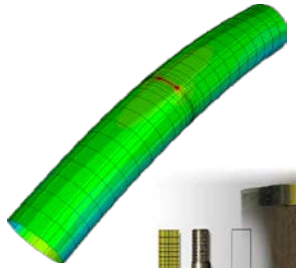
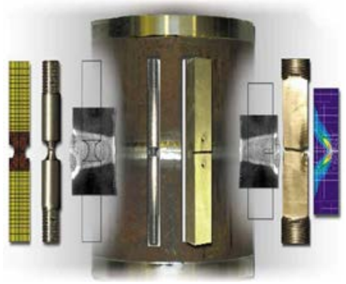
Materials integrity in sub-sea pipelines for H_2 gas transport

Green Hydrogen Webinars 24.03.21

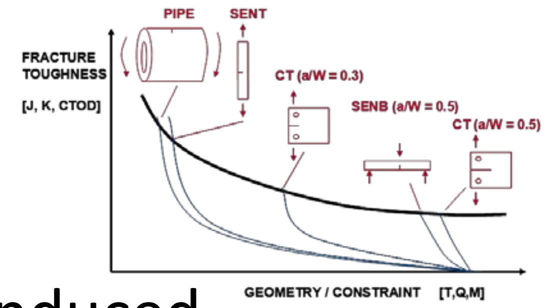
Vigdis Olden, SINTEF Industry

SINTEF's role in sub sea pipeline development in the North Sea

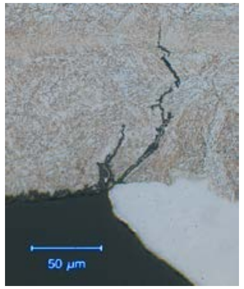




- Development of weld and weld repair procedures (hyperbaric).
  - Qualification Testing (mechanical and corrosion properties incl H_2S)
- Ensuring fracture toughness and fatigue properties.
  - Evaluate the influence from plastic deformation during pipe laying.
  - Analyse the criticality of local flaws (ECA).
  - Analyse the influence of shut-downs, residual stresses, erosion …



- Evaluate the influence of H from CP with respect to Hydrogen Induced Stress Cracking (HISC)
  - Development of test methods
- Development of Standards and Guidelines for pipeline design in close collaboration with DNV
  - DnV Guidelines for HISC & ECA of pipelines



