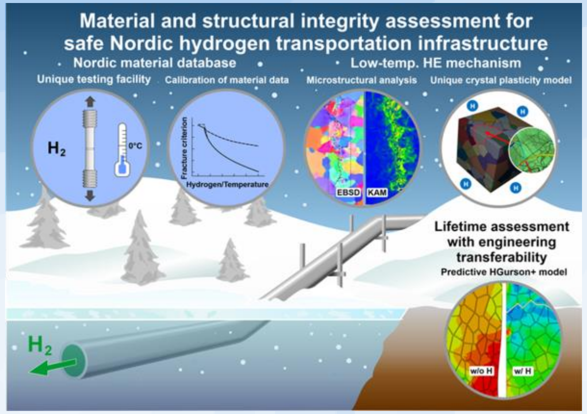
Nordic
Hydrogen Valleys
as Energy Hubs



The MatHias project

- *Material and Structural Integrity Assessment for safe Nordic Hydrogen Transportation Infrastructure*

Vigdis Olden, SINTEF, Sakari Pallaspuro, University of Oulu, Bård Nyhus, SINTEF,
Haiyang Hu, Uppsala University, Zhiliang Zhang, NTNU, Elina Huttunen-Saarivirta, VTT

The Nordic Hydrogen Valleys Conference , 22-23 January, Luleå University of Technology, 2025

Nordic Energy Research

The consortium

Research Partners

- SINTEF, Norway (Project Lead)
- University of Uppsala, Sweden
- VTT, Finland
- University of Oulu, Finland
- NTNU, Norway

Industry partners

- SSAB, Finland
- Equinor, Norway

Observers

- Gasgrid Finland
- Nordion Energi, Sweden
- Tukes, Finland

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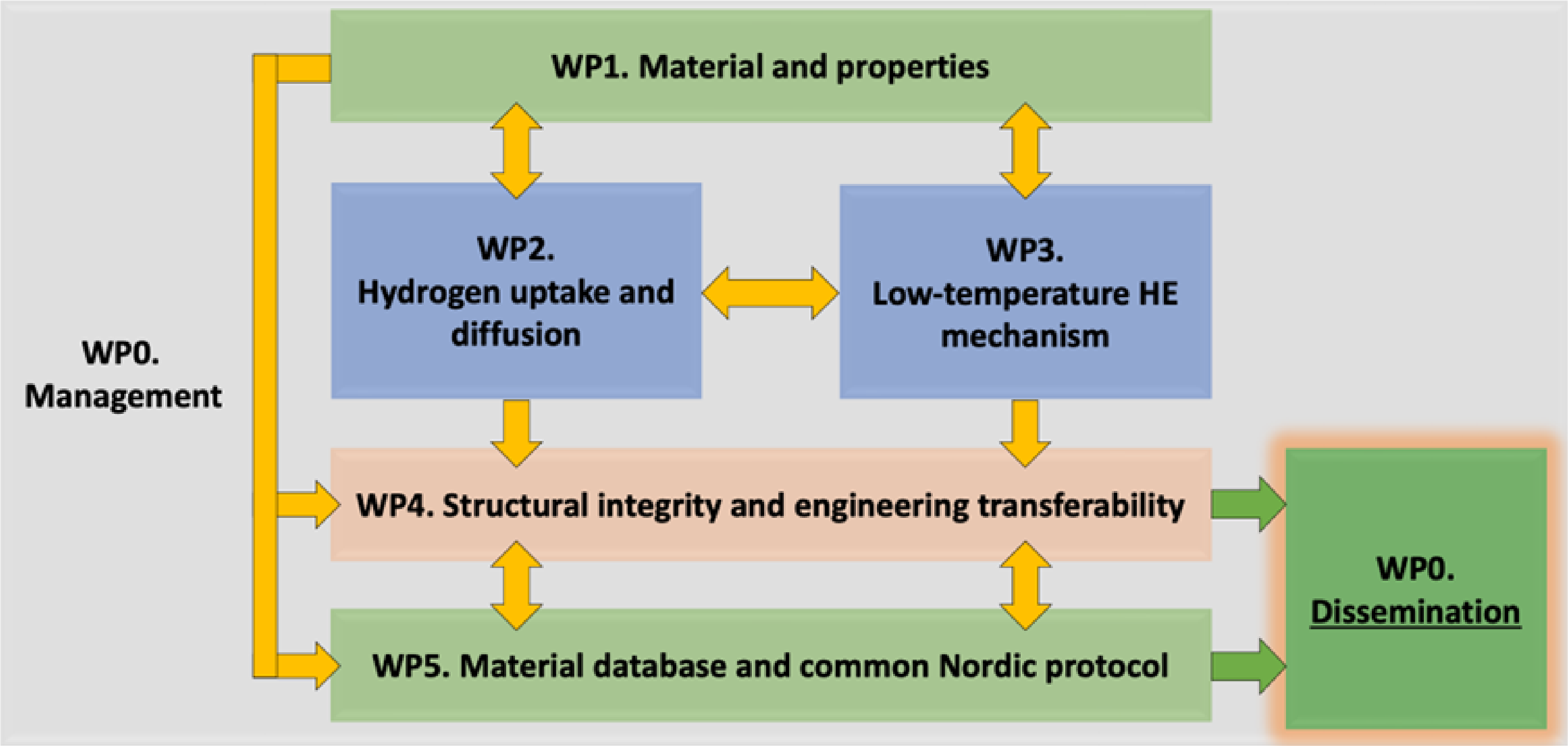
Structure of MatHias



WP1: Uni. of Oulu (Sakari) 

