Overview of hydrogen conditions in applications

Ida Heintz

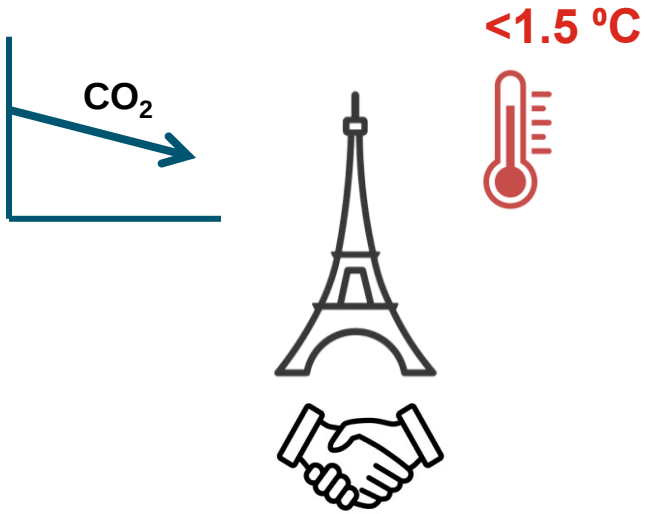
Nuria Fuertes

Research and business coordinator H_2-metals

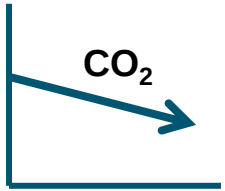
Swerim AB

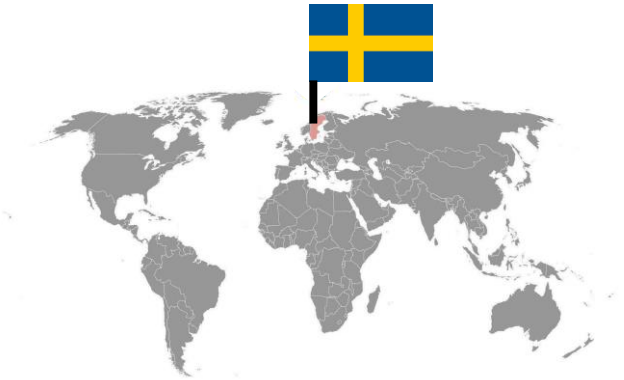
- ~ 200 researchers Luleå & Stockholm
- H_2 production, CCUS, processing, alloy design, hydrogen-metal interaction, metallurgical processes.
- > 20 years with hydrogen embrittlement research.
- Research institute in Sweden performing H_2 mechanical testing.
- Member programs, bilateral projects, EU/national projects

Importance of Hydrogen in a Fossil-Free Society



Importance of Hydrogen in a Fossil-Free Society





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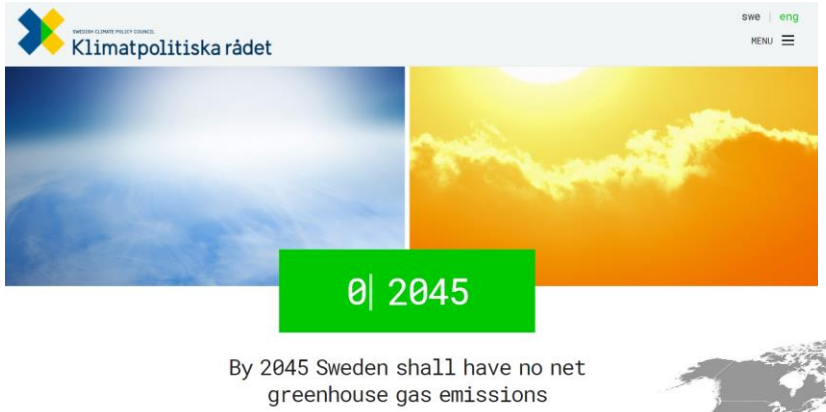
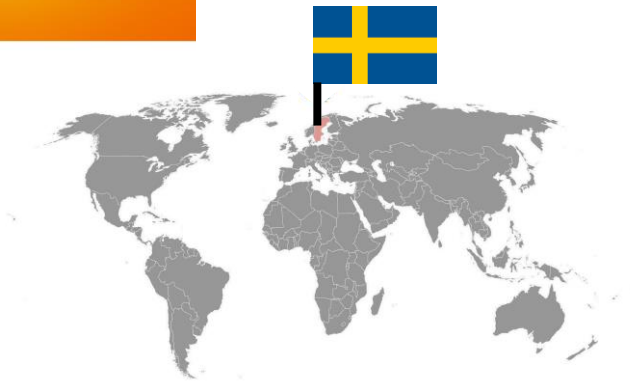


Sweden's global greenhouse gas emissions:

