All-digital Sensor System for Distributed Downhole Pressure Monitoring in Unconventional Fields

DE-FE0031781

Investigators:

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DOE/NETL Project Kickoff Meeting, WebEx, October 4, 2019

Outline

- Project Elements/Overview
- Introduction and Technical Background
- Project Objective
- Key Personnel, Roles and Responsibilities
- Technical Approaches
- Scope of Work and Milestones
- Data Analytics/Machine Learning (DA/ML)
- Project Management Plan
- Risk Management

Project Elements/Overview

- **Awarded under DOE DE-FOA-0001990 - AOI 1A - Improving Ultimate Recovery from Unconventional Oil and Gas Resources**
- **Interdisciplinary team between two universities and an industry partner**
  - Clemson University (Lead)
  - University of Oklahoma (Subcontractor)
  - Quest Drilling Facilities LLC (Subcontractor)
- **Three-year project started on Oct. 1, 2019**
- **Total project budget: $1,750,000 ($1,500,000 from DOE and $250,000 from the participants as costshare)**

Background

- **Unconventional Oil and Gas (UOG) developments**
  - Became possible and profitable due to technological advancements such as extended-lateral horizontal drilling and multistage high-volume hydraulic fracturing
  - Has dramatically increased U.S. production of oil and natural gas
  - Are projected to contribute 70.1% of total U.S. oil production and 76.1% of total U.S. natural gas production in 2050 (EIA's 2018 Annual Energy Outlook)
  - Are extremely cost sensitive and marginally economical in many instances
  - Have low recovery efficiency (20% in gas-rich shale reservoirs and less than 10% in liquid-rich plays)
- **Technology advancements to recover UOG resources are critical in maintaining future U.S. oil and gas production levels.**

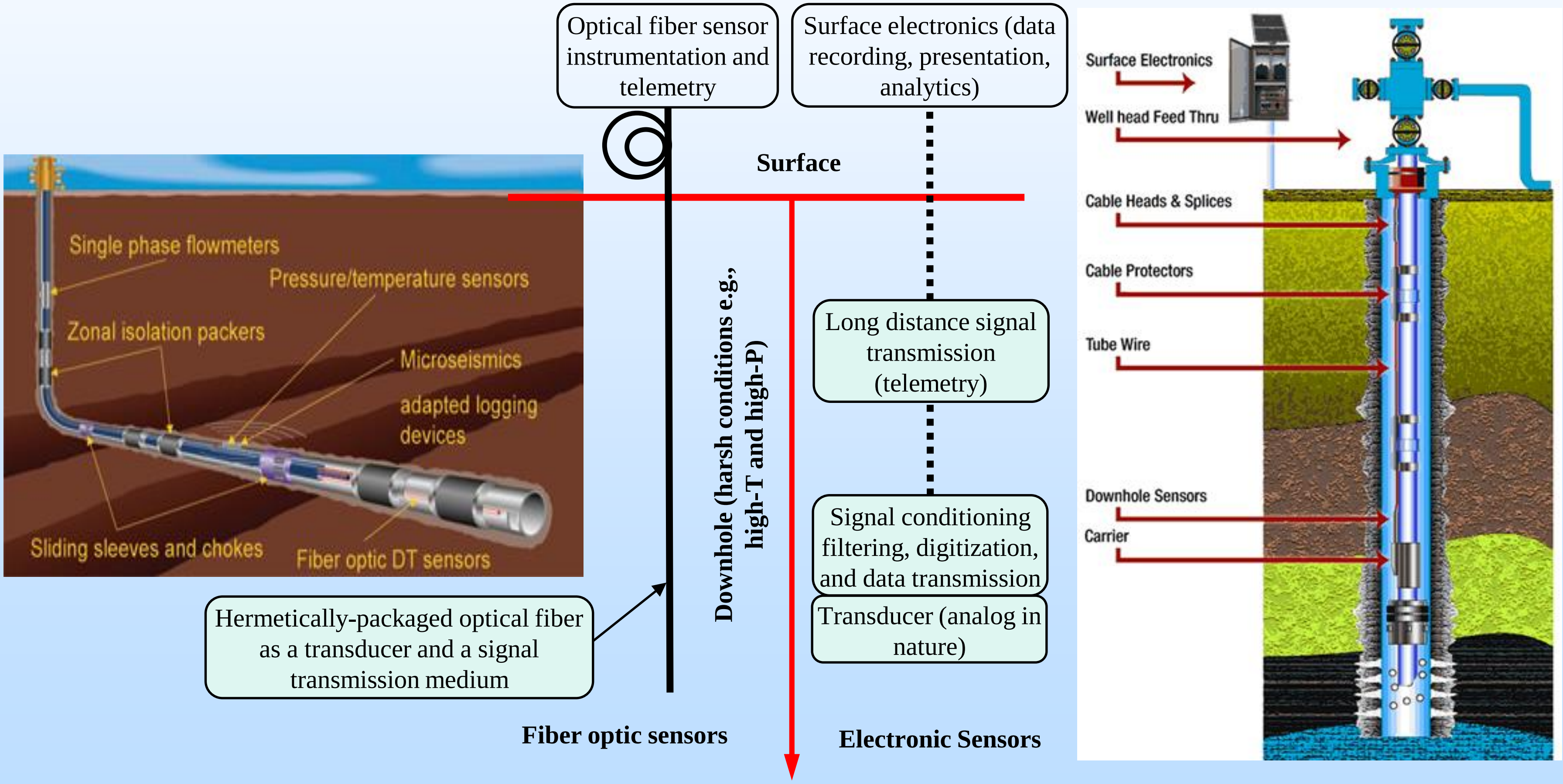
Pressure Monitoring for UOG

- **Permanently-installed distributed downhole pressure sensors would**
  - Monitor fracture propagation
  - Assess the overall effectiveness of hydraulic fracturing
  - Optimize hydraulic fracturing placement
  - Increase the recovery efficiency

- **However, downhole distributed pressure sensors are too costly (>$100k per well)**

