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

DE-FE0031779

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### Project Cost, Dates, and Objectives

- Project Cost (Total for 4 years, plus 1-year NCTE): \$14,425,550
  - \$7,893,649 Federal share
  - \$6,531,900 Cost share (45.28%)
- Important Dates:
  - Project Kickoff meeting: October 2019
  - NCTE granted: July 2020
  - Project Completion: June 2024
- Objectives:
  - Establish field laboratory in emerging PRB plays
    - Shale plays: Belle Fourche and Mowry
    - Tight sands: Frontier
  - Create basin-wide development strategy plan

#### **Project Participants**



# Background



Source: Chesapeake Energy, 2017

- The PRB is a premier, emerging tight oil basin in the U.S.
  - 5,000 bbl in 2010
  - >130,000 bbl in 2019
- Currently, Parkman, Niobrara, and Turner contribute most to production
- Mowry (focus of project)
  - By far largest unconventional resource in basin
  - 1,280 MMBOE gross recoverable resource potential

# Background

- Mowry shale is the most prolific source rock in PRB
- Unconventional production from Turner, Frontier, and Mowry
  - In 2019:
    - Turner contributed
      67,000 bbl/D
    - Frontier produced >10,000 bbl/D
    - Mowry shale produced 3,000 bbl/D



# Background

- Mowry shale characteristics in PRB
  - TOC ranges from 2 to 3+% Type II and Type III kerogen
  - Expelled 11.9 BBO in the basin (Momper & Williams, 1984)
  - Mowry is extensive and pervasive across the PRB
    - Thickness ranges between 150 ft and 200 ft everywhere in PRB
    - Graphic indicates extent of the Mowry at greater than 8000' of burial depth (the Mowry "kitchen" area)



# Technical Approach/Project Scope

- Develop "optimized" completion design for emerging shale play
  - Characterize (basin-wide) Mowry, Belle Fourche, and Frontier formations in southern PRB
    - Detailed geological mapping across southern PRB from well logs
  - Learn from recent and current completion practices
    - Perform SOA analysis and MVA using recent completion data (type, stage spacing, proppant volumes, etc.) to develop optimized completion design
    - Incorporate machine learning to aid optimization
  - Characterize rock
    - Collect core from pilot hole or other appropriate location
    - Pore-scale visualization of fluid movement
    - Geomechanical studies: mineralogy, stress, permeability, fracture mechanics

## Technical Approach/Project Scope

- Drill and complete new horizontal well (field laboratory)
  - Incorporate latest technology to monitor completion and production in real time
- Refine completion design as informed by feedback from field laboratory
- Share development strategy with stake holders
  - Developmental benefits, impacts, and challenges
  - Technical and economic viability for proposed strategy
  - Project risks and mitigation strategies
- Identify possible consortium members additional operators

#### Basin-Wide Geological Model of Frontier, Belle Fourche, and Mowry



#### Historical Well Completions Data

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	A	B	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	
1	=A	PI #	Spud Date	TVD (ft)	Completion Date	Lateral Length	First Perforation	Last Perforation	Perforated Length (ft)	Service Company	# of Stages	Avg Frac Stage Length (ft) 🗸	Type of Treatment	Major Proppant Type	Major Proppant Size	Major Proppant Mass (lbs)	Secondary Proppant	Proppant Size	Proppant Mass (2nd)	Total Prop
144	143 490056	18510000	11/25/2013	8903	3/10/2014	9570	18757	9382	9375	Halliburton	32	293	Crosslinked	Ceramic	16/30	4958720	TAO	16/30	1220340	6:
145	144 490056	18520000	10/11/2014	8699	3/17/2015	9132	18304	9433	8871	Schlumberger	30	296	Hybrid	Sand	16/30	3925326	Sand	16/30, 100 Mesh	1439179	51
146	145 490056	18560000	7/30/2017	11853	6/16/2018	9071	21386	12424	8962		55	163	Slickwater							26
147	146 490056	18690000	5/6/2013	8584	8/15/2013	4378	14393	10170	4223	Consolidated Oil Well Services LLC	13	325	XL Gel	Ceramic	16/30	1546056	CRC-C, Sand	16/30, 100 Mesh	388440	19
148	14/ 490056	18850000	6/28/2013	9958	9/8/2013	4170	14203	10170	4033	Halliburton	12	336	Hybrid	sand	16/30	3/86978	Common White Sand	100 Mesh	223548	44
149	148 490056	188/0000	6/14/2013	9/41	9/20/2013	4370	15016	10696	4320	Consolidated Oil Well Services LLC	13	332	XL Gel	Ceramic Resin Control	16/30	1609888	CRC-C, Sand	16/30, 100 Mesh	368005	11
151	150 490056	18950000	5/14/2014	11195	7/26/2014	3179	14145	1138/	2/58	Halliburton	14	216	Crosslinked	Sand	20/40	3332720	Sand	40/70	602960	34
152	151 490056	19060000	6/9/2014	11530	10/7/2014	4008	15620	12260	3360	Halliburton	14	240	Crosslinked	Sand	20/40	3331976	Premium White Sand	40/70	602144	35
452	1000000		0/02/0010	10107			10.003	11053		Concellulated Coll world Concerning			Consultation	Course la	10/00		coc c cond	te da tao titut		