HISC and HE research funded by the RCN and industry

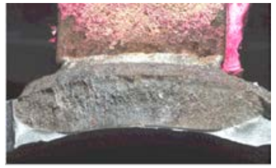
HAC from H2 gas

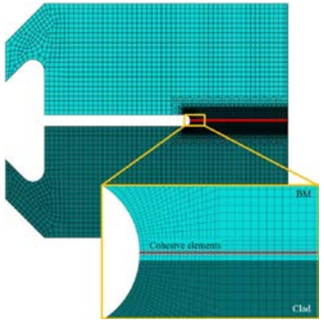
INFRASTRUCTURE SMART-H 2020

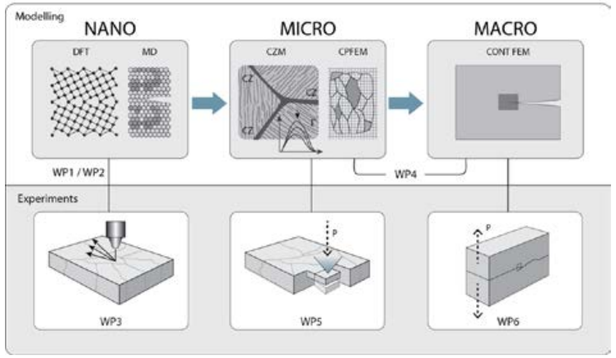
H2 NINJA 2020 - 2023

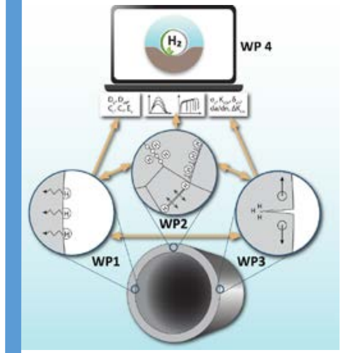
KPN HyLINE 2019 - 2023

HISC from CP









RP HyFlex

KPN ROP

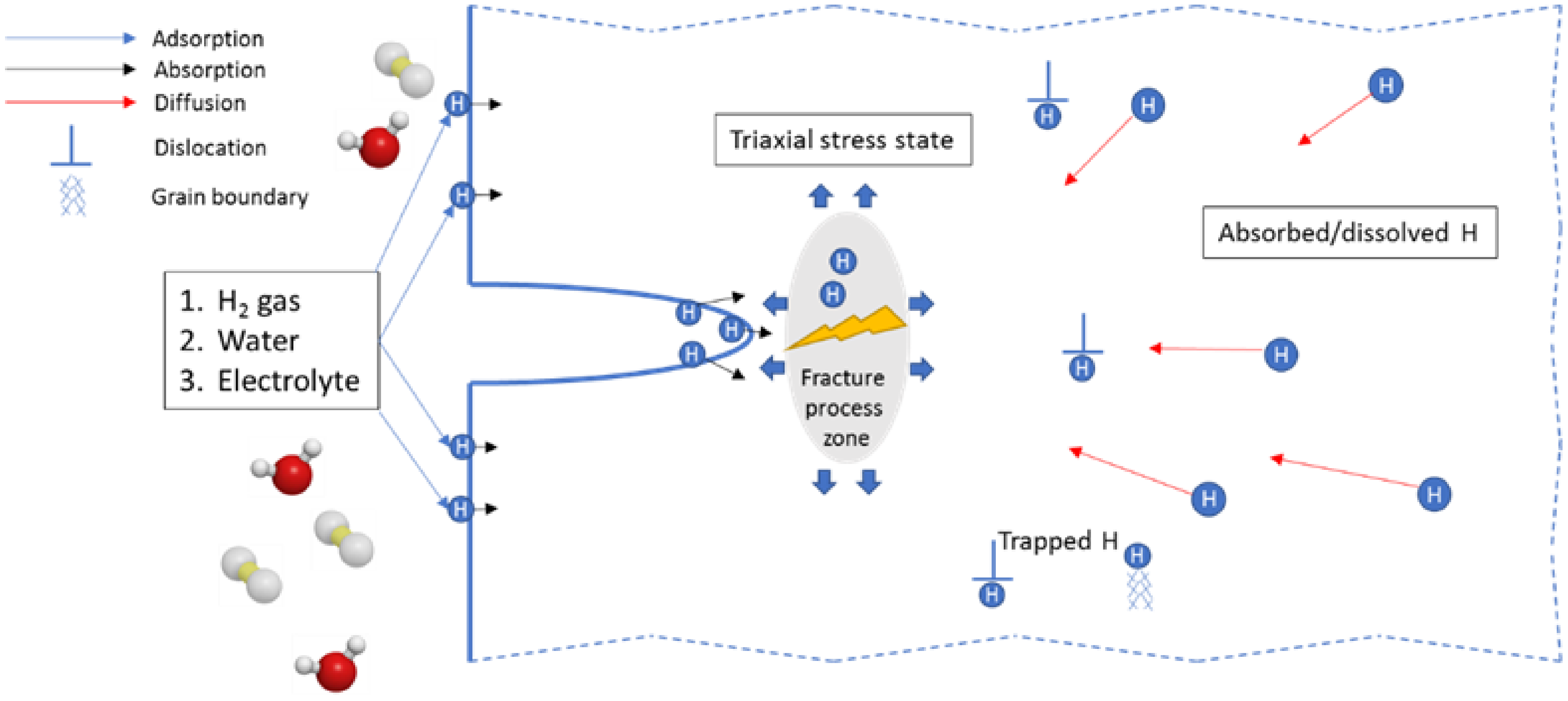
RP HIPP

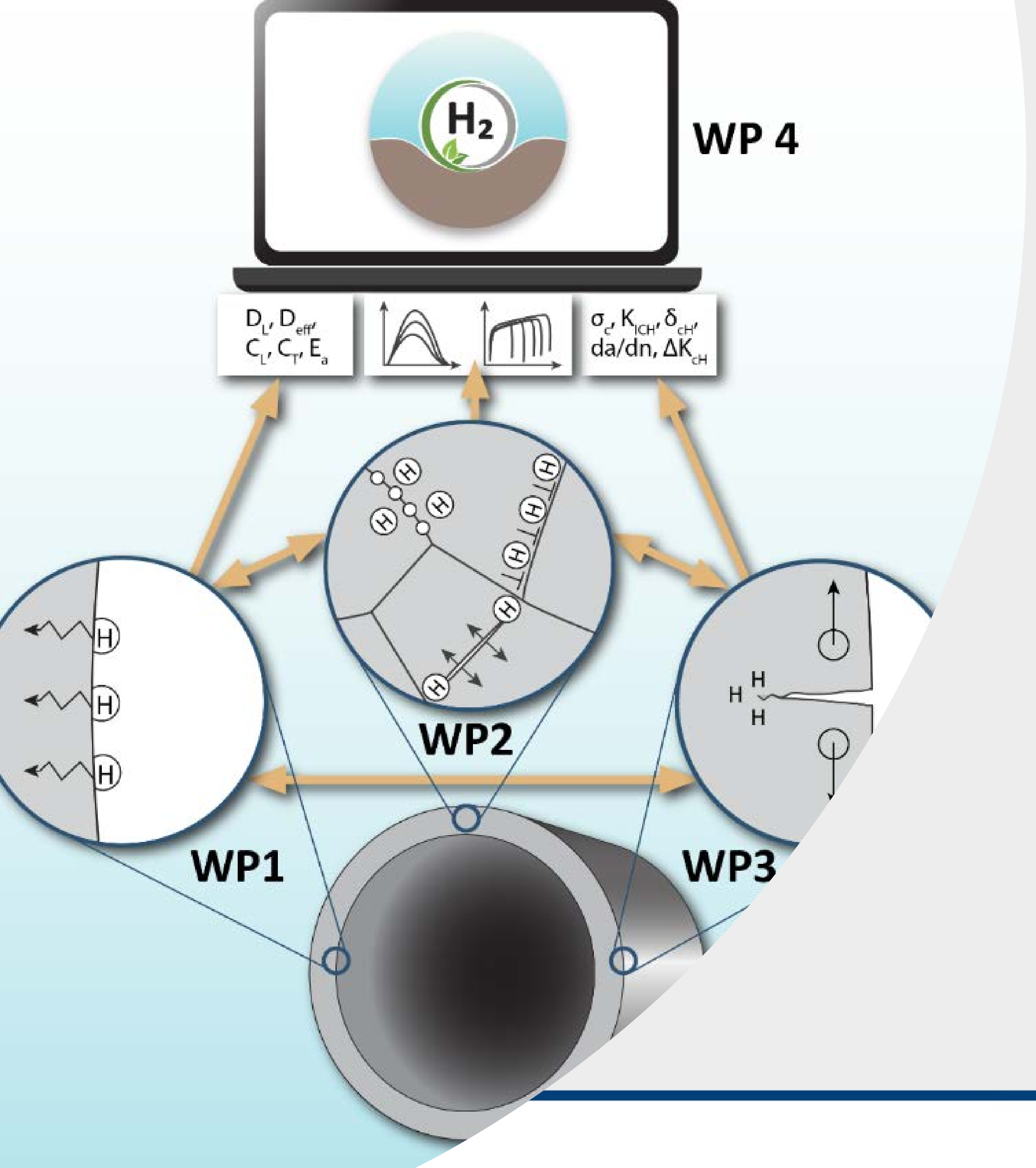
KPN DEEPIT

HISC I-IV

