Development of CO_2 plume and leakage monitoring system for offshore CCS/CCUS

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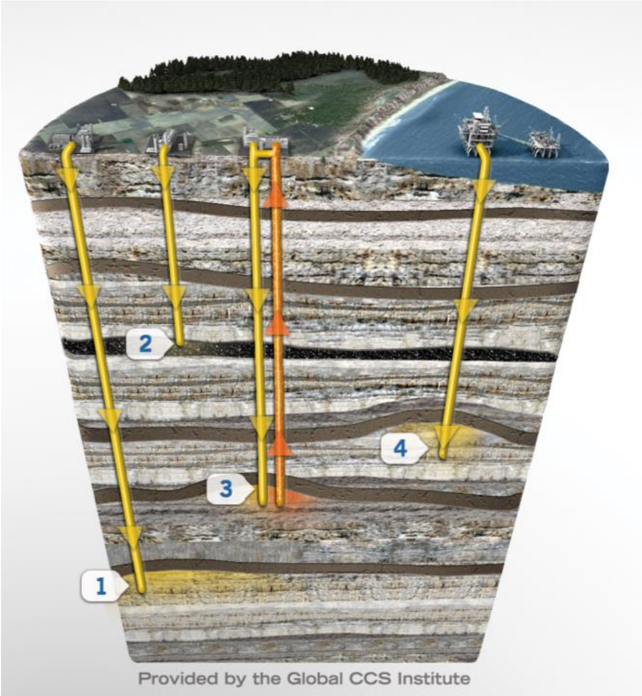
Carbon Capture and Storage (CCS)

CCS Technology is feasible

- Societal acceptance
- Economic reason

Measurement, Monitoring and Verification framework (MMV)

- *Containment :* security of CO2 injection target reservoir
- *Conformance :* understanding of behavior of the CO2 storage
- *Contingency :* assessing of contingency in the case of leakage



Safe and efficient long-term storage, maintaining social trust

Monitoring of CCS

Wide-ranging containment and environment monitoring program
→ Comprehensive risk-based measurement

Monitoring Task

- Monitor CO_2 plume development inside the storage complex.
- Monitor pressure development inside the storage complex.
- Monitor injection well integrity.
- Monitor geological seal integrity.
- Monitor for any CO_2 emissions into the hydrosphere/atmosphere.

Seismic Monitoring

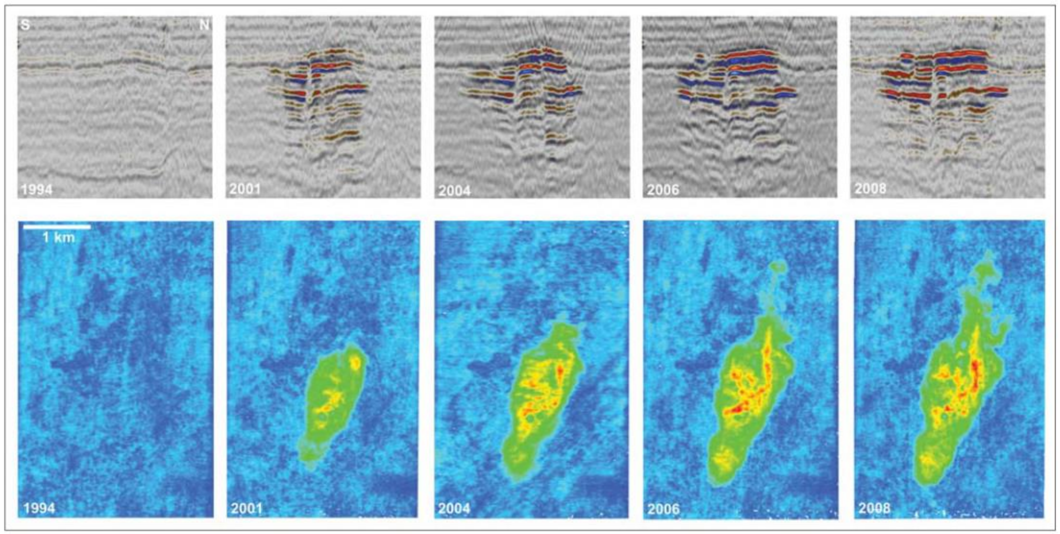


Figure 1. Time-lapse seismic images of the Sleipner CO_2 plume. NS inline through the plume (top); plan view of total reflection amplitude in the plume (bottom).

Chadwick et al., 2010

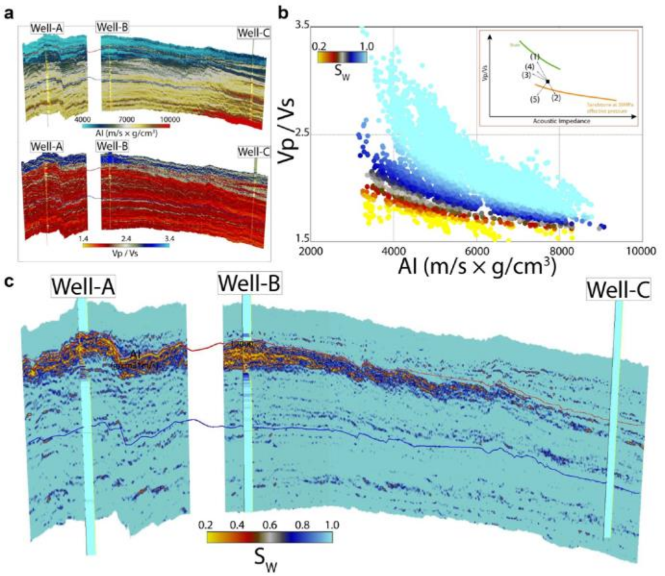


Figure 1. An example of a fluid response in a hydrocarbon field on the Norwegian Continental Shelf, (**a**) AI and Vp/Vs ratio profiles obtained from a seismic inversion with hydrocarbon-bearing wells (Well-A, Well-B), and a dry well (Well-C), (**b**) Data along the seismic lines plotted on the AI-Vp/Vs plane show that the fluid effect can be isolated and quantified using our proposed rock physics model, (**c**) the resulting fluid saturation profile indicating the hydrocarbon anomaly and it's extent. The inset in (**b**) does also show how the brine saturated sandstone will plot as the (1) shale content increase, (2) the amount of cement increase, (3) the porosity in the sandstone increase, (4) the effective stress in the formation decrease and (5) the saturation of gas increase within the sandstone[18].

