ERA FINAL REPORT

ERA Project ID: F0160780

Title of Project: Demonstration of a Full-Scale Multilateral Junction Assembly

Name and information of Recipient contact: Kyle Maguire, kmaguire@modernwells.com

Name of ERA Project Advisor: Aaron Baugh/Prashant Pandey

Start date of the Project: July 1 ,2020

Completion date of the Project: December 31, 2023

Technology Readiness Level (TRL) at Project initiation: 4

TRL at Project completion: 7 to 9

Total actual ERA funds received: $3,500,000.

Total actual Project costs, including a breakdown of total eligible and total ineligible costs.

	Total Eligible Costs, $	Total Ineligible Costs, $	Total Project Costs, $
Labour	1,762,543		1,762,543
Travel	212,267		212,267
Equipment	8,804,909		8,804,909
Sub-contractors & Consultants	1,430,959		1,430,959
Materials & Supplies	2,334,781		2,334,781
Overhead	902,879	29,845	932,724
	15,448,338	**29,845**	**15,478,183**

FOR submission date: March 20, 2024

Short Project description with high level results for the ERA website (maximum 1000 words):

Modern Wellbore Solutions has developed the world's first Multilateral Junction Tool Assembly (MJT) to allow oil and natural gas companies to drill, complete, and operate multilateral wells in unconventional assets. The MJT can be applied to new and existing wellbores, and results in more efficient drainage of reservoirs, reduced environmental impacts, and curtailed capital and operating costs. By enabling multistage and multi-fracturing of several laterals from just one vertical wellbore, the technology has a 50% smaller land footprint and requires significantly less time and equipment to construct, cutting capital expenditures by more than 20%. Methane and other GHG emissions from both construction and ongoing well operation are drastically reduced. Minimized artificial lift requirements and operating time per wellbore further lowers operating costs by 10%.

The project consisted of 3 pilot wells with increasing levels of complexity. The first well was run in a suspended well landed in the vertical section and tested the basic features of the multilateral junction. All the pilot goals were accomplished with learnings and improvements implemented for the second pilot.

The second and third pilot well was a re-entry candidate that required a new stimulation. This well required cementing and a high-pressure fracture. The upper lateral was drilled and completed with a small volume and pressure frac. The lower lateral was fractured and acidized then brought on production.

The fourth and final pilot was in a new drill with the extended reach functionality for the upper lateral. This feature is required to run a full-length upper liner while ensuring the junction orients and couples reliably. This pilot had an improved whipstock and sidetrack system which removed any interference while running the upper lateral and removed time for remedial operations.

The tool design is continually improving and modified to work in different formations to give the best system for clients.

Contents

Table of Figures

Executive Summary

The project consisted of 3 pilot wells with increasing levels of complexity. The first well was run in a suspended well landed in the vertical section and tested the basic features of the multilateral junction. All the pilot goals were accomplished with learnings and improvements implemented for the second pilot.

The second and third pilot well was a re-entry candidate that required a new stimulation. This well required cementing and a high-pressure fracture. The upper lateral was drilled and completed with a small volume and pressure frac. The lower lateral was fractured and acidized then brought on production.

The fourth and final pilot was in a new drill with the extended reach functionality for the upper lateral. This feature is required to run a full-length upper liner while ensuring the junction orients and couples reliably. This pilot had an improved whipstock and sidetrack system which removed any interference while running the upper lateral and removed time for remedial operations.

The technology was developed for several years at our testing facility with a custom designed bench that could recreate drilling rig forces and flow rates. The testing was systematic with each of the subcomponents tested individually to ensure pressure rating and load capability. The parts were combined to create the full assembly which was then tested in the same manner as it would be in the field. This in house testing ensured that we would have a high degree of certainty the tool would function in the field as designed without requiring a pilot well to test each feature. This greatly reduced the cost to create a field ready tool.

The outcome of the project was successful but the path we took to get there was much different than originally planned. Our initial project partner was acquired, and the new corporation did not want to continue with the additional pilots. We had to modify our next pilot wells to a joint venture structure. This gave the partner companies more faith and confidence to run the tool, derisking the project.

The environmental benefits of the first two wells were negligible as the wells were already drilled prior to testing the tool. The third pilot well had environmental benefits by reducing the drill time and associated fugitive emissions from having a single wellhead for a multilegged cased well. In normal operations there would have to be two wellheads for two cased laterals.

