H_2 Sensing with an Optical Fiber Sensor in the Subsurface H_2 Storage Conditions

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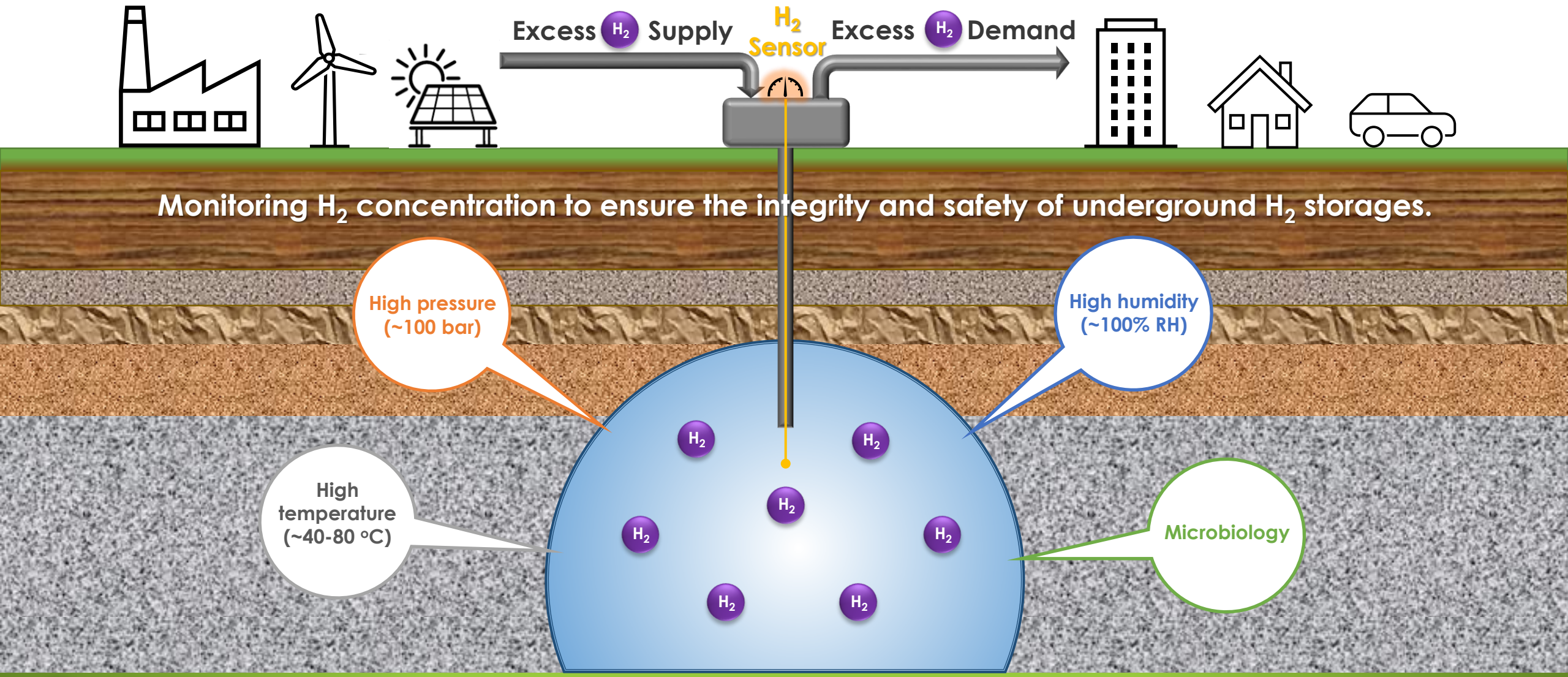
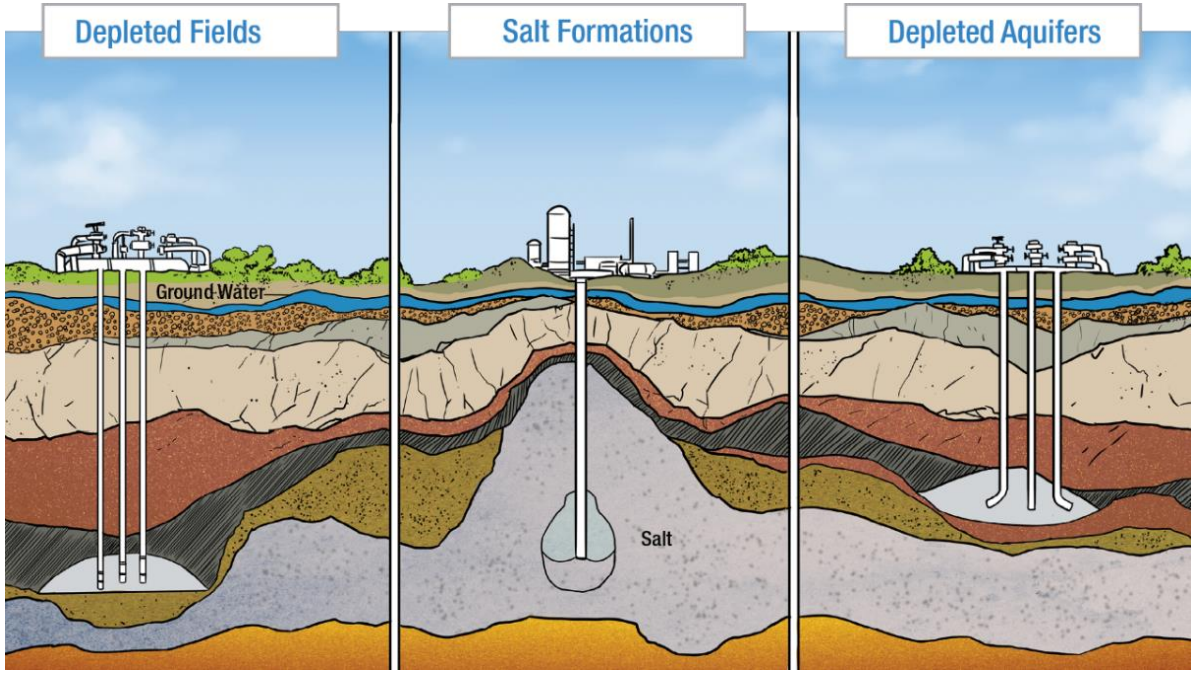
Subsurface Hydrogen Storage

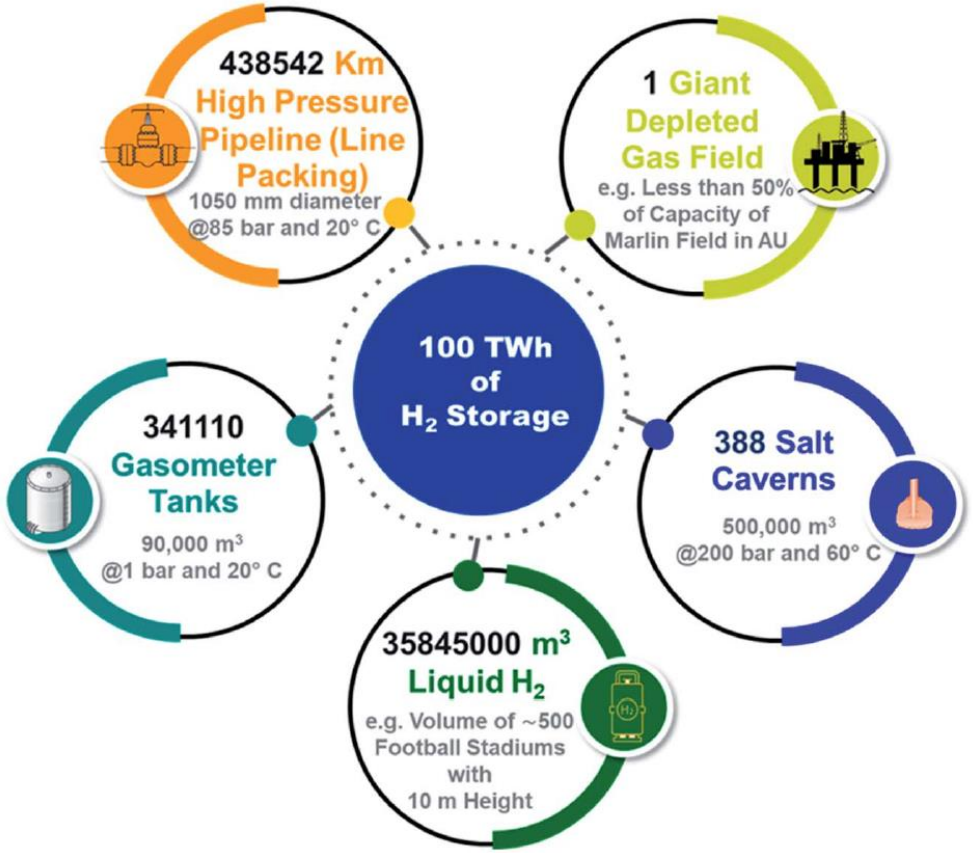


Capacity of Subsurface Hydrogen Storage



Three different types of underground gas storage.

