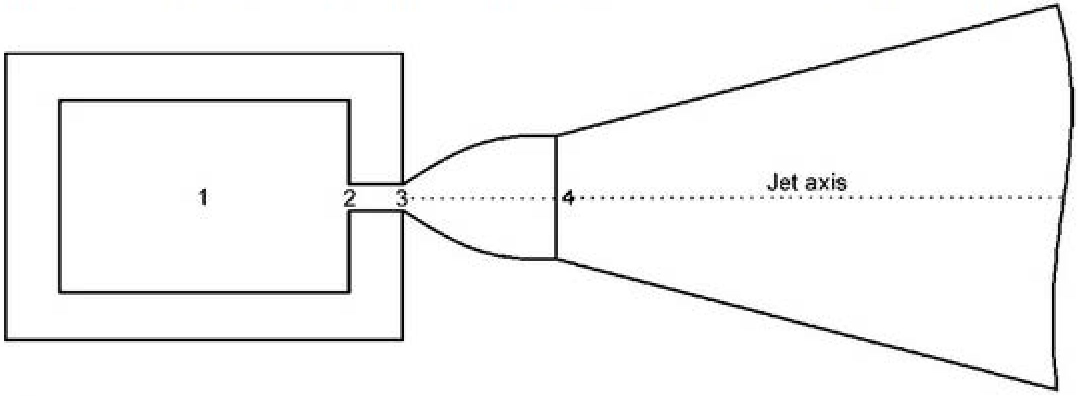
Calculation of upper limits of hydrogen inventory in closed space

e-Engineering (explicit sample)

Cyber Laboratory

Underexpanded jet parameters

The model describes parameters in an underexpanded jet through characteristic stages of its development - in reservoir (1), orifice (3), and effective nozzle diameter (4). The model is based on Abel-Noble equation of state for hydrogen; conservation equations for mass and energy; assumption that at state (4) (so called "effective nozzle diameter") pressure is equal to the ambient one and velocity is equal to the local sound speed. The model does not account pressure losses in the nozzle (between states (2) and (3)).



Reference:

- Free eBook: V. Molkov Fundamentals of Hydrogen Safety Engineering", www.BookBoon.com, October, 2012

INPUT VALUES

Units for pressure input:	[bar]	
Pressure in tank:	700	[bar]
Temperature in tank:	240	[K]
Orifice diameter:	2	[m]
Ambient pressure:	650	[bar]

RUN

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e-Engineering (explicit sample)