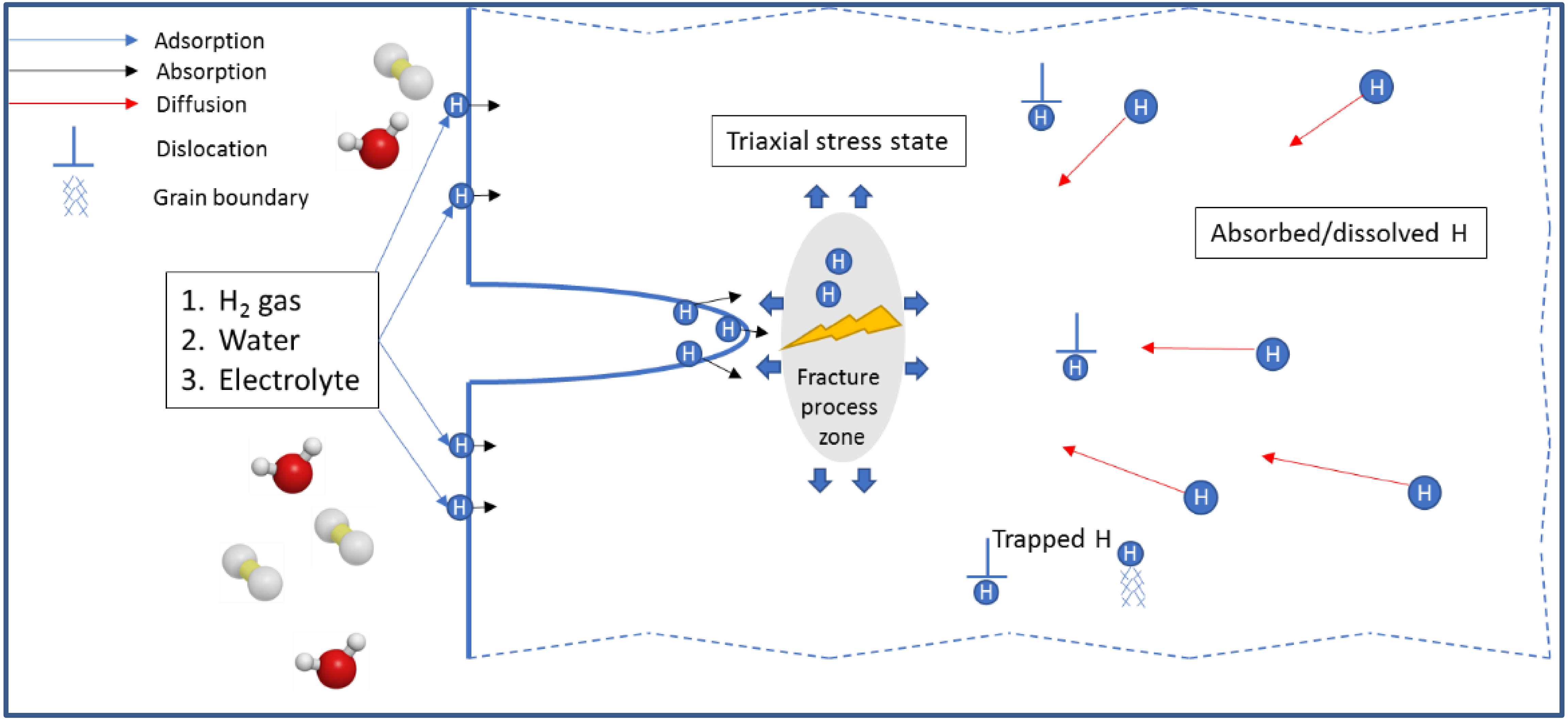
WP2: SINTEF (Bård) 

WP3: Uppsala Uni. (Haiyang) 

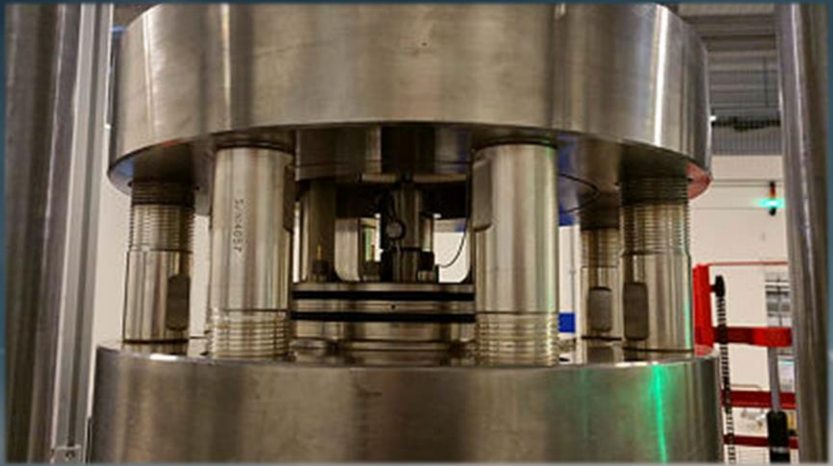
WP4: NTNU (Zhiliang) 

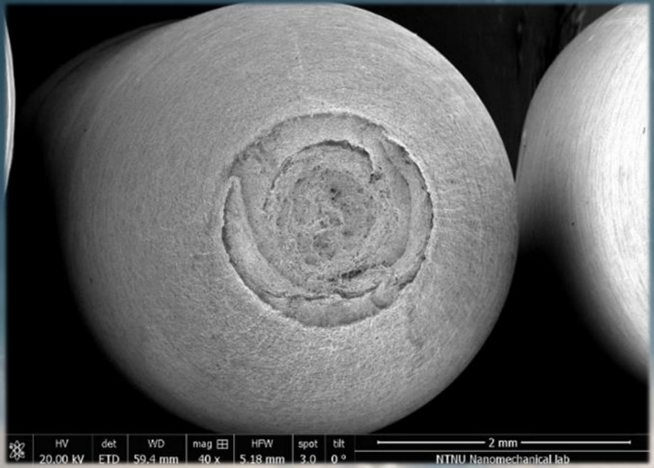
WP5: VTT (Elina) 

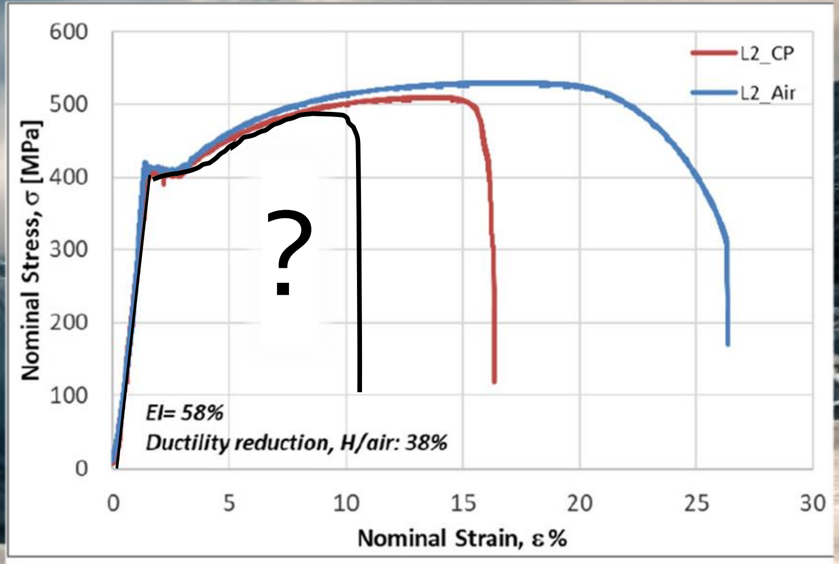
WP0: SINTEF (Vigdis) 

