Dear Dr. Johnson,  
  
Your manuscript JoVE54179R1 "Design and Use of a Full Flow Sampling System (FFS) for the Quantification of Methane Emissions" has been peer-reviewed and the following comments need to be addressed.   
  
Please keep JoVE's formatting requirements and the editorial comments from previous revisions in mind as you revise the manuscript to address peer review comments. Please maintain these overall manuscript changes, *e.g.*, if formatting or other changes were made, commercial language was removed, *etc.*   
  
Please track the changes in your word processor (*e.g.*, Microsoft Word) or change the text color to identify all of the manuscript edits. When you have revised your submission, please also upload a separate document listing all of changes that address each of the editorial and peer review comments individually with the revised manuscript. Please provide either (1) a description of how the comment was addressed within the manuscript or (2) a rebuttal describing why the comment was not addressed if you feel it was incorrect or out of the scope of this work for publication in JoVE.  
  
**Your revision is due by Nov 13, 2015. Please note that due to the high volume of JoVE submissions, failure to meet this deadline will result in publication delays.**  
  
To submit a revision, go to the [*JoVE* Submission Site](http://www.editorialmanager.com/jove) and log in as an author. You will find your submission under the heading 'Submission Needing Revision'.  
  
Sincerely,  
  
Nam Nguyen, Ph.D.   
Science Editor  
[JoVE](http://www.jove.com/)  
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tel: 617-674-1888   
    
  
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**Editorial comments:**  
  
The manuscript has been modified by the Science Editor to comply with the JoVE formatting standard. Please maintain the current formatting throughout the manuscript. The updated manuscript (54179\_R1\_100615.docx) is located in your Editorial Manager account. In the revised PDF submission, there is a hyperlink for downloading the .docx file. Please download the .docx file and use this updated version for any future revisions.   
  
Changes made by the Science Editor:  
  
1. There have been edits made to the manuscript.   
  
Changes to be made by the Author(s):  
  
1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues. The JoVE editor will not copy-edit your manuscript and any errors in the submitted revision may be present in the published version.

**The document has been modified based on the reviewer comments and a separate review for formatting and grammar has been completed.**  
  
2. Formatting:  
-Please provide catalog numbers to items in the Materials/Equipment list.

**Catalog numbers are not given for the components used in this protocol. Websites are given where all available equipment or calibration gases can be obtained along with specific model numbers for user reference.**

-In step 2.4, is the reference to 2.3 correct? Or should this be 2.2?

**Changed to 2.2.**

-There are several instances where portions of steps are not in the imperative, and such information could be included as Notes. For example, step 2.7 (“If…to be created.”) and step 3.8 (“Faults..sample fittings.”).

**Non-imperative steps modified as notes.**

3. Please correct the grammar in the Introduction: “The values in Figure 1 the average published fugitive methane emissions…”

**Grammar fixed.**  
  
4. The second sentence of 4.2.1 will be difficult to visualize. We recommend incorporating this into the associated Note. Alternatively, please provide direction on aggregating and sampling these sources.

**The second sentence was included as a Note and a separate step 4.2.2 was included.**  
  
5. Additional detail is required  
-1.6/1.7-What constitutes “acceptable” signals or ranges?

**1.6 – The output voltage of the MAF should be between 0-5V. This range was included in the step.**

**1.7 – The following note was added.**

**Note: Ensure that the MAF calibration spans at least 25% of the minimum flow rate of the LFE used for calibration. Do not exceed the maximum previously calibrated flow rate of the LFE, if larger flow rates are to be calibrated, use a larger LFE.**

-1.7-8, 2.6-What needs to be clicked on in the software to accomplish these actions?

**Button reference added.**

-4.2-Should the probe of the detector be positioned/held in a specific way?

**Added: Position the probe sample inlet orthogonal to the surface to minimize dilution.**

-4.2.1-What are examples of inaccessible sources?

**Modified Note - Note: Inaccessible sources could include vent pipes that are beyond a safely accessible height as determined by the site operator. Aggregated sources may include multiple pneumatic valves attached to a manifold or enclosed by a service box. If the source or multiple sources can be examined as a whole using an enclosure, aggregate the sources.**

6. Branding should be removed:  
-4.1/5.4/5.5/5.8-Snooper program—unless this is open source, the software should appear in the materials table and not be referenced by name in the text.

**It is based on open source code and written internally but references were removed.**

-Results-Meriam.

**Removed.**  
  
7. In the Results, please include a general label (e.g., Reference) on the X-axis in Figure 1.

**Added.**  
  
8. In the Discussion, please elaborate on the advantages of this technique over others, and provide independent superscript references.

