Development of an affordable new seismic source-receiver system for 4D mapping of CCS plume fronts and passive seismic monitoring

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SensorEra

Howard Wilkinson

Green Products USA (GPUSA)

Special Section 10, 361A
Session: Recent Advances in CCS Monitoring: Technology and Case Study
August 30, 2023 from 8:50 AM to 9:15 AM

SensorEra
GPUSA
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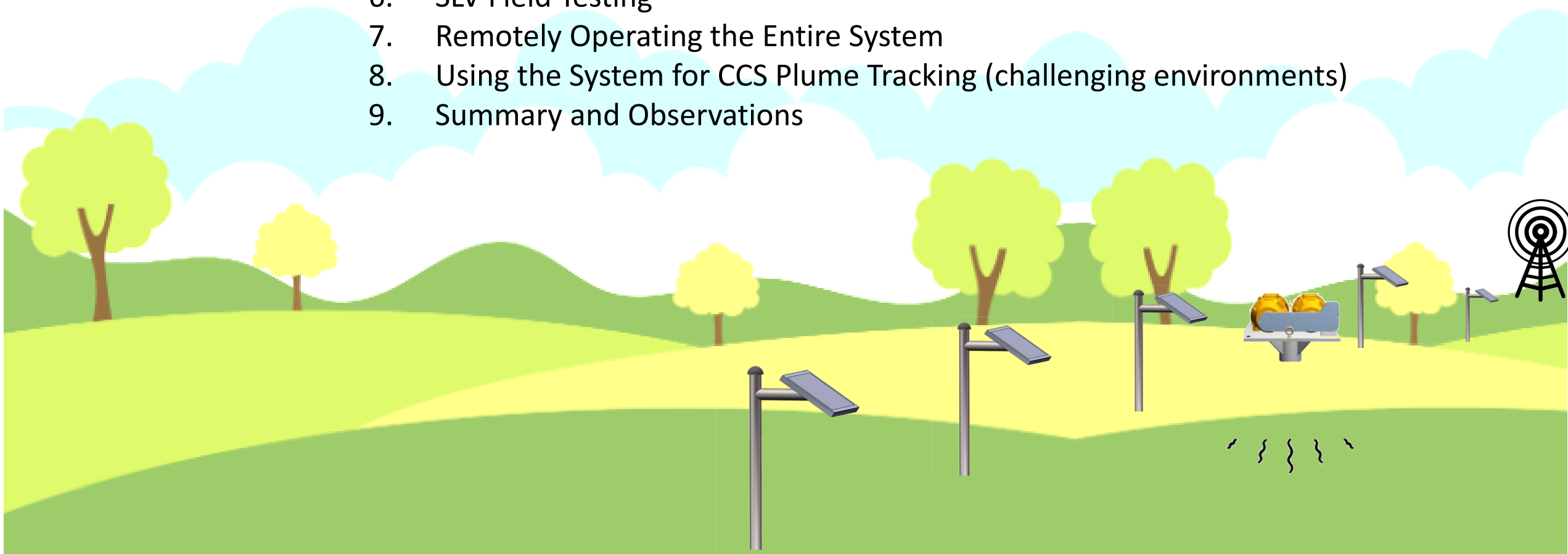
International Meeting for Applied Geoscience & Energy

Talk Structure:

1. What is this all about?
2. What is a MEMS Sensor?
3. What is a Surface Linear Vibrator?
4. What is a Helical Anchor?
5. Sensor(s) Field Testing
6. SLV Field Testing
7. Remotely Operating the Entire System
8. Using the System for CCS Plume Tracking (challenging environments)
9. Summary and Observations



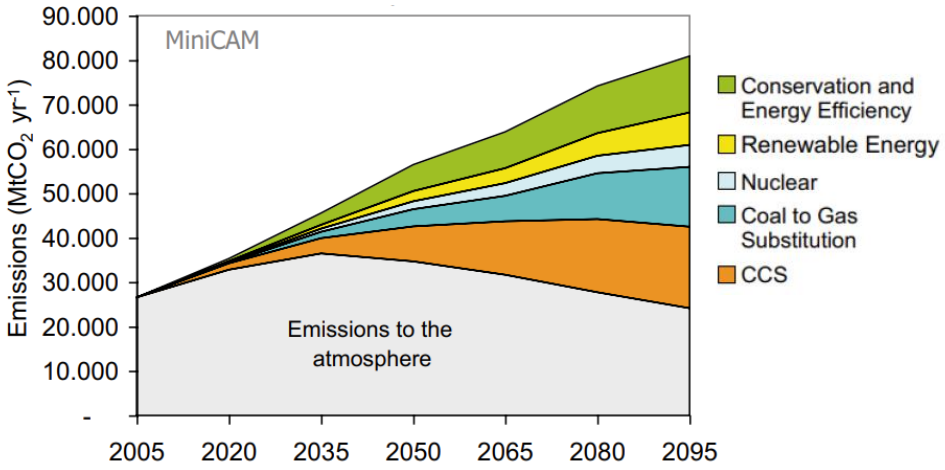
What is this all about?