- 66 columns of data on 805 different wells
- Still a work in progress (green cells)
- Data collected from online sources and physical well files at WOGCC
- Data used for state-of-the-art analysis and multi-variate analysis
- All new core/data to be added

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189 18	8 49005621120000	8/8/2014	10207	11/1/2014	4772	15104	10741	4363	Consolidated Oil Well Services LLC	13	336	Crosslinked	Ceramic	16/30	1595260	CRC-C, Sand	16/30, 100 Mesh	397724	15
190 18	9 49005621170000	4/25/2014	10234	8/26/2014	4244	14425	10464	3961	Cudd Energy Services	12	330	Hybrid	Sand	16/30	4067180	Sand	100 Mesh	406500	44
191 19	0 49005621180000	12/30/2013	10295	3/5/2014	4122	14666	10675	3991	Halliburton	12	333	Hybrid	Premium White Sand	16/30	4432292	Common White Sand Sand	100 Mesh	282818	4
192 19	1 49005621220000	12/5/2013	10538	5/7/2014	4602	15858	11300	4558	Consolidated Oil Well Services LLC	13	351	XL Gel	Ceramic	16/30	1561794	CRC-C, Sand	16/30, 100 Mesh	373590	15
193 193	2 49005621230000	11/7/2013	10707	2/1/2014	4589	15461	10976	4485	Consolidated Oil Well Services LLC	13	345	Crosslinked	Ceramic	16/30	1603334	CRC-C, Sand	16/30, 100 Mesh	390001	15
194 193	3 49005621290000	12/18/2018	9782	9/13/2019	9390	19647	10430	9217	Halliburton	47	196	XL Gel	Sand	20/40	7575525	Sand	40/70	1893842	94
195 19	4 49005621330000	10/16/2014	15142	7/16/2016	4275	15072	10867	4205	EOG Resources, Inc.	18	234	Slickwater	Sand	100 Mesh	5168171				5
196 19	5 49005621350000	11/23/2014	12350	8/14/2015	9982	22355	12820	9535	Sanjel	30	318	Hybrid	Sand	30/50	4563880	Sand	40/70	1440560	6(
197 19	6 49005621360000	10/7/2014	10722	12/13/2014	4474	15330	10910	4420	Consolidated Oil Well Services LLC	13	340	Crosslinked	Ceramic	16/30	1603181	CRC-C, Sand	16/30, 100 Mesh	386755	11
198 19	7 49005621370000	6/30/2014	9813	11/1/2014	4268	15318	11106	4212	Consolidated Oil Well Services LLC	12	351	Hybrid	Ceramic	16/30	1499633	CRC-C, Sand	16/30, 100 Mesh	397878	18
199 198	8 49005621440000	11/30/2014	7453	3/24/2015	5470	13062	7727	5335	Halliburton	14	381	Hybrid	Sand	20/40	3920020	Sand	100 Mesh	112361	44
200 19	9 49005621460000	12/14/2014	10183	4/15/2015	9074	19598	10674	8924	Halliburton	24	372	Hybrid	Premium White Sand	16/30	9466560	Common White Sand Sand	100 Mesh	840060	10
201 200	0 49005621500000	3/31/2014	10102	8/21/2014	4032	14307	10415	3892	Halliburton	11	354	Hybrid	Sand	16/30	4151000	Common White Sand Sand	100 Mesh	265000	44
202 20	1 49005621530000	4/9/2014	10133	7/30/2014	4098	14406	10436	3970	Halliburton	11	361	CO2 Frac	Premium White Sand	16/30	2701265	Sand	100 Mesh	256974	44
203 203	2 49005621560000	3/5/2014	10049	5/19/2014	3961	14350	10555	3795	Cudd Energy Services	12	316	Hybrid	White Sand	16/30	4414800	Sand	100 Mesh	261220	46
204 203	3 49005621990000	8/19/2014	10035	1/21/2015	9641	19888	10386	9502	Halliburton	24	396	Hybrid	Premium White Sand	16/30	9484100	Common White Sand	100 Mesh	917020	10 .
205 20-	4 49005622020000	11/27/2013	10472	2/13/2014	4325	15279	11018	4261	Consolidated Oil Well Services LLC	13	328	Crosslinked	Ceramic	16/30	1617418	CRC-C, Sand	16/30, 100 Mesh	394142	20