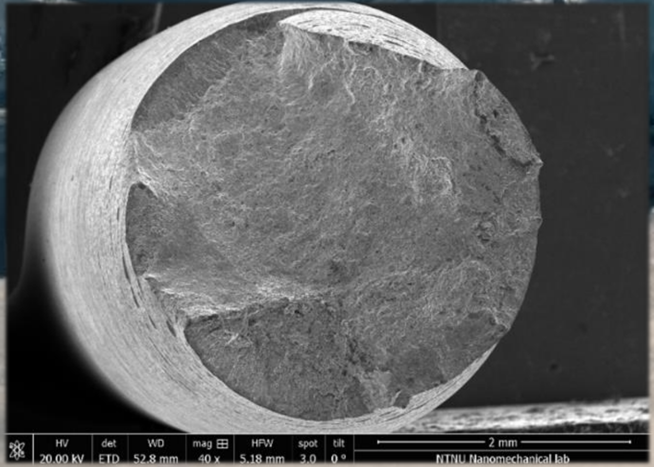


Adsorption
Absorption
Diffusion
Dislocation
Grain boundary
1. H_2 gas
2. Water
3. Electrolyte
Triaxial stress state
Fracture process zone
Absorbed/dissolved H
Trapped H
H



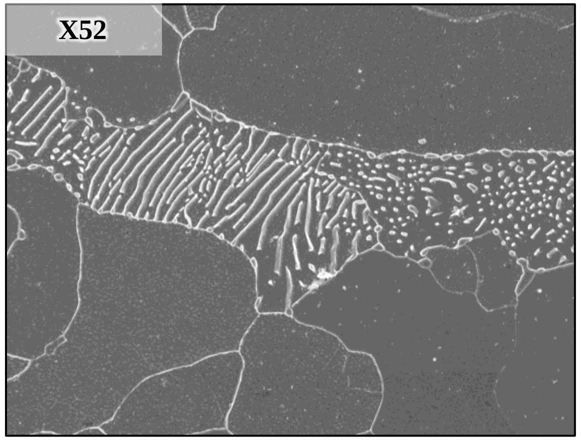

HV 20.00 kV
det ETD
WD 59.4 mm
mag 40 x
HFW 5.18 mm
spot 3.0
tilt 0 °
2 mm
NTNU Nanomechanical lab

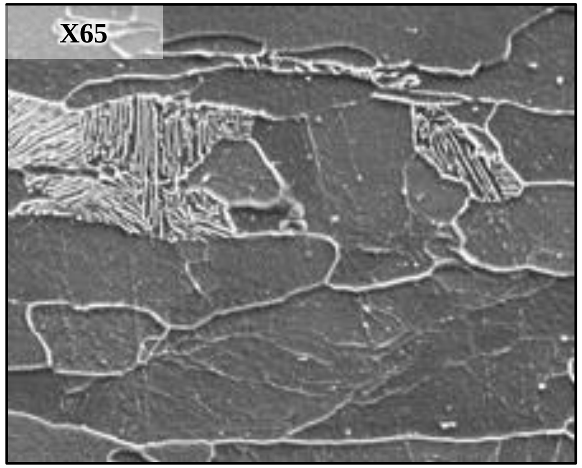

Nominal Stress, σ [MPa]
Nominal Strain, ε %
0
100
200
300
400
500
600
0
5
10
15
20
25
30
L2_CP
L2_Air
?
El= 58%
Ductility reduction, H/air: 38%

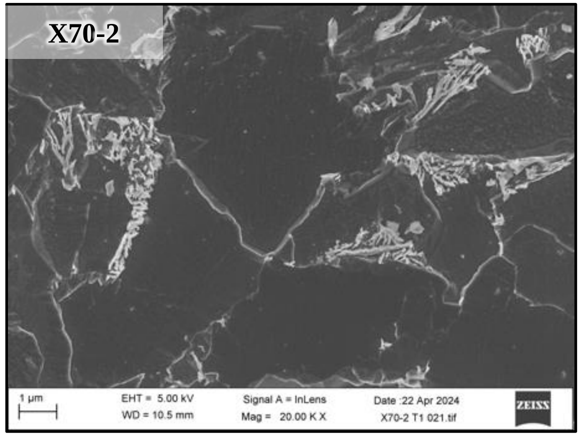

HV 20.00 kV
det ETD
WD 52.8 mm
mag 40 x
HFW 5.18 mm
spot 3.0
tilt 0 °
2 mm
NTNU Nanomechanical lab

Materials and properties

Material	Production method	Microstructure	YS / TS (BM) [MPa]
X52 (L360NE)	Normalised	Ferritic-pearlitic (~ 16 % pearlite)	426 / 620
X60 L415ME / X60ME-PSL2	Mechanical rolling	Ferritic-pearlitic / granular bainite	505 / 578
X65 SAWL (vintage pipe, 38 of use)	F-P, DSAW welded X-conf. double-joint	Ferritic-pearlitic	472 / 573
X70-1 (fresh modern small pipe)	Thermomechanical rolling, accelerated cooling (ME)	Bainitic (~ 2 % C-rich features)	594 / 658
X70-2: MODEL (fresh modern large pipe)	Thermomechanical rolling, accelerated cooling (ME)	Bainitic (~ 7 % C-rich features)	606 / 705





