Development of PEM Fuel Cell Stack Reference Test Procedures for Industry Stack-Test

(FCH-JU GA: 303345)

Ludwig Jörisssen
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Germany
http://stacktest.zsw-bw.de

PROJECT OVERVIEW

- Call topic (e.g. SP1-JTI-FCH.2011.5.4)
- Application Area Cross Cutting Issues
- Duration: 01.09.2012 to 31.08.2015
- Total Budget: 5 638 T€
  FCH JU contribution: 2 910 T€
- 11 partners
- Development and validation of harmonized test procedures to assess performance, endurance, safety and environmental properties of polymer electrolyte membrane fuel cell stacks.
- The project has finished 31.08.2015

PROJECT TARGETS AND ACHIEVEMENTS

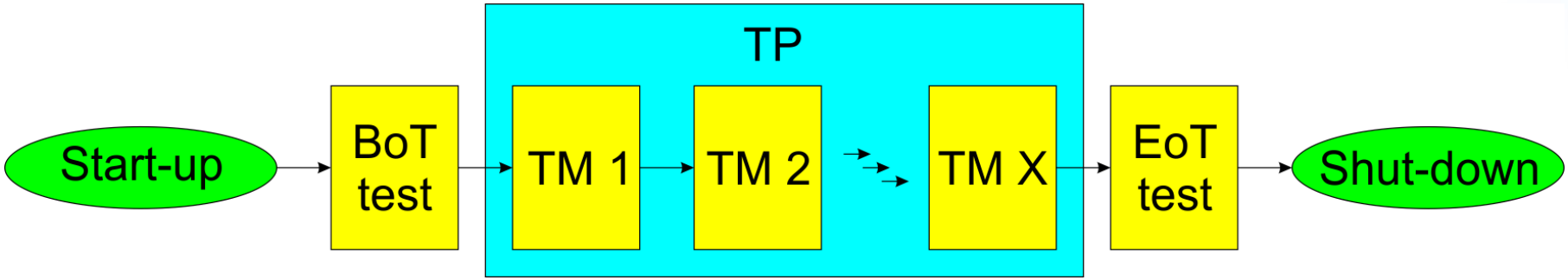
Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
MAIP			
Development of a specific technology assessment framework	Definition and validation of Test Modules and Test Programs for PEM fuel cell stacks in two revisions.	Stack Test Modules and Test Programs for performance, endurance, and safety were written and finally validated.	Use of Test Modules and Test Programs as basis of testing within R&D-programs and transfer to international standardization
RCS strategy coordination	Liaison with Standard Developing Organizations. If deemed necessary initiation of new work item proposals.	Assessment of international standards for testing PEM fuel cell stacks. Preparation of a new work item proposal on PEFC-stacks performance testing	New work item proposal submitted to IEC TC 105

PROJECT TARGETS AND ACHIEVEMENTS

Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
AIP			
Performance, endurance, efficiency and safety tests under regular and harsh environments	Development of generic Test Modules and application oriented Test Programs for performance, endurance, and safety tests.	Test Modules and Test Programs were defined and validated in two stages. A proposal how to treat efficiency testing on a stack level has been developed	Use of Test Modules an Test Programs in other R&D-projects. Proposal to industry and international standardization.
Accelerated lifetime tests	Where possible combine output to a "Zero" version to accelerated lifetime testing.	Durability Test Program has been carried out.	Contribution to the understanding of degradation effects

PROJECT TARGETS AND ACHIEVEMENTS

- Develop and validate generic test modules (TM)
  - Variation of one Test Input Parameter (TIP)
  - Measurement of different Test Output Parameters (TOPs)
- Develop and validate application specific test programs (TP)
  - Combination of TMs to TP
  - Recommend specific parameter set for different applications
  - Combine the variation of different Test Input Parameters (TIP)



PROJECT TARGETS AND ACHIEVEMENTS

- Work based on previous projects FCTESTNET, FCTES^{QA}, and FCTEDI. Reviewed, confirmed, and further improved methodology to describe PEM fuel cell stack testing.
- Assessment of international standards of PEM fuel cell stack testing given and updated.
- Feedback from stakeholders has been taken into account in writing the test modules and test programs.
  - Provision of a master document describing fundamental issues
  - One page abstract for each test module and test program (to be used by experts)
- Consistent test results achieved during validation experiments.
  - 2 types of PEM fuel cell stacks supplied to each partner for carrying out validation experiments.
- Series of documents are available from the web-page.
  - Still lots of paper but with the effort to avoid ambiguities
- Transfer of methodology to other projects where the partners are involved
  - Contribution to European effort on single cell testing
- Four dissemination workshop held