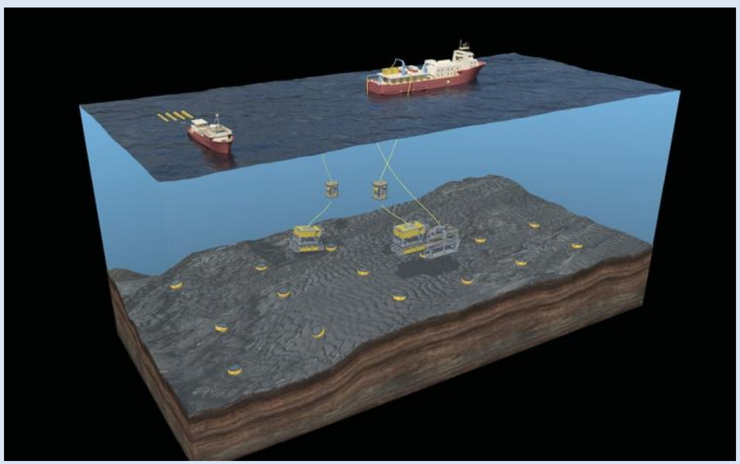
Fawad and Mondol, 2022

Existing Seismic Monitoring Technologies

Current options are expensive for reservoir monitoring

A. *Retrievable OBN surveys with ROVs:* *<u>High OPEX</u>*
B. *Permanent seabed cable installation (PRM):* *<u>High CAPEX</u>*
C. *Towed-streamer, VSP-DAS, gravity…*

