Unlocking the Tight Oil Reservoirs of the Powder River Basin, Wyoming

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U.S. Department of Energy

National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
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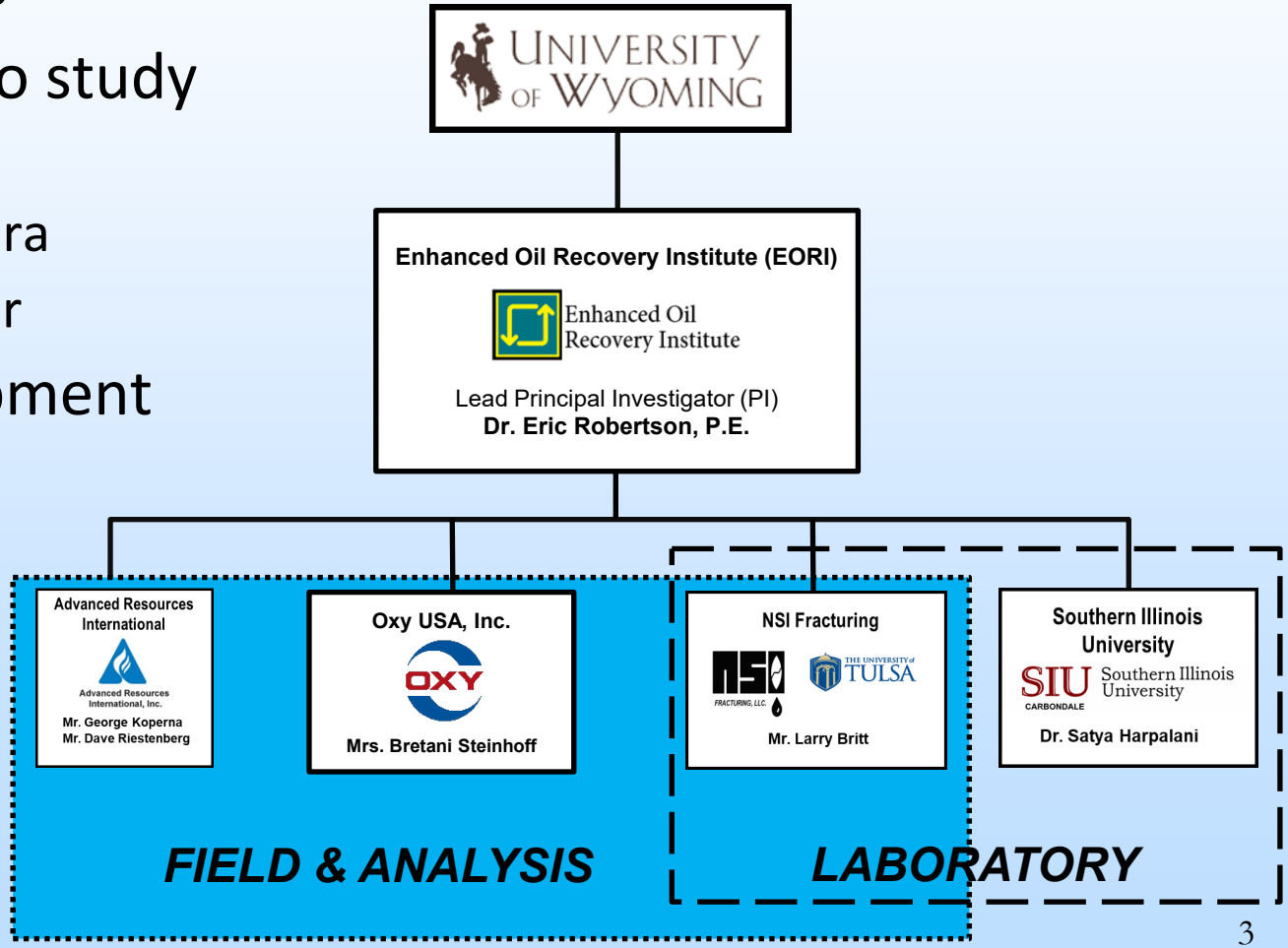
Project Funding and Dates

- Project Funding: Total of $14,898,759 for 4-year project
  - $7,833,908 in Federal
  - $7,064,850 in Industry cost share (47.42%)
- Important Project Dates
  - Project kicked-off in October 2019
  - 1-yr, no-cost technical extension granted in July 2020
  - Projected completion of the project is September 2024

