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Fiber-optic Monitoring of CO_2 Storage Wells: State-of-the-art Review

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Presentation Outline

- Importance of continuous life cycle monitoring for well integrity and injection surveillance of a CO_2 storage well
- Fiber-optic distributed temperature sensing (DTS)
- Fiber-optic distributed acoustic sensing (DAS) and DAS-Vertical Seismic Profile
- Summary/Comments

REF: Ashry, Islam et al, "A Review of Distributed Fiber-optic Sensing in the Oil and Gas Industry", Journal of Lightwave Technology, 2021

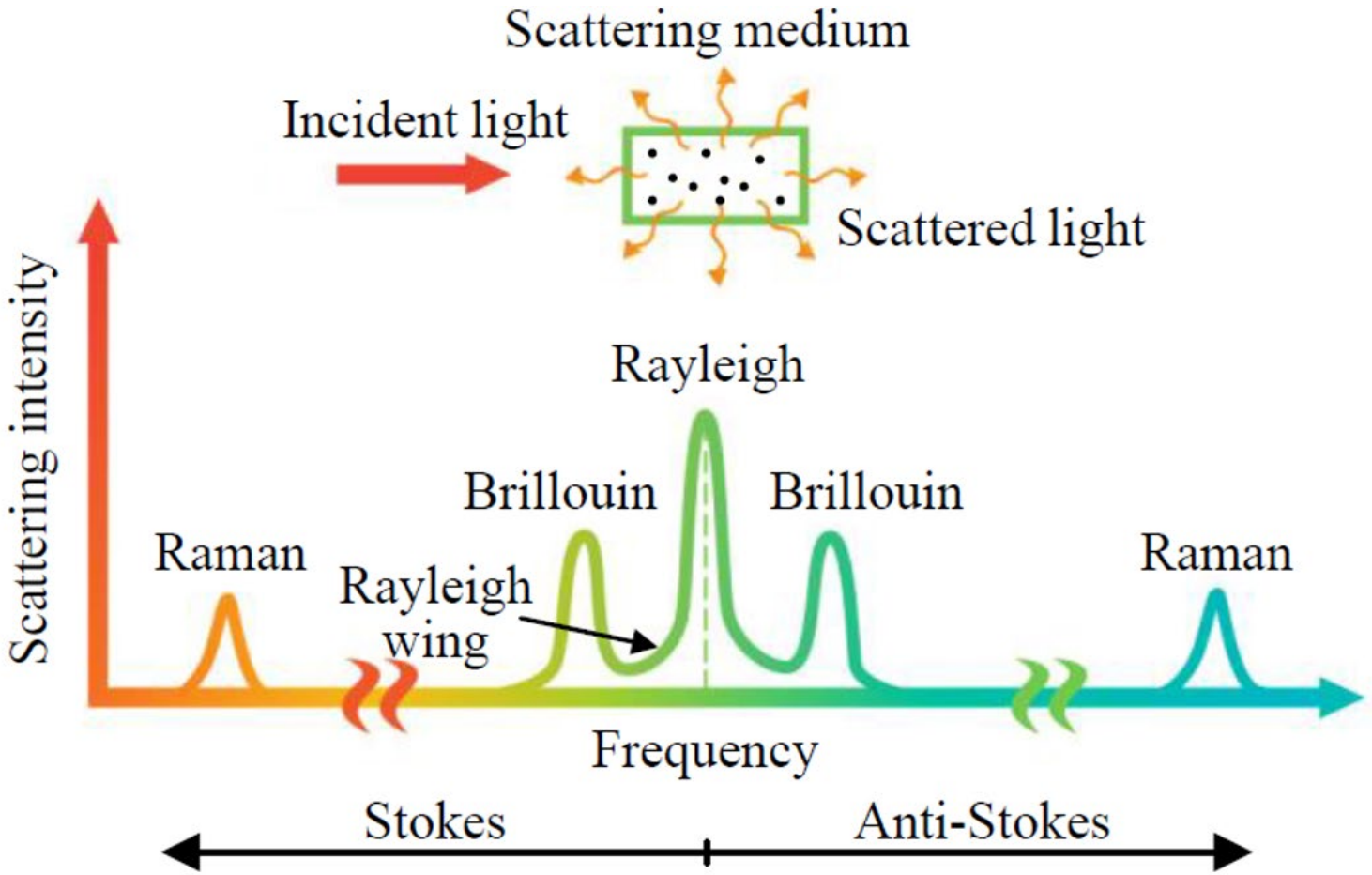


Fig. 3. A typical spectrum of spontaneous light scattering.