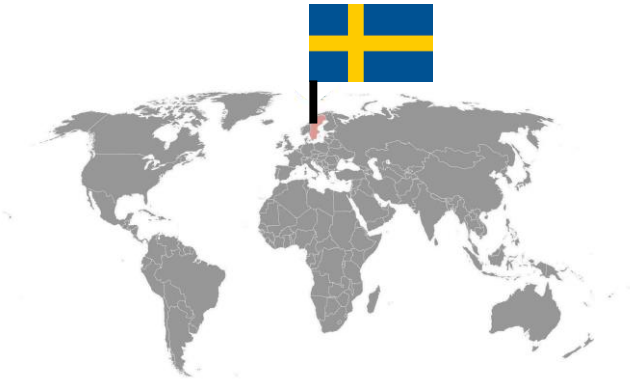
0.15% globally

0.3% including consumption



- ✓ NET ZERO by 2045
- ✓ ROLE MODEL
- ✓ PIONEERING CLIMATE-FRIENDLY SOLUTIONS

Importance of Hydrogen in a Fossil-Free Society



Importance of Hydrogen in a Fossil-Free Society

SWERIM

LKAB

August, LKAB

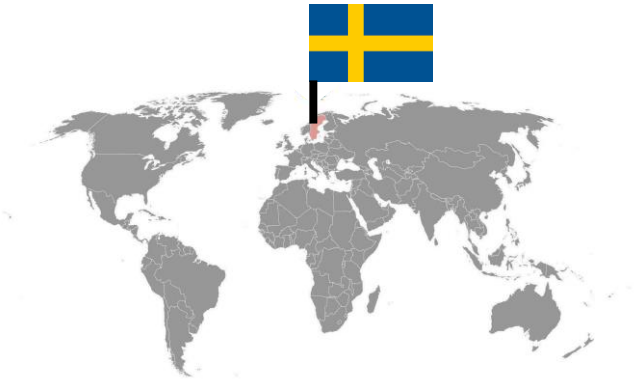


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Photo: Stegra

Photo: SSAB

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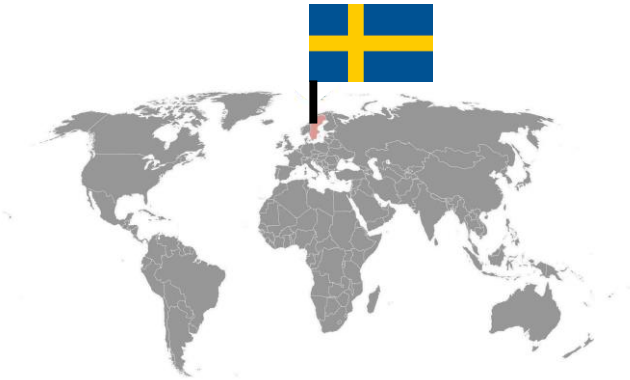
August, LKAB



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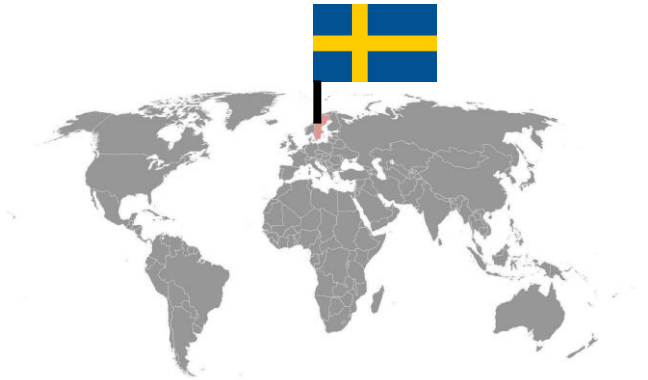

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Photo: SSAB

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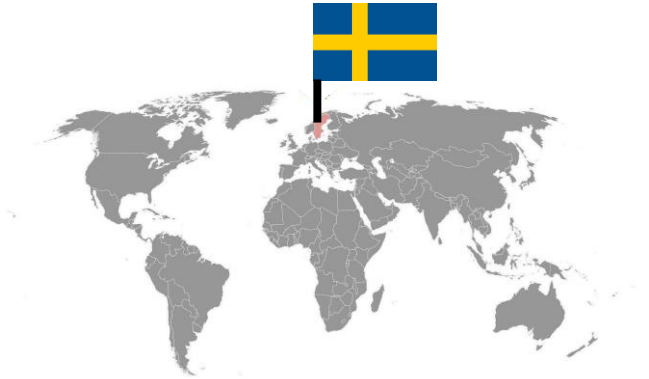

OVAKO

2023, Photo: OVAKO

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8th October DN.se

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Photo: Kanthal

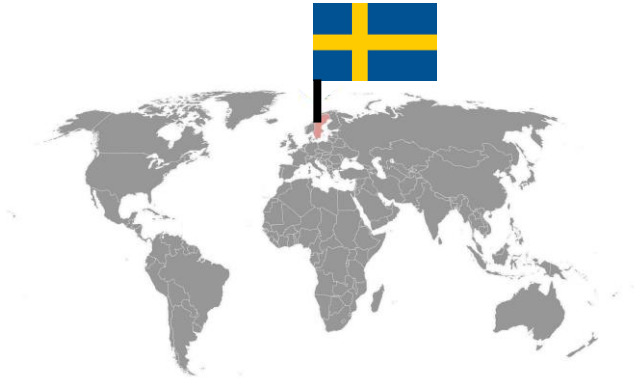
KANTHAL

Photo: Stegra

Photo: SSAB

LKAB

August, LKAB



OVAKO

Sweden's largest electrolyser project inaugurated to produce hydrogen for green steelmaking

Ovako's facility in Hofors will use renewable H2 for industrial heat rather than direct iron reduction, in bid to decarbonise downstream steel processing

2023, Photo: OVAKO

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8th October DN.se

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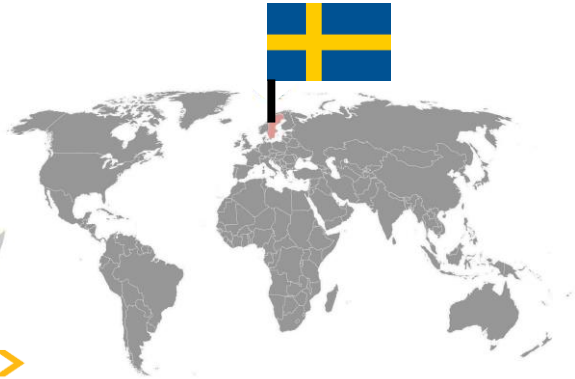
LKAB

August, LKAB

Photo: GKN

GKN AEROSPACE



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2023, Photo: OVAKO

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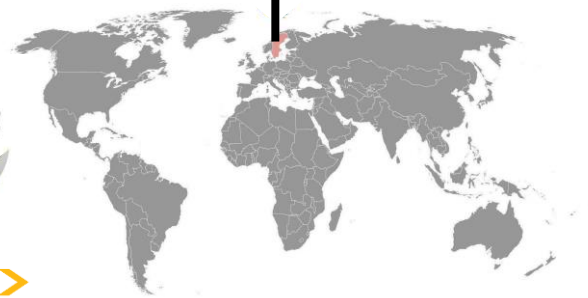

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GKN AEROSPACE

SIEMENS energy

Photo: Siemens Energy

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SCANIA VOLVO

Photo: Stegra

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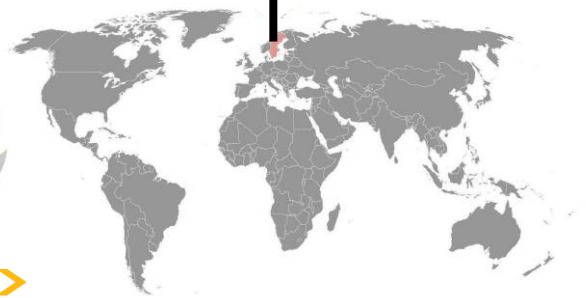