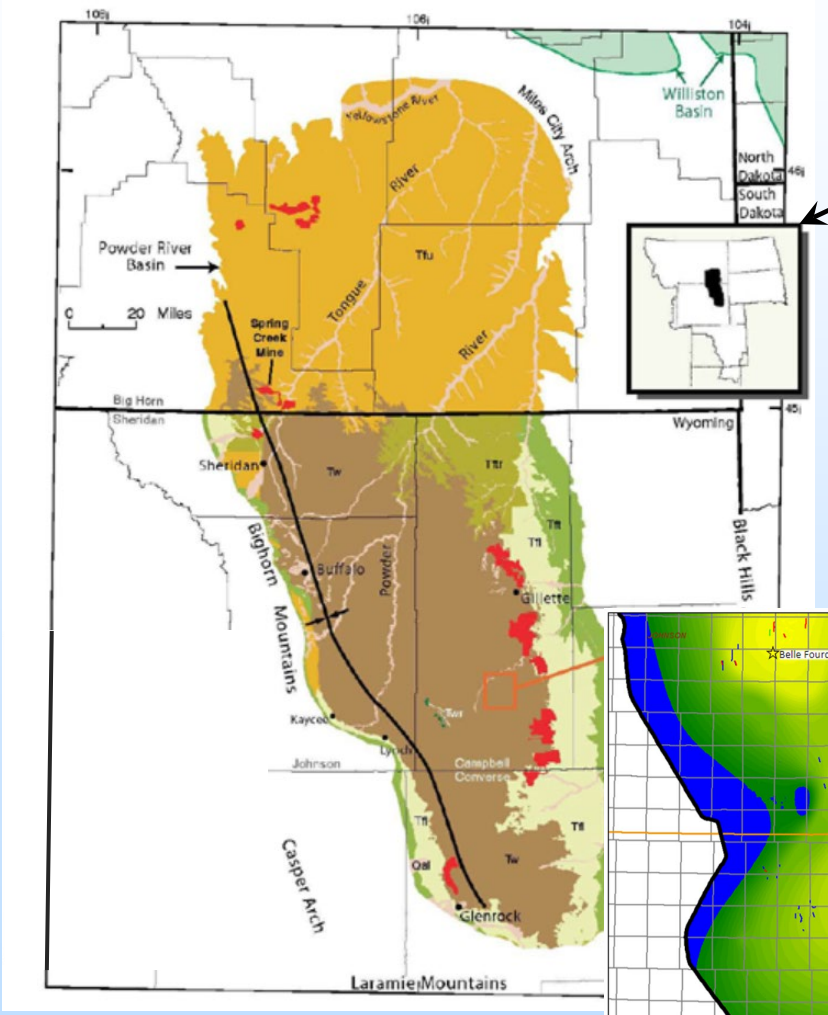
Project Objectives and Participants

- Overall Project Objectives
  - Establish field laboratory to study emerging PRB plays
    - Shale plays: Mowry, Niobrara
    - Tight sands: Turner/Frontier
  - Create basin-wide development strategy plan
- Project Participants



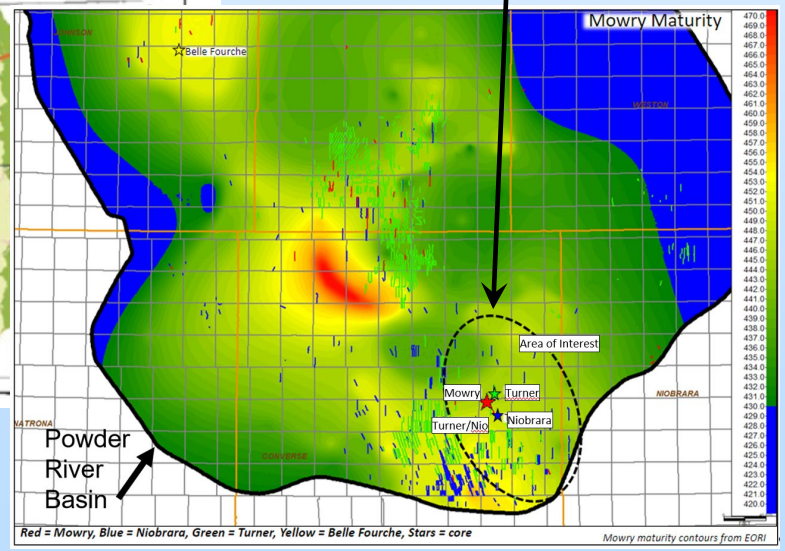
Size of the Prize – Southern Powder Tight Reservoirs

- Mowry has expelled roughly 11.9 billion barrels of oil
- Mean estimates of technically recoverable undiscovered continuous resource
  - Mowry: 198 million bbl, 198 Bcf, and 11.9 million bbl NGL*
  - Niobrara: 227 million bbl, 227 Bcf, and 13.6 million bbl NGL*