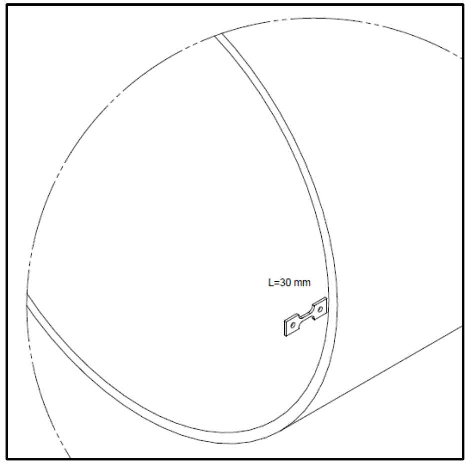


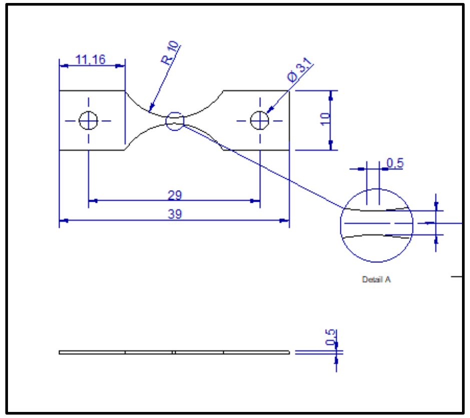
Mechanical properties and test methods

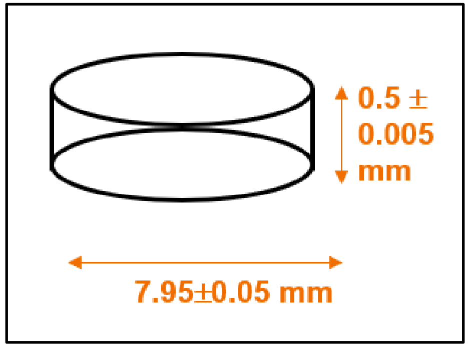
In situ H-charged mechanical testing (SINTEF, VTT, University of Oulu)
- Small-punch tests
- Slow-strain-rate tensile tests (SSRT)
- Fracture toughness testing

--> Comparison of pipeline steel grades
→ Fracture toughness as a function of hydrogen pressure & temperature
→ Equivalent conditions

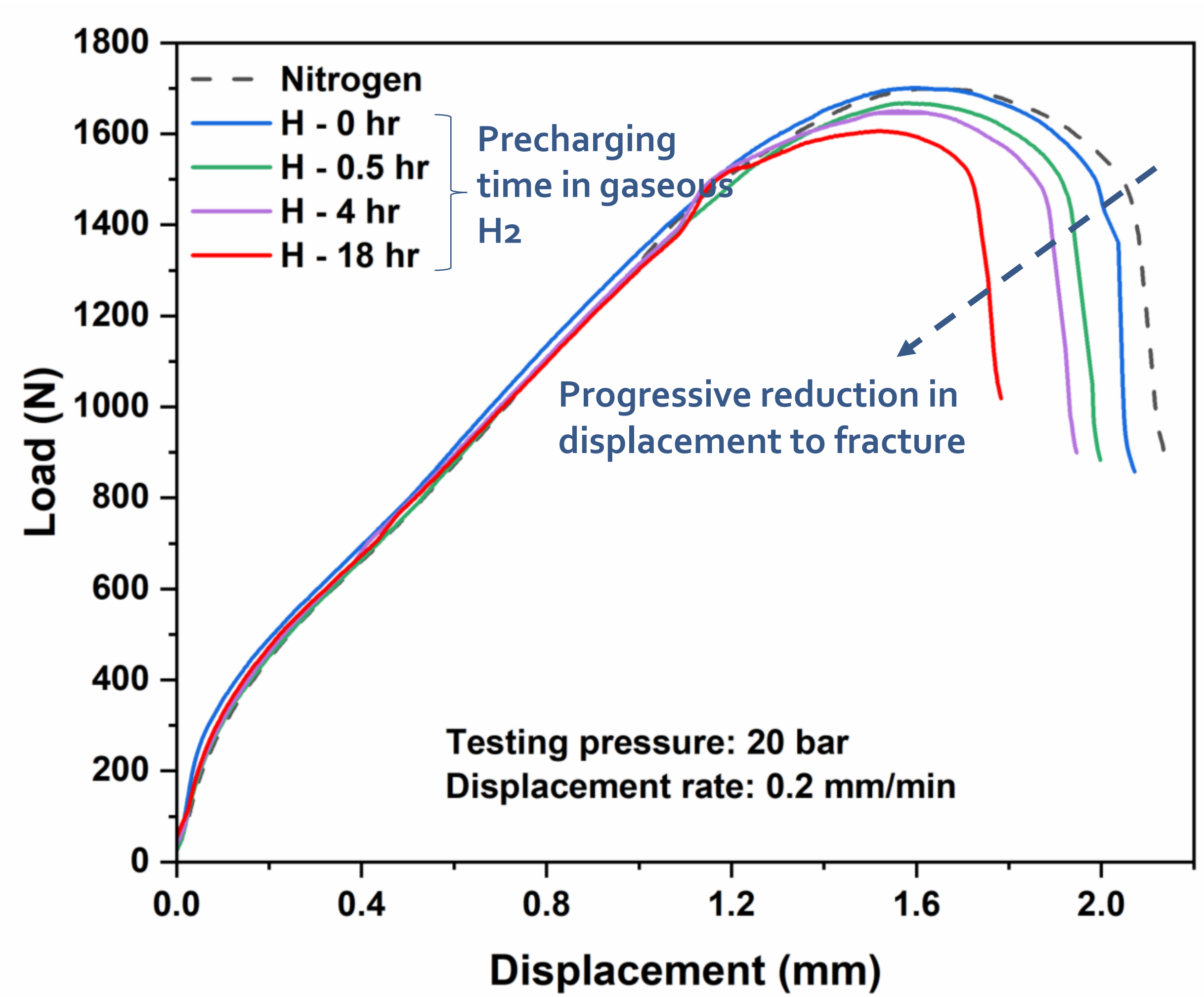
First results:
- The model material X70 behaves ductile even at -80 °C (in air)
- First hydrogen-charged tests done, mixed results under exposure to H