Existing Downhole Sensing System

- **Two general types of sensing systems**
  - Electronic sensors: point sensing, need downhole electronics, drift and costly
  - Fiber sensors: distributed, no downhole electronics, drift and costly



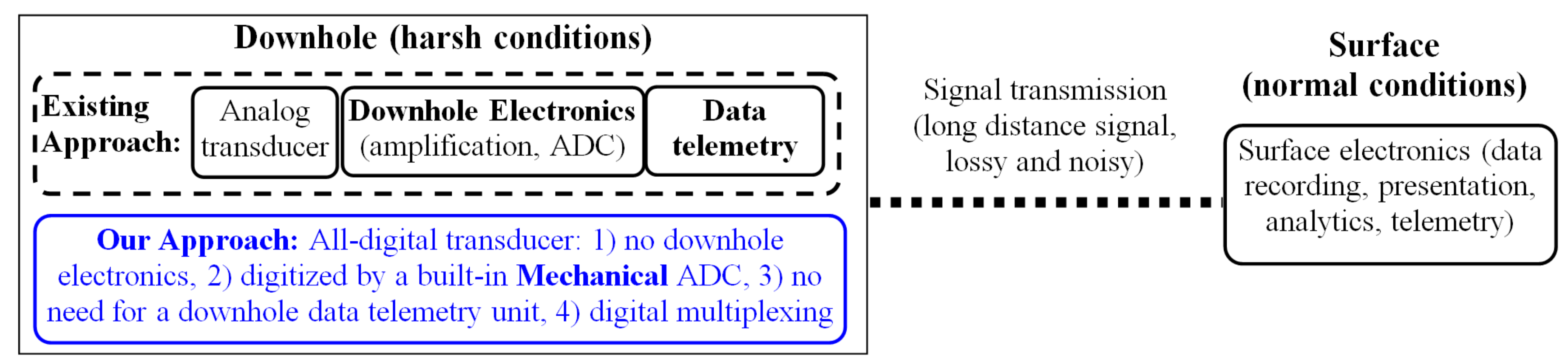
Why High Cost?

- **Fiber sensors**
  - Optical fibers are intrinsically insensitive to pressure (unlike temperature and strain), so special fiber sensor devices need to be designed, fabricated and packaged
  - Need rigorous packaging of the fragile optical fiber cable

- **Electronic sensors**
  - Rigorous packaging and high temperature electronics to battle errors and drifts of transducer materials, circuits, and the sensor structures
  - Lack of multiplexing capability
  - Complicated and specialized data telemetry from downhole to the surface

Proposed Solutions

- **Do we really need downhole electronics?**
- No, if we have an all-digital sensor, which has built-in nonelectronic amplification and the nonelectronic analog to digital converter (i.e., a mechanical ADC)
- A digital signal can be transmitted over a much longer distance than an analog signal
- Multiple digital sensors can be multiplexed together



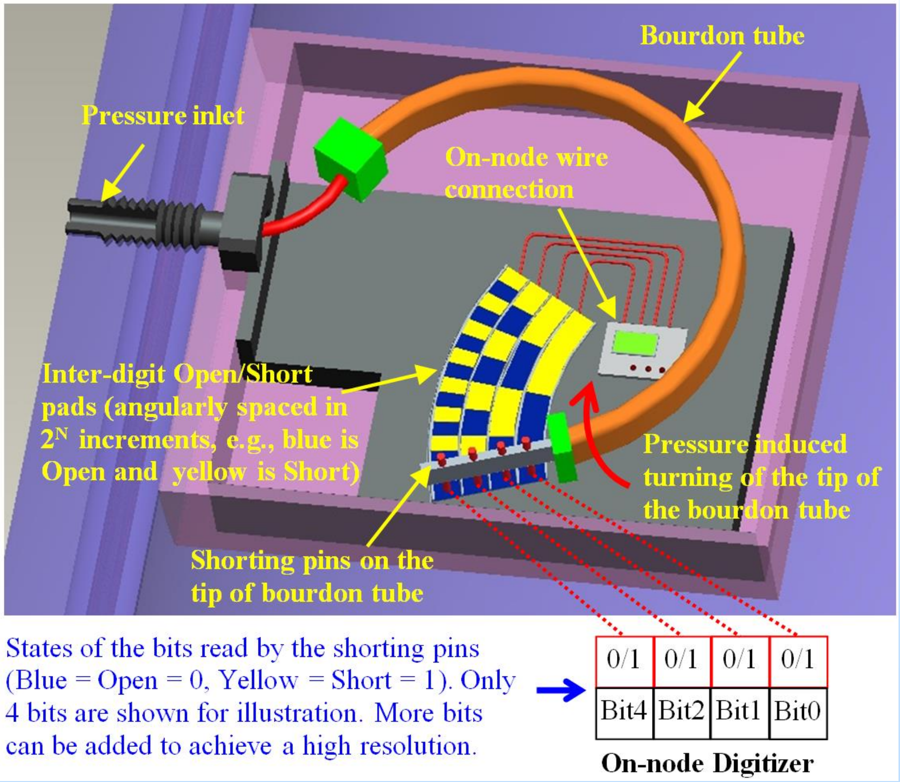
An Example Design

- **A bourdon tube as the sensing element**
- **Shorting pins mounted at the coil tip to touch a coding pad at the bottom as the bourdon tube rotates**

blue = "open" = digital "0"
yellow = "short" = digital "1"