Importance of Monitoring of Well Integrity and Injection Surveillance of CO_2 Storage Wells

Safe and secure geologic storage of CO_2 requires continuous life cycle monitoring of well integrity and surveillance of the injected CO_2

Fiber-optic sensing systems – Distributed Temperature Sensing (DTS), Distributed Acoustic Sensing (DAS), Distributed Vibration Sensing (DVS), Distributed Strain Sensing (DSS), Distributed Pressure Sensing (DPS), Distributed Chemical Sensing (DCS)

Fiber-optic methods for monitoring and injection surveillance of CO_2 storage wells (DTS, DAS and Vertical Seismic Profile – VSP) are discussed

REF: Ashry Islam et al, Journal of Lightwave Technology, 2021

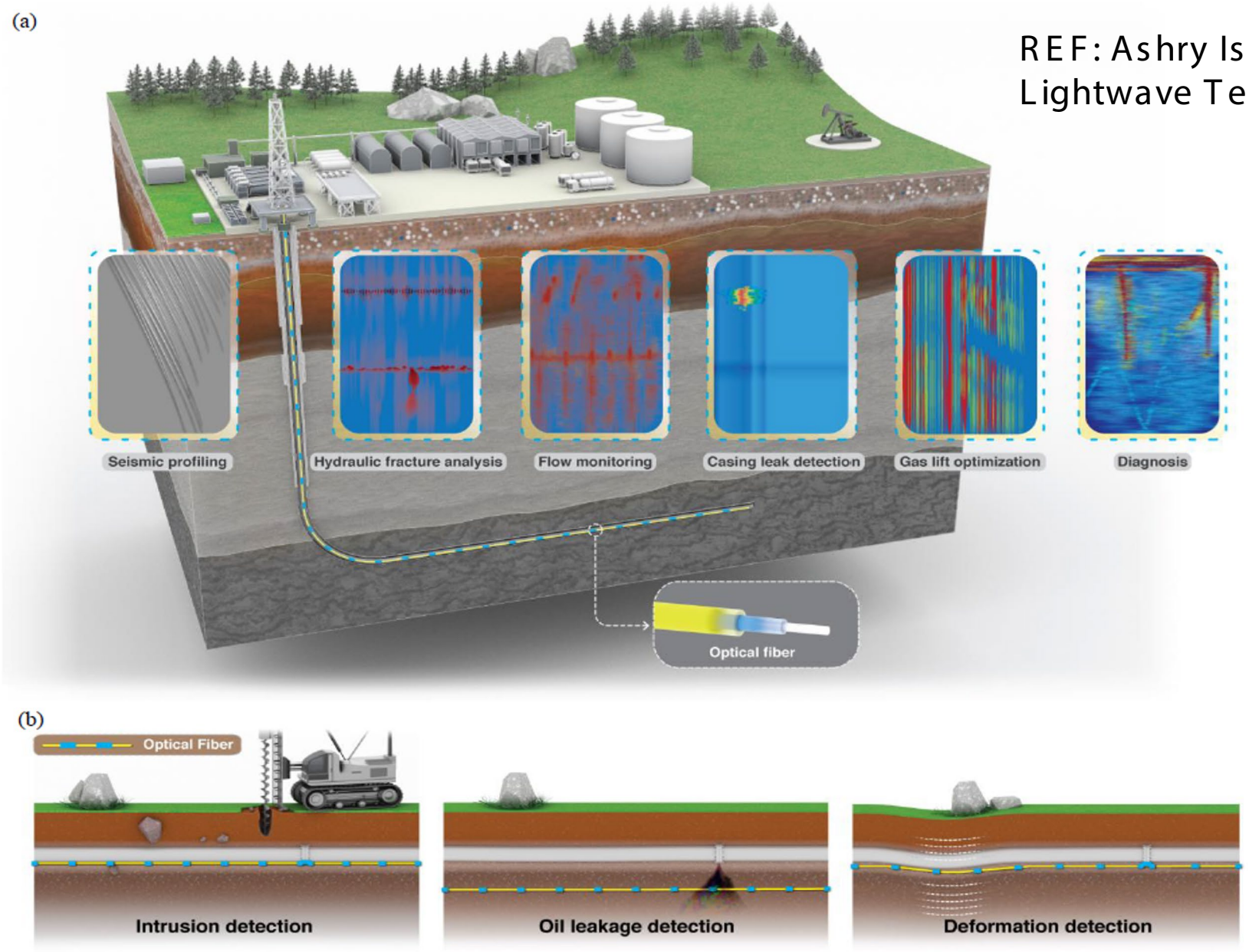


Fig. 2. Examples of distributed fiber–optic sensing applications in the downhole environment (a) and along pipelines (b). ©King Abdullah University of Science and Technology (KAUST).

Fiber-optic Distributed Temperature Sensing (DTS)

DTS Overview

- DTS system based on spontaneous Raman scattered signals and Optical Time Domain Reflectometry (OTDR) and consists of a DTS box and a fiber deployed in well
- Temperature at any point of the fiber is a function of the intensity ratio of Raman stokes (backscattered light with higher wavelength) and Raman anti-stokes (backscattered light with lower wavelength)