(energyinfrastructure.org)



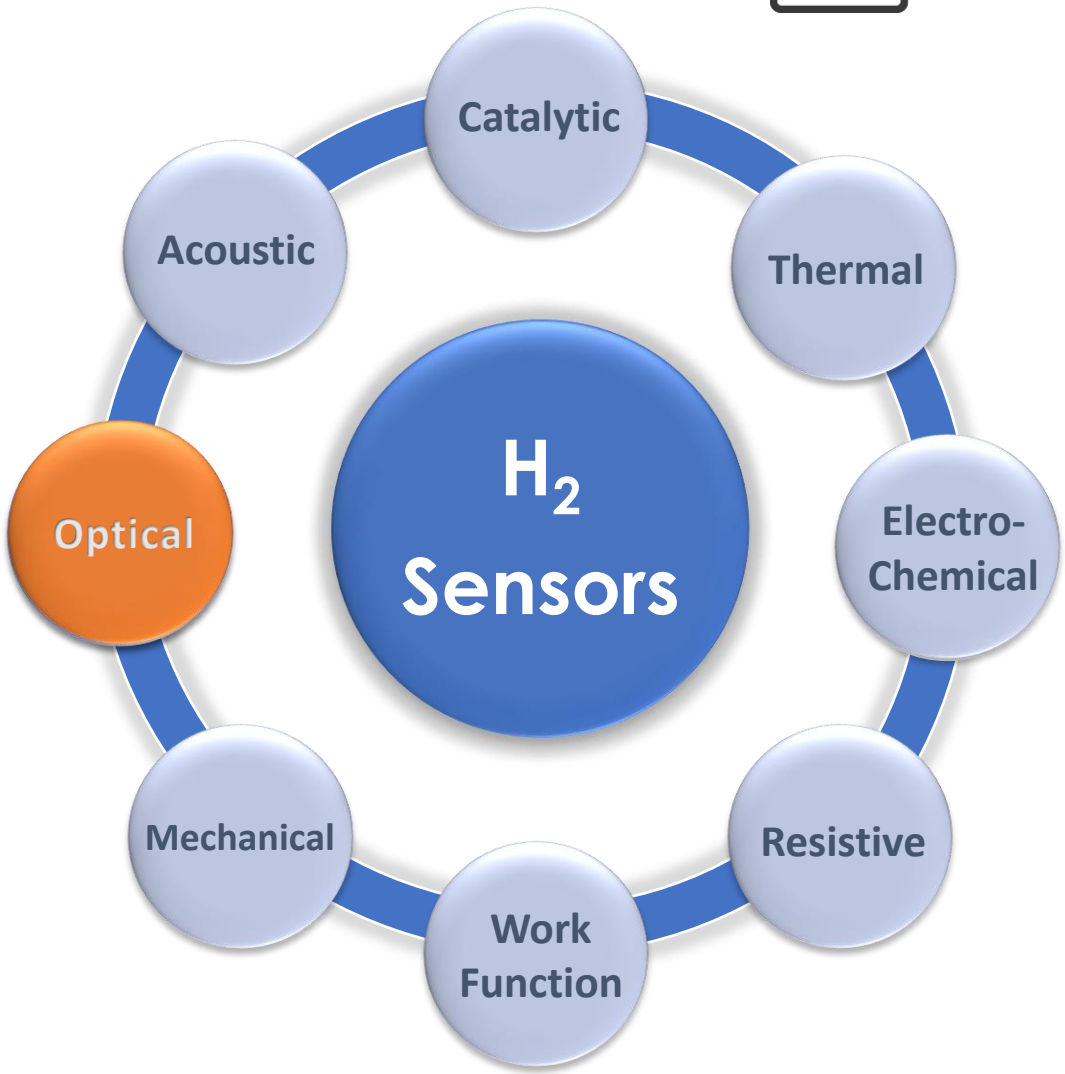
Volumes of different media require to store 100 TWh of H_2 energy.

(Epelle et al. Sustainable Energy & Fuels, 6 (2022) 3324-3343)

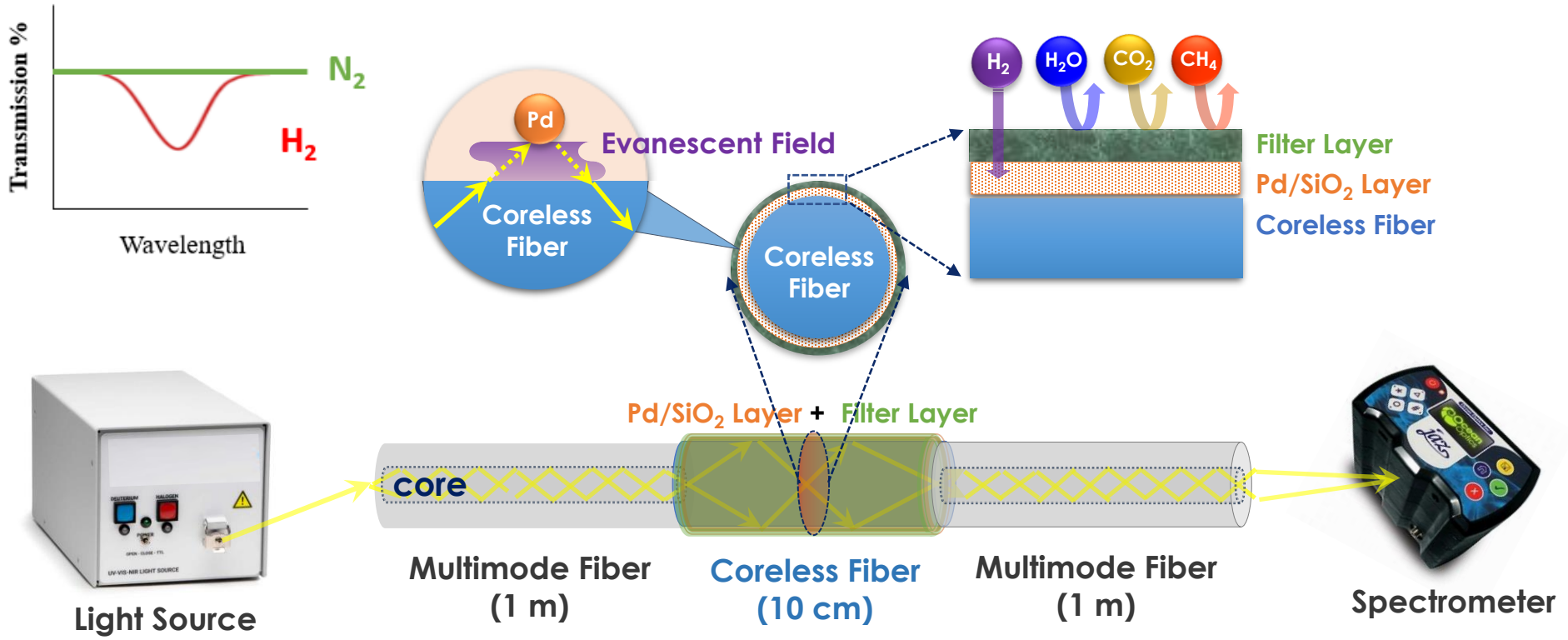
Optical Fiber Hydrogen Sensors

- **Advantages:**
  - Immune to electro-magnetic interference
  - Resistant to high temperatures and pressures
  - Chemically inert
  - Small and lightweight
  - Suitable for remote and in-situ sensing

