Prenormative REsarch for Safe use of Liquid HYdrogen

Thomas Jordan, KIT; Donatella Cirrone, Ulster University

Hydrogen Liquefaction Symposium

27 September 2019, Perth, Australia

Pre-normative REsearch for Safe use of Liquid HYdrogen

Outline

- Motivation
- PRESLHY Overview
- WP3 Release
- WP4 Ignition
- WP5 Combustion
- Exploitation
- Closure

Motivation

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- Scale-up of existing and new applications increase H2 demand.
- Liquid hydrogen (LH2) provides **larger densities** and gains in **efficiency** and **potentially reduces risks** compared to compressed gaseous transport and storage
- Many **knowledge gaps** wrt accidental behavior of LH2 and **inconsistent** and **potentially over-conservative RCS** (e.g. NFPA 2 and EIGA)

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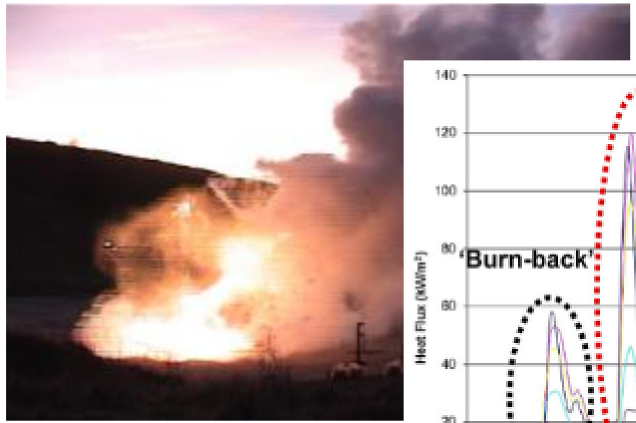
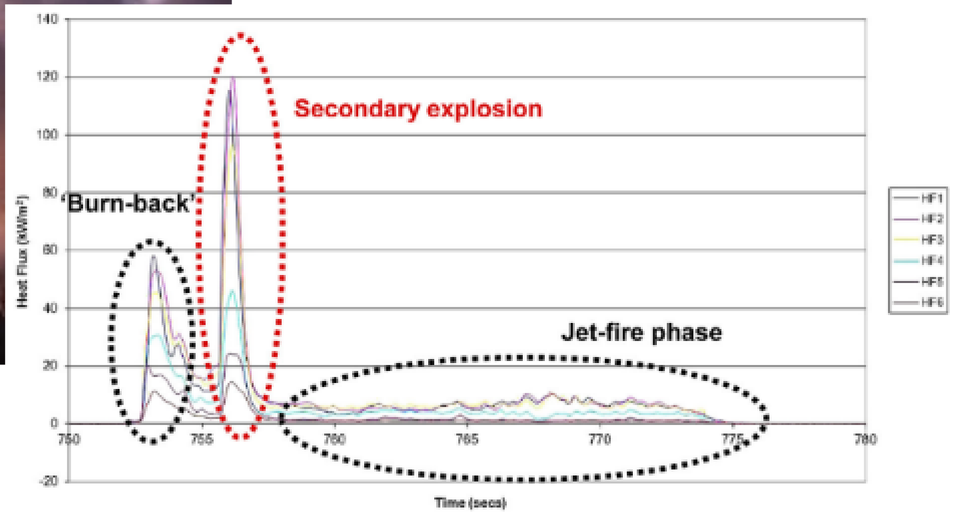
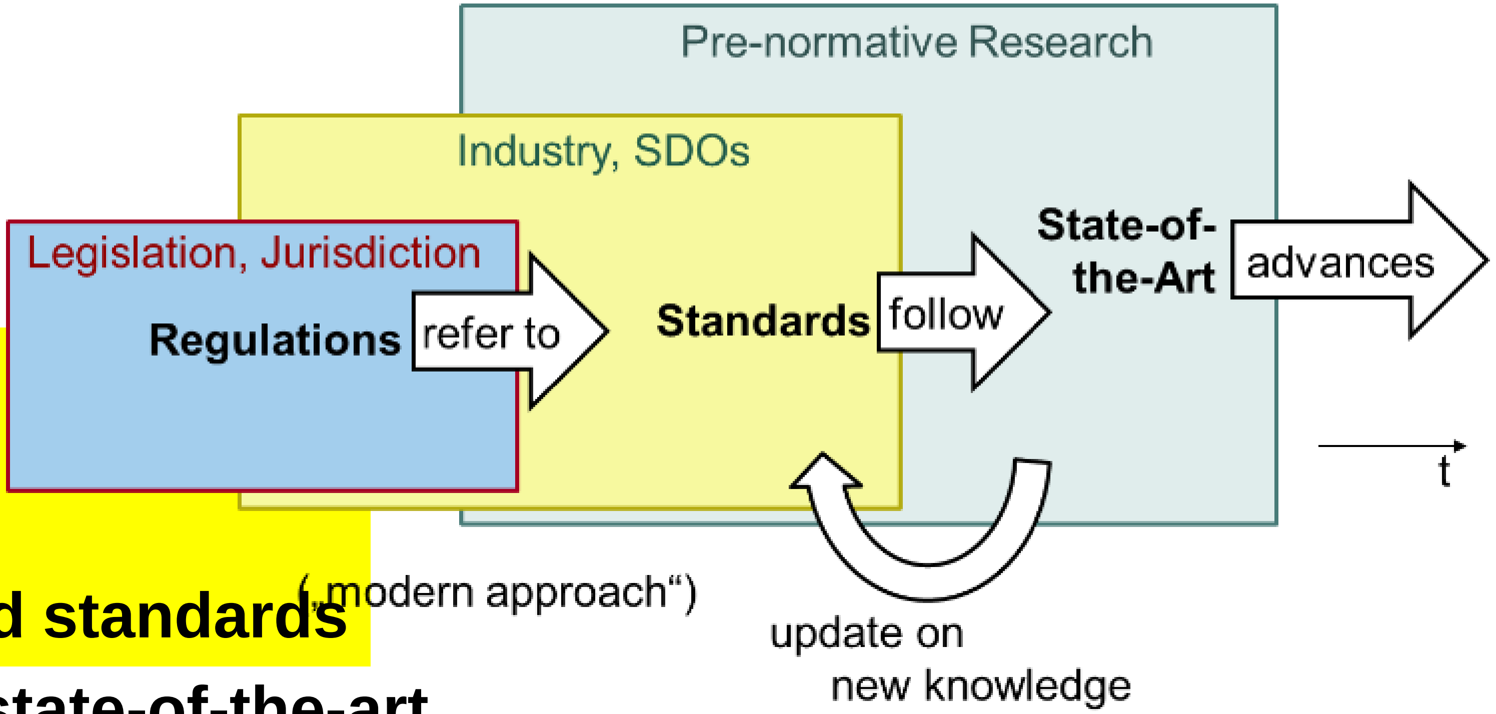



PRESLHY Objectives

- Report **initial state-of-the-art and knowledge gaps** with priorities wrt intended use of LH2
- Execute adjusted **experimental program** addressing release, ignition and combustion phenomena with highest priorities
- Document and publish detailed, aggregated and interpreted data in a FAIR way
- Develop **suitable models and engineering correlations** and integrate them in a suitable open risk assessment toolkit
- Provide **enhanced recommendations for safe design and operations** of LH2 technologies
- **Support international SDOs** in
  - **updating of existing standards** or
  - developing of **new international performance based and risk informed standards**
- Document and disseminate the **enhanced state-of-the-art**



Partners & Advisors

Partner	Short Name	Nation
Karlsruhe Institute of Technology	KIT	Germany
Air Liquide	AL	France
Health & Safety Laboratory	HSE	United Kingdom
International Association for Hydrogen Safety	HYSAFE	Belgium
INERIS	INERIS	France
National Center for Scientific Research "Demokritos"	NCSRD	Greece
Pro-Science GmbH	PS	Germany
University of Ulster	UU	United Kingdom
The University of Warwick	UWAR	United Kingdom

Advisor	Company	Nation
Andrei Tchouvelev	AVT, ISO TC 197	Canada
Christoph Haberstroh	Uni Dresden	Germany
Ethan Hecht	SNL	US
Derek Miller	Air Products	US
Etienne Studer	CEA	France
Franz Grafwallner	ET Energiesysteme	Germany
Herve Barthelemy	CEN/CENELEC	EU
John Khalil	IEA Hydrogen Task 37	US
Jens Franzen	Daimler	Germany
Julien Salvat	Toyota Motor Europe	Belgium
Karl Verfondern	Jülich	Germany
Klaus Schäfer	DLR	Germany
Lee Philips	Shell	UK
Olav Hansen	Lloyds	UK
Salvador Aceves	LLNL	US
Shoji Kamiya	KHI	Japan

External Networking / Dissemination

PRESLHY

Presentation planned for next meeting

HySafe (+ Hydrogen Safety Pa

RCS SCG

JRC (HIA

ISO TC 197

IEA Hydrogen Task

US DOE

ISO/PWI 24077: „Safe Use of LH2 in Non-Industrial Settings“ established on 6.12.2018

Presentation on 19.10.2018

ISO®

FCH – Fuel Cells and Hydrogen Joint Undertaking

WP1 – Management (KIT)

WP2 - Strategy (AL)

WP3 – Release & Mixing (NCSRD)

WP4 – Ignition (HSL)

WP5 – Combustion (KIT)

WP6 – Implementation (UU)

PRESLHY Advisory Board

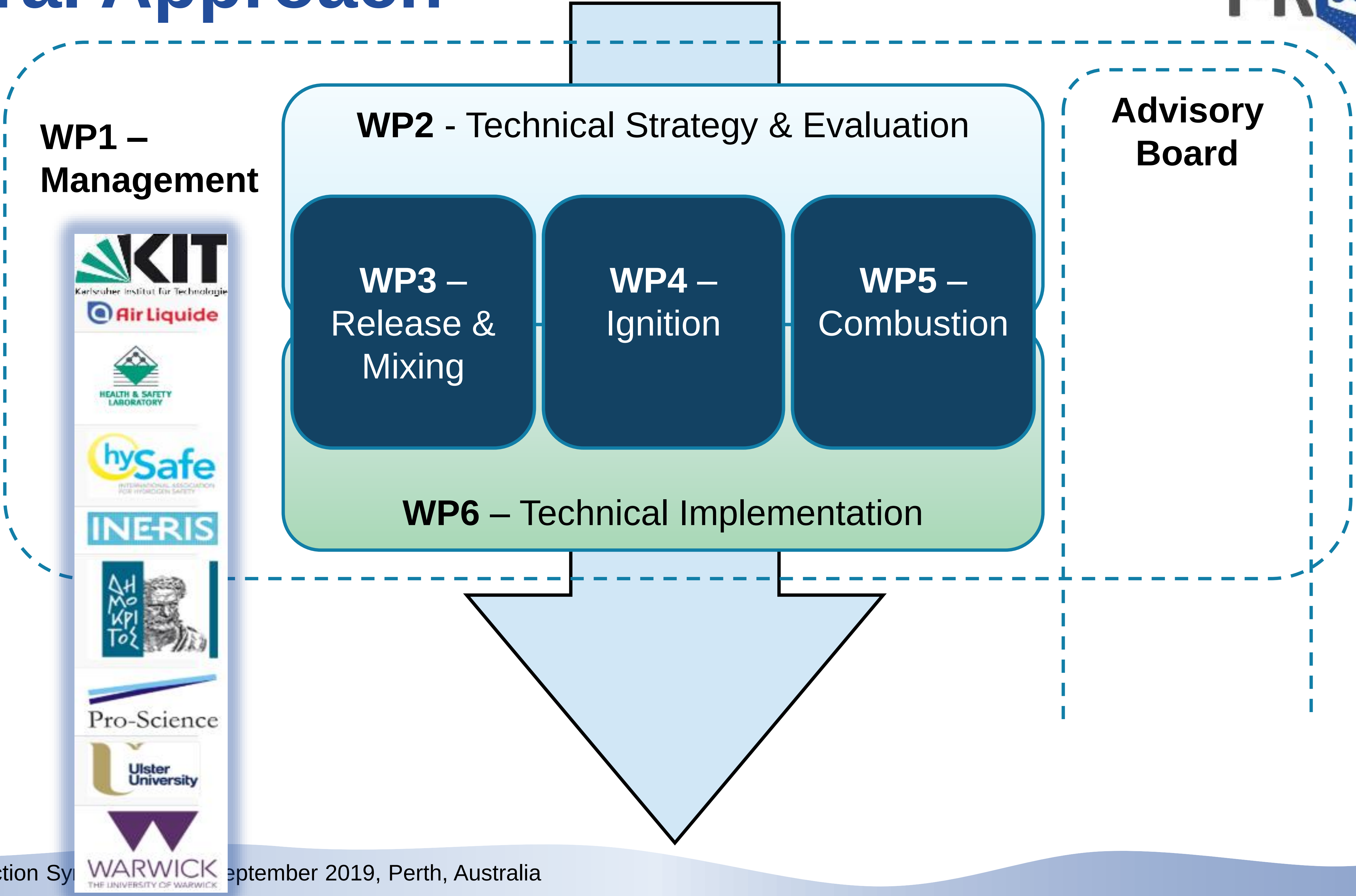
H2@Scale U.S. Department of Energy SNL

SH2IFT

GexCon, IFE, Equinor

KHI, Toyota

General Approach



WP2 - Refined Work Programme

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WP3 - RELEASE & MIXING

- Two-phase flow and dispersion
- Impinging and/or wall attached jets
- LH2 pool formation and evolution
- Wind effect on large-scale LH2 releases
- Release in congested/ confined spaces