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KANTHAL

Energimyndighet rapport, 2023

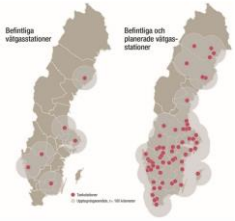


Photo: Volvo

SCANIA VOLVO

Photo: Stegra

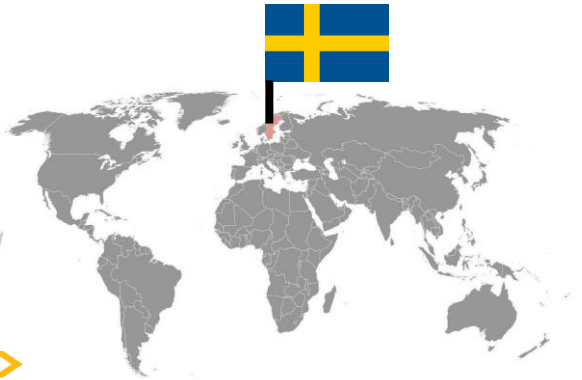
Photo: SSAB

LKAB

August, LKAB

ALFA LAVAL

Photo: Alfa Laval



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GKN AEROSPACE

SIEMENS energy

Photo: Siemens Energy

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Sweden's largest electroliser project inaugurated to produce hydrogen for green steelmaking

Ovako's facility in Hofors will use renewable H2 for industrial heat rather than direct iron reduction, in bid to decarbonise downstream steel processing

2023, Photo: OVAKO

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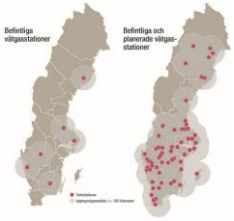

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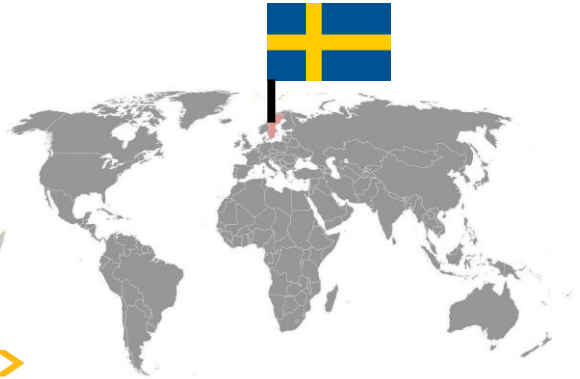

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2023, Photo: OVAKO

Photo: Alleima

outokumpu

Alleima

ESAB

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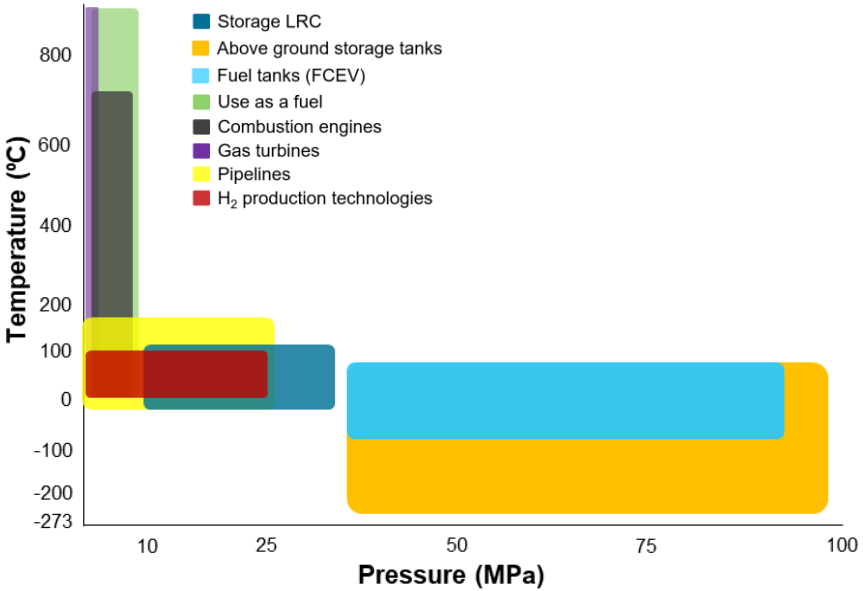
8th October DN.se

Hydrogen Applications and Their Specific Challenges

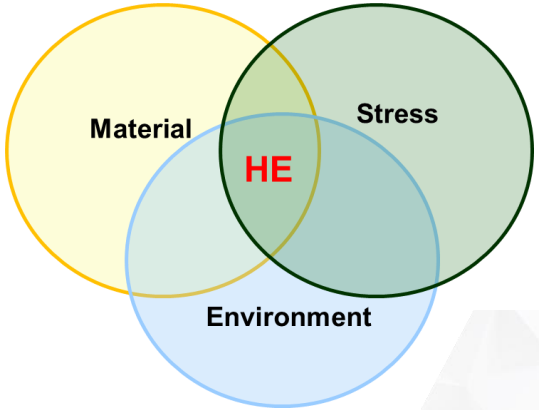
Feasibility study 2021-22:

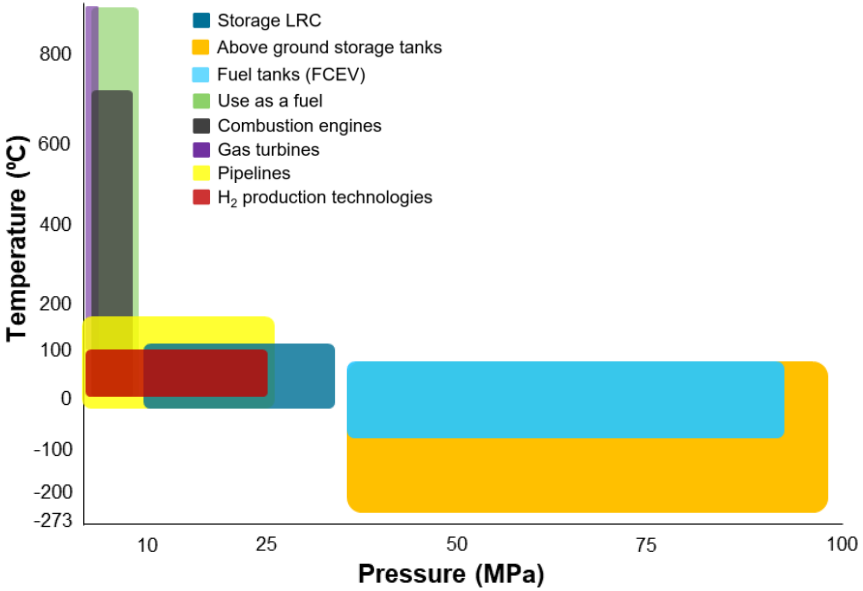
VINNOVA HyMech project
Graph based on input from 15 interviews
H_2 end-users, process and steel industry

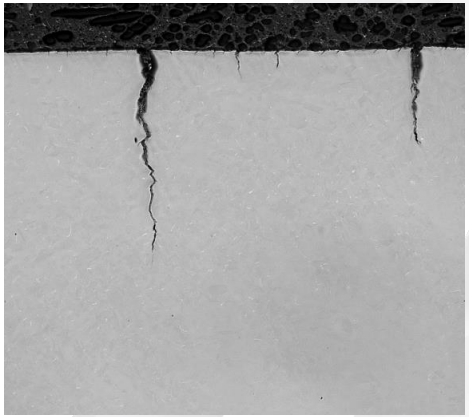


Hydrogen Applications and Their Specific Challenges

Hydrogen embrittlement (**HE**) can potentially lead to catastrophic failures in equipment used in hydrogen environment.

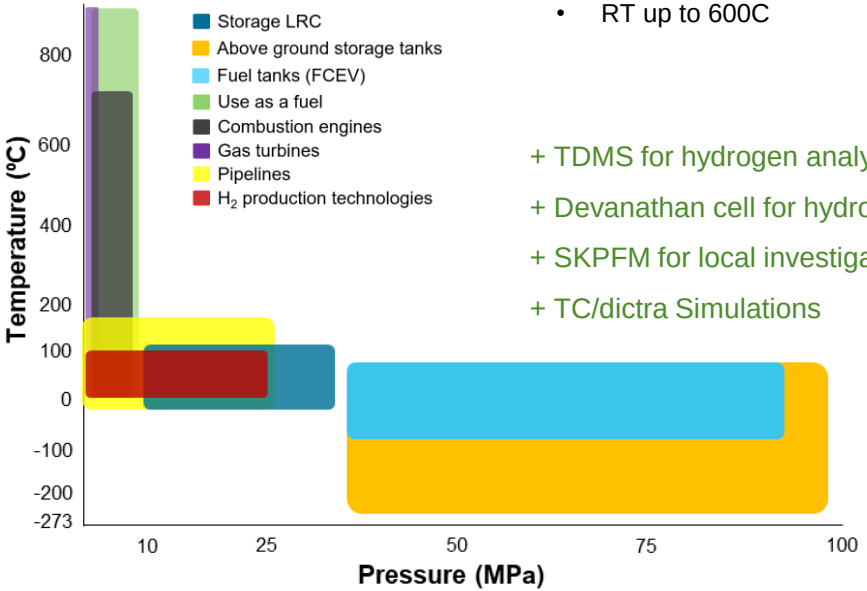






Hydrogen Applications and Their Specific Challenges

SWERIM



Static autoclave

- Thermal gas charging
- H uptake at different conditions
- Effect of trapping sites, surface treatments
- RT up to 600C

+ TDMS for hydrogen analysis

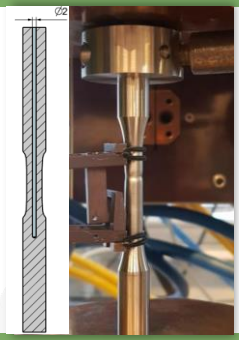
+ Devanathan cell for hydrogen permeation

+ SKPFM for local investigations

+ TC/dictra Simulations

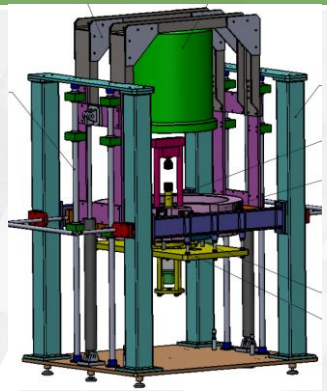
Hollow specimen

- ISO 7039:2024
- SSRT; fatigue
- -150C up to 1000C
- P up to 1000 bars
- Allows FN measurements
- Innersurface: Ra-value max 0.2 µm



Dynamic autoclave

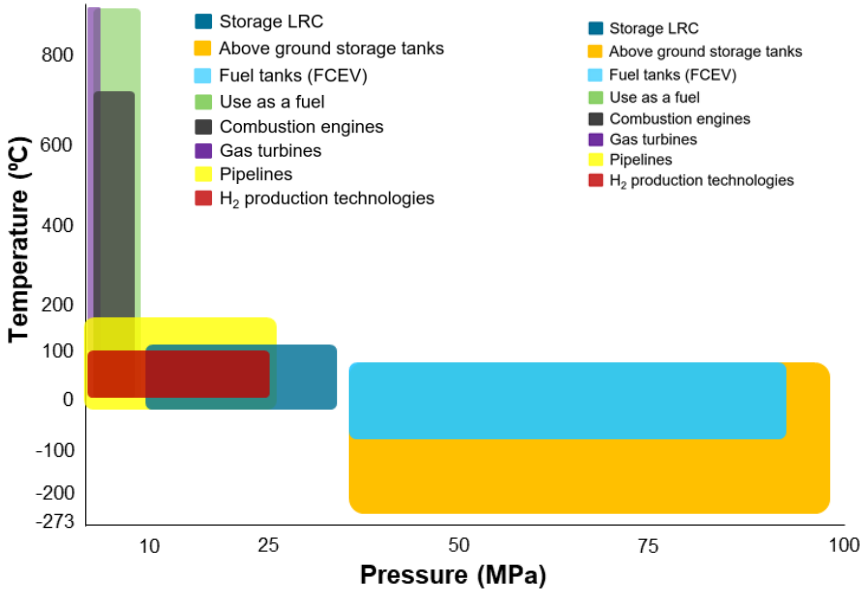
- P up to 1000 bars
- Temperature -80C to 80C
- Allows fracture mechanics testing (CT, K IC, da/dN)
- HCF; LCF, SSRT
- Testing of welds:yes



