Technical Reviewers' Rating Summary

Proposal Number G-024-055 Application Title Improved Directional Drillin Submitted By Laserlith Corporation Request For $500,000.00 Total Project Costs $1,039,346.00

Section A. Scoring

Statement	Weighting Factor	G-024-007	G-024-08	G-024-09	Average Weighted Score
1. Objectives	9	**2**	**3**	**4**	**27**
2. Achievability	7	**2**	**2**	**3**	**14**
3. Methodology	8	**4**	**4**	**3**	**24**
4. Contribution	8	**4**	**2**	**4**	**24**
5. Awareness / Background	5	**3**	**3**	**2**	**10**
6. Project Management	3	**3**	**4**	**2**	**9**
7. Equipment / Facilities	2	**4**	**3**	**2**	**6**
8. Value / Industry - Budget	4	**4**	**3**	**3**	**12**
9. Financial Match - Budget	4	**3**	**3**	**4**	**12**
Average Weighted Score		**156**	**146**	**161**	**154**
	Total: 50				**250 possible points**

OVERALL RECOMMENDATION

FUND			
FUNDING TO BE CONSIDERED	**X**	**X**	**X**
DO NOT FUND			

Section B. Ratings and Comments

1. The objectives or goals of the proposed project with respect to clarity and consistency with North Dakota Industrial Commission/Oil and Gas Research Council goals are:

   The technology has the potential to create jobs, I am not totally sure of the how the technology will be truly helpful, a connection needs to be made why the gyro will add wellbore placement and why well bore placement is important in the Bakken. I am not buying the cost savings, as put forward, as they ignore the probability of loss time occurring. Is Baker implying that these procedures always require remediation and there system if subject ot compromise: I would suspect not.

- Reviewer: G-024-007
- Rating: 2

The project objectives and goals are clear and consistent within the proposal; however it is difficult to weigh the alignment with the goals of the North Dakota Oil and Gas research Council given the uncertainty of impact to the state of North Dakota beyond just job creation. This technology could very well be used to develop the state's oil and gas resources, but given the commercial potential would also likely be used extensively in other areas. Given the amount of capital requested coupled with the fact the Council has already funded $200,000 for phase 1 development of the technology. This may lead to the idea that partnerships with the end-users of the product, or other states, could be pursued to fund some of the project to help offset costs and reduce the amount requested from the North Dakota Oil and Gas Research Council.
- Reviewer: G-024-08
- Rating: 3

The objective of the proposed project is to increase horizontal drilling efficiency through the use of miniature MEMS gyroscope. This is consistent with the North Dakota Industrial Commission/Oil and Gas Research Council goals of • Promoting efficiency and creating jobs in North Dakota • Bringing about new opportunities in the oil and gas industry • Encouraging and promoting the use of new technology
- Reviewer: G-024-09
- Rating: 4

Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. The inertial guidance system improves directional drilling technology directly relevant for oil/gas exploration in North Dakota. The advantages include: a. The technology enables lower drilling costs for multiple laterals from the same well bore. This could be relevant for reducing the drilling cost in North Dakota with multiple oil-rich formations including the Bakken and the Three Forks. The economics of the savings from multiple laterals was actually quantified by engineers from Baker Hughes to be ~$196,000 per lateral present value (~$150,000 in Year 2000 dollars). [Ref 1] For the Intermediate Radius Re-entry application, Baker Hughes has estimated that $115,000 (year 2000 dollars) per well can be saved based on net rig time savings and avoiding the need to plug back and re-drill the sidetrack (Figure 1). For the Casing Window Cutting application, Baker Hughes has estimated that adding gyroscopes to the current MWD tool can save approximately $35,000 (year 2000 dollars) per well based on avoidance of the cost to plug back and re-drill (Figure 1). b. MWD: The ability to position the directional sensor directly behind the drill bit allows much faster response. Faster response translates into improved drilling accuracy, reduce shale strikes and lower costs. Reducing shale strikes also increases production. In the last several years, the price of oil has fluctuated wildly. With the economy weakening and price of oil dropping, reducing the cost of drilling will safeguard economic development in North Dakota counties with higher breakeven prices of oil. c. Safety: The inertial guidance system improves safety by preventing the chance for collision with other pipes and metallic objects. The system is not affected by proximity to metallic objects, which is a significant improvement to existing magnetometer MWD technology. d. Environment: Improved

guidance technology immune from proximity to metallic objects facilitates pad drilling for reduced environment impact. Furthermore, improved accuracy and reduced shale strikes may reduce the risk of impact to the local environment including the local water table. e. Jobs and Technology Development in North Dakota: The proposed project is anticipated to create 20-30 jobs in full production. Furthermore, The Laserlith team is performing state-of-the-art research under the Department of Energy/RPSEA (Figure 2). North Dakota university research capability is being enhanced at the University of North Dakota through internships and collaboration. Since 2008, Laserlith has employed 14 graduates and students from the University of North Dakota as well as students and graduates from the NDSCS. Collaboration with Laserlith also directly resulted in funding several graduate students at the University of North Dakota. f. Relevance to Directional Drilling: The relevance of the technology is supported by the involvement of significant players with substantial experience in the field – Schlumberger, Weatherford/Tech21 and Bourgoyne Enterprises. Their letters of support are attached.
- Applicant