WP4 - IGNITION

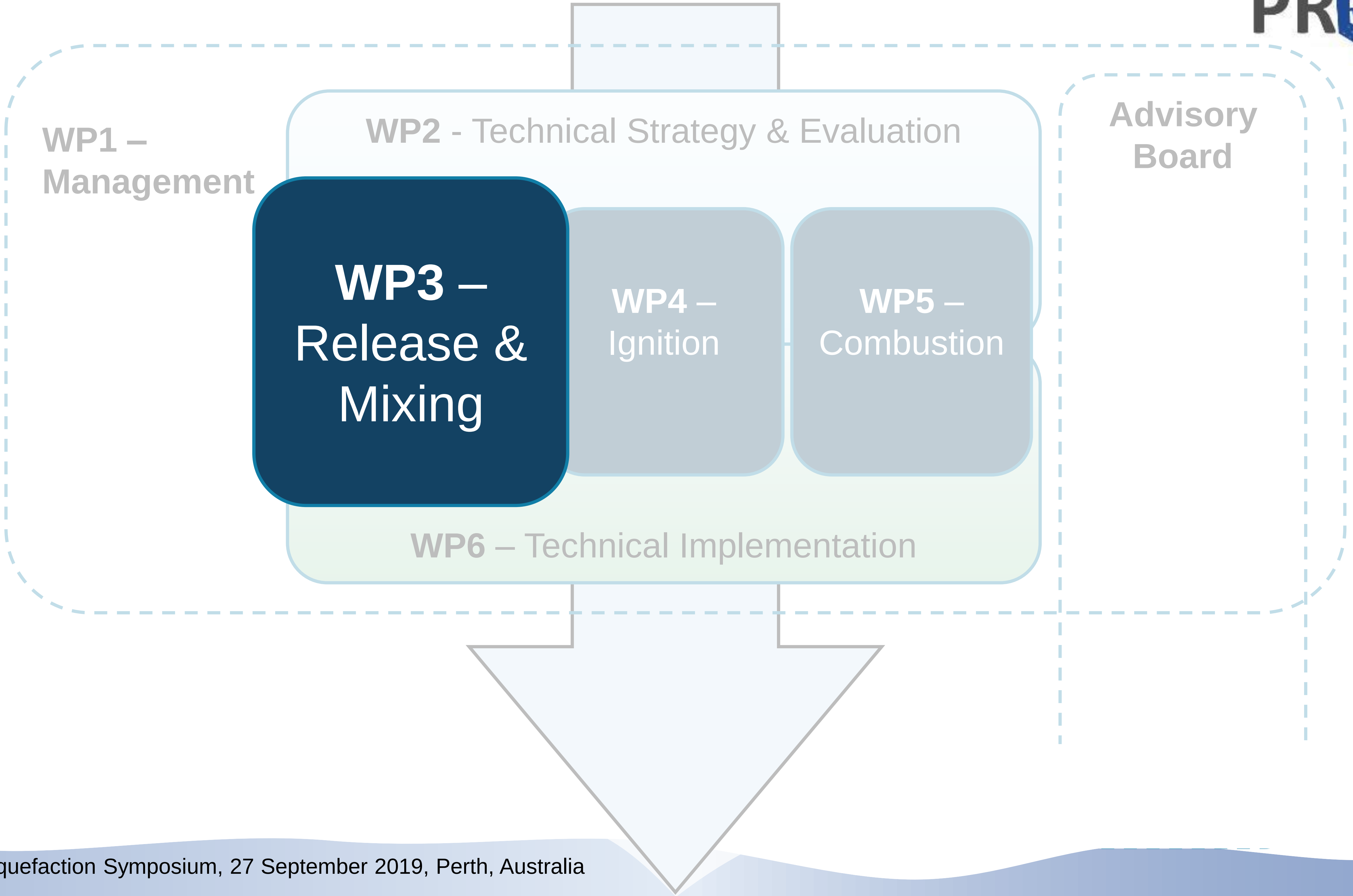
- Electrostatic charge in cold jet/plume
- LFL, UFL and MIE for cryogenic H2
- H2/condensed O2 phase mixtures
- LH2 pool ignition

WP5 - COMBUSTION

- Cryogenic and LH2 jet fires
- LH2 pool fires
- Flame acceleration FA and DDT
- Combustion in congested or confined areas
- BLEVE

ISO

Envisaged revision of ISO/TR 15916:2015 “Basic considerations for the safety of hydrogen” via ISO PWI24077


WP1 – Management
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Advisory Board
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WP4 – Ignition
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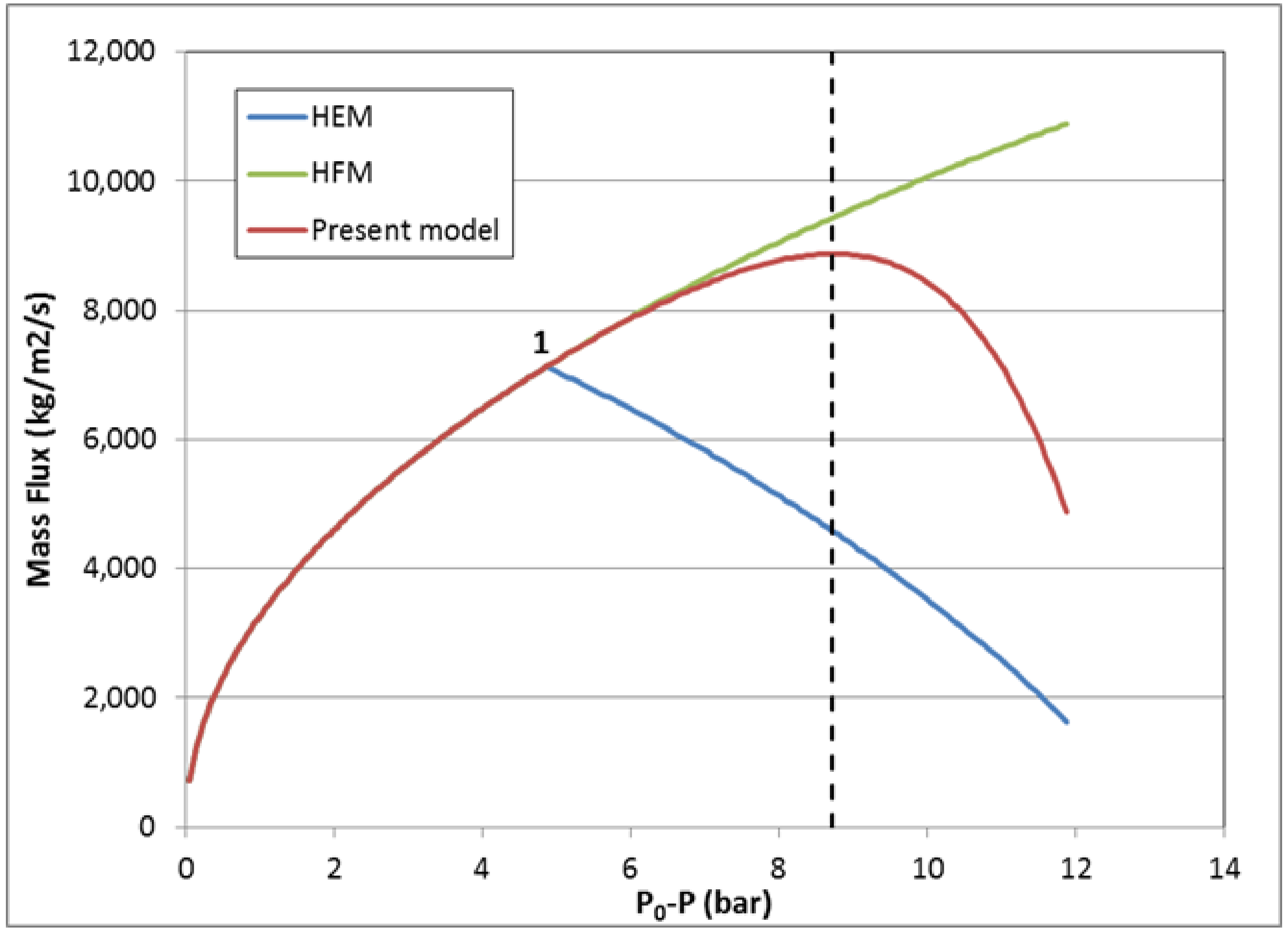
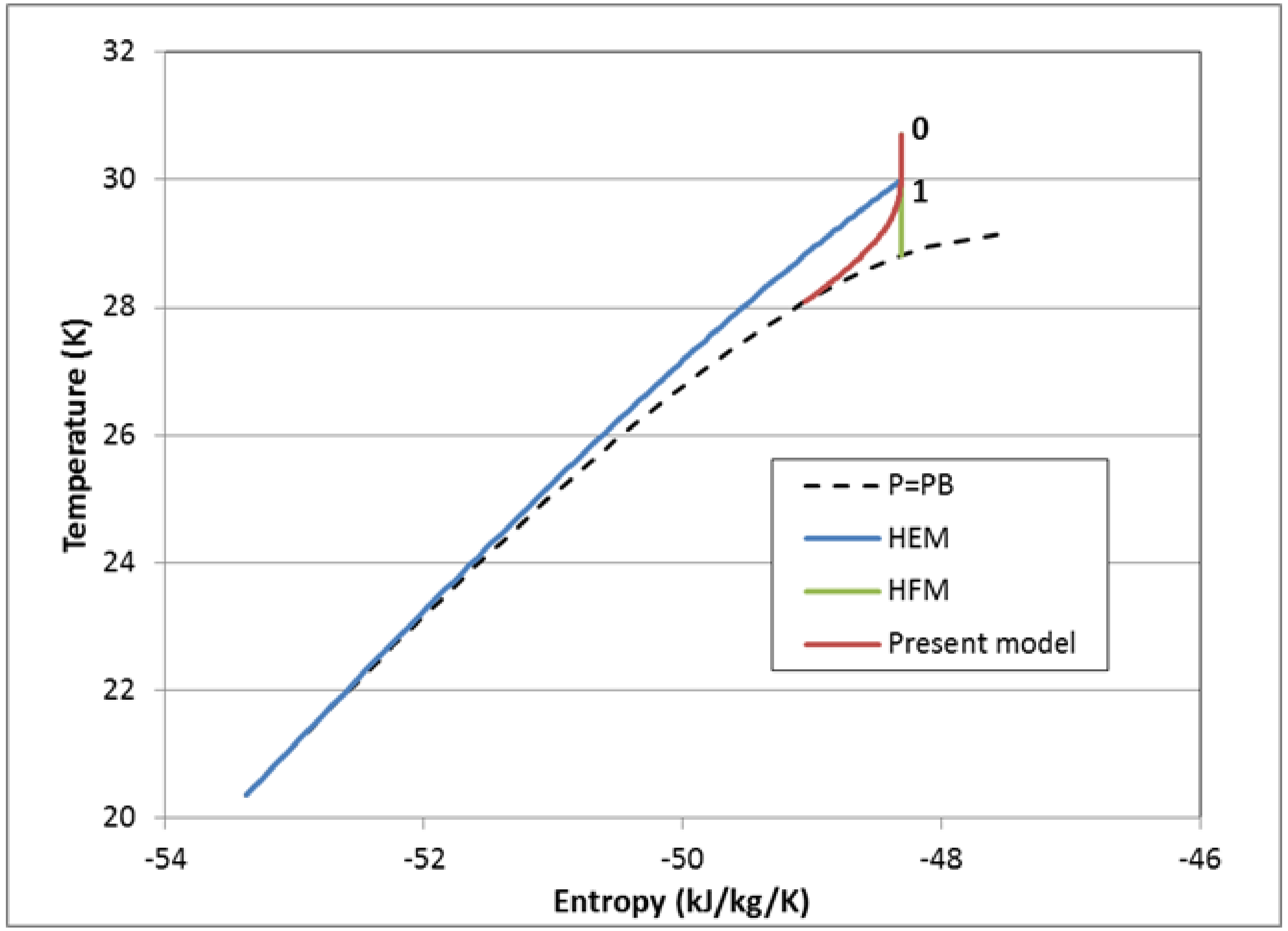
WP6 – Technical Implementation