Powder River Basin

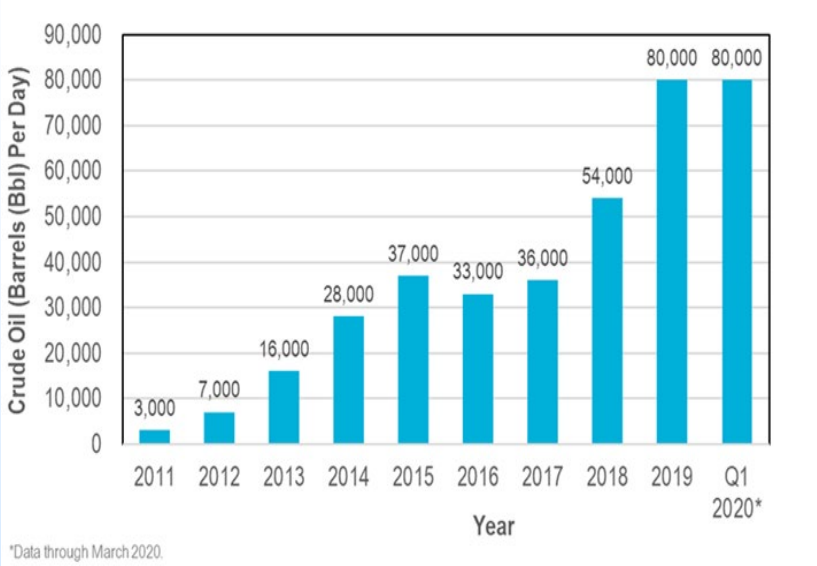
Field Laboratory Area

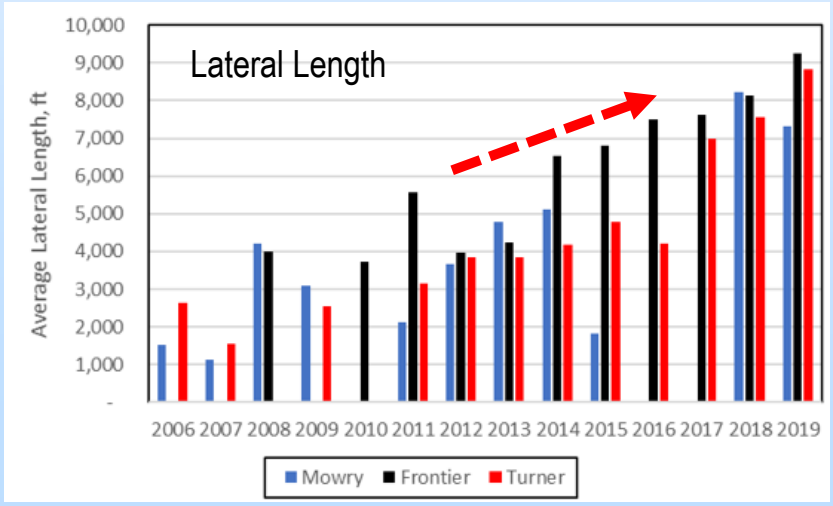


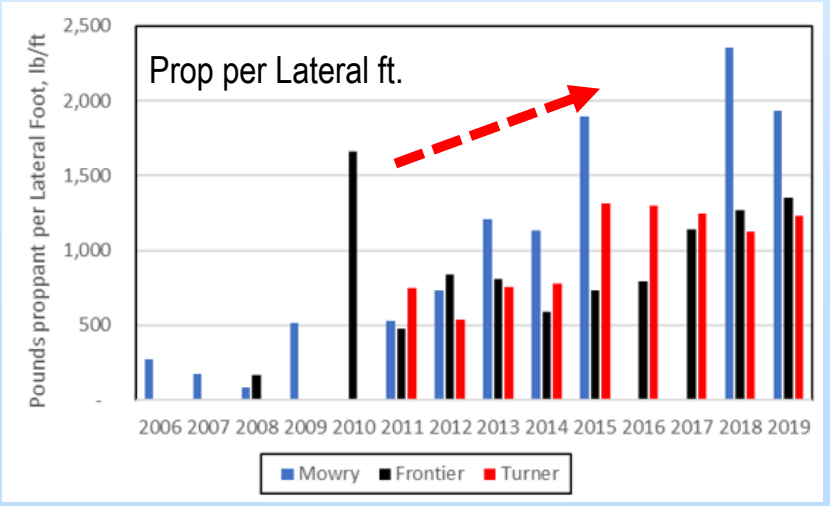
* Lawrence O. Anna and Troy A. Cook, 2008, "Assessment of the Mowry Shale and Niobrara Formation as Continuous Hydrocarbon Systems, Powder River Basin, Montana and Wyoming,"

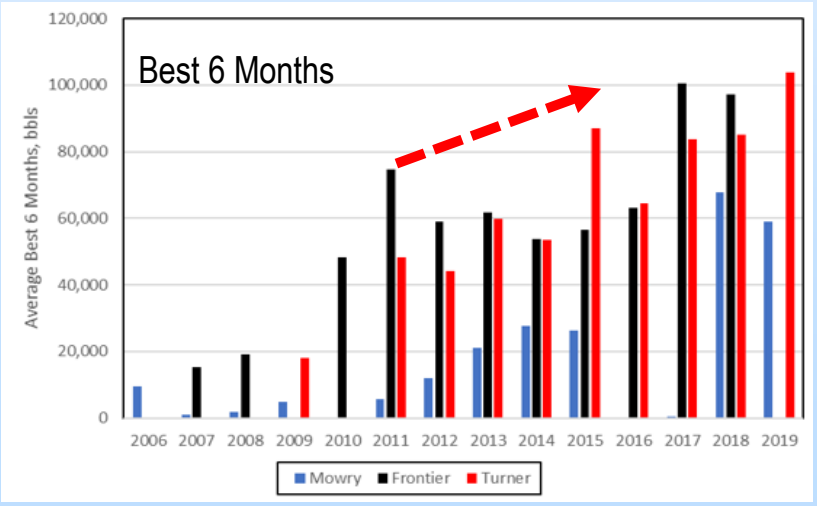
Background – Well Completion Trends

- Crude oil production from the Powder River Basin's tight oil formations has grown rapidly.
  - From 3,000 B/D to over 80,000 B/D in 2019/2020.
  - Turner Formation – 67,000 B/D (2019)
  - Frontier Formation – 10,000 B/D (2019)
  - Mowry Shale – 3,000 B/D (2019)
- From 2006 – 2019, completion and production trends in the PRB indicate increases in average lateral length and proppant per lateral foot which impacts best 6 months production.





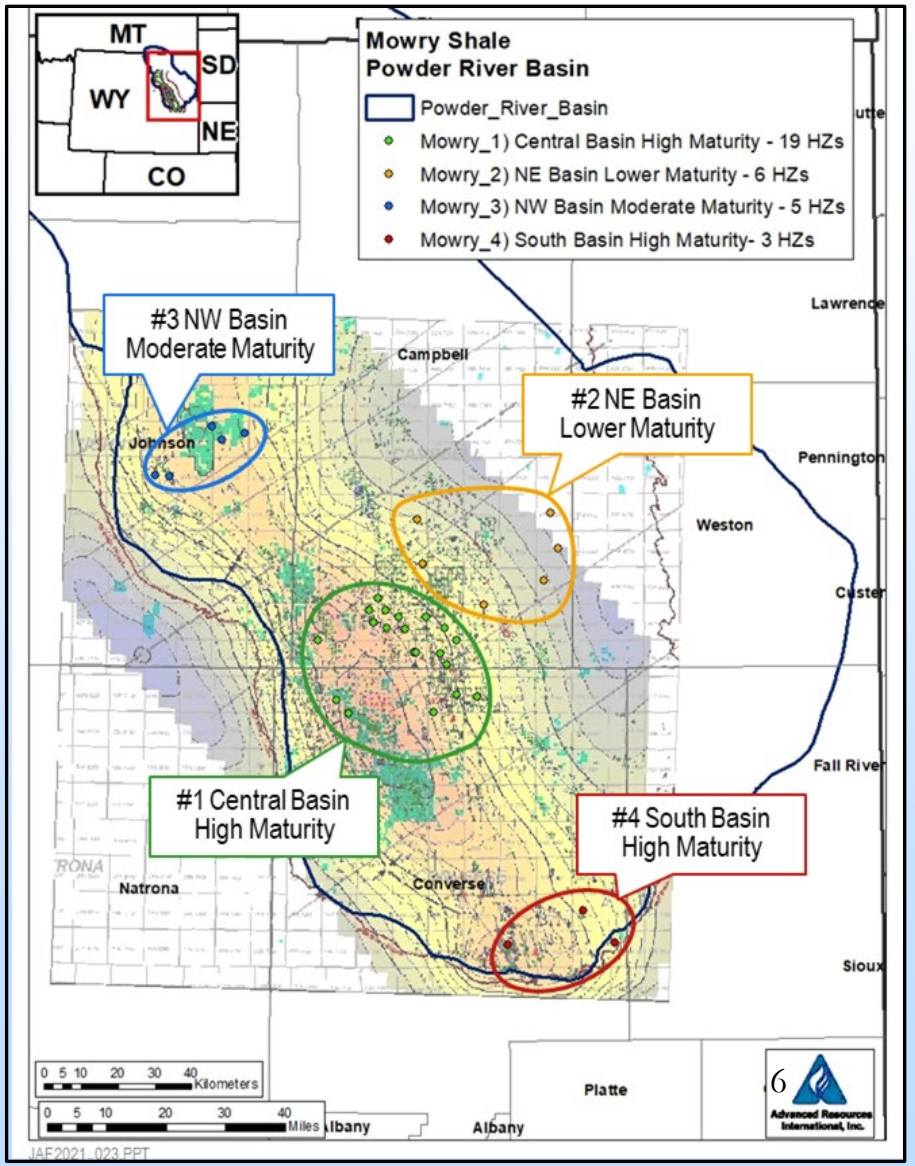




Well Completions Progression through Time

- Group wells based on geologic partitions
- Mowry completions highlight evolving completion practices
- Compare results from early and later wells from partition #1 Mowry wells

