AFFORDABLE ZERO-EMISSIONS FAIL-SAFE ELECTRIC DUMP VALVE ACTUATOR (Fail-Safe EDVA)

Final Report
May 25, 2022

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Executive Summary

This final report summarizes the outcomes of the project concerning the Affordable Zero-Emissions Fail-Safe Electric Dump Valve Actuator (Fail-Safe EDVA). Linear Motion Technologies Canada undertook the project in collaboration with Petroleum Technology Alliance Canada (PTAC). This project commenced on May 13, 2019 and concluded on March 31, 2022.

The project performed applied research, prototype design and development, bench testing, and field testing of an affordable and fail-safe electric dump valve actuator (EDVA) that will replace existing pneumatic valves in the oil and gas industry. The applied research for the EDVA and test unit supply effort was performed by LMT-Canada's parent company LMT Management Corporation in Houston, Texas. Due to the 2020-2022 pandemic, systems engineering, controls development, dump valve actuator integration, prototype shop testing, field trial planning, and field testing were also performed by LMT Management Corporation with three field tests in Texas. Canadian oil and gas companies Cenovus Energy, Husky Energy, Shell Canada, and Whitecap Resources participated in the project. PTAC Petroleum Technology Alliance Canada provided project management in Calgary, Alberta.

The objective of this project was to complete, based on an initial proof of concept, the prototype design and testing of a zero-emission, fail-safe, and affordable electric dump valve actuator (EDVA). The Fail-Safe EDVA will enable the replacement of existing pneumatic valve actuators which cause a large percent of methane emissions in production sites across Canada (i.e., British Columbia, Alberta, Saskatchewan, and Manitoba) which will support Canada's goal towards air emissions reduction from the oil and gas sector.

Completing the project offers the opportunity for significant greenhouse gas emissions reductions estimated to be at 3.3 million tonnes of carbon dioxide equivalent (CO2e) after year 5 of deployment in the Canadian oil and gas sector, contributing to Canadian targets for emissions reductions and the Net Zero vision. The EDVA project also supports Canada's competitiveness while transitioning the technology landscape to a low carbon economy and creating market growth. The potential market rollout of EVDA units represents a manufacturing and installation revenue of up to $38 million per year and the creation of up to 40 full-time equivalent jobs in Canada, further strengthening economic opportunities.

1. Introduction

The Challenge

For 2014, the Alberta Energy Regulator (AER) estimated oil and gas methane emissions at 33.3 million tonnes CO_2e ($MtCO_2e$). Global estimates are 1,300 $MtCO_2e$ per year. Venting and leaks from pneumatic instruments (excluding pumps) contribute to 22% of Alberta oil and gas methane releases.[1] Dump Valve Actuators (DVA) make up most of those pneumatic instruments. The

[1] *2018 Alberta Upstream Oil & Gas Greenhouse Gas Emissions Inventory and Methodology* by Clearstone Engineering, prepared in 2019 for the Alberta Energy Regulator

Alberta and Canadian governments have introduced strong methane emissions targets to reduce industry GHG emissions. However, operators struggle to bear the extra costs of compliance amidst poor market conditions. There is an acute need for innovative, affordable, reliable technologies to replace pneumatic devices, particularly DVAs. Linear Motion Technologies (LMT) Canada's SmartRam™ Electric Dump Valve Actuator (EDVA) is perfectly aligned to meet this demand.

The Solution

The EDVA will replace a large percentage of pneumatic devices currently in use and provide a more efficient and affordable alternative for new installations. Replacing pneumatic actuators with EDVAs completely eliminates all associated methane emissions. Furthermore, the EDVA requires fewer and far simpler parts than competitive devices, resulting in a more reliable technology that is cheaper and easier to install and maintain.

In 2019, PTAC and LMT Canada initiated the EDVA project Phase 1 with support from Natural Resources Canada (NRCan) and Alberta Innovates concerning the design, development, and field test of an Affordable, Zero-Emission, Fail-Safe EDVA for 1" valve applications.

In 2020, the EDVA project Phase 2 was added with support from Emissions Reduction Alberta concerning the development and testing of a larger EDVA for 2" to 4" valves with the addition of modulating precision control capability.