Modelling HEM / HNEM Two-Phase Choked Flow

e.g. NASA test 1197 (P_0=12.9 bar, T_0=30.7 K)





PRESLHY

Benchmarking

- KIT / PS
  - Design and set-up of tests E3.1, E3.4
- HSL
  - Design of tests E3.5
- INERIS
  - Sharing of existing LHe experiments data
  - Excluded tests
    - test 0 for no humidity info
    - tests 1,2 for too large wind variation
    - tests 7-9 for no H1, H2, L info
  - Tests 3 and 6 selected for validation

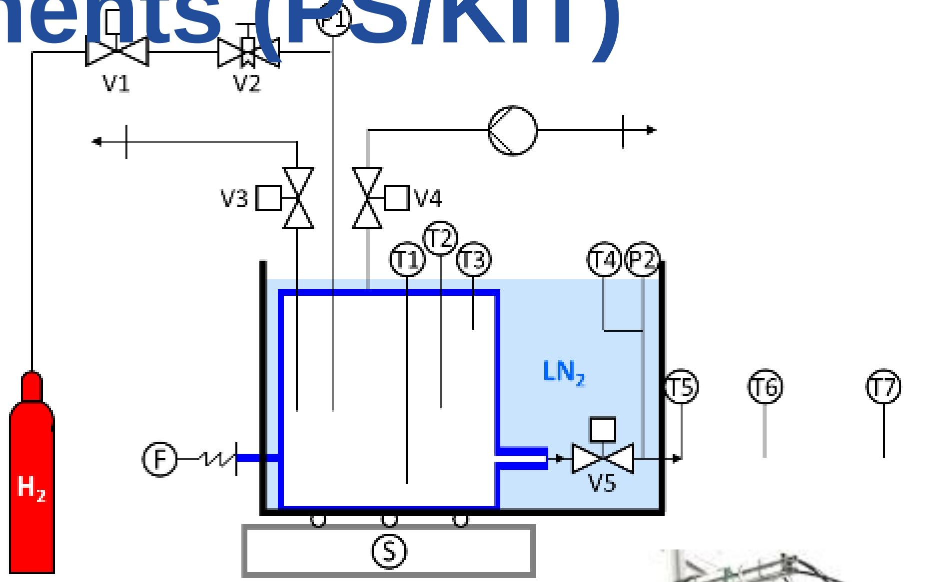
Issue n°	duration (s)	Mass flow rate (kg/s)	Wind speed (m/s) at 3 m height	Humidity (%)	Temp (°C)	H1 (m)	H2 (m)	L (m)
0	60	1,5	6	/	16	3	5	20
1	50	1,4	4,0±1,0	86	17	5	17	50
2	52	1,4	5,2±1,0	90	17	5	17	50
3	52	2,1	3,0±0,5	84	12	12	32	80
4	43	2,1	4,0±0,5	84	12	7	35	75
5	34	2,1	5,5±0,5	88	12	7	30	70
6	43	2,1	4,5±0,5	88	11	7	30	70
7	63	1,2	2,0±0,5	85	12			
8	65	1,2	2,0±0,5	85	12			
9	71	2,2	2,0±0,5	85	12			

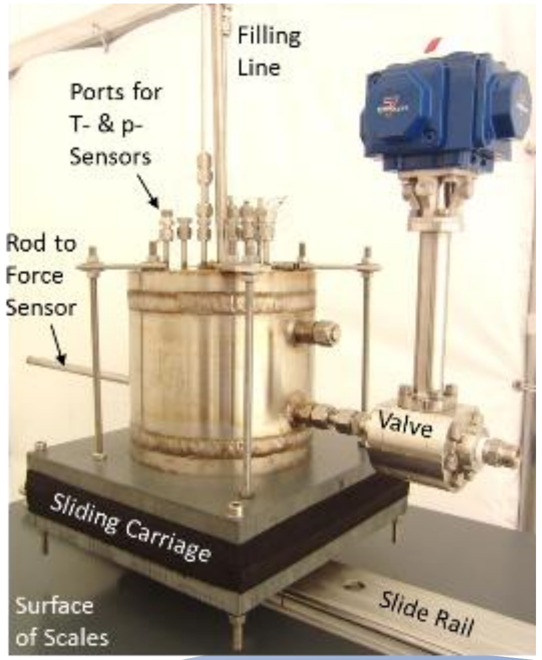
L the length of the cloud on the ground
H_1 the height of the base of the cloud
H_2 the height at the top of the cloud.

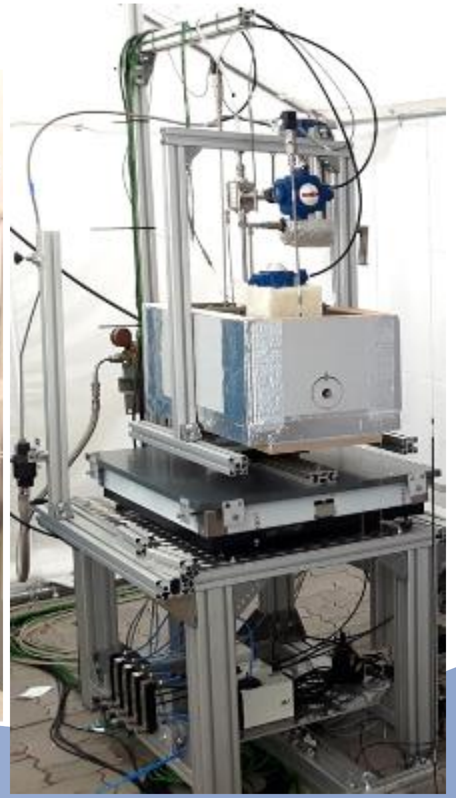
Experimental series E3.1a

Small Scale Multiphase Release experiments (PS/KIT)

- > 200 tests performed at DISCHA facility at HYKA / KIT
- Warm tests (ambient temp) and cold tests (77 K $T_{sat,LN2}$) where 2.81 L stainless steel vessel and release line cooled by bath of LN_2
- 4 nozzle diameters (0.5, 1, 2, 4 mm)
- 7 initial vessel pressures (5, 10, 20, 50, 100, 150, 200 bar)
- Every experiment was repeated at least 2 times (> 100 warm and ≈ 100 cold tests in total)
- Only single (gaseous) phase conditions at nozzle were achieved
- D3.4 delivered M18 and data for selected tests published in website