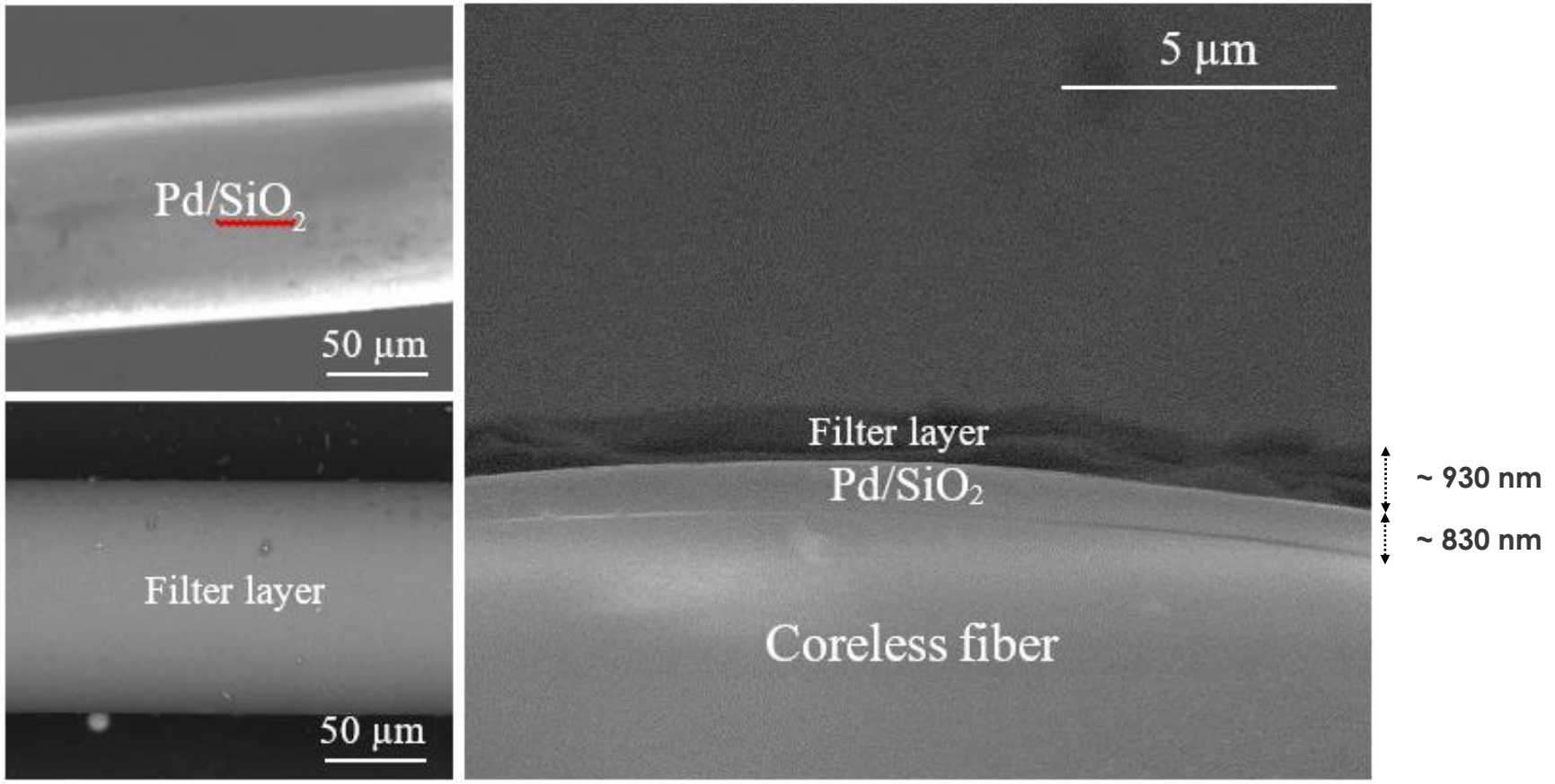
- **Disadvantages:**
  - Susceptible to physical damage
  - Interference with humidity
  - Unproven under microbial environments



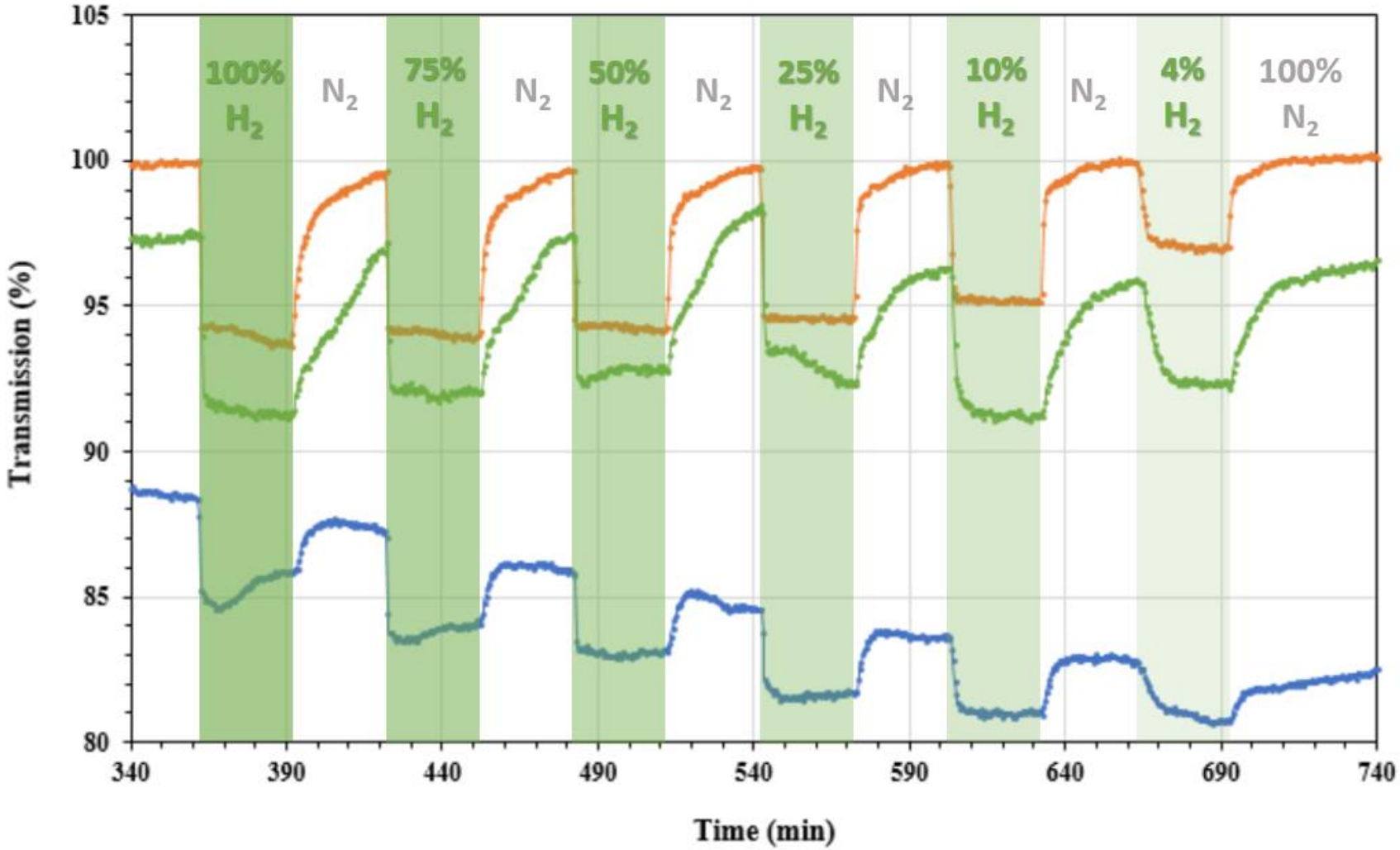
Evanescent Field-Based Optical Fiber H_2 Sensor



SEM Images of the Pd/SiO_2 and Filter Layer



Hydrogen Sensing at 99% RH (100% to 10% H_2)