Hydrogen Applications and Their Specific Challenges

Feasibility study 2022:

VINNOVA HyMech project
Graph based on input from 15 interviews
H_2 end-users, process and steel industry



2022-2025 **VINNOVA HYMECH II**

Hydrogen gas induced degradation of mechanical properties in new applications

Hydrogen Applications and Their Specific Challenges

STORAGE and TRANSPORT

POWER GENERATION
and
HEATING TECHNOLOGIES

TRANSPORTATION

HYMECH II

Materials performance in H_2 applications

Hydrogen Applications and Their Specific Challenges

SWERIM

STORAGE and TRANSPORT

POWER GENERATION
and
HEATING TECHNOLOGIES

TRANSPORTATION

SWERIM VINNOVA

HYMECH II

Materials performance in H_2 applications

HYBRIT FOSSIL-FREE STEEL · SSAB · LKAB · ALFA LAVAL · outokumpu · ESAB · SIEMENS energy · KANTHAL · OVAKO · SCANIA · VOLVO

EFFECT OF HYDROGEN GAS ON TENSILE PROPERTIES OF AUSTENITIC STAINLESS STEELS AT SUBZERO, ROOM AND ELEVATED TEMPERATURES

H2 Science, Trondheim, June 2024

SWERIM

Increasing Nieq

EN	Outokumpu grade	Cr. wt.%	Mo. wt.%	Ni. wt.%	Mn. wt.%	Si. wt.%	C. wt.%	N. wt.%
1.4404	Supra 316L/4404	16.5 to 18.5	2.00 to 2.50	10.0 to 13.0	≤ 2.00	≤ 1.00	≤ 0.03	≤ 0.10
1.4420	Supra 316plus	19.5 to 21.5	0.50 to 1.50	8.0 to 9.5	≤ 2.00	≤ 1.00	≤ 0.03	0.14 to 0.25
1.4435	Supra 316L/4435	17.0 to 19.0	2.50 to 3.00	12.5 to 15.0	≤ 2.00	≤ 1.00	≤ 0.03	≤ 0.10

Pressure: 200 bar (H_2 quality 4.5)

Temperature: -50 °C, 23 °C, 100 °C

Strain rate: $5*10^{-5}$ s^{-1}

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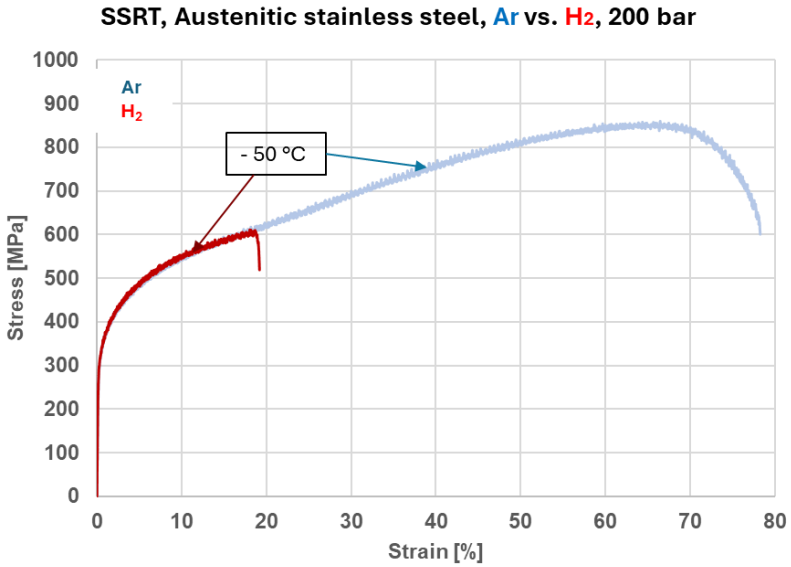
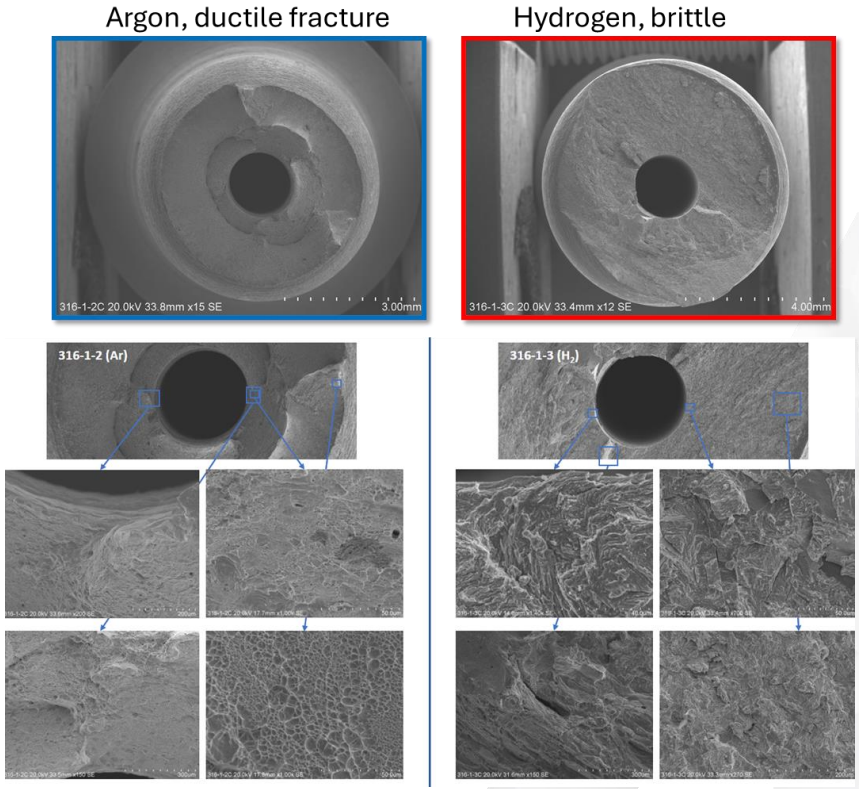