Federal Register / Vol. 75, No. 237 / Friday, December 10, 2010 / Rules and Regulations

- Testing and monitoring to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure (e.g., the pressure front) by using:

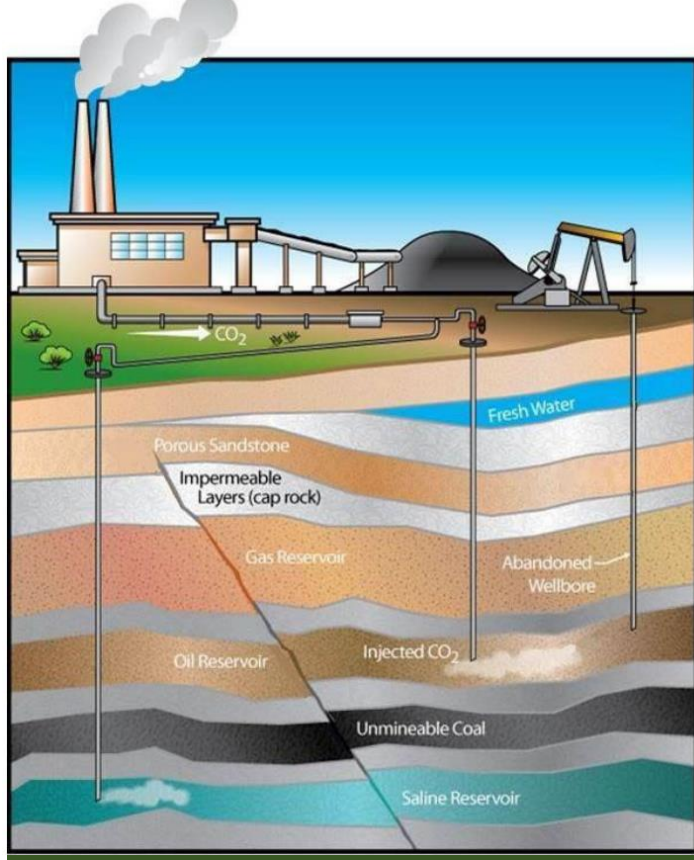
(1) Direct methods in the injection zone(s); and,

(2) Indirect methods (e.g., seismic, electrical, gravity, or electromagnetic surveys and/or down-hole carbon dioxide detection tools)



Global Estimation of CCS as part of a mitigation portfolio (MiniCAM model, courtesy of IPCC)

- CCS provides the largest individual contribution to Paris Agreement Net zero goals
- To get there we need about 271 'Shell Quest Sized' projects every year for next 28 years!!!
- Plume front needs to be mapped and induced seismic events mitigated
- Geophysical Technologies need to be LOW-COST and LONG-TERM



Carbon Capture & Storage (CCS), image: epa.gov

There is a Need for Permanent Surveillance of Dynamic CO2 Plumes

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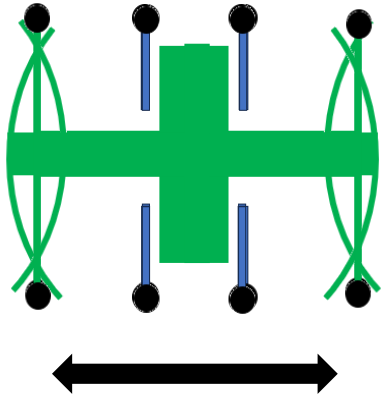
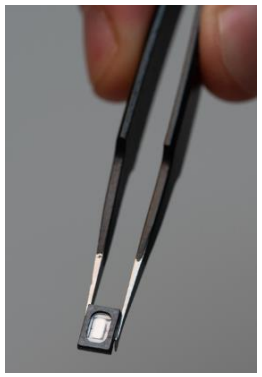
What is a MEMS Sensor?



Motion sensing via capacitance change



Tiny in size

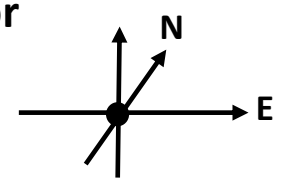
MEMS Speaker, Source: AudioXpress

Three axis motion using PCBs

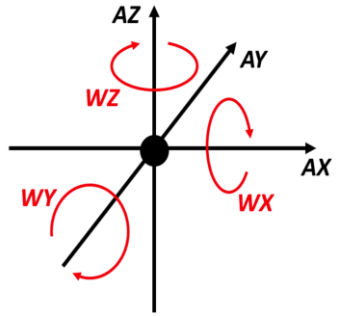
- MEMS = Micro-electro-mechanical System
- Measured mechanical motion to electrical signal
- New Seismic Sensor: accelerometer/gyroscope/magnetometer
- Silicon based materials (Perfectly Hookean)
- Etching used in manufacture
- Packaged for purpose (in this case seismic)
- Mechanical parts are smaller than 1 mm

SeismicityAlert™ MEMS sensor

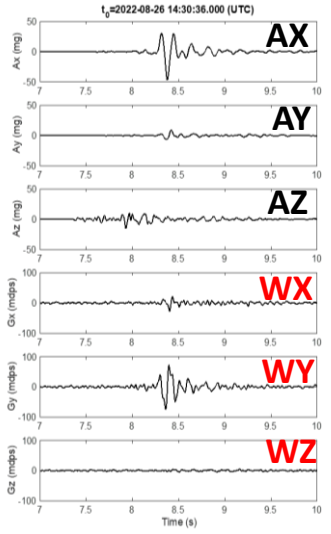
New 6C motion + 3C orientation MEMS seismic sensor sonde being deployed (1.9” diameter)



Three-Component Orientation



Six-Component Motion



What is a Surface Linear Vibrator (SLV)?