Mowry Partition #1	No. of Wells	Well Completion				Well Performance		
		Lateral Length	No. of Stages	Proppant Concentration		Oil EUR	Hydrocarbon EUR	Oil EUR/ 1,000'
		(ft)	(#)	(tons)	(lbs/ft)	(MB)	(MBOE)	(MB)
Early HZs (2012 – 2015)	9	4,840	30	3.4	1,420	210	430	37
Late HZs (2018 – 2019)	8	9,330	52	11.7	2,500	410	920	44

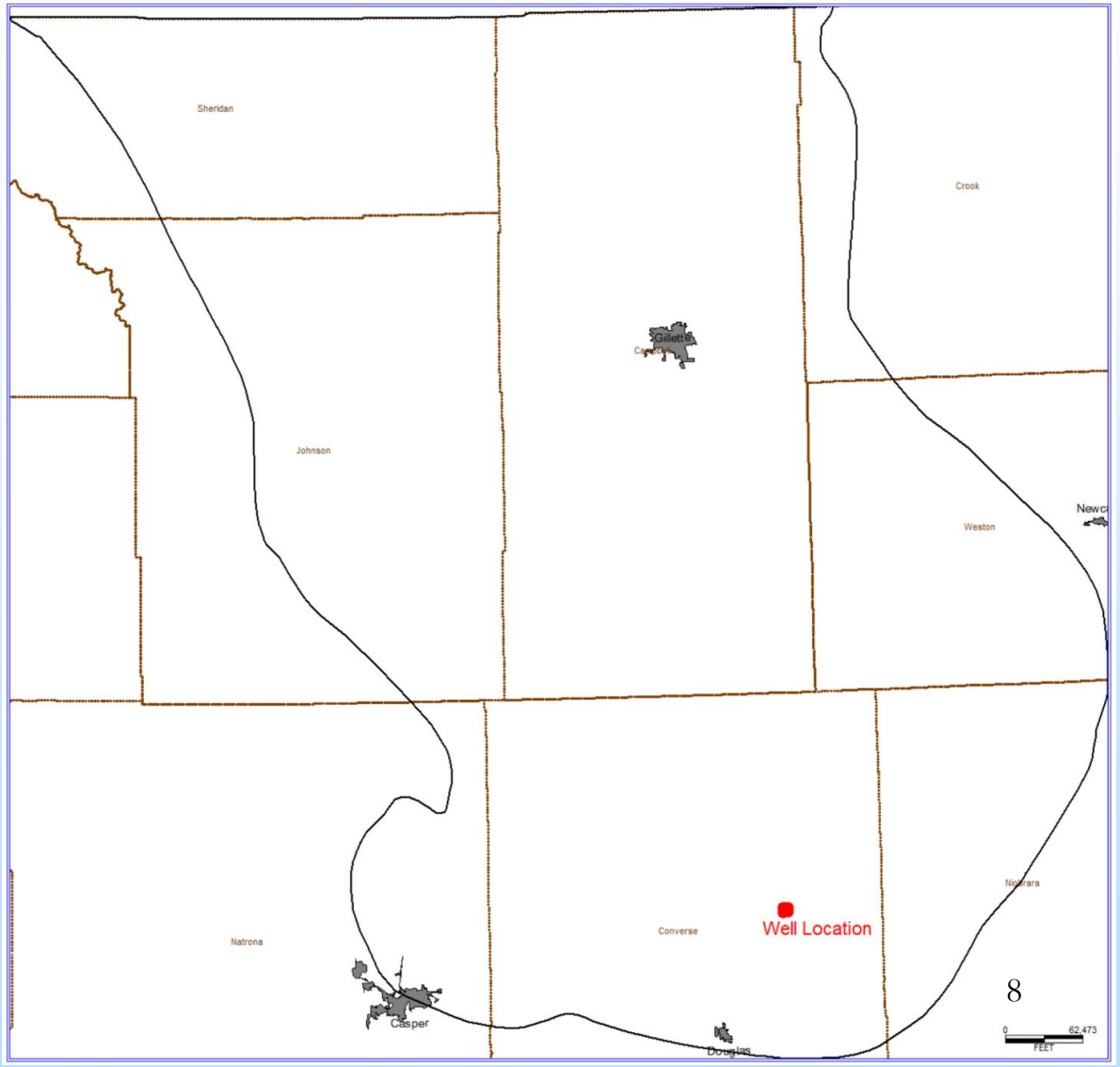


Well Completions Database

- Parameters tracked include data from over 750 wells
- The database contains summarized data about each well within the study
  - Multi-Variate Analysis (MVA) performed on *initial data* from well completions database
  - Minitab statistical software was used for MVA
- Results: no viable statistical correlations were found between input data and well productivity
  - Conclusion: Need to refine the data

Establishing a Field Laboratory – Core and Geologic Model

– Collect well logs and cores
  - Oxy donated 210 ft of Turner core
  - Collected 191 ft of Mowry core from vertical pilot hole drilled in Dec 2021 through Jan 2022



