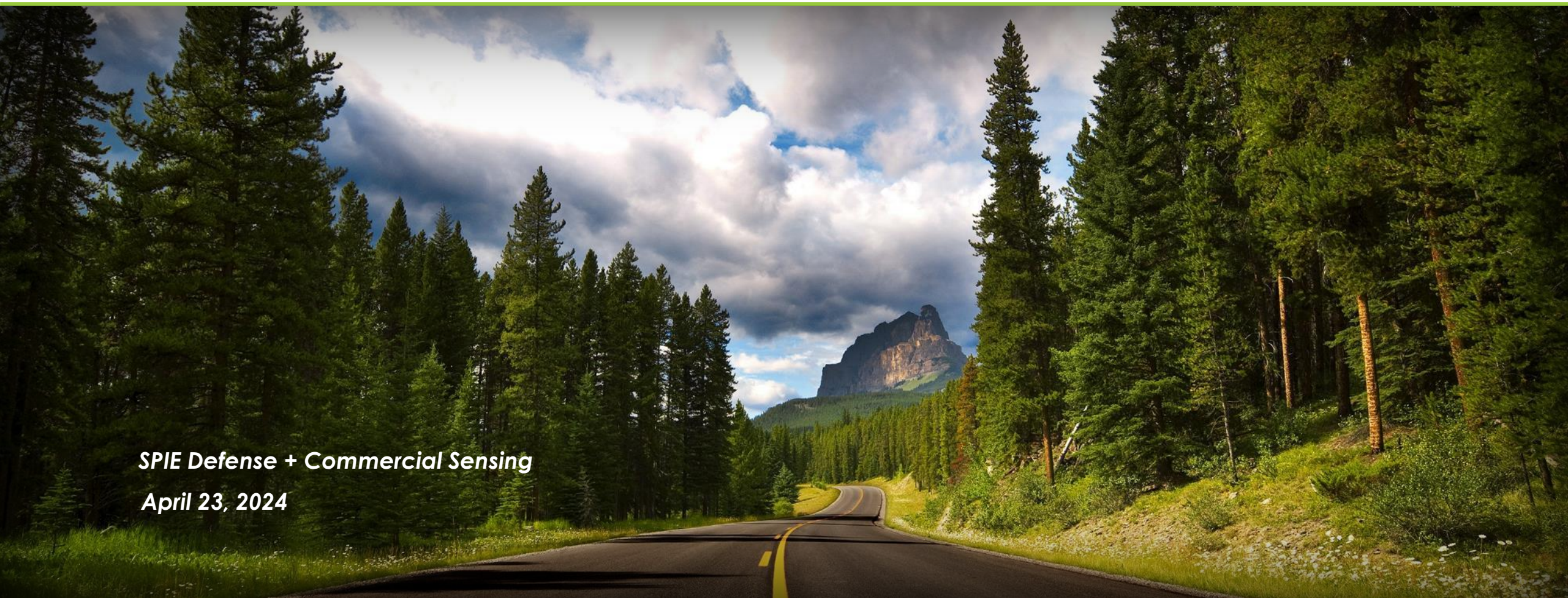
Optical Fiber Sensors Capable of Monitoring Hydrogen in the Subsurface Hydrogen Storage Environment

Daejin Kim
NETL Support Contractor



SPIE Defense + Commercial Sensing
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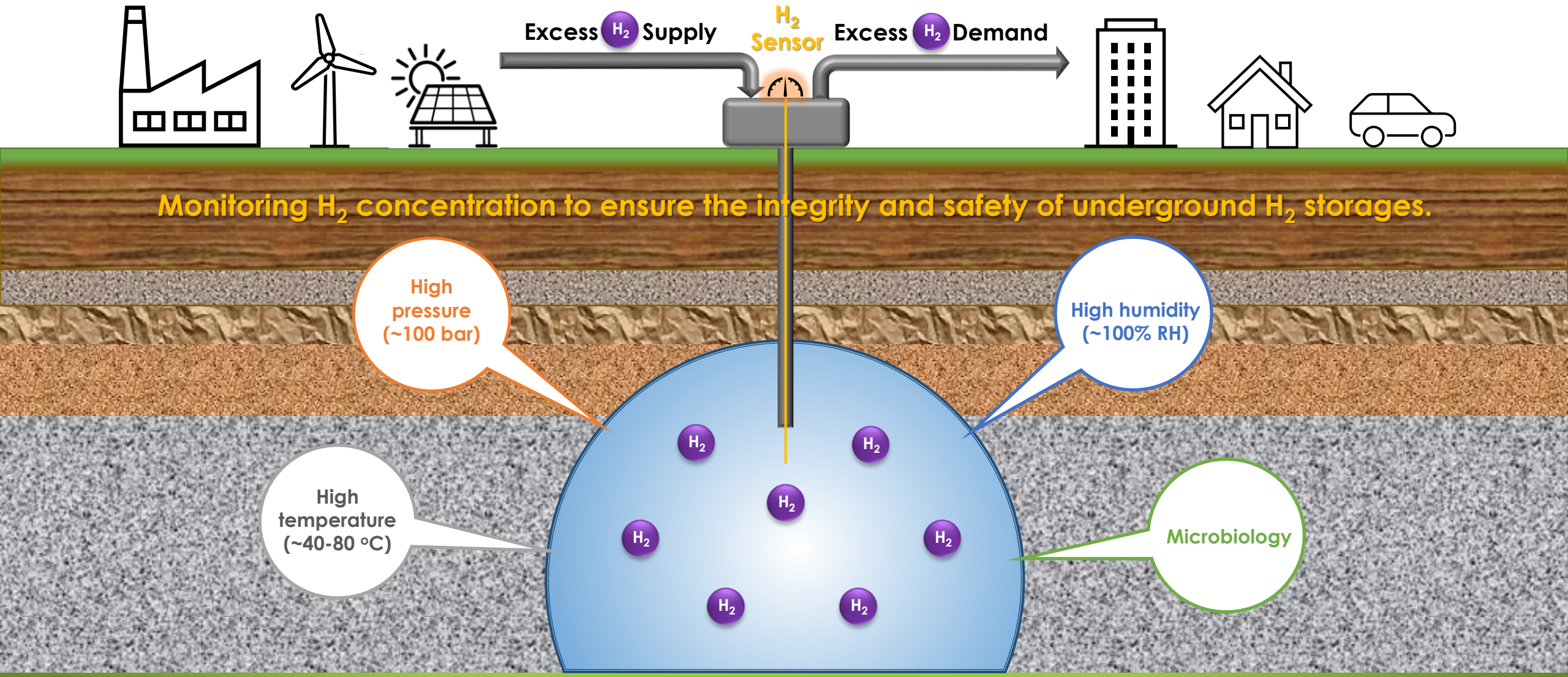
Subsurface Hydrogen Storage



Optical Fiber Hydrogen Sensors

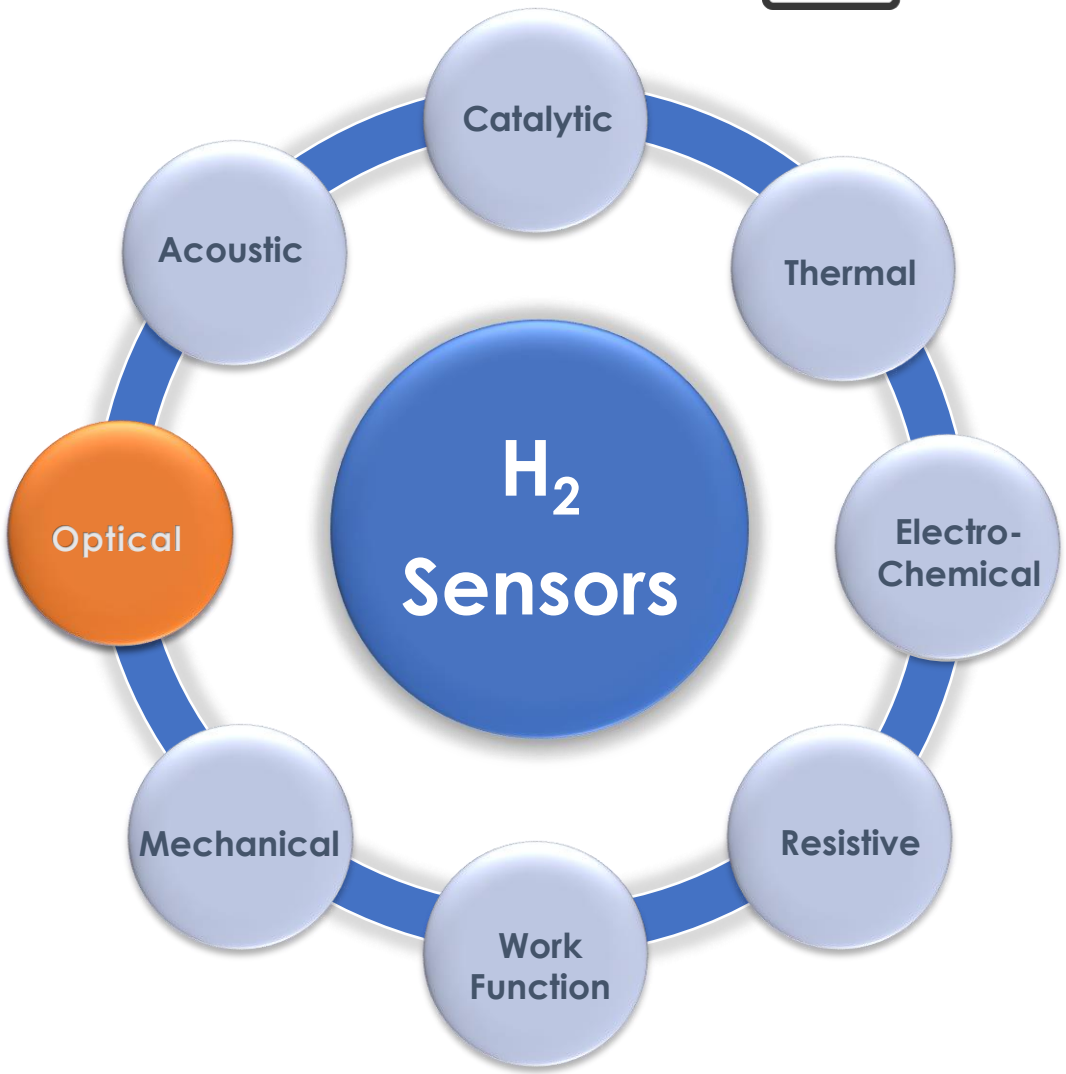
NATIONAL ENERGY TECHNOLOGY LABORATORY

Advantages:

- Immune to electro-magnetic interference
- Resistant to high temperatures and pressures
- Chemically inert
- Small and light weight
- Suitable for remote and in-situ sensing

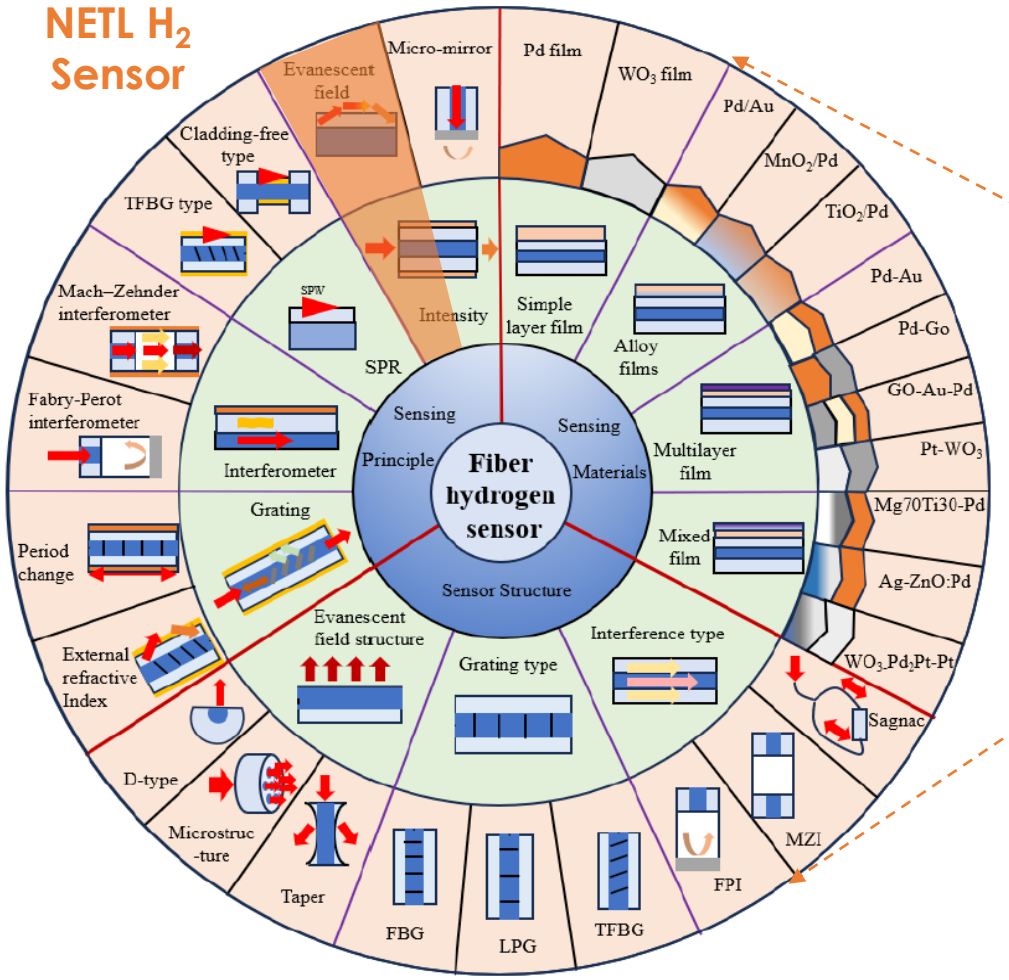
Disadvantages:

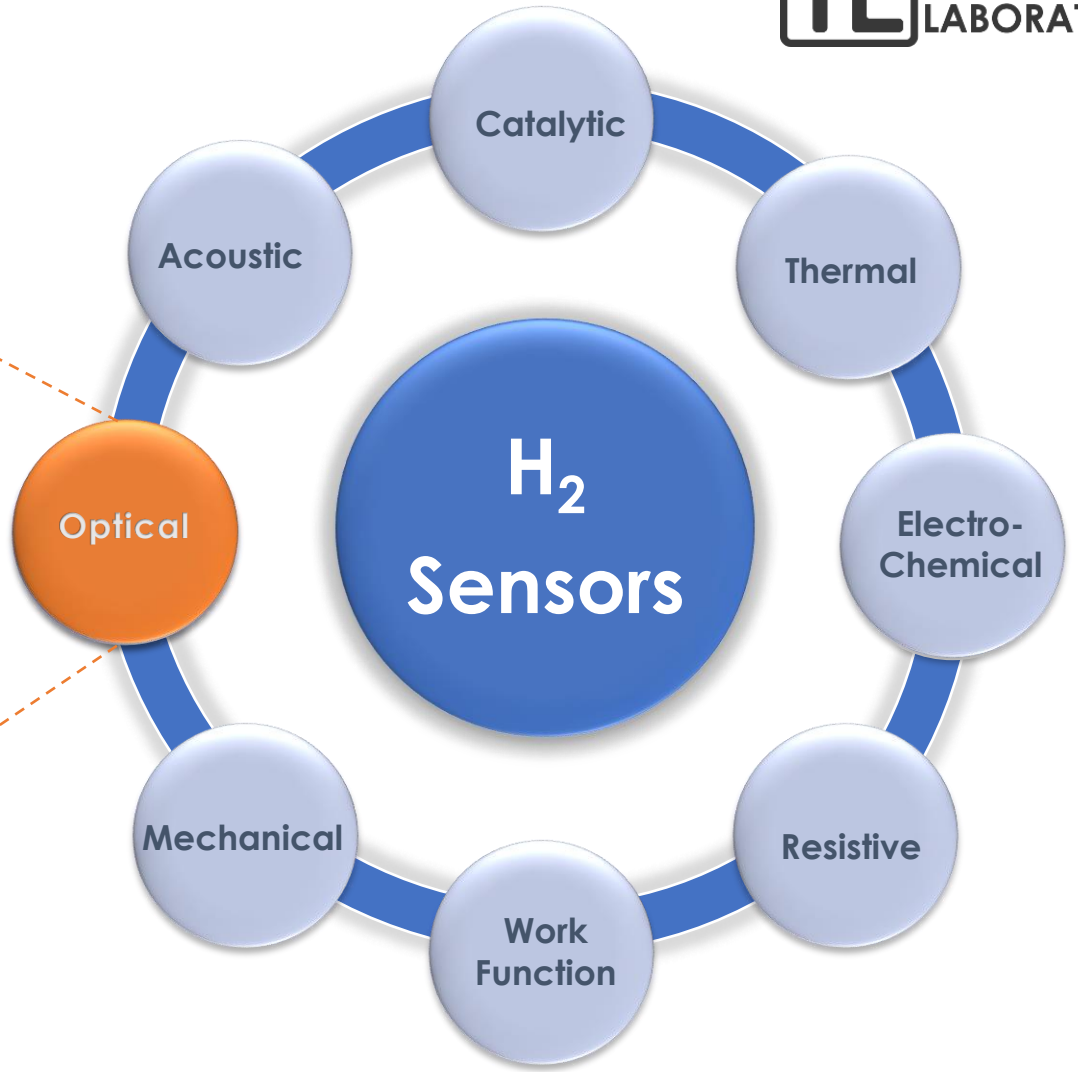
- Susceptible to physical damage
- Interference with humidity
- Unproven under microbial environments