- Two types of fiber modes: (1) Single-mode (generally used for DAS) and (2) Multimode (generally used for DTS) with higher attenuation than single-mode

Fiber-optic Distributed Acoustic Sensing (DAS)

DAS Overview

- DAS based on digital optical detection of elastic Rayleigh backscattered light due to variations of refractive index along a fiber. Makes use of traditional optical time domain reflectometry (OTDR) (with a laser source) to detect seismic waves along entire length of fiber
- iDAS records the full wavefield amplitude, frequency and phase throughout the length of the fiber. iDAS can obtain measurements equally well with both single-mode (SM) and multi-mode (MM) fiber
- Both DTS and DAS measurements can be made in a single well (using two fiber optic cables) to obtain temperature as well as seismic wave data

CO_2 Storage Applications of DTS/DAS/VSP

- DTS Applications: - (1) Detect near wellbore leakage, (2) evaluate casing and cement integrity, (3) monitor temp and CO_2 flow within injection zones (warm-backs), (4) CO_2 leakage to overburden, and (5) location of thermal anomalies
- DAS Applications: - (1) seismic monitoring, (2) hydraulic fracturing monitoring, (4) flow monitoring/injection profile, (5) well integrity/casing/tubing leaks
- DAS-VSPs – Time-lapse seismic surveys obtained with distributed acoustic sensing fiber (DAS-VSPs) to monitor CO_2 plume/reservoir fluids and CO_2 conformance and containment within the storage reservoir