The concurrent development, production, and testing of EDVAs of two sizes will also significantly reduce the cost for oil and gas end-users, resulting in a higher uptake of the technology among Canadian operators. This increased interest means more pneumatic devices will be replaced, resulting in further emissions reduction. Canada's natural gas operations' safety, reliability, and profitability will also be increased.

Project Scope

1. **Phase 1 – Demonstration Prototype Unit (DPU)**

   1.1 Finalize the demonstration prototype unit (DPU)

   To create a first prototype Electric Dump Valve Actuator (EDVA) for a standard 1" or 2" O&G Control Valve.

   The DPU will be capable of functioning as a 1" or 2" fail-closed valve, with a yoke and position indicator. The results of this effort will form the basis for Bench Test Unit (BTU) requirements.

2. **Phase 2 - Bench Test Unit (BTU)**

   2.1 Bench testing unit (BTU) design

   2.2 Complete BTU Procurement Fab, Assembly & Checkout

   2.3 Complete Bench Test

   The BTU will include the instrumentation interfaces necessary to evaluate BTU power consumption and output performance, and safe operation. Research tasks will include

functional and limited environmental testing to determine if the design options will meet the technical requirements and identify any required design modifications. Initial quantification of design performance will be achieved.

The BTU will be capable of functioning as a 1" or 2" fail-closed valve at a reasonable duty cycle for a minimum of two weeks.

3. **Phase 3 - Field Test Unit (FTU)**
   - **3.1** Field testing unit (FTU) Design
   - **3.2** Complete FTU Procurement Fab, Assembly Checkout
   - **3.3** Complete Field Tests

To design, assemble and test the 1” diameter FTU and the 2” diameter FTU with the required user-specified functionalities.

To improve the electronic controller card to enable manufacturing using automated manufacturing equipment.

The FTU will be capable of safely functioning a 1" or 2" fail-closed valve at a reasonable duty cycle for a minimum of 10 years in all control valve operating environments.

4. **Phase 4 - Project and Technical Management**
   - **4.1** Technical Management

Management of the technical activities.
Task technical reports

- **4.2** Project Management

Overall project management and reporting.
Quarterly progress and financial reports, financial management and final reporting.

2. Background

The LMT Intellectual Property (I.P.) includes trade secrets and patented elements. The SMA wirepack is treated as a commercially supplied "black box", with specifications defined at the assembly level during this project. LMT’s EDVA uses a uniquely capable Shape Memory Alloy (SMA) actuation technology that relies on the alloy's ability to return to a given shape when heated and relax to the original shape when cooled.

The EDVA SMA technology controls the dump valve actuator by electrically activating bundles of tensioned wires (wirepacks) using simple Joule-resistance heating, which functions much like a light bulb filament. SMAs can return to, or "remember," a predetermined shape when heat or an electrical charge is applied to the metal and then relax to their original shape when the charge is removed. When a tensioned or stretched SMA wire contracts in response to an electrical current, it exerts an extremely powerful "muscular" force. An SMA can be envisioned as an "electric muscle", although it is much more powerful than human muscle (i.e., 100x to 1000x more

powerful than human muscle) with very high energy density. The two off/on states: 1) the “off”, cooled martensitic, in which state it is relatively soft and easily deformed; and 2) the “on”, warmed austenitic state, above the transition temperature range (TTR), at which point the SMA becomes much stiffer and harder.

Many different SMA alloys exist today that exhibit a shape memory effect, and SMAs can deliver high energy-density for actuators. However, SMAs used today in commercial actuator systems for heavy-duty operations are usually applied to single- or low-cycle applications, since current commercially available alloys suffer significant performance constraints that limit combined long term, high-force, and high-cycle functionality. LMT’s SMA system overcomes this combined high-force and high-cycle constraints using exclusive sole-source Trade Secret capabilities. LMT's SmartRam™ SMA technology has benefited from many millions of dollars in prior successful investments in development, testing, production, and application in combined high-force, high-cycle uses that demand ultra-reliability in hostile environments. (More details on Trade Secret capabilities are available under strict LMT-approved nondisclosure agreement.) In addition, LMT uses a previously pioneer-patented, unique hydraulic interface system that ensures maximum energy efficiency and simple, heavy duty, reliable, bolt-on drive train performance.