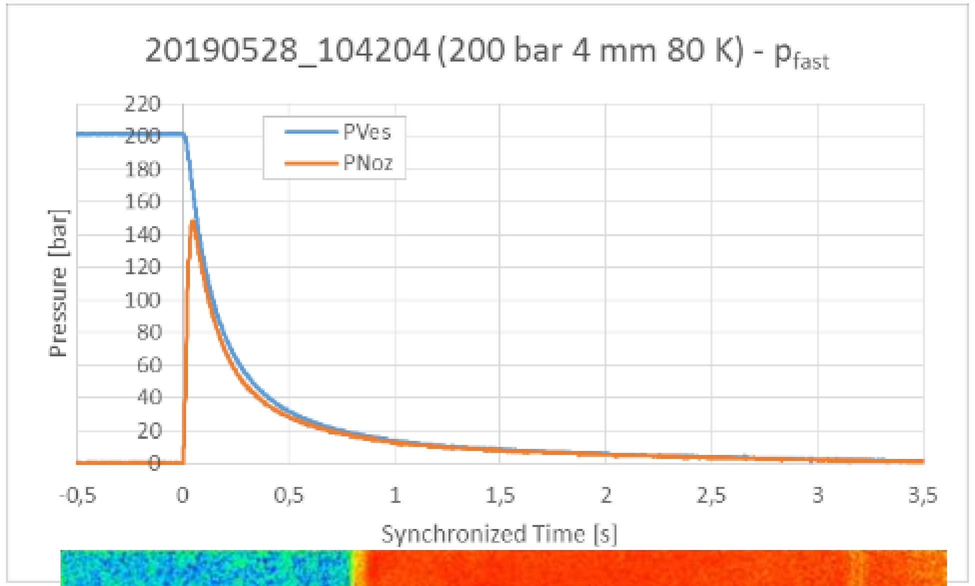


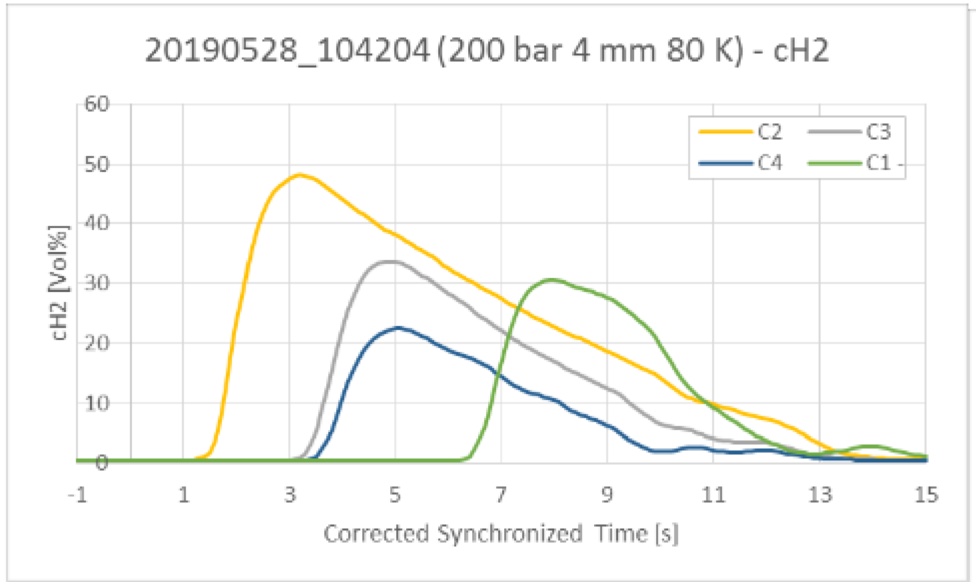


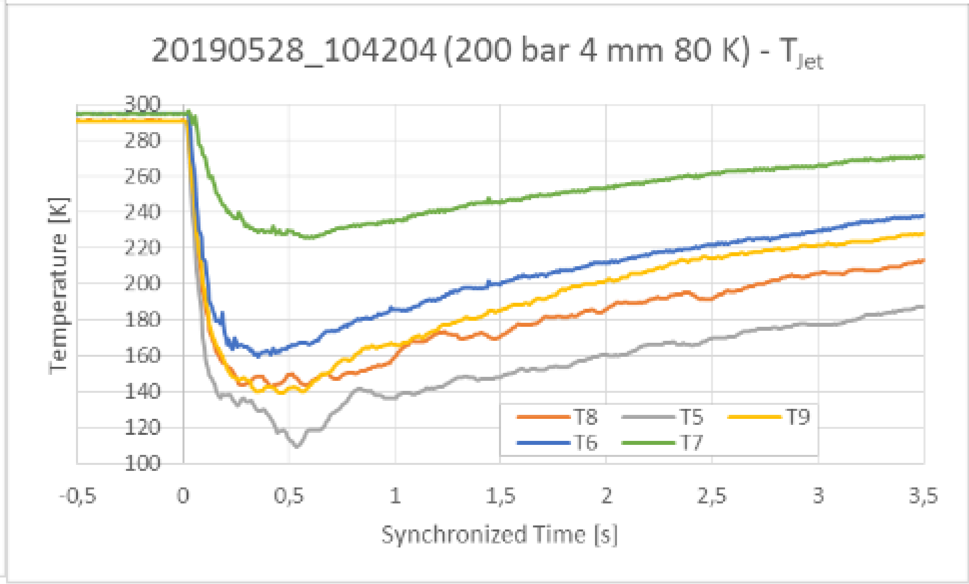


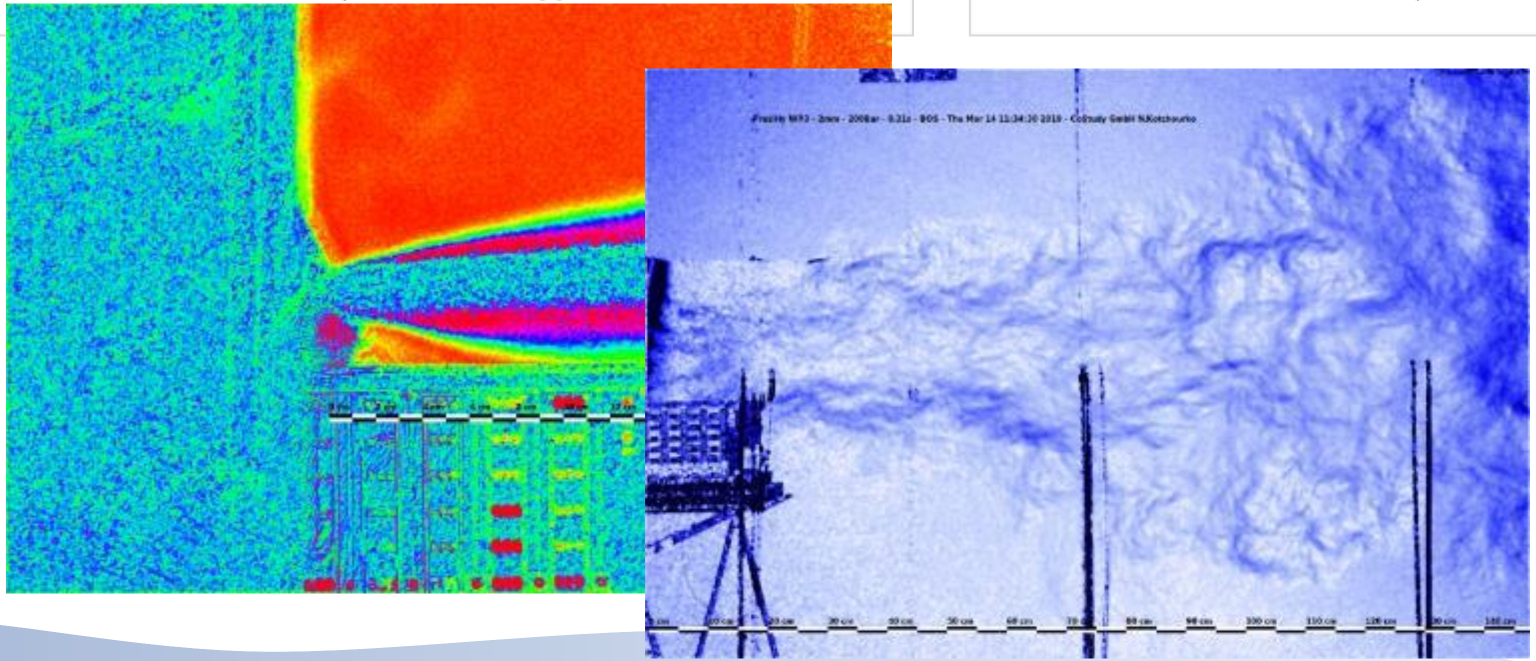
Experimental series E3.1a

Small scale, high p 80K +300 K release experiments





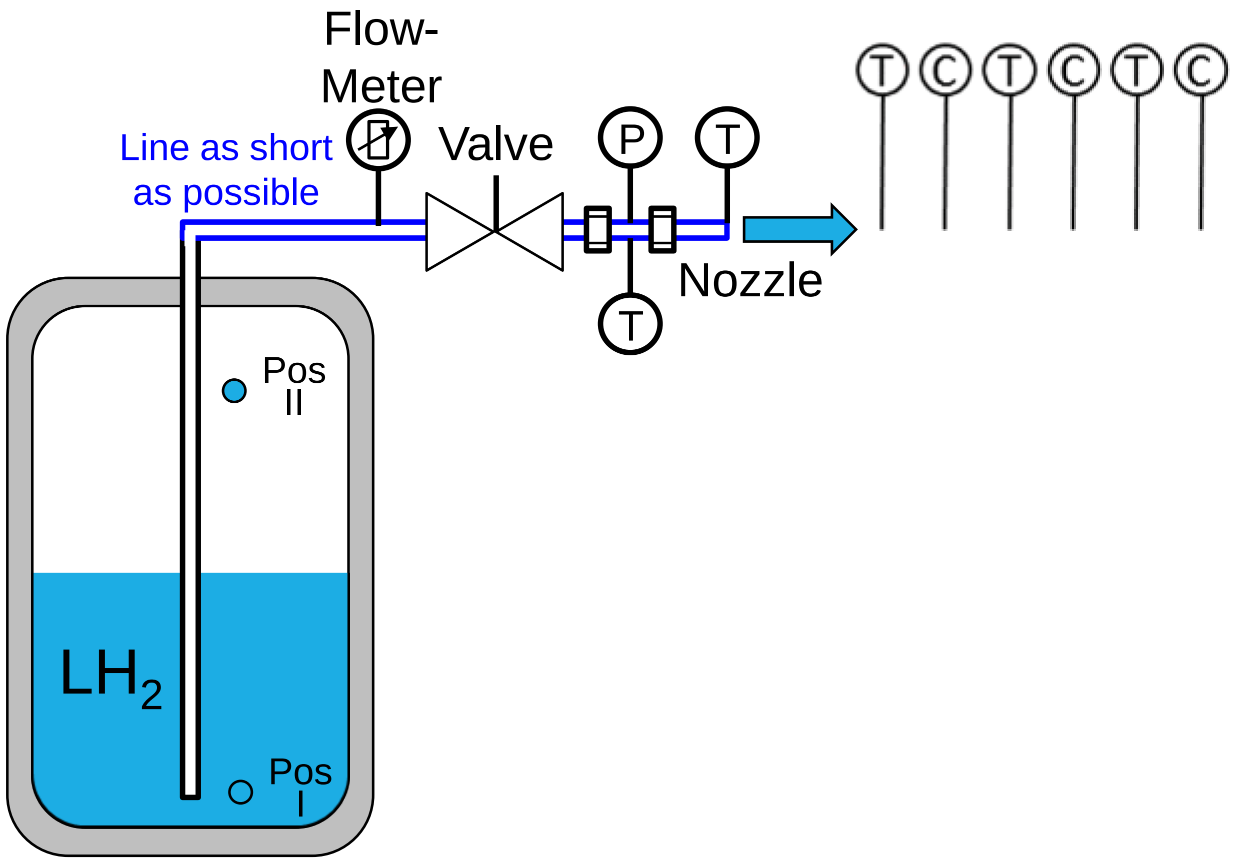


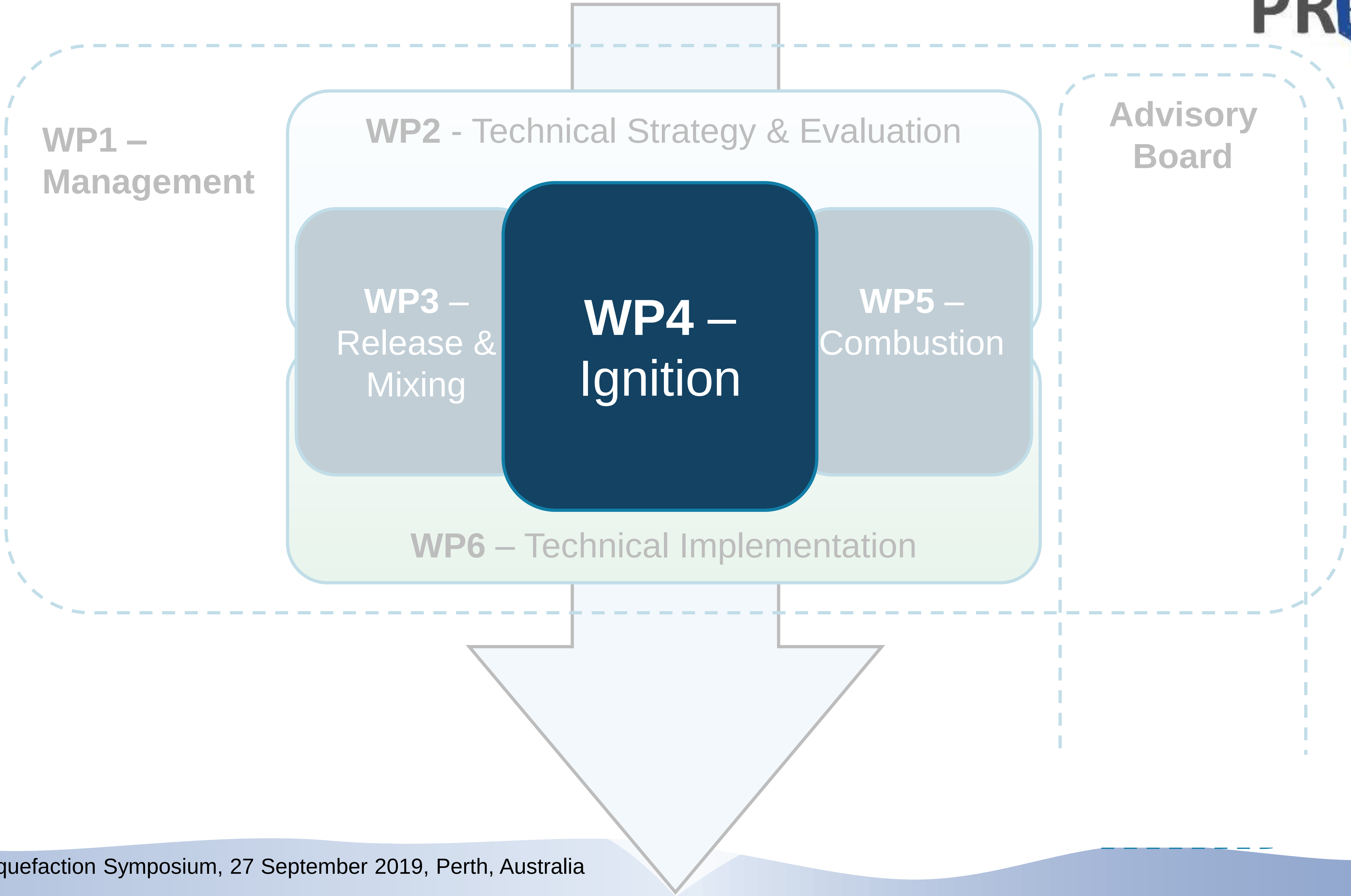


see https://doi.org/10.5445/IR/1000096833.