DAS-VSP Survey

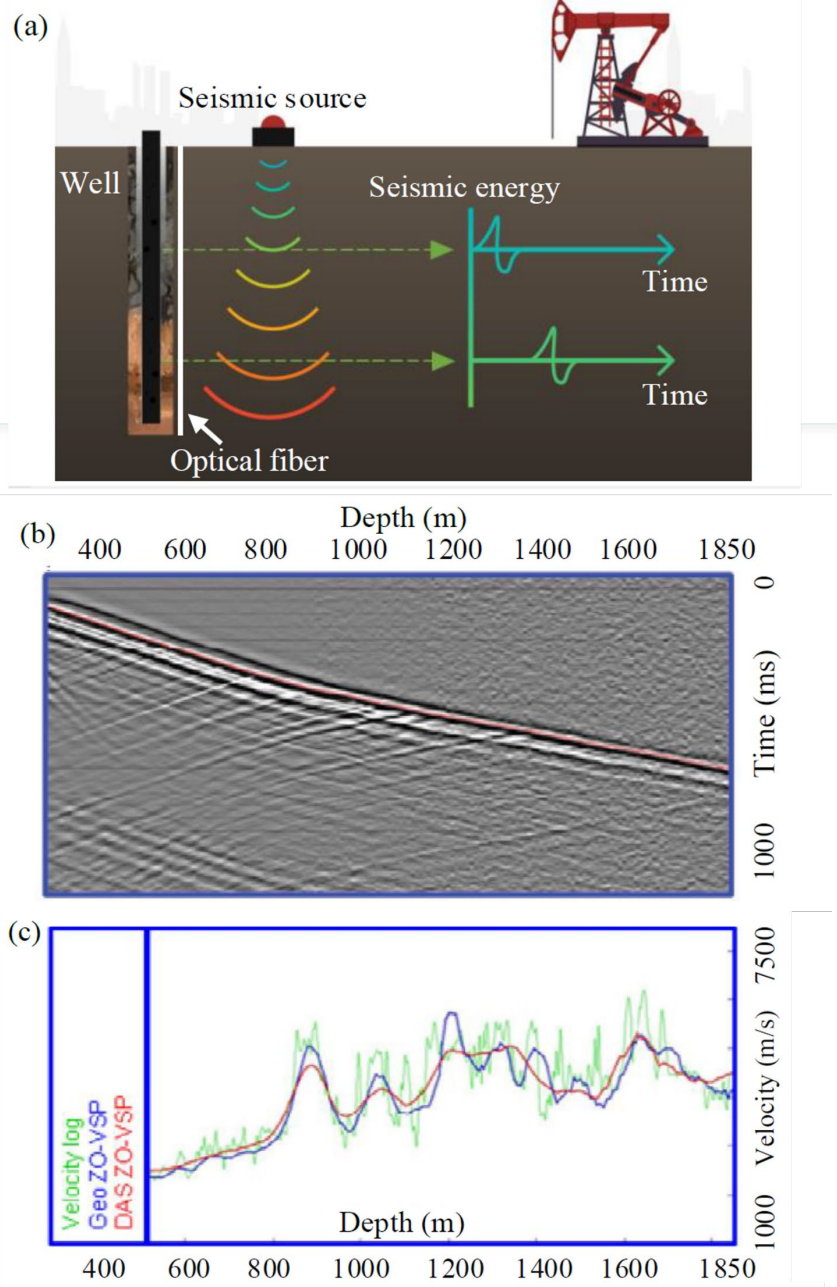


Fig. 6. (a) Acquiring a VSP survey using a fiber–optic DAS. (b) A VSP survey recorded with DAS. (c) Velocity profiles recorded with different sensing systems. ((b) and (c) are reproduced from [54] with permission).

REF: Ashry, Islam et al, Journal of Lightwave Technology, 2021
(Example – CO2 Storage Project)

Fiber deployment

Permanent installation – fiber optic encased in ¼" OD control line and strapped/cemented to outside of casing or tubing during initial completion

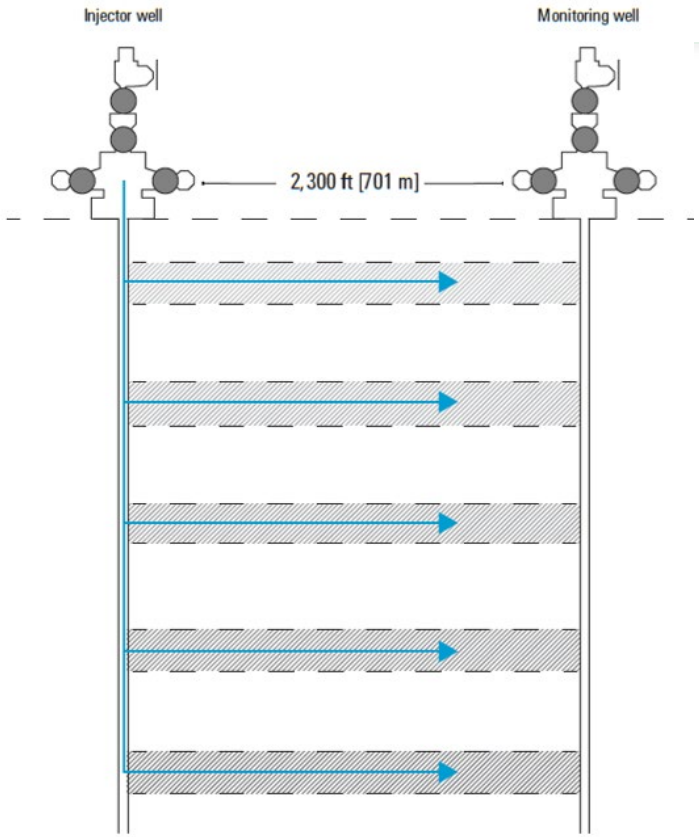
Carbon rods – fiber optic encased in 5/8" OD carbon fiber rod and rod is snubbed into the well