Result - Underexpanded jet parameters

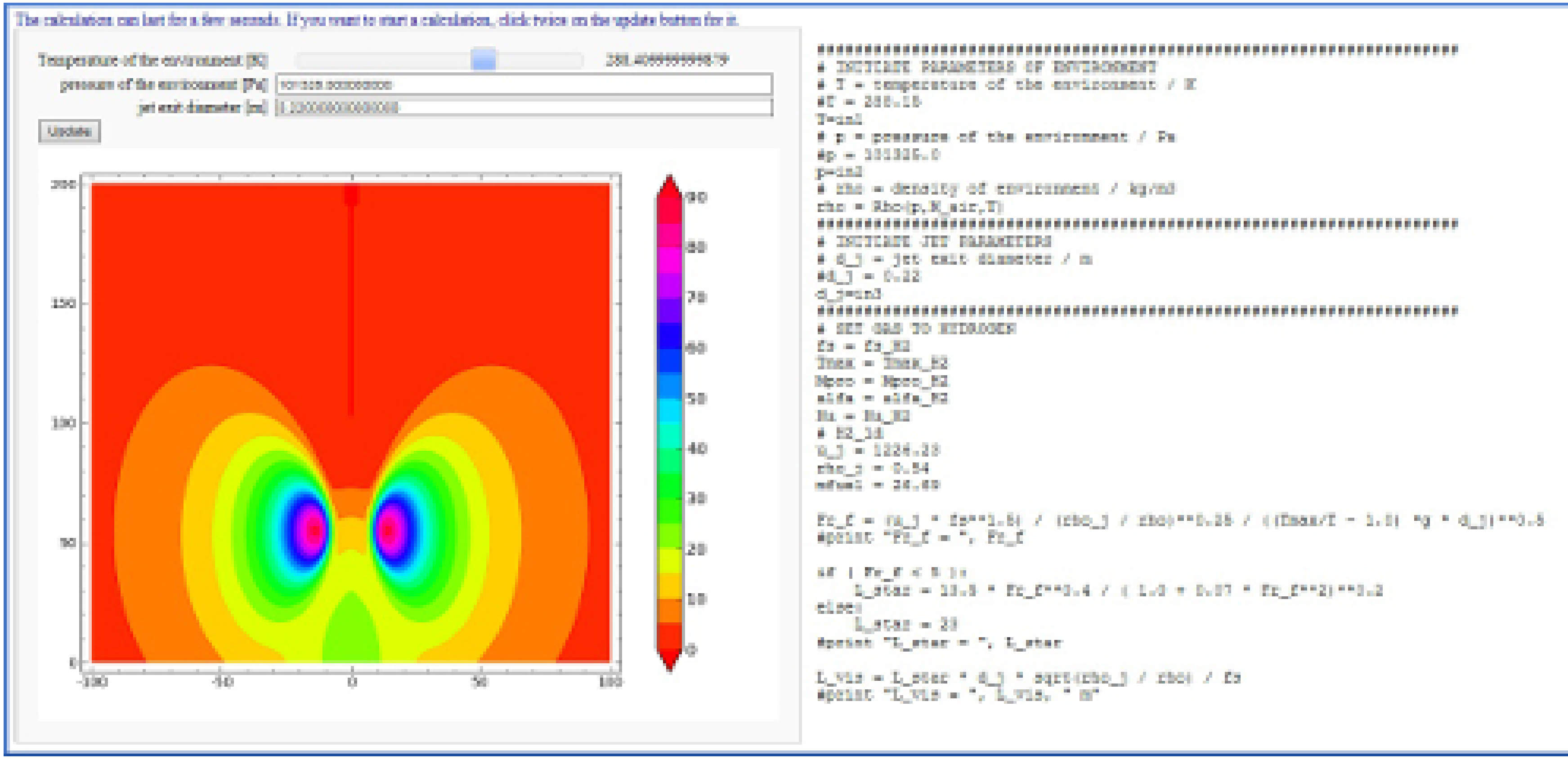
INPUT VALUES

Pressure in tank:	700.0	[bar]
Hydrogen temperature in reservoir:	240.0	[K]
Orifice diameter:	2.0	[m]
Ambient pressure:	650.0	[bar]