Next Release & Mixing Experiments

- E3.1b CRYOSTAT 2-Phase release (KIT/PS)
- E3.4 Pool release (KIT/PS)
- E3.5 Rain-out tests (HSE)

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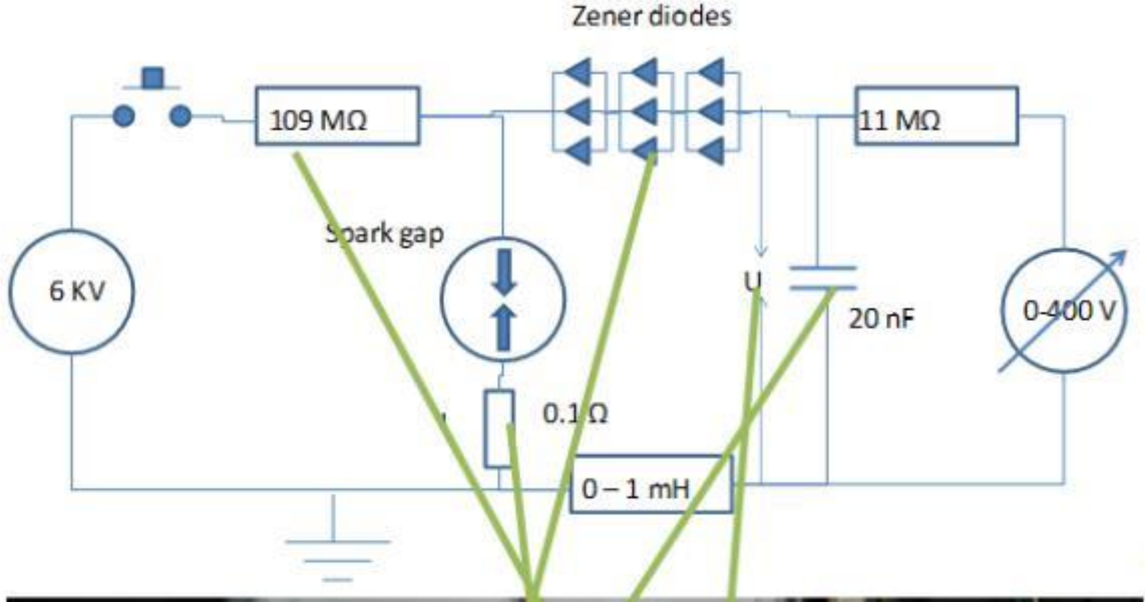
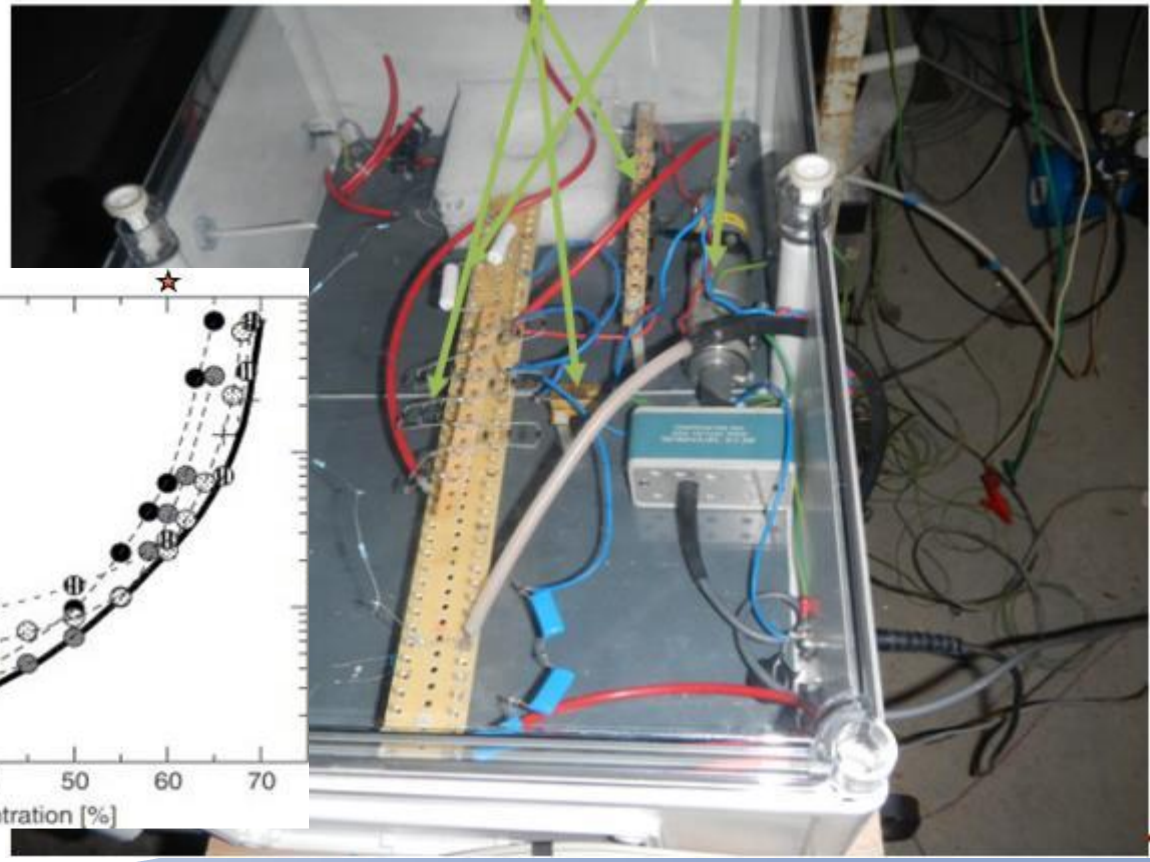
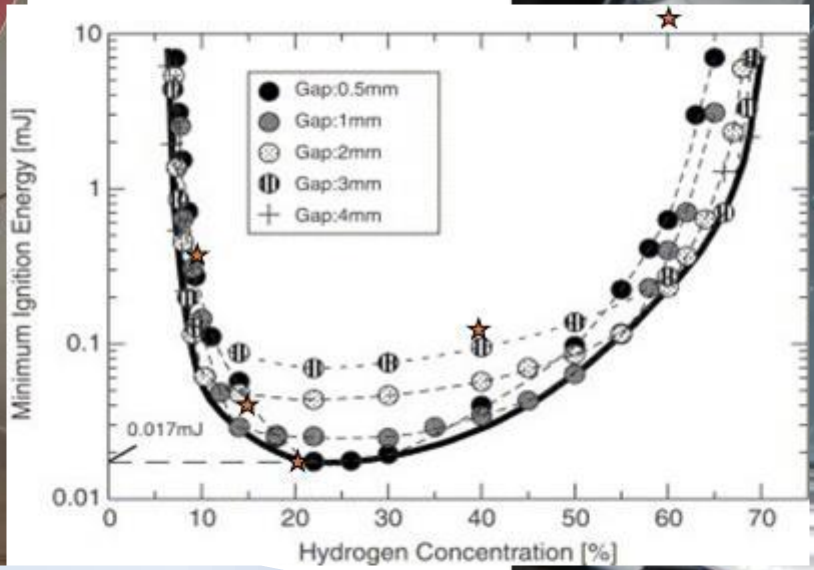
E4.1 MIE Device (INERIS)

- Triggered spark
- Current and voltage measured in the spark gap
- Inductance = 1 mH or zero
- Capacitance : variable
- From a few microjoules to 1 joule
- Ambient reference tests successful

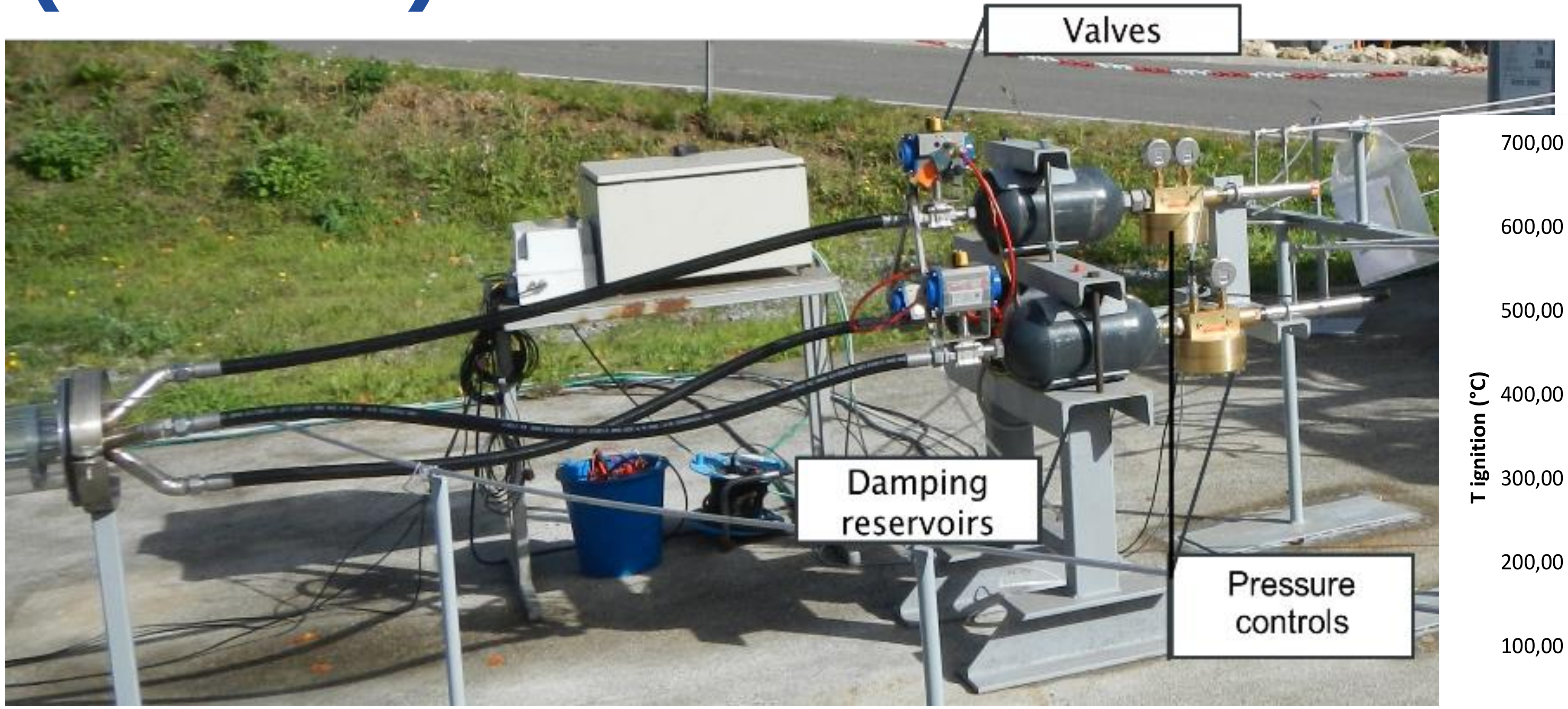
- 80K tests under preparation

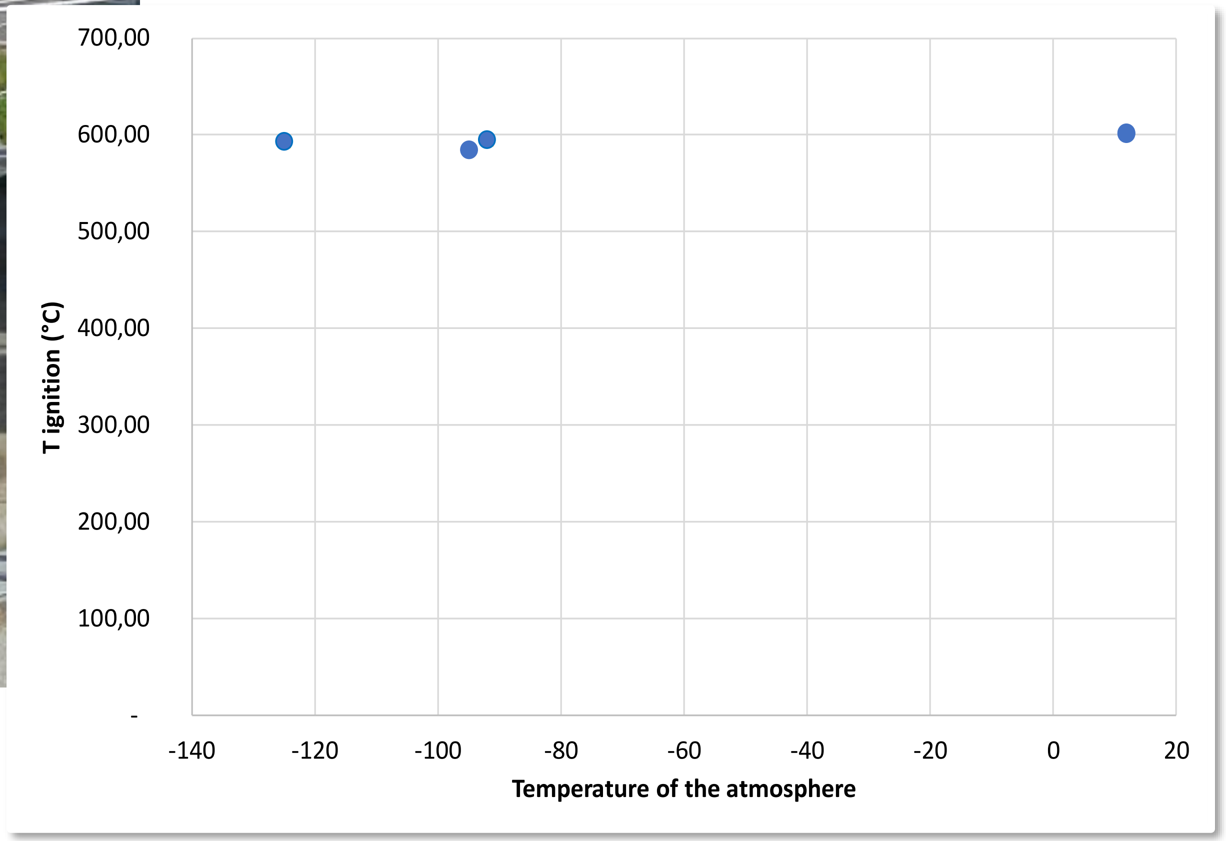






E4.1 Ignition by hot surfaces/power (INERIS)