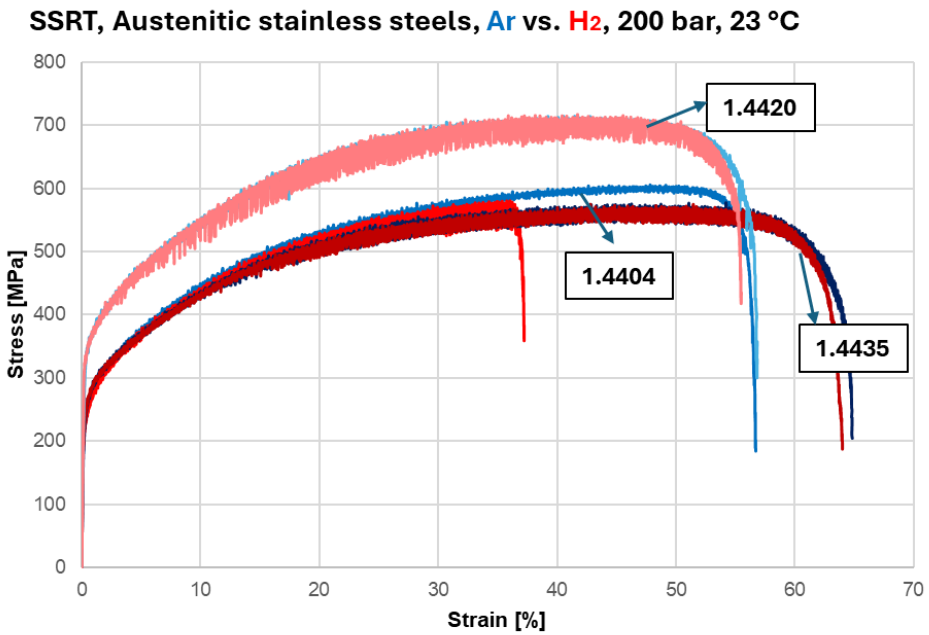
Large effect of testing conditions



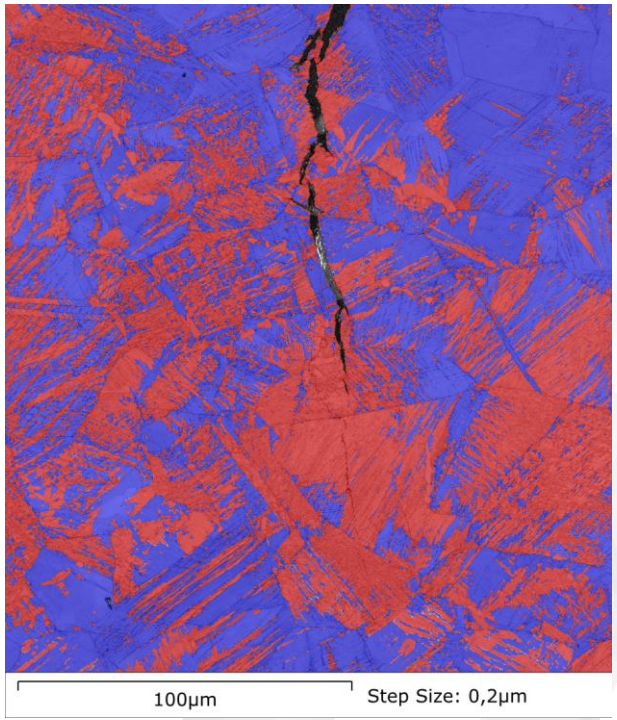
EFFECT OF HYDROGEN GAS ON TENSILE PROPERTIES OF AUSTENITIC STAINLESS STEELS AT SUBZERO, ROOM AND ELEVATED TEMPERATURES

SWERIM

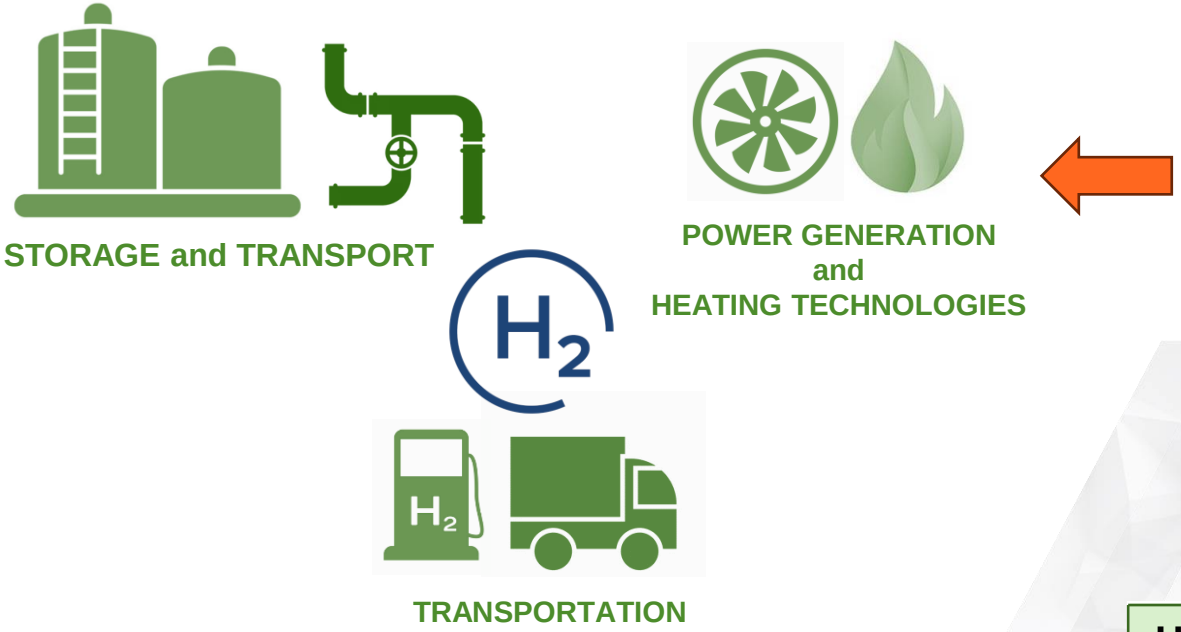
EN 1.4404 vs EN 1.4435 vs EN 1.4420



Important to know which grade of stainless steel!