Optical Fiber Hydrogen Sensors

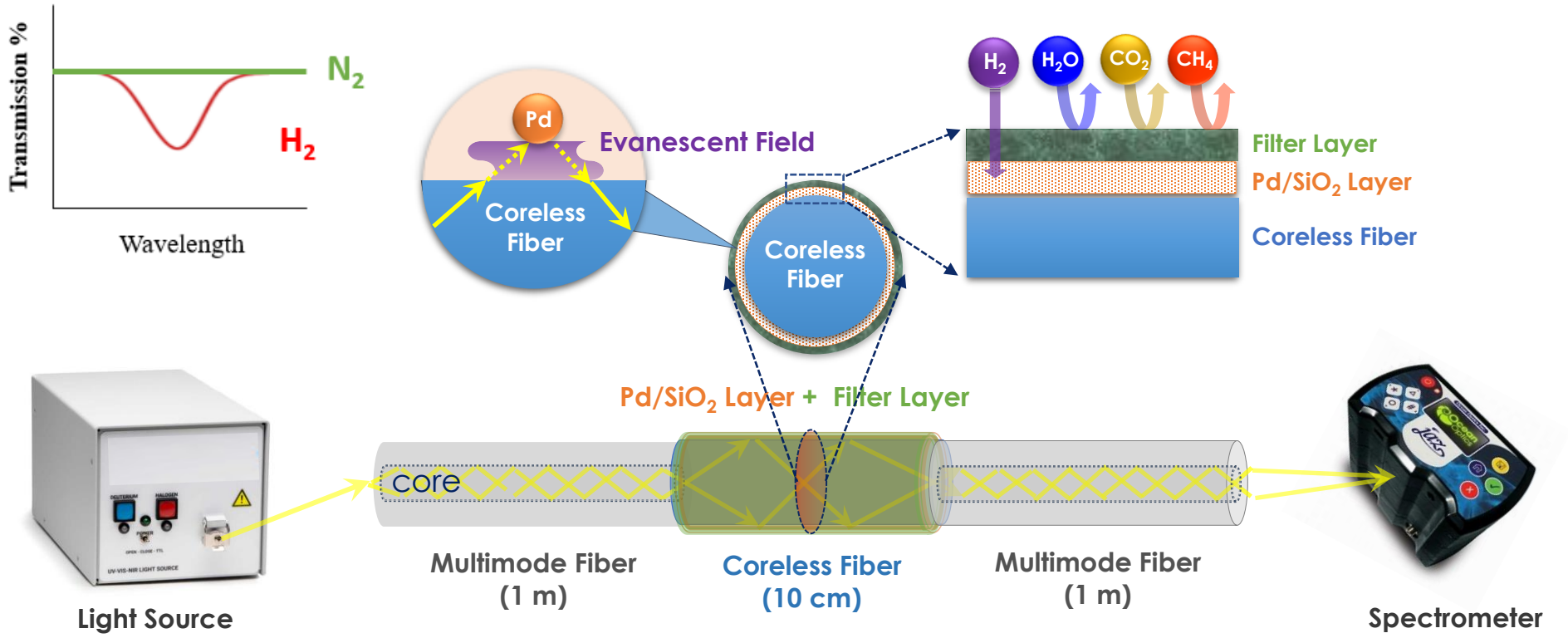
NETL H_2 Sensor



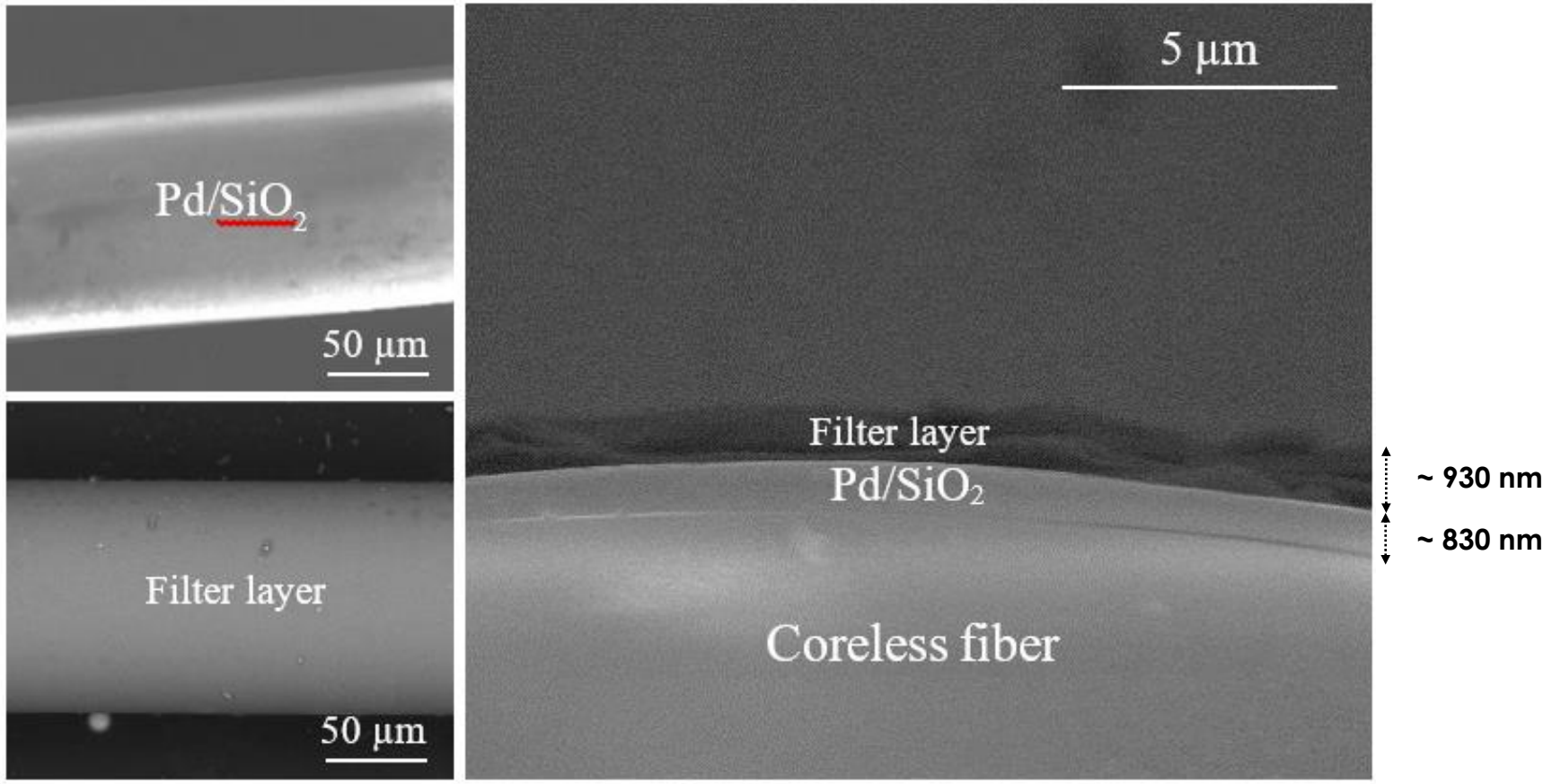


(Shen et al. Review of the Status and Prospects of Fiber Optic Hydrogen Sensing Technology, Chemosensors 2023, 11, 473)

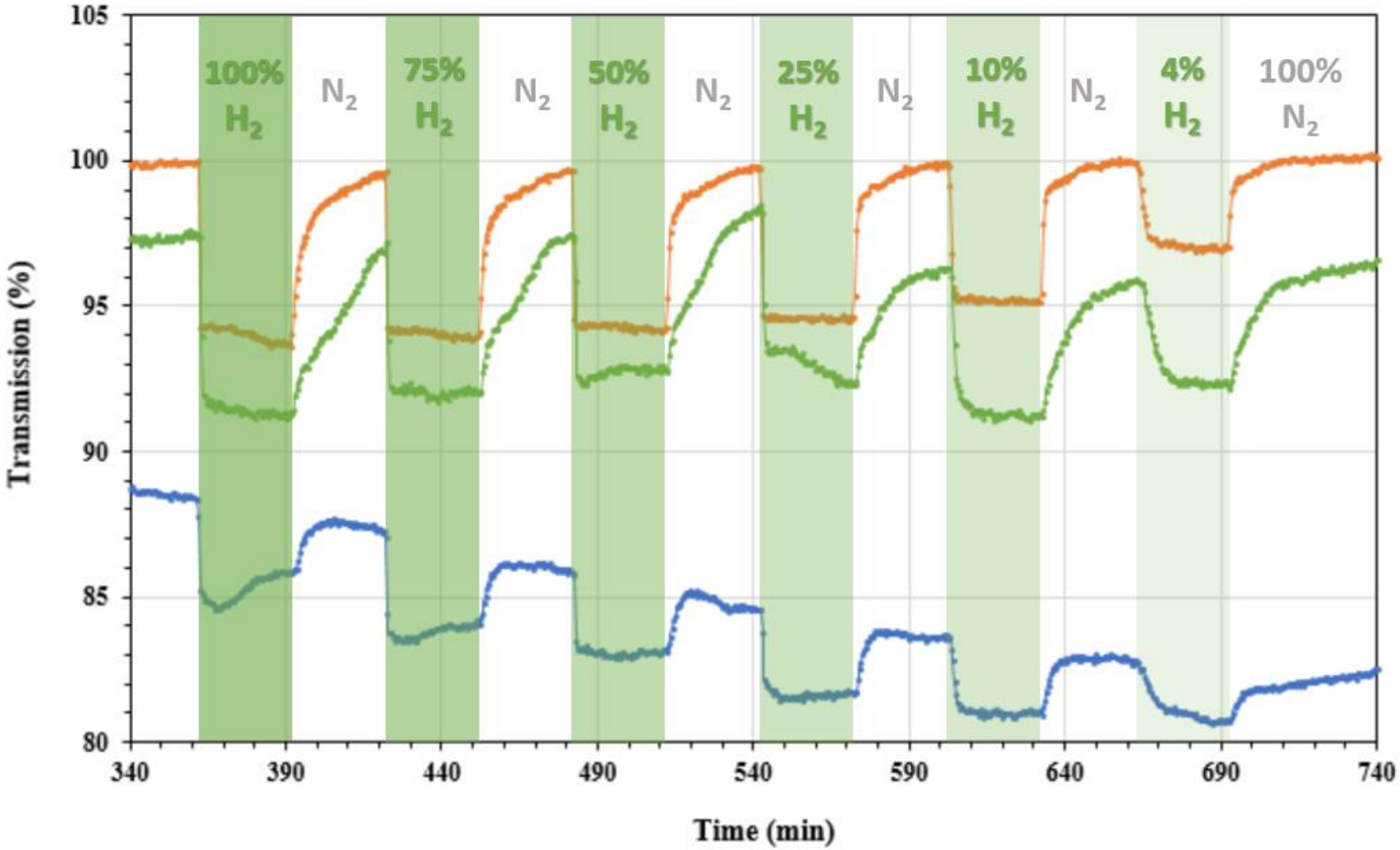
Evanescent Field-Based Optical Fiber H_2 Sensor



SEM Images of the Pd/SiO_2 and Filter Layers



With and Without Filter Layers at 99% RH (Room Temp.)