Canadian operators in the Petroleum Technology Alliance Canada (PTAC) network indicate the need for an affordable, fail-safe, electric level controller and dump valve actuators to replace pneumatic devices. To date, transition away from gas-pneumatics has been hampered by the lack of both affordability and true, mechanical failsafe performance available with the electric options. O&G operators rightly require dependable long-life mechanical failsafe devices in critical control tasks to ensure continued production without disruption, and to avoid casualty and property losses, and avoid environmental degradation.

The goal of this project has been to demonstrate that LMT’s unique SMA technology can meet operators’ affordability and critical safety needs with an EDVA that otherwise meets or exceeds the performance of gas pneumatics. The LMT SMA’s heavy duty, high cycle capability combined with the EDVA’s mechanical failsafe provides end users with the assurance of years of strong and safe performance in critical operations. ***This report discusses LMT’s successful accomplishment of the NRCan’s project goals and the benefits it will offer to industry and corporate partners.***

3. Objectives and Performance Measures

3.1 Clean Energy Technology Progression

- Technology progression in the Technology Readiness Level (TRL) scale, beginning at TRL 5 and ending at TRL 7 at the end of the project.

3.2 Demonstration Prototype Unit

- Development and evaluation of a Demonstration Prototype Unit (DPU) completed (an improvement of initial prototype), reaching TRL 5.

3.3 Bench Testing Unit

- Development of a Bench Test Unit (BTU) and testing in conditions representative of operating wellsites) completed, reaching TRL 6.

3.4 Field Testing Units

- Original contract scope included development of the 1” Field Test Units (FTUs) and testing at an operating wellsite completed, reaching TRL 7.
- The contract scope was extended to include development of the 2” FTUs with modulating capability and testing at an operating wellsite completed, reaching TRL 7.

4. Project Results

4.1 Project Achievements

4.1.1 Achievement 1 - Development and Testing of the DPU EDVA

The DPU was built in September 2019. The task was to upgrade an existing boardroom demonstration unit to create an EDVA for a standard 1” or 2” Oil and Gas Dump Valve. The DPU unit was tested and determined to be capable of fully opening a fail-closed valve with a yoke and position indicator in an on/off control mode. This achievement was completed with a 1" D2T Fisher valve.

4.1.2 Achievement 2 - Bench Testing of the 1” BTU EDVA

The BTU was completed in February 2021 and extensive bench testing was conducted through mid summer 2021. The design, construction, and testing of the BTU included:

- Design and fabrication of a prototype test unit.
- Development of actuator force output requirements.
- Wire pack engineering.
- Hydraulics engineering.
- Hydraulics testing.
- Enclosure design.
- Ambient temperature bench testing; and,
- Field installation and test planning and preparation.

This achievement included design and fabrication of the BTU and testing in a laboratory environment, using a field-compatible power supply. LMT’s BTU was designed with integrated instrumentation for performance measurement. Two weeks of BTU laboratory testing was required, but testing was ultimately conducted for a period of five weeks. Instrumentation measured reliability and repeatability indicators, power consumption, force output, hydraulic efficiency, spring failure performance, and shutoff performance (a DVA valve leakage test).

The SmartRam™ wire pack, hydraulic system and failsafe spring were designed to deliver enough force to achieve ANSI Class IV shutoff against a 500-psi upstream nitrogen pressure source. The

SmartRam™ BTU was installed on a hydraulic system and tested with a Fisher D2T valve. The BTU test at ambient temperature yielded a leakage rate of less than 0.10 SCFH against a 500-psi upstream nitrogen pressure, far exceeding the industry certification requirement.

During BTU testing the potential for variable stroke capability was validated in several ways and for many cycles and provided confidence that a full range of stroke lengths is readily achievable. (Supporting data is available on request with an LMT-approved nondisclosure agreement.).

4.1.3 Achievement 3 - Field Testing of the 1" FTU EDVA

The final major milestone in the original project scope was achieved upon completion of field testing of the wellsite-compatible 1" FTU. With the Canadian/USA border closed due to COVID-19, it was impossible to do a field test in Canada with the four operators participating in the project as originally planned. After consultation with PTAC/NRCan, LMT identified and engaged with an operator in the U.S. to perform field testing at one of their typical natural gas wellsites. The operator had several production sites north of Houston, Texas, and a property in Leon County was selected.