2. With the approach suggested and time and budget available, the objectives are:

   It is noted on page 7, "Due to funding constraints, the Phase I portion of the project fabricated a standard room-temperature for testing purposes only." I am not sure if Phase II will hold any better, perhaps the budget needs to be reviewed for addtional funding. I believe the project time line lacks sufficent description.
   - Reviewer: G-024-007
   - Rating: 2

   The actual timetable and budget of the objectives to prepare a sensor for down-hole testing could possibly be achieved, but may require more time and money than anticipated due to the downhole environment the tool will have to withstand (i.e. prolonged exposure to high temperature and drill string vibrations coupled with high RPM bit rotation).
   - Reviewer: G-024-08
   - Rating: 2

   The objective of the proposed project is to increase horizontal drilling efficiency through the use of miniature MEMS gyroscope. This is consistent with the North Dakota Industrial Commission/Oil and Gas Research Council goals of • Promoting efficiency and creating jobs in North Dakota • Bringing about new opportunities in the oil and gas industry • Encouraging and promoting the use of new technology
   - Reviewer: G-024-09
   - Rating: 3

   Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. While the Laserlith team acknowledges that the proposed project would represent a significant advance beyond the current state-of-the-art, the risks are substantially addressed: 1. The Phase I goal was achieved within budget. As discussed, a video documenting the successful demonstration will be shown to the North Dakota Industrial Commission, Oil and Gas Research Program. 2. The Bakken Formation is substantially

lower temperature than the demonstrated temperature conditions of the Phase I gyrocompass system. As shown in Figure 3, the temperature of the Bakken does not appear to exceed 125 degrees C. [Ref 2] While there are deeper (thus hotter) oil-rich layers in North Dakota, this leaves substantial margin for engineering tradeoffs. The target Phase II deliverable is an integrated system that will operate at downhole temperature conditions for the anticipated drilling time (at least 1 week continuous operation). 3. In response to similar concerns from the US Department of Energy/RPSEA, the team successfully demonstrated the survivability of the critical microbump technology in simulated oil drilling high-temperature high-shock test environments. As shown in Figure 4, this includes accelerated aging temperature cycling tests performed at more than 10X the shock level and 100 degrees C above the anticipated Bakken downhole environment. 4. The validity of the approach is supported by the involvement of significant players with substantial experience in the field – Schlumberger, Weatherford/Tech21 and Bourgoyne Enterprises. Their letters of support are attached. 5. The inertial guidance system is designed to work while the system is drilling. As the team's Working Committee suggested, if there is concern for operating during actual drilling, the system can also be operated while casing is being added. This more conservative mode of operation will allow longer integration time (more than a minute) for the system to gyrocompass, improving accuracy. 6. The team has successfully demonstrated the inertial guidance system for high temperature environments in a simulated high temperature test apparatus (Figure 5). A video of the successful high-temperature operation of the system was shown at the July 2011 US Department of Energy/RPSEA conference. The same demonstration video of the successful high-temperature inertial guidance system will be presented to the North Dakota Industrial Commission, Oil and Gas Research Program. The project has met the Phase 1 milestone as originally proposed to the Oil & Gas commission within budget. The goal of the proposed Phase II project is to demonstrate the necessary gyrocompass accuracy under simulated high-temperature downhole environment. As discussed, the target Phase II deliverable is an integrated system that will operate at downhole temperature conditions for the anticipated drilling time (at least 1 week continuous operation).
- Applicant

3. The quality of the methodology displayed in the proposal is:

The steps for design and fabrication of the proposed technology is well thought out and very clear.
- Reviewer: G-024-007
- Rating: 4

The quality of the methodology displayed in the proposal is very good. All objectives and requirements of the project are clearly stated. The concepts are broken down into easy to understand terms and a very good history of the MEMS gyroscope technology is presented. Overall, the project is technically sound. Oil and gas drilling operations could stand to benefit significantly from a near bit drilling sensor, however how much specific benefit it could provide to actual current Bakken drilling operations is subject to debate (see further explanation in overall comments section).
- Reviewer: G-024-08

- Rating: 4

This is the second phase of this project and with the progress made during the first phase, the approach for the second phase is certainly achievable. It is important that the separate processing of MEMS result in a working product. The team seems to have the experience necessary to produce the sensing structure and build the circuit and integrate both into a down-hole drill bit. The discussion about the integration into the structure of the drill bit is missing.
- Reviewer: G-024-09
- Rating: 3

Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. The inertial guidance improves directional drilling technology directly relevant for oil/gas exploration in North Dakota. The technology also enables lower drilling costs for multiple laterals from the same well bore. This could be relevant for reducing the drilling cost in North Dakota with multiple oil-rich formations including the Bakken and the Three Forks. The economics of the savings from multiple laterals was actually quantified by engineers from Baker Hughes to be ~$196,000 per lateral present value (~$150,000 in Year 2000 dollars). [Ref 1] For the Intermediate Radius Re-entry application, Baker Hughes has estimated that $115,000 per well can be saved based on net rig time savings and avoiding the need to plug back and re-drill the sidetrack (Figure 1). For the Casing Window Cutting application, Baker Hughes has estimated that adding gyroscopes to the current MWD tool can save approximately $35,000 per well based on avoidance of the cost to plug back and re-drill (Figure 1). Furthermore, the ability to position the directional sensor directly behind the drill bit allows much faster response. Faster response translates into improved accuracy, reduce shale strikes and lower costs. Reducing shale strikes also increases production. In the last several years, the price of oil has fluctuated wildly. With the economy weakening and price of oil dropping, reducing the cost of drilling will safeguard economic development in North Dakota counties with higher breakeven prices of oil. The inertial guidance system will be installed as close to the drill bit as the specific application will allow. The inertial guidance system will be packaged in a vacuum package/chamber that is sized to fit into the drill pipe. The hermetic chamber is for maintaining the necessary vacuum level for the MEMS gyroscope to operate. This includes vacuum getters and bakeout for maintaining the appropriate vacuum level at the required temperature range for downhole applications. The system will utilize electrical power (2 watt specification) from an electrical supply outside of the chamber and will also utilize communications modules from outside the chamber.
- Applicant