Fiber in coil tubing – fiber is pre-deployed into 1.57" coil tubing

Wireline (E-line or slickline) retrievable fiber with pressure control equipment

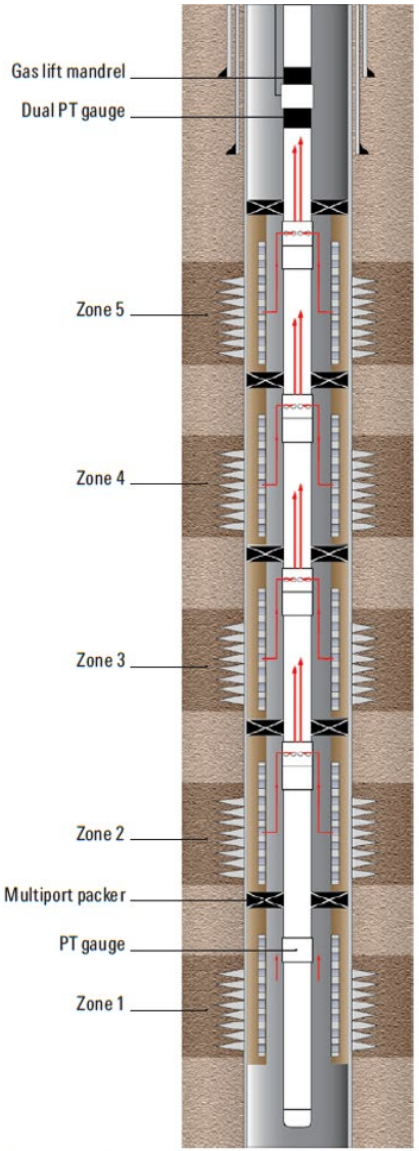
Pump-down dissolvable single-use bare fiber