Project Description

Introduction

Modern Wellbore Solutions has developed a multilateral junction tool assembly (MJTA) that will allow multiple laterals to be drilled from a single vertical fracking well. With this technology, a single well can now have multiple laterals, improving the amount of a reservoir that can be accessed from a single well for a lower cost. The assembly will allow for a reduced number of vertical wells to be drilled thereby reducing the emissions associated with diesel-powered drill rigs and reduces fugitive emissions over time.

Background of the Project

Modern Wellbore Solutions originally partnered with Petroleum Technology Alliance Canada (PTAC), Seven Generations Energy, Argus Machine, and Pinnacle Oil tools, to develop a Multilateral Junction Tool Assembly (MJTA) which leads to permanent and scalable reductions of greenhouse gas emissions, economic development, and job creation. All these companies are leaders of their respective discipline to manufacture, design, and run the technology in its target formation.

Modern is developing the world's first multilateral junction that will allow natural gas operators to drill, complete, and operate multibranched wells for unconventional reservoirs. The MJTA enables multi-stage fracturing of several laterals from one vertical wellbore and associated facilities. This technology provides operators a reduction in GHG emissions and land footprint by up to 50% with less construction intensity and elimination of fugitive emissions; a decrease in capital expenditures by more than 20% with less well construction time and equipment with one vertical wellbore; and a reduction in operating costs by more than 10% with a reduction in artificial lift needs and maintenance time per wellbore.

Project objectives

1. Demonstration of erosion resistance of the MJTA
2. Demonstration of a field rated pressure of 15,000 psi (Engineered to a pressure of 16,700 psi).
3. Demonstration of mating the lower and upper junction housings during subsurface conditions.
4. Demonstration of milling a window with suitable ovality and dimension during subsurface conditions.
5. Demonstration of full borehole internal diameter access to all laterals during subsurface conditions.
6. Demonstration of interventional-less completion during subsurface conditions.
7. Demonstration of a one-trip lateral selection system to select which lateral will be entered during subsurface conditions.
8. Demonstration of liner rotation capability to achieve extended reach horizontals during subsurface conditions.

The project objectives were all met in either the field demonstrations or in house on our test bench. The objectives remained consistent over the course of the project.

The corporate structure remained the same during the project except the Modern team which needed to be reduced once we lost our original pilot partner. This reduced our burn rate to a level which aligned with the new path. Our consortium added members to run the pilot wells once we lost our first member. We needed to compress the amount of pilot wells we were running as Seven Generations originally agreed to an 8 well pilot program. The amount of pilot wells was reduced to 4 and we increased the number of tasks for each pilot.

Risk	Identified Risk	Mitigation
Technology	Uncertainty around technology performance in situ.	Testing apparatus set up in lab facility to simulate field conditions to test each stage of product development prior to downhole testing
	Sealing mechanism does not hold under fracking pressure	Iterative design and testing in custom lab facility at pressures exceeding those of fracking operations will minimize risk of failure in field tests
	Intervention-less method is challenged in situ	Iterative design and testing in custom lab facility will be conducted to de-risk before testing downhole

Project Work Scope

This Project designed, built, and test several multilateral junction tool assembly (MJTA) units in stages with each stage de-risking a component of the technology in a stepwise manner. The first stage of work will focus on demonstration of the junction prototype functionality in a shut-in well. This stage focused on an up-hole formation for testing the operation. The second stage of work was considered the early development period. This involved a single multilateral junction while hydraulically fracturing the upper lateral, thus demonstrating the tool's ability to enable lateral drilling, and functionality at fracturing pressure in an active well. The third stage of work was considered the mature development period. This involved a single multilateral junction while hydraulically fracturing the lower lateral by shifting the internal sleeves. This further demonstrated all operational one-trip systems of installation. The last stage of work was considered the commercial period. At this stage it is targeted to pilot the technology in an extended reach multilateral formation to complete all commercial technical objectives.

Documentation of lessons learned at each step occurred, with design optimizations incorporated into MJTA design for subsequent stages of work. Each test had a subsequent report that included the objective, description of test and procedure, results, and conclusion. This method helped us to organize the results and provide numerical data to the design specifications of the tool. The critical factors for the tool (pressure, tension, torque) were all captured with sensors and gauges within the test bench.