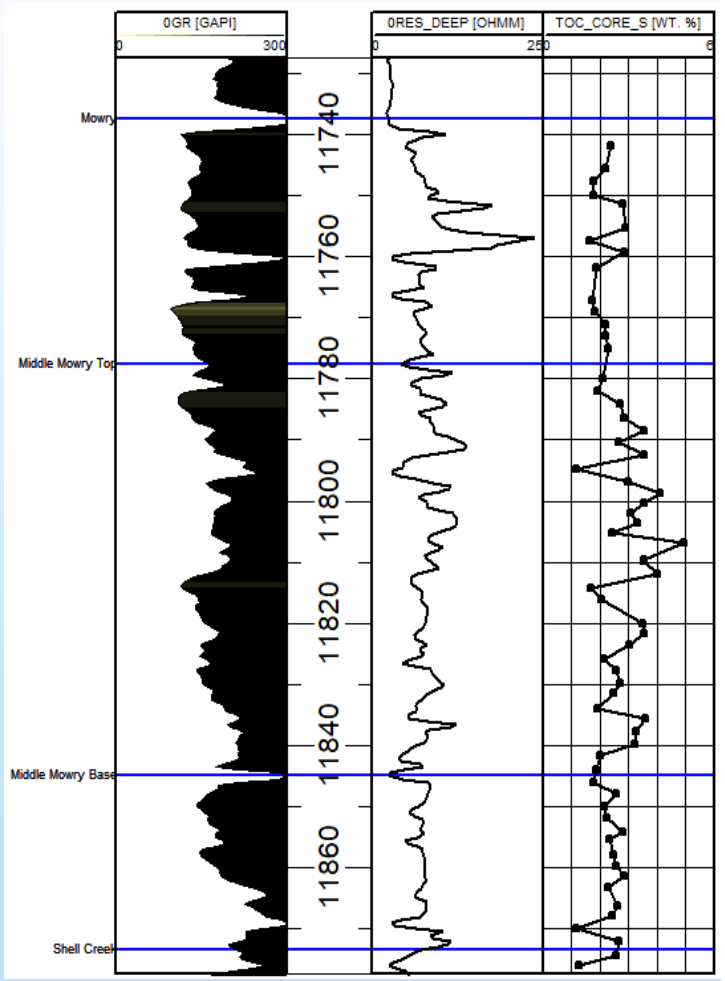
Pilot Well – Mowry Coring Operations

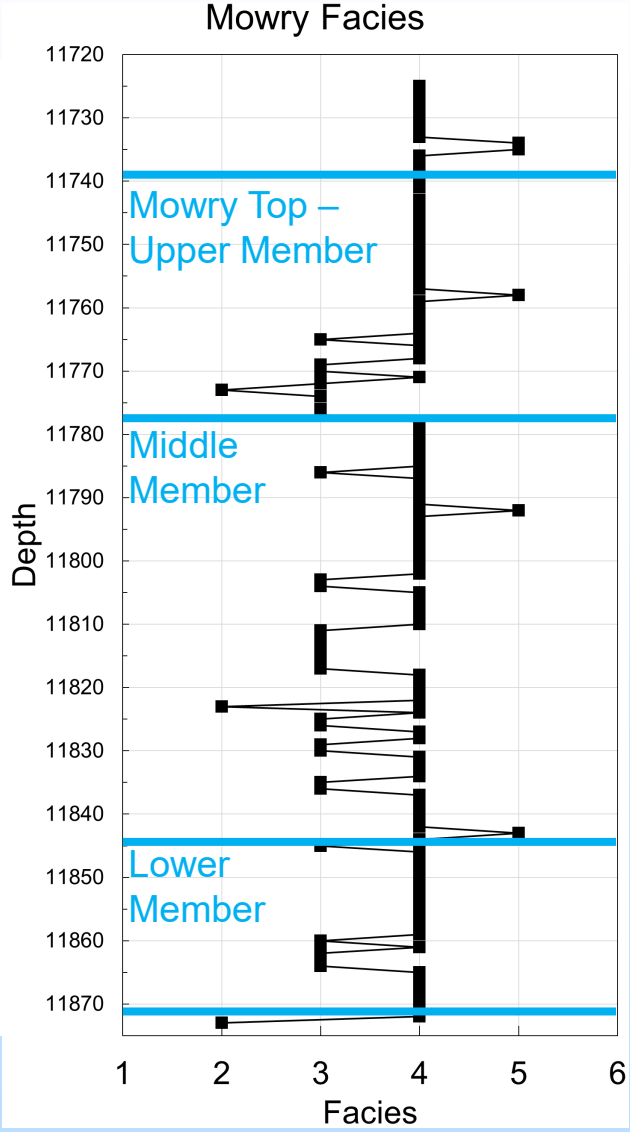
- Core point: 11,704 ft (30 ft above top of Mowry)
- Core to 11,743 ft, jammed, TOOH
  - Core 1: recovered 39 ft
- Core to target depth of 11,895 ft, TOOH
  - Core 2: recovered 152 ft
- Total core recovery: 191 ft
  - 35 ft from Belle Fourche
  - 135 ft from Mowry
  - 18 ft from Shell Creek
  - 3 ft from Muddy
- Five 1-ft samples preserved at well site at
  - 11,752 ft
  - 11,775 ft
  - 11,799 ft
  - 11,820 ft
  - 11,850 ft

Mowry Core and Geologic Model

- Described the Mowry core
- Assign geologic facies to each foot of core
  - Defined 5 different facies

Facies #	Facies Name	Average Bioturbation Level	Frequency (ft)
1	Subtidal sheet, oxic	0	0
2	Subtidal sheet, suboxic	2.3	3
3	Subtidal sheet, dysoxic	1.3	28
4	Subital sheet, anoxic	0.3	111
5	Bentonite	0.0	5