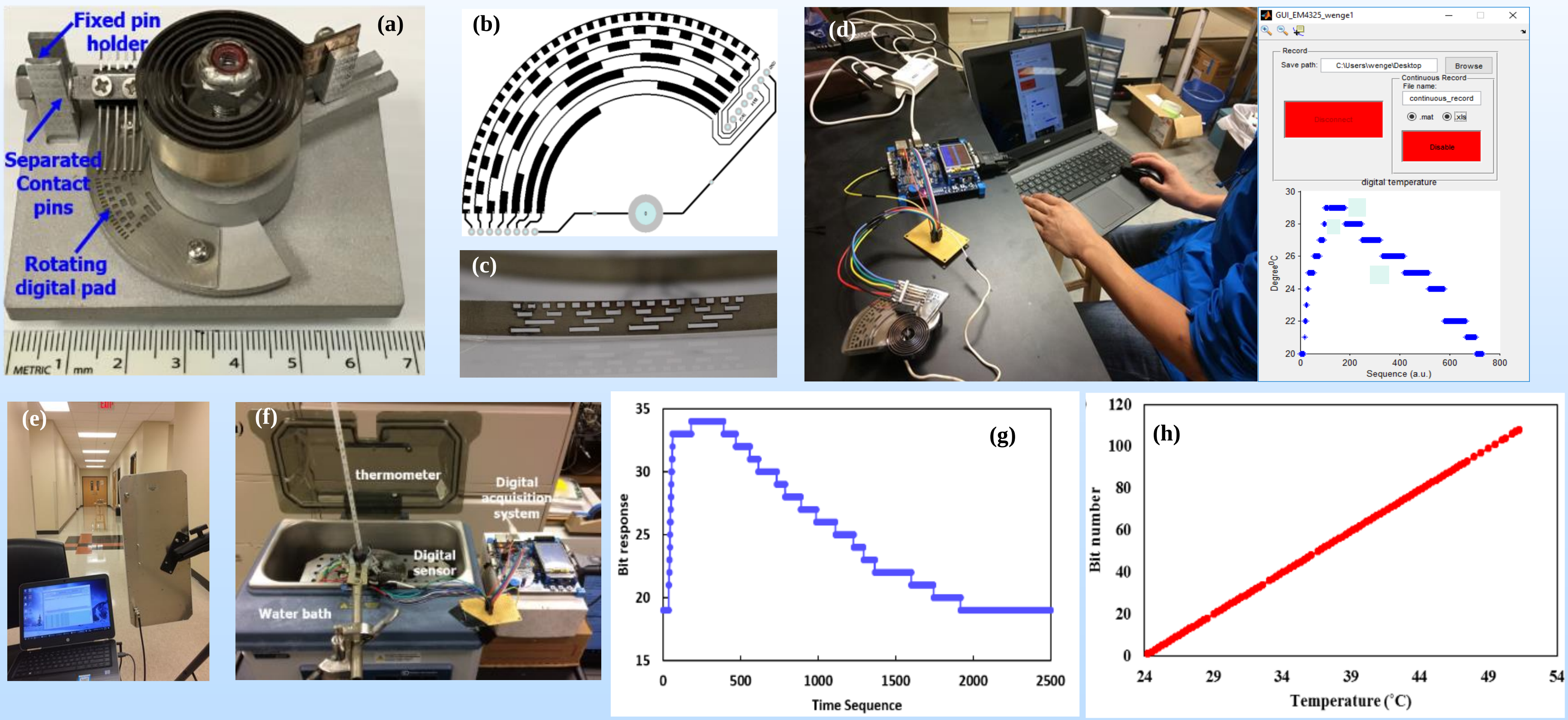
Advantages for downhole sensing

- High-temperature and high-pressure capability
- Low-cost implementation
- Multiplexed for distributed sensing
- Reliable digital signal transmission over a long distance
- The all-digital platform can be modified to measure other downhole parameters such as temperature and acoustic



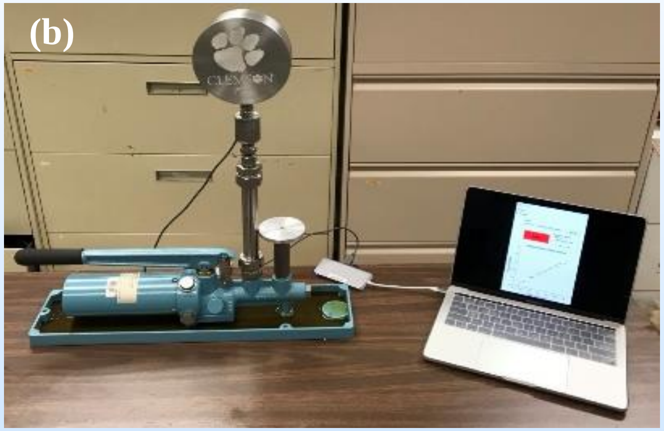
All-Digital Temperature Sensors

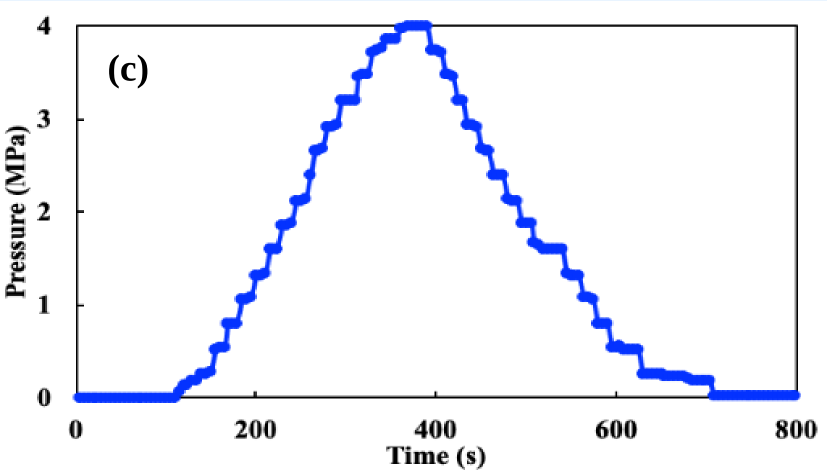
- A bimetallic coil that rotates when the environmental temperature changes
- Digital pad with open/short codes, with 10 bits to resolve 0.1%
- Passive RFID reading to allow battery-less and wireless operation



All-digital Pressure Sensors

- Bourdon tube as the pressure sensing element
- Stainless steel digital pad with 8-bit binary coding
- Tested and showed excellent response to pressure