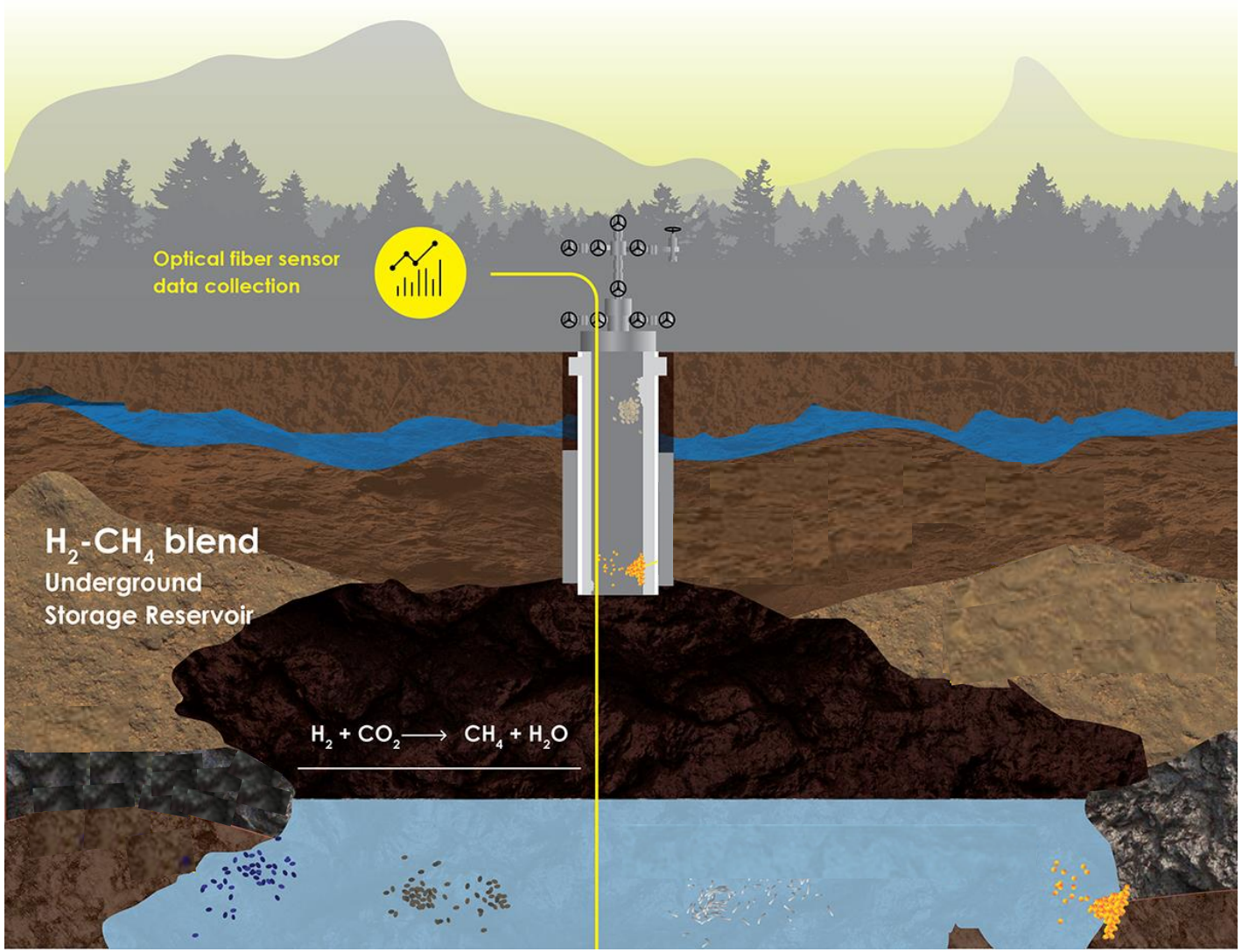
Dry gas **without** the filter layer

Wet gas **with** the filter layer

- **The filter layer reduced the effect of water vapor** on H_2 sensing.

Wet gas **without** the filter layer

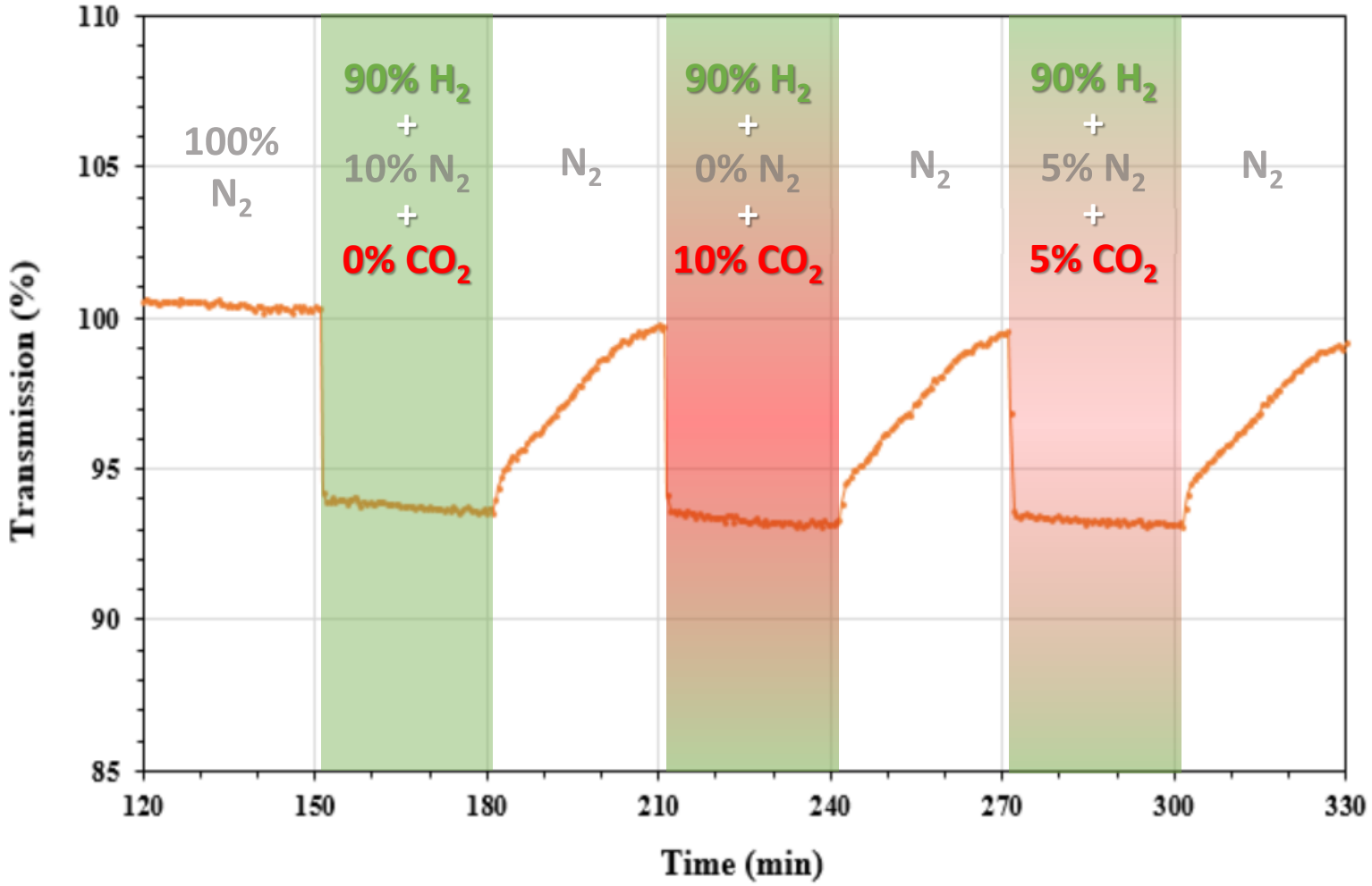
CO_2 and CH_4 in Subsurface Storage Wells



- The subsurface gas storage is filled with a **cushion gas** such as CO_2 or N_2 to guarantee a minimum reservoir pressure.
- The abandoned **natural gas** can be used toward the **cushion gas** requirement.