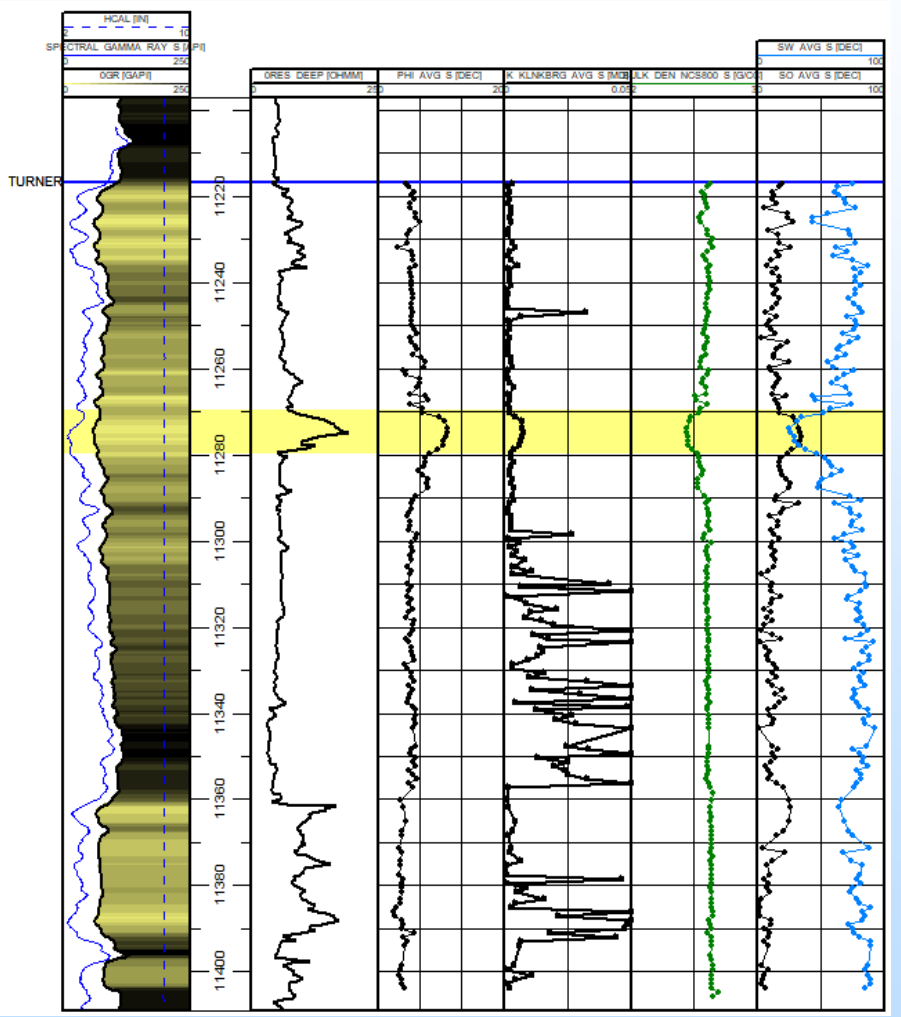


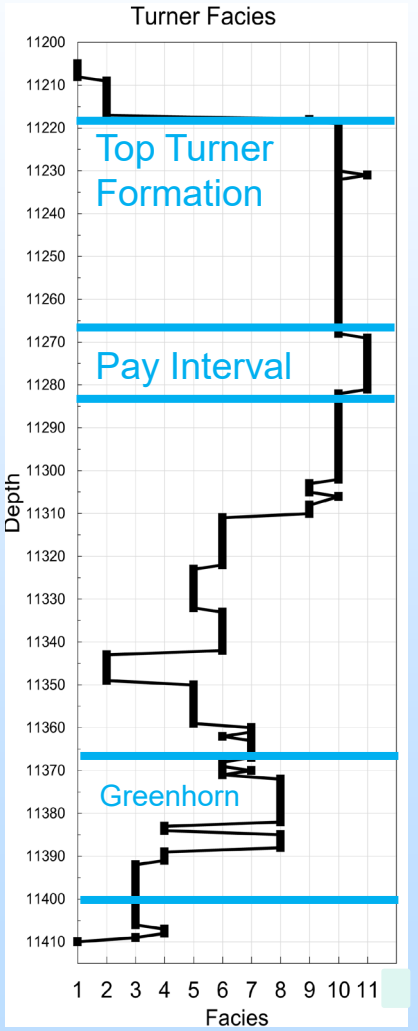


Turner Core and Geologic Model

- Described the Turner core
- Assign geologic facies to each foot of core
  - Defined 11 different facies
  - Facies 11 (the clean sandstone) correlates with the interval with higher porosity and higher oil saturation

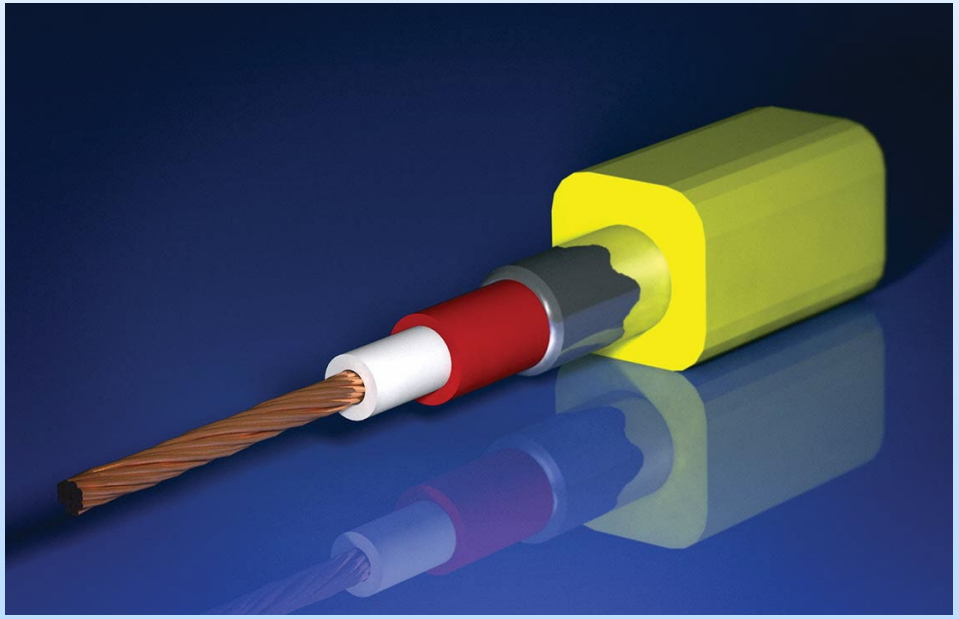
Facies #	Facies Name	Average Bioturbation Level	Frequency (ft)
1	Massive to faintly bedded mudstone	1.6	7
2	Sandy/Silty Mudstone	1.9	16
3	Calcareous Sandy/Silty Mudstone (Limestone)	3.7	16
4	Calcareous Laminated Mudstone, Siltstone, Sandstone (Limestone)	1.9	8
5	Laminated Mudstone, Siltstone, Sandstone	1.7	20
6	Bioturbated Heterolithic Silty/Sandy Mudstone	2.8	27
7	Burrow Mottled Heterolithic Mudstone	3.7	7
8	Bioturbated Heterolithic Calcareous Silty/Sandy Mudstone (Limestone)	3.1	14
9	Bioturbated Argillaceous Sandstone	3.6	8
10	Burrow Mottled Argillaceous Sandstone	3.8	70
11	Clean Sandstone	3.4	14