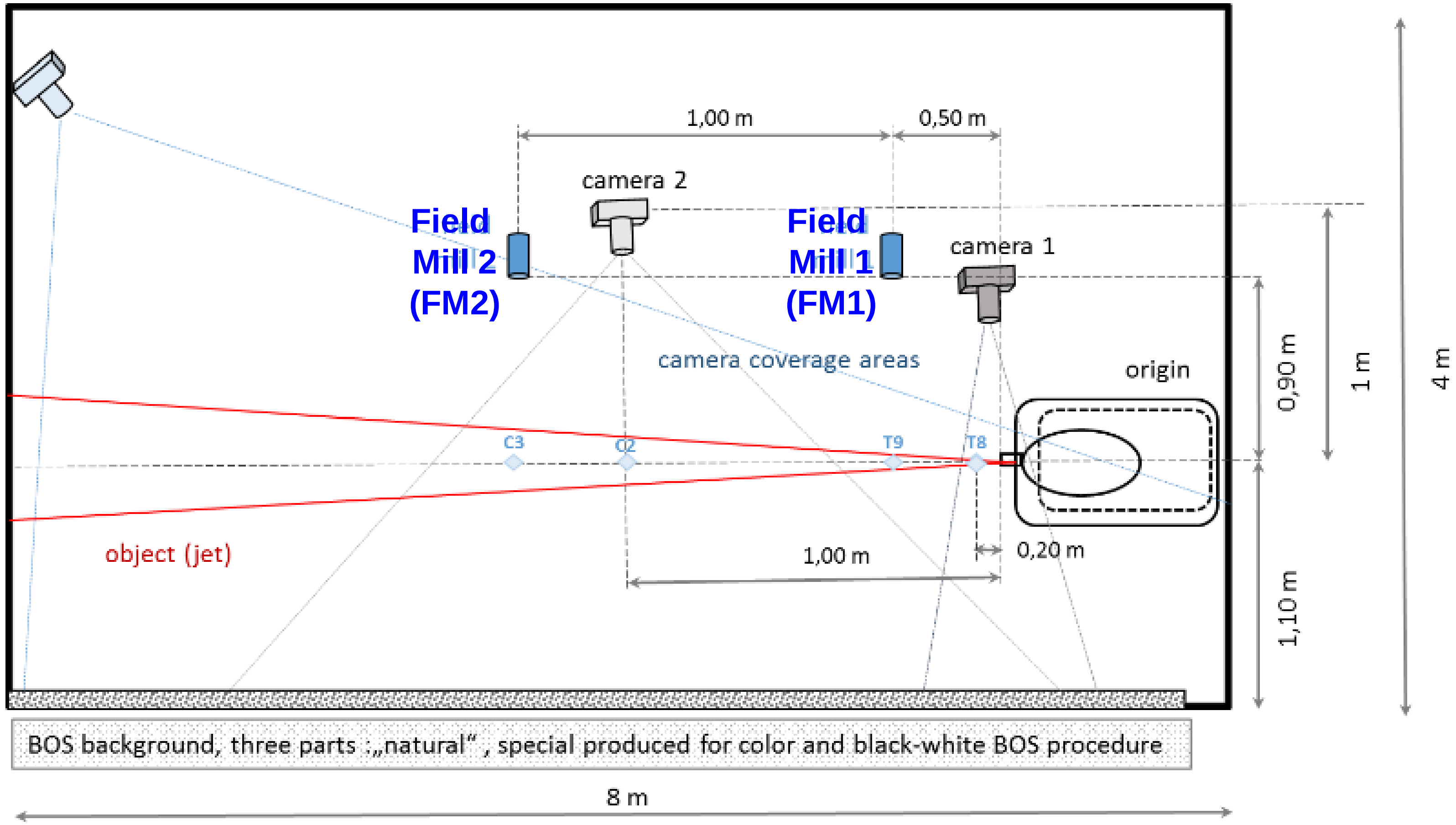
First results:

– Ignition on hot surface independent on T of surface

– Stoichiometry and flow velocity marginal influence

E4.2 Electrostatic Ignition in cold jet (KIT)

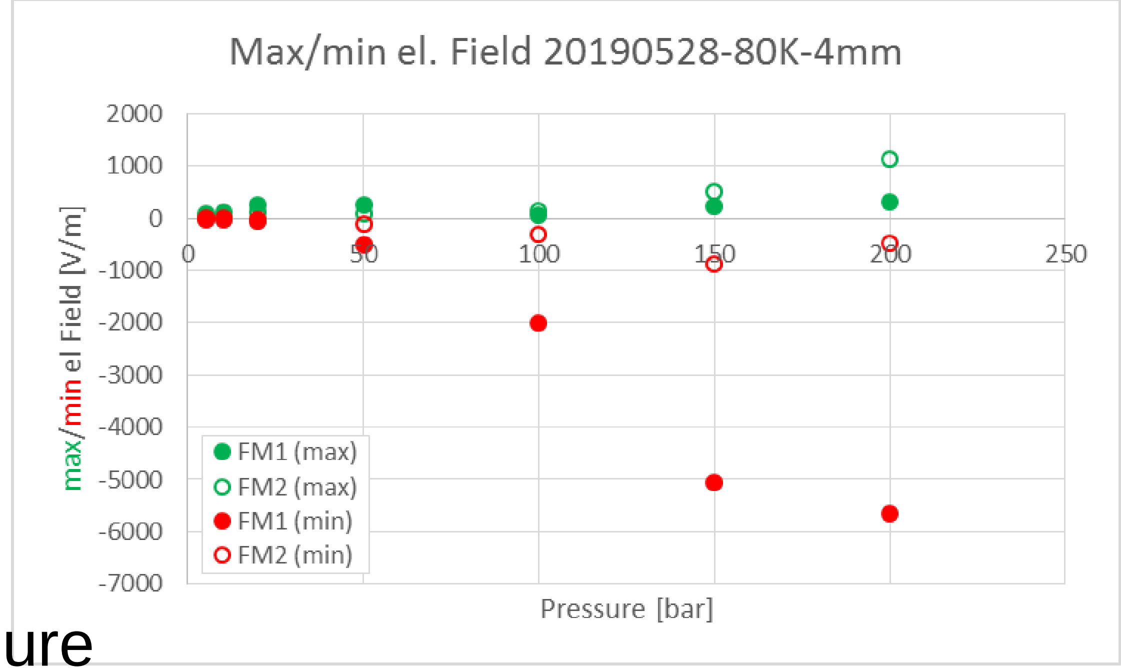
- The electrostatic ignition experiments in cold jets are completed
- Electrostatic field measurements with 2 field mills were performed in more than 100 DisCha-experiments (➔ E3.1a)
- **No spontaneous ignition** was observed in the complete DisCha-campaign (> 200 experiments)

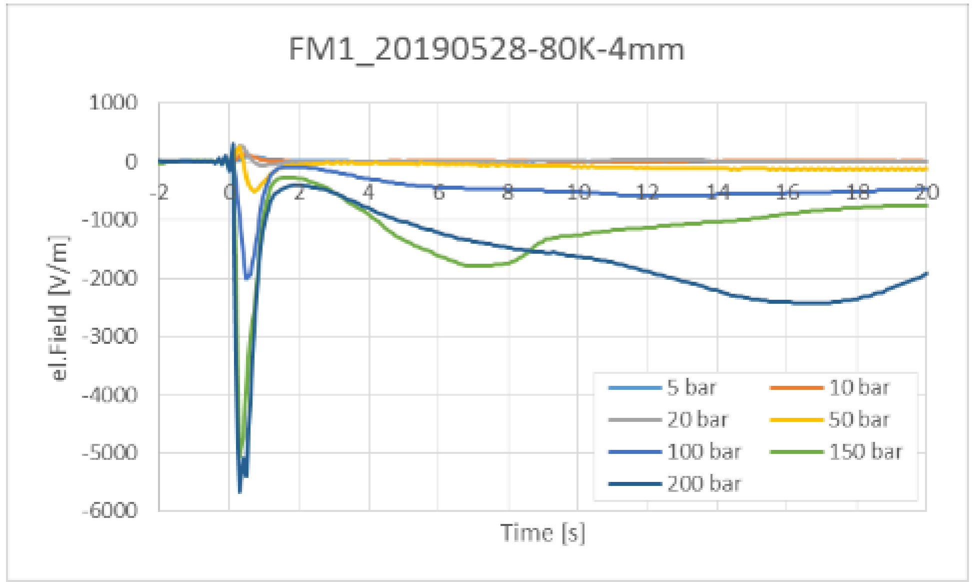


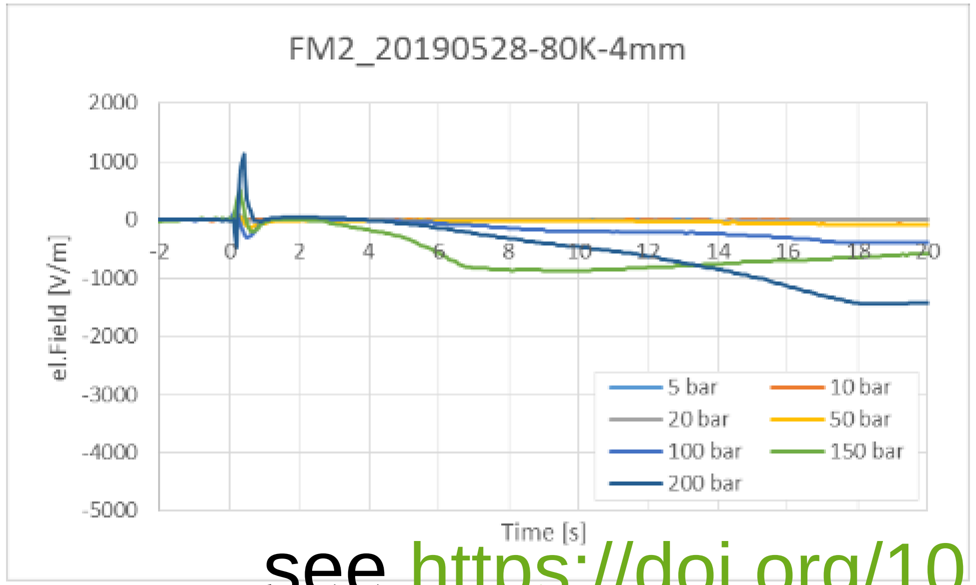
E4.2 Electrostatic Ignition in cold jet (KIT)

Preliminary results

- Strong electrostatic fields (~6000 V/m)observed for 80 K releases (~ factor 100 larger than at ambient T)
- Positive as well as negative values
- Larger electrostatic fields close to nozzle (field mill FM1) than at farther position (FM2)
- Larger electrostatic fields for cold than for warm releases
- Increasing electrostatic field values with increasing pressure