Multizonal Intelligent Completion



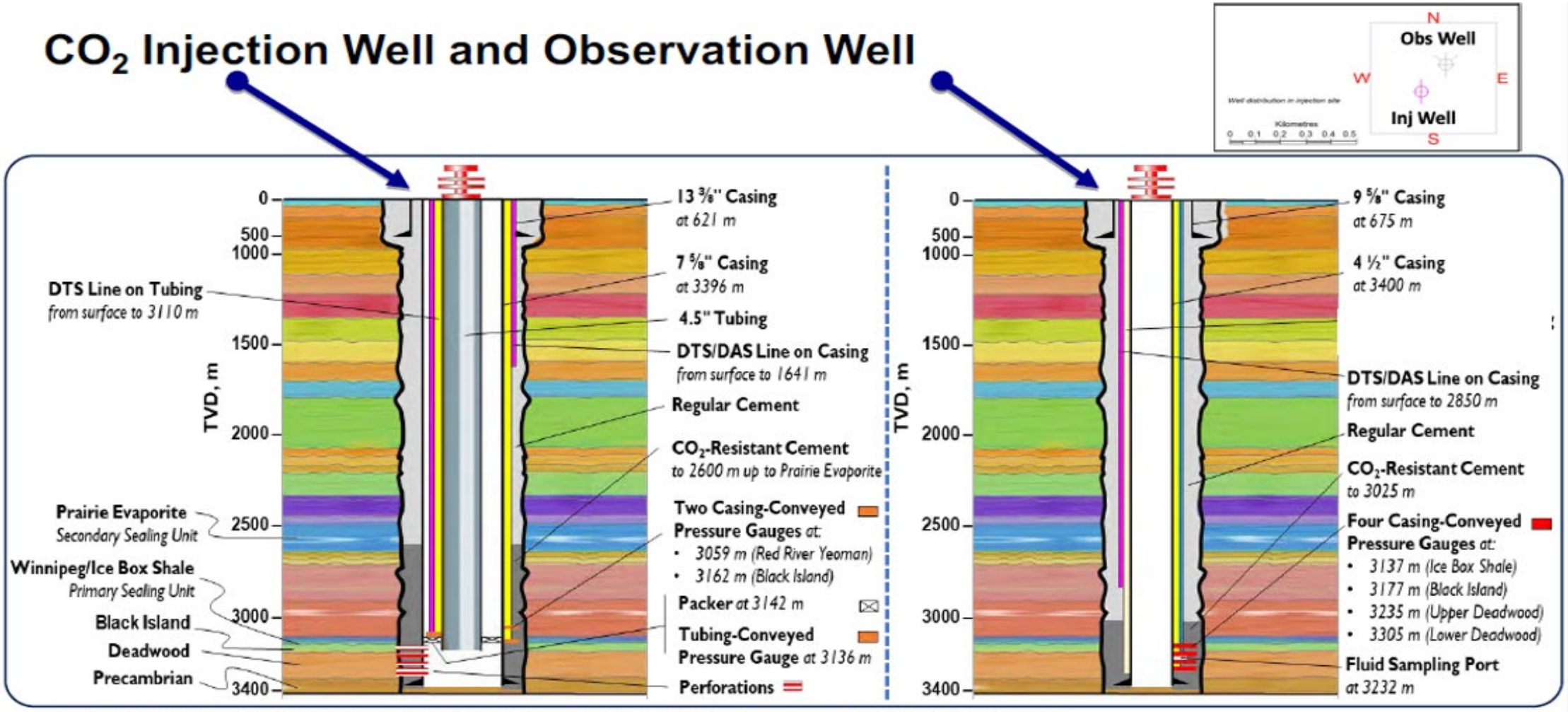
Captured carbon is pumped into the multilayered reservoir, and samples are regularly taken from the monitoring well to ascertain the storage behavior.

REF: DOE_ADM-Schlumberger



A five-zone intelligent completion in the monitoring well provides insight into the effects of CO_2 injection in the different zones. Opening the flow control valves enables collection of downhole fluid samples to identify changes in reservoir conditions.

Example – CO_2 Storage Well Schematic with DTS/DAS "Part I: Field-Based Observations for CO_2 Geological Storage from 6 Years of CO_2 Injection at Aquistore", Webinar R. Chalaturnyk, April 14, 2021



DTS lines are located along the length of the ***tubing of injection well***, and the ***casing of the observation well*** *(~spaced every 100 m)*.
DTS lines do NOT cover the targeted CO2 storage interval. NOT capable of profiling the injection flowrate in the 4 perfed zones.

TABLE I
DISTRIBUTED FIBER–OPTIC SENSING COMPANIES WITH APPLICATIONS IN THE OIL AND GAS INDUSTRY.