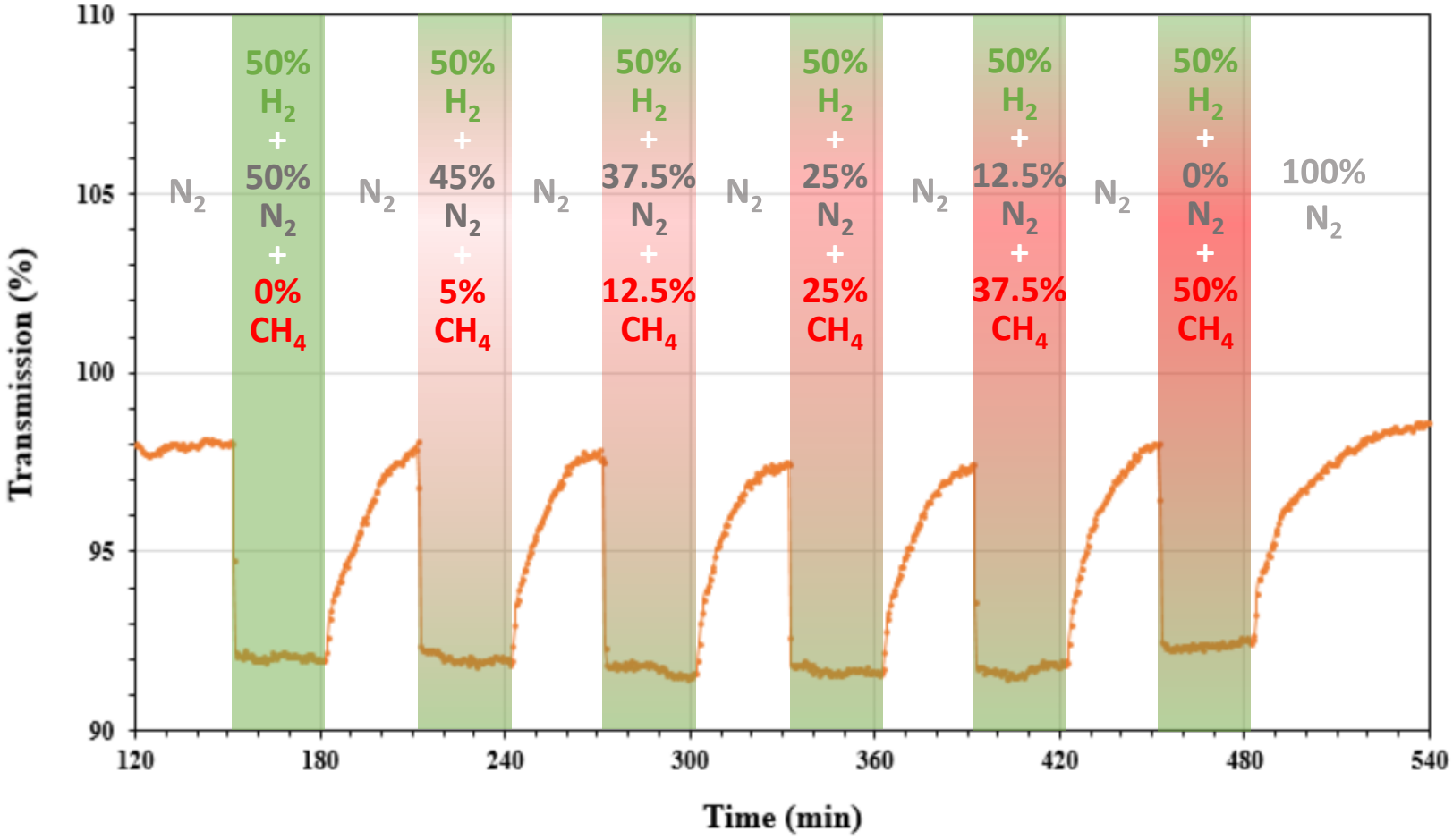
SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

H_2 Sensing in the Presence of CO_2



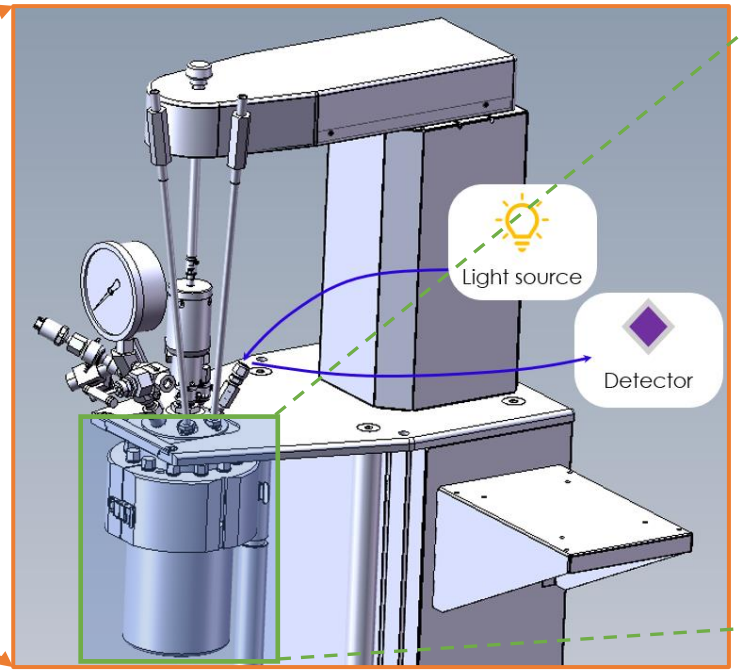
- Humidity: **99% RH**
- Shows the negligible impact of **CO_2** on H_2 sensing under the humid condition.

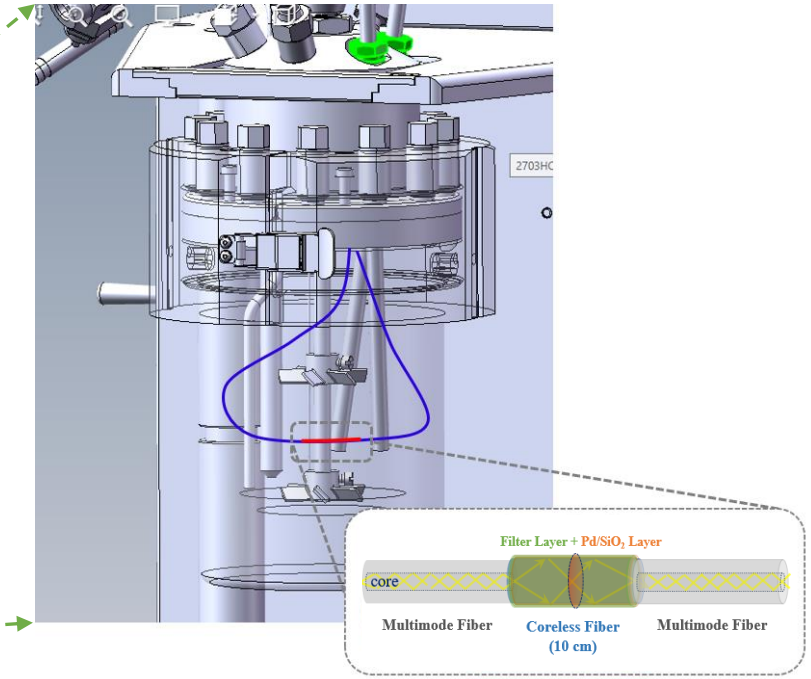
H_2 Sensing in the Presence of CH_4



- Humidity: **99% RH**
- Shows the negligible impact of **CH_4** on H_2 sensing under the humid condition.

Subsurface Sensor Development Reactor (SSDR)





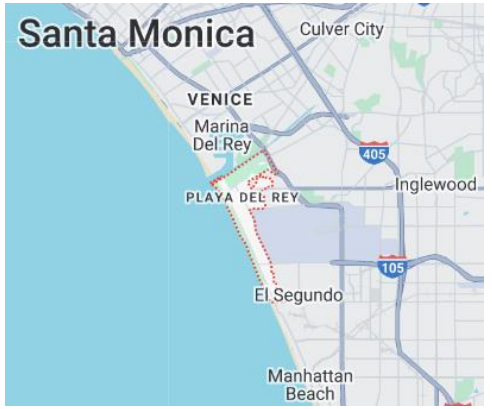
- **Automation** with LabVIEW
- **High-Temperature High-Pressure**: 450 °C, 4,500 psi
- **Multi-phase**: aqueous, gas
- **Gas**: **H_2**, CO_2, **CH_4**, N_2, Air

Experimental conditions:
~ 80 °C, 1,000 psi, 99% RH

H_2 sensor
installed inside the vessel

SSDR Tests with Biological Samples

- **Biotic Samples**: procured from Playa del Rey (PDR) in CA
- **Abiotic samples**: filtered from the biotic samples



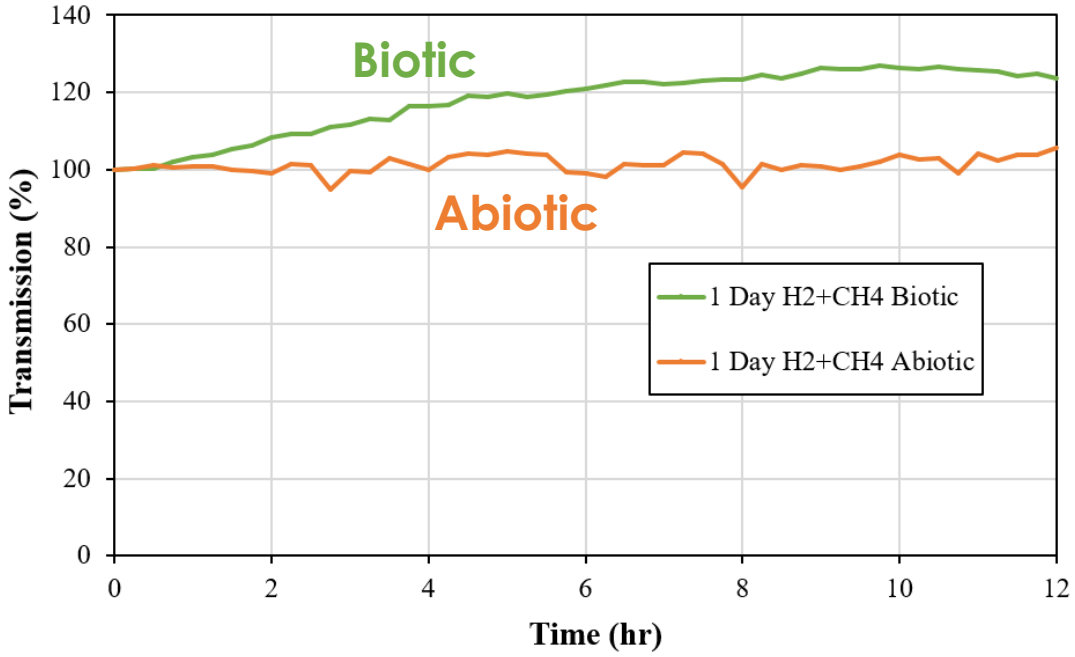
SSDR Test Conditions:

1) **Abiotic** PDR samples and **100% CH_4** for 1, 3, and 7 days
2) **Biotic** PDR samples and **100% CH_4** for 1, 3, and 7 days
3) **Abiotic** PDR samples and **20% H_2/80% CH_4** for 1, 3, and 7 days
4) **Biotic** PDR samples and **20% H_2/80% CH_4** for 1, 3, and 7 days

H_2 Sensing with Biological Samples for 1 Day

Biotic vs. Abiotic

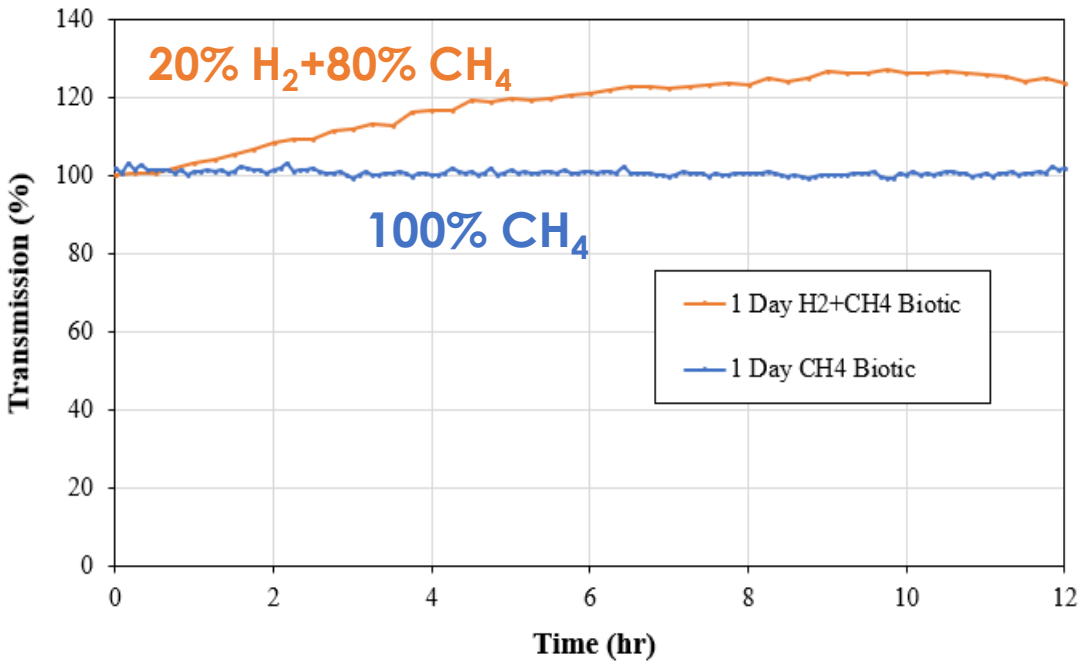
(at 530 nm)



- The **biotic** sample has a **higher effect** on hydrogen sensing than the **abiotic** sample.

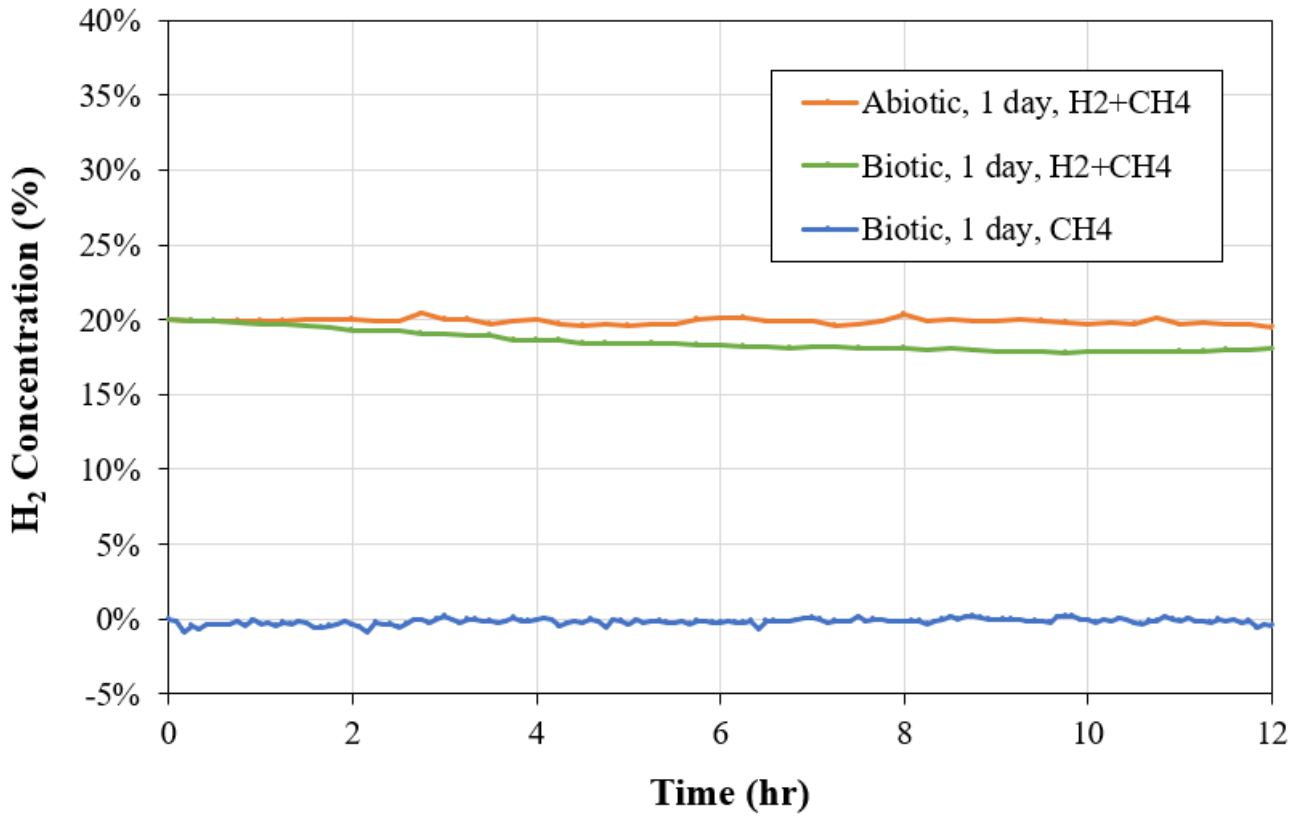
20% H_2+80% CH_4 vs. 100% CH_4

(at 530 nm)



- The CH_4 alone **did not affect** H_2 sensing with the biotic sample for 1 day.