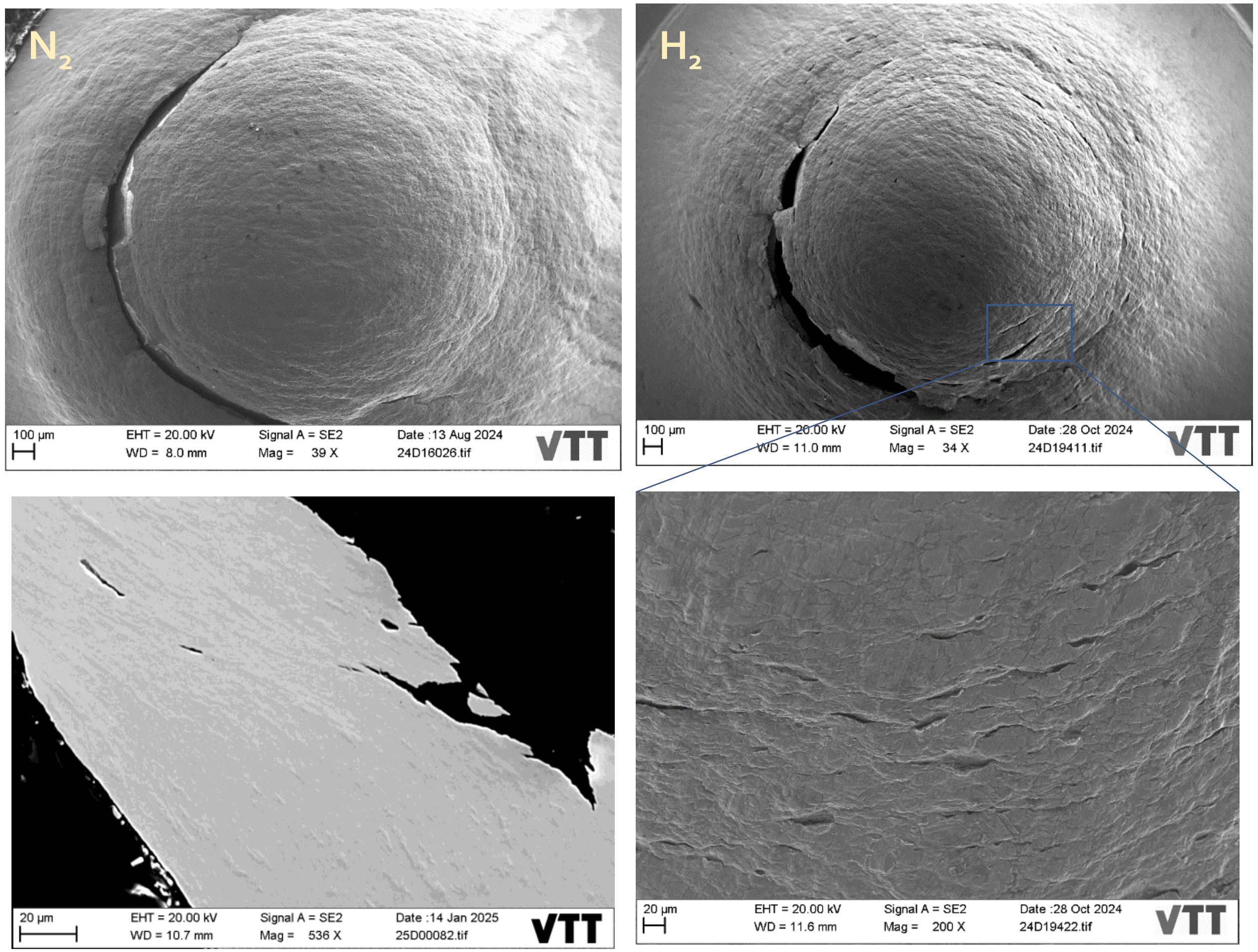




Small punch tests



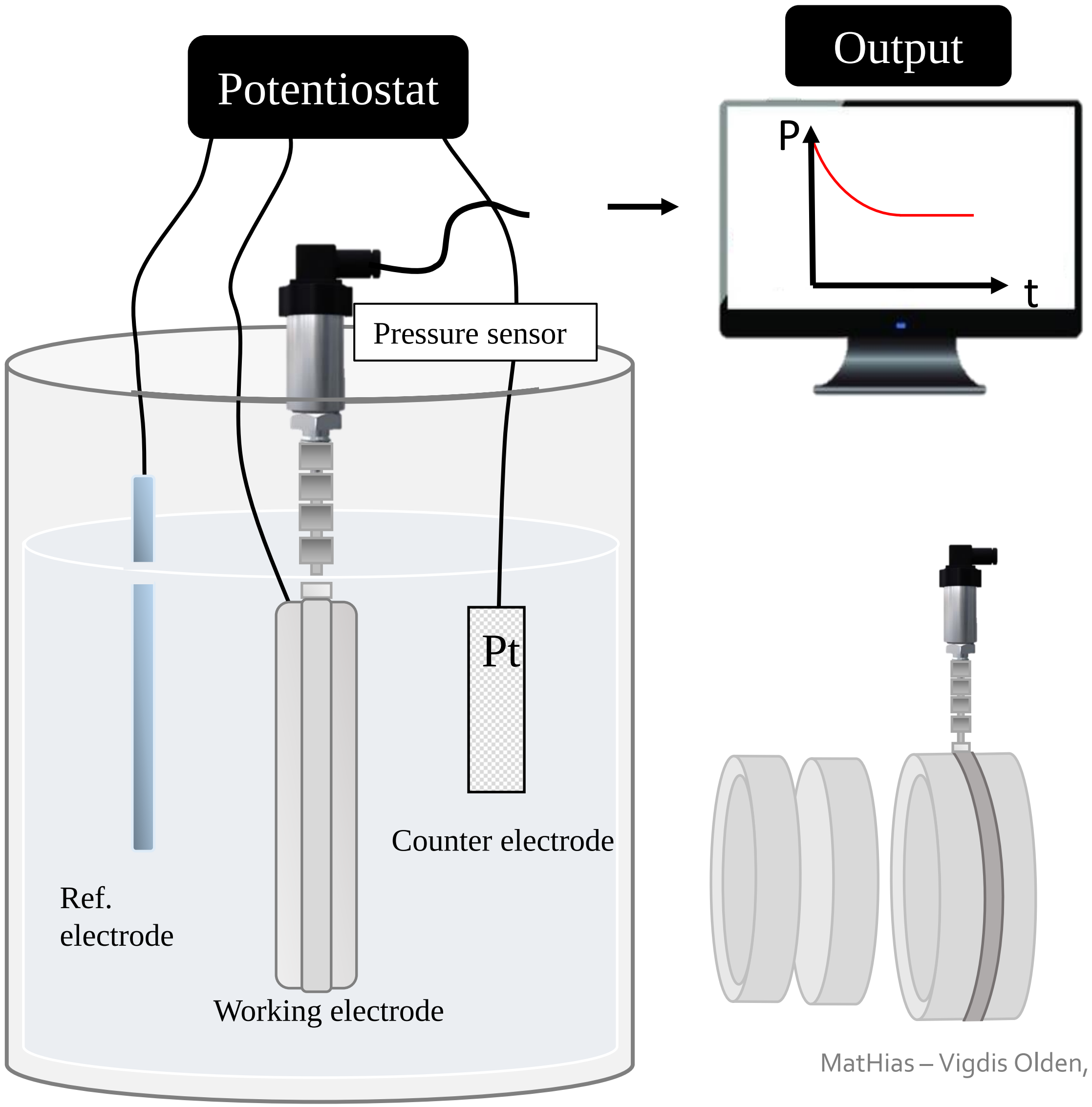
→ ***Selection of test conditions for further tests***