Figure 1. Photo of the Well Test Site Separator

Note: Single phase water/gas separator with average sized 1" dump valve

The site selected was remote in that there was no utility power or cellular service at the well pad. The production company responsible for the wellsite gave LMT permission to enter the property under the following conditions:

1. Minimal production interruption to on-going wellsite operations.
2. Existing equipment to remain intact and operational.
3. FTU to run in parallel with the existing installed system.
4. FTU to support switching back to the existing system with no interruption to production.
5. Proper safety protocols to be observed on-site by all personnel participating in the test (Hard Hat, Steel Toed Boots, Safety Glasses, and Fire-Retardant Clothing).
6. The wellsite to be left in its original condition.

7. Any issues or concerns experienced at the wellsite to be reported to the operator immediately.

LMT made several visits to the wellsite to assess conditions, measure and record existing system performance data, and take photos and videos, including the photo in Figure 1.

LMT determined from the field test site survey the information and conditions shown in Table 1 below.

Table 1. Equipment and Operating & Site Conditions	
Separator	Vertical 2 Phase (Gas over Water)
Separator Size	14” OD x 12’ H
Separator Pressure	150-250 psig
Separator Connection	2" Connection for CV and 1" Connection BV Isolated/Plugged
Level Switch	Norriseal Series 1001 Snap Acting Pilot Level Controller
Control Valve	Norriseal Series 2220 Reverse Actuator 1" C.S. Body 3/8" Trim FTC
Supply Gas	150-250 psig regulated down to 25 psig to controller
Power Availability	Solar or Self-Generated Power
Fluid	Production Water and Gas
Site Ambient Temperatures	Day Time: 90-105 °F Nighttime: 71-76 °F

LMT worked closely with the operator to ensure installation met their requirements. For the field test, the dump valve in the FTU was installed in parallel with the operator’s existing liquid dump valve system. This arrangement satisfied the operator's requirements of minimizing production downtime, leaving existing equipment in its original condition and providing switchover to the operator’s installed system at any time with no production loss. The approach and equipment portability facilitates testing at any wellsite.

LMT used the BTU to check performance of key FTU components prior to FTU assembly to reduce field test risk, including validation that the selected explosion-proof pressure switch would function as required. The pressure switch was installed on the BTU in August 2021 to configure and test with the Programmable Logic Controller (PLC). LMT had, a professional engineering firm with extensive automated test systems, test the unit at 200 PSIG with a pressure switch activating the electric actuator system to ensure everything worked properly and to allow time to make any needed adjustments prior to the field test. LMT changed the closing time to a faster 6 seconds to

mimic separator control conditions, and the field engineer signed off on the unit to be put into the field for testing.

With minimal space available upstream of the existing valve installation, LMT decided the best solution to meet the operator's requirements would be to use the secondary nozzle connection on the separator for the inlet connection to the LMT valve. LMT installed a piping tee just downstream of the check valve on the outlet of the existing valve, where it could be connected to the LMT line to the outlet of the LMT valve. The LMT outlet line included a check valve and strainer to prevent backflow and valve contamination. LMT used flexible 1,000 psig-rated high-pressure hoses to make the connection with quick connects for easy assembly and disassembly. LMT installed a tubing tee with isolation valves so that the pressure switch could be installed on the output gas from the level controller to the existing valve actuator.

The FTU was connected to the high-pressure hoses for testing. LMT isolated the existing valve and brought their unit online. In the first cycle of the test, the pressure switch was observed activating the LMT wire pack when the level controller increased the gas output load above the setpoint, i.e., when commanded by the float switch, the LMT EDVA activated and successfully opened the dump valve. When the separator float level controller was next satisfied that the liquid level had dropped to meet its setpoint, it started venting the gas to reduce the pressure below the pressure setpoint. Once this decreased below the setpoint, the EDVA allowed the valve to move to the closed position, which maintained the spring return seat valve closure forces needed for successful failsafe operation.

The only issues experienced during testing of the 1" EDVA were with the valve mount and pipe brackets that were initially insufficiently aligned and temporarily caused valve stall or jamming. When this misalignment malfunction was discovered and electronically sensed, corrective bracket mounting workarounds were installed, and tests were later re-commenced with the same LMT SMA EDVA system operating perfectly to complete all testing objectives.