Hydrogen Applications and Their Specific Challenges



HYMECH II

Materials performance in H_2 applications

EFFECT OF HIGH-PRESSURE H2 AT ROOM AND HIGH TEMPERATURE ON THE MECHANICAL PERFORMANCE OF CONVENTIONAL AND ADDITIVELY MANUFACTURED Ni-BASE ALLOYS

European Conference on Fracture, August 2024

Frans Palmert[1], Zhe Chen[1], Birhan Sefer[2], Pontus Rydgren[2], Nuria Fuertes[2], Eduard Navalles[2], Emil Edin[3], Lars Olof Nordin[3]

[1] *Siemens Energy AB, SE-612 31, Finspång, Sweden*

[2] *Swerim AB, Box 7047, 164 07 Kista, Sweden*

[3] *LKAB, Material Laboratory, Box 952, SE-971 28 Luleå, Sweden*

Burner manufactured by Laser Powder Bed Fusion (LPBF)

Photo: Siemens Energy

Materials:

Hastelloy X (Ni-Cr-Fe-Mo alloy)

Comparison of LPBF (additively manufactured) vs Hot rolled

→ 1 piece instead of welding 13 parts!

Method: SSRT, H2, 200bar

SGT-800 gas turbine from Siemens Energy

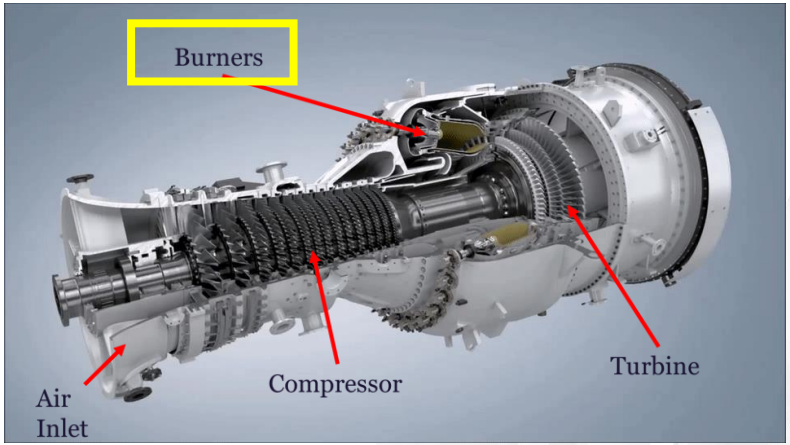


Photo: Siemens Energy

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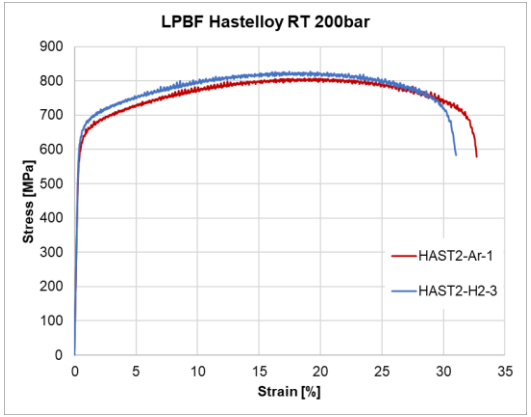
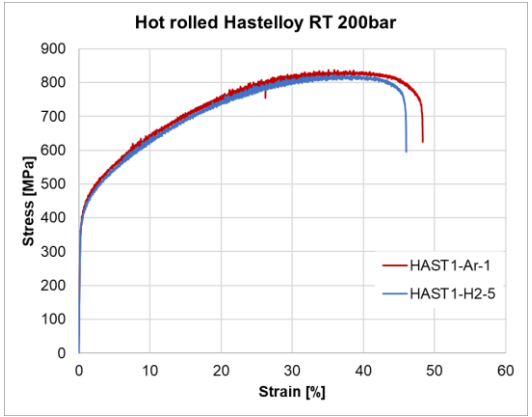
European Conference on Fracture, August 2024





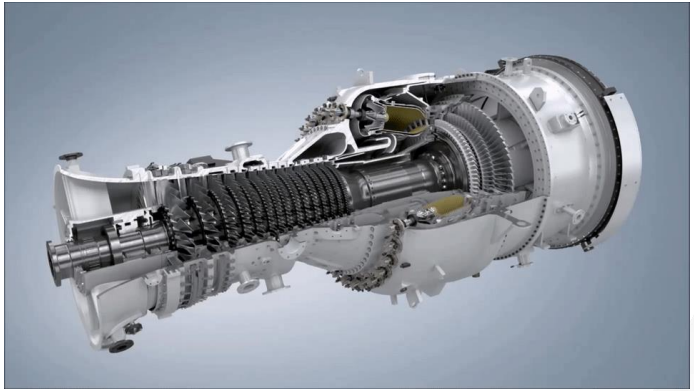
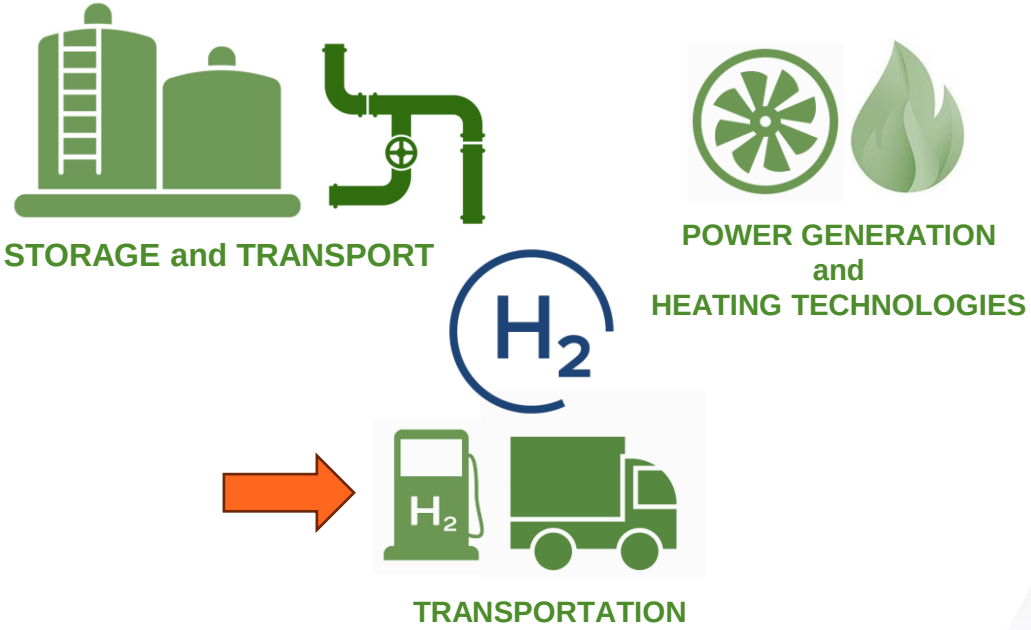