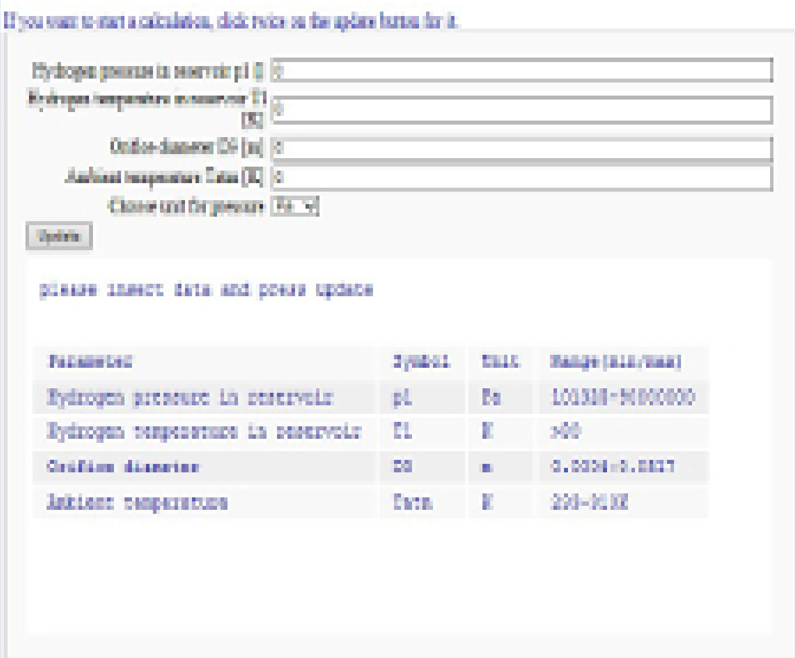
OUTPUT VALUES

Density in the tank:	45,80589 [kg/m^3]
Density at the orifice:	27,68593 [kg/m^3]
Pressure in orifice:	26240224,60627 [Pa]
Velocity in orifice:	1300,72777 [m/s]
Temperature at the orifice:	180,87414 [K]
Diameter of effective nozzle exit:	1,69233 [m]
Density in effective nozzle exit:	49,12897 [kg/m^3]
Velocity in effective nozzle exit:	1023,76062 [m/s]
Temperature in effective nozzle exit:	199,5842 [K]
Mass flow rate:	113134,56842 [kg/s]

e-Engineering (flame radiation)



e-Engineering (flame length and separation distance for jet fires)



If you want to start a calculation, click twice on the update button for it.

Hydrogen pressure in reservoir p1 []
Hydrogen temperature in reservoir T1 [K]
Orifice diameter D0 [m]
Ambient temperature Tatm [K]
Choose unit for pressure
Update

please insert data and press update

Parameter	Symbol	Unit	Range (min/max)
Hydrogen pressure in reservoir	p1	Pa	101325–50000000
Hydrogen temperature in reservoir	T1	K	>60
Orifice diameter	D0	m	[illegible]
Ambient temperature	Tatm	K	[illegible]

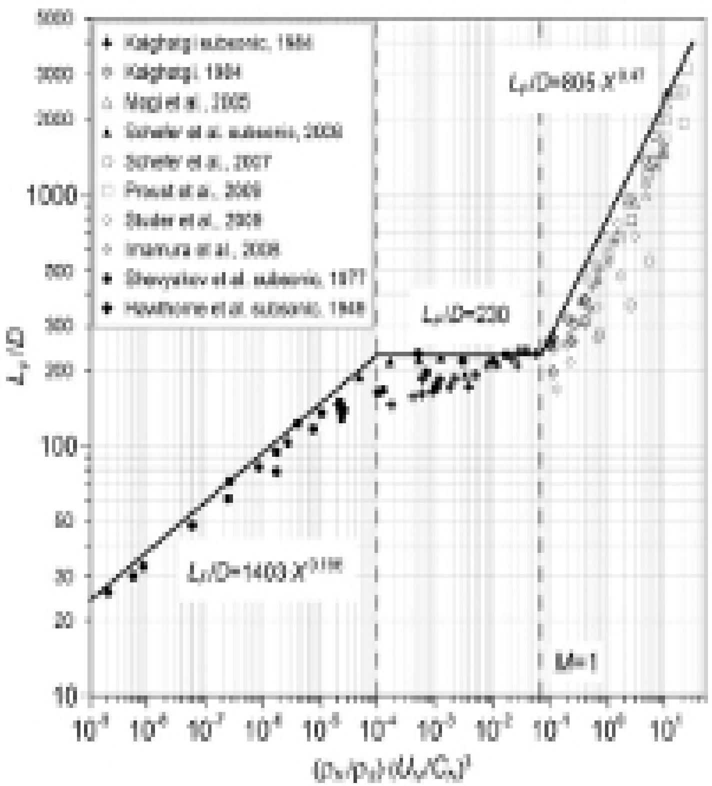


Figure 1 – Dimensionless (conservative) correlation for hydrogen jet flames (in formulas shown in figure "X" denotes the similarity group $(\rho_N/\rho_S)\cdot(U_N/C_N)^3$ (Molkov & Saffers, 2013)

e-Engineering (model for passive ventilation in an enclosure with one vent)

MODEL DESCRIPTION FOR STEADY-STATE HYDROGEN UNIFORM CONCENTRATION

The neutral plane (NP) is a horizontal plane where pressure inside and outside an enclosure are equal. In general case of passive ventilation of the enclosure with release of gas lighter than air, the neutral plane is located at or below the half height of the vent for steady-state conditions. Below NP air enters the enclosure and above NP lighter hydrogen-air mixture exits the enclosure (Fig. 1, left).