Note that the LMT SMA motor and EDVA actuator system did not need any repair when it encountered a stall situation as mentioned above, only a bracket alignment was corrected. Even after being operationally jammed and stalled during many high-force electric actuator test operations, the EDVA later continued to function without any damage as planned, where all the test objectives were successfully met. This also means, this encountered stall/jamming issue demonstrated a key benefit offered by LMT's SmartRam™ EDVA – the ability to encounter a stall/jamb situation and later continue operation without damage. Typically, when a traditional "rotary electric motor + gearing" valve actuator repeatedly encounters stalls when actuating (whether caused by similar misalignments that LMT encountered, or by ice or foreign dirt materials) the traditional electric motor+gears system will stall. After several stall situations, the rotary electric motor may burn out (which would then require motor/actuator replacement). This motor-burnout situation didn't and wouldn't happen with LMT's SMA technology, which is considered an "inherently robust and forgiving system" on encountered situations where jamming/stall is caused by unforeseen obstructions. This same "forgiveness" ability is considered

a valuable attribute to remote hostile aerospace and astrospace uses, and this forgiveness ability will benefit the remote oil and gas fields too.

Furthermore, in addition to the "forgiveness", in the event of an encountered blockage, LMT's technology also offers another benefit of invoking an added "overclocking" or "get a bigger hammer" effect, that provides the LMT SMA actuator with extra-muscle power (via controlled extra wattage) when needed to "create a higher-than-normal force. Basically, overclocking allows an LMT actuator system to "power-through" a stall or breaking free a blocking material. Again, this overclocking can and will be a benefit to remote oil and gas separator dump valves, which sometimes freeze and jams with ice (these are commonly called "stuck dump valves", and these events can cause significant large methane venting to water/oil tanks when this occurs). So, the LMT EDVA system has added robust and forgiving benefits that: can smart sense a blockage, it can overclock and many times to possibly break free the ice/obstructions, and then robustly continue in operation remotely without any motor/actuator replacement or human intervention.

<u>The 1" EDVA field test proved that:</u>

- LMT's actuator technology works in the field to power/replace gas pneumatic dump valves.
- LMT's actuator technology can operate at 109° F ambient temperature in the Texas sun.
- LMT's prototype EDVA can currently achieve 6-second on, 6 second-off timing, which operators have said is considered desirably fast for current dump valve operation. Faster timing is achievable, if desired, in future devices.

1" FTU EDVA field testing successfully demonstrated the performance of LMT's electric muscle technology in an electric, zero-emission dump valve actuator meriting further development. All test results indicated that an LMT EDVA can meet functional and environmental requirements, and that market deployment will offer the desired emission reductions at an affordable cost.

4.1.4 Achievement 4 - Field Testing of the 2" FTU EDVA

The 2" valve FTU was built with the ability to modulate, using design and construction like the 1" FTU. The 2" FTU was designed with instrumentation to enable monitoring of individual components within the actuator system, so that any problems that could arise from the continuous cycling of the system could be quickly addressed.

In December 2021, LMT moved the 2" FTU to the wellsite location. The August and September field tests had provided a lesson learned concerning the attachment alignment (valve mount and pipe brackets needed absolute alignment to the valve actuator) of the FTU valve. New sturdier welded valve mount and pipe brackets were installed to overcome prior field test valve misalignments and the changes eliminated prior problems. Please note, as was importantly discussed earlier in this report, that the LMT SMA actuator system still functioned, despite the FTU bracket misalignment obstruction.

As was done during the 1” FTU testing, LMT isolated the wellsite’s existing valve and brought the 2” FTU online. In the first cycle of the test, the pressure switch activated the LMT muscle when the level controller increased the gas output load above the setpoint, i.e., when commanded by the float switch the LMT EDVA activated and successfully opened the dump valve. When the separator float level controller was next satisfied that the liquid level had dropped to meet its setpoint, it started venting the gas to reduce the pressure below the pressure setpoint. Once this pressure decreased below the setpoint, the LMT EDVA was deactivated, allowing the valve to move to the failsafe closed position.