**Last paragraph modified to highlight advantages, references included.**

**Overall, the system and its methods have proven beneficial in efforts to quantify accurately the methane emissions from various sources. The system is scalable and user friendly. The developed system has an uncertainty of +/-4.4% compared to current commercial systems with an uncertainty of +/-10% 72. With proper calibrations, this system can easily quantify leak rates up to 140 SCFM compared to current commercial systems that are capable of quantifying leaks up to 8 SCFM with full battery charges 64,72. While the system requires connection to house power, this offers advantages of consistent sample rates and sample rates much higher than current systems. The user interface reduces post-processing requirements and reduces reporting efforts. In addition, the laser-based sensors are non-destructive to the leak sample, which allows for direct measurement of the sample with multiple analyzers 65. Laser based measurements also do not require separate sensors for ambient, small and large leak measurements or sensor transitions, which contribute to additional sources of inaccuracy. Future studies focus on continued optimization of the FFS and its user interface. Additional research is being conducted which combines experimental research data and computation fluid dynamics to develop additional best practices to ensure consistent and optimal measurement techniques.**

**Reviewers' comments:**  
  
**Editor’s Note:**Please note that the reviewers raised some significant concerns regarding your method and your manuscript. Please thoroughly address each concern by revising the manuscript or addressing the comment in your rebuttal letter.

**We thank the Editor and the reviewers for their feedback and the opportunity to address their comments to improve the overall quality of the paper. Please see the bolded responses in this rebuttal and the tracked changes to ensure that we have addressed all comments**.   
  
**Editor’s Note:**We do not require in depth or novel results for publication in JoVE, only representative results that demonstrate the efficacy of the protocol. However, please ensure that all claims made throughout the manuscript are supported by either results or references to published works.

**We have added additional references to specific comparisons of similar approaches. Please let us know if there are other specific concerns regarding this comment.**  
  
**Reviewer #1:**   
*Manuscript Summary:*  
General comments: The authors rightly state that measurements of methane emissions are sorely needed from many different aspects of the natural gas supply chain, and the existing techniques for making these measurements all have drawbacks. However, I am not convinced that this proposed method will make the measurements easier. There are three main drawbacks to the method proposed in this paper, all of which are minimized in the paper and which make the instrument problematic: 1), the power needs are never described although I assume the system needs a substantial generator which makes it hardly "portable"; 2), these methods need to be intrinsically safe, meaning they will not explode in a high-methane environment like a natural gas compressor station, and I think many of these components are likely not intrinsically safe; and 3), there is no information about the sensor that measures methane such as the concentration range, accuracy, etc. Since the end of the paper specifies this is a Los Gatos instrument, these data should be included. I have not worked with this instrument previously but I suspect it is most accurate at lower (near atmospheric) concentrations. The range of measurements possible with this method is also not clear and this is a critical piece of information for potential users.

**We appreciate the feedback from the reviewer and have made changes where possible but have also included objections against certain recommend changes. Please see the following rebuttal and tracked changes version.**

**We do not necessarily present out method has easier than the other methods/technologies. We develop this technology and protocols to mimic what is currently used in industry but to do so with higher accuracy and over a much larger range compared to currently available methods.**

1. **We have included the power requirements that do show we require a grid connection. However, the system is still portable in the sense that it is movable around an entire site. See the following.**

**System platforms included portable carts, on-road, and off-road vehicles. Power consumption does require the use of generator power or house power through standard 120 VAC connections. However, through this use of ‘grid’ power the system can sample at much higher flow rates yet still be used in conjunction with extension cords and long sampling houses for portability around a given site of interest. Current battery operating systems have decreased performance as a function of battery discharge, which is eliminated using grid power.**

1. **We agree that safety of the site and the user is of the highest importance. Currently the system has been designed to minimize or mitigate any explosive issues. Upon production of a marketable system, it would require the testing and demonstration of compliance when required. The system was developed with safety in mind and in conjunction with industry. The certification of intrinsic safety has not been completed at this time, even for the currently sale and use of the Los Gatos Research Ultra-Portable Greenhouse Gas Analyzer. See the added safety note.**

**Note: The FFS has been engineered with safety in mind to eliminate or reduce the possibility of ignition of a methane or natural gas source. Natural gas is flammable in ambient conditions from volume concentrations from 5 to 15%. When marketed the system will be tested and demonstrated to meet intrinsic safety requirements. Modification or tampering with the system could cause serious injury.**

1. **We have provided information regarding the current use of the LGR. See below. Beyond the current configuration we have also examined this and other laser based sensors that operate well beyond 10% methane by volume to produce total system uncertainties at or below +/-10% of the HI FLOW system. If we targeted this level of uncertainty the measurable leak rate range, (which is already and order of magnitude higher than the HI FLOW) would be extended by another order of magnitude.**