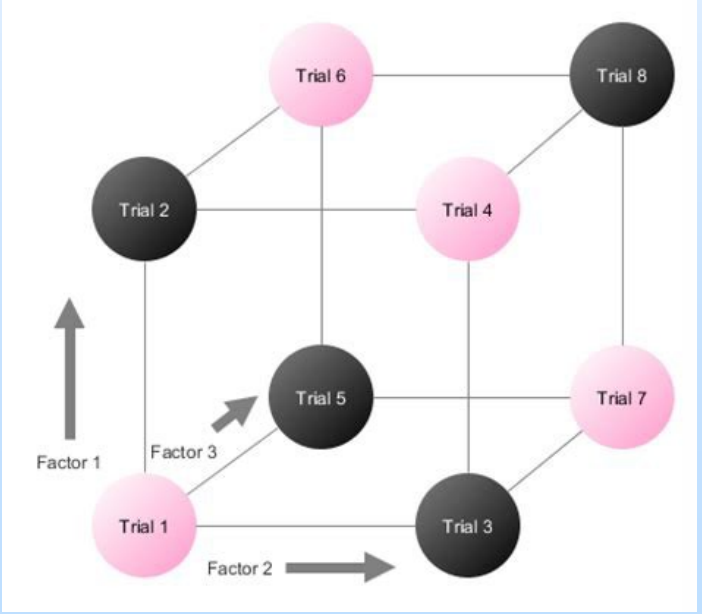


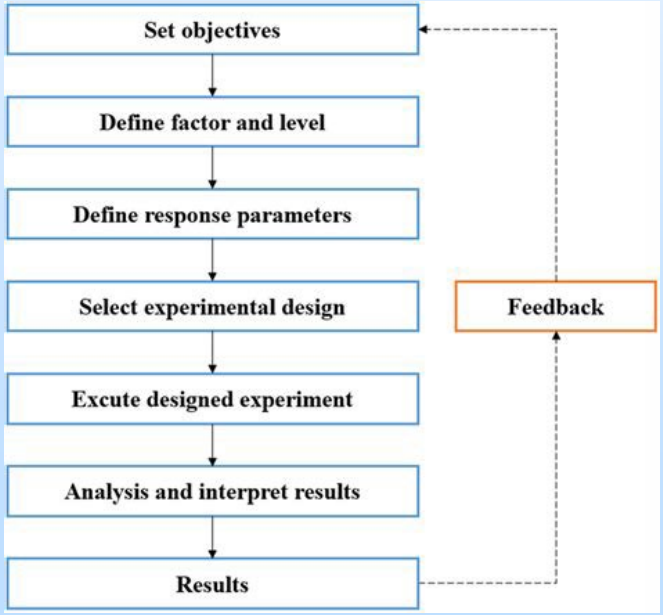
Completions Data Collection

- Fiber optic cable to be permanently placed in 10,000-ft Niobrara lateral for detailed monitoring of and data from individual stages
- Design of Experiments (DoE) to optimize stage parameters



Courtesy of Schlumberger





Permanent Fiber – Pros and Cons

Advantages

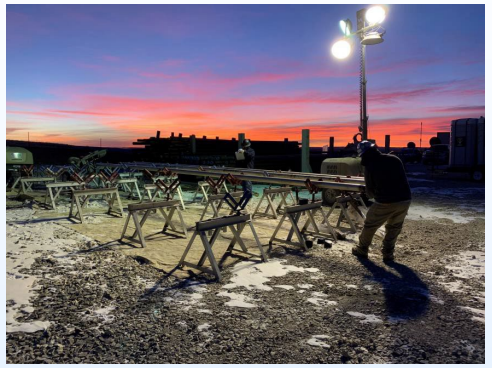
- Fiber optic cable can measure pressure, temperature, and flow rate at each stage along the length of the well
- Able to collect results at the stage level as opposed to the well level
- Allows DoE on single well
  - Completion can be optimized using multiple experimental frac stages in one well versus multiple experimental wells

Disadvantages

- More expensive than other data collection methods
- Placement of fiber in two-mile-long horizontal well is difficult (no rotating pipe to toe)
- Turner formation has challenging drilling environment and not a good candidate for fiber

Project Steps and Work Plan

- Completed
  - Current state of the art analysis
  - Drill pilot hole and collect vertical core
- Ongoing
  - Refine geologic and numerical models (ongoing)
  - Laboratory testing on Mowry core (ongoing)
    - Perm changes with pressure
    - Mechanical properties
    - Fluid flow properties (matrix and propped fractures)
- Future
  - Complete horizontal wells (future work)
    - Drill and install fiber optic cable
    - Complete well according to the DoE and collect production data
    - Reduce and analyze data to optimize future completions
  - Extrapolate optimized completions model to whole area based on geologic model and core learnings (future work)
  - Deliver final report on best practices for well completions in these formations (future work)



Key Milestones

- Nov 2019 – Project kickoff
- Sep 2020 – Baseline geology, state of the art, completions database
- Nov 2021 – Oxy joins project
- Jan 2022 – Pilot well completed and Mowry core retrieved
- Jun 2023 – Horizontal wells completed and stimulation data logged
- Dec 2023 – Production monitoring and completions optimized
- Sep 2024 – Project ends with best practices identified and final report submitted

Success Criteria and Risks/Mitigation

- Project success criteria
  - BP1: Selection of the Field Laboratory Site
  - BP2: Collect Logs/Core from Pilot Hole
  - BP3: Completion of Field Lab Horizontal Production Well(s) and the Field Laboratory Geologic Model
  - BP4: PRB Development Strategy Plan and Upload all data to EDX
- Project risks and mitigation strategies
  - Failure to place the optical fiber is a risk
  - Mitigated by drilling multiple HZs with redundant—although not as precise—data collection methods (microseismic)