Field Test Results and Conclusion

The field trial of the complete skid, triggered by a level switch on the well's separator, was performed at the same location the 1” EDVA testing was performed in Leon County in south Texas. The test objective was to control the level at several different valve strokes. The valves used for tests were 1” and 2" valves normally used in most if not all separator dump valve service.

- The well was encountered in normal production operation. The LMT skid, consisting of a 2" valve, the hydraulic system, and the wire pack, were piped in parallel with the normal pneumatic liquid dump system. A pressure switch was connected to the existing pneumatic level controller to provide the open/close signal to the LMT skid. When all connections were completed and tested, the flow was opened to the LMT skid with the test hardware, and the pre-existing normal dump valve was isolated.
- While not a requirement for the 2” FTU testing, two valve stroke lengths were cycle-tested: a short stroke (that operated the valve for the 6 second on-time dump cycle) and a second, 50% longer, stroke (that dumped more fluid). After two preparation cycles, nine dumps were performed with the short stroke, and then six dumps were performed with the slightly longer valve stroke. Based on all testing conducted on both the BTU and 2” FTU, LMT doesn’t anticipate any constraints regarding stroke lengths.

In summary, the field test of the 2” FTU was completed and demonstrated exceptional field performance, meeting all the requirements of wellsite dump valve actuation with the spring return failsafe feature. The EDVA successfully handled a variety of loads and conditions likely to be encountered during field operations.

4.2 Project Challenges

4.2.1 Challenge 1 - Environmental Testing

The environmental chamber was finally prepared for tests with dry runs (non-flowing fluid in the test dump valve) in late February 2022. The dry run represented a worst-case scenario, since flowing fluid would heat the valve and reduce the effectiveness of the cold test. The LMT EDVA system was designed to accommodate both cold, working, and frozen, non-moving dump valve operation. The complete unit was slowly cooled down to -36°F. The testing program was set to stroke every 15 minutes. The unit operated properly through that 3rd stroke when the test

temperature was about -23°F. However, the fourth stroke was short, and as the unit continued to cool down, the reaction strokes continued to shorten with lower temperature.

LMT has identified the problem for the lowering of valve stroke during the arctic temperature test as "having inadequate temperature compensation of the hydraulic fluid," which is most easily solved by having a larger thermal compensator volume chamber diameter.

The EDVAs hydraulic system volume was greater than anticipated due to underestimation of the thermal coefficient of contraction. This occurred because the supplier of the arctic-grade hydraulic fluid was unwilling to provide thermal expansion coefficient data for the artic fluid used, saying that it was proprietary and not releasable. A best "engineering guess" based on a U.S. military standard "arctic hydraulic fluid" value was used for the volume contraction.

As a result of the environmental test, it was clear that the LMT EDVA system needs a slightly larger compensator volume (that is now determinable from the arctic temperature test data that was gathered).

Other than the hydraulic volume compensator system, the rest of the EDVA system worked as designed for all arctic/cold conditions. A simple change to slightly increase the diameter will easily enable the EDVA to operate to -60° F or lower.

The arctic temperature testing successfully demonstrated that:

- the LMT SMA-based actuation technology functioned almost entirely as designed and is fully capable of meeting wellsite requirements in northern Canada winter conditions; and,
- the LMT hydraulic system hardware and electric controls functioned as designed and are also fully capable of meeting winter wellsite requirements.

5 Conclusion & Follow-Up

5.1 Summary Conclusion

The desired outcomes of the LMT EDVA technology development project (both initial and expanded scopes) were successfully accomplished. The prototype LMT EDVAs functioned nearly perfectly in real-world dump valve separator field testing, and the large and small sizes targeted (for 1” & 2” valves) should allow the vast majority of dump valves used in North America to have a more affordable zero emission answer.

<u>Accomplished Hardware and Testing</u>

EDVA hardware testing on all the DPU, BTU and 1” and 2” FTUs experienced only minor test rig alignment issues that were corrected, and none of which reflect any inability of LMT’s SMA technology and EDVA designs to meet all end user objectives. Testing conducted confirmed that LMT’s SmartRam™ EDVAs can meet or exceed low-power consumption, high-force output, hydraulic efficiency, spring failsafe performance, and tight valve shutoff performance requirements. This electric LMT EDVA also opens the door for affordable smart IIOT actuator

controls on separators, which according to experts is desired but is not widely done today. The configurations tested provide strong confidence in the flexibility of LMT's technology and designs. The goal of providing EDVA products that address larger multiple sizes and types of valves and valve operations (slow or fast on/off, modulating, hold-open, etc.) are readily achievable with little added power.