2000 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

Hydrogen atoms enter and affect the properties of metallic materials





KPN HyLINE

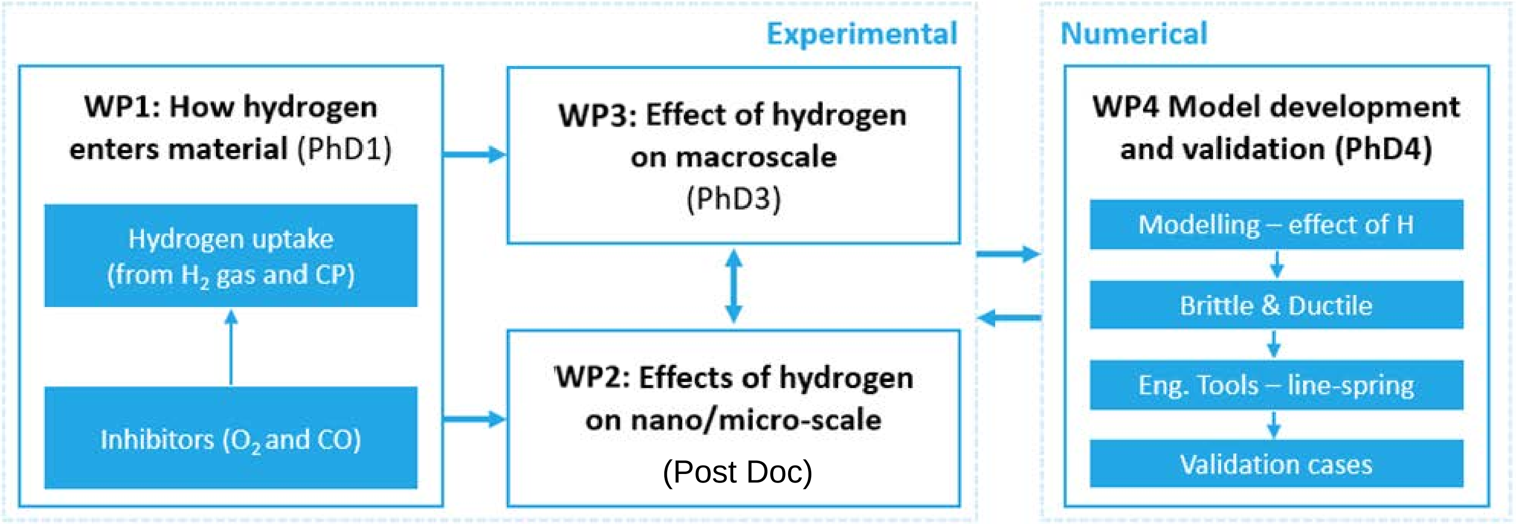
2019 - 2023

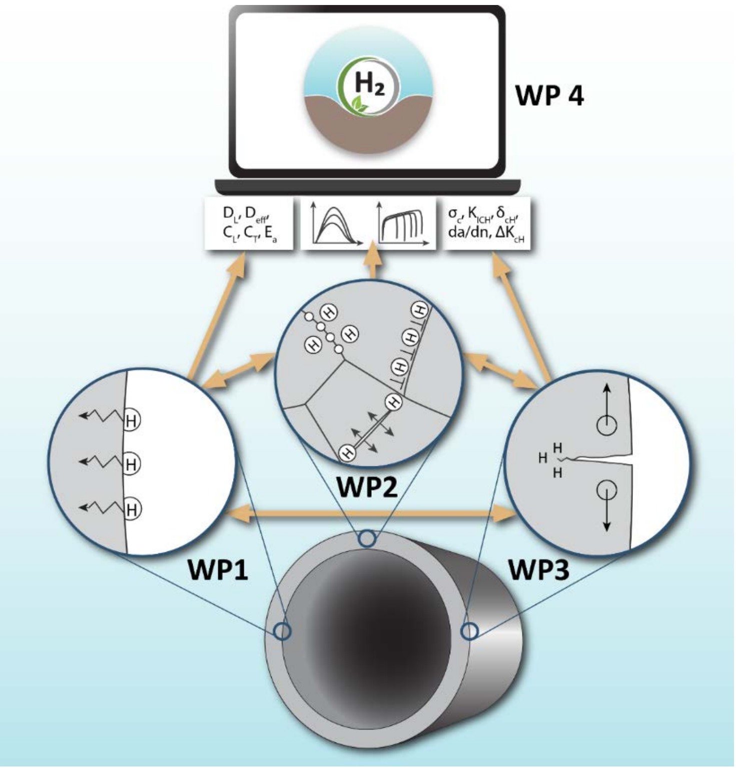
"The main objective of HyLINE is to establish fundamental knowledge about the effects of hydrogen gas on pipeline steels to enable a safe and efficient use of existing and new subsea pipeline infrastructure for future large-scale transport of hydrogen gas."