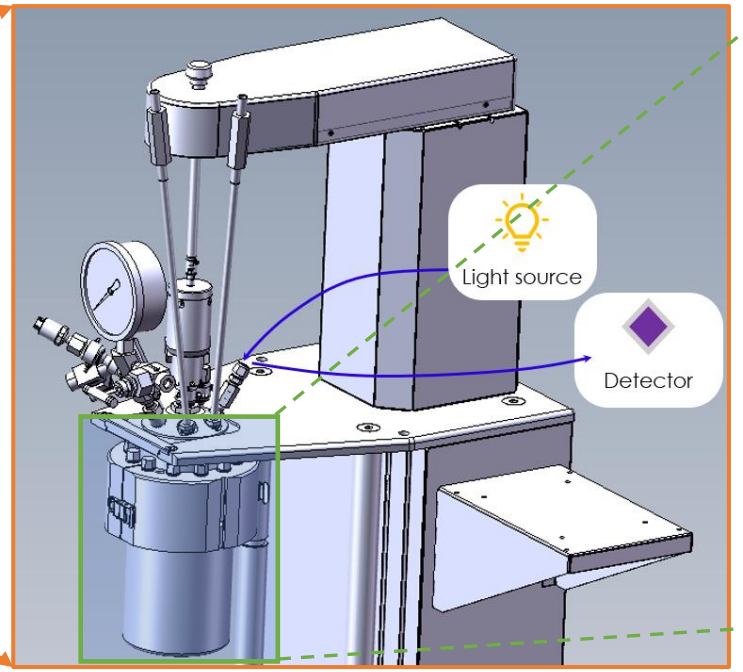


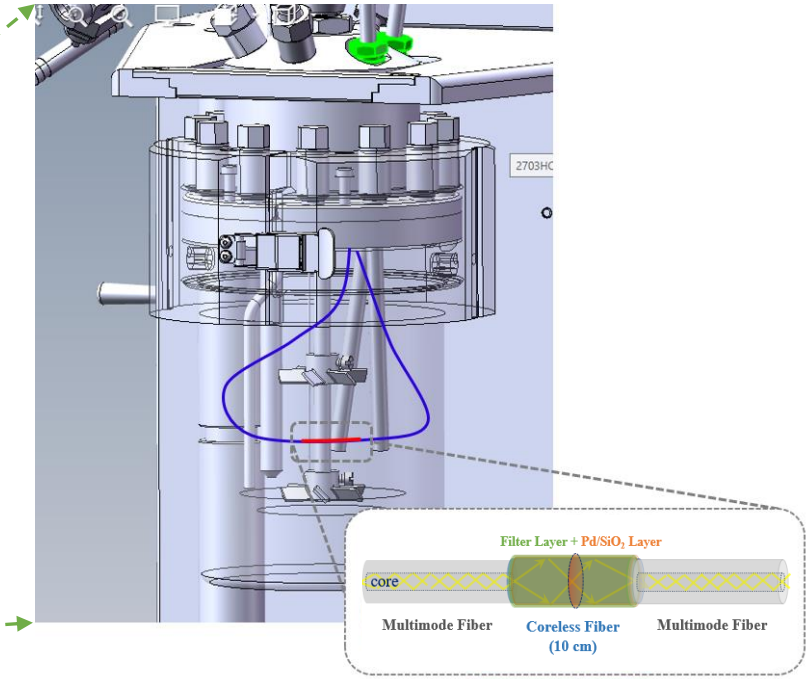
Dry gas without the filter layer

Wet gas with the filter layer

Wet gas without the filter layer

Subsurface Sensor Development Reactor (SSDR)





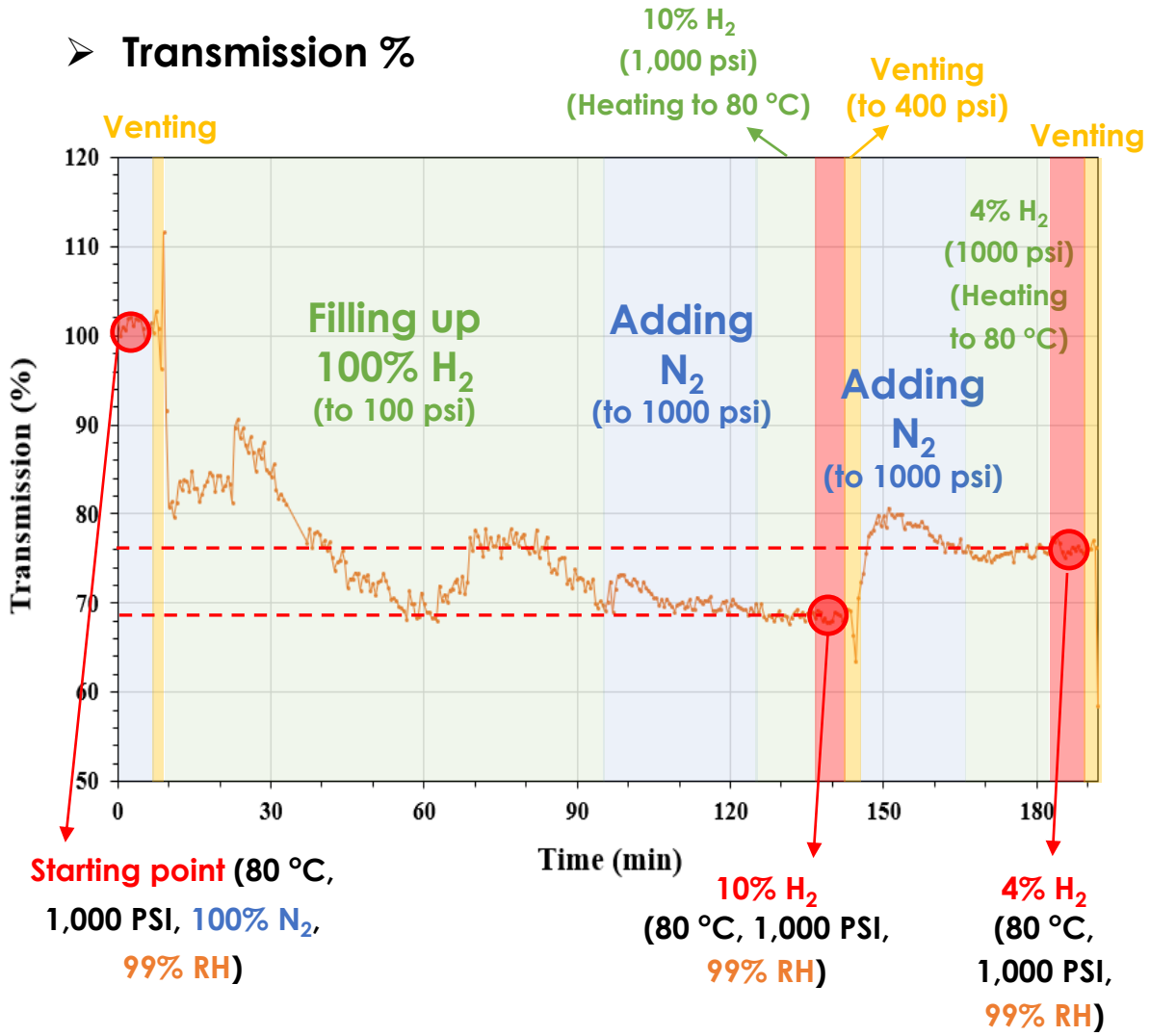
- **Automation** with LabVIEW
- High-temperature high-pressure: 450 °C, 4,500 psi
- **Multi-phase**: aqueous, gas
- **Gas**: **H_2**, CO_2, **CH_4**, N_2, Air

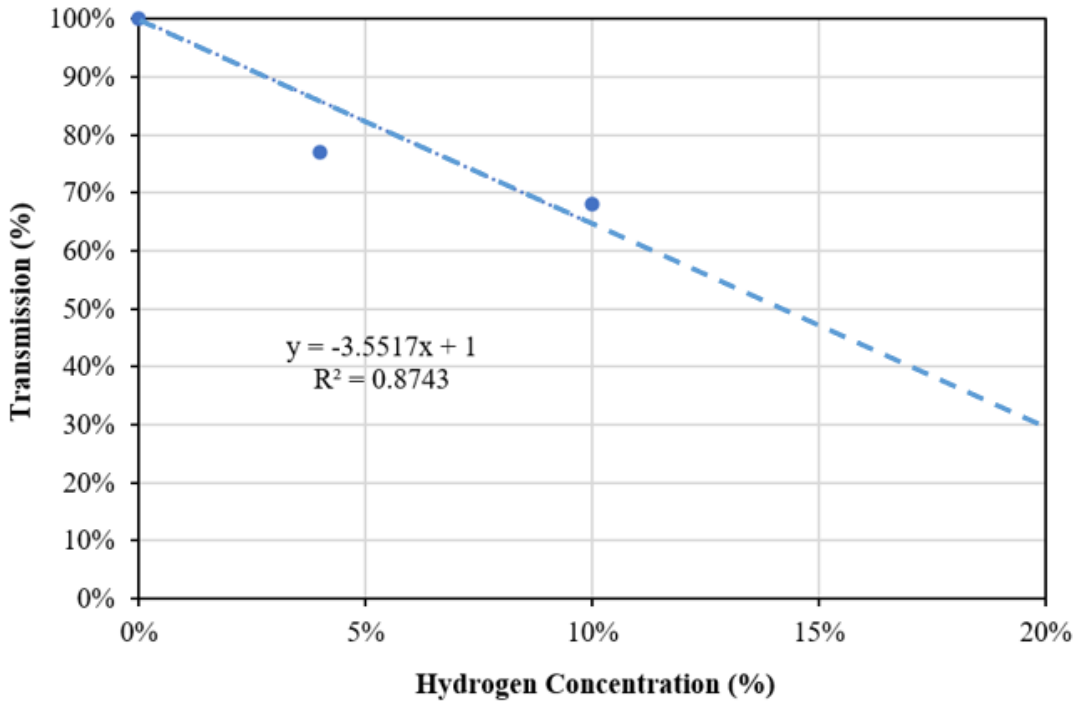
Experimental conditions:
~ 80 °C, 1,000 psi, 99% RH

H_2 sensor installed inside the vessel

Calibration of the H_2 Sensor at 80 °C, 1,000 PSI, 99% RH

➢ **Transmission %**





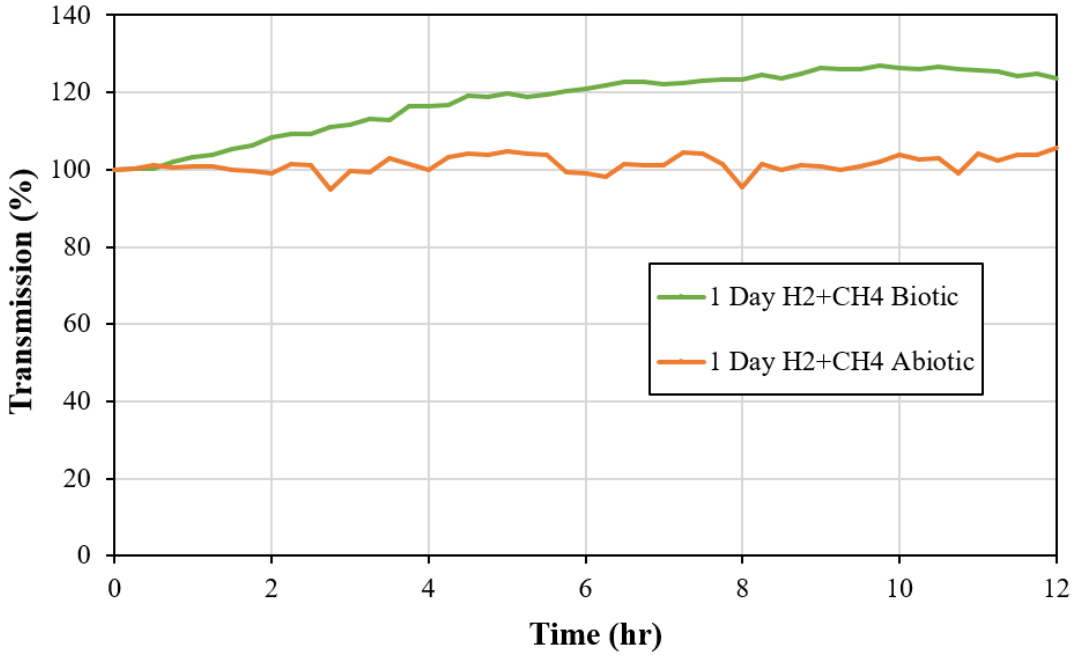
➢ Calibrated **up to 10% H_2** which is the maximum H_2 concentration the SSDR allows.