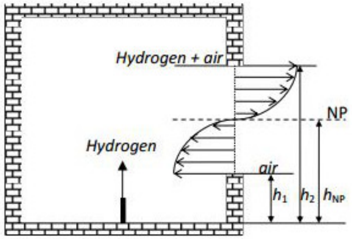


Figure 1. Flow velocity through the vent for a case when neutral plane is between the lower edge and half height of the vent.

1.STEADY-STATE HYDROGEN UNIFORM CONCENTRATION FOR THE GIVEN RELEASE RATE AND VENT SIZE

You can calculate the mass flow rate by using the hydrogen jet parameters model

If you want to start a calculation, click twice on the update button for it.

Hydrogen mass flow rate ṁ [kg/s] 0
Ambient pressure p_2 [choose] 0
Ambient temperature T_2 [K] 0
Vent height H [m] 0
Vent width W [m] 0
Discharge coefficient CD [-] 0.600000000
Choose unit for pressure Pa ▼
Update

please insert data

e-Engineering (computing mass balances at the anode & cathode of an operating PEM fuel cell)

If you want to start a calculation, click twice on the update button for it.

Cell surface area S [m2]
Number of cells n [ND]
Current density I [A/m2]
Stack temperature T [K]
Anodic ratio to stoichiometry [illegible] [ND]
Cathodic ratio to stoichiometry [illegible] [ND]
Anodic pressure (inlet) pa [Pa]
Cathodic pressure (inlet) pc [Pa]
Anodic pressure drop Δpa [Pa]
Cathodic pressure drop Δpc [Pa]
Anodic relative humidity HRa [%]
Cathodic relative humidity HRc [%]
Fraction of produced water that crosses the membrane α [ND]

Update

please insert some data

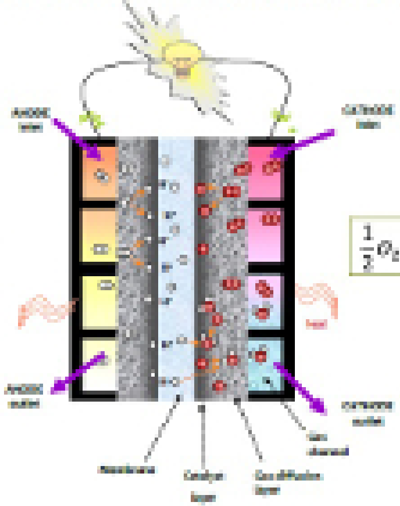
Parameter	Symbol	Unit	Range (min/max)
Cell surface area	S	m^2	5*10^-4 / [illegible]
Number of cells	n	ND	1 / 1000
Current density	I	$A*m^{-2}$	1 / 5*10^4
Stack temperature	T	K	293.15 / [illegible]
Anodic ratio to stoichiometry	[illegible]	ND	1.01 / 10
Cathodic ratio to stoichiometry	[illegible]	ND	1.2 / 10
Anodic pressure (inlet)	p_a	Pa	10^5 / 4*10^5
Cathodic pressure (inlet)	p_c	Pa	10^5 / 4*10^5
Anodic pressure drop	Δp_a	Pa	0 / 0.5*10^5
Cathodic pressure drop	Δp_c	Pa	0 / 0.5*10^5
Anodic relative humidity	HR_a	%	0 / 100
Cathodic relative humidity	HR_c	%	0 / 100
Fraction of produced water that crosses the membrane	α	ND	-1 / 1

Simple tool for computing mass balances at the anode & the cathode of an operating PEM fuel cell (CEA)

Introduction / description

From user data about the cell or stack operating conditions (for instance stoichiometric ratios, relative humidity), the model computes the input data that is needed for designing a fuel cell system or test bench (for instance mass flows for the different species, requirements for gases hydration).

$$H_2 \rightarrow 2H^+ + 2e^-$$



$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$$

Figure 1 – Simple schematic of a fuel cell

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e-Science (samples of tools)