Monitoring H_2 Concentration Change for 1 Day



Abiotic, H_2+CH_4

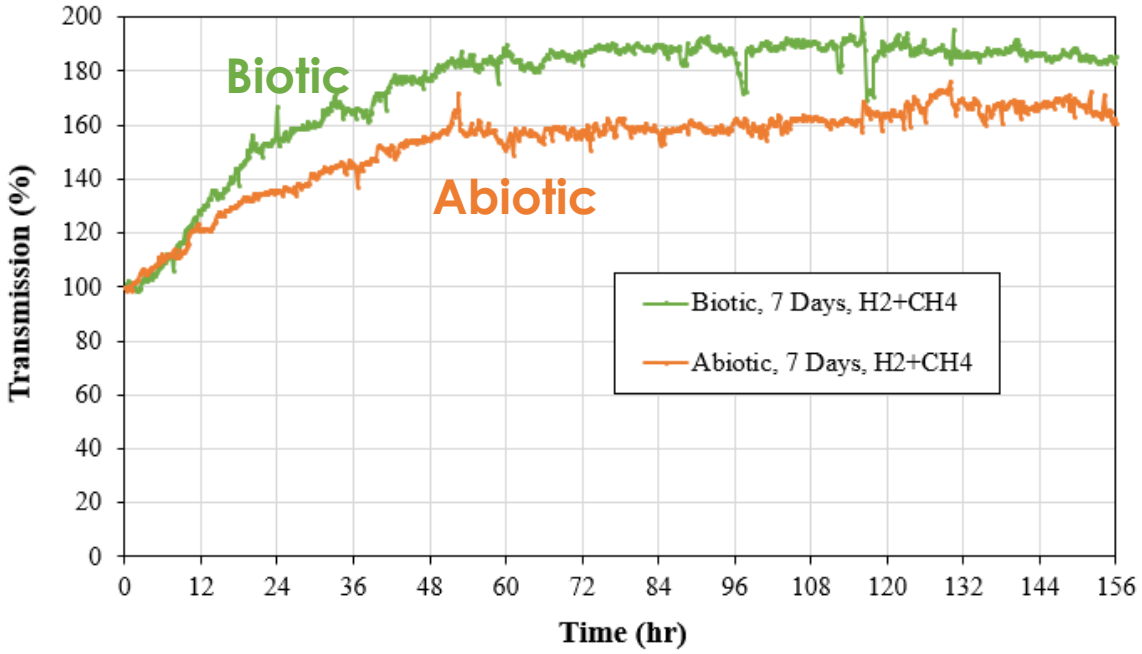
Biotic, H_2+CH_4

Biotic, 100% CH_4

- **H_2 concentration** has **decreased** by **~2%** with the **biotic** sample for 1 day.

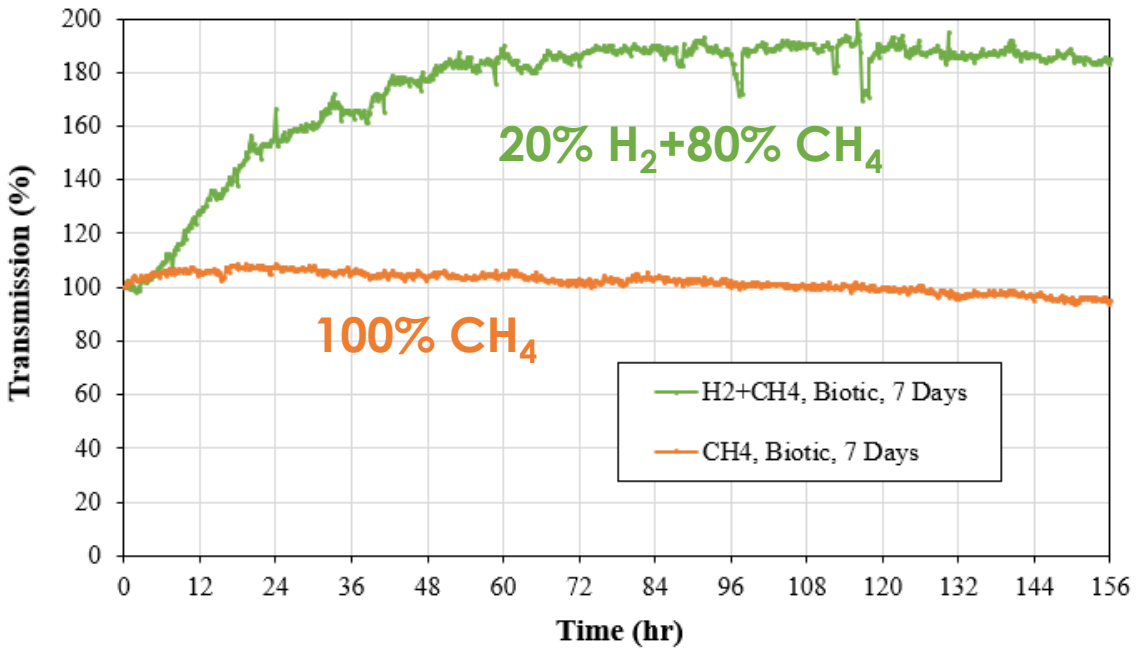
H_2 Sensing with Biological Samples for 7 Days

Biotic vs. Abiotic (at 530 nm)



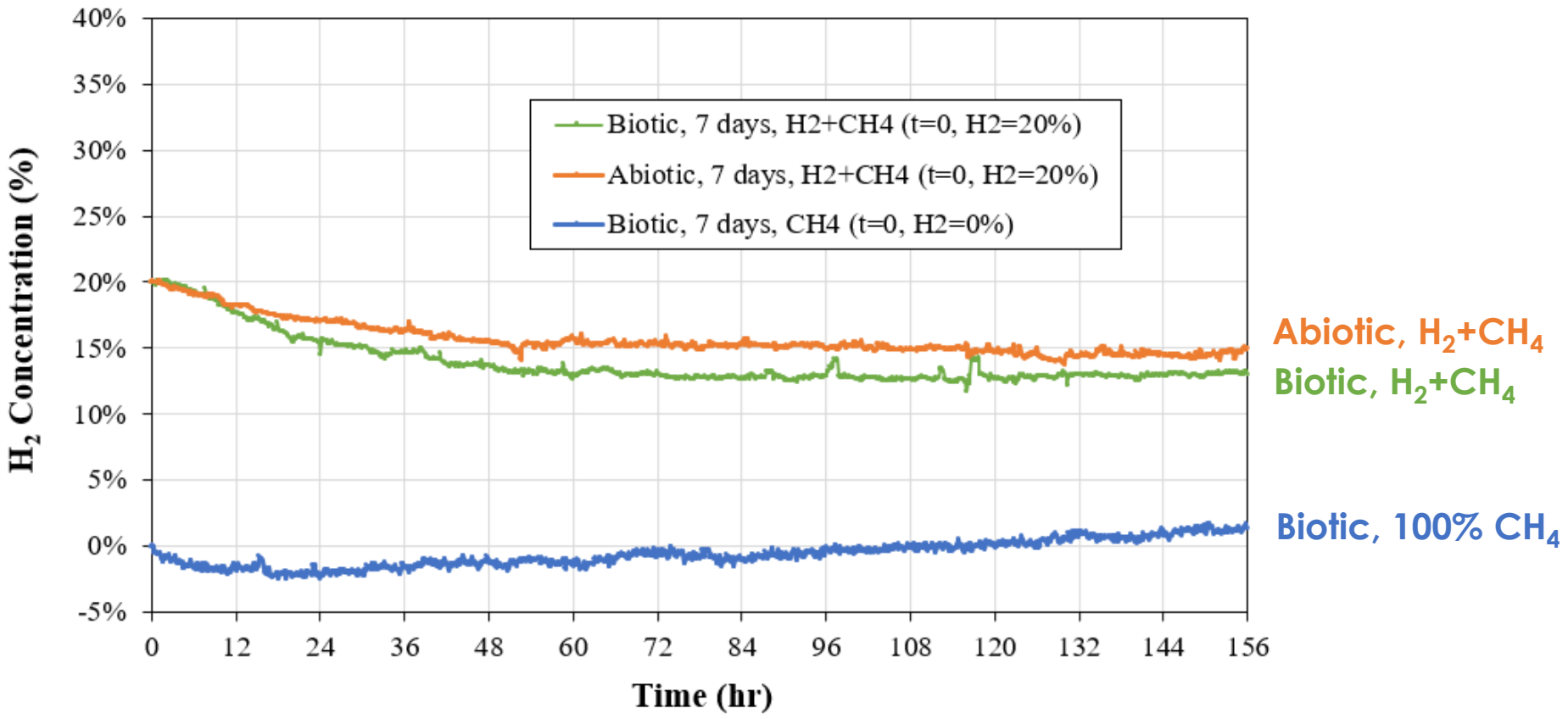
- The **biotic** sample has shown much **higher impact** on H_2 sensing for 7 days.