SSDR Tests

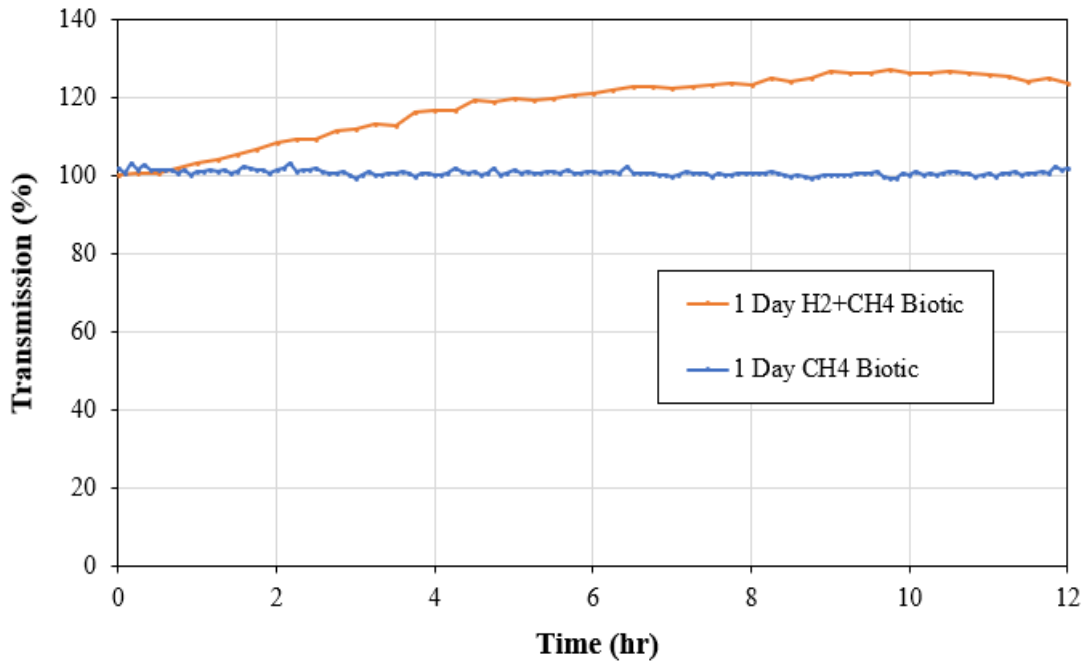
1) **Abiotic** SoCalGas samples and **100% CH_4** for 1, 3, and 7 days
2) **Biotic** SoCalGas samples and **100% CH_4** for 1, 3, and 7 days
3) **Abiotic** SoCalGas samples and **20% H_2/80% CH_4** for 1, 3, and 7 days
4) **Biotic** SoCalGas samples and **20% H_2/80% CH_4** for 1, 3, and 7 days

Abiotic vs. Biotic, 20% H_2+80% CH_4 vs. 100% CH_4, 1 Day

(at 530 nm)

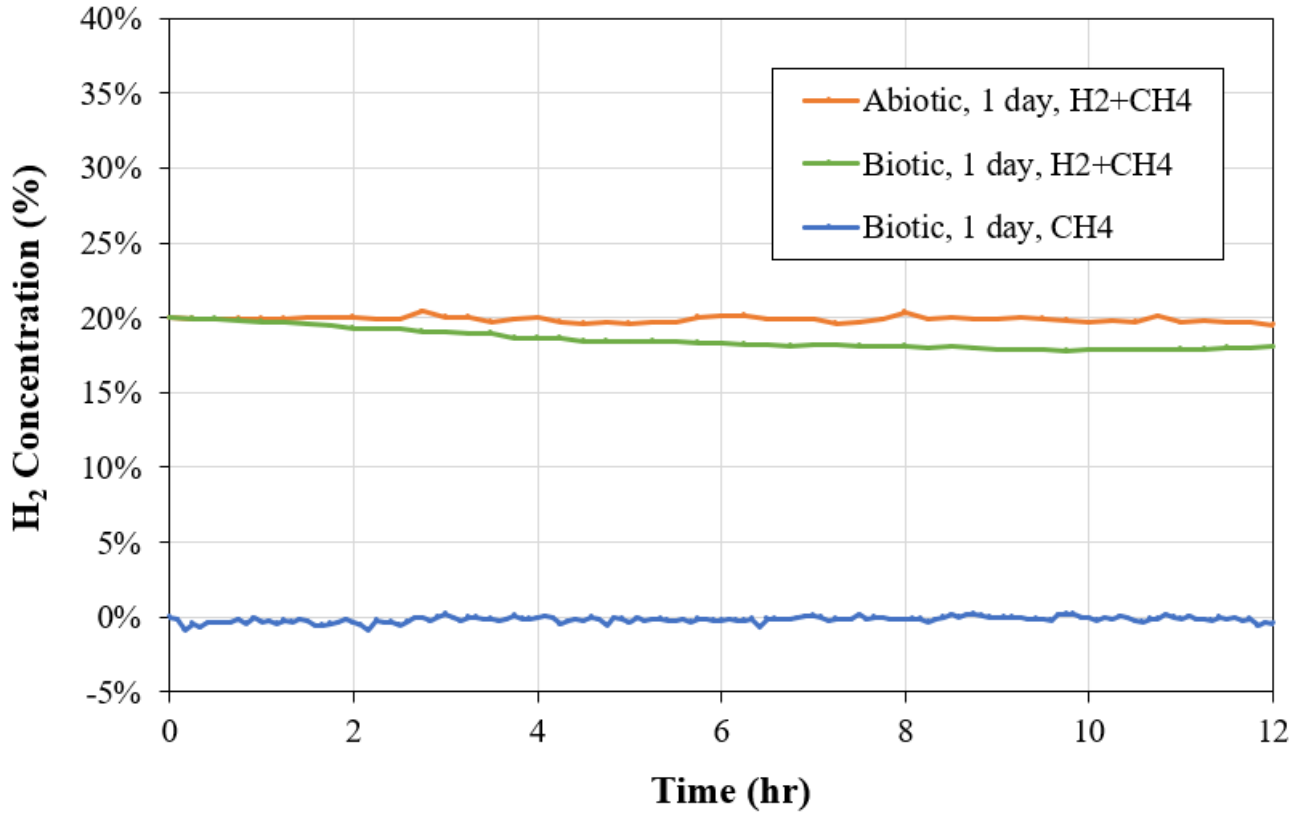


(at 530 nm)



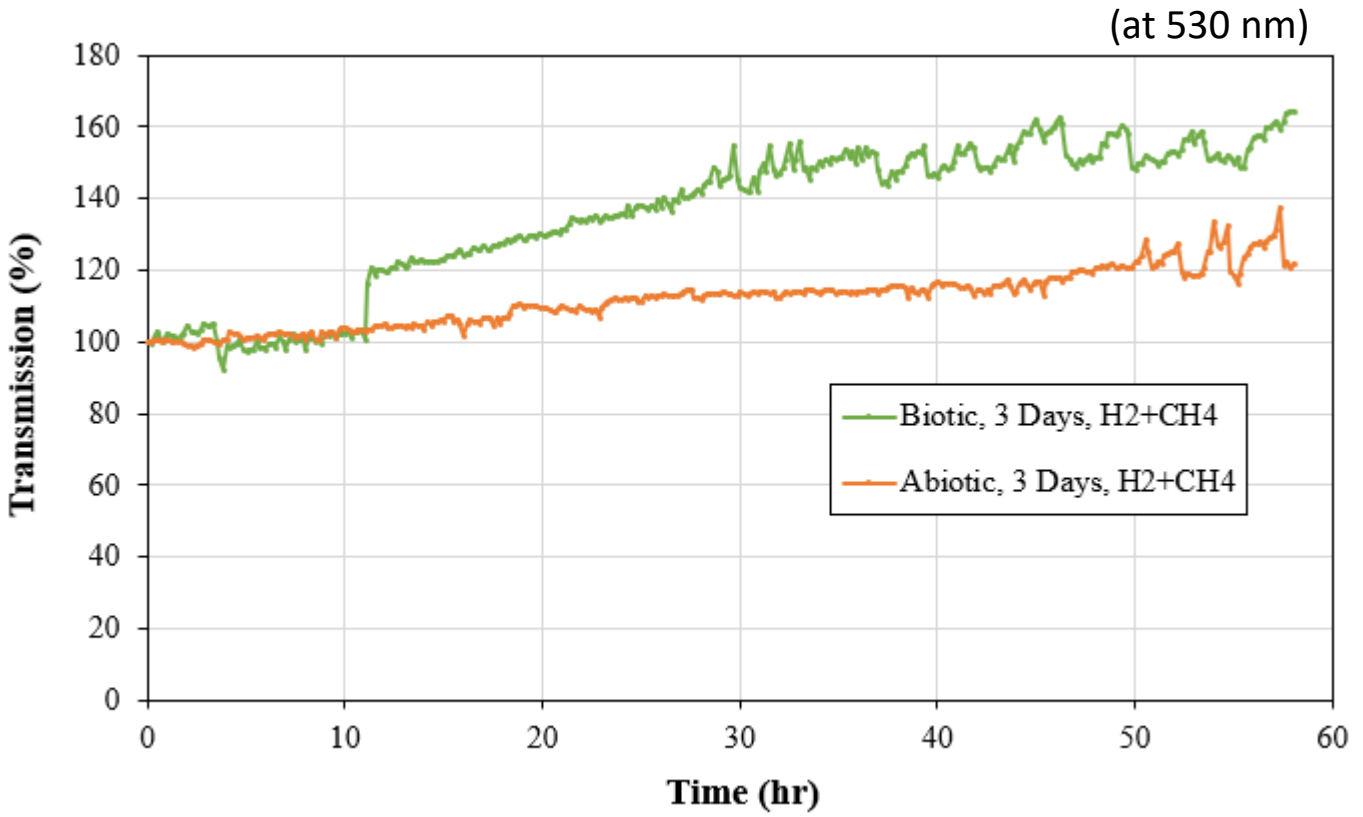
- The **biotic** sample has a **higher effect** on hydrogen sensing than the abiotic sample.
- The CH_4 alone **did not affect** H_2 sensing with the biotic sample for 1 day.