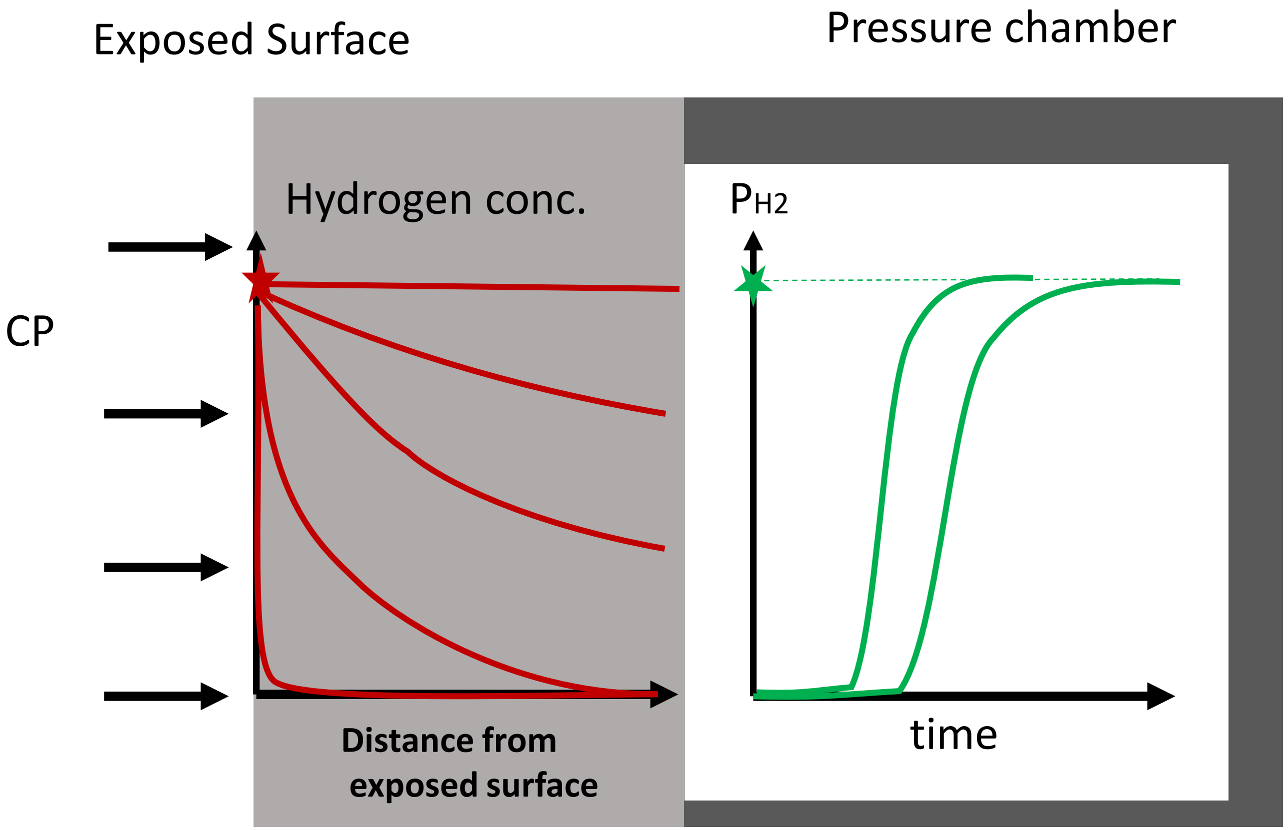


Cross-sectional view of hydrogen induced cracks

Hydrogen induced secondary cracks

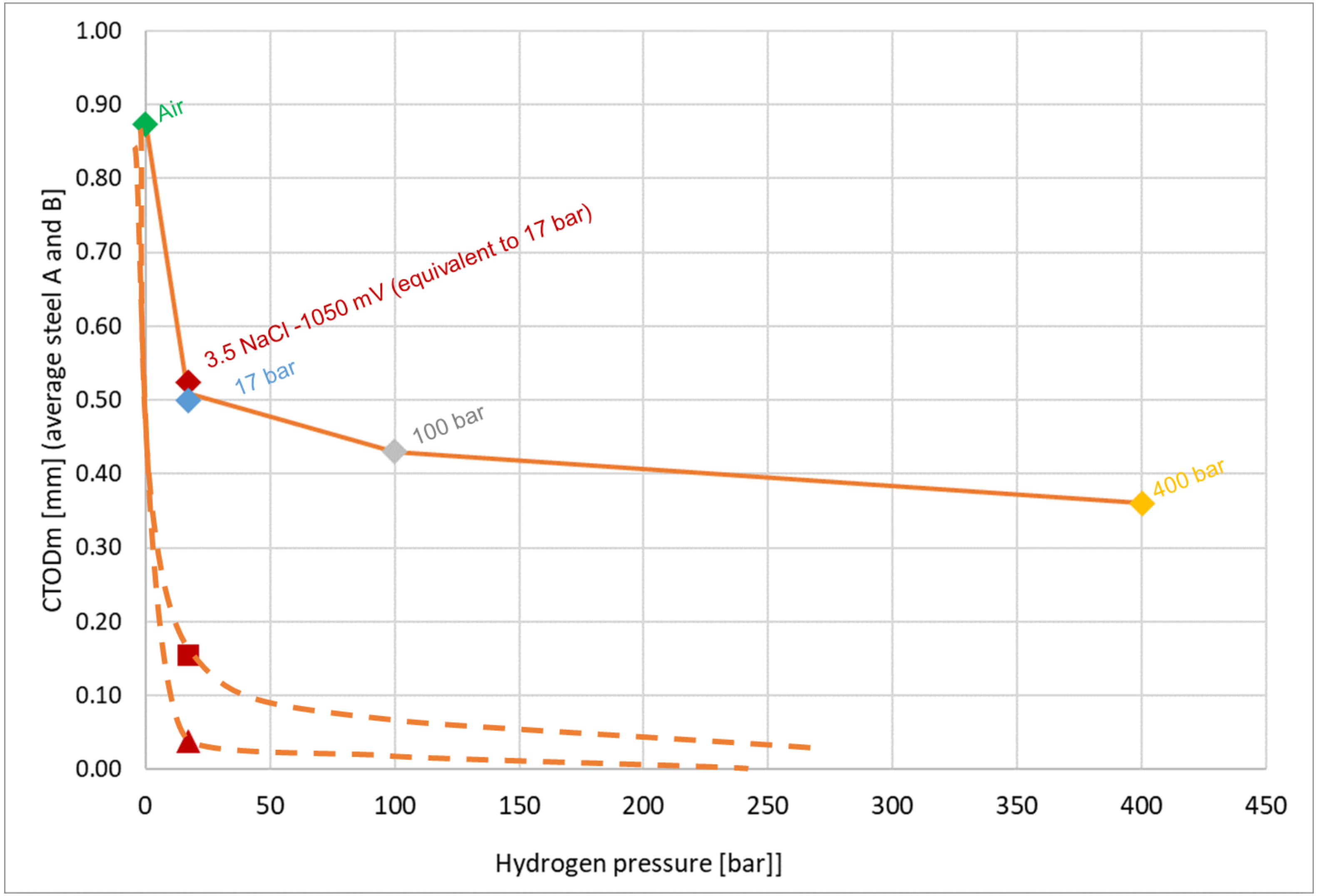
Hydrogen charging – equivalency between electrochemical and gaseous conditions





Equivalent fracture mechanics test conditions?