Figure 1: Test Bench Delivered to Shop

The surface tests were conducted at pressures exceeding those anticipated in the field (i.e., between 15,000 to 16,700 psi) to build safety factors into the design.

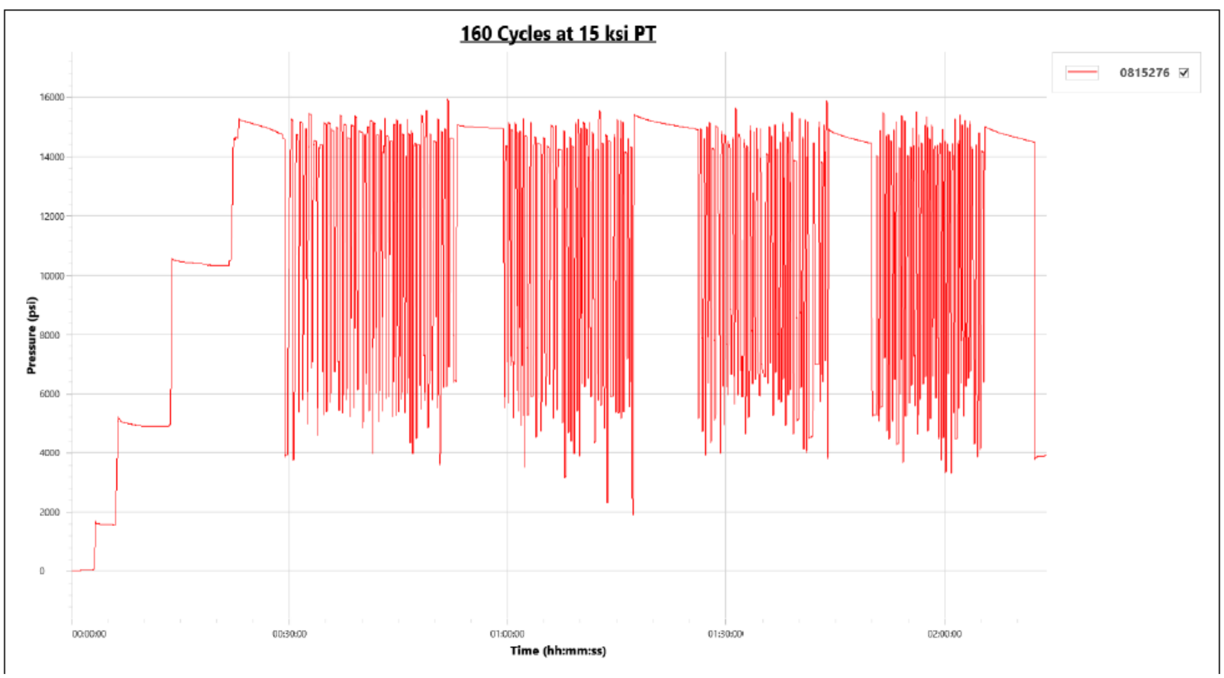

Figure 2: 15ksi Pressure Test Cycle

Prior to manufacturing each component was design with strict inner and outer diameter limits. Pressure test simulations and formulas were used to ensure the part had a sufficient safety factor. The modeling and simulations were very close to the real-world results. Multifactor calculations were used later in the project to deal with pressure and tension/compression because of internal pistons and ballooning. This led to improvements in the design and simulation techniques to reduce the frequency of in-house high-pressure testing.

Figure 3: Pilot 1

The first pilot was run in a suspended well and landed on top of a bridge plug in the vertical section. The lower junction was set, and the milling BHA created a rathole. This was pulled out of the hole to run the directional equipment with gyro due to inclination being below 5 degrees to drill the upper lateral. We learned that gyro was a very time-consuming process compared to alternative methods. Our operational procedures on the following wells ensured the whipstock was landed with at least 5 degrees inclination.

After the upper lateral was drilled the tools were pulled, and the whipstock was fished out of the hole, extending the lower junction to align with the upper lateral. The upper junction was run in hole and aligned and oriented as confirmed with the alignment key shear force and depth. The liner hanger above the upper junction was set and pressure tested. The objectives of the well were all successful.