Company	Product and/or Service	Application
AP Sensing	DTS, DAS systems and services, sensor cables	Well and reservoir monitoring, liquefied natural gas monitoring, pipeline monitoring, geo- and hydrological applications, power cable monitoring, railway monitoring and train tracking
Aragon Photonics Labs	DAS systems	Reservoir monitoring, seismic monitoring, pipeline monitoring, power cable, subsea cable, railway/highways monitoring
Baker Hughes, a GE company	DTS, DSS, DAS services	Upstream oil and gas
Bandweaver	DTS, DAS systems	Oil and gas, pipeline and process, power and utilities, fire and security monitoring
DarkPulse	DTSS systems and solutions	Exploration/production monitoring in oil and gas industry, including drill string, casing, wellhead, and production trees monitoring, pipeline monitoring, mine safety monitoring
Fiber SenSys	DAS systems and solutions	Perimeter security monitoring for oil and gas industry
Fotech Solutions	DAS solutions	Pipeline, transport, energy, security, infrastructure monitoring
Halliburton	DTS, DSS, DAS services	Well, reservoir and fracture monitoring
HAWK Measurement	DTS, DSS, DAS systems and solutions	Pipeline monitoring and leak detection, conveyor health monitoring, tailings dams monitoring, perimeter security and threat detection, power cable monitoring
Hifi Engineering	DAS systems	Pipeline and downhole applications, pressure wave leak detection, direct commodity leak detection, flow analysis, pig tracking, seismic detection and measurement
IFOS	DTS systems and services	Oil and gas wells, concrete curing, pipeline flow and leakage, electric power transmission lines, reactor vessel insulation, environmental remediation, fire detection
LIOS Sensing, a NKT Photonics company	DTS, DSS systems, sensor fibers and cables	Oil and gas applications, industry temperature monitoring, power transmission monitoring, structural monitoring
OFS Fitel, LLC, a Furukawa company	DTS, DAS systems, sensor fibers, cables, and components	Oil and gas, electricity, alternative energy
Omnisens	DTS, DSS, DAS systems, solutions, and services, sensor cables	Reservoir, pipeline, power cable, subsea, structural health monitoring, test and measurement of optical fiber and cable
Optasense, a Luna company	DAS systems and solutions	Oilfield services, pipeline monitoring, highway and railway monitoring, power cable monitoring, security surveillance
Optromix	DTS, DAS systems	Oil and gas well and reservoir monitoring, pipeline leakage detection, vibroacoustic monitoring of oil wells, temperature monitoring of transmission and distribution power lines
OZ optics	DSTS systems, sensor components and modules	Oil and gas, utility and cable applications, civil engineering applications, security, fire applications
Petrospec Engineering	DTS, DAS systems and services, sensor fibers	Reservoir and wellbore monitoring
Schlumberger	DTS, DAS, DTSS systems and services	Borehole seismic operations, reservoir monitoring, downhole condition monitoring
Sensornet	DTS systems and solutions, sensor cables	Pipeline leak detection, intrusion detection
Silixa & Welldog	DTS,DSS, DAS systems and services, sensor cables	Oil and gas applications, mining, alternative energy, environmental and earth sciences, infrastructure
Solifos	DTS, DSS, DAS systems, solutions, sensor cables	Pipeline monitoring, reservoir monitoring, tank monitoring, geotechnical monitoring, fire protection in production facilities
VIAVI	DTS, DTSS systems, sensor modules	Pipeline monitoring, power/communication cable monitoring
Weatherford	DTS, DAS services	Downhole sensing and permanent reservoir monitoring for well production, injection, storage, and monitoring purposes
Yokogawa Electric Corporation	DTS systems and services, sensor components and modules	Pipeline leak detection, power cable monitoring, fire detection, furnace monitoring
Ziebel	DTS, DAS solutions	Well integrity, well interference, seismic monitoring, flow allocation, stimulation monitoring

Distributed Fiber-Optic Sensing Companies – Ashry, Islam et al, Journal of Lightwave Technology, 2021

Summary – Fiber Optic (DTS/DAS) Monitoring of CO_2 Storage Wells

- Fiber optic sensing and its applications (DTS/DAS/VSP) have revolutionized the energy industry - allows continuous, real-time measurements along the entire length of a fiber-optic strand with multiple options for fiber deployment
- DTS monitoring applications:(1) near wellbore leakage, (2) evaluate casing and cement integrity, (3) temperature and CO_2 flow within injection zone/injection profile and CO_2 leakage to overburden, (4) location of thermal anomalies
- Time-lapse seismic surveys with DAS-VSPs (in lieu of conventional wellbore geophones) can provide a better understanding of CO_2 plume growth and containment within the storage reservoir
- Both DTS and DAS can be run in a single well (using two fiber optic cables) to obtain temp as well as seismic wave and strain data