H_2 Concentration vs. Time for the 1 Day Tests



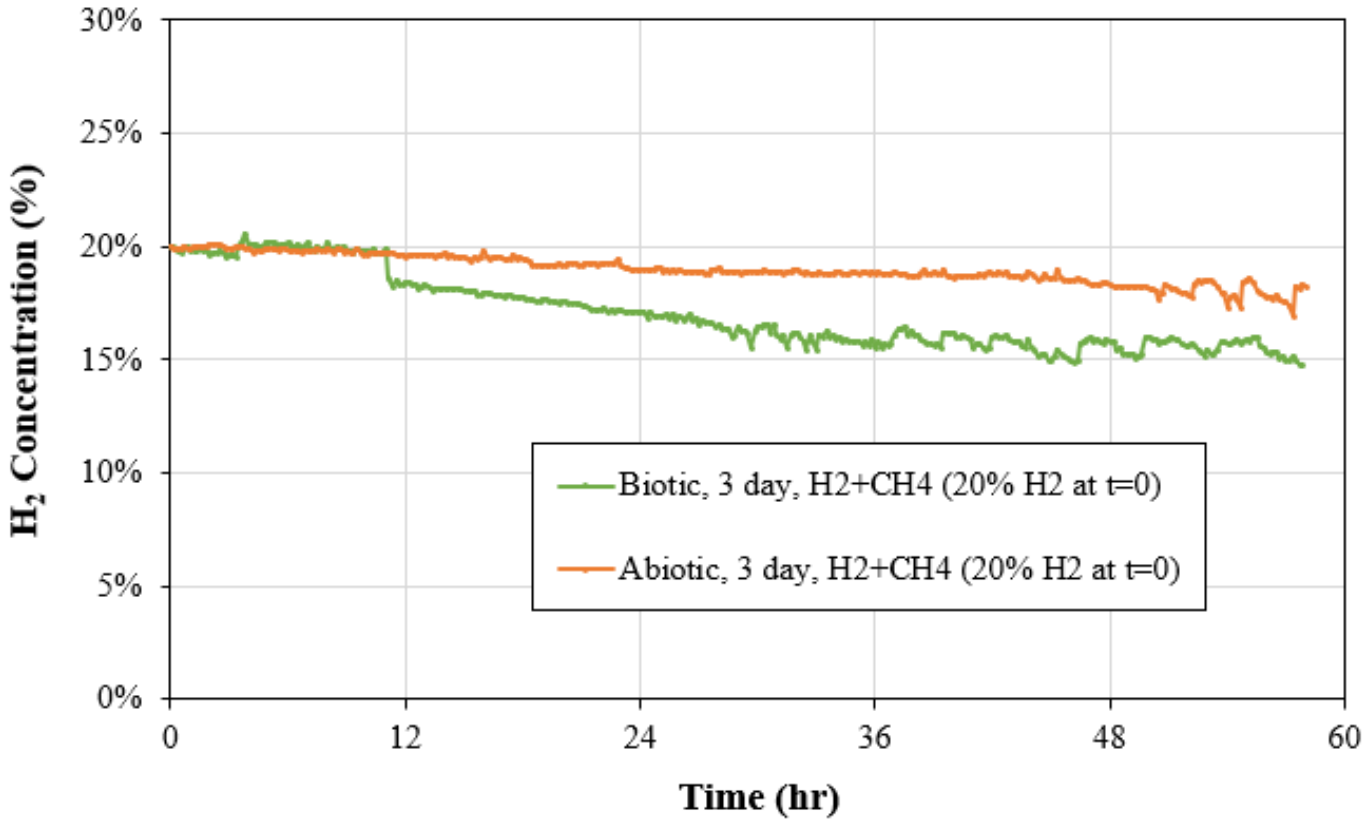
- **H_2 concentration** has **decreased** by **~2%** with the **biotic** sample for 1 day.

Abiotic vs. Biotic Samples in 20% H_2 + 80% CH_4 (3 Days)



- The **biotic** sample has shown much **higher impact** on H_2 sensing for 3 days.

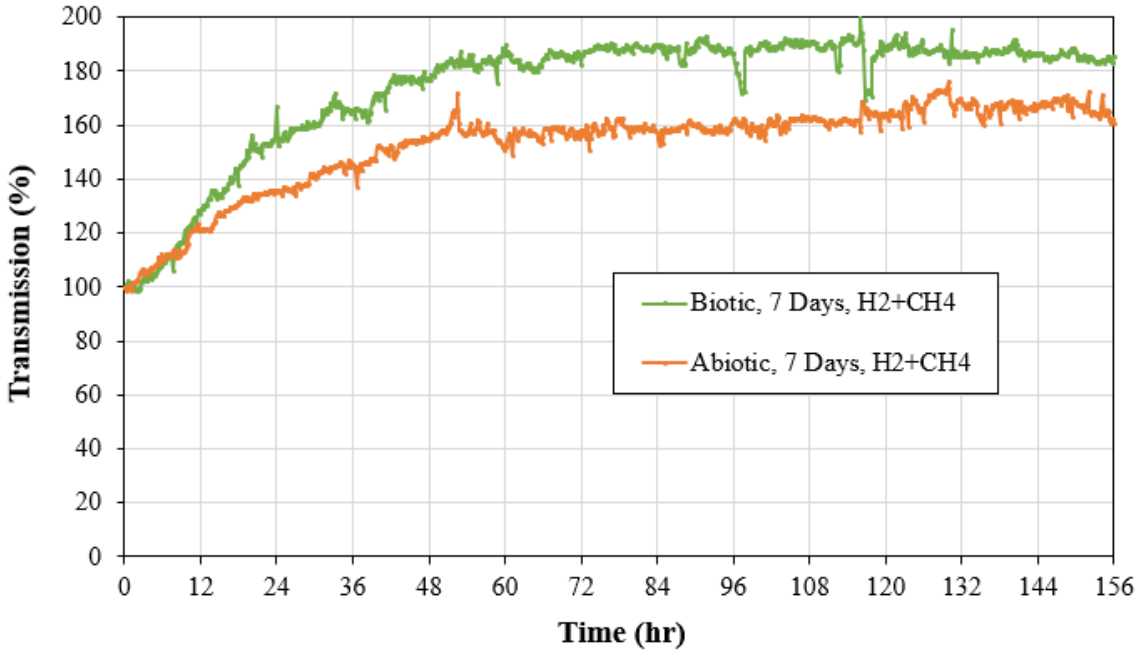
H_2 Concentration vs. Time for the 3 Day Tests



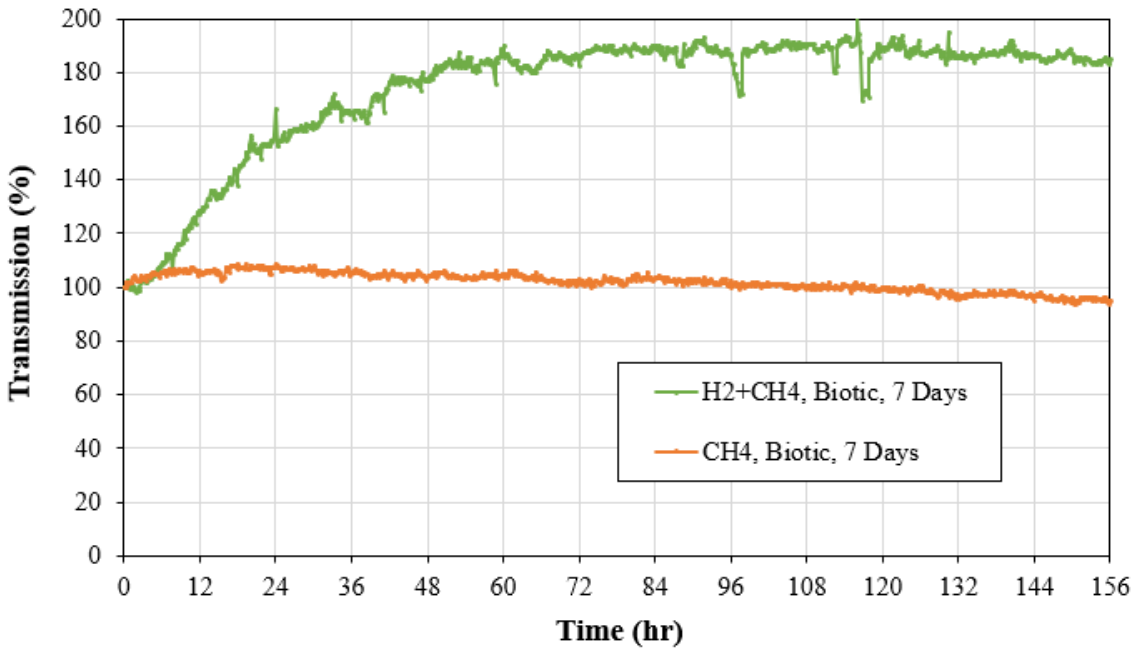
- **H_2 concentration** has **decreased** for **3 days** by about **2%** and **4%** with the **abiotic** and **biotic** sample, respectively.