PROJECT TARGETS AND ACHIEVEMENTS

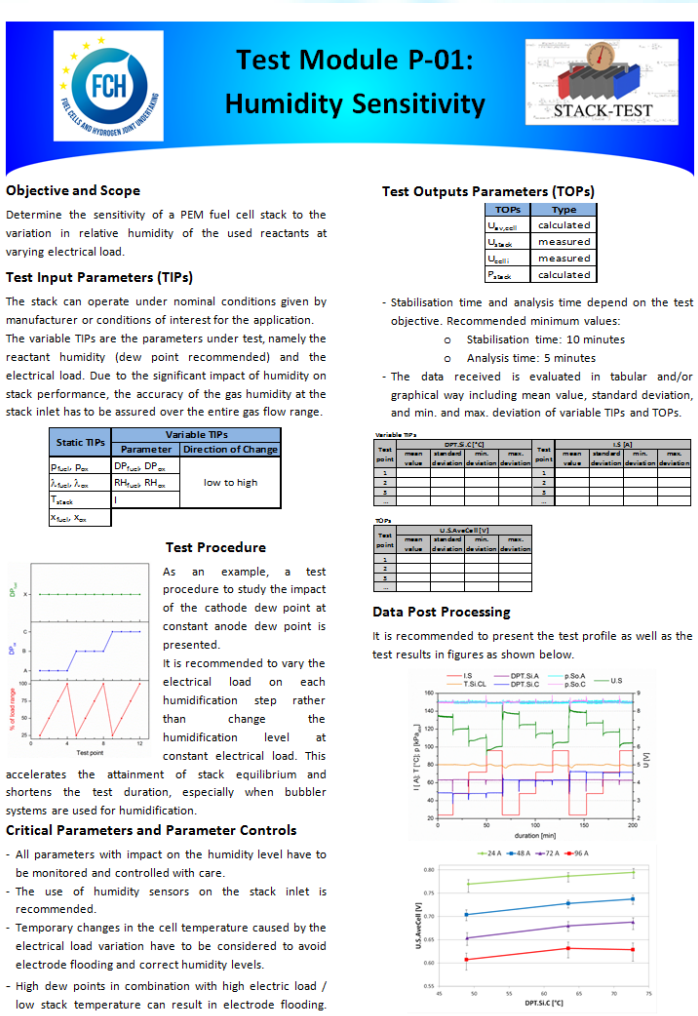
Structure of Test Modules and Test Programs

One page Abstract for Experts

- Summarize test
- Input and Output parameters
- Proposed data analysis and reporting format

Deatiled Description:

- Objectives and Scope
- Test setup
- Test execution
- Parameters and boundaries
- Reporting format



Test Module P-01: Humidity Sensitivity

STACK-TEST

Objective and Scope

Determine the sensitivity of a PEM fuel cell stack to the variation in relative humidity of the used reactants at varying electrical load.

Test Input Parameters (TIPs)

The stack can operate under nominal conditions given by manufacturer or conditions of interest for the application. The variable TIPs are the parameters under test, namely the reactant humidity (dew point recommended) and the electrical load. Due to the significant impact of humidity on stack performance, the accuracy of the gas humidity at the stack inlet has to be assured over the entire gas flow range.

Static TIPs	Variable TIPs	
	Parameter	Direction of Change
$p_{t,cell}$, p_{ex}	$DP_{t,cell}$, DP_{ex}	low to high
$\lambda_{t,cell}$, λ_{ex}	$RH_{t,cell}$, RH_{ex}	
T_{stack}	I	
$x_{t,cell}$, x_{ex}		

Test Procedure

As an example, a test procedure to study the impact of the cathode dew point at constant anode dew point is presented.

It is recommended to vary the electrical load on each humidification step rather than change the humidification level at constant electrical load. This accelerates the attainment of stack equilibrium and shortens the test duration, especially when bubbler systems are used for humidification.

Critical Parameters and Parameter Controls

- All parameters with impact on the humidity level have to be monitored and controlled with care.
- The use of humidity sensors on the stack inlet is recommended.
- Temporary changes in the cell temperature caused by the electrical load variation have to be considered to avoid electrode flooding and correct humidity levels.
- High dew points in combination with high electric load / low stack temperature can result in electrode flooding.