4. The scientific and/or technical contribution of the proposed work to specifically address North Dakota Industrial Commission/Oil and Gas Research Council goals will likely be:

There is an important technological project that could create a tool that would reduce well bore uncertainty, which a sore spot in the industry.
- Reviewer: G-024-007
- Rating: 4

The direct benefit to the state of North Dakota from this project is the creation of 20-30 potential jobs and development of the technology within the state of North Dakota. Given the advanced state of current drilling techniques and equipment it is hard to justify a 1% increase in what can be economically extracted, or drastically reducing drilling costs to the point that the Bakken shale is more economic at lower commodity prices. In this reviewer's opinion the amount of capital requested is quite large considering there are much more prevalent issues that Bakken development faces in the eye of the general public. Issues such as gas flaring, water management (both produced water and water used for fracturing), hydraulic fracturing education, and other environmental issues such as these may be better suited for a grant of this type. Given the potential commercial application of this product, funding could also possibly be obtained from oilfield service companies in a joint development scenario since they will be the end users and benefit greatly from the technology.
- Reviewer: G-024-08
- Rating: 2

This project is in line with the following goals and objectives of the North Dakota Industrial Commission/Oil and Gas Research Council: • Positively affecting ultimate recovery from North Dakota's existing oil and gas pools. • Identify oil and gas exploration and production technologies presently not used in North Dakota.
- Reviewer: G-024-09
- Rating: 4

Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. The inertial guidance system improves directional drilling technology directly relevant for oil/gas exploration in North Dakota and addresses several safety and environmental concerns. As discussed, the technology enables lower drilling costs for multiple laterals from the same well bore. Baker Hughes quantified the savings to be ~$196,000 per lateral (~$150,000 in Year 2000 dollars). The inertial guidance system improves safety by preventing the chance for collision with other pipes and metallic objects. The inertial guidance is not affected by proximity to metallic objects, which is a significant improvement to existing magnetometer MWD technology. As discussed earlier and illustrated in Figure 1, Baker Hughes quantified the savings possible directly from the availability of a high temperature gyroscope to be ~$196,000 per lateral present value (~$150,000 in Year 2000). [Ref 1] Improved guidance technology immune from proximity to metallic objects facilitates pad drilling for reduced environment impact. Furthermore, improved accuracy and reduced shale strikes may reduce the risk of impact to the local environment including the local water table. The relevance of the technology is supported by the involvement of significant players with substantial experience in the field – Schlumberger, Weatherford/Tech21 and Bourgoyne Enterprises. Their letters of support are attached.
- Applicant

5. The background of the principal investigator and the awareness of current research activity and published literature as evidenced by literature referenced and its interpretation and by the reference to unpublished research related to the proposal is:

I think that the PI's background does not allow this person to have the gravitas to determine

I think that the PI's background does not allow this person to have the gravitas to determine product development. However, the PI is being supported by some top technical people familiar with the "devil" in the detail.
- Reviewer: G-024-007
- Rating: 3

The proposal appears to be very in tune with current research regarding MEMS gyroscope technology with regards to the literature referenced. The company appears to be very in tune with the history and future of the technology based on past experience and proven track record. The proposal does an excellent job of explaining phase 1 work results, the illustration of the gyroscope design, and how the MEMS chip is manufactured.
- Reviewer: G-024-08
- Rating: 3

No literature was reviewed. No references to current or relevant publications are made in the proposal. Brief background of key personnel was provided which limits the ability to evaluate qualifications.
- Reviewer: G-024-09
- Rating: 2

Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. Directional drilling currently relies on magnetometer-based guidance systems. These systems have proven to be robust in the high temperature down-hole environment. However, there are a number of problems that limit the accuracy and reliability of these systems. Magnetometers by nature are affected by proximity to many metals. [Ref 3] Magnetometers' sensitivity to interference from metallic objects limits their reliability and utility in pad drilling because of nearby numerous metallic objects. Thus, the guidance sensor is typically installed 50 to 80 feet behind the drill bit. This increases the system's response time, thus increasing drilling time and drilling cost. Furthermore, magnetometers need to be recalibrated when the local magnetic field fluctuates. Drilling must stop while recalibration is ongoing. There are wireline gyroscopes that are currently in the market, but they cannot operate at the temperatures requires for drilling in the Bakken and, since drilling must be stopped to take a single-shot measurement, can increase total drilling time. [Ref 4] There are currently MEMS gyroscopes designed for mass-market applications, such as automotive anti-roll, as well as game controllers, camera and camcorder stabilization. [Ref 5,6] But these applications are not for high temperature operation, and commercial MEMS gyroscopes simply cannot function at high temperatures. The market for high-temperature gyroscopes is very limited and typically does not justify the investment in R&D. Attempts to modify existing commercial designs to operate at higher temperatures are often stymied by the architecture of gyroscope. Surface micromachined gyroscopes are currently produced by Analog Devices [Ref 7] and Bosch, [Ref 8] and other groups, such as Invensense, are also developing similar products. [Ref 9] Analog Devices supplies gyroscopes using an integrated process. [Ref 10] However, yields of these complex processes are low and, thus costs are high. Furthermore, the parasitic capacitance resulting from the use of polysilicon interconnects is still high, and integrated processes are restricted to antiquated and noisy transistors. These sensors are currently limited to vehicle stability and camcorder stabilization applications. Personnel: Chopin Hua, Senior Engineer at Laserlith, leads several MEMS