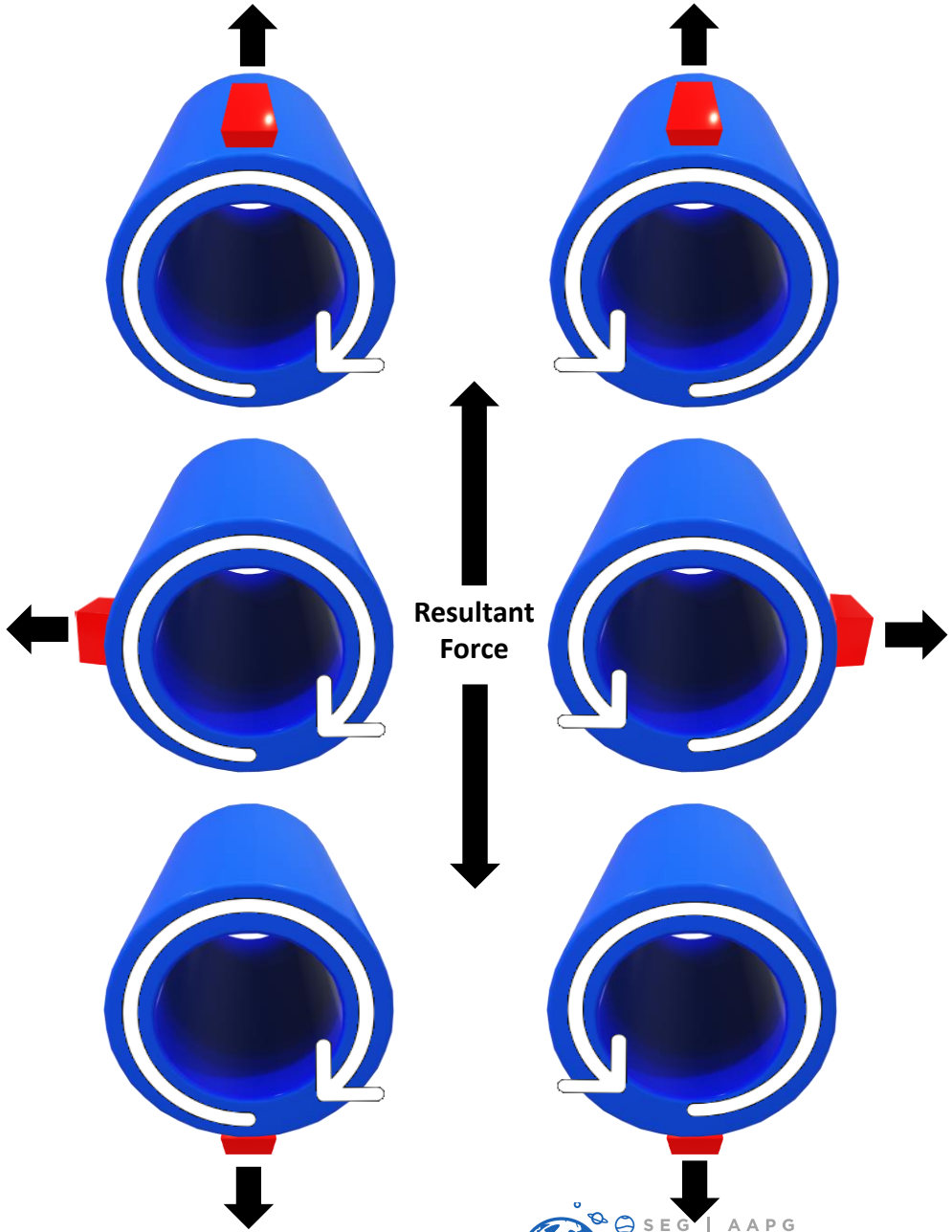
- SLV = Surface Linear Vibrator

(Not to be confused with SOV - Surface Orbital Vibrator)

- Based on eccentric weights and powered by electrical motors
- Two masses are spun in opposing directions to create linear motion
- Very high power output relative to size
- Needs to be attached (coupled) to the Earth

Decoupled with Earth shows vertical linear motion (California Test Site) 11,000lb version

Coupled with Earth All vibrations pass through (Houston Test Site) 4,200lb version

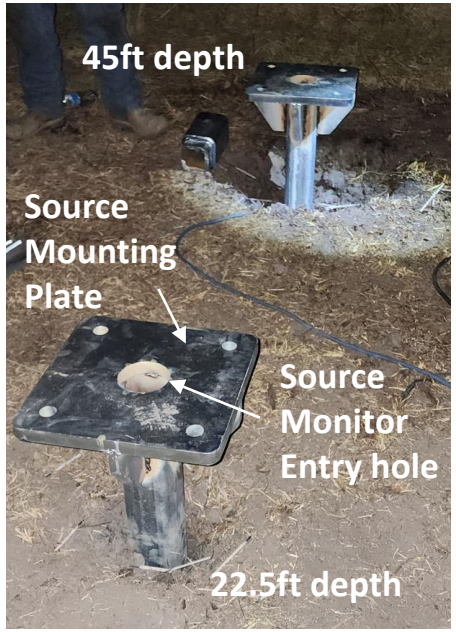


What is a Helical Anchor?

- Helical Pile – high compressional strength
- Helical Anchor – high compressional & tensional strength
- Used all over the world by civil engineers
- Screwed in to required depth or max torque strength of steel
- Over 100ft depth is possible
- Earth coupling of source in Land, river, lake, swampland environments
- Very small footprint