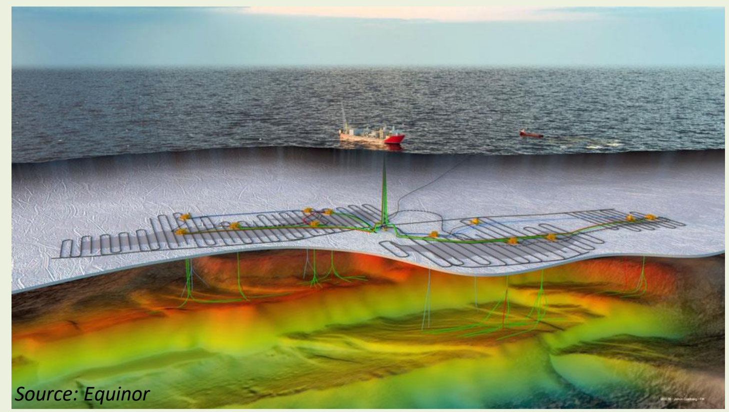
A. Retrievable OBN surveys



Li et al., 2019

https://www.pxgeo.com/ocean-bottom-nodes

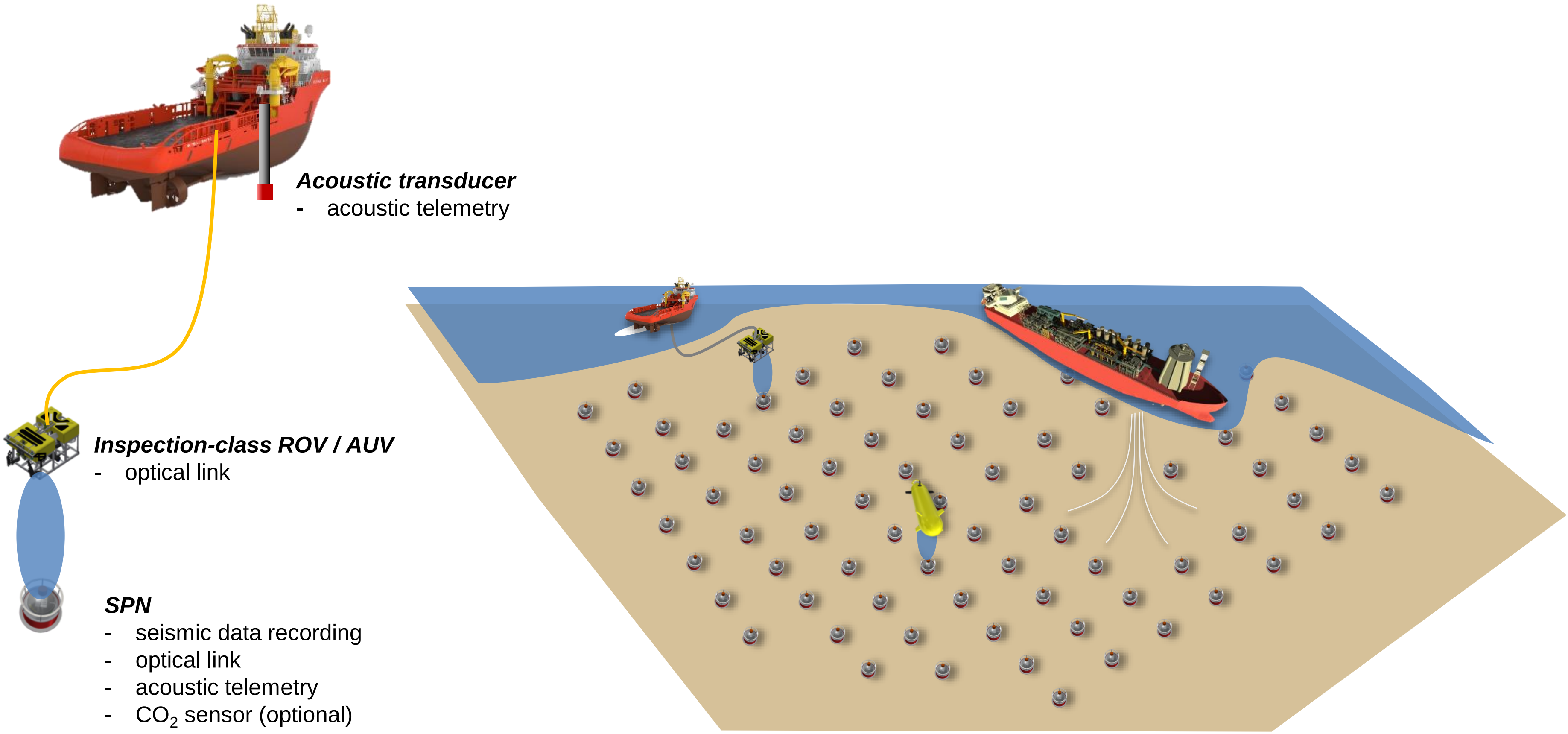
B. Permanent seabed cable installation



Source: Equinor

Maas et al., 2015

Semipermanent Ocean Bottom Seismic Node (SPN)



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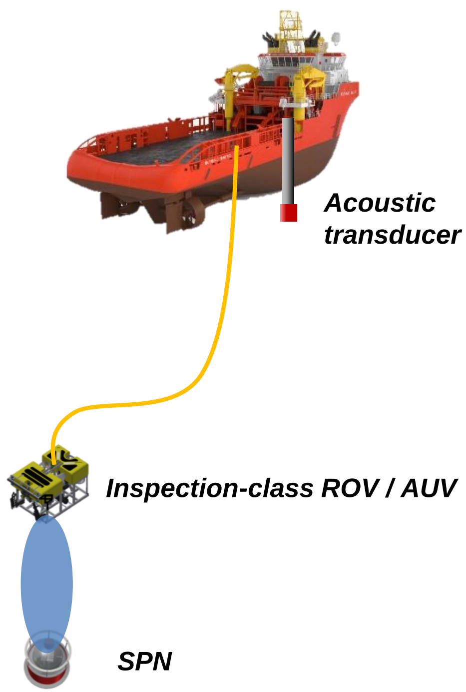
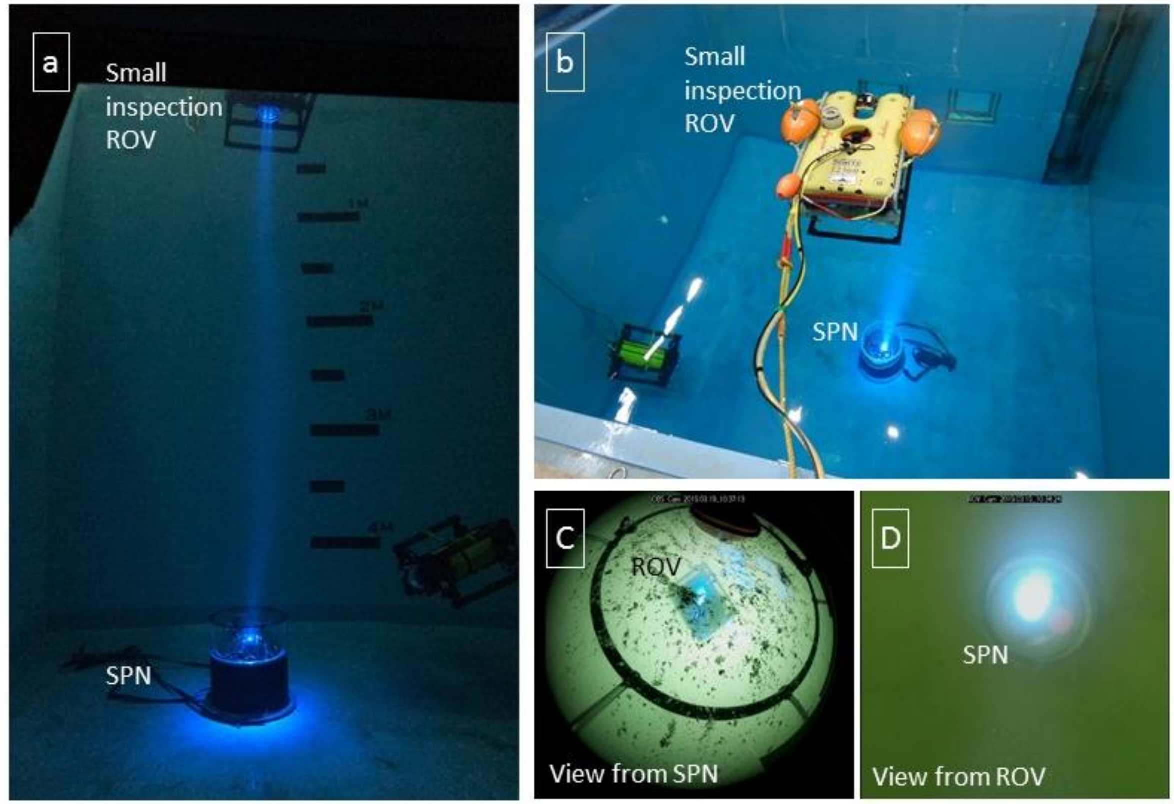
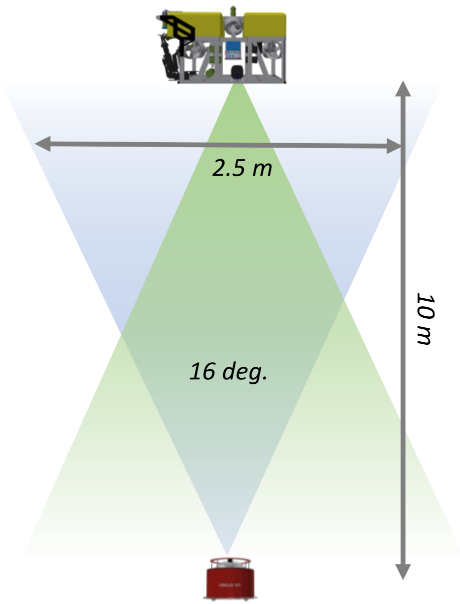
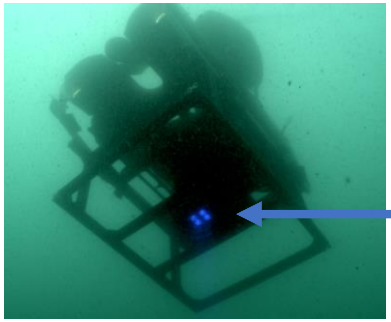




