17-ARPC-07

NSERC FlareNet Strategic Network

I. Proposal Summary (Executive Summary)

Project Scope:

The overarching objective of the NSERC FlareNet Strategic Network is to provide quantitative understanding of flare-generated pollutant emissions critical to enabling evidence-based regulations, accurate pollutant inventories, understanding of climate forcing and health implications, and engineering design and assessment of mitigation strategies to make fossil fuels cleaner. The Strategic Network unites leading experts from Carleton University, University of Alberta, University of British Columbia, Western University, University of Waterloo, and National Research Council with diverse and complementary skillsets to tackle crucial research questions organized under five closely integrated themes. These are:

1. Flare Emissions during Flowback Operations at Hydro-Fractured Wells
2. Refinery and Upgrading Flares: Effects of Air- and Steam-Assist on Emissions Control
3. Effects of Turbulent Crosswinds on Flare Emissions
4. Properties of Black Carbon and Other Particulate-phase Species Emitted during Flowback and Routine Flaring Operations
5. Development and Application of Novel Technology for Field Measurements

The FlareNet Strategic Network was formally launched by Federal Minsters McKenna and Duncan on October 19, 2016 and is backed by a strong array of partner organizations including PTAC, CAPP, World Bank, Alberta Energy Regulator (AER), Environment Canada, Natural Resources Canada, Alberta Environment and Parks, Clearstone Engineering Ltd., Telops, and Carbon Limits. Primary funding for this $6.9 million project is from the NSERC Strategic Networks Partnership Program, which is contributing $5.5 million over the 5 year duration of the network. PTAC, representing industry through the AUPRF funding program, is the lead industrial partner with a proposed commitment of $150,000/year over five years. This AUPRF application is for year 2 of this funding.

FlareNet is a national-scale initiative that promises to be the most significant applied research undertaking in the history of AUPRF, directly and thoroughly tackling a wide array of key, lingering knowledge gaps in the AUPRF priority issues list. Experiments will be staged among two main research facilities and selected measurement sites in the field. Controlled experiments applying advanced in- and post-flame optical diagnostics and sampling techniques to vertical flares operating under a wide range of conditions will be performed in the Flare Test Facility within the Energy & Emissions Research Lab at Carleton University. This facility permits quantitative experiments on lab-scale flares up to 80 mm diameter with turbulent flames up to 3 m tall, and will serve as a platform for research focused on flaring during flowback operations at hydrofractured oil and gas wells, refinery and upgrading air- and steam-assisted flares, and detailed optical property and morphology measurements of emitted black carbon and other target species of interest. This facility will also serve as a staging ground for ambitious, larger-scale experiments of flares burning in controlled turbulent crossflows to be performed in the Boundary Layer Wind Tunnel Facility at the University of Western Ontario. This globally unique windtunnel facility was specifically designed to research effects of turbulent boundary layer flows on large-scale structures and features a 5 m × 4 m test section that is ideally suited to measurements on flares.

Finally, field measurements of black carbon emission rates will be performed at selected oil and gas flare sites in the field, building on novel optical technology developed by network members and

tested during field trials leading up to this proposal. The organization of all five themes is thus designed to maximize scientific impacts through the integration of controlled experiments at a range of scales with full-scale field measurements. The anticipated outcomes will have far-reaching applications for industry operators, policy decision makers, regulators, combustion scientists, climate modellers, developers of optical measurement techniques, and engineers developing mitigation strategies.

Knowledge Gaps Addressed:

FlareNet was formed with the specific intent of directly addressing key knowledge gaps identified by the PTAC AUPRF and ARPC, and consistently raised by industry and government stakeholders. These include specific gaps on emissions from hydraulic fracturing, air emissions inventories, BTEX compounds, and flaring/venting/fugitives which form the basis for the five main research themes of FlareNet. It is worth noting that these critical knowledge gaps have persisted, primarily due to the complexity and scale of the research problem, which is exacerbated when the flare stream originates from unconventional extraction processes or bitumen upgrading. Essentially, all current understanding of flares has been the result of large team efforts that have each focused on limited aspects of the larger problem. The NSERC FlareNet Strategic Network closely integrates a diverse group of leading researchers capable of meeting these research challenges through ambitious, collaborative, large-scale experiments that will significantly advance the field.

Project Benefits:

The energy sector is a dominant force in the Canadian economy, contributing more than $84 billion in GDP and providing direct employment to more than 264,000 people, not including an additional 92,000 people employed in downstream trade and distribution [NRCan, 2013]. As the world, and Canada in particular, shifts to exploiting unconventional sources of fossil fuels, there is a critical need to enable cleaner extraction and processing technologies. Efficient and responsible development of unconventional resources is restricted, however, by a lack of quantitative emissions models sufficient to develop science-backed regulations capable of mitigating associated pollutant emissions.

This network will directly address these critical issues. Policy decision makers and regulators will be empowered with essential knowledge and models required for effective, science-based regulations. Industry operators will benefit significantly from quantitative guidance in operating procedures to ensure maximum environmental and economic performance. Environmental scientists, combustion scientists, and climate modellers will gain invaluable new data on climate forcing and emissions from a globally important source. Engineers and technology developers will finally acquire detailed information necessary to develop new and practical mitigation solutions. Ultimately, society as a whole will benefit from access to cleaner fossil fuels, where the low-carbon potential of unconventional gas resources is fully achieved.