Photo: Siemens Energy

- ✓ **No sensitivity to hydrogen embrittlement**
- ✓ **Additively manufactured behaves as good as conventional material**

Hydrogen Applications and Their Specific Challenges



HYMECH II

Materials performance in H_2 applications

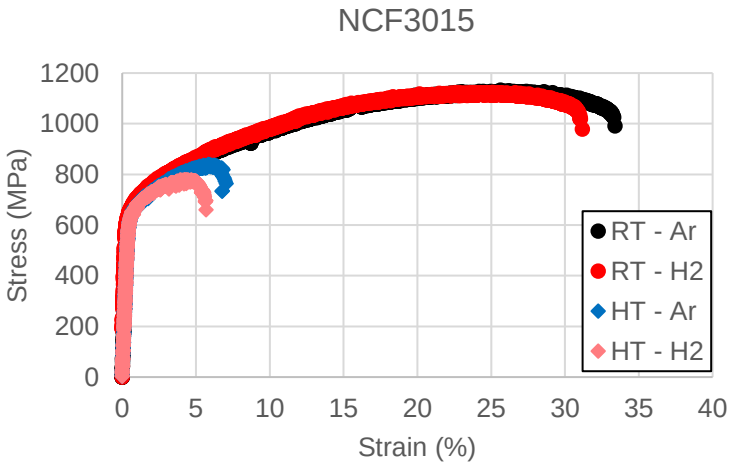
SCREENING OF MECHANICAL DEGRADATION OF COMBUSTION ENGINE AND EXHAUST METALLIC MATERIALS IN HIGH PRESSURE AND HIGH TEMPERATURE HYDROGEN GAS ENVIRONMENT

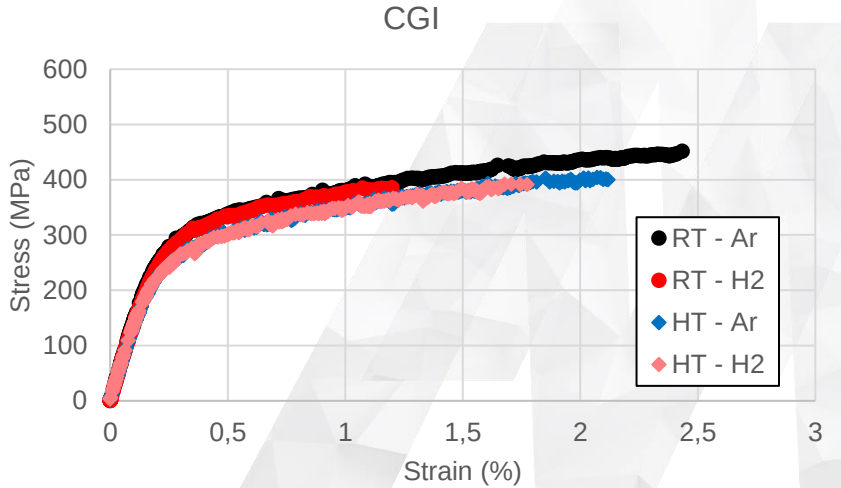
European Conference on Fracture, August 2024

Photo: Volvo

- ✓ **Is it possible to use internal combustion engines (ICE) with hydrogen combustion instead of diesel?**
- ✓ **How do the materials behave?**

→ First results showed a large impact of hydrogen on mechanical properties, need to investigate further the effect of fatigue testing





SURFHY
Surface treatments for improved HE resistance

NEW

HYSTRENGTH
Improved material utilization for more sustainable H2 applications

NEW

FINAST PhD project
Carbon steels for H_2 storage and transport

NeXT Center
Neutron and X-ray science for industrial technology Transitions

Microstructure and damage evolution in hydrogen environment

COMING SOON

+ 1 proposal submitted for PhD project

+ HORIZON/RFCS with EU partners

STORAGE and TRANSPORT

POWER GENERATION and HEATING TECHNOLOGIES

TRANSPORTATION

HydrAM PhD project

Hydrogen embrittlement of advanced AM components

OXELHY
Oxide formation in hydrogen combustion heating

HYMECH II
Materials performance in H_2 applications

Challenges and Collaboration Needs

- Need for **safe and reliable material** performance in hydrogen applications
- **Knowledge gaps** on material behaviour in H2
- **Evaluation methods** close to service conditions:
  - Hollow Specimen Method / Autoclave method / Thermal gaseous charging
  - Need for Round Robin tests
- **Unavailable equipment:** high cost, specialized equipment with limited access
- **Time constraints:** hydrogen embrittlment is a time-dependent process
- **New standards**

Conclusion:
Towards a Fossil-Free Society with Hydrogen

SWERIM

- Hydrogen importance in reducing carbon emisions:
  - Clean energy source
  - Energy Storage and Flexibility

- Numerous initiatives in Sweden and abroad.

To ensure hydrogen technologies contribute effectively to a fossil-free society

- ✓ Need for continued research
- ✓ Development
- ✓ Collaboration

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