206 203	5 49005622030000	12/20/2013	9519	1/19/2014	4351	14078	9856	4222	Halliburton	12	352	Hybrid	Premium White Sand	16/30	4674320	Common White Sand Sand	100 Mesh	285620	45
207 20	6 49005622060000	9/30/2014	9957	12/28/2014	10238	20078	10513	9565	Halliburton	40	239	Hybrid	Premium White Sand	16/30	944390	Common White Sand	100 Mesh	916380	18
208 20	7 49005622110000	3/8/2014	10164	6/30/2014	9635	20079	10550	9529	EOG Resources, Inc.	47	203	Slickwater	Sand	100 Mesh	8649700				8
209 200	8 49005622140000	5/30/2014	10810	8/30/2014	4920	15684	11281	4403	Consolidated Oil Well Services LLC	13	339	XL Gel	Ceramic	16/30	1601896	CRC-C, Sand	16/30, 100 Mesh	297778	15
210 20	9 49005622420000	7/16/2014	10645	10/1/2014	4478	15071	11099	3972	Consolidated Oil Well Services LLC	13	306	XL Gel	Ceramic	16/30	1614460	CRC-C, Sand	16/30, 100 Mesh	368357	15
211 21	0 49005622520000	2/10/2014	10891	6/6/2014	5118	15954	11490	4464	Consolidated Oil Well Services LLC	13	343	Crosslinked	Ceramic	16/30	1650389	CRC-C, Sand	16/30, 100 Mesh	359509	20
212 21	1 49005622610000	2/20/2014	10302	5/30/2014	4502	14772	10792	3980	Consolidated Oil Well Services LLC	13	306	Crosslinked	Ceramic	16/30	1614430	CRC-C, Sand	16/30, 100 Mesh	358443	15
213 21	2 49005622680000	4/14/2014	10202	7/5/2014	4027	14073	11168	2905	Consolidated Oil Well Services LLC	13	223	XL Gel	Ceramic	16/30	1600300	CRC-C	16/30	325000	15
214 21	3 49005622700000	3/14/2014	10531	8/21/2014	4054	14532	11096	3436	Consolidated Oil Well Services LLC	13	264	XL Gel	Ceramic	16/30	1622627	CRC-C, Sand	16/30, 100 Mesh	370644	15
215 21	4 49005622710000	2/4/2014	10315	4/26/2014	4684	14948	10860	4088	Consolidated Oil Well Services LLC	13	314	Crosslinked	Ceramic	20/40	1585453	CRC-C, Sand	16/30, 100 Mesh	359964	15
216 21	5 49005622720000	4/22/2014	10429	7/17/2014	4916	15294	10997	4297	Consolidated Oil Well Services LLC	13	331	XL Gel	Ceramic	20/40	1606767	CRC-C, Sand	16/30, 100 Mesh	370465	15
217 21	6 49005622760000	4/8/2014	10396	6/29/2014	4641	14999	10984	4015	Consolidated Oil Well Services LLC	13	309	XL Gel	Ceramic	16/30	1604609	CRC-C, Sand	16/30, 100 Mesh	384931	15
218 21	7 49005623030000	2/26/2014	11604	5/24/2014	4406	15850	11876	3974	Halliburton	14	284	XL Gel	Sand	20/40	3332254	Premium White Sand	40/70	603620	31
219 21	8 49005623070000	5/8/2020	11565	9/27/2015	4657	15894	11988	3906	Halliburton	28	140	XL Gel	Premium White Sand	20/40	3417080	Premium White Sand	40/70	587200	40
220 21	9 49005623150000	12/12/2014	10582	3/28/2015	4823	15402	11329	4073	Consolidated Oil Well Services LLC	13	313	XL Gel	Ceramic	20/40	1600355	CRC-C, Sand	20/40, 100 Mesh	380269	15
221 22	0 49005623260000	4/2/2014	12360	7/25/2014	3900	16545	12799	3746	Halliburton	28	134	Crosslinked	Sand	40/70	2063742	CRC, Sand	20/40, 100 Mesh	1674388	31
222 22	1 49005623270000	2/28/2014	11489	6/24/2014	4459	15799	11878	3921	Peak Energy Resources LLC	14	280	Hybrid	PRC	20/40	3412176	Premium White Sand	40/70	594890	4 👻 1
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# **Completion Practices: a State-of-the-Art Analysis**