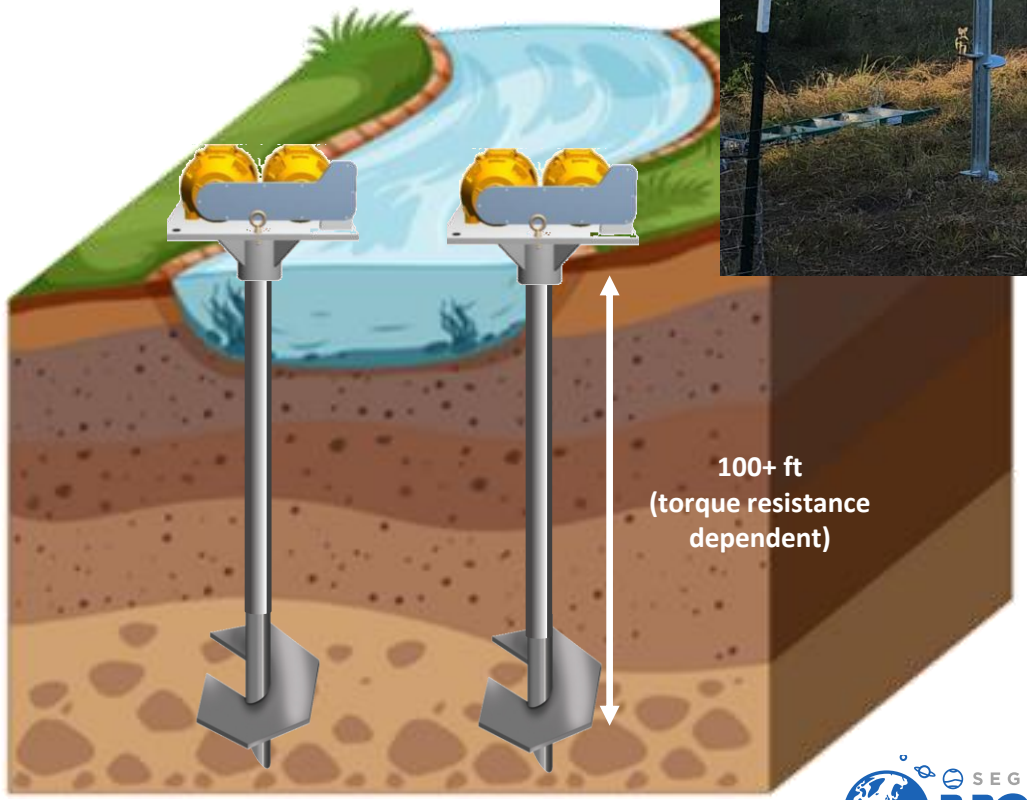
Anchors are used for foundations and other engineering support problems
Image: Ox Foundation Solutions

Anchors are commonly deployed on land and in shallow waters
Image: Alpha Anchor & Pile



Two helical anchors installed at our Houston test site in August 2023.
(Installed in a few hours)

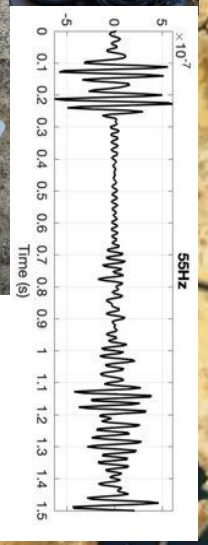
Helical Anchor Installation at Test Site

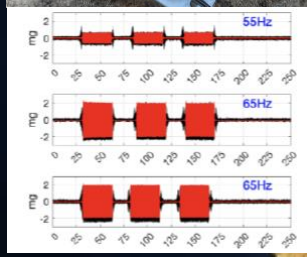


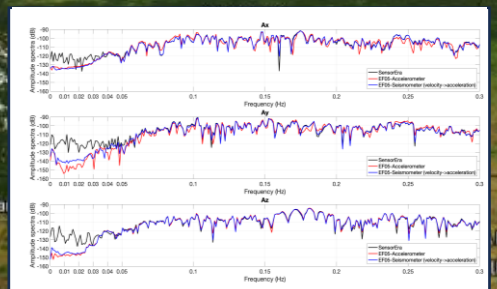
MEMS (and low frequency geophone) Sensor Field Testing

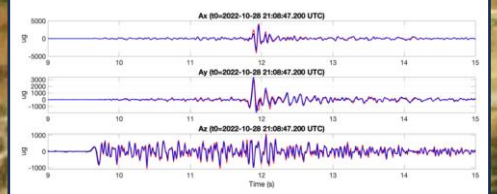
September 2022
Paso Robles Site

- 500 Acres
- SLV testing
- Natural earthquake monitoring
- StarLink Comms test
- 9 stations
- 1 x Source







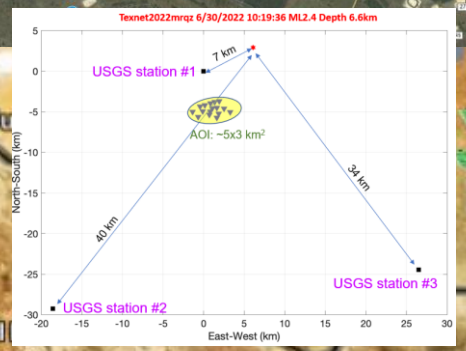


August 2022
Midland Basin

- Induced Seismic Monitoring
- Comparison with Seismometers
- 4 stations

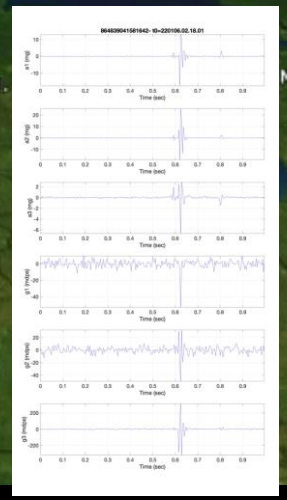
June 2022
Eagle Ford

- Frac Monitoring
- Depth tests
- Rapid Deployment
- Reprocessing of TexNet events with dense array
- 16 stations



August 2023
New Houston Site

- SLV testing
- Autonomous Power
- 8 seismic stations
- Hollow helical anchors
- Full remote control