Thermo-physical properties of Hydrogen

Release and dispersion phenomena

- e-Science
  - Property tools
    - 1. Hydrogen physical properties using state of EOS to calculate density, enthalpy, entropy, specific heats, etc. as functions of pressure, temperature and vapor quality
    - 2. The Abel-Noble EOS to
  - Electrochemistry tools
    - 1. Fundamental electroch
  - Storage tools
    - 1. Comsol Multiphysics for simulation of tanks and integrated systems “tank-FC”
  - FC tools
    - 1. Modelling of transport processes in electr
  - HyFOAM
    - 1. Release and dispersion of horizontal under-expanded hydrogen jet (HSL)
    - 2. Large scale deflagration in the open atmosphere (Fraunhofer ICT)
    - 3. Blast wave and fireball from high-pressure tank rupture in a fire (Weyandt)
    - 4. Hydrogen/helium dispersion in vented enclosures (CEA)

Blast waves and fireball from high pressure tank rapture

Hydrogen/Helium dispersion in vented enclosures

e-Science (explicit sample)

- Normal thermo-physical properties of hydrogen using the NIST-EoS, (Helmholtz free energy based)

- Obtain properties in the gas-liquid-supercritical range as function of P, T
- Level of complexity high
- Code built in Java, by NCSRD

- **J. W. Leachman, R. T. Jacobsen, S. G. Penoncello, and E. W. Lemmon, “Fundamental Equations of State for Parahydrogen, Normal Hydrogen, and Orthohydrogen,” J. Phys. Chem. Ref. Data, vol. 38, no. 3, p. 721, 2009**

Description

$$\alpha(\tau,\delta)=\alpha^0(\tau,\delta)+\alpha^r(\tau,\delta) \qquad \tau=\frac{T_c}{T} \qquad \delta=\frac{\rho}{\rho_c}$$

$$\alpha^0=\ln\delta+1.5\ln\tau+a_1+a_2\tau+\sum_{k=3}^{N}a_k\ln[1-\exp(b_k\tau)]$$

$$\alpha^r(\tau,\delta)=\sum_{i=1}^{l}N_i\delta^{d_i}\tau^{t_i}+\sum_{i=l+1}^{m}N_i\delta^{d_i}\tau^{t_i}\exp(-\delta^{p_i})$$

$$+\sum_{i=m+1}^{n}N_i\delta^{d_i}\tau^{t_i}\exp[\varphi_i(\delta-D_i)^2+\beta_i(\tau-\gamma_i)^2]$$

$$P(T,\rho)=\rho RT\left[1+\delta\left(\frac{\partial\alpha^r}{\partial\delta}\right)_\tau\right] \qquad Z(T,\rho)=\frac{P}{\rho RT}=1+\delta\left(\frac{\partial\alpha^r}{\partial\delta}\right)_\tau$$

Complexity: Iterations required to find ρ from P, T.

Description (continued)

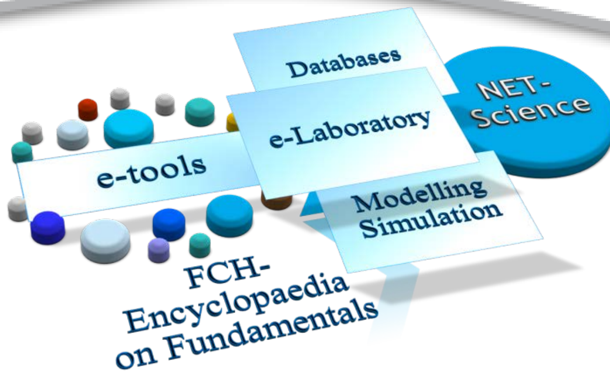
$$h(T,\rho) = RT\left\{\tau\left[\left(\frac{\partial\alpha^0}{\partial\tau}\right)_\delta + \left(\frac{\partial\alpha^r}{\partial\tau}\right)_\delta\right] + \delta\left(\frac{\partial\alpha^r}{\partial\delta}\right)_\tau + 1\right\}$$

$$s(T,\rho) = R\left\{\tau\left[\left(\frac{\partial\alpha^0}{\partial\tau}\right)_\delta + \left(\frac{\partial\alpha^r}{\partial\tau}\right)_\delta\right] - \alpha^0 - \alpha^r\right\}$$