Summary

- Lessons learned
  - Quality control data; bad data results in strange results
  - Expect setbacks and be ready to pivot, if needed
- Future plans
  - Finish drilling and completing horizontal wells
  - Collect production data, complete core investigations, geologic modeling, and DoE and MVA analysis
  - Share results
- “Take-away” message
  - Although expensive, permanent fiber may offer a cheaper, faster way to optimize horizontal well completions
  - Regional geologic modeling combined with well completion optimization offers methodology to apply learnings to the whole southern Powder River Basin

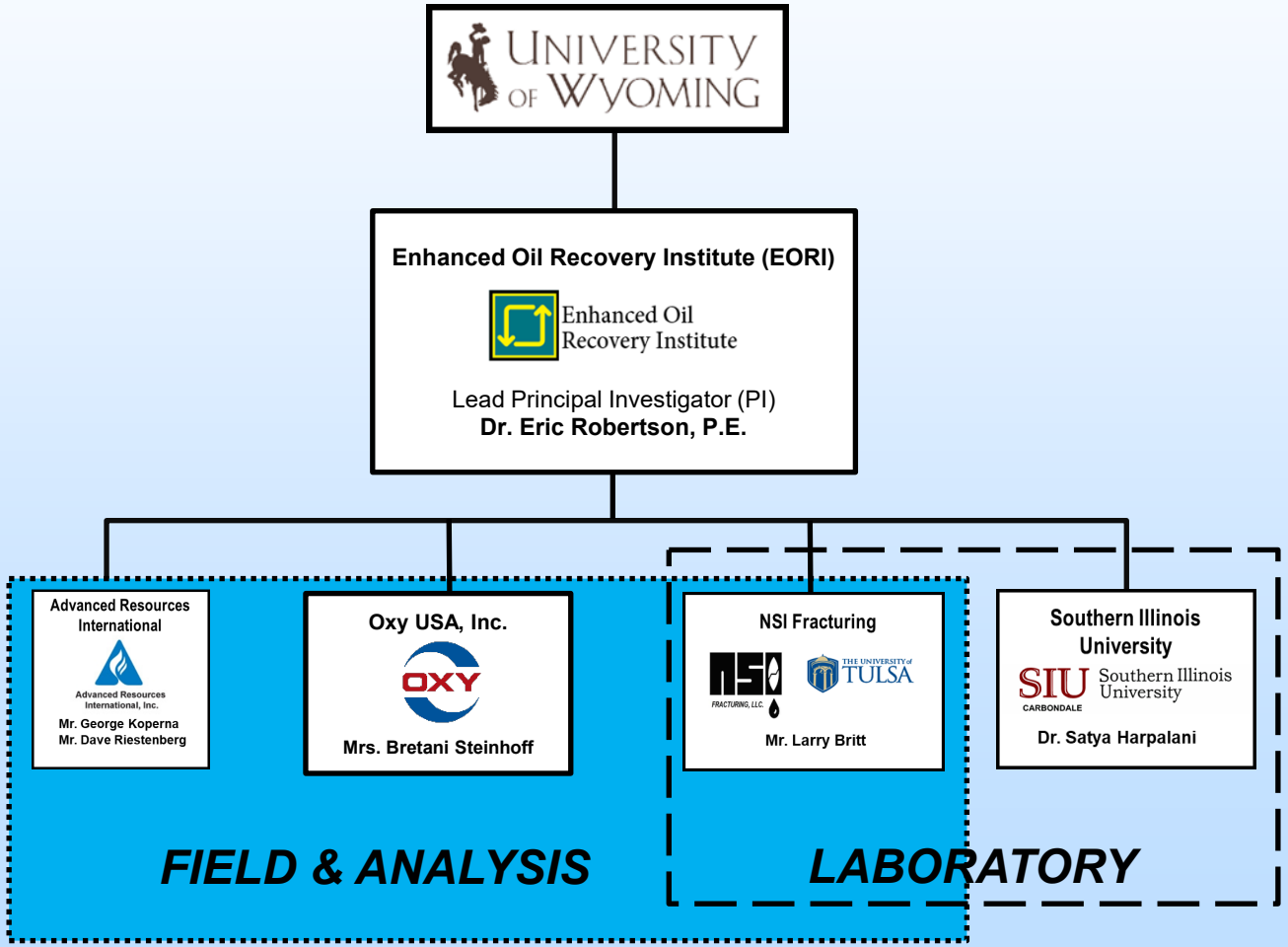
Thank You!

– Thanks to all the partners on this project, but especially to:
  - Occidental Petroleum
  - Advanced Resources International
  - Our awesome Project Manager, Rick Baker
– Time for questions or comments
– Contact:
  - Dr. Eric Robertson, Project P.I.
  - eric.robertson@uwyo.edu

Appendix

– These slides will not be discussed during the presentation but are mandatory.

Organization Chart



Simplified Project Gantt Chart

Task Number	Task Name	Year	2019				2020				2021				2022				2023				2024			
		Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Project Management & Planning																									
2	Workforce Readiness Plan																									
3	Baseline Data Gathering and Models																									
	Deliverable: PRB SOTA and Field Laboratory Site Selection												▲													
4	Develop Work Plans for Field Laboratory																									
	Deliverable: Pilot Hole Work Plan																									
	Go/No-Go Decision Point												▲													
	Deliverable: Field Laboratory Work Plan												▲													
5	Pilot Hole Well Drilling and Data Acquisition																									
	Deliverable: Pilot Hole Data Collection Summary														▲											
6	Laboratory Core Work																									
	Deliverable: Laboratory and Core Analysis Results																						▲			
7	Feedback Loop - Geologic and Fracture Mechanics Results																									
	Deliverable: Site-specific Design Plan Update																▲									
8	Production well Drilling, Completion, Stimulation, and Monitoring Results																									
	Deliverable: Final Well Completion																			▲						
9	Feedback Loop - Production Data and Advanced Core Analysis																									
	Deliverable: Final Well Completion and Stimulation Evaluation																				▲					
10	PRB Development Strategy Plan																									
	Deliverable: PRB Development Strategy Plan																									▲

1-yr extension of project due to covid