Test Outputs Parameters (TOPs)

TOPs	Type
$U_{av,cell}$	calculated
U_{stack}	measured
$U_{cell,i}$	measured
P_{stack}	calculated

- Stabilisation time and analysis time depend on the test objective. Recommended minimum values:
  - Stabilisation time: 10 minutes
  - Analysis time: 5 minutes
- The data received is evaluated in tabular and/or graphical way including mean value, standard deviation, and min. and max. deviation of variable TIPs and TOPs.

Data Post Processing

It is recommended to present the test profile as well as the test results in figures as shown below.

Contact Stack-Test:
Stacktest.zsw-bw.de

The research leading to these results has received funding from the **European Union Seventh Framework Programme** (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint Technology Initiative under grant n° 303445.

PROJECT TARGETS AND ACHIEVEMENTS

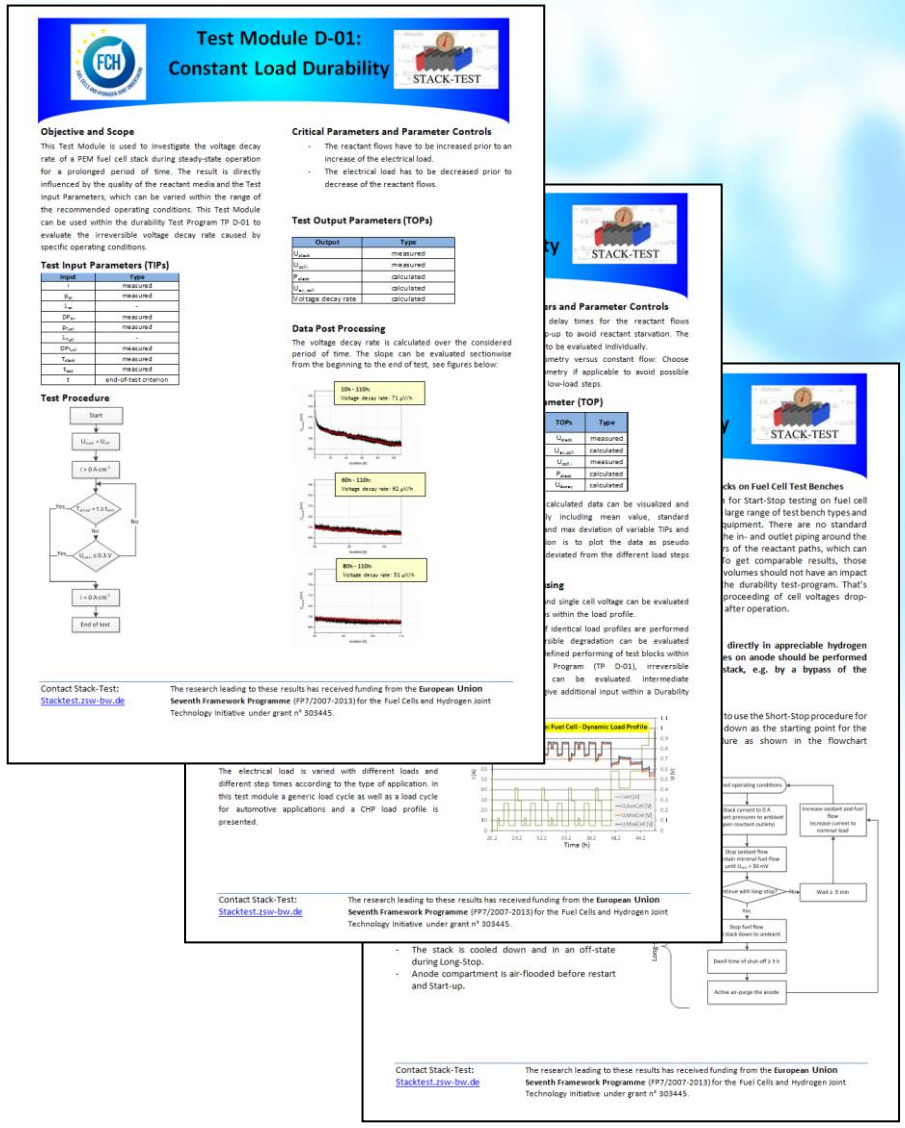
Recommendation of Test Operating Conditions (TOC) for different application areas:

- Based on the state-of-the-art PEFC technologies
- Input from Industrial Advisory Board of Stack-Test and additional OEMs