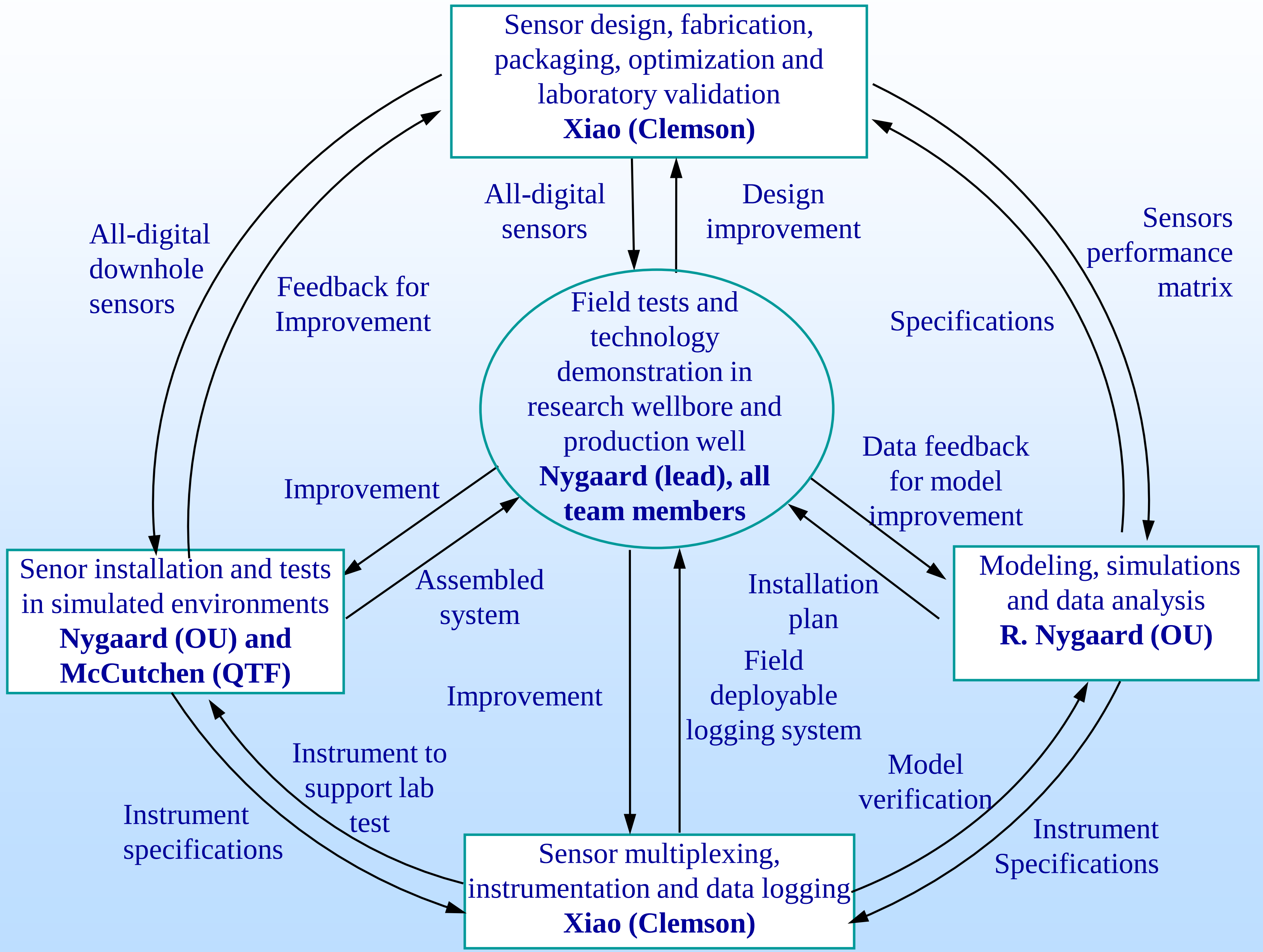
Objective

- **The main objective is to develop and validate a low-cost all-digital sensing technology for distributed downhole pressure monitoring in UOG fields.**

The Team

- **Hai Xiao (PI)**
  - Professor, Electrical Engineering, Clemson University
  - Sensors and instrumentation
- **Runar Nygaard (Co-PI)**
  - Professor, Petroleum Engineering, University of Oklahoma
  - Drilling, simulation, testing and data analysis
- **Brian McCutchen (Co-PI)**
  - Operation Manager / Owner, Quest Test Facility LLC
  - Drilling and sensor deployment
- **Svein Hellvik (Senior Personnel, Industry Advisor)**
  - Senior Advisor New Technology Development, Engineering / Wellbore Technologies, National Oilwell Varco (NOV)
  - Drilling and well instrumentation

Roles, Responsibilities and Collaborations



Scope of Work

- **Three Budget Periods**

Budget Period I (12 months): Design, fabricate, package and validate of the all-digital pressure sensors.

Budget Period II (12 months): Develop and test time domain reflectometry (TDR) based sensor multiplexing technology, fabricate and validate the prototype sensors and instrumentation through pilot tests.

Budget Period III (12 months): Conduct a field test in a production well to demonstrate and confirm the performance of the proposal new distributed downhole pressure monitoring technology.

Technical approach

- **Sensors:** Design, engineer, fabricate, package and test/validate the all-digital pressure sensors to operate in harsh downhole environments with desired performance

- **Instrumentation:** Develop and test/validate TDR based sensor multiplexing methods for distributed pressure sensing

- **Pilot test and validate** the prototype sensors and instrumentation in research wellbores