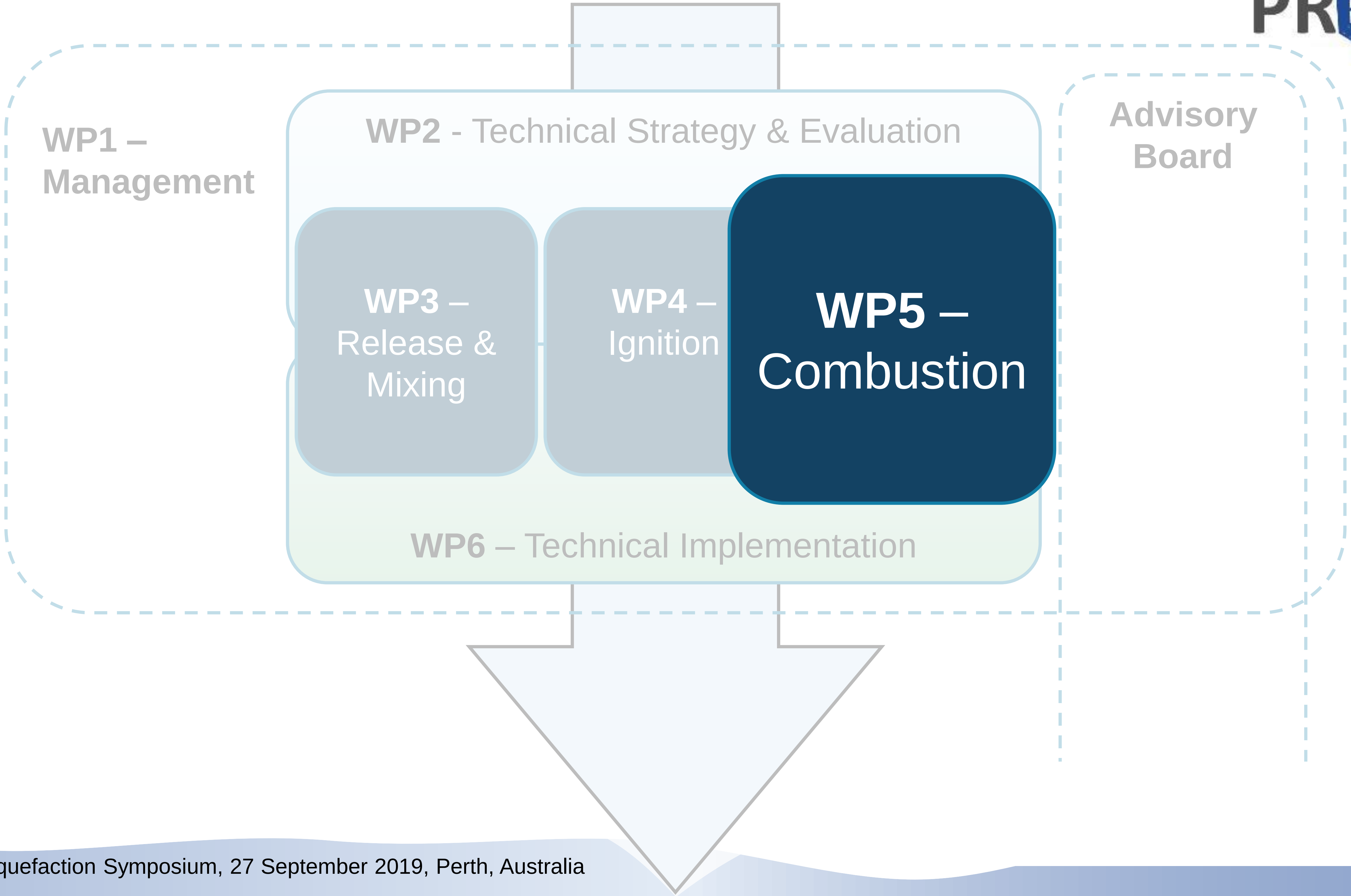




see https://doi.org/10.5445/IR/1000096833.

Next Ignition Experiments

- E4.1b Cold MIE (INERIS)
- E4.3 Electrostatic Ignition in plume (HSL)
- E4.4 Ignition above pool (KIT)
- E4.5 Condensed phase ignition (HSL)



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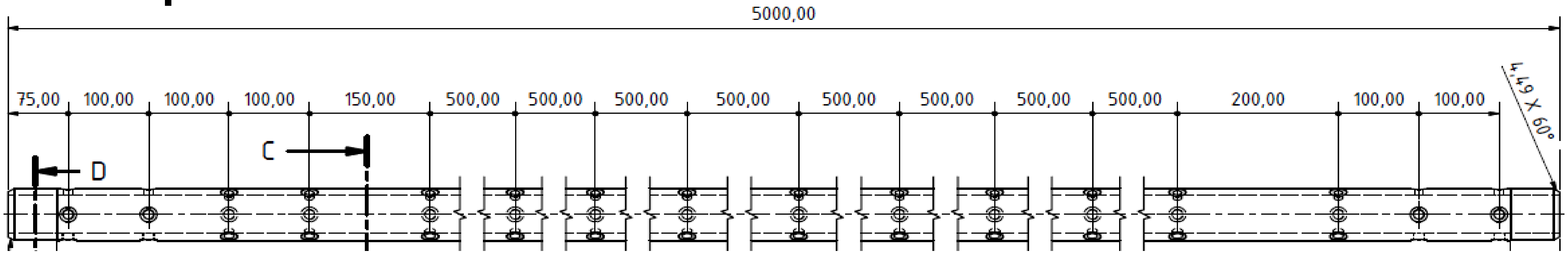
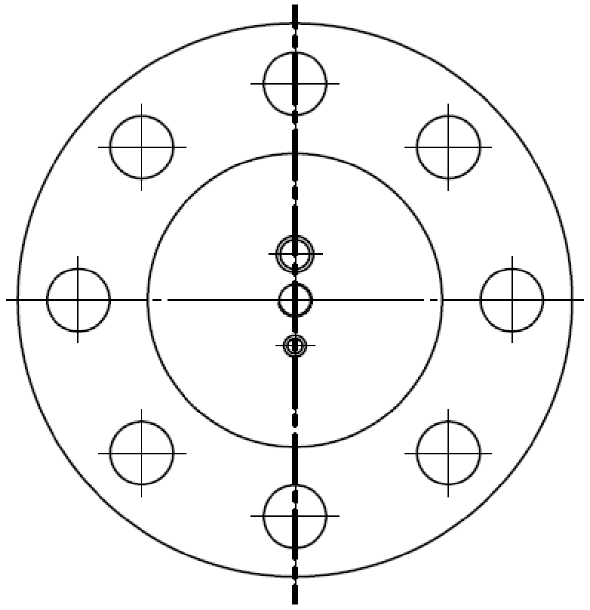
E5.2: Combustion-Tube-Facility

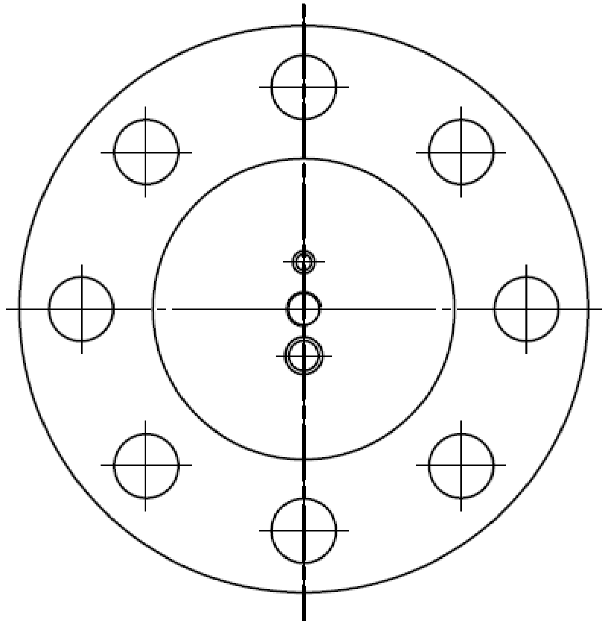
Tube experiments for FA and DDT criteria for T down to 80K



- Front-Flange with ports for:
  - Gas-Inlet
  - Glow-Plug
  - Thermocouple



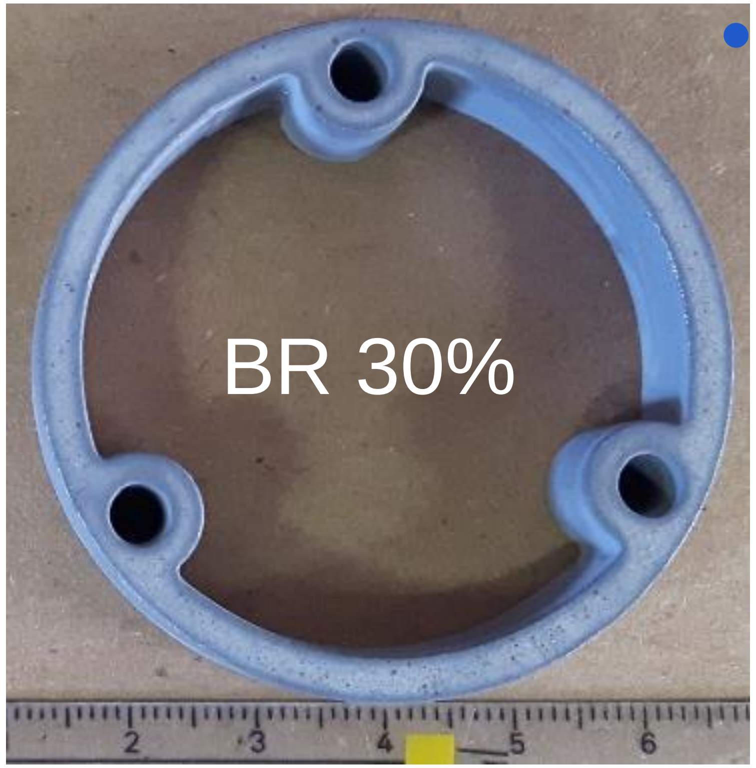
- End-Flange with ports for:
  - Thermocouple
  - Pressure-Sensor
  - Gas-Outlet