Summary of the project

• Type of project:	Competence project for the Industry
• Duration:	2019-2023 (4 years)
• Budget:	34.2 mill NOK (~3.6 mill €)
• Funding:	58% Research Council of Norway, 35% industry, 7% own funding.
• Fellowship grants:	3 PhDs 1 Post Doc.
• Research partners:	SINTEF, NTNU & KU
• Industry partners:	6 Companies
• International coop.:	3 Universities

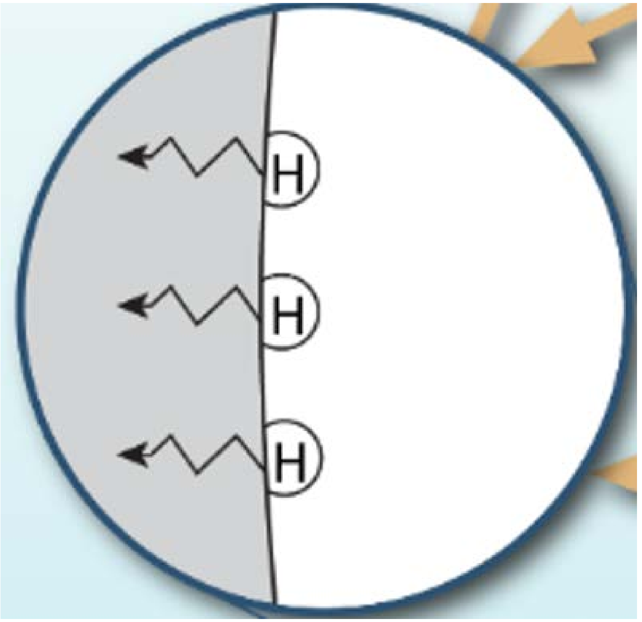
The work packages





Link to project description: https://www.sintef.no/en/projects/hyline-safe-pipelines-for-hydrogen-transport/

WP1 Hydrogen uptake and diffusion

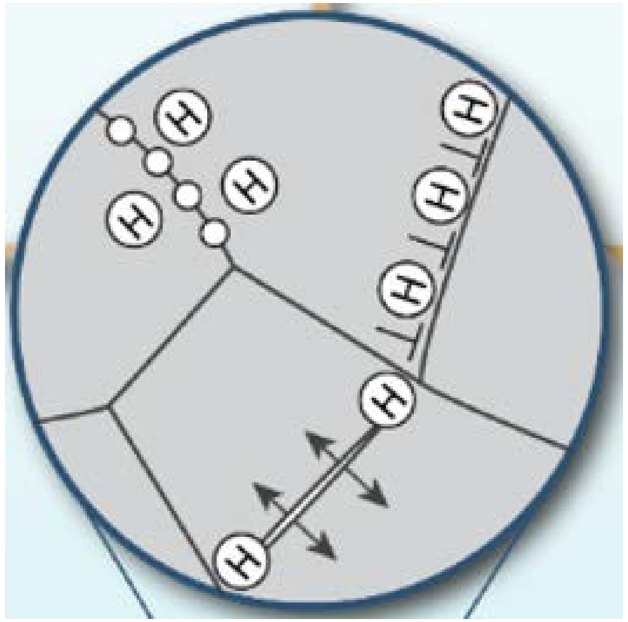


- Task 1.1 Absorption and concentration
  - Characterize H diffusion properties and trapping after H charging under various hydrogen charging conditions (CP and H_2).

- Task 1.2 Influence of inhibitors
  - Examine the influence of adding ppm levels of inhibiting gases in pressurized hydrogen gas on the fatigue properties.

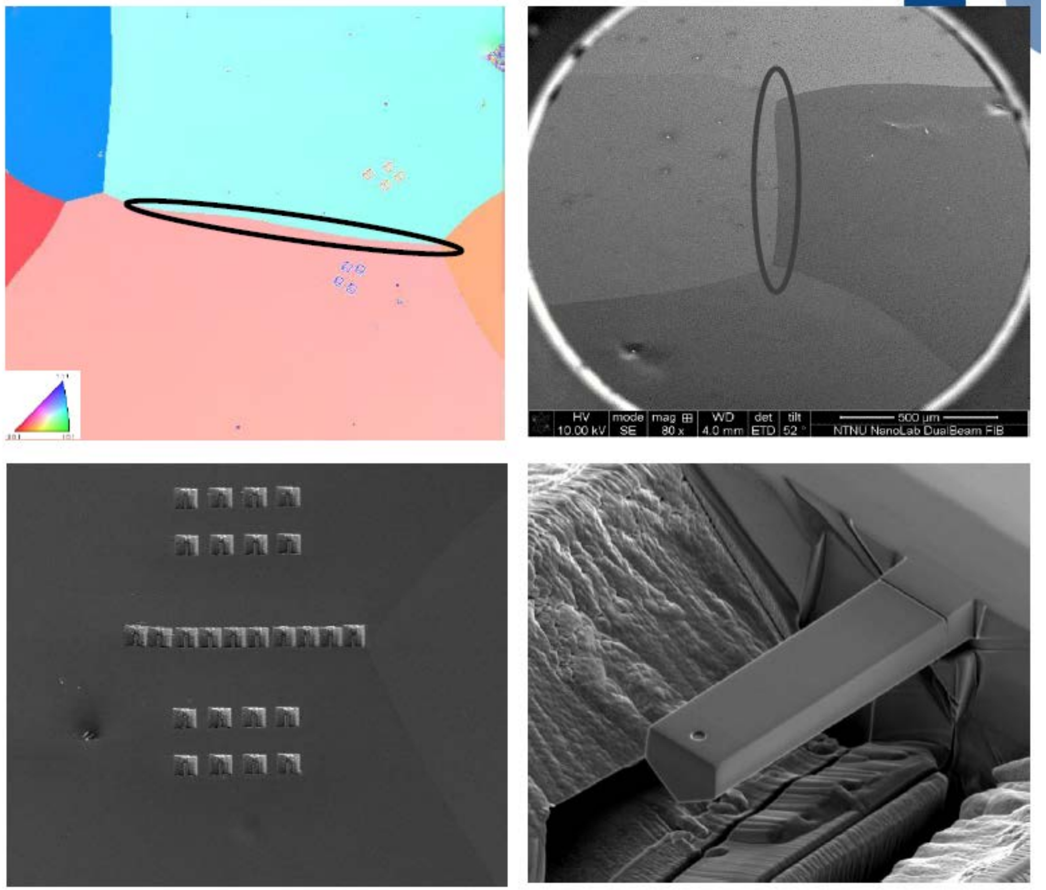
Close collaboration with Kyushu and Fukuoka University, Japan