- This method (HySat) predicted that equivalent charging conditions to 3.5 NaCl -1050 mV is 17 bar hydrogen pressure
- Fracture mechanics verification testing indicates that equivalent charging established from the HYSAT test gives the similar fracture toughness



Pre-charging

- Pre-charging of Charpy specimens, current density of -50 mA/cm² v
- 3.5 wt.% NaCl
- 3 weeks pre-charging

Nordic Energy Research

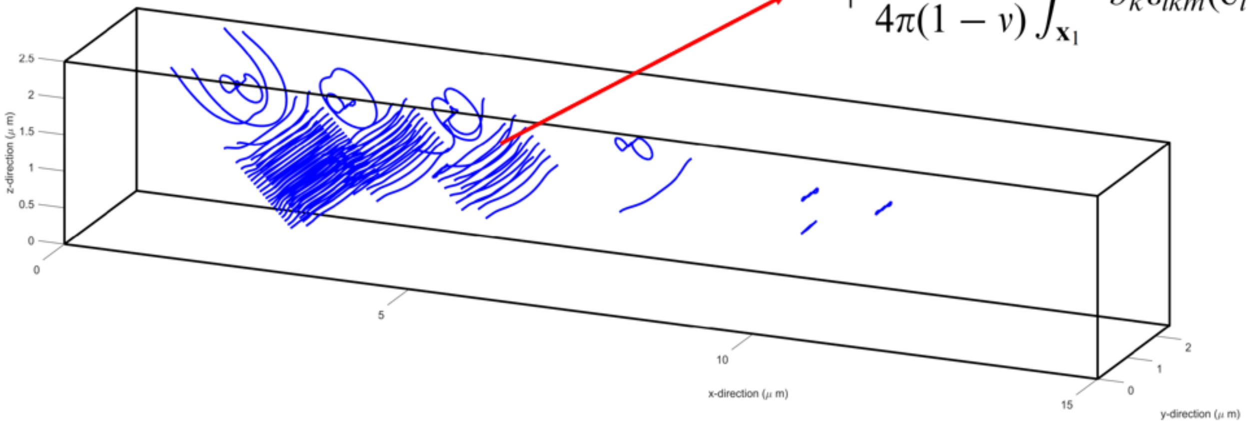
Nordic Hydrogen Valleys as Energy Hubs

Low-temperature HE mechanisms

— Tool established: hydrogen diffusion is coupled with dislocation dynamics model

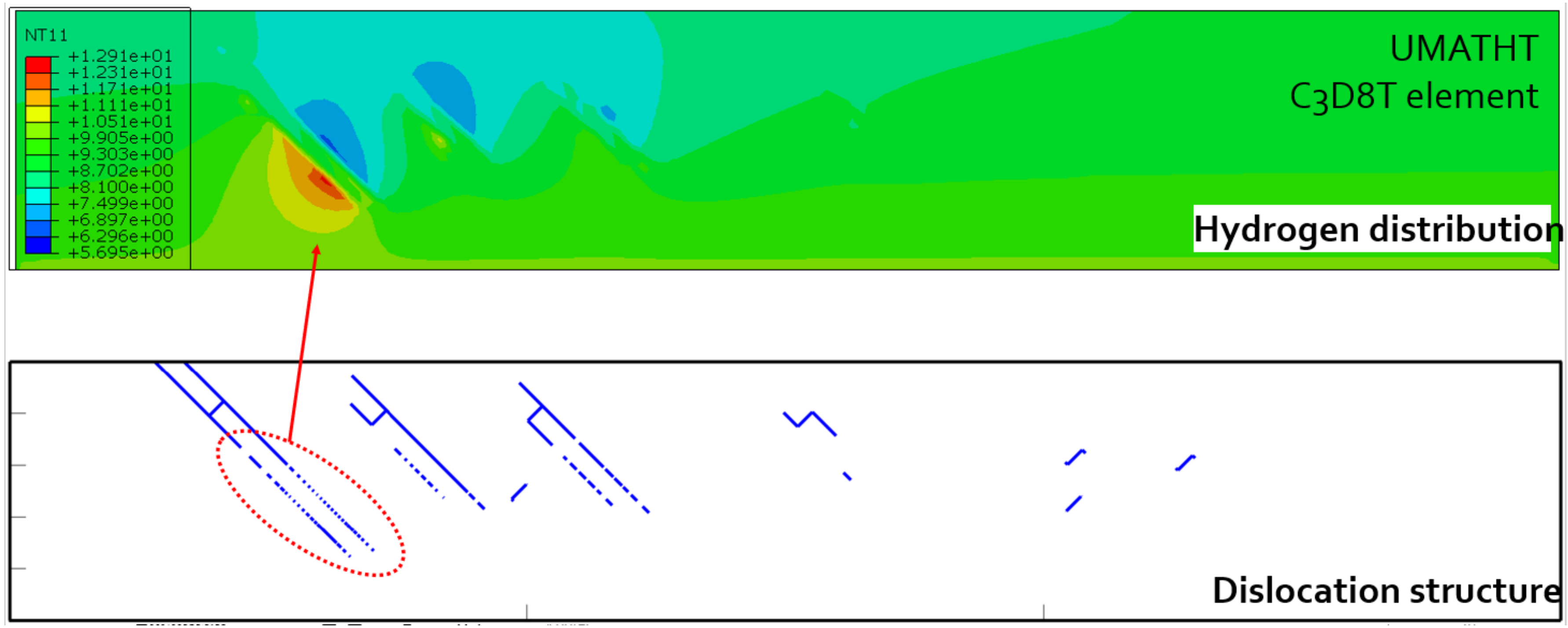
$$\boldsymbol{J} = -D\nabla C_L + \frac{D}{RT} C_L \bar{V}_H \nabla \sigma_H$$

$$\sigma_{ij}^{\mathrm{ns}}(\mathbf{x}) = \frac{\mu}{8\pi} \int_{\mathbf{x}_1}^{\mathbf{x}_2} \partial_l \partial_p \partial_p R_a b_k (\varepsilon_{ilk}\, \mathrm{d}x'_j + \varepsilon_{jlk}\, \mathrm{d}x'_i) + \frac{\mu}{4\pi(1-\nu)} \int_{\mathbf{x}_1}^{\mathbf{x}_2} b_k \varepsilon_{lkm} (\partial_l \partial_i \partial_j R_a - \delta_{ij} \partial_l \partial_p \partial_p R_a)\, \mathrm{d}x'_m$$