20% H_2+80% CH_4 vs.100% CH_4 (at 530 nm)



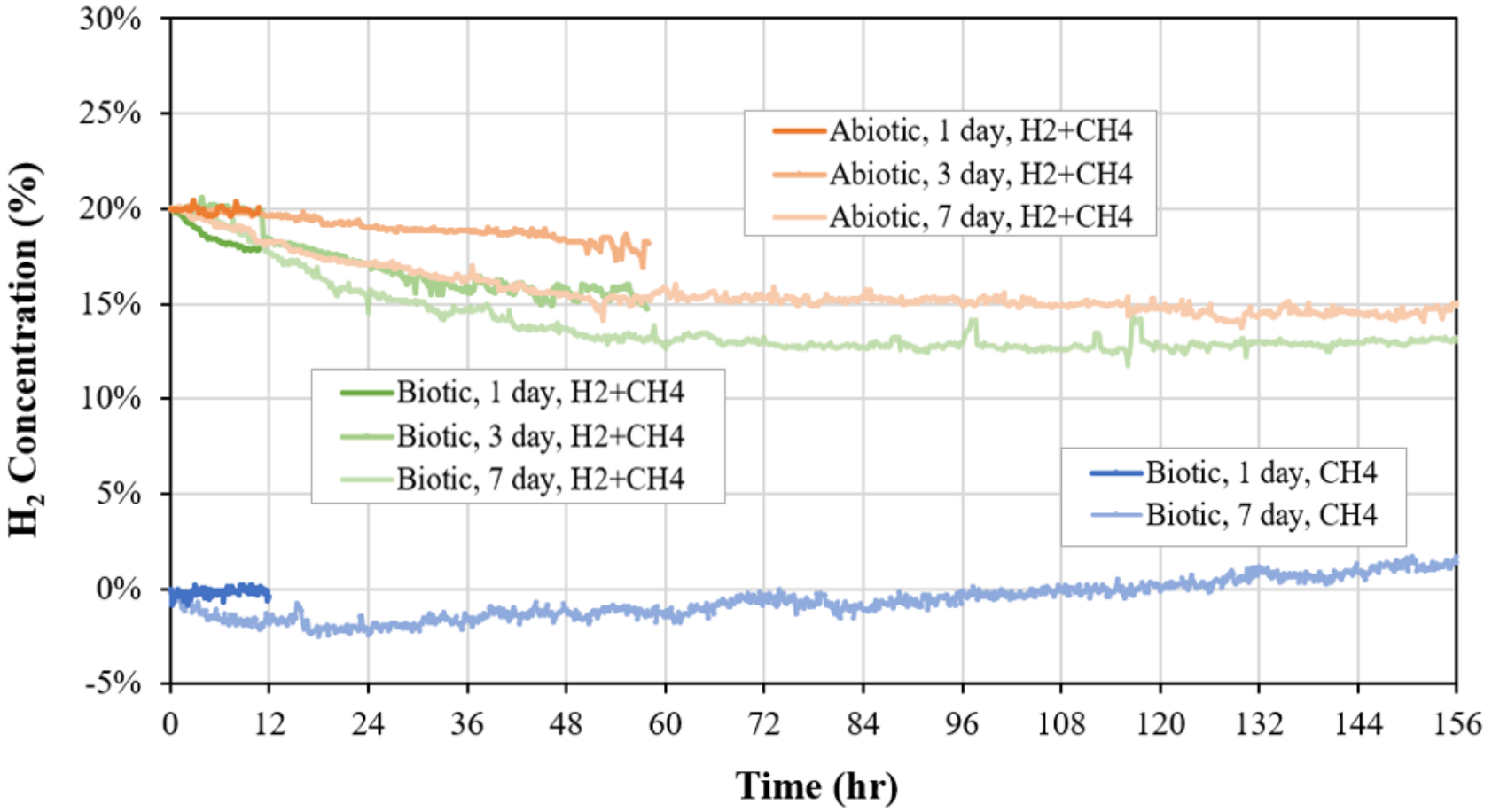
- The biotic sample with **H_2 gas** has shown much higher impact on H_2 sensing for 7 days.

Monitoring H_2 Concentration Change for 7 Days



- **H_2 concentration** has **decreased** for **7 days** by about **5%** and **7%** from 20% with the **abiotic** and **biotic** sample, respectively.

Real-Time H_2 Sensing in Subsurface Storage Conditions



- **Monitoring H_2 concentration** with the optical fiber H_2 sensor **at 80 °C, 1,000 psi, and 99% RH.**

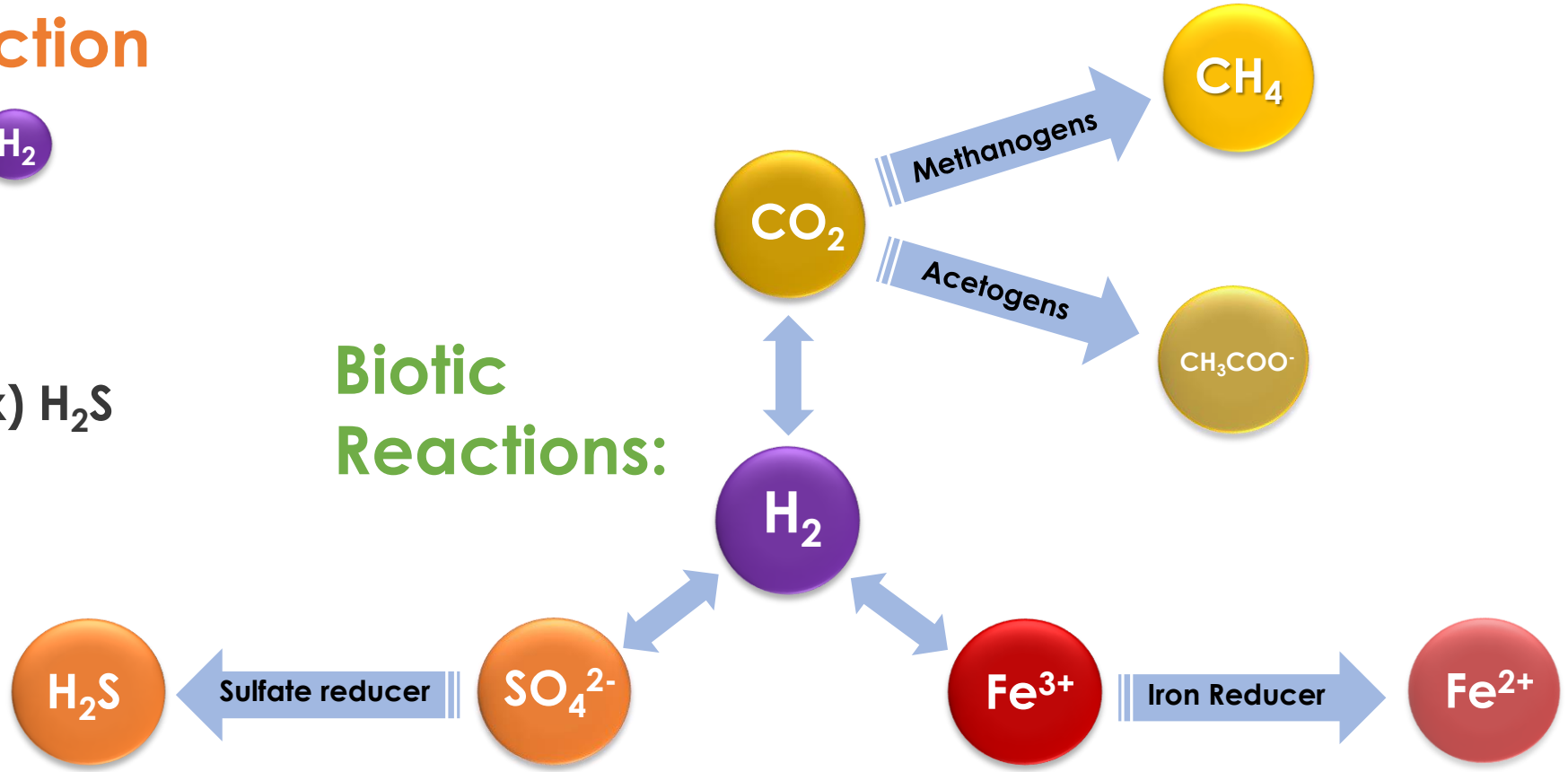
Potential Abiotic/Biotic Activities in Subsurface Storage

Abiotic Reaction

$FeS_2 + (1\text{-}x)\ H_2$

$FeS_{1+x} + (1\text{-}x)\ H_2S$

Biotic Reactions:



(Ram Gupta, et al., Compendium of Hydrogen Energy: Volume 2. Hydrogen Storage, Distribution and Infrastructure, Elsevier, 2015.)

Summary

- The **optical fiber hydrogen sensor** was capable of detecting H_2 concentration **at high temperatures** and **pressures** in the presence of **biological samples**.
- The **H_2 concentration** has **decreased** more with the **biotic sample** than the abiotic sample.
- The H_2 sensing responses indicate that **H_2 is consumed with both abiotic and biotic samples** under the subsurface storage environment.
- **Further analysis** on the quantification of hydrogen consumption detected by the H_2 sensor will be performed **with gas chromatography**.
- **Repeatability** of hydrogen sensing at different temperature and pressure will be carried out in near future.

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