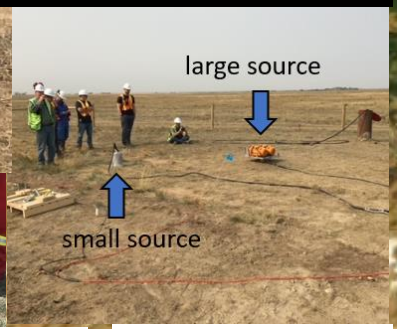


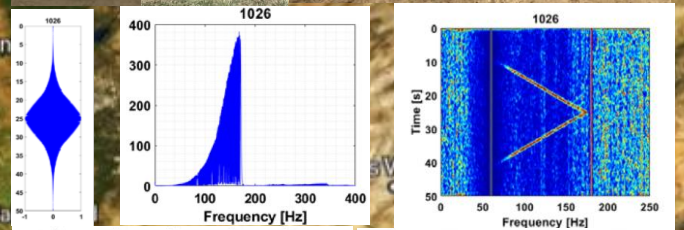
January 2022
Moss Bluff Salt Dome

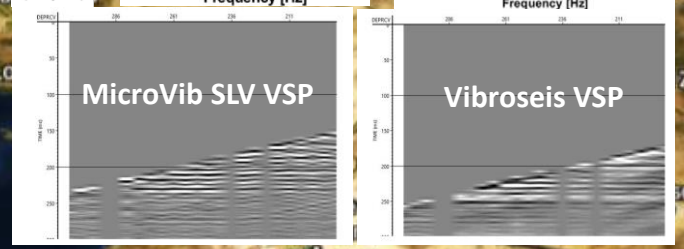
- Ground Coupling Tests
- 6C Motion Observed
- 9 Stations

SLV Seismic Source Field Testing

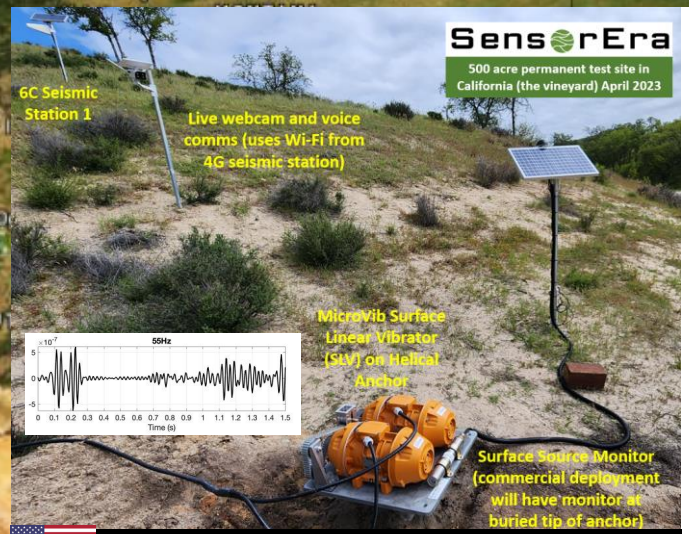
CaMI **Vibroseis Comparison**
(Carbon Management Canada)
published 2018



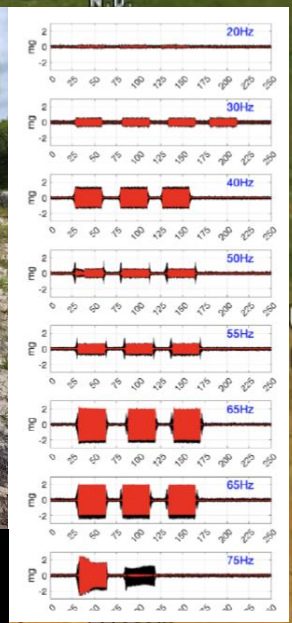




Ref: Spackman & Lawton, *Processing and analysis of data recorded from a buried permanent seismic source,* 2018, CREWES Research Report — Volume 30