Figure 4: Pilot 2

The second pilot was a re-entry candidate into a live well. Frac sleeves were run into the lower lateral, cemented, and liner hanger set. The lower junction was stabbed into the lower liner hanger and set with compressive force. All shear values went as planned and the rathole drilling started. The milling BHA became stuck in the hole which required a fishing operation that removed the trapped bit. During the fishing operation a non-API spec rental crossover sheared off from the high torque. This led us to design all our crossover equipment moving forward. We also increased the thread size of each of the mills to increase torque and tensile yield.

The backup milling string was run in hole to finish the rathole. Since the inclination of the well was greater than 5 degrees, MWD was used to orient the directional equipment. This sped up the upper lateral drilling time substantially. The whipstock was pulled out of the hole, extending the lower junction to align with the window. The frac sleeves and casing were then run in hole and cemented. A dissolvable stage tool was used to cement the upper lateral which became the new method for cementing the upper junction and removed the need for a side seal.

Figure 5: Dropping Frac Ball at Pilot 2

After the cementing was completed the frac head was put on the wellhead and the toe port ball was dropped to start the frac. The job was met all the objectives.

Figure 6: Running Coil to Switch Junction Sleeves for Milestone 3

For the third milestone coil was run into the upper junction to switch the isolation sleeve into the open position to access the lower lateral. Coil shifting tools along with locator subs gave us an accurate indication of depth and which lateral we were running through. The coil shifting tool gives the ability to frac both laterals without the need to return to surface, or intervention-less completion. The upper isolation sleeve was shifted down but there were issues getting into the lower lateral. After extensive investigation it was discovered that the upper junction did not orient accurately, and the isolation sleeve opening was not aligned with the lower junction. The upper junction was pulled from the well and an auxiliary stab in tool was run in to provide pressure isolation from surface to the lower lateral. The lower lateral was fractured then acidized and put on production.

The investigation into the misalignment showed that the first iteration of the extended reach tool was causing excess friction on the articulation joints while riding up the lower junction face prior to mating. The revised extended reach tool removed any excess friction and had the same torque requirements with zero to 30,000 lbs of compressive force loaded on it.

Figure 7: Pilot 4 Lease

The final pilot well was the most successful and tested the revised extended reach tool which gives the tool commercial feasibility. The upper lateral was 500m long which is required for the multilateral well to have the most reservoir exposure. The extended reach feature was tested extensively in the months prior to the pilot. The tool transfers compressive force through an inner string to the liner hanger above the upper junction. The allows the articulating components of the upper junction to remain free floating even though there up to 30,000lbf compression pushing on the bottom of the tool. This compressive is a result of the liner drag as it's being run into the well. The other steps of this pilot were like the first 3. All the objectives of this pilot were successful, and the well is currently producing.

Commercialization

Our last pilot was very successful for our partner. We are in continued talks to run another tool later in 2024. We have had increased discussions with end users post pilot to see if our tool is a fit in their formation. The tool can make unprofitable formations commercial as two laterals can be lined or lined and fractured.

Project Objectives:

1. Demonstration of erosion resistance of the MJTA – Completed in the field and bench.

2. Demonstration of a field rated pressure of 15,000 psi (Engineered to a pressure of 16,700 psi). – Completed on the bench at 15,000 psi and in the field at 12,500 psi
3. Demonstration of mating the lower and upper junction housings during subsurface conditions. – Completed on the bench and subsurface
4. Demonstration of milling a window with suitable ovality and dimension during subsurface conditions. – Completed on the bench and subsurface
5. Demonstration of full borehole internal diameter access to all laterals during subsurface conditions. – Completed on the bench and subsurface
6. Demonstration of interventional-less completion during subsurface conditions. - Completed on the bench and subsurface
7. Demonstration of a one-trip lateral selection system to select which lateral will be entered during subsurface conditions. – Completed on the bench and subsurface with coil.
8. Demonstration of liner rotation capability to achieve extended reach horizontals during subsurface conditions. – Completed on the bench and subsurface

Business model is direct sales:

- Currently only selling directly to the operator
- Commercial selling price $345,000

R&D Development or JV:

- New or existing wells owned by pilot partners.
- Selling price $125,000

Growth market strategy

- Diversification of operators and formation types
- Diversification with Alberta base geothermal projects

TRL is commercial for specific formations and reservoirs. Improvements need to be made to the tool to make it reliable in deep high-pressure formations. TRL between and 7 and 9.