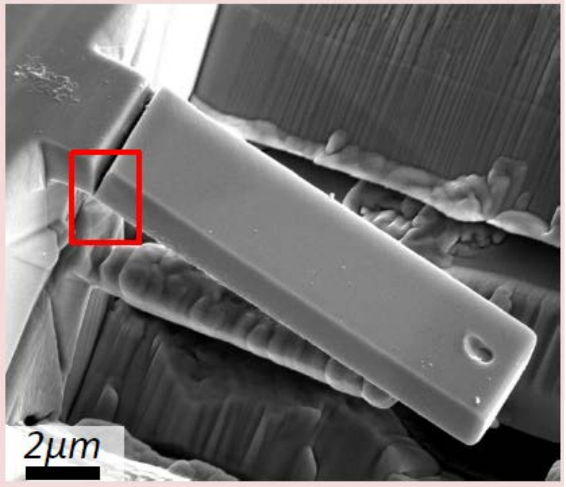

WP2 Nano and micro scale effects

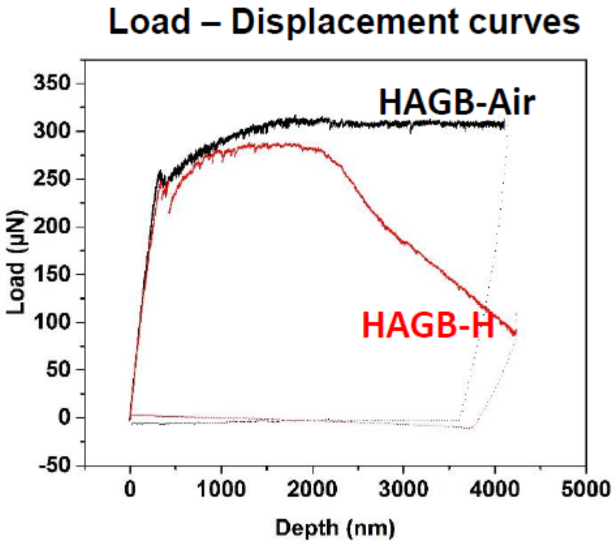


- Task 2.1 Small scale mechanical testing
  - In situ nano and micro-mechanical testing under different H charging conditions. Focusing on the mechanical response.

- Task 2.2: Advanced multiscale characterization
  - Material and microstructural characterization ranging from observation of single dislocations to strain localization behaviour in the microstructure under H influence.



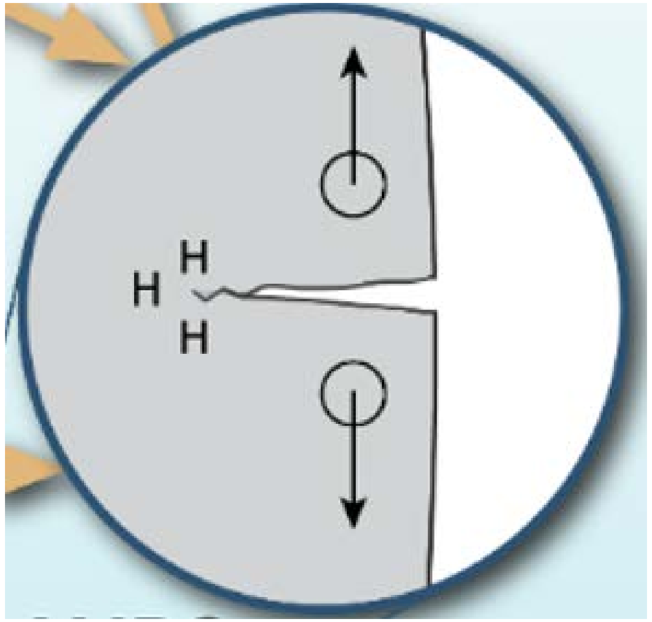




WP2 Nano and micro scale effects




WP3 Effects of hydrogen on mechanical performance



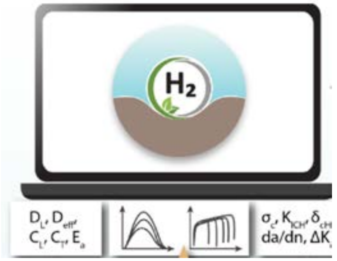
- Task 3.1 Material screening program
  - Mechanical testing and metallurgical characterization to give basis for choice of materials for the main study.
- Task 3.2 Fracture toughness
  - SENT testing under H2 gas and electrochemical charging conditions.
    Establish fracture toughness threshold.
- Task 3.3 Fatigue properties
  - Fatigue crack growth rate testing under various H charging conditions, including H2 gas with inhibitors.
  - Close collaboration with Kyushu University
    (performs testing in H2 gas)