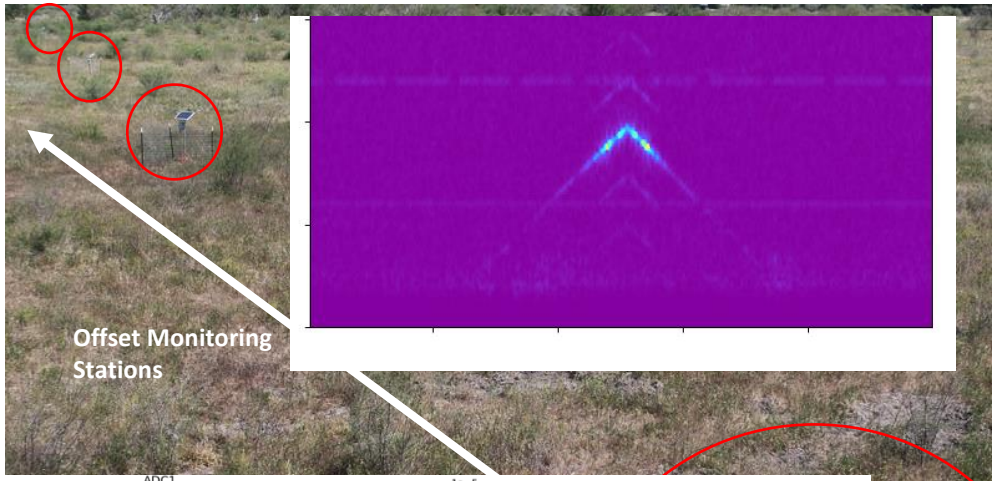


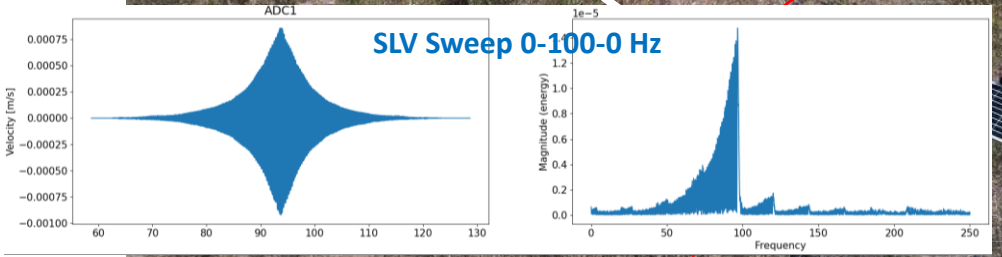
Private test Site California
Signal Tests April 2022

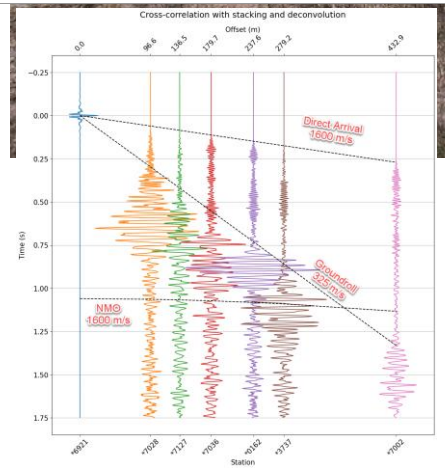


New Houston Test Site
August 2023
Remote Controlled Sweep Tests with Autonomous Power

Houston (Needville) New Test Site Data

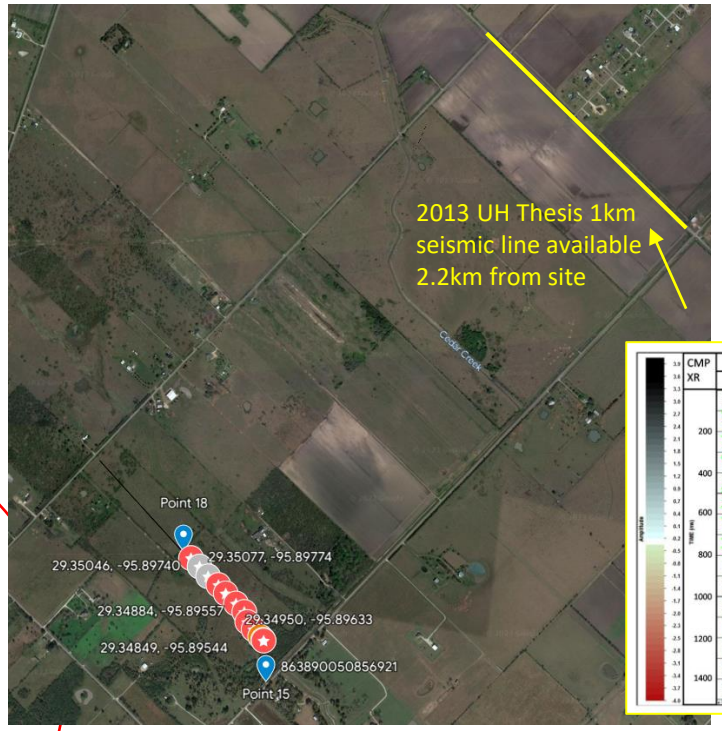


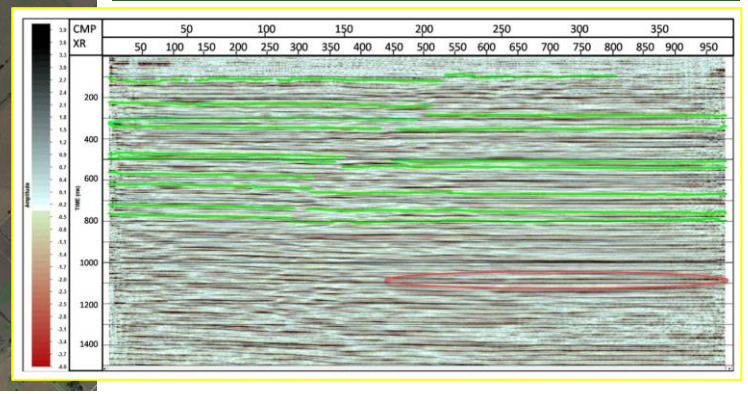




Sensor Data (time)

SensorEra test-site 100Hz sweep
Stack of approx. 80 sweeps
Early morning (lower noise)





Private Test Site:

- Visits available on request
- Full solar-powered-seismic
- Remote testing
- Off-grid
- Source testing ongoing

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Technology Required for Remote Operations

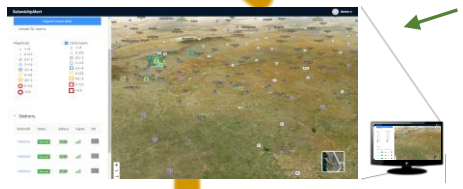
Control IoT sources and receivers via cloud

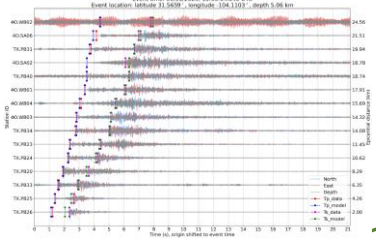
Plume Front and Seismic Events

Start the SLV Source Remotely

Raw Data

Lets try that new sweep!