Parameter		Automotive application				Stationary		Portable Generators	
Name	Symbol	Propulsion [1]	Propulsion [2]	Range extender [3]	APU [4]	Residential CHP [5]	Backup Power [6]	H_2-PEMFC [7]	DMFC [8]
Stack temperature (Coolant inlet)	T_{stack}	80 °C	68 °C	75 °C	75 °C	70 °C	65 °C	50 °C	70 °C
Reactant inlet temperature	$T_{gas,in}$	85 °C	73 °C	80 °C	80 °C	75 °C	70 °C	ambient	ambient
Fuel (H2) stoichiometry	λ_{fuel}	1.3	1.4	1.5	1.5	1.2	1.25	1.2	5.0
Oxidant (Air) stoichiometry	λ_{ox}	1.5	1.6	2	2.0	2.0	2	2	2.5
Fuel relative humidity	RH_{fuel}	50%	40%	80%	80%	80%	40%	50%	-
Dew point temperature fuel	DP_{fuel}	63.5 °C	48.2 °C	69.5 °C	69.5 °C	65 °C	45.5 °C	36.5 °C	-
Oxidant relative humidity	RH_{ox}	30%	50%	80%	80%	80%	40%	ambient	ambient
Dew point temperature oxidant	DP_{ox}	52.6 °C	52.7 °C	69.5 °C	69.5 °C	65 °C	45.5 °C	ambient	ambient
Fuel outlet pressure	p_{fuel}	220 kPa_{abs}	220 kPa_{abs}	150 kPa_{abs}	150 kPa_{abs}	ambient	120 kPa_{abs}	150 kPa_{abs}	ambient
Oxidant outlet pressure	p_{ox}	200 kPa_{abs}	200 kPa_{abs}	150 kPa_{abs}	150 kPa_{abs}	ambient	ambient	ambient	ambient