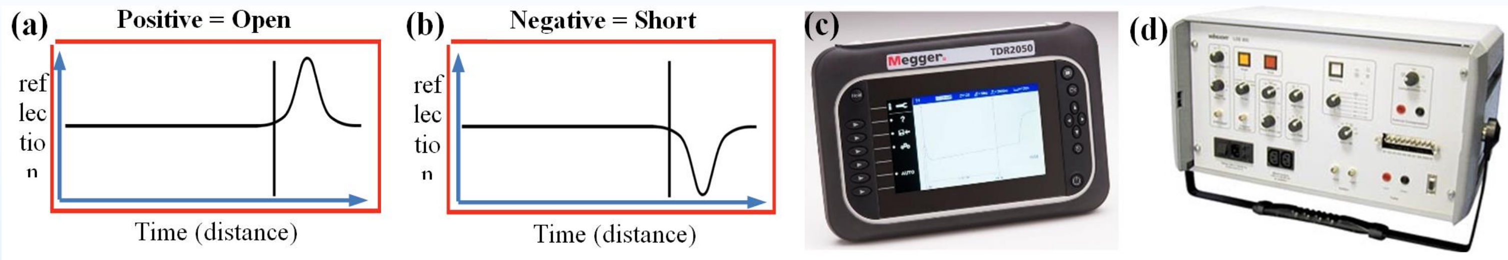
- **Field test and validate** the integrated all-digital pressure monitoring system in a production well

Engineer the Sensors

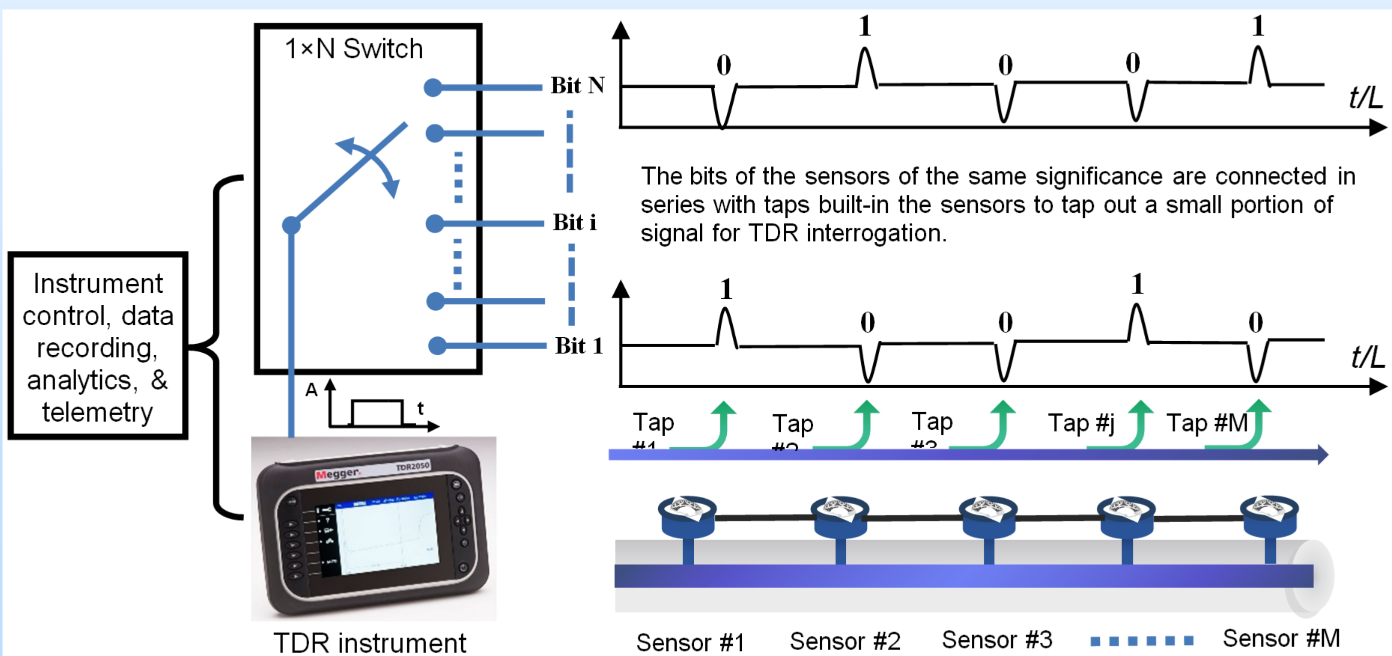
- **All metal design to survive high temperatures and minimize drift**
- **Stainless steel digital pad, ball head contact needles, and guiding grooves to minimize temperature dependence and sustain vibrations/shock**
- **Reduce the footprint of the sensor**
- **Hermetical metal packaging and sealed cable access**
- **Auxiliary coding mechanism to achieve high resolution in a high-pressure background**

Instrumentation

- **TDR-based Remote Sensor Interrogation**



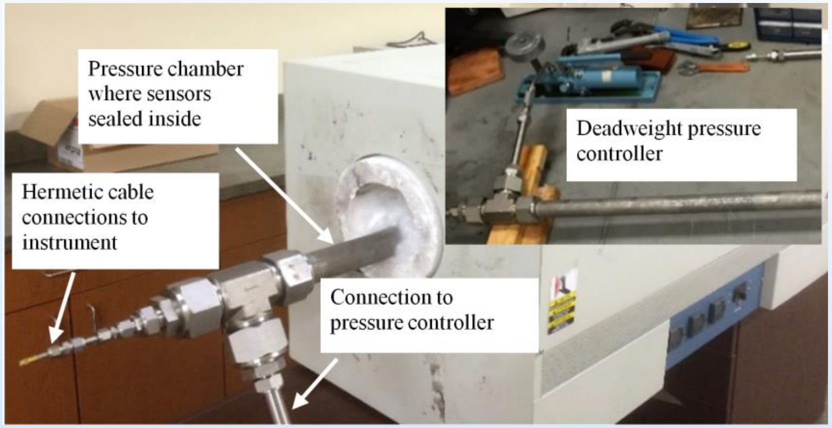
(a) and (b) Typical TDR signals for open and short of the cable, respectively; (c) and (d) pictures of the TDR 2050 (TDR instrument) and LDE800 (booster), Megger Group Limited, respectively.