programs including the gyroscope program, MEMS fuzing components such as explosive foil initiators and safe & arm devices. He has more than 5 years of experience in FEA analysis of MEMS devices, including fuze components, accelerometers and gyroscopes. He is also experienced in harsh environment microdevice design/packaging of gyroscopes, as well as accelerometers and MEMS fuze components. This includes FEA analysis of device package as well as the entire packaged device for high-g impact. Mr. Hua is also experienced in the high-g testing of microbump bonded components, including micropackages, switches, accelerometers at up to 100,000g. High-g test equipment include in-house air gun and drop towers. For harsh environment micropackaging and integration, Mr. Hua focuses on microbump bonding processes for hermetic sealing of a broad array of MEMS devices. The microbump bonding process is also critical for low parasitic integration of MEMS and CMOS that enables high sensitivity sensors. The microbump process has been implemented in a number of MEMS devices including RF MEMS switches, high-g accelerometers, and resonators. The process has also been utilized to assemble complex multi-layer structures including high fill-factor micromirrors based on comb-drive actuators. He received his B.S. (Mechanical Engineering) from UC Berkeley. Mr Hua's relevant publications include: 1. C. Hua, M. Cohn, K. Chang, B. Kirby, R. Millenacker, "Low-Cost MEMS Initiators," Proceedings of the 54th Annual Fuze Conference, May 2010. 2. C. Hua, K. Chang, R. Millenacker, B. Kirby, W. Tang, M. Cohn. "MEMS Fuze-on-a-Chip." Proceedings of the 55th Annual Fuze Conference, Salt Lake City, UT, 26 May 2011. Michael Cohn, Director, developed hermetic micropackaging technologies for MEMS packaging applications. He has fourteen years of experience in the semiconductor manufacturing process development. His experience includes device transfer processes, thin-film solder processes, mechanical latches for MEMS assembly process development for various resonator-based sensors, and development of assembly processes for disk drive heads. Dr. Cohn developed the SOI MEMS processes for fabricating the gyroscope, as well as other sensors such as strain sensors and accelerometer. He also developed RF MEMS processes for wireless communications and low power radar applications. Dr. Cohn has over 40 publications and patents. He received his Ph.D. in EECS from University of California Berkeley in 1997. The following is a sample of his publications: 1. Cohn, M.B., Assembly Techniques for Microelectromechanical Systems, Ph.D. Thesis, EECS Department, University of California, Berkeley, December, 1997. 2. Cohn, M.B; Chang, K.; Papavasiliou, A; Olivier, S.; Kim, G.; Matus, G.; Xiao, Z.; Cheung, S.; Saechao, K.; Roehnelt, R. "High Performance Adaptive Optics Using Microscale Assembly." SPIE, MOEMS-MEMS 2006 Micro and Nanofabrication, 21-27 January 2006, San Jose, CA 3. Brown, E.B.; Cheung, S.C.; Cohn, M.B.; Kim, G.H.; McCormick, D. "RF MEMS Package with 0.1 dB Insertion Loss Using Bonded Membrane", Government Microcircuit Application Conference (GOMAC), Apr. 2005, paper 16-6. 4. Brown, E.B.; Cheung, S.C.; Cohn, M.B.; Kim, G.H.; McCormick, D. "Wafer-Scale RF MEMS Package with <0.12 dB Insertion Loss to 40 GHz" InterPACK 2005 Conference, 17-22 July 2005, San Francisco, CA. William H. Semke, Associate Professor in Mechanical Engineering at University of North Dakota, is involved in the research and development of precision motion and vibration control, smart structures, and aerospace hardware design. He established the Vibration and Precision Engineering Laboratory (VPEL) within the School of Engineering & Mines. Dr. Semke is currently the Co-Director of Payload Development within the UND Center of Excellence for UAS and