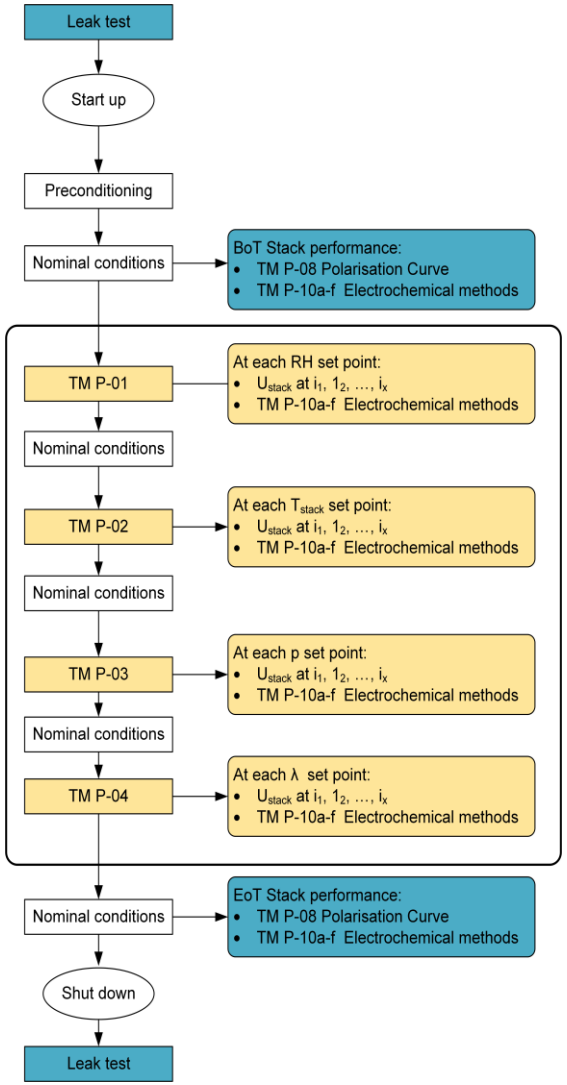
PROJECT TARGETS AND ACHIEVEMENTS

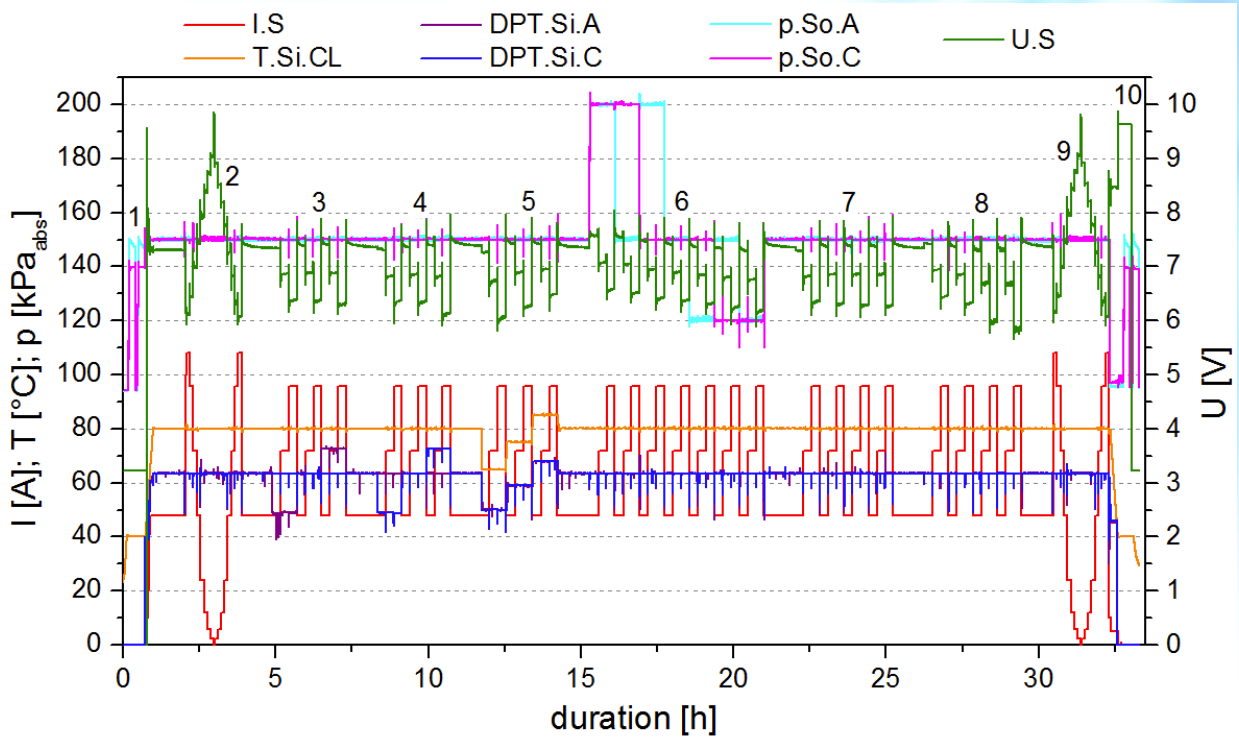
- Master-Document
  - Definitions
  - Requirements
- Performance Testing
  - 11 dedicated Test Modules
  - 5 Test Programs.
- Endurance Testing
  - 4 Test Modules
  - 1 Test Program
- Safety and Environmental Testing
  - 8 Test Modules
  - 3 Test Programs



PROJECT TARGETS AND ACHIEVEMENTS

Test Program TP P-02: Stack Performance Mapping





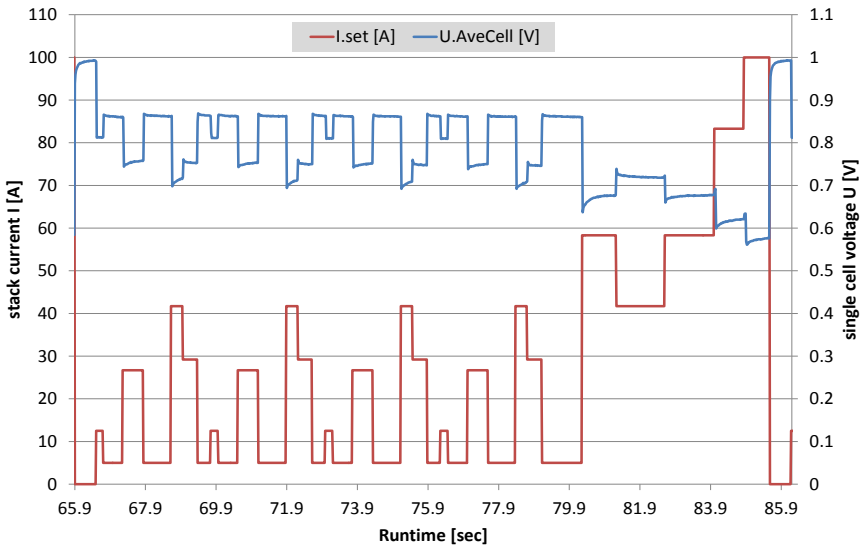
1: leakage BoT
2: PolCurve BoT
3: P-01aAnode Hum.
4: P-01b Cathode Hum.
5: P-02 Temperature
6: P-03 Pressure
7: P-04a Anode Lambda.
8: P-04b Cathode Lambda.
9: PolCurve EoT
10: Leakage EoT