Lessons Learned

The project had several challenges and delays that were all overcome. Our initial pilot project partner, Seven Generations was acquired after our first pilot well. They terminated our eight well pilot program agreement and the company had to restructure. Through our extensive industry network, we found another project partner that was aligned with the advancement of the tool for their assets. At the beginning of due to our Seven Generations partnership we were only focused on developing the tool for a specific area, but we realized that the tool can be very beneficial in numerous formations. This has helped us increase our total potential market size and give us more flexibility.

The project was delayed slightly due to finding a new pilot partner after Seven Generations and contract negotiations between our pilot 4 partner and their landholder. These obstacles are out of our control, and we have budgeted for delays in our working capital.

Environmental Benefits

Emissions Reduction Impact

The GHG reduction was calculated using our Delphi emissions calculator and the daily drilling reports from the most recent pilot.

	Length, m	Weight, kg/m	Weight, kg
Surface Casing	128	48.06	6,152
Intermediate	1098	34.22	37,574
Slotted Liner	318	17.26	5,489
Slotted Liner 2	476	17.26	8,216
Surface Cement, tonnes			11
Intermediate Cement, tonnes			41
Total Days			10
Modern Extra Leg, Days			3
Total Diesel Cost			$ 37,048
Diesel, $/L			$ 1.50
Diesel, L			24,699
Vertical + Lateral, L			17,289
Second Lateral, L			7,410

Figure 8: Table of Pilot Inputs

The diesel volume was estimated based on the fuel cost for the drilling rig. The diesel was split into days required to drill the first vertical and horizontal leg and time Modern run in our multilateral technology to completion. On days alone it only takes another 3 days to complete another lateral compared to the conventional 7 days, saving 4 days.

In this specific area the depth of the reservoir isn't as deep as our target market so the GHG reduction will be much higher the deeper the well.

The GHG emission reduction for this job was 301 tonnes of CO_2e or a 16.2% reduction over baseline of two separate wells drilled.

RESULTS SUMMARY

Results Summary (Demonstration Project)

	Greenhouse Gas Emissions CO2e Tonnes
Standard Emissions Metrics	
Baseline Emissions	1,860
Project Emissions	1,559
Net Emission Reductions	**301**
GHG Reduction, %	**16.2%**

Quantification Period 6 years

Figure 9: Project GHG Impact

General Information			
Parameter	**Quantity**	**Units**	**Source**
Baseline Period	6	years	Modern Wellbore
Project Period	6	years	Modern Wellbore
Baseline Wells	2	wells	Modern Wellbore
Project Laterals	2	laterals	**Sonoro Pilot Project**
Baseline and Project Well Drilling Length	1550	m	**Sonoro Pilot Project**
Lateral Drilling Length	550	m	**Sonoro Pilot Project**
Shale Gas Updated for GHGenius - 2011 - Well Drilling Length	6000	m	Shale Gas Updated for GHGenius - 2011

Component Production (P1, B1)			
Vertical + Single Lateral Well	**Quantity**	**Units**	**Source**
Steel	51,941	kg	**Sonoro Pilot Project**
Cement	52	tonnes	**Sonoro Pilot Project**

Lateral Well	**Quantity**	**Units**	**Source**
Steel	8,216	kg	**Sonoro Pilot Project**
Cement	0	tonnes	**Sonoro Pilot Project**

Transportation to Site (P2, B2)			
Transportation distance to site	500	km	estimation

Drilling (P3, B3)			
Vertical + Single Lateral Well	**Quantity**	**Units**	**Source**
Logistics - Diesel	15,984	L	Shale Gas Updated for GHGenius - 2011
Drilling - Diesel	17,289	L	**Sonoro Pilot Project**
Drilling - Gasoline	723	L	Shale Gas Updated for GHGenius - 2011
Well Test Flaring - CH_4	99,717	m3	Shale Gas Updated for GHGenius - 2011