Simulation Applications. Previously, he led the design of several aerial and space remote sensing payloads. He received his PhD (ME) from University of Wisconsin-Madison. Dr. Dimitrios Peroulis, Associate Professor of Electrical and Computer Engineering at Purdue University, has been in the micromachining field since 1998. Dr. Peroulis' group has developed low-noise sense circuitry for MEMS gyroscopes based on high temperature SOI CMOS foundry processes. He is an expert in micromachining particularly related to RF MEMS and reconfigurable high frequency circuits and antennas. He has developed novel RF MEMS devices such as switches, varactors and inductors as well as tunable filters, matching networks, power amplifiers and antennas. He has extensively studied low-voltage RF MEMS switches with a focus on RF performance, residual stress, actuation voltage and power handling. He also worked in integrating MEMS switches into lowpass and bandpass switchable filters with tuning ratios of 3:1 and 2:1 respectively – the highest presented today for mm-wave MEMS switchable filters. Prof. Peroulis' group recently demonstrated the highest tuning range (4:1) analog RF MEMS varactors among high-frequency parallel plate varactors. These varactors have very high Q (>200 at 40 GHz) with power handling of >4W (hot tuning) for over 10 billion cycles. He has over 20 referred journal and conference publications. He has been a reviewer of several journals including the IEEE Transactions on Microwave Theory & Techniques, IEEE Microwave and Wireless Components Letters and the IEEE Transactions on Antennas and Propagation. Dr. Peroulis received his PhD and MS degrees in EE from the University of Michigan. The following are some of his relevant publications: 1. D. Peroulis and L.P.B. Katehi, "Electrostatically-Tunable Analog MEMS Varactors with Measured Tuning Range of 300%", Proceedings of the IEEE MTT-S International Microwave Symposium, vol. 3, pp. 1793-1796, June 2003, Philadelphia, PA. 2. D. Peroulis, K. Sarabandi, and L.P.B. Katehi, "Design of Reconfigurable Slot Antennas", IEEE Transactions on Antennas and Propagation, vol. 53, no. 2, pp. 645-654, Feb. 2005. 3. Y. Lu, D. Peroulis, S. Mohammadi and L.P.B. Katehi, "A MEMS Reconfigurable Matching Network for a Class AB Amplifier", IEEE Microwave and Wireless Comp. Letters, vol. 13, pp. 437-439, 2003. 4. D. Peroulis, A.D. Margomenos, and L.P.B. Katehi, "RF MEMS and Silicon Micromachining in High Frequency Applications", Proceedings of the IEEE Radio and Wireless Conference (RAWCON), pp. 265-268, August 2002, Boston, MA (Invited Paper). 5. D. Peroulis, Yumin Lu and Linda P.B. Katehi, "Highly Reliable Analog MEMS Varactors", Proceedings of the IEEE MTT-S Int. Microwave Symposium, vol. 2, pp. 869-872, 2004, Fort Worth, TX. The team is guided by many industry veterans, including directional drilling technologies. Support letters from Schlumberger, Weatherford and Bourgoyne Enterprises are attached. Figure 6 illustrates the makeup of the project management team with a Working Committee that includes Chevron, Weatherford/Tech21 and Bourgoyne Enterprises. Tech21/Weatherford is led by Angus Jamieson who is leading directional drilling technologists with more than 65 years of combined experience and involved in the directional drilling team that intercepted the BP Gulf of Mexico leak. Bourgoyne Enterprises is led by Ted Bourgoyne, an industry veteran with over 40 years experience, including 29 years at Louisiana State University where he became Chair of the Petroleum Engineering Department and later the Dean of Engineering. His industry experience is broad, including consulting and work done at BP, Conoco, Weatherford, and Pennington, and numerous other companies. He has also served on the steering committee of the International Association of Drilling Contractors that coordinated

the development of a manual on well control practices for deepwater drilling operations. Dwayne Bourgoyne, also part of Bourgoyne Enterprises, was a professor at Colorado School of Mines and previously worked at Exxon. Charles Crawley is on Laserlith's Working Committee for the RPSEA program and is working to add additional Committee Members.
- Applicant

6. The project management plan, including a well-defined milestone chart, schedule, financial plan, and plan for communications among the investigators and subcontractors, if any, is:

I believe the project time line lacks sufficent description. A search on the word communication in the proposal yields zero hits. A formal communication plan would be of value for this application.
- Reviewer: G-024-007
- Rating: 3

The overall project management plan appears to be very well laid out. A well thought out strategy will be employed in order to develop the end product for testing, and with quarterly progress reports all involved parties should be well informed of progress. Given the corporation's background, history, and experience with this type of technology they are probably one of the most qualified organizations in the country to commence development of a technology that could benefit drilling operations worldwide. Additionally, the backing and funding from Research Partnership to Secure Energy for America (REPSA) adds credibility to the project and its potential success.
- Reviewer: G-024-08
- Rating: 4

The project management including responsibilities is defined. The 1-year project time table is presented. Financial planning is not addressed. A general budget for the project is provided. Communication plans are not presented in detail.
- Reviewer: G-024-09
- Rating: 2

Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. Tasks: Task 1 Optimize Mechanical Sensing Element: Phase I of this project designed and fabricated a gyroscope for high temperature and shock applications. Phase II will optimize the micromechanical gyroscope sensing element for operating in downhole drilling environments. The key to the phase II work will involve optimizing the aspect ratio of the gyroscope mechanical features. The aspect ratio is determined by the capability of the Deep Reactive Ion Etch (DRIE) process that forms narrow deep trenches/features. The high aspect ratio is critical for electrostatic sensing, which has a 2nd power dependence on gap. This approach takes full advantage of Laserlith's 'divide and conquer' approach that separates the mechanical element fabrication from the electronic circuit fabrication. Thus, the best possible DRIE process for high aspect features will be utilized without concern for harming the electronic circuits chip. The team has demonstrated DRIE processes with high aspect ratio (>30:1) and high selectivity (>100:1). Task 2 Electronics Circuit: High