Always On Power Supply

4G Booster Stations

G-PowerStation

Remotely Controlled Solar Seismic Sources, below weathering layer

IoT Solar Seismic Stations (buried sensors)

Wi-Fi Booster Stations

Vibrations from below weathering layer

Plume growth & Induced Seismic

Suitability for Plume Front Mapping and ISM

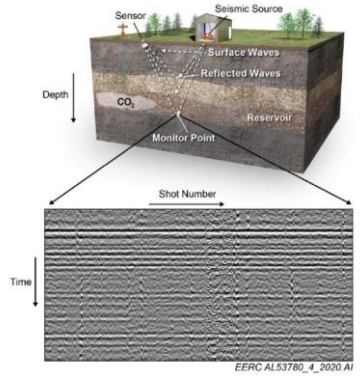
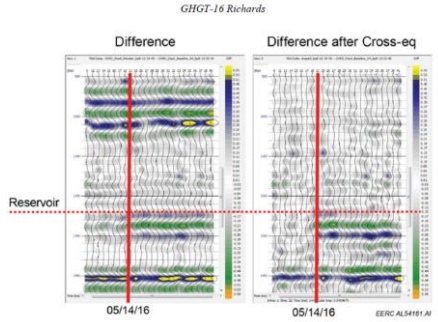


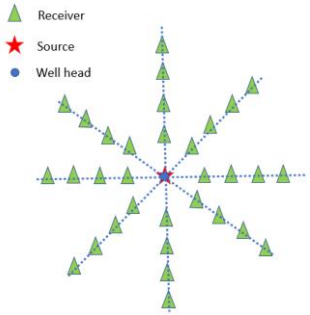
Fig. 8. Generalized SASSA surface design from Bell Creek oil field, Montana, USA.

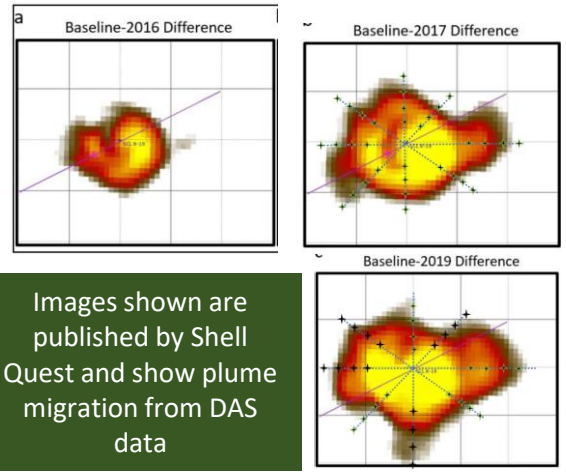


Proven technology demonstrated by EERC from a DOE sponsored project (2016):

- Forty-one sets of data were successfully acquired
- Ambiguity in identifying changes due to CO2 exists mostly because of acquisition noise levels
- Future iterations and technology advances will likely produce significant improvements and efficiencies.

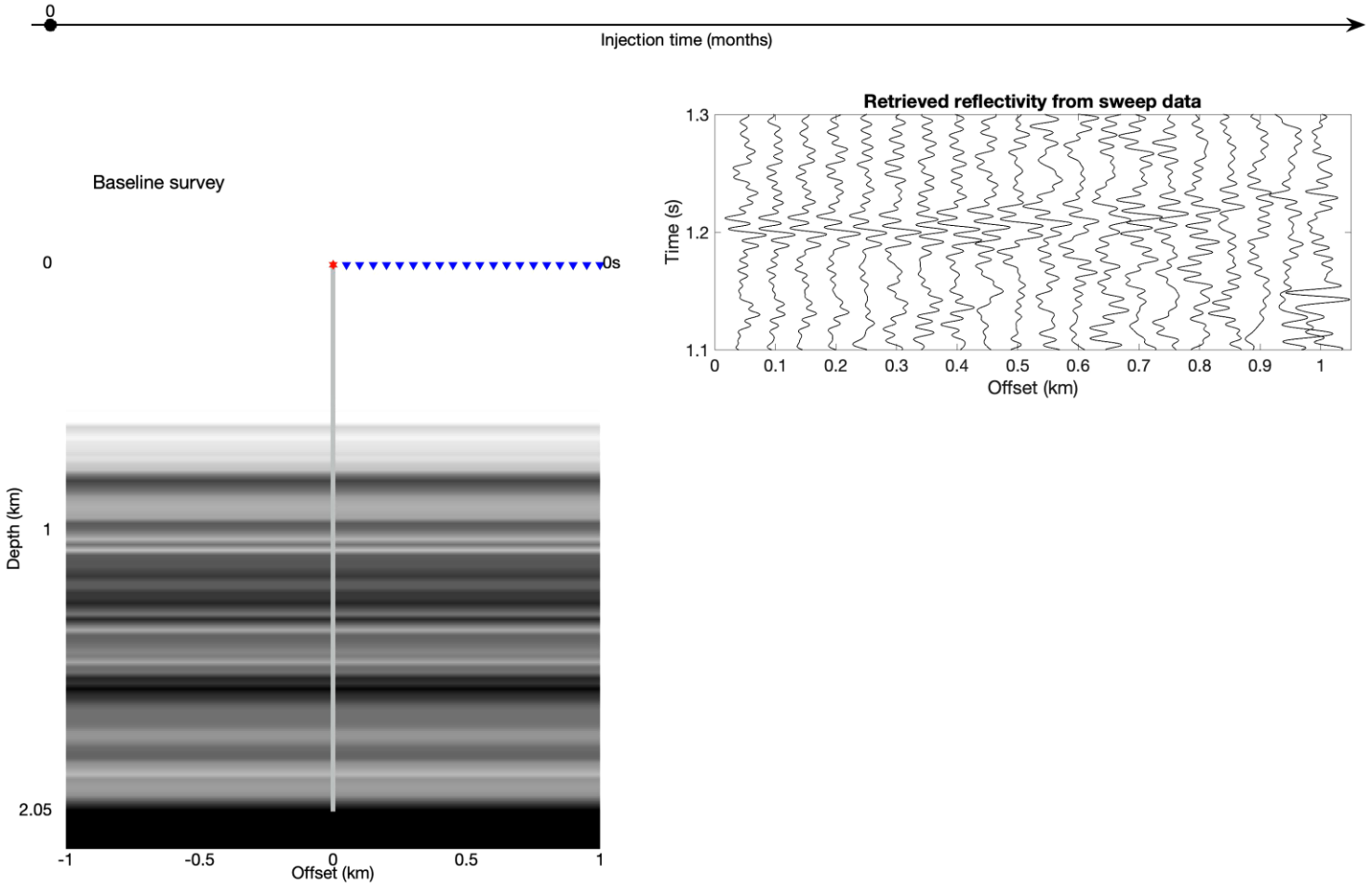
Ref: https://www.osti.gov/servlets/purl/1413495