Shimizu et al., 2019 TLE

Optical Communication





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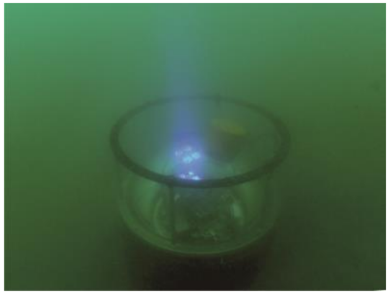
Excellence in Science

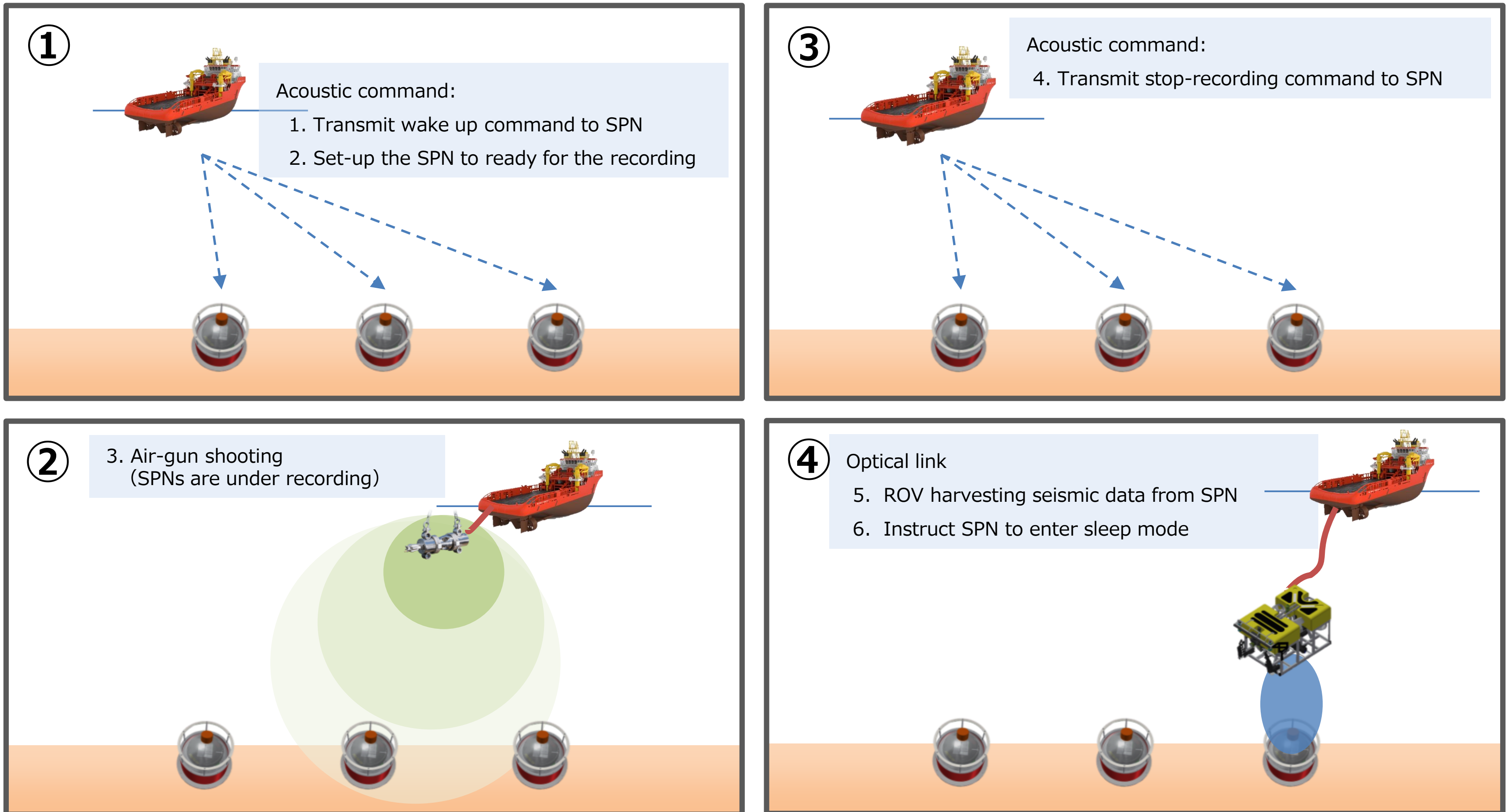
ROV / AUV
Optical device attached on the bottom of vehicle