**Due to limitations of these methods and systems, a new quantification system was developed. The full flow sampling system (FFS) employs the same design concept as dilution systems used in automotive emissions certification 66-68. The FFS consists of a hose that feeds an explosive-proof blower that exhausts the leak and dilution air sample through a mass airflow sensor (MAF) and sample probe. The sample probe is connected to a laser based methane analyzer through a sampling tube. The analyzers uses cavity enhanced absorption for measurement of CH4, CO2, and H2O. The analyzer is capable of measuring CH4 from 0-10% by volume, CO2 from 0-20,000 ppm, and H2O from 0-70,000 ppm. Repeatability/precision (1-sigma) for this configuration is <0.6 ppb of CH4, <100 ppb CO2, and <35 ppm for H2O 69. The sample is drawn from the steam at a constant volumetric rate. The system is instrumented with data logging equipment. Figure 2 illustrates the schematic of the FFS. Prior to operating the FFS, the grounding connection on the sampler hose is attached to a surface that allows the system to be grounded. This is a preventive action to dissipate any static charge on the end of the hose, which could result from airflow through the hose. Data acquisition occurs on either a smart phone, tablet, or laptop computer. We developed software for data collection, processing, and reporting.**

The paper was also somewhat confusing to review. Part of it reads like a normal journal article, but a large part of it is just a numbered list that is hard to follow. I also have problems with the references cited. Some of the numbers cited in the text do not make sense for that particular paragraph, so either the references are misnumbered or they are inappropriate. I have noted some cases of this below.

**We agree that there were some errors in numbering/missing references, which have been fixed in this edit. We have followed the formatting that is for use in this journal. For sections outside of the protocol, we present cited literature and detailed results as would be presented within a typical journal. The protocol sections do appear as numbered lists but are in line with the formatting of this journal. We will work with the editor to ensure the final paper meets the quality and formatting requirements.**

Finally, I received a request to review another paper by the same authors from another journal that is extremely similar to this one, and neither paper cites the other. Publishing the same material in two different papers is not viewed favorably in my field.

**We agree that we have multiple publications that reference the general full flow sampling system. In fact, it was one of these publications (Environmental Science and Technology) that aroused interest in developing an article for JoVE by a JoVE Editor. We were contacted by an editor to provide a paper that specifically focuses on additional details and operation of the system, which we have presented here. We have double-checked all language to ensure that there is no self-plagiarism. The new article has also been included as reference 72.**

Specific comments:  
Abstract: As stated above, it is critical to discuss the power needs, safety requirements, and the possible measurement range in the abstract (and addressed in the paper as well).

**See above and below responses to this and other reviewer comments, which address these issues.**

Line 68: Human activities can contribute biogenic greenhouse gas emissions too.

**Edited as follows. CO2 and methane originate from both natural processes and human activities 3.**

Line 78: Cows are not a natural source of methane and these references are not appropriate for this statement.

**Call out of specific examples was removed.**

Line 83: Also not the correct reference.

**We agree that during formatting this reference was entered incorrectly.**

**14. Natural Resources Defense Council. Leaking Profits: the U.S. Oil and Gas Industry can Reduce Pollution, Conserve Resources, and Make Money by Preventing Methane Waste. (2012). http://www.nrdc.org/energy/files/Leaking-Profits-Report.pdf**

Line 89: Is reference 20 a peer-reviewed article? Not clear what this is.

**This is not a peer reviewed article but a report by ICF to the EDF. A link to the full report has been included in the updated citation.**

[**https://www.edf.org/sites/default/files/methane\_cost\_curve\_report.pdf**](https://www.edf.org/sites/default/files/methane_cost_curve_report.pdf)

Lines 95-96: Need to make reference to the lower CO2 emissions from burning natural gas versus oil or coal here.

**We respectfully disagree on this need for additional reference. Based on 100% combustion efficiency and only examining the combustion process there will be lower CO2 emissions. However, this is an area of hot debate due to combustion efficiency, complete life-cycle analysis, equivalent CO2, thermal efficiency losses, etc.**

Line 110: Some of the studies cited here are review papers or estimates only, and the references in the figure are not numbered according to the references cited section.

**We agree and a note on measured and estimated values has been included. We chose to use the author name and data as when presented with just a reference number, the chart seemed confusing. We will work with the editor to see what method works best for publication.**

Line 112: At this point it is still unclear whether measurement inaccuracies, problems with scaling up, or both are responsible for the uncertainty in fugitive methane emissions.

**While we agree that there are multiple causes of possible error the statement is true that without accurate measurements, the uncertainty is only compounded but we did add a note for clarity.**

Line 121 - 127: Here you kind of mix and match two different bagging references. The "Calibrated Bagging" is a bag expansion method used specifically for vent measurements ("Vent- Bag") and typically takes 3 to 20 seconds to make a measurement; the 15 - 20 minutes in that paragraph is for flow through standard bagging.