Images shown are published by Shell Quest and show plume migration from DAS data

Superimposed are suggested source and receiver locations for sparse seismic mapping of the plume using SLV and low-cost autonomous seismic stations



SLV with low-cost receivers for on demand daily seismic surveys. By keeping sources and receivers fixed and remotely operated, the only dynamic change is the movement of the injected CO2 plume. The plume can be mapped by analyzing the seismic reflection at the same depth point

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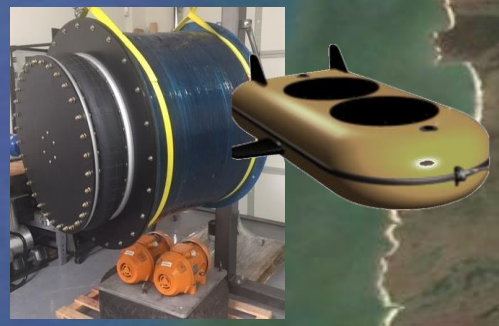
Challenging CCS Environments – Seismic Flexibility

Shallow 'Solid' Waterbed

Waterproof Vibrating Source Tie-back power

Hold-Down

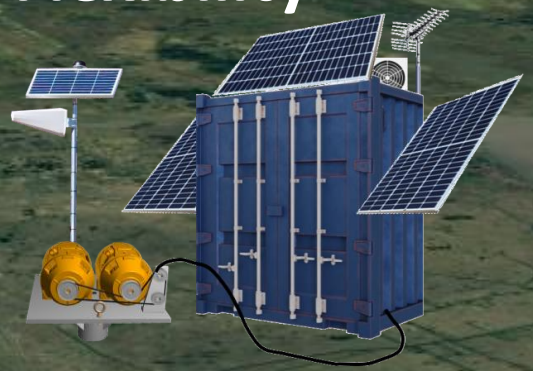


GPUSA's Marine Vibrator (offshore CCS)

- 10 Hz-100Hz (on hold to concentrate on a lower frequency model)
- 0.5 Hz to 5 Hz - currently under development and testing with a private company. Ocean testing is scheduled for Q2 – 2024

LAND

Autonomous 6C Seismic Receivers down to 0.03Hz
Low frequency/high sensitivity Geophone

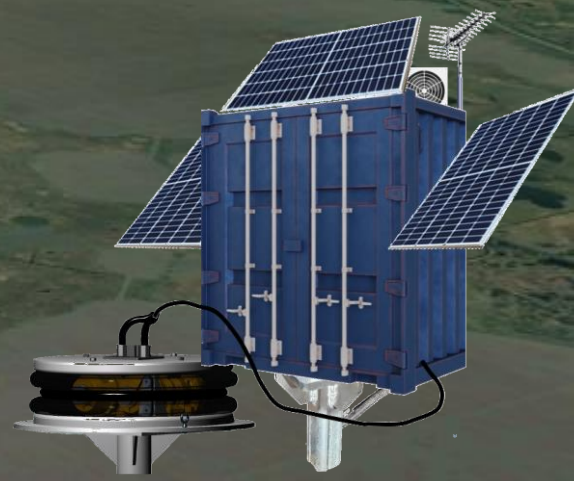


LAND

Autonomous SLV on Helical Anchor
Deep receivers at base of anchor

RIVERS/LAKES/SWAMPS

Waterproof SLV Enclosures Vibrating Source on helical anchor
G-PowerStation on helical anchor



RIVERS/LAKES/SWAMPS

Deep seismic sensors in anchors
Anchors as additional source locations

SensorEra & GPUSA Autonomous Sources and Receivers

Conclusions and Wrap Up

- We have demonstrated a low-cost, simple and repeatable solution using fit-for-purpose seismic stations and autonomous remotely operated seismic sources
- Sensors have been verified against seismometers
- Sources have been verified against vibroseis but ongoing tests are required
- The source-receiver solution is immune to weathering layer changes and environmental effects due to sources and receivers being permanent, Cloud-controlled and below weathering layer
- Low-cost off-grid IoT solar-powered sources and receivers can address the MMV requirements for CCS Plume mapping and induced seismicity concerns
- Suitable for land, swamp, marshland, lakes & rivers (offshore marine vibrator source option)

More questions?
More detailed discussion available at IMAGE booth #903

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