Abiotic vs. Biotic, 20% H_2+80% CH_4 vs.100% CH_4, 7 Days

(at 530 nm)

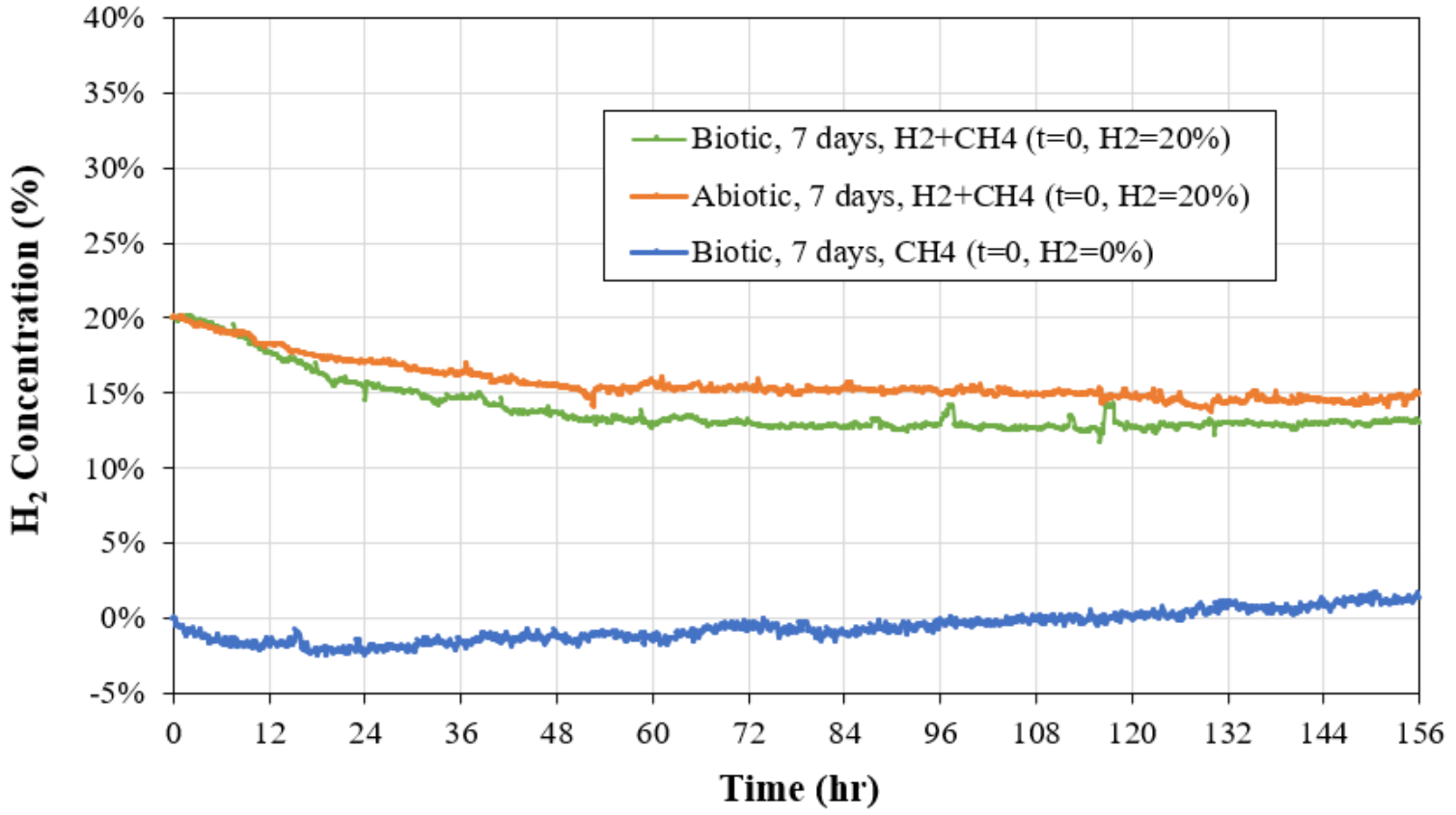


(at 530 nm)



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

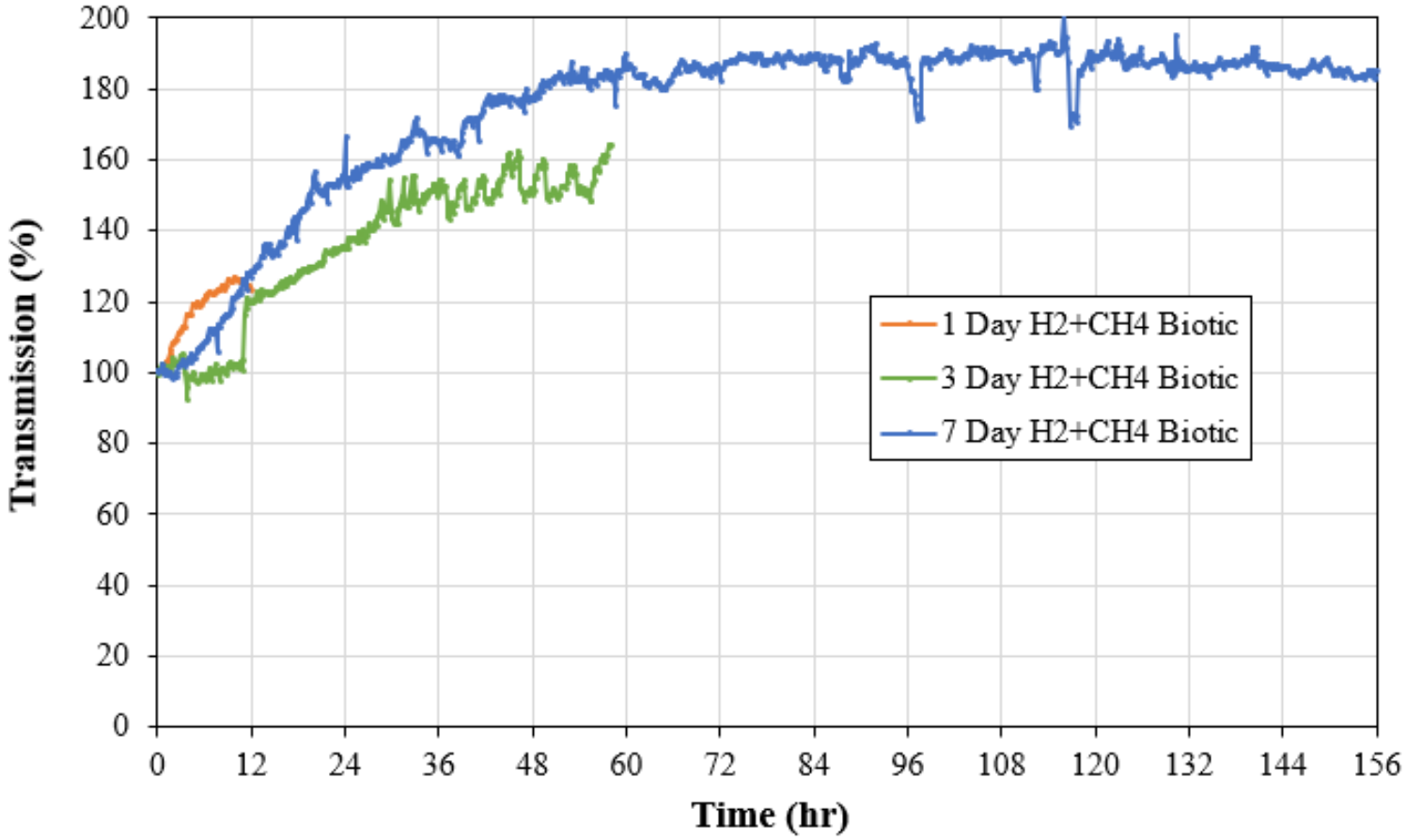
H_2 Concentration vs. Time for the 7 Day Tests



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

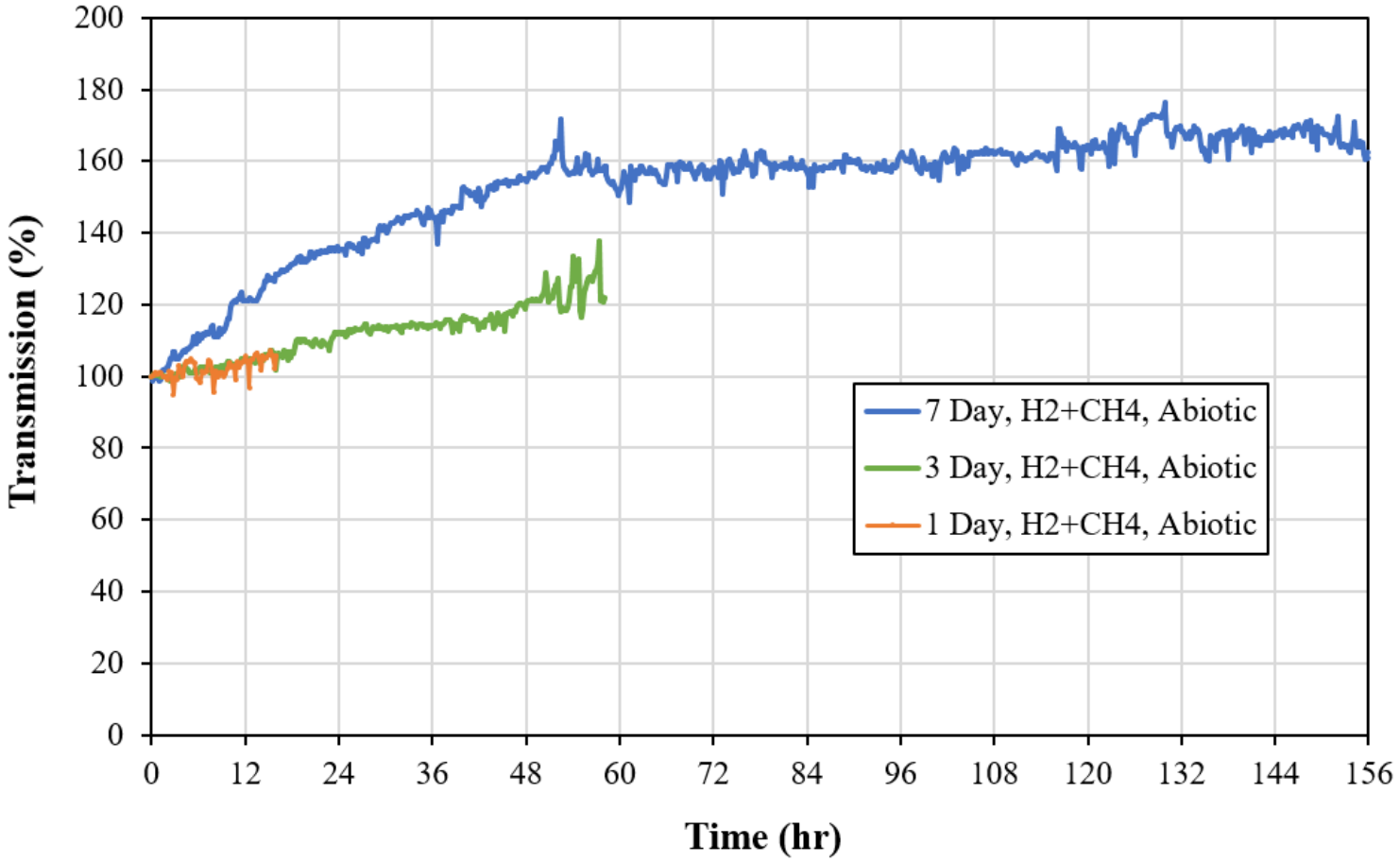
1, 3, 7 Days with a Biotic Sample in 20% H_2+80% CH_4