$$c_p(T,\rho) = c_v + R\frac{\left[1 + \delta\left(\frac{\partial\alpha^r}{\partial\delta}\right)_\tau - \delta\tau\left(\frac{\partial^2\alpha^r}{\partial\delta\partial\tau}\right)\right]^2}{\left[1 + 2\delta\left(\frac{\partial\alpha^r}{\partial\delta}\right)_\tau + \delta^2\left(\frac{\partial^2\alpha^r}{\partial\delta^2}\right)_\tau\right]}$$

$$w(T,\rho) = \sqrt{\frac{RT}{M}\left[1 + 2\delta\left(\frac{\partial\alpha^r}{\partial\delta}\right)_\tau + \delta^2\left(\frac{\partial^2\alpha^r}{\partial\delta^2}\right)_\tau - \frac{\left[1 + \delta\left(\frac{\partial\alpha^r}{\partial\delta}\right)_\tau - \delta\tau\left(\frac{\partial^2\alpha^r}{\partial\delta\partial\tau}\right)\right]^2}{\tau^2\left[\left(\frac{\partial^2\alpha^0}{\partial\tau^2}\right)_\delta + \left(\frac{\partial^2\alpha^r}{\partial\tau^2}\right)_\delta\right]}\right]}$$

General Objectives



- Development of an e-Educational Platform
  subdivided into:
- e-Learning
  - Conventional Learning Management System (LMS)
  - Technical features to support users concerning communication, planning, exchange of documents, etc.
  - Quality assurance (probably review)
  - Guidelines
- e-Repository of FCH relevant information
  - Database
  - Documentations
  - e-books ?
  - Guidelines

E-Learning (explicit example)

- Educational materials
  - Course materials
  - Survey of existing course materials

- Specific Courses (Master Courses) in collaboration with **TeacHy**
  - Course Curricula (University level)
  - Content descriptions (based on modules)
  - Specific educational course materials
  - List of European Universities providing the master course (faculties, professors, lectures, etc.)
  - Access for students and teachers (lectures)

- e-Learning for Industrial Use
  - Typical industrial demands
  - Industrial level (technicians and engineers)
  - Facing industrial problems

E-Learning (more specific)

- Provide a comprehensive platform for online courses (MOOCs) for teaching on technologies on various levels (from vocational to academic education) with innovative features compared to existing online education platforms
- Provide an overview and incorporate existing educational materials and important players in the field of fuel cells and hydrogen, industry and academia
- Provide online courses as first examples in relevant areas for the sector and analyze their impact. Suggested areas are (subject to Advisory Board discussion):
  - Basis to hydrogen (physical (also thermodynamically) and chemical behavior, economic and ecological aspects)
  - Basic processes of hydrogen production and technologies
  - Transportation, storage and handling of hydrogen as an energy carrier
  - Complete Fuel Cell technology, systems and applications
- Start compiling/hosting online courses/digital from other education and training institutions beyond the NET-Tools consortium
- Develop tools and guidelines for acceptance and certification of online/digital education