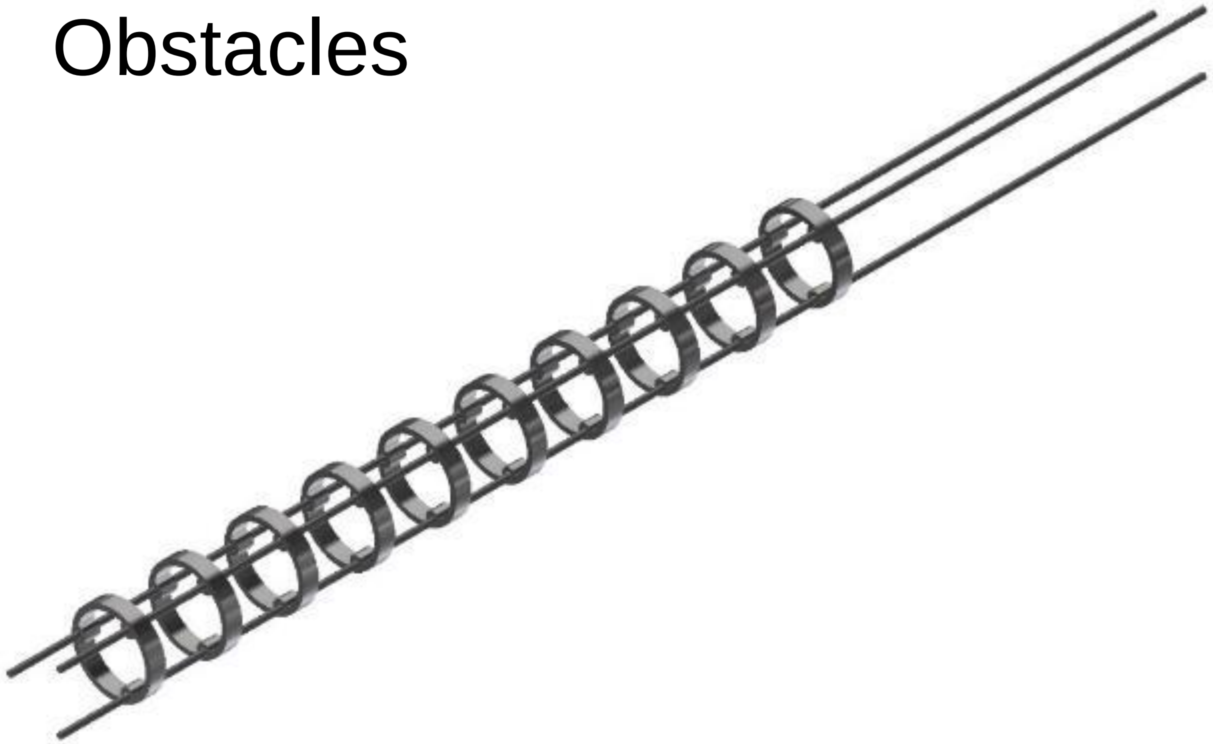


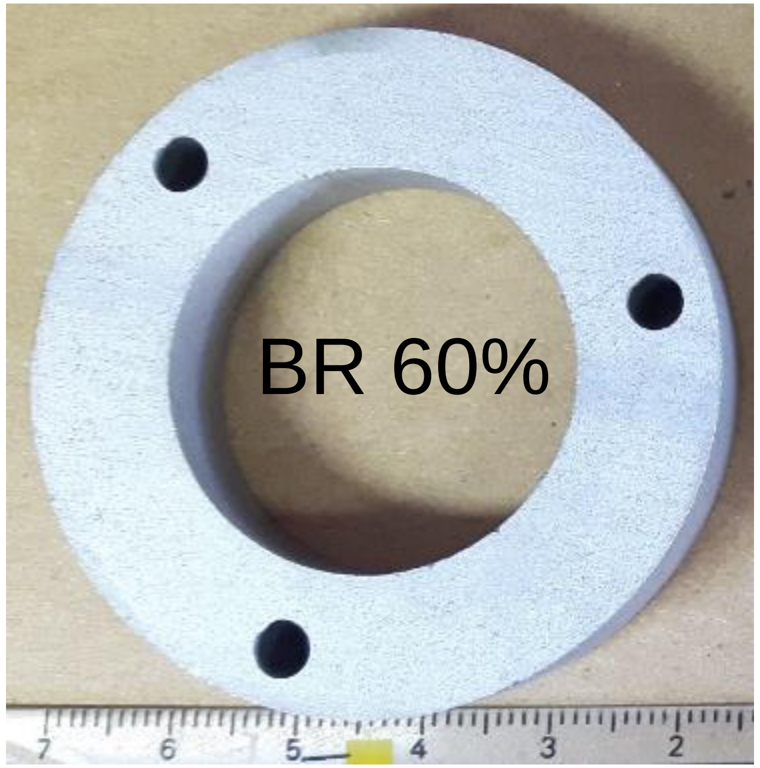
- Along the tube 52 ports for:
  - Pressure Sensors (2 different types),
  - Phototransistors

E5.2: Combustion-Tube-Facility

- Obstacles







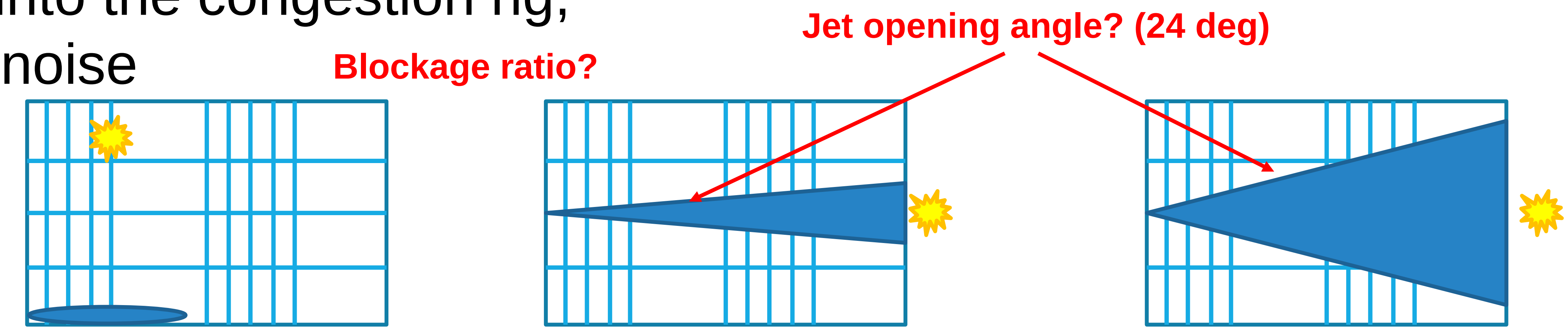
- 2 different obstacles (BR 30% and BR 60%),
- obstacles will be positioned evenly along the complete tube length (spacing: 1 inner diameter of tube) via three thin threaded rods,
- obstacles were manufactured externally (already delivered).

E5.5: Integral test in congested space

Variables:

- LH2 pool or jet
- Congestion level
- Confinement level
- LH2 jet flow rate

Ignition source located just downstream of rig to limit inventory of unburnt gas prior to entry into the congestion rig, this is to limit noise



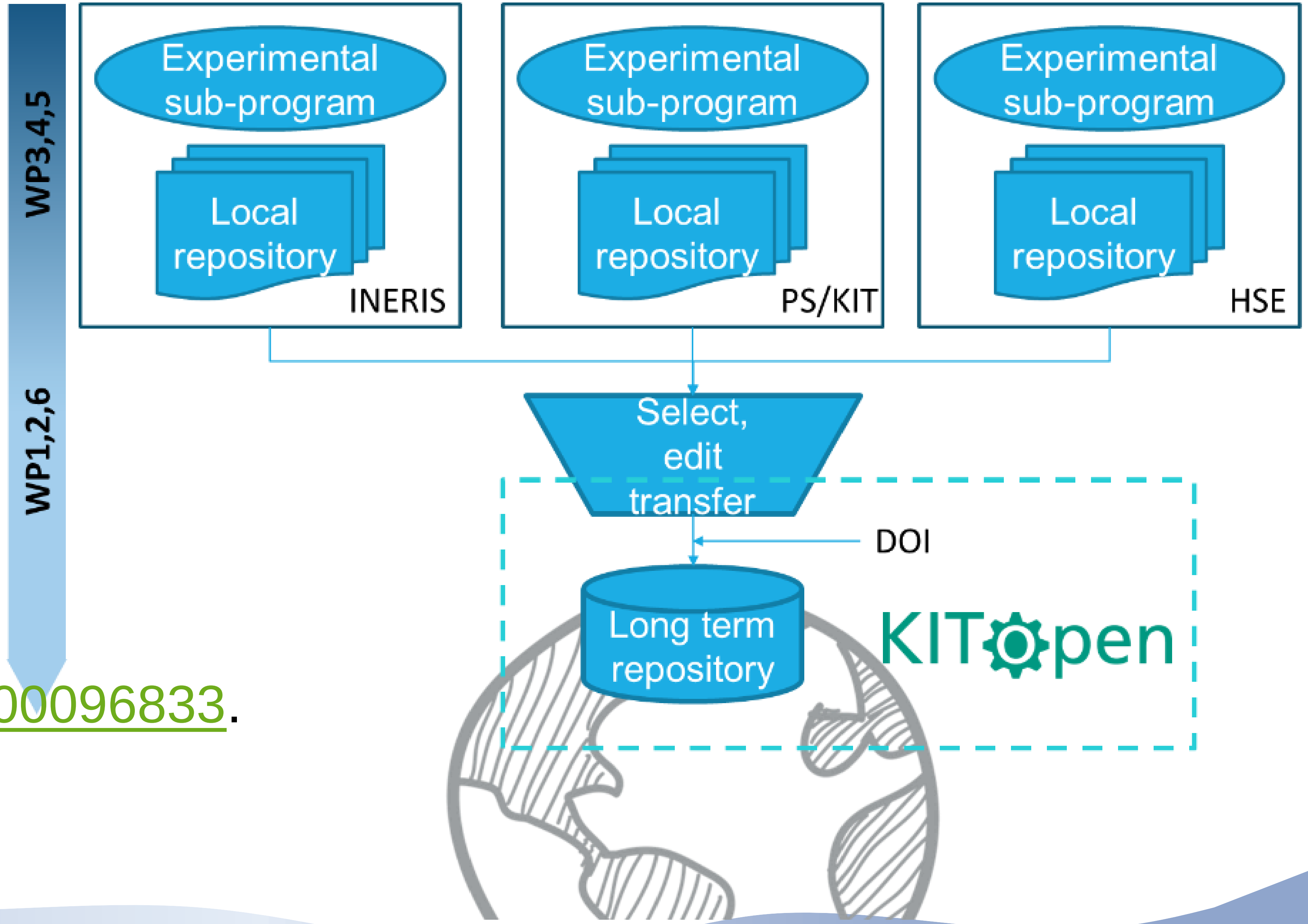
Pool in congestion rig

Jet release into congestion rig

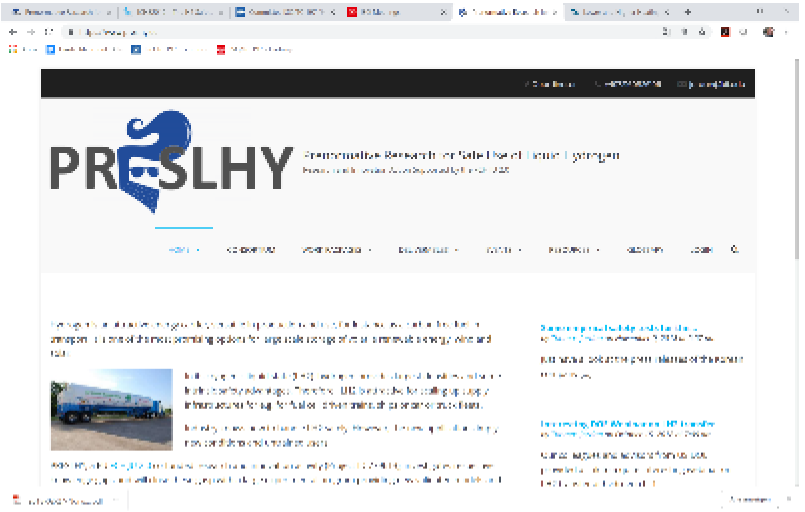
Higher flow rate release into rig, larger orifice

FAIR Data Management

- Development of the Data Management Plan
- Comparison and final selection of KITopen for the project Open Scientific Data Repository
- First prototypical data published for WP3 experimental series E3.1 https://doi.org/10.5445/IR/1000096833.



Outreach



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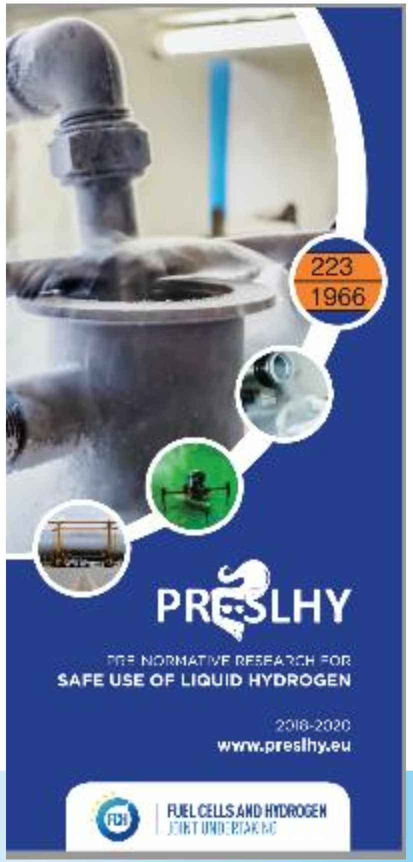
PRESLHY Exploitation & Dissemination Activities

- **Management (WP1)**
- **Implementation (WP6)**

Task 1.3 Website – **Data Management** – **Engineering tools** – **Handbook** – **Guidelines** – **RCS Recom-mendations** – **White Paper** – **Task 6.6 Dissemina-tion Conference**



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FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

European Commission | Horizon 2020 European Union funding for Research & Innovation

… and many thanks to all contributors (e.g. Equinor, SHELL, …)