PROJECT TARGETS AND ACHIEVEMENTS

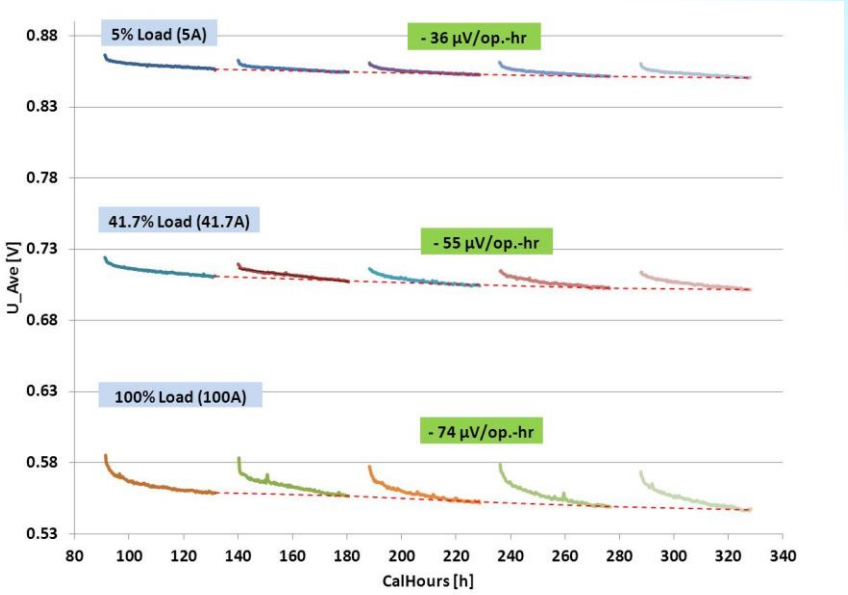
Progress Has Been Made But There Are Still Issues Remaining!

A way to represent „Degradation“ has been agreed upon, however, test-bench results need further validation in field systems.

‘Fuel Cell Dynamic Load Cycle‘:



Repetition of identical test blocks- Degradation investigation:



RISKS AND MITIGATION

- Analysis of Endurance Test Data revealed non linear behavior
  - Separation of reversible and irreversible degradation phenomena is complicated.
  - Processes involved in reversible degradation include cathode catalyst surface oxidation, water redistribution and anode catalyst surface poisoning.
  - First results indicate effect mitigation by controlled start-stop procedures
- Definition of Accelerated Lifetime Tests on stack level need a more in depth understanding and separation of reversible from irreversible degradation effects.

SYNERGIES WITH OTHER PROJECTS AND INITIATIVES

- Project builds on previous projects, particularly FCTESTNET, FCTEDI and FCTES^{QA}.
- One partner received national funding to cover differences of project cost and FCH-JU funding.

FCH and FP projects	Interaction and/or joint activities
AutoStack-CORE	Transfer of validated Test Modules and Test Programs
IMPACT	Support in test definition
IMPALA	Support in test definition
NanoCat	Support in test definition
SAPPHIRE	Support in test definition
SOCTESQA	Transfer of methodology and document exchange
HYCORA	Transfer of validated Test Modules and Test Programs

HORIZONTAL ACTIVITIES

- Training and education
  - PhD-students were working in the project
- Safety, regulations, codes & standards
  - A New Work Item Proposal (NWIP) on stack testing has been submitted to IEC TC-105
- General public awareness
  - A total of 4 public workshops have been organized

DISSEMINATION ACTIVITIES

- Contributions to more than ten national and international conferences
- Organization of four public workshops for stakeholders
- Four publications in peer reviewed journals
  - Further publications will follow

EXPLOITATION PLAN/EXPECTED IMPACT

- The project provided validated test modules and test programs to assess performance, endurance and safety / environmental related issues in PEM fuel cells at stack level.
  - Project results are used in other FCH-JU projects
  - Project results provide a basis for PEM fuel cell stack assessment
- The project triggered a New Work Item Proposal on PEM fuel cell stack testing in international standardization

Acknowledgement

Thank you very much for your kind attention!

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) for Fuel Cell and Hydrogen Joint Technology Initiative under Grant nº 303445 (Stack-Test).