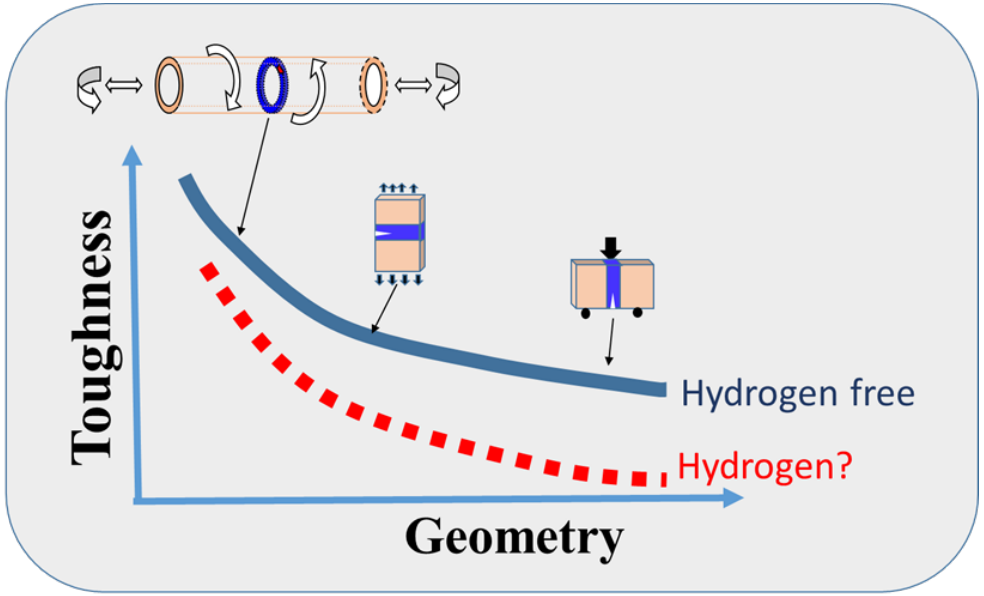
Effect of H on macro-scale

Electrochemical test set up at SINTEF

High pressure H test rigs at KU

WP4 Structural integrity assessment & model development

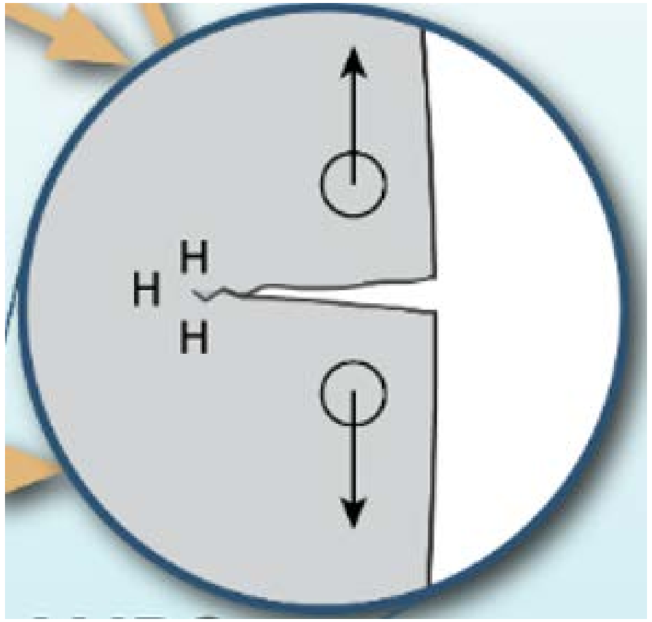




- Task 4.1 Hydrogen related parameters
  - Empirical models for entry, diffusion and trapping of H as a function of the charging conditions.
- Task 4.2 Hydrogen influenced Gurson model
  - Modification of the Gurson damage model to take hydrogen enhanced plasticity into account.
  - PhD3 (Prof. Zhiliang Zhang)
- Task 4.3 Cohesive zone model
  - CZM is sought extended to account for H assisted fatigue and combined with the Gurson model to capture ductile to brittle transition.
  - Collaboration with Uni Poitiers (Prof. Gilbert Hénaff, Damien Halm)




WP3 Effects of hydrogen on mechanical performance



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Pipeline Materials

Strength class	OD [mm]	WT [mm]	Production
X65	770	26	LT Weld
X70	1100	41	-"-
X65	810	21	-"-
X65	321	15	Seamless

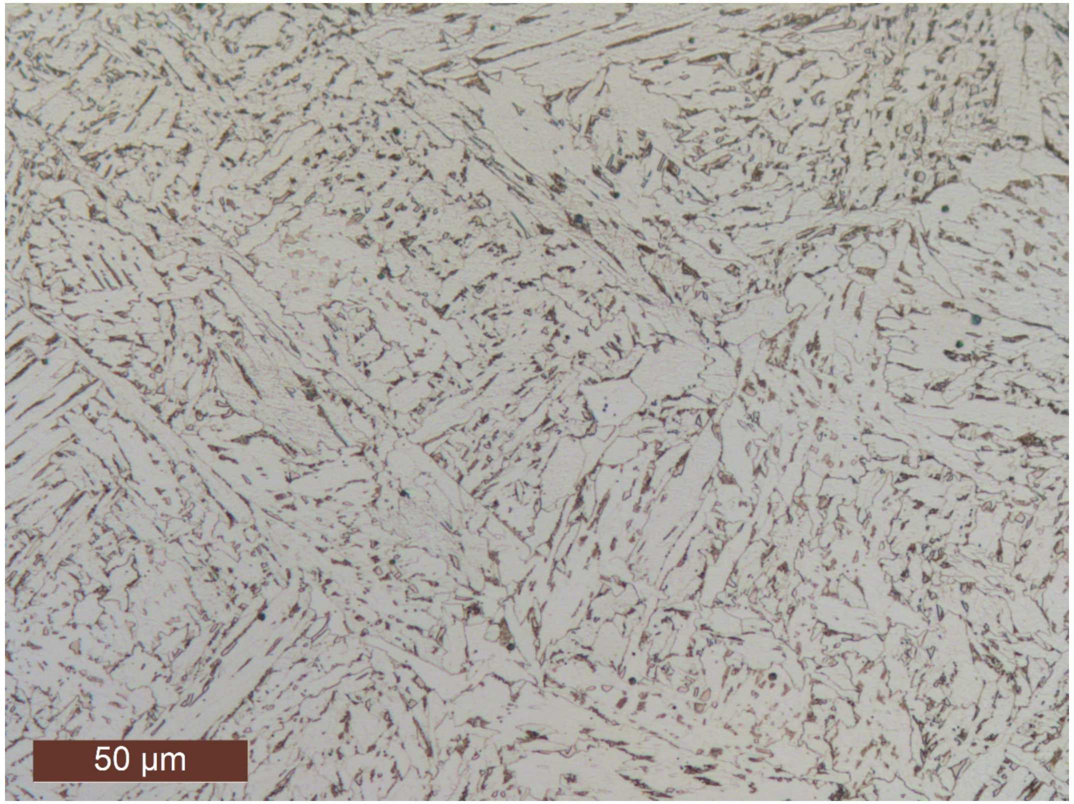
Base metal and weld simulated (CGHAZ) steels were:

- characterized with respect to microstructure and hardness
- tested for tensile properties in air and hydrogen charging conditions applying a low strain rate

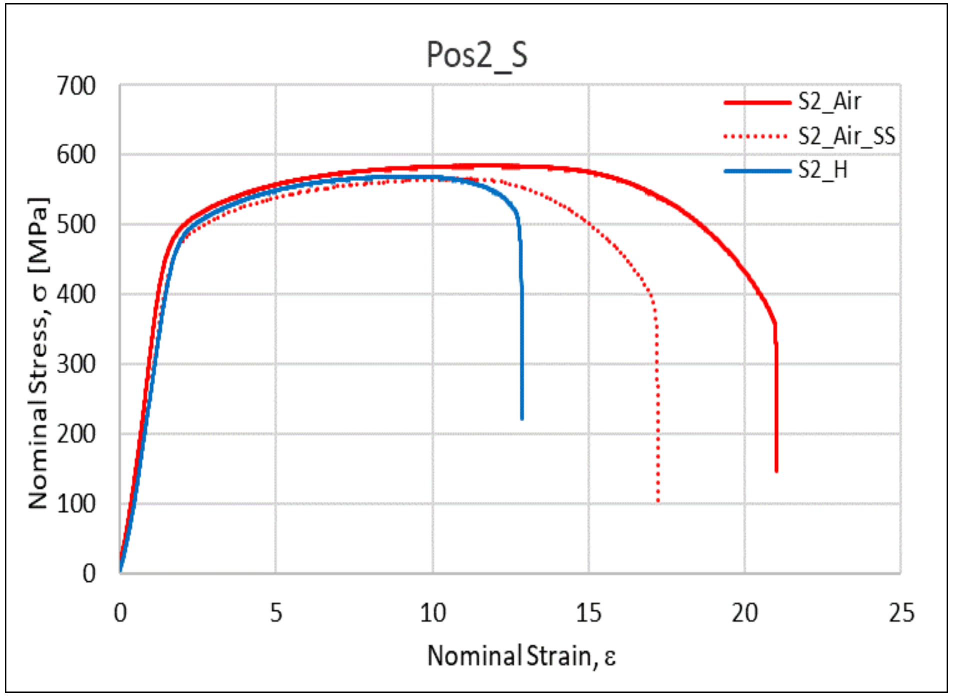
Microstructure: X65 welded pipe

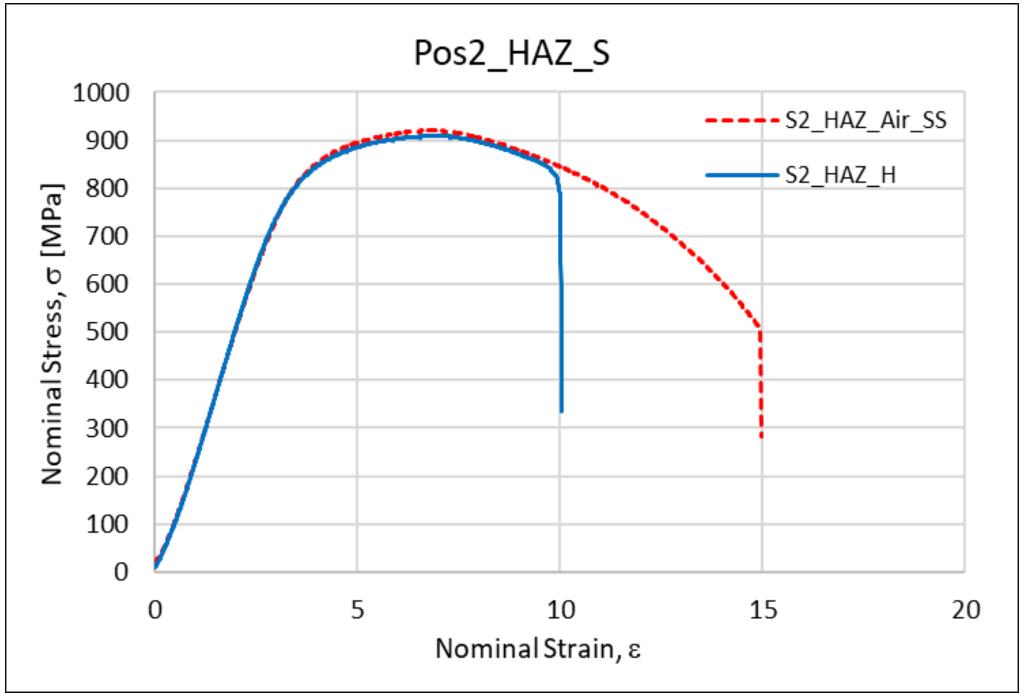
Base metal – longitudinal

CGHAZ– longitudinal

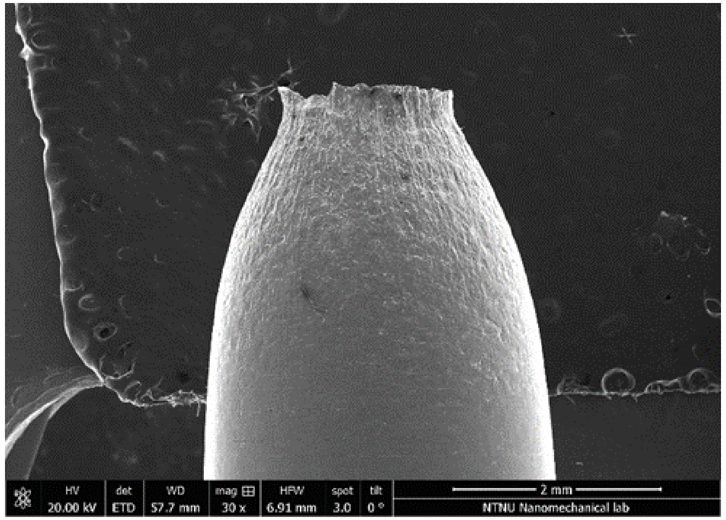


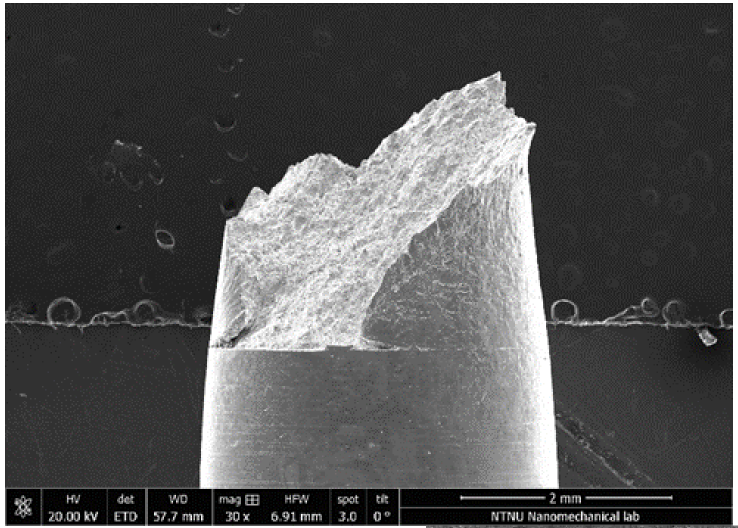
Slow strain rate testing - BM



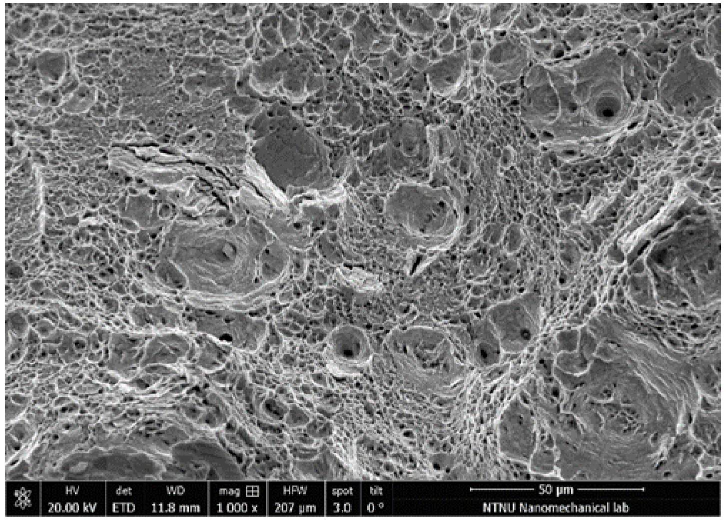