E-Infrastructure

Technical Realisation	Implementation	Exploitation

WP2
Specification and Development of NET-Tools digital Infrastructure

WP3 e-Laboratory

WP4 e-Learning and Education Materials

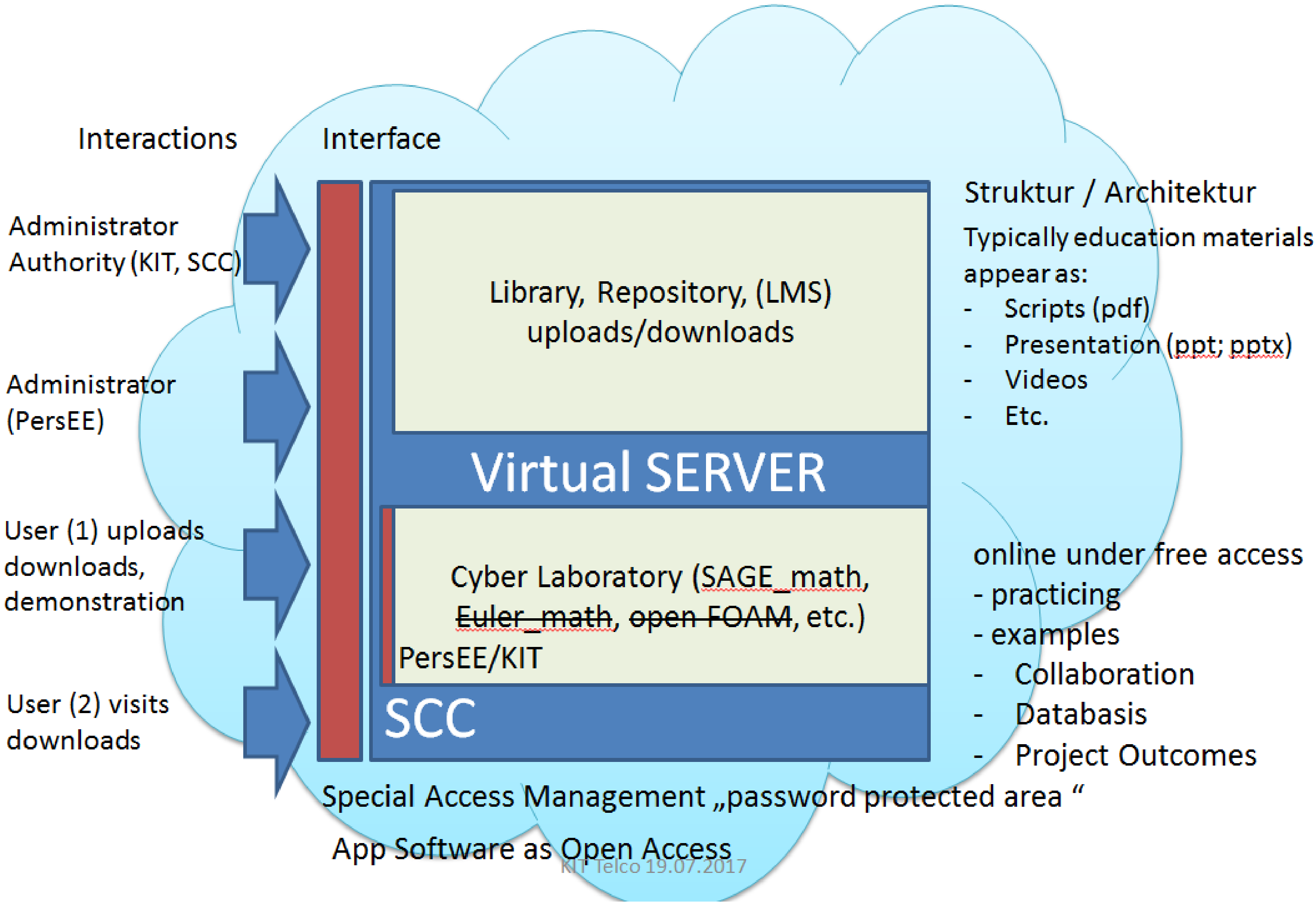
WP5
Networking

Dissemination
Knowledge
Experience

- Expert Workshop
- Educational Schools
- Flying Teachers
- International Collaboration

WP1 Consortium Management, Project Monitoring, Business Strategy

E-Infrastructure



Direct Collaboration and Inputs

- HySafe (Network of Excellence)
- HyFOAM
- H2FC (Research Infrastructure Project)
- SUSANA Project (FCH-Joint Undertaking)
- TeacHy (FCH-Joint Undertaking)
- International Institutions (e.g. DOE, Japan)
- Hydrogen Europe (industry grouping)
- Hydrogen Europe Research (research grouping)
- others

Direct Collaboration and Inputs

- Expert Workshop (2018)
  - Stakeholders from Industry
  - Stakeholders from Academia
  - Advisory Board Members
  - Others
- Two Educational Schools (2018 and 2019)
  - To enrol and test NET-Tools e-platform on practical level (in operando)
  - Feedback for further improvement and development
- Flying Teachers
  - To enrol and test the acceptance of new teaching strategy in combination with NET-Tools
  - H2FC (Research Infrastructure Project)
- Newsletter