- Finished SOTA analysis on Turner, Frontier, and Mowry formations
- Results of Mowry analyses shown here as examples:
  - 42 horizontal wells in emerging play, one-third completed after 2018
    - 26 wells located in south-central portion of basin
    - Most recent activity occurring in areas of higher thermal maturity

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### **Completion Practices: a State-of-the-Art Analysis**

- Mowry Results (as example):
  - Mowry partitioned into four categories (see map) •
    - Central basin, high maturity (green dots)
    - NE basin, low maturity (orange dots)
    - NW basin, moderate maturity (blue dots)
    - South basin, high maturity (red dots)
  - Partitions further separated by time-slice to show • changes in completion designs over time
  - Key learnings: •
    - Lateral length has increased with time (currently approaching 9,000 ft) along with number of fracture stages
    - Proppant/stage increased from 50 tons to 370 tons
    - EUR/1000 ft increased from 20 MBOE to 42 MBOE



#### Concerns

- Collect core from pilot hole or other appropriate location(s) has been delayed
  - Causing critical lab work to be delayed as well
  - Originally planned to drill and collect core for characterization in 2020
  - Drilling of pilot hole postponed due to oil price collapse & COVID

#### **Current Plans to Obtain Suitable Core**

- Working with additional operators active in area of interest (AOI)
- Work with nearby Glenrock field operator to obtain core drilled through Mowry and Belle Fourche shales in November/December 2020
  - Well location is roughly 8 miles from AOI and less mature
  - Geomechanics and fracture characteristics will be similar
  - Belle Fourche logs indicate possibly higher TOC than in AOI
  - Mowry logs appear very similar between Glenrock and AOI
  - Obtaining Bell Fourche and Mowry core will allow:
    - establishment of facies relationships
    - better understanding of TOC and organic distribution
    - calibration of core to logs
    - understanding of how the bentonites affect these horizontal plays
  - Core data are always helpful in some way
- Core from well to be drilled through Mowry at Dry Fork Station (CarbonSAFE Phase III) in June 2021 (65 mi north of AOI)



#### **Future Plans**

- Complete multi-variate analysis of completion designs to determine critical variables and optimize design
- Characterize rock
  - Collect core from pilot hole or other appropriate location(s)
  - Pore-scale visualization of fluid movement
  - Geomechanical studies: mineralogy, stress, permeability, fracture mechanics
- Drill and complete new horizontal well (field laboratory)
  - Incorporate latest technology to monitor completion and production in real time
- Refine completion design as informed by feedback from field laboratory
- Share development strategy with stakeholders
  - Developmental benefits, impacts, and challenges
  - Technical and economic viability for proposed strategy
  - Project risks and mitigation strategies
- Add additional operators/consortium members if possible

#### Summary

- Project will significantly aid the development of a key emerging unconventional oil play in Wyoming's Powder River Basin
  - A young project (< 1 yr) with delays (COVID-19, very low oil prices)</li>
  - Expected to achieve outlined goals
- Key findings include better understanding of Mowry and completion practices
  - Pervasive, continuous, uniform thickness, and has at lease three main zones of higher TOC rock
  - Small number of wells, but operators are beginning to focus in on a standard completion
- Future plans include:
  - Continue with work to promote further exploitation of the Mowry resource
  - Partner with additional operators to grow the impact of its results