Fracture morphology in air and H

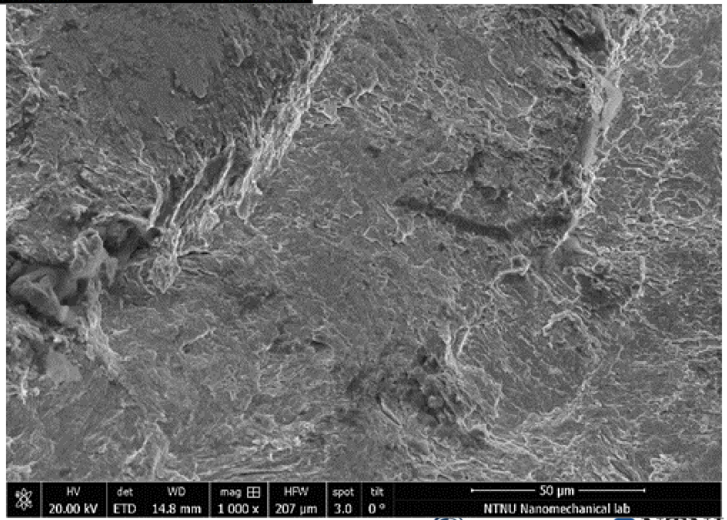




Air



Hydrogen



Further work

- Two X65 pipeline steels will be subjected to:
  - Fracture and fatigue testing in pressurized gaseous conditions includingas the effect of adding inhibitors to the H_2 gas
  - Investigations of hydrogen uptake and trapping under various hydrogen charging conditions (electrochemical and gaseous).
  - Nanomechanical testing and characterization under H influence.

Thank you!