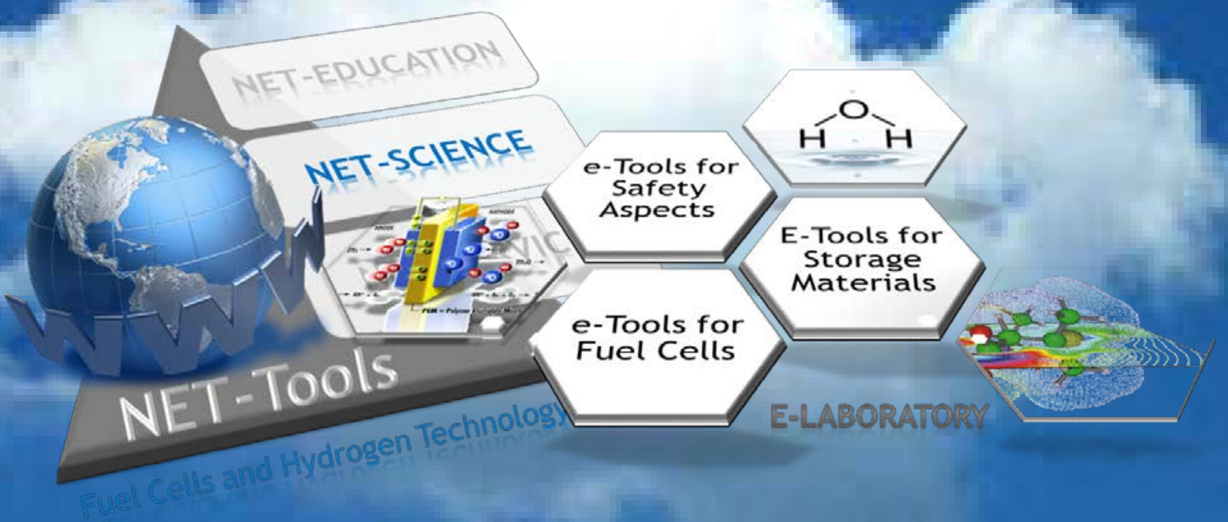
NET-Tools Conclusions

Development and compilation of specific e-tools

Development of e-Laboratory (scientific and engineering basis)

Development of e-Education (repository and LMS)

Development of e-Platform (cloud based) to provide e-Laboratory and e-Education under free access



TO PROVIDE an EUROPEAN DIGITAL PLATFORM to the FCH Community

NET-Tools Consortium

Acronym	KIT coordinator leader WP 1	Membership
KIT	Karlsruher Institute of Technology GERMANY (KIT) Research Organisation	ON.ERGHY
Acronym	PersEE leader WP 2	
PersEE	PersEE FRANCE Small and Medium Enterprise (SME)	Hydrogen Europe
Acronym	NCSRD	
	National Center For Scientific Research DEMOKRITOS GREECE University (Higher Education)	ON.ERGHY
Acronym	UU leader WP 3	
Ulster University	University of Ulster UNITED KINGDOM University (Higher Education)	ON.ERGHY
Acronym	DTU leader WP 4	
DTU	Danmarks Tekniske Univeritet DENMARK University (Higher Education)	ON.ERGHY
Acronym	IEES leader WP 5	
IEES	Bulgarian Academy of Science **BULGARIA** Institute of Electrochemistry and Energy Systems University (Higher Education)	ON.ERGHY
Acronym	UNIPG	
	Università Delgi Studi di Perugia ITALY University (Higher Education)	ON.ERGHY
Acronym	EE leader industrial advisory board	

Basic Project Data and Acknowledgement

- Grant agreement No: **736648**
- Action acronym: **NET-Tools**
- Action full title: **Novel Education and Training Tools based on digital applications related to Hydrogen and Fuel Cell Technology**
- Topic: **Novel education and training tools**
- Type of action: **Coordination & support action**
- Granting authority: **Fuel Cells and Hydrogen 2**
- Action duration (in months): **36**
- Starting Date of Action: **1 March 2017**
- **NET-Tools gets funding from**

FCH | FUEL CELLS AND HYDROGEN JOINT UNDERTAKING


NET-Tools
e-tools for education in modern FCH-technology
Created by Olaf Jedicke