temperature sensor readout circuits will be designed and procured from proven suppliers. The Phase II portion will be focused on optimizing the circuit with the Phase II mechanical element. Important aspects to the work include high resolution control of the bias voltages for the quadrature correction as well as resonant frequency tuning. Quadrature correction is necessary for high performance MEMS gyroscope products to compensate for any minor fabrication irregularities typical in high volume production. Resonant frequency tuning is necessary for matching sense and drive resonant frequencies to improve sensitivity. Gyroscope control circuitry was demonstrated in Phase I, and will be modified to work appropriately with Phase II devices. Task 3 Module System Design, Components Integration and Assembly: An inertial guidance system will be designed and assembled based on the assembled MEMS gyroscopes. The micromechanical sensing elements will be integrated with readout circuits using an in-house low-loss electrical interconnection process. Vacuum packaging is critical to maintain the vacuum level necessary for the MEMS gyroscope to function properly. Stable resonant frequency requires maintaining strict control of the vacuum level over the entire operating temperature range of the drilling environment. The existing vacuum package / chamber will be improved for operating for longer time periods. This includes eliminating any outgassing materials from the assembly including organic o-ring materials and wire insulation. Task 4 Qualification of Inertial Sensor System: Mechanical vibration, thermal and shock validation of the sensor module will be performed. As discussed, the key Phase II deliverable is an integrated inertial guidance system with a demonstration of system operation simulated at downhole temperature conditions for the anticipated drilling time (at least 1 week continuous operation). Milestones: 1. Assemble optimized gyro for operating at 200 degrees C. Circuit and MEMS gyro will undergo mechanical shock, vibration, temperature cycling and thermal shock tests. 2. The target Phase II deliverable is an integrated system with a demonstration of the system operating simulated at downhole temperature conditions for the anticipated drilling time (at least 1 week continuous operation). Communications Plan: The Laserlith team intends to communicate the results of the proposed project through a variety of channels. This includes: a. Periodic updating to the North Dakota Industrial Commission, Oil and Gas Research Program. b. Periodic updating the US Department of Energy/RPSEA which is well attended by Oil companies such as Chevron and Exxon, service companies such as Baker Hughes and Schlumberger, and government official from the Department of Energy and the National Energy Technology Laboratory (NETL). The team reported the high temperature demonstration result in the Annual RPSEA conference in Houston within 3 months of achieving the result. The Working Committee also includes Chevron, Weatherford and Bourgoyne Enterprises. Letters of support from Weatherford, Schlumberger and Bourgoyne Enterprises are attached. c. Led by team members from University of North Dakota and Purdue University, all of the participating researchers have made a commitment to publish in a timely manner all the relevant scientific information that they will derive during this project. The research and educational outcomes of this project will be disseminated to the broader community through a broad variety of media, including reputable journals, research and educational conference presentations and proceedings, industry and conference short courses, industry and university seminars, webinars and websites. d. Unpublished non-proprietary information, including but not limited to experimental and numerical protocols, raw experimental data and software codes, will be made available to interested parties via a

request to Project PI Ms. Cassindy Chao. The sharing of unpublished information may be subject to confidentiality issues relating to our collaborations with other scientists in academic or corporate laboratories, and will need to be discussed with the appropriate institutions (Purdue University) and collaborating companies (Bourgoyne Enterprises, Microassembly Technologies) before any request is granted, wholly or in part. Long-term data management will occur using Laserlith's internal resources. The Laserlith team will provide stewardship and curation of data and will supply consultations and tools to facilitate ingestion of data and appropriate metadata conforming to community standards. Industry-standard protocols such as OAI-PMH will be used to expose resources in a variety of contexts, including search engines such as Google Scholar. Data will be accessible for project-appropriate periods and archived thereafter. The team will also assign Digital Object Identifiers (DOIs) and expose documentation about the data sets in the repository. Financial Plan: The cost associated with each task is broken down as follows: Task 1 Optimize Mechanical Sensing Element: $388,544. Task 2 Electronics Circuit: $159,763. Task 3 Module System Design, Components Integration and Assembly: $258,895. Task 4 Qualification of Inertial Sensor System: $232,144. Total: $1,039,346. Mechanical vibration, thermal and shock validation of the sensor module will be performed. As discussed, the key Phase II deliverable is an integrated inertial guidance system with a demonstration of system operation simulated at downhole temperature conditions for the anticipated drilling time (at least 1 week continuous operation).
- Applicant

7. The proposed purchase of equipment and the facilities available is:

   The application makes it clear that dedicated purpose equipment and facilities are key to these successful completion of the project.
   - Reviewer: G-024-007
   - Rating: 4

   The current laboratories of Laserlith Corporation and Ideal Aerosmith coupled with close proximity to the UND campus, would likely be more than adequate for undertaking a project of this magnitude. The purchase of the required equipment/labor to complete a MEMS gyroscope sensor for down-hole testing is also justified. The project breakdown costs appear to be in line with current electronic sensor manufacturing processes.
   - Reviewer: G-024-08
   - Rating: 3

   Material and equipment budget for each year is $100K. No justification or detail is provided for equipment and material purchases in the proposal.
   - Reviewer: G-024-09
   - Rating: 2

   Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. Table 1 shows the breakdown of the materials and equipment budget. Estimated total costs for materials and equipment lease is $100,296 total (1 year total). Laserlith's materials to be purchased total $33,456. This includes 100 silicon wafers at $19.90 per

silicon wafer, 50 SOI wafers at $320 per SOI wafer, 40 alumina wafers at $247.34 per alumina wafer, 2 gallons of plating chemical at $1,743.17 per gallon, and 4 printed circuit boards at $521.58 per printed circuit board. Laserlith's equipment to be leased total $66,840. This includes a wafer coater leased for 10 months at the rate of $1,395.31 per month, wafer developer leased for 10 months at the rate of $990.22 per month, and a barrel etcher leased for 10 months at the rate of $ 4,298.45 per month. Total costs for materials purchase and equipment lease is estimated at $100,296. Justification for Materials: 1. SOI Wafers: SOI wafers are the substrate with which the mechanical sensing element is fabricated. 2. Alumina Wafers: Alumina wafers are the substrate with which the circuit and interconnects to the mechanical sensing element is fabricated. 3. Silicon wafers: Silicon wafers are the lower-cost substrates for process development. 4. Plating Chemicals: Plating chemicals are needed for thick plating metal structures to form certain metallization layers for the gyroscope. 5. Printed Circuit Board: Printed circuit board will be needed for additional gyroscope control/sense circuitry. Justification for Equipment: 1. Wafer Coater: Spin coating is a procedure used to apply uniform thin films to flat substrates. Spin coating is used in microfabrication, to deposit photoresist thin films for lithography. 2. Wafer Developer: After a wafer is coated with resist, exposed to UV under a photolithography mask, the developer is used to expose the image from the mask. This is a semiconductor industry standard. 3. Barrel Etcher: Barrel Etcher uses chemically reactive plasma to remove material deposited on wafers. The plasma is generated under low pressure (vacuum) by an electromagnetic field. High-energy ions from the plasma attack the wafer surface and react with it. The etcher is used for etching oxides, as well as for plasma cleaning. Facilities: MEMS gyroscopes will be developed and produced in a MEMS production line that is supported by more than $15 million of funding from the Department of Defense (Figure 8). The team has all of the capabilities and equipment for producing SOI MEMS products including gyroscopes, switches and other micromachined components. The facilities house all of the manufacturing equipment necessary for the SOI process, including a mask aligner, lithography, deep reactive ion etching (DRIE), sputter, plate, critical point dry, clean, align and bond. The facilities enable tighter controls and reduced costs compared to outsourced foundries. Other MEMS assembly tools include a Finetech die align-bond systems with 1-micron alignment accuracy, wafer-scale bonder. Other tools include CMP tools, critical-point-dry systems, and a Perkin Elmer sputtering machine. Test and measurement tools include Wyko optical profilometer, stress measurement system and Dektak mechanical profiler. Testing and module production will be performed in East Grand Forks at Ideal Aerosmith with substantial manufacturing and test infrastructure for module production, serving the aerospace, defense and oil drilling sectors. Ideal Aerosmith has an impressive array of inertial test equipment that will be used extensively in the development and integration process. This will enable the system to be evaluated at both the component and system level. The facilities meet all applicable environmental laws and regulations of federal, state, and local Governments for, but not limited to, the following groupings: airborne emissions, waterborne effluents, external radiation levels, outdoor noise, solid and bulk waste disposal practices, and handling and storage of toxic and hazardous materials.
- Applicant

8. The proposed budget "value"1 relative to the outlined work and the commitment from other sources is of:

For what is to be designed, created and tested, the project offers excellent value.
- Reviewer: G-024-007
- Rating: 4

There will likely be an adequate value to this project given the amount of work and technical outcome for the capital spent. However, with some of the companies proposed economic impacts being somewhat uncertain (i.e. 1% increased extraction and significant drilling cost reduction – see overall comments for further explanation) it would be beneficial to proceed with caution and undertake considerably more research on the topic if considering giving a higher than "adequate" rating for the value of this particular project.
- Reviewer: G-024-08
- Rating: 3

The proposed work for a period of 1 year for $500K with a matching fund of $490K seems adequate.
- Reviewer: G-024-09
- Rating: 3

Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. As discussed in Section 1, the inertial guidance provides a direct value for oil/gas exploration in North Dakota. The technology enables multiple laterals from the same well bore, which is specifically relevant for reducing the drilling cost in North Dakota with multiple oil-rich formations including the Bakken and the Three Forks. The economics of the savings from multiple laterals was actually quantified by engineers from Baker Hughes to be ~$196,000 per lateral present value (~$150,000 in Year 2000 dollars). [Ref 1] For the Intermediate Radius Re-entry application, Baker Hughes has estimated that $115,000 per well can be saved based on net rig time-savings and avoiding the need to plug back and re-drill the sidetrack (Figure 1). For the Casing Window Cutting application, Baker Hughes has estimated that adding gyroscopes to the current MWD tool can save approximately $35,000 per well based on avoidance of the cost to plug back and re-drill (Figure 1). The ability to position the directional sensor directly behind the drill bit allows much faster response. Faster response translates into improved accuracy, reduce shale strikes and lower costs. Reduced shale strikes translate to increased production. Reducing shale strikes also increases production. In the last several years, the price of oil has fluctuated wildly. With the economy weakening and price of oil dropping, reducing the cost of drilling will safeguard economic development in North Dakota counties with higher breakeven prices of oil. Finally, The relevance of the technology to directional drilling is supported by the involvement of significant players with substantial experience in the field – Schlumberger, Weatherford/Tech21 and Bourgoyne Enterprises. Their letters of support are attached.
- Applicant

9. The "financial commitment"2 from other sources in terms of "match funding" have been identified:

The source of funds are described on page 14 of the application, however Laserlith's contribution of $50,000 via indirect costs is lacking sufficent detail.
- Reviewer: G-024-007
- Rating: 3

- Rating: 3

The project meets the financial commitment guidelines since 51.9% of the funds will be derived from other sources (i.e. RPSEA and Laserlith Corporation). It also appears that the down-hole gyroscope package will be tested by "Schlumbereger personnel" and with the letter of interest from Schlumbereger, this could be interpreted as an industry partnership or commitment.
- Reviewer: G-024-08
- Rating: 3