# Appendix

- Organizational Chart
- Gantt Chart

#### **Organization Chart**



#### **Gantt Chart**

D	Task Name	2020 2021 2022 2023 2 Otr 3 Otr 4 Otr 1 Otr 2 Otr 3 Otr 4 Otr 1 Otr 3 Otr 4 Otr 1 Otr 3 Otr 4 Otr 4 Otr 1 Otr 3 Otr 4 Ot	:024 Otr 1   Otr 2   Otr 2
1	Task 1.0 Project Management & Planning		
2	Work Product 1.1: Revised Project Management Plan	♦ 10/1	
3	Work Product 1.2: Data Management Plan	9/30	
4	Work Product 1.4: Data Submitted to NETL-EDX		💊 6/30
5	Year 4 Milestone: Upload data to EDX		💊 6/30
6	Task 2.0 – Workforce Readiness Plan		
7	Work Product 2.0a: Workforce Readiness Plan	6/30	
8	Work Product 2.0b: Workforce Readiness Plan Update 1	♦ 6/30	
9	Work Product 2.0c: Workforce Readiness Plan Update 2	6/30	
10	Work Product 2.0d: Workforce Readiness Plan Update 3		🔶 6/30
11	Task 3.0 – Baseline Data Gathering and Models		
12	Subtask 3.1 - Gather available data and identify gaps		
13	Subtask 3.2 – PRB baseline geologic model		
14	Subtask 3.3 – Develop current SOA for PRB well completion/stimulation		
15	Subtask 3.4 – PRB baseline numerical flow model		
16	Subtask 3.5 – PRB baseline economic assessment		
17	Subtask 3.6 – Siting Field Laboratory		
18	Year 1 Milestone: Field Laboratory Site Selection	♦ 3/31	
19	Work Product 3.0: PRB SOA Development Strategies and Field Laboratory Site Selection	♦ 6/30	
20	Task 4.0 – Develop Work Plans for Field Laboratory		
21	Subtask 4.1 – Pilot hole testing and development plan		
22	Go/No-Go Decision Point	♦ 6/30	
23	Work Product 4.1: Pilot Hole Work Plan	6/30	
24	Subtask 4.2 – Production well testing, development, and monitoring plan (completion and stimulation testing)	n letter lette	
25	Work Product 4.2: Field Laboratory Work Plan	6/30	
26	Task 5.0 – Pilot Hole Well Drilling and Data Acquisition		
27	Subtask 5.1 – Pilot hole drilling		
28	Subtask 5.2 – Coring and logging		
29	Work Product 5.2: Pilot Hole Data Collection Summary	♦ 12/31	
30	Year 2 Milestone: Collect Logs/Core from Pilot Hole	▶ 12/31	

#### **Gantt Chart**

ID	Task Name	2020 2021 2022 2022 2023 2024 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4	3
31	Task 6.0 – Laboratory Core Work		
32	Subtask 6.1 – Pore scale fluid flow studies		
33	Subtask 6.2 – Geomechanics and pressure decay permeability studies		
34	Subtask 6.3 – Fracture mechanics studies		
35	Subtask 6.4 – Routine Core Analysis		
36	Work Product 6.0: Laboratory and Core Analysis Results	• 6/	30
37	Task 7.0 – Feedback Loop – Geologic and Fracture Mechanics Results		
38	Subtask 7.1 – Log analysis and hydrocarbon-in-place estimates		
39	Subtask 7.2 – Update geologic models		
40	Subtask 7.3 – Well completion and stimulation plan update		ㅓ
41	Subtask 7.4 – Update flow models		
42	Work Product 7.0: Site-Specific Design Plan Update	3/31	
43	Year 2 Milestone: Site Specific Well Completion & Stimulation Design	♦ 3/31	
44	Task 8.0 – Production Well Drilling, Completion, Stimulation, and Monitoring Results	· · · · · · · · · · · · · · · · · · ·	
45	Subtask 8.1 – Drilling and MWD data collection		
46	Subtask 8.2 – Final well completion and stimulation design		
47	Subtask 8.3 – Well completion and stimulation activities		
48	Subtask 8.4 – Stimulation monitoring protocols		
49	Work Product 8.0: Final Well Completion Report	◆ 12/31	
50	Year 3 Milestone: Completion of Field Lab Horizontal Production Well(s)	◆ 12/31	
51	Task 9.0 – Feedback Loop – Production Data and Advanced Core Analysis		
52	Subtask 9.1 – Post well completion and stimulation evaluation		
53	Subtask 9.2 – Flow profile survey		
54	Subtask 9.3 – Final Field Laboratory geologic model		
55	Subtask 9.4 – Final Field Laboratory numerical flow model		
56	Work Product 9.0: Final Well Completion and Stimulation Evaluation	• 12/31	
57	Year 3 Milestone: Field Laboratory Geologic Model	♦ 6/3	
58	Task 10.0 – Powder River Basin Development Strategy Plan		
59	Subtask 10.1 – Geologic characterization		
60	Subtask 10.2 – Developmental Benefits, Impacts, and Challenges		
61	Subtask 10.3 – Emerging PRB Play Development Strategy		
62	Work Product 10.0: Development Strategy Plan	6/3	0
63	Year 4 Milestone: PRB Development Strategy Plan	♦ 6/3	0