Lateral Well	**Quantity**	**Units**	**Source**
Logistics - Diesel	5,672	L	Calculation
Drilling - Diesel	7,410	L	**Sonoro Pilot Project**
Drilling - Gasoline	257	L	Shale Gas Updated for GHGenius - 2011
Well Test Flaring - CH_4	35,383	m3	Shale Gas Updated for GHGenius - 2011

Production (P7, B7)			
Baseline	**Quantity**	**Units**	**Source**
Fugitives	6,632	kg CH4/yr	Calculation
Project	**Quantity**	**Units**	**Source**
Fugitives	5,883	kg CH4/yr	Calculation

Abandonment (P9, B9)			
Vertical Well	**Quantity**	**Units**	**Source**
Abandonment Fuel	4,350	L	Modern Wellbore
Cement	2	tonnes	Modern Wellbore

Figure 10: GHG Impact Input Data

PROJECT CALCULATIONS

Demonstration Project GHG Calculations

SSR	Greenhouse Gas Emissions			
	CO2	CH4	N2O	CO2e
	Tonnes	Tonnes	Tonnes	Tonnes
One-Time-Only, Before Project				
P1 Component Manufacture	140			140
P2 Transportation to Site	12			
One-Time-Only, During Project				
P3 Drilling	525			525
On-Going, On-Site				
P7 Production		35		882
One-Time-Only, After Project				
P9 Well Decomissioning	12			12
Totals	**688**	**35**	**0**	**1,559**
	CO2	CH4	N2O	CO2e

Figure 11: Project Specific GHG Impact

BASELINE CALCULATIONS

Baseline Calculations - Demonstration Project

SSR	Greenhouse Gas Emissions			
	CO2	CH4	N2O	CO2e
	Tonnes	Tonnes	Tonnes	Tonnes
One-Time-Only, Before Project				
B1 Component Manufacture	236			236
B2 Transportation to Site	20			
One-Time-Only, During Project				
B3 Well Drilling	606			606
On-Going, On-Site				
B7 Production		40		995
One-Time-Only, After Project				
B9 Well Decomissioning	24			24
Totals	**885**	**40**	**0**	**1,860**
	CO2	CH4	N2O	CO2e

Figure 12: Baseline GHG Emissions

Once commercial we expect multiple deployments a year. As of right now there is no immediate comparison for unconventional multilaterals. We have taken a conservative approach of 2-4 junctions in the first year with a 50% increase for 3 years. A more conservative 10% increase in sales after that due to market saturation in specific formations. We will be modifying the technology for use in multiple formations moving forward to have the highest possible market size.

Using the pilot well GHG reductions as the baseline reduction we have a cumulative GHG reduction of ~430,000 tonnes of CO2e.

Year	Junctions Sold, per year	CO2e Reduction, tonnes	Cumulative CO2e Reduction, tonnes
2024	2	602	602
2025	4	1,204	1,806
2026	8	2,408	4,214
2027	16	4,816	9,030
2028	18	5,298	14,328
2029	19	5,827	20,155
2030	21	6,410	26,565
2031	23	7,051	33,616
2032	26	7,756	41,372
2033	28	8,532	49,904
2034	31	9,385	59,289
2035	34	10,324	69,613
2036	38	11,356	80,969
2037	41	12,491	93,460
2038	46	13,741	107,201
2039	50	15,115	122,315
2040	55	16,626	138,942
2041	61	18,289	157,230
2042	67	20,118	177,348
2043	74	22,129	199,477
2044	81	24,342	223,820
2045	89	26,777	250,596
2046	98	29,454	280,050
2047	108	32,400	312,450
2048	118	35,640	348,090
2049	130	39,204	387,293
2050	143	43,124	430,417

Figure 13: Table of Projected GHG Reduction

Other Environmental Impacts

Per one junction installation compared to the baseline of two horizontal wells.

- The land usage with be reduced by 50% in non pad drilling formations.
- CO2e reduced equal to 44,000 trees planted and sequestered.
- 14,000 trash bags of drilling cuttings reduced.
- 35,000L of drinking water saved with less drilling fluid.

Economic and Social Impacts

The project has helped create a one a kind test bench in Alberta that multiple companies have used to test their prototype tools. This has not only helped Modern further develop our technology but other companies technology that is now commerical.

The tool has a direct cost saving with each junction installation. As of now we are only installing one junction at a time but we plan on installing or stacking multiple junctions to reduce the D&C initial costs by >35%. Due to the reduced initial capital required to develop assets the breakeven cost per barrel is reduced and will help lower production costs and increase royalties to the province.