SPN
Optical device built in the glass sphere

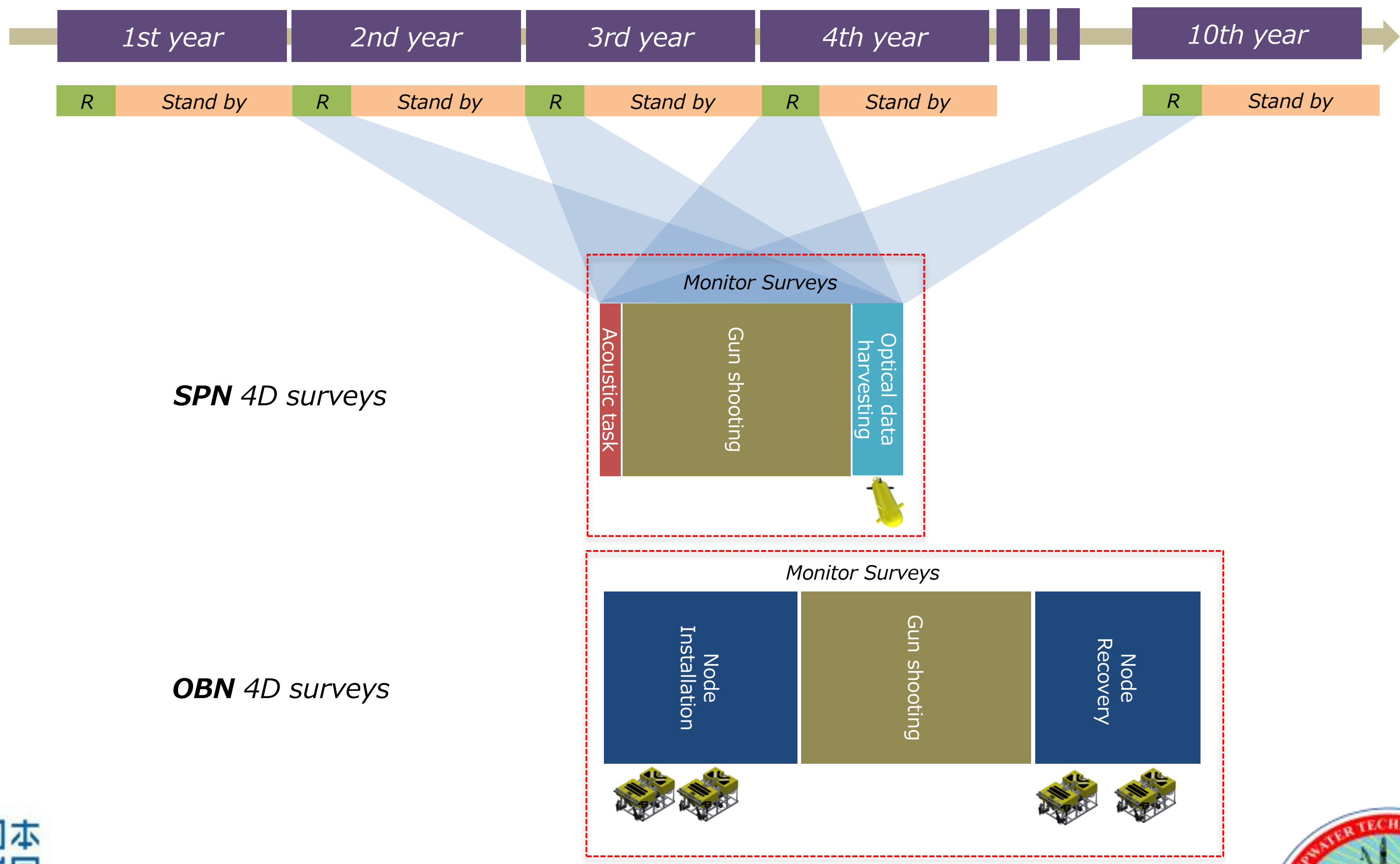
OCEAN INNOVATION

Survey Scenario



SPN Monitor Survey Model

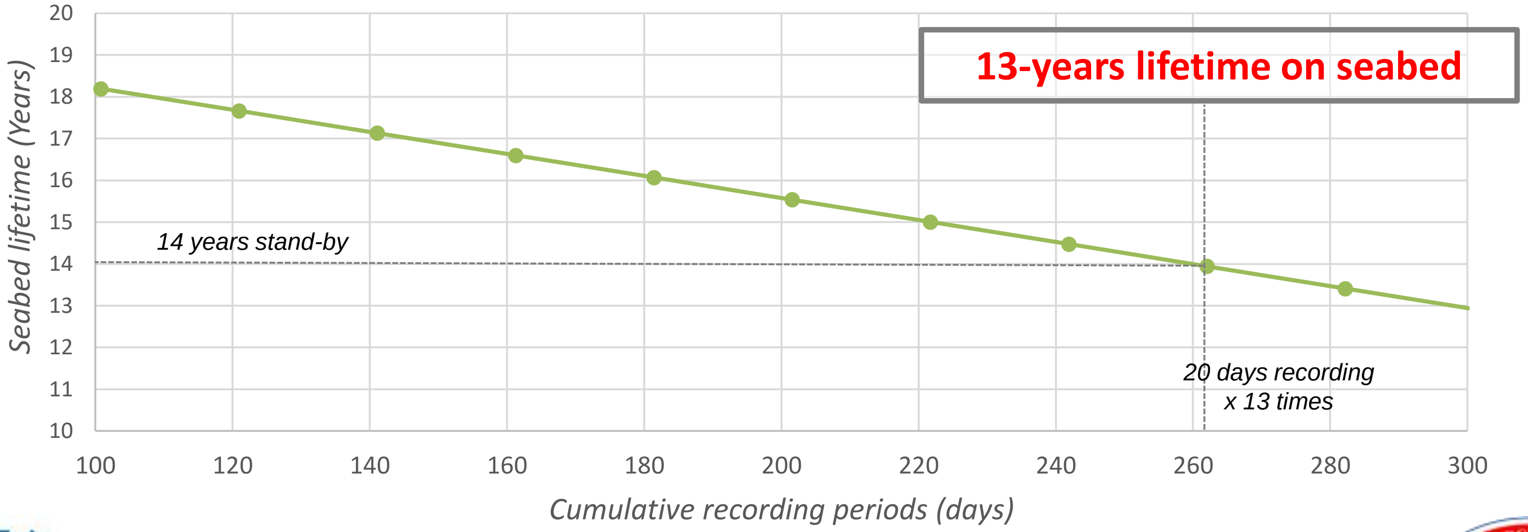
Ex) Yearly monitors



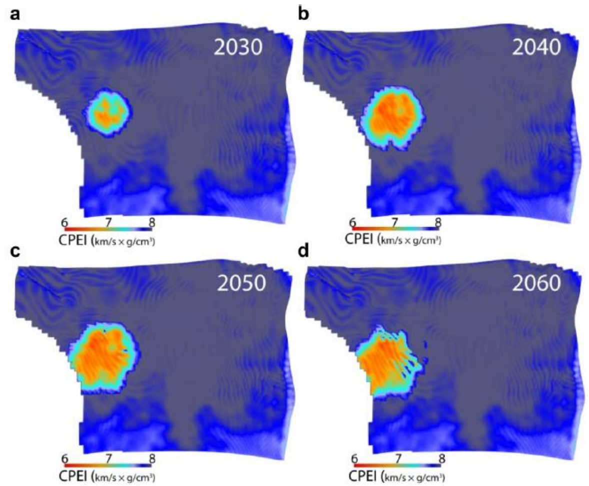
10 – 15 Years lifetime of SPN

Assumed survey dimension for calculation