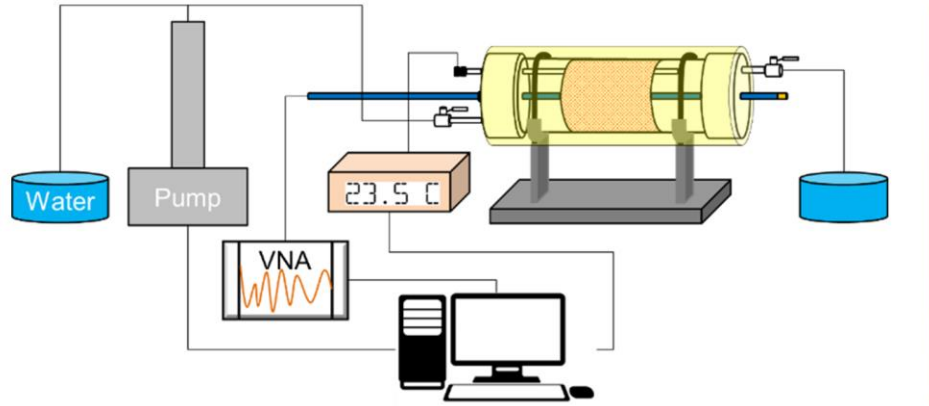
Laboratory Tests

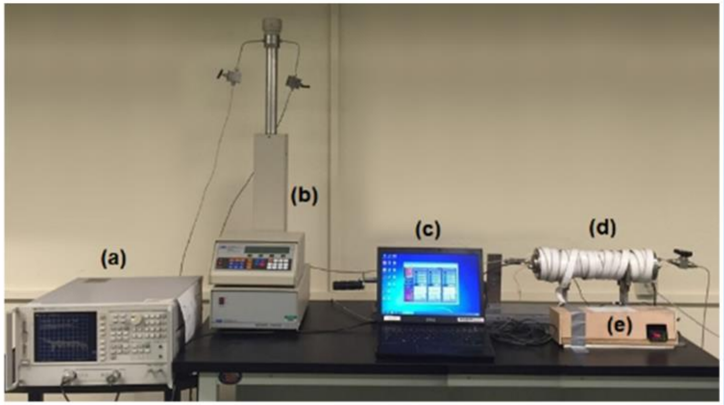
- **Test the prototypes in a simulated downhole environment**
  - At high temperature (up to 250°C)
  - At high pressure (up to 10,000 psi)

Sensor performance test facility available Clemson. The 6-foot long, 3-section furnace with a test chamber can test sensors at a simulated high temperatures and high pressure (up to 5,000psi) environment.



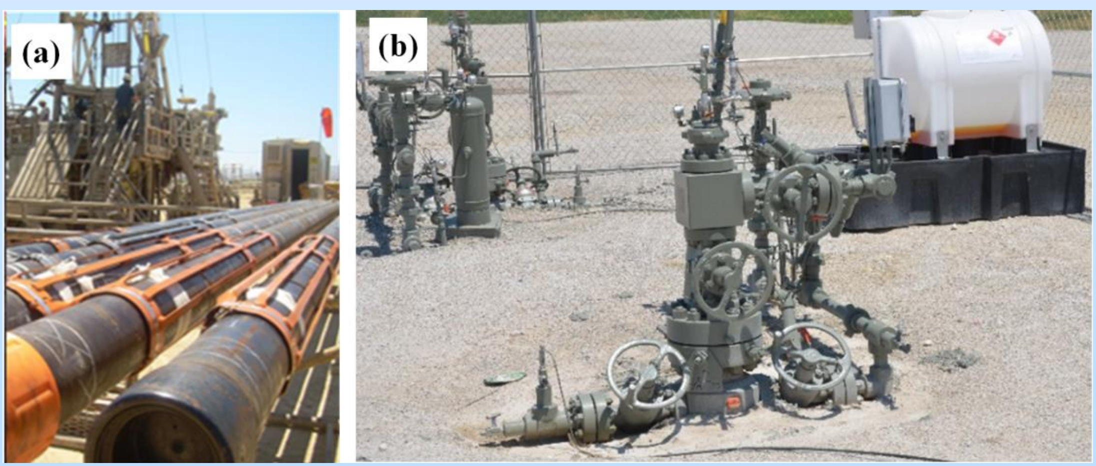
Schematic and photograph of the HPHT temperature sensor testing system at OU which can tests sensors up to 10,000 psi.