Yes.
- Reviewer: G-024-09
- Rating: 4

Note: Please refer to the appendix (sent separately) for figures, tables, support letters and references. The budget for the Phase 2 project is $1,039,346. Requested funding from the Oil and Gas Research Council is $500,000. Matching funds are $489,346 from RPSEA contract and $50,000 from Laserlith Corporation. The $50,000 cost share from Laserlith will be funded through direct labor and overhead costs. The PI and senior engineer at Laserlith would each contribute 1 month as the cost share. The direct labor and labor overhead costs for this cost share would amount to $50,000. Laserlith has one all-encompassing indirect rate as Laserlith's indirect costs include G&A, IR&D and overhead costs. All indirect costs (i.e. G&A, R&D, overhead) are added together to form the overhead pool, which is then divided by direct labor, resulting in a labor overhead rate. Laserlith's labor overhead rate of 145.16% for FYE 4/30/2012 has been pre-approved by the Department of Defense Contract Audit Agency (DCAA) (Figure 9). DCAA Minneapolis completed an accounting system audit about 2 years ago and found Laserlith's accounting system to be adequate for accumulating and billing costs under Government contracts.
- Applicant

1 "value" – The value of the projected work and technical outcome for the budgeted amount of the project, based on your estimate of what the work might cost in research settings with which you are familiar. A commitment of support from industry partners equates to a higher value.

2 "financial commitment" from other sources – A minimum of 50% of the total project must come from other sources to meet the program guidelines. Support less than 50% from Industrial Commission sources should be evaluated as favorable to the application; industry partnerships equates to increased favorability.

General Comments

This is an interesting proposal, the project has excellent technical and business supported by Federal funding. The question remains, can the the product arrive on time and on a budget that works. The upside is very good, the possibilty of creating addtional jobs, and perhaps additional new industries that would server to retain ND's best and brightest. I would recommend that at the very least the project recieves partial funding. This a good project for the State of ND.
- Reviewer: G-024-007

Overall the technical merit of the project is very sound. The development of a near bit sensor for

directional drilling applications would be beneficial to the oil and gas industry as a whole in many different areas of the world. Currently, as referenced in the grant application, existing drilling surveys are magnetometer based requiring some distance (usually spaced out with monel collars) between the mud motor/bit to negate the effects of ferrous metals on the survey measurements. This distance creates a lag time between actual bit position and when the surveys are taken. Lag time can create many issues such as shale strikes (especially when drilling in very thin layers of the Middle Bakken shale), non-productive rig time to re-orient the directional assembly, and many other issues. Additionally, many existing rotary steerable directional tools possess a near bit sensor that reads inclination only, but this technology is sometimes unreliable due to inconsistent readings caused by torsional forces induced by bit rotation. As referenced in the grant application the system would mostly benefit casing window cutting and intermediate radius re-entry applications through cost savings in the drilling process. However, the direct cost savings for bit steering applications has yet to be determined which would likely be the biggest benefit for current Bakken drilling operations considering some of the most prolific challenges are avoiding shale strikes, staying within a particular stratigraphic sequence of the middle Bakken shale, or trying to produce a more consistent non-undulating wellbore trajectory. Through micro seismic studies it has been proven that when the middle Bakken shale is hydraulically fractured a large portion of the fractures tend to propagate upwards, perhaps making it less necessary to stay within a particular sequence during drilling. This factor could potentially lead to a relaxation of drilling targets which also helps to decrease total drilling time of a middle Bakken lateral from spud to total depth utilizing existing directional equipment. Drilling times with existing directional assemblies (i.e. mud motor and MWD) are still very good for the Bakken shale. It is also important to note that many of these current MWD tools have to go through extensive research and development with significant capital requirements to withstand prolonged exposure to high down hole temperatures and drill string vibrations such as lateral vibration (which is especially damaging to current MWD tools), torsional (stick-slip) vibration, and axial (bit bounce) vibration. With the understanding that current MEMS gyroscopes have already been developed by the Laserlith team that can withstand high g-shock and temperature cycling required for military it is tough to determine how the sensors will actually perform under the downhole conditions mentioned above coupled with high RPM (typically 35-70 RPM) bit rotation. There is a potential that more capital may be required than estimated by the team to prepare the sensor package for down hole testing in order to provide meaningful results. It appears that the largest impact to the state of North Dakota from this project would be job creation (20-30 jobs). The 1% increase in extraction of Bakken hydrocarbons through use of this technology is hard to justify and likely just speculation. If a near bit directional survey could be attained it would undoubtedly reduce drilling costs, but how significant of a reduction compared to the big picture costs of drilling a Bakken well would only be realized once the technology was in regular industry use.
- Reviewer: G-024-08

Considering that this is the second phase of the project. Funding should be considered to continue the project to conclusion. The proposal leaves some gaps in technical discussions about integrating the MEMS gyroscope into the down-hole package - the bit, the color, or the pipe. Results from the first year developing the high temperature microchip that will withstand extreme temperatures were also missing. The fact that the gyroscope seems to be responding and the output is corresponding closely with the input signal is very positive. The presentation of the result was not substantial. The team work and team responsibility was well defined and the plan for task assignment seems

reasonable. The partnership with other entities and the university is definitely a plus. Overall, my recommendation is to consider funding.
- Reviewer: G-024-09