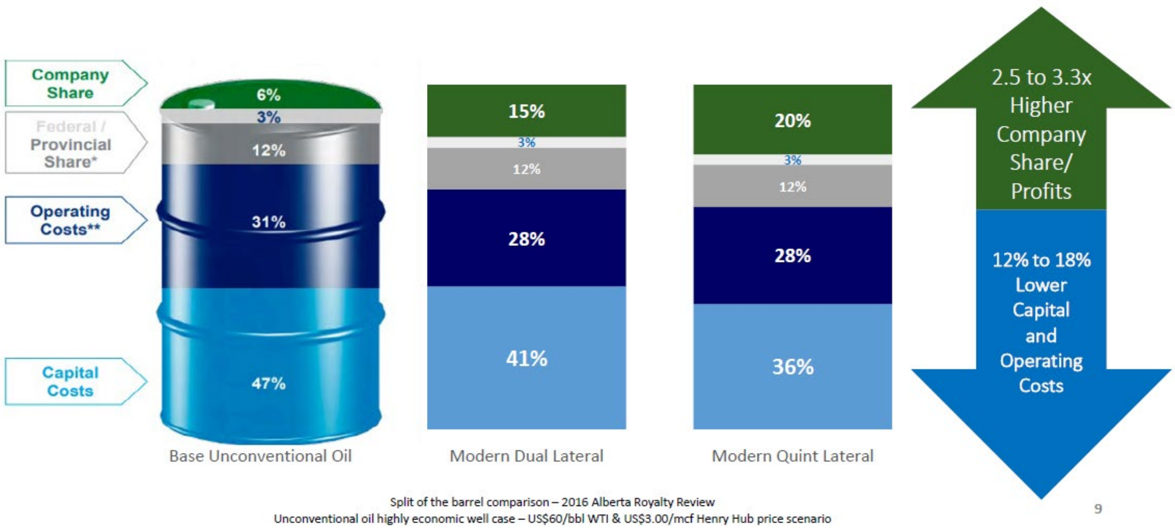

Figure 14: Modern Multilateral Economic Benefit

Our employees have continued to train and aid in developing the tool. The skills learned will be very unique and required to run this technology. Once commercial they will teach other toolhands and transfer this knowledge.

Scientific Achievements

Modern's method and process patents to date:

IP Asset Type	Region(s)	Identifying Number	Status	Filing Date	Ownership	Description
Patent Appl.	US	16/094,177	Pending	Dec 18, 2015	Owned	Initial apparatus and method design of the multilateral junction tool assembly - Mating mechanism associated with whipstock - Configuration of fluid diversion and pressure isolation in the upper junction only - Apparatus and method claims around the 2016 embodiment.
	CA	3,020,992	Pending	July 1, 2014	Owned	
Patent Appl.	PCT	N/A	Anticipated	2020	Owned	Improved apparatus and method design of the multilateral junction tool assembly from development of the technology over time. - Improvements to the mating mechanism associated with whipstock - Configuration of fluid diversion and pressure isolation with the lower junction included - Apparatus and method claims around the 2020 embodiment
	PCT	N/A	Anticipated	2021	Owned	
Trade Secret	Global	Actively Controlled	Active	NA	Owned	Surface multilateral drilling test bench set up and operation

Figure 15: Modern Patents

United States

- No. 10907411 – Issued on February 2, 2021

Canada

- No. 2915624-request for accelerated examination filed.

In-progress of filing additional defensive patents for innovational aspects

Modern presentations:

- Darcy Partners virtual forum on September 6, 2023, for a multilateral well construction
- D&C Innovation forum on September 21, 2023, for all the large O&G companies within Alberta

Overall Conclusions

Overall, the project was successful even with the changing of major project partners and modified timelines. We had hoped to have more commercial success to this point, but the uptake seems to be gaining traction after the success at pilot 4. The development of the tool has surpassed our initial expectations with all the revisions and testing required to get it to this point.

There were minor GHG reductions at the last pilot attributed to the company only requiring one wellhead and vertical section to get access to two lined horizontals. The emissions from the fugitive emissions of two wells will be cut in half by the junction installation.