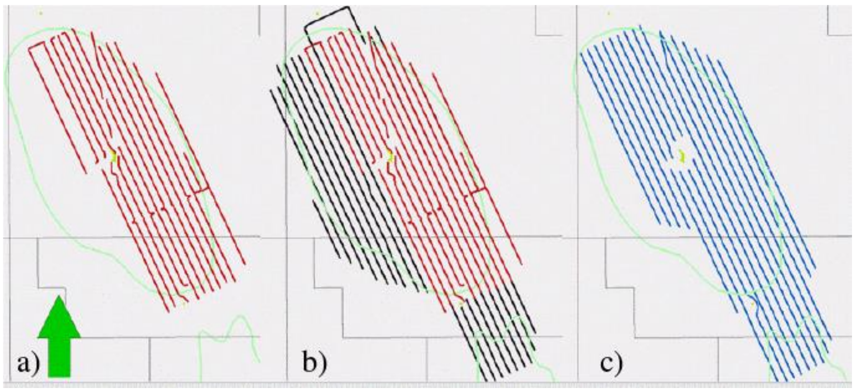
Receiver area :	50 sq. km
Shooting area :	150 sq. km
Receiver grid :	250 m x 250 m
Number of nodes :	858 nodes
Shooting line interval :	50 m
Shooting periods:	14.5 days - 20 days (including possible downtime)



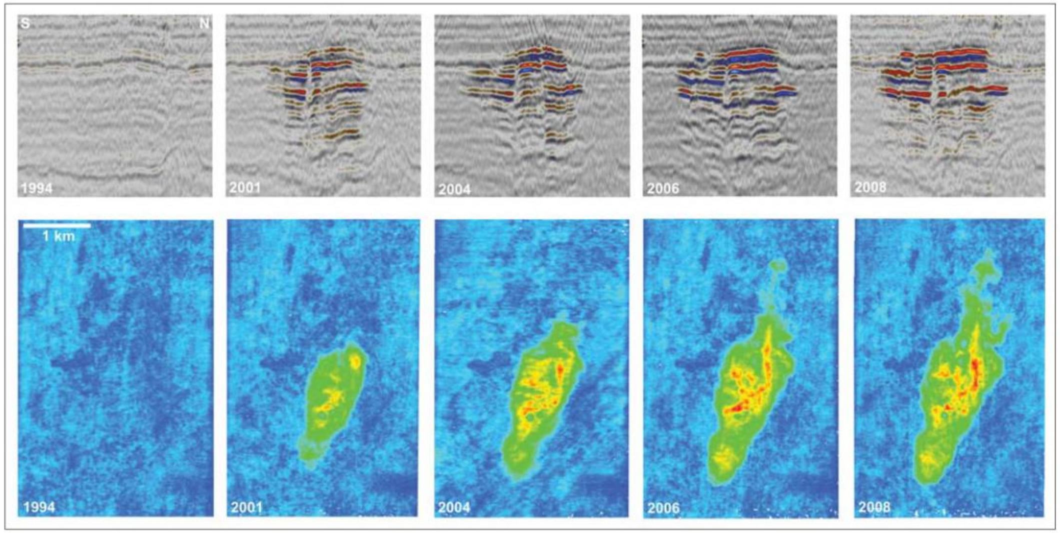
Changing Requirements and Areal Coverage