(at 530 nm)

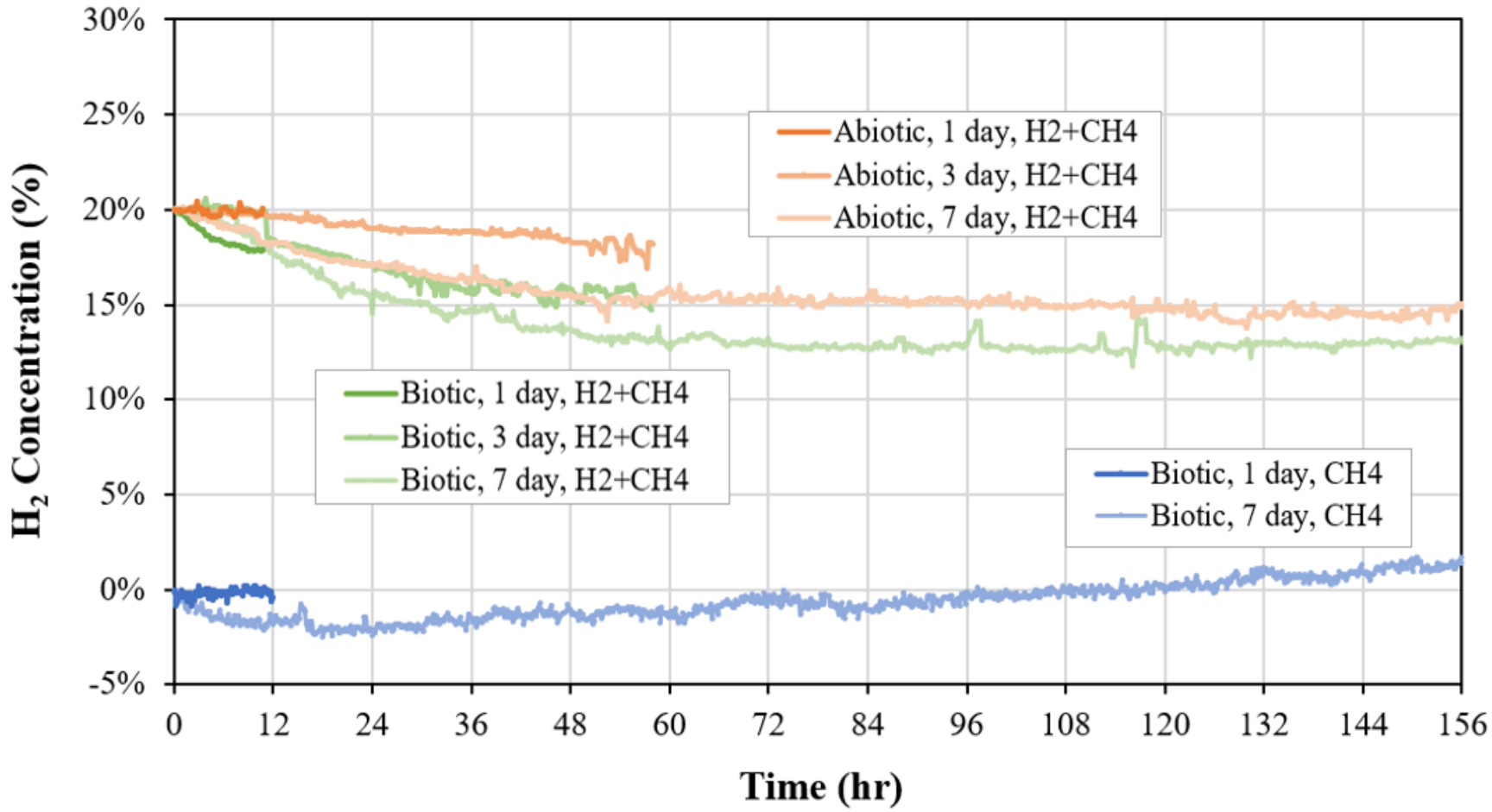


1, 3, 7 Days with an Abiotic Sample in 20% H_2+80% CH_4

(at 530 nm)



Real-Time H_2 Sensing in Subsurface Storage Conditions



Potential Abiotic/Biotic Activities in Subsurface Storage

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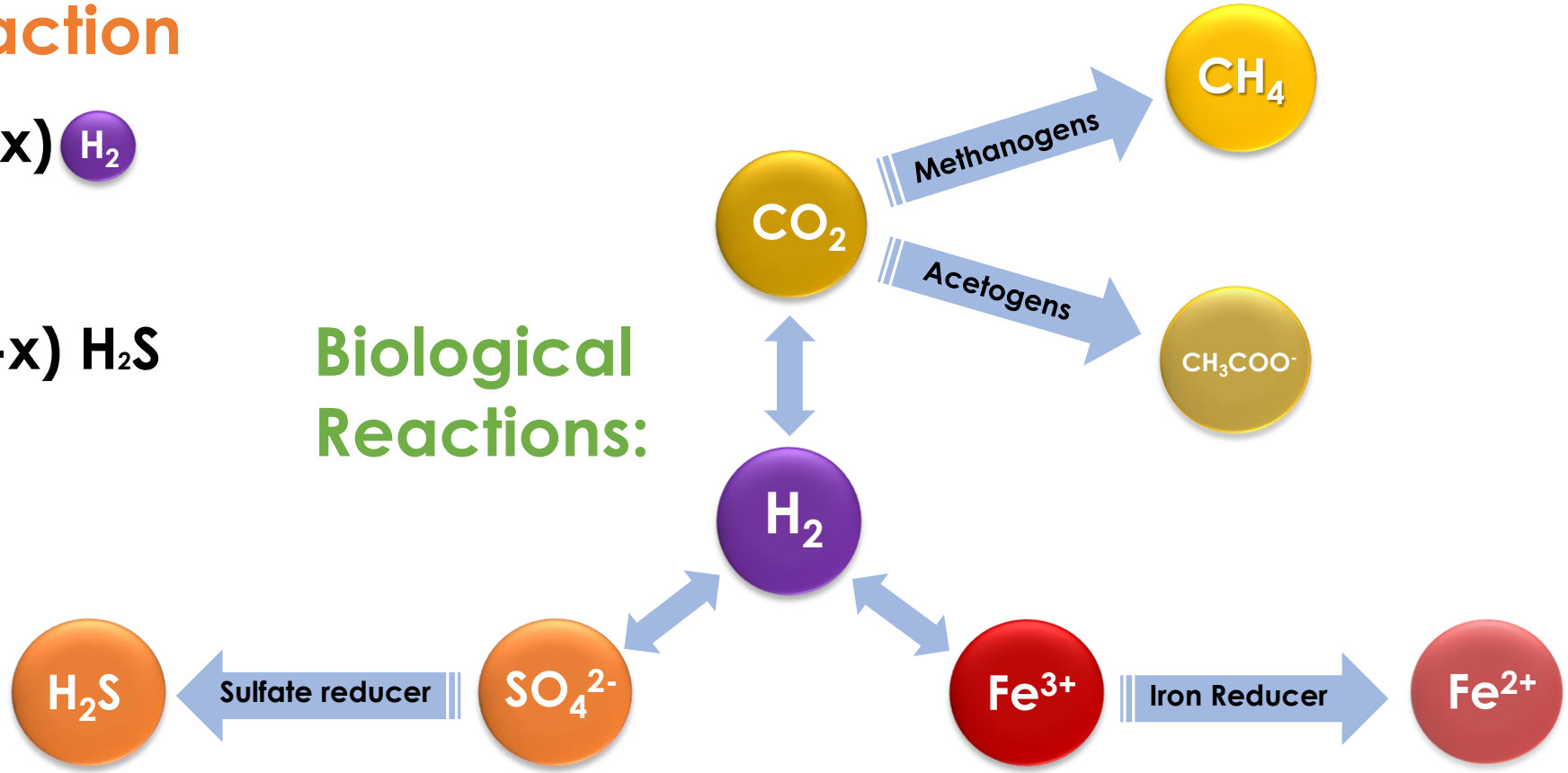
Abiotic Reaction

$FeS_2 + (1-x)\ H_2$

$\downarrow$

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

Biological Reactions:



Summary

- The optical fiber sensor developed at NETL was able to detect H_2 concentration **at high temperatures** and **pressures** with **biological samples**.
- The **biotic sample** has more **significant impact on H_2 sensing** 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 more accurate calibration and gas chromatography.
- The developed H_2 sensor has demonstrated the **potential** of monitoring H_2 in the subsurface storage reservoirs.

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