Lowest Cost Interchangeable/Modular Parts

LMT also planned and designed for a lowest-cost interchangeable and modular parts, such as SMA power pack, built specifically for remote EDVA dump valve service. The goal was to have sharable interchangeable parts for both 1" and 2" dump valves (that would cover 95+% of DVA market need). LMT was successful at this goal, and LMT built and tested units with desirable fast on/off speed and low-wattage power consumption for remote electric use. Details on this system design and electric wattage energy data can be made available under approved confidential NDA request, but on average the power consumption was considered to be very low by several O&G industry subject matter experts whom are experienced in the DVA area (i.e., as an example, an LMT EDVA actuation consumed between 75 and 175 watts, could power activate to fully on/open a DVA valve within 6 seconds, and could failsafe reset within 6 seconds).

Larger Valve Size Test

It was LMT's opinion that keeping focused on the majority-used 1" and 2" dump valves for the first product target was the best choice for delivering the maximum methane emission reduction impact. This 1"and 2" focus will also maximize and facilitate the best business commercialization launch success, and this was also pointed out and suggested by one of the ERA/NRCan judges. However, it should be noted that one of the LMT EDVA NRCan project team operator participant did desire to have the ability to power even larger valves (3" to 6" and possibly larger say 10" to 20"). So, LMT did contemplate and design into the EDVA system the ability to be modular and later easily-scale for larger valve sizes too (with minimal bolt-on system modifications to accomplish this). Baking this modular and scalable ability into the EDVA design sets the stage for later multi-use products expansion that can accelerate the important lowest-cost product goal.

Variable Stroke Modulating Valve Test

Even though the EDVA dump valve first product target is primarily done today with on/off valves, the LMT EDVA was also designed and tested for a variable-stroke modulating valve usage, since one of the LMT EDVA NRCan project team operator participant desired this ability. So, this variable stroke and modulation ability was successfully demonstrated and achieved on the LMT BTU and FTU units. This modulation ability is a valuable attribute that can lead to even more methane reduction for other gas-pneumatic devices. Baking this modulation ability into the EDVA design sets the stage for later multi-use products expansion that can accelerate the important lowest-cost product goal.

Product Cost and Use

LMT is confident that the final production units based on a well-engineered manufacturing design will be extremely cost competitive with any competitor's devices, and that the promise of affordable replacement gas pneumatics can be achieved. (additional information is available upon approved confidential request).

Field installation and connections are straightforward, with one or two electrical connections. Testing of both the 1" and 2" FTUs demonstrated the ease of retrofitting existing wellsites. Testing throughout the project also confirmed that the LMT EDVAs as designed will require little to no periodic maintenance.

LMT's tested EDVAs have proved to be simpler machines than electric competitors (compared to other electric motor+gears actuators and compressed instrument-air skids) in terms of the number and complexity of components, supporting the future ability to provide highly reliable devices and long device lives, even at very high cycle rates.

Comparatively, the simple LMT EDVA design will require 80+% fewer parts and with far simpler components than competitive devices, reducing hardware and installation costs (estimated to be 33%-75%), improving reliability, decreasing regulatory/maintenance costs, and enhancing wellfield digitization and automation.

LMT IP and Technology Advantage

Overall LMT's prior existing IP (patents and trade secrets) and the EDVA performed testing demonstrated on this project will provide LMT with a strong market advantage differentiator, giving the assurance that LMT's heavy-duty fail-safe EDVAs will deliver strong and safe performance in critical operations that will not tolerate failure in high-cycle applications.

Cold Arctic Testing

The LMT EDVA was also purposely designed for arctic service use, and the environmental testing that was performed here proved this functionality to -26°F. This testing also identified and defined the minor design improvements that will allow it to be readily implemented for even more severe cold arctic service down to -40°F or -60°F for Canada and elsewhere.