Fawad and Mondol, 2022



Mirne et al., 2019



Chadwick et al., 2010

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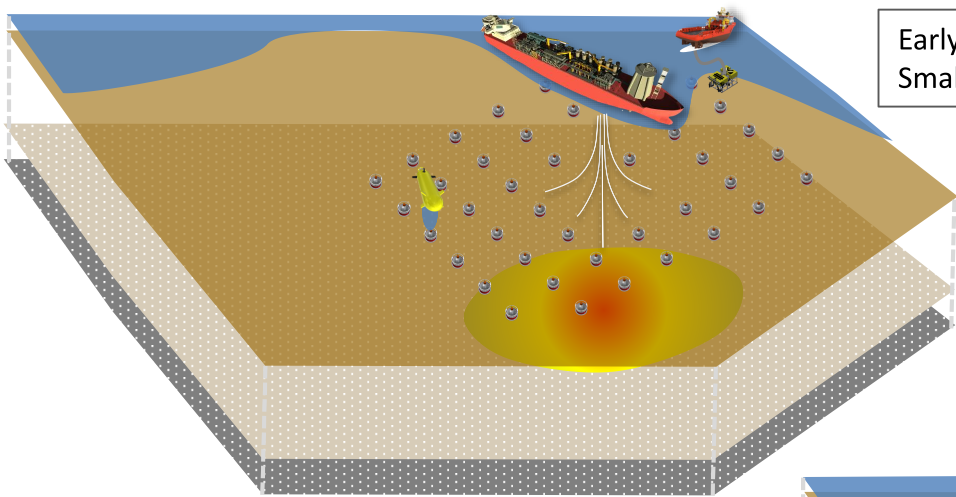
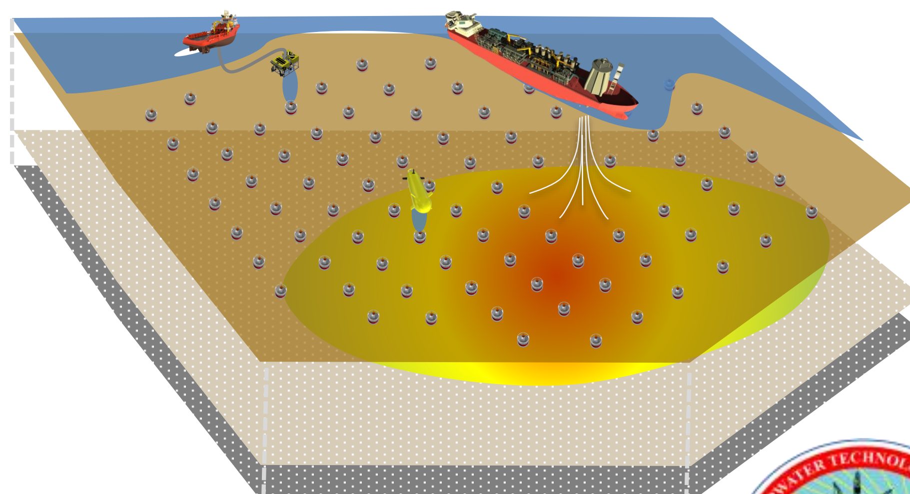
Flexibility for Areal Coverage



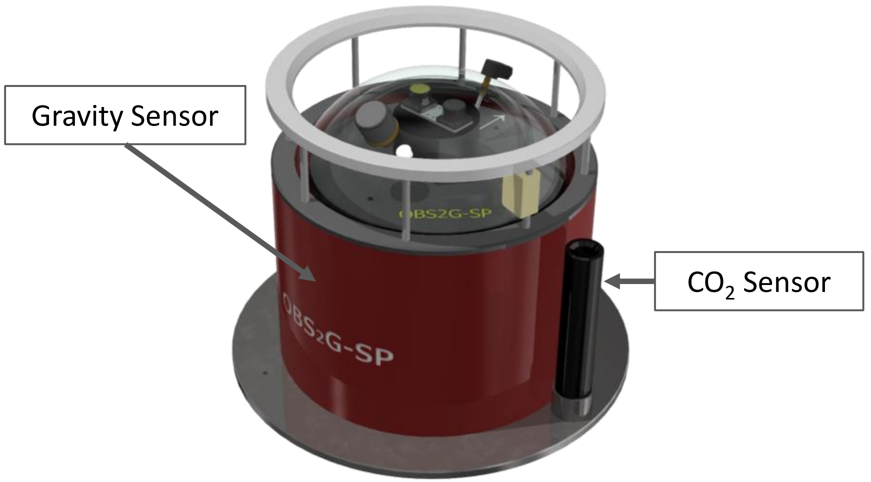
Early stage of injection:
Small area of CO2 plume ; Small coverage with SPNs

SPNs are ***movable***, ***replaceable***, and ***expandable*** in response to the evolution of CO_2 plume

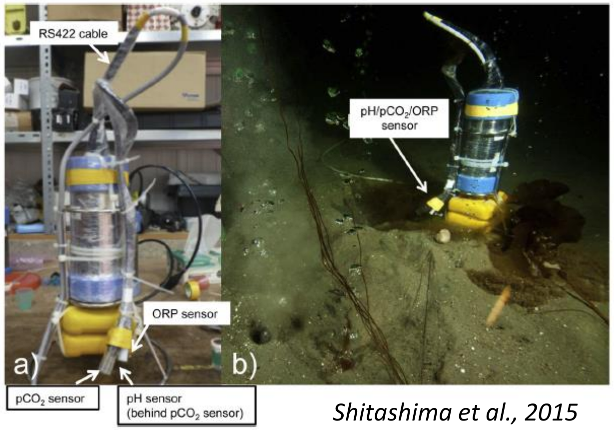


Later stage of injection:
Larger area of CO2 plume ; Larger coverage with SPNs

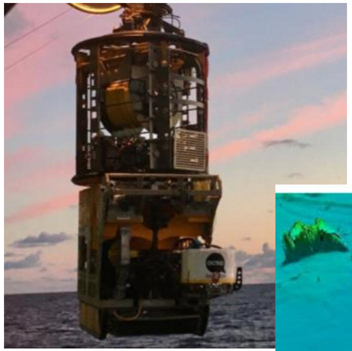
CO_2 leakage and Seafloor Deformation Detections