Tests in a Research Wellbore

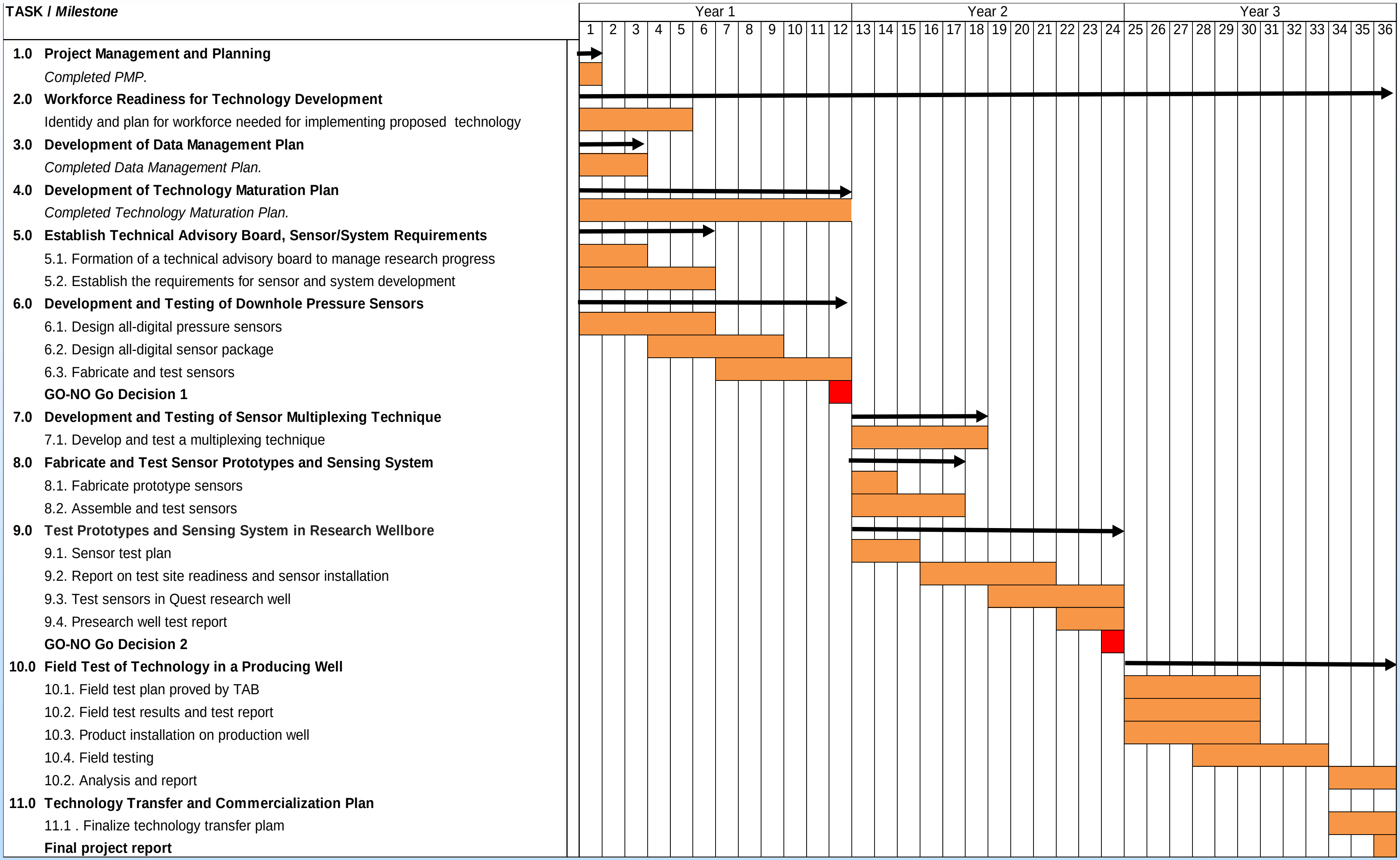
- **Two steps: 450 ft and 3,000 ft**
- **Wells drilled by Quest Test Facility in Payne county, OK**
- **Performance parameters**
  - Survivability: Meaningful outputs are generated continuously from the installed sensors
  - Multiplexing capability: At least 5 sensors are multiplexed
  - Reaching distance: 3,000 ft downhole
  - Pressure resolution: 0.2% of its full scale
  - Pressure sensor stability (drift)



Field Tests

- **Further testing in production or R&D wellbores**
  - Fairway Resources or other OK operator production wells
  - University of Oklahoma R&D drilling wellbores
  - NOV R&D drilling site in Burton, TX
- **Testing down to 10,000 ft. total well depth**
- **10 sensors multiplexed**

Gantt Chart


TASK / Milestone
Year 1
Year 2
Year 3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
1.0 Project Management and Planning
Completed PMP.
2.0 Workforce Readiness for Technology Development
Identidy and plan for workforce needed for implementing proposed technology
3.0 Development of Data Management Plan
Completed Data Management Plan.
4.0 Development of Technology Maturation Plan
Completed Technology Maturation Plan.
5.0 Establish Technical Advisory Board, Sensor/System Requirements
5.1. Formation of a technical advisory board to manage research progress
5.2. Establish the requirements for sensor and system development
6.0 Development and Testing of Downhole Pressure Sensors
6.1. Design all-digital pressure sensors
6.2. Design all-digital sensor package
6.3. Fabricate and test sensors
GO-NO Go Decision 1
7.0 Development and Testing of Sensor Multiplexing Technique
7.1. Develop and test a multiplexing technique
8.0 Fabricate and Test Sensor Prototypes and Sensing System
8.1. Fabricate prototype sensors
8.2. Assemble and test sensors
9.0 Test Prototypes and Sensing System in Research Wellbore
9.1. Sensor test plan
9.2. Report on test site readiness and sensor installation
9.3. Test sensors in Quest research well
9.4. Presearch well test report
GO-NO Go Decision 2
10.0 Field Test of Technology in a Producing Well
10.1. Field test plan proved by TAB
10.2. Field test results and test report
10.3. Product installation on production well
10.4. Field testing
10.2. Analysis and report
11.0 Technology Transfer and Commercialization Plan
11.1 . Finalize technology transfer plam
Final project report

Deliverables

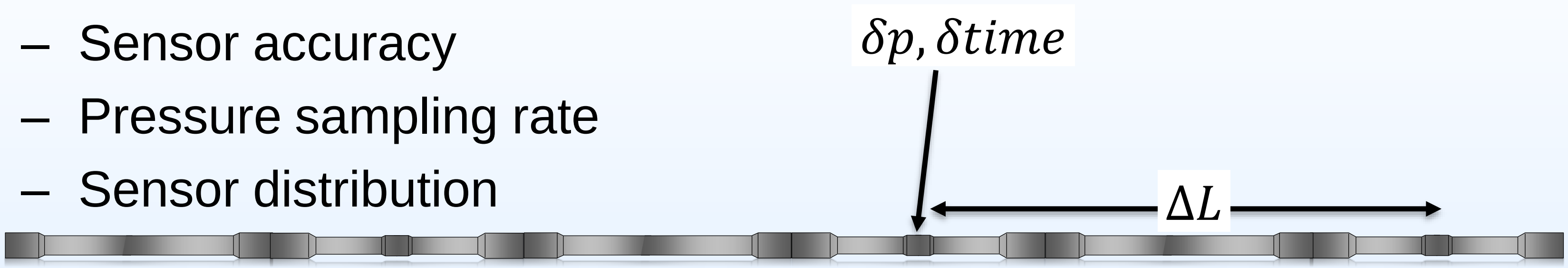
Tasks/Subtasks	Deliverable title	Due date
Task 1.0	Project Management Plan	Update due 30 days after award Revisions to the PMP shall be submitted as requested by the NETL Project Manager.
Task 2.0	Workforce Readiness Plan	The initial plan is due with the first continuation application. Subsequent updates, as necessary, are due at continuation application intervals.
Task 3.0	Data Management Plan	Due to DOE within 90 days after award and be updated as necessary throughout the project as requested by the Project Officer.
Task 4.0	Technology Maturation Plan	Due with the first continuation application. Subsequent updates to the Plan, as necessary, are due at continuation application intervals.
Task 5.0		
Subtask 5.1	Technical advisory board	Established within Q1
Subtask 5.2	Sensor and instrument specifications	WRP due 30 days after Q2
Task 6.0		
Subtask 6.1	Sensor schematics and key components test results	WRP due 30 days after Q2
Subtask 6.2	Package design schematics & test results	WRP due 30 days after Q3
Subtask 6.3	Sensor prototype laboratory test results	WRP due 30 days after Q4
End of Budget Period I, Go/No Go point. The success criteria are: the sensor has a 0.5% or better resolution, and the sensor has a drift (400 hours) less than 3% as demonstrated under laboratory simulated conditions (250^{o}C and 5,000 psi)		