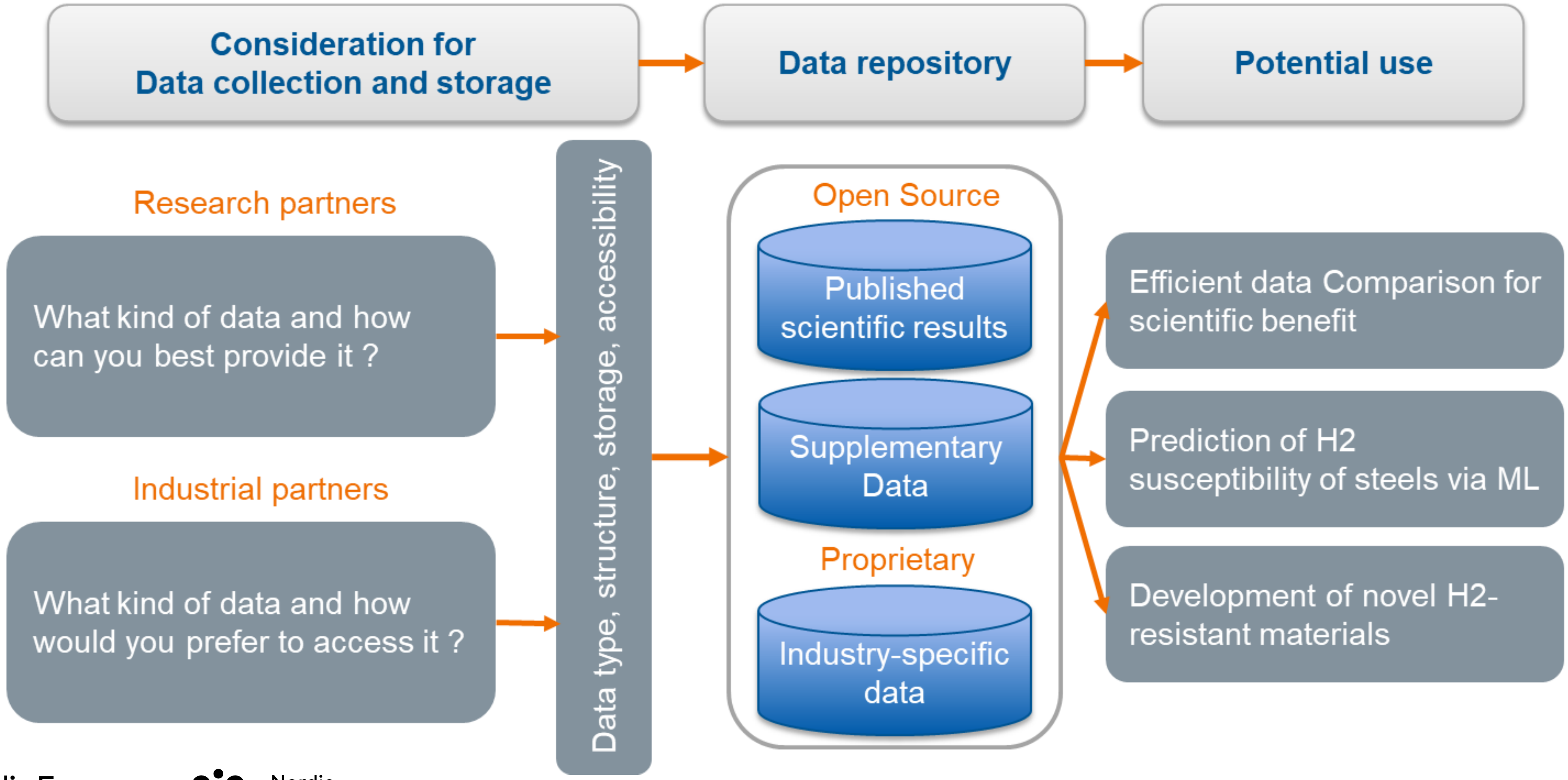


WP3 Low-temperature HE mechanisms

— Tool established: hydrogen diffusion is coupled with dislocation dynamics model



Material database and common Nordic protocol



Dissemination

Upcoming disseminations of the results during 2025:

ASTM Conference on Hydrogen in Materials, La Rochelle – France, 3-6/6

- Vigdis Olden: "MatHias project presentation and current status" (the project)
- Behnam Mirshekari: "Interaction of hydrogen with modern and vintage pipeline steel microstructures" (WP1)
- Chandrahaasan Soundararajan: "Accelerated hydrogen embrittlement screening via Small Punch Test: Case study on X70 pipeline steel" (WP1, WP3)
- Haiyang Yu: "Hydrogen-dislocation interactions simulated with the DDD approach" (WP3)

Pressure Vessels and Piping conference, Montreal-Canada, 20-25/7/2025

- Sebastian Lindqvist: "Influence of Hydrogen on Low Temperature Fracture Toughness Behavior of Pipeline Steel X70 in Nordic Operation Conditions"

Steel&Hydrogen, International Conference on Metals and Hydrogen, Ghent – Belgium, 14-16/10

- Behnam Mirshekari: "Unravelling the role of temperature on hydrogen embrittlement in pipeline steels"

A comprehensive review on HE

Chemical Reviews > Vol 124/Issue 10 > Article

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Hydrogen Embrittlement as a Conspicuous Material Challenge—Comprehensive Review and Future Directions

Haiyang Yu*, Andrés Díaz, Xu Lu, Binhan Sun, Yu Ding, Motomichi Koyama, Jianying He, Xiao Zhou, Abdelali Oudriss, Xavier Feaugas, and Zhiliang Zhang*

Chemical Reviews

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Thanks!

BUSINESS FINLAND

Swedish Energy Agency

Forskningsrådet