II. Project Timeline/Budget Timeline

Milestones for Year 2 of 5 of FlareNet:

Theme 1: Flare Emissions during Flowback Operations Investigative experiments on flare performance with directly injected salt-water aerosols

- Experiments to quantify potential range of effects on flare efficiency and particulate matter emission rates as water droplets with various salt concentrations and loadings are injected into flare. Early experiments will be invaluable by quantifying potential measurement ranges and screening for important effects requiring deeper investigation, as part of developing sampling

protocols for gas and particulate species (including measurements of chlorinated hydrocarbon species), and designing and implementing more realistic aerosol entrainment systems.

Development of gas-phase measurement protocols (including quantification of key trace concentration species of concern) at Carleton University facility:

- Development and testing of a quantitative sampling protocol to accurately measure potential for formation (or lack of formation) of target species of interest as identified in collaborative work with the AER hydraulic fracturing technical committee. Methodology will be based on existing protocols for stack sampling combined with flare efficiency measurement methodologies developed at Carleton University [32], with a key focus on quantifying measurement accuracy and lower detection limits.
- Design, construction, and testing of an "artificial lung" system for rapid large-volume sample collection into Tedlar® or similar sample bags, allowing samples to be subsequently slowly drawn through sorbent tubes over several hours as a critical part of quantifying trace levels of critical chlorinated hydrocarbon species.

Detailed analysis of flaring practices in Canada using well-level, industry-reported data obtained in collaboration with AER:

- Detailed analysis to determine operating characteristics of hydrofractured oil and gas wells in Canada, including flowback durations, flared volumes, vented volumes, and drilled lengths.
- Results will guide ongoing experiments to ensure relevance to current industry practices.

Theme 2: Effects of Air- and Steam-Assist on Emissions Control Design, construction, and initial testing of air-assist burners, and completion of exploratory experiments

- Design and construction of a robust and easily usable burner to be shared with other researchers in FlareNet.
- Visualization and characterization of the flow conditions near the exit plane of the burner so that these inflow boundary conditions are well-defined.
- Completion of exploratory emissions experiments.

Design, construction, and initial testing of steam-assist burner, and completion of exploratory experiments:

- Design and construction of a robust and easily usable burner to be shared with other researchers in FlareNet.

Theme 3: Effects of Turbulent Crosswinds on Flare Emissions Modifications to the Western University Boundary Layer Windtunnel to facilitate flare combustion experiments.

- Design and construction of gas handling systems.
- Design and construction of windtunnel purging systems.
- Design, installation, and commissioning of gas detection / safety systems.
- Construction of unassisted flare systems for use in wind tunnel.
- Design, installation, and commissioning of gas analysis systems

Protocols for windtunnel-based flare measurements:

- Tracer-dilution measurements in tunnel using cavity ring-down gas analyzer shared from Carleton University to quantify tunnel volume and leak rates at different flow rates.
- Formulation of detailed mathematical approaches for closing a carbon mass-balance to calculate flare conversions efficiencies and emission rates.

- MATLAB modelling of measurement methodologies to analyze potential of different measurement methods and assumptions (e.g., inclusion of particulate mass in calculations, assumptions about plume molecular mass, etc.).
- Monte Carlo uncertainty analysis of derived methods and submission of final developed protocols for peer review.

Theme 4: Properties of Particulate-phase Species Emitted during Flowback and Routine Flaring Operations Particle measurement systems and protocols

- Development of a portable sample extraction, conditioning, and splitting apparatus which achieves representative and stable sampling from the flare exhaust plume and mitigates further evolution of the particulate morphology during transition through the sampling system.
- Development and documentation of particle and BC mass, number, and mobility size measurement protocols critical to ensuring consistency and accuracy among experiments.
- Experiments on the Carleton University flare to complete the first-ever systematic study of the morphology and optical properties of particles from "conventional" flares over a range of flares sizes and gas velocities.

Development of UAV instrument package:
- Procurement and modification of lightweight instruments for particle sampling and measurement.
- Completion of test experiments to confirm that UAV instruments agree with other aerosol instruments.

Theme 5: Application of Novel Technology for Field Measurements

- Sky-LOSA method development
- Processing of field measurement data from a recent campaign in Ecuador co-sponsored by World Bank and UNEP CCAC to generate first-ever measurements of flare BC yield as a function of flare inputs.
- Development of new Sky-LOSA processing algorithms to enable more accurate processing in overcast sky conditions.
- Development of generalized field measurement protocols with specified requirements for camera angles, relative sun positions, imaging settings, etc. to achieve measurements within acceptable uncertainty bounds based on comprehensive Monte Carlo simulations and Bayesian analysis.
- Submission of a paper on the new Sky-LOSA protocol and using this as a basis for submission of proven Sky-LOSA protocols for consideration as an official Other Test Method by the U.S. EPA.
- Enhancement of data processing and uncertainty quantification by incorporating optical and morphological data acquired via Theme 4 and UAV measurement in Theme 5.

Field measurement of BC from flares during flowback:
- In collaboration with AER, work to plan and execute field measurement campaigns to determine BC emissions from flares during flowback via sky-LOSA.
- Analysis of data from campaigns of flare emissions during flowback for emission factors and BC optical properties.

III. Research Team

NSERC FlareNet Strategic Network: Research Team Network & Scientific Director, Prof. Matthew Johnson, Carleton University Associate Director, Prof. Larry Kostiuk, University of Alberta Principal

Investigator, Prof. Kyle Daun, University of Waterloo Principal Investigator, Prof. Greg Kopp, University of Western Ontario Principal Investigator, Prof. Jason Olfert, University of Alberta Principal Investigator, Prof. Steven Rogak, University of British Columbia Principal Investigator, Prof. Kevin Thomson, Carleton University

Attachments Appendex B & C
Appendix B: Biographies of the FlareNet Network Research Team Appendix C: Selected Recent Publications

IV. Budget

2017 AUPRF Funding Request: $150,000
Total Leveraged Funding: $1,231,928