CO2 leakage to the seafloor

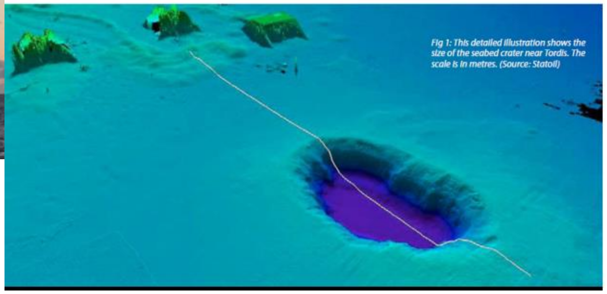


Shitashima et al., 2015

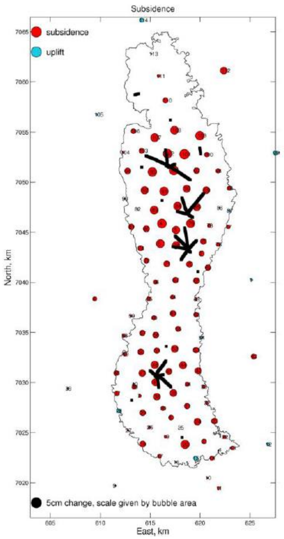


Source: OCTIO

Seafloor deformation



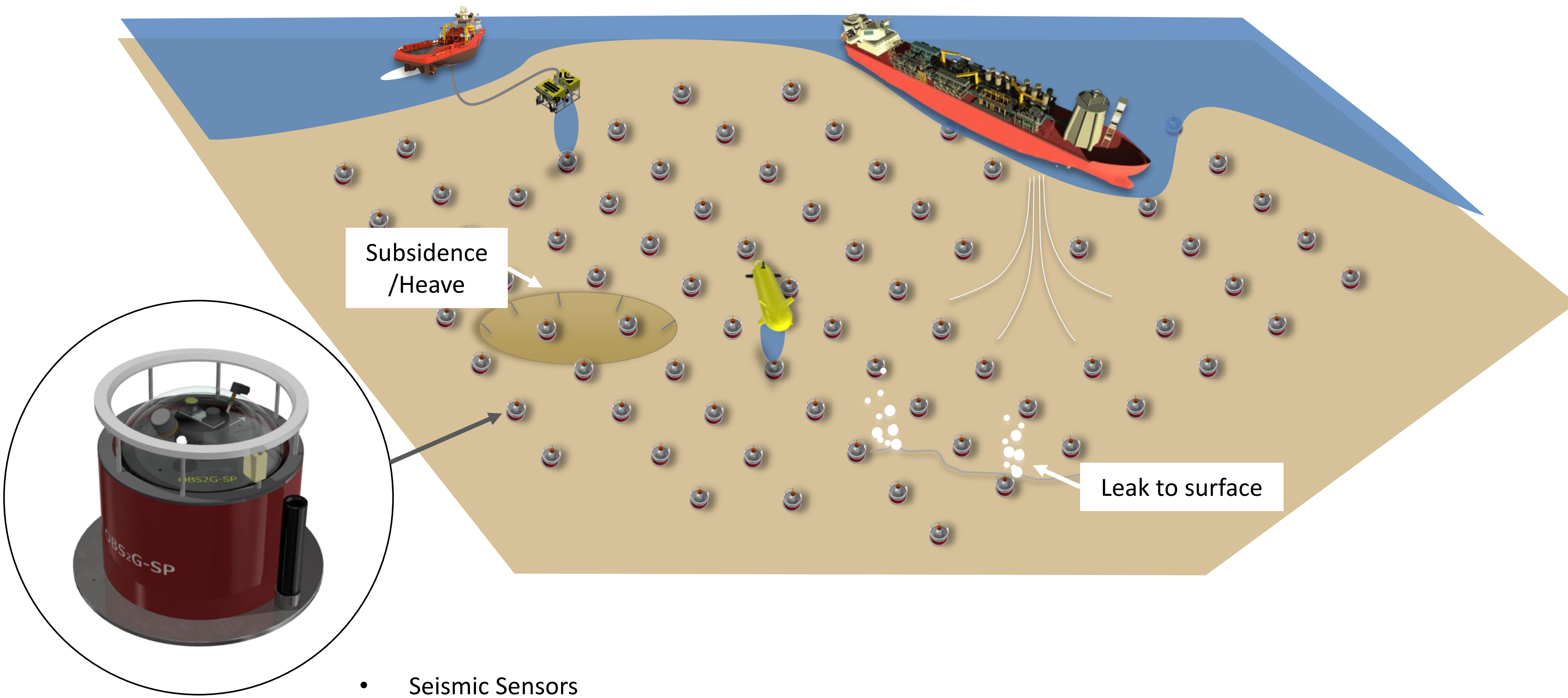
Source: NPD



Vatshelle et al., 2017

Dean et al., 2020

As Multi-Sensor Station For Contingency Monitoring



- Seismic Sensors
- CO_2 Sensor
- Gravity Sensor

Summary

- CCS/CCUS requires the monitoring for containment, conformance, and contingency
- Time-lapse seismic is a key technology for the subsurface monitoring
- SPN can significantly reduce CAPEX and OPEX, compared with existing technologies
- SPN has long lifetime on seabed (10 – 15 years)
- Areal coverage of node patch is flexibly adjustable (move, replace, expand) in response to the CO2 plume evolution
- SPN can function as multi-sensor stations for contingency monitoring (leak, deformation..) in addition to containment and conformance monitoring