Deliverables

Task 7.0	Test report on prototype instrument	WRP due 30 days after Q5
Task 8.0		
Subtask 8.1	Prototype sensors and instrument	WRP due 30 days after Q5
Subtask 8.2	Sensor and instrument test results	WRP due 30 days after Q6
Task 9.0		
Subtask 9.1	Test plan	WRP due 30 days after Q5
Subtask 9.2	Report on test site readiness and sensor installation	WRP due 30 days after Q7
Subtask 9.3	Sensor and system test results	WRP due 30 days after Q8
Subtask 9.4	Research well test report	WRP due 30 days after Q8
End of Phase II, Go/No Go point. The success criteria are 1) the system can multiplex at least 5 sensors, the reaching distance is at least 3,000ft, and 3) the pressure resolution is 0.2% or better, as demonstrated through the tests in research wellbores.		
Task 10.0		
Subtask 10.1	Field test plan proved by TAB	WRP due 30 days after Q9
Subtask 10.2	System assembled and tested	WRP due 30 days after Q9
Subtask 10.3	Report on test site readiness and sensor installation	WRP due 30 days after Q10
Subtask 10.4	Field test results and test report	WRP due 30 days after Q11
Subtask 10.5	Field test reports	WRP due 30 days after Q12
Task 11.0	Technology transfer plan	WRP due 30 days after Q12
	Final project report	WRP due 90 days after completion of project
The final project success criteria at the end of the project are: 1) the system can multiplex at least 10 sensors, the reaching distance is at least 10,000ft, and 3) the pressure resolution is 0.2% or better, as demonstrated through the tests in a production wellbore.		

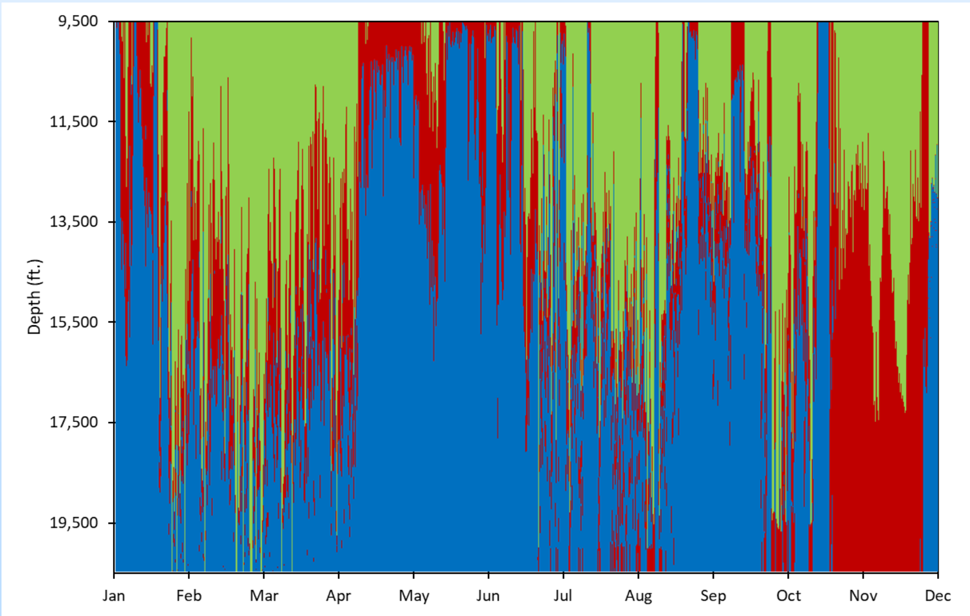
Data Analytics/Machine Learning (DA/ML)

- **Machine learning will determine**
  - Sensor accuracy
  - Pressure sampling rate
  - Sensor distribution



- **Numerical simulation of fracturing and production will create training set to establish data driven models and input to sensor design.**

Heat map of pressure variation in a horizontal oil producer in one year (synthetic data).



Data Analytics/Machine Learning (DA/ML)

Data Analytics Workflow

Sensor recording	Pre-processing	Processing	Results analysis	Data-storage
Laboratory Experimental data.	Formatting	Visual analytics	Sensor accuracy	Down sampling of data
Down hole data from field experiments.	Data-corrections	Regression analysis	System reliability	Storage of data
	Timestamping	Time series analysis		Storage of metadata
	Filtering	Anomaly analysis		

Project Management

- PI responsible for managing and coordinating the project
- Weekly meetings within research sub groups
- Bi-weekly online meetings of the entire research groups (DOE manager invited)
- Bi-Annual review meetings with industry advisory board to review progress and input on field testing

Risk Management

Technical Risks	Mitigation
Packaging and deployment of the sensors system in a harsh environment downhole.	Lab experiments and tests that take the downhole conditions into account.
Large number of sensors to be multiplexed along the same cable.	Add additional amplifiers, reduce the TDR pulse width, and monitor the phase.
Not successful installation due to wellbore construction related issues.	Extra sensors will be manufacture, which has been budgeted in this project.
Financial Risks	**Recycle or borrow cables to conduct field tests**
Schedule Risks	**Multiple sources of testing sites**
Management Risks	**Technical advisory board**

Thank You!

Questions?