Covid-19 Impact

The COVID-19 pandemic significantly impacted the project's ability to demonstrate our EDVAs in Canada and we regret this. LMT's portable Field Test Simulator (FTS; described below), simplifies field-testing, making future testing in Canada more easily accomplished. Testing in the U.S. did provide very useful exposure to U.S. operators, which may benefit Canada in the long run as well.

Added Portable Field Test Separator for Easier Test Witnessing

In addition to the NRCan EDVA program, a new full-flow FTS was designed and built to exactly replicate the actual well site separator LMT tested on, which means it has verifiable fully-loaded dump valve separator demonstration ability. It is presently set up in Houston at our subcontractor shop site, and it

allows for significantly easier and lower cost witness access than visiting the actual wellsite (which is much more expensive in time, money, and personnel),

It should also be noted that this beneficial FTS demonstrator did not take away any funding from either NRCan or ERA project funds and was fully funded by contribution from the LMT team. Since LMT and the LMT subcontractors fully paid for this FTS, it also adds more demonstration of LMT skin-in the-game project cost-share, and it improves the important goal of facilitating the next step of project funding (gov't, corporate, and other investor sources) needed to get the LMT technology readied for product to market manufacture, supply, and use and for impactful methane reduction.

The FTS was also made to be truck-transportable for set up, allowing data-confirmed witnessing from oil company professionals and executives that want to view/witness the performance of the FTU in action, say in their parking lot at their work campus.

For Canada, the Covid cancelled EDVA field test that was originally intended, this FTS also means that that, if funded, it can be truck transported to Canada for a lowest cost witness demonstration.

5.1 Next Steps

5.1 PTAC

Per NRCan reporting guidelines, PTAC will be contacting all partners involved in the project every year for five-years to request performance statistics and further updates on LMT progress.

5.2 LMT

LMT is and has been courting and stage setting for continued capitalization to support continued product deployment on the EDVA.

At this time, it is intended that the core SMA wire pack element will be designed and manufactured by LMT in a dedicated manufacturing facility, and then supplied to valve companies/suppliers/packagers in Canada and the United States. This will allow for credible supply chain that operator end user customers trust and prefer. All required tasks for LMT can be accomplished using only commercially available design tools, materials, and production equipment. For all other aspects of design, production, and delivery, LMT will select and establish contractual agreements with Canadian and U.S. firms with established expertise, including an industrial product design firm, experienced energy industry manufacturing contractors, sales representatives, distributors, and suppliers.

Please note that prior high QA/QC pilot manufacturing has been previously accomplished for LMT SMA tech in other markets that are not publicly known. This means there is even more reduced LMT EDVA risk because that SMA pilot manufacturing technology know-how has already been de-risked for successfully used products in other market products. (Details here can be discussed under strict and approved confidential NDA). This pre-existing manufacture know-how IP, along with the above described pre-existing ‘LMT IP Tech Advantage’ will and is greatly facilitating and increasing commitment for corporate-partners and investment funds that are needed for the EDVA product deployment success.

LMT's "core-manufacture and partner-package/supply" approach will ensure that all steps are completed in the most efficient ways possible and minimize the investments required to deliver LMT products to end users. Going forward, as different products are added, a dedicated manufacturing center designed with assembly lines segmented for various devices and applications, will enable LMT to maximize deliveries for each configuration.

LMT also intends to partner with traditional established large valve manufacturers/distributors, and LMT has already started this process of interaction and down select. In fact, this LMT EDVA project success is helping to facilitate this partnering effort now.

LMT is focusing on delivering the first SmartRam™ EDVA to pilot market, which needs further TRL refinement for scaling mass-supply re-design refinement and related added tests. Here, LMT has already started this process to locate, negotiate and secure next needed funding necessary for this "redesign for mass-manufacture" and delivery of LMT's first EDVA product.

To accomplish this, LMT has been and is now interviewing and negotiating with several leading supply-chain partners (Canada and USA), and LMT is also involved in several interactions and negotiations with O&G operators for continued EDVA support for this deployment readiness (for more perfected manufactured designs, and further related re-testing, and possible pre-purchase orders along this process). LMT is also simultaneously courting several types of interested investor capital sources (CVCs, VCs, PEs, SPACs, Angels, etc.) that align with O&G/ESG goals and Climetech/Cleantech goals.