**We agree that the presentation was confusing between the methods and have reorganized as follows.**

**The bagging method involves placing an enclosure in the form of a "bag" or tent around a fugitive emission source 60. There are two variations of the bagging method. In one, a known flow rate of clean gas (typically inert) passes through the enclosure to create a well-mixed environment for measurement. Once equilibrium is reached, a gas sample is collected from the bag and measured. The fugitive emission rate is determined from the measured flow rate of clean gas through the enclosure and the steady-state methane concentration within the enclosure 61. Depending upon enclosure and leak size, the time required to reach the necessary steady state conditions for the leak rate measurement is between 15 to 20 minutes 61. The bagging method can be applied on most accessible components. However, it may not be suitable for abnormally shaped components. This method type is capable of measuring leaks ranging in size from 0.28 cubic meters per minute (m3/min) to as large as 6.8 m3/min 60.The other bagging technique is known as Calibrated bagging. Here, the bags sealed around a fugitive emission source are of a known volume. The fugitive emission rate is calculated based on the amount of time required for the expansion of the bag, and corrected to standard conditions.**

Lines 133-134: Not consistent with using the written name of a compound, the chemical formula, or other ("R12").

**Edited to remove inconsistency.**

**Tracer gases commonly employed are helium, argon, nitrogen, sulfur hexafluoride, among others.**

Lines 147-159: This section describing the Hi-Flow system doesn't describe the background probe which is an important part of how the instrument works.

**Sentence added for clarity.**

**The system uses a separate background sensor and probe which corrects the leak concentration relative to the background concentration.**

Line 165: only states they used a laser based methane analyzer but don't give specs - min and max concentrations measurable?

**The paragraph was rewritten to include additional specifics. See below.**

**Due to limitations of these methods and systems, a new quantification system was developed. The full flow sampling system (FFS) employs the same design concept as dilution systems used in automotive emissions certification 66-68. The FFS consists of a hose that feeds an explosive-proof blower that exhausts the leak and dilution air sample through a mass airflow sensor (MAF) and sample probe. The sample probe is connected to a laser based methane analyzer through a sampling tube. The analyzers uses cavity enhanced absorption for measurement of CH4, CO2, and H2O. The analyzer is capable of measuring CH4 from 0-10% by volume, CO2 from 0-20,000 ppm, and H2O from 0-70,000 ppm. Repeatability/precision (1-sigma) for this configuration is <0.6 ppb of CH4, <100 ppb CO2, and <35 ppm for H2O 69. The sample is drawn from the steam at a constant volumetric rate. The system is instrumented with data logging equipment. Figure 2 illustrates the schematic of the FFS. Prior to operating the FFS, the grounding connection on the sampler hose is attached to a surface that allows the system to be grounded. This is a preventive action to dissipate any static charge on the end of the hose, which could result from airflow through the hose. Data acquisition occurs on either a smart phone, tablet, or laptop computer. We developed software for data collection, processing, and reporting.**

Line 215: Again you need more description of the greenhouse gas analyzer and its measurement range, accuracy, and precision. Why can't you be specific in the paper about which analyzer you are using?

**See above for species, ranges, etc. Per JoVE requirements, name brands/logos/companies cannot be mentioned within the paper itself. However, we have added the above details.**

Line 371 - this is in the section that reads like an instruction manual but it says to take a local background and says to click on that button but it doesn't say how it does it - i.e, where the back ground probe is located, does it switch to that probe, and are there different delay times. Background concentration measurements will be very important here because the method uses flow rates from 40 to 1500 scfm, which means you're drawing in far more background air to dilute the leak with than with the High Flow. It is important to have the background measured while the system is capturing the leak.

**An additional note has been included for the discussion of local background. The system offers local and global backgrounds. See below.**

**Note: The program automatically switch the sampling location of the outlet of the FFS to a port just behind the inlet to the sampling hose for a local background. The sampling hose must be in the same measurement position as is used for the sample quantification.**

Line 433 - sounds like the only part of the system that's explosion proof or intrinsically safe. This could cause a fatal safety hazard if you suck a large leak in and exhaust it around the equipment.

**We agree that the measurement of natural gas or methane leaks does pose a safety risk. The system has been designed to eliminate or minimize these risks. When marketed the system will undergo the necessary testing and demonstration to be approved as Class 1 Division 1 acceptable. A special note was added to the beginning of the protocol.**

**Note: The FFS has been engineered with safety in mind to eliminate or reduce the possibility of ignition of a methane or natural gas source. Natural gas is flammable in ambient conditions from volume concentrations from 5 to 15%. When marketed the system will be tested and demonstrated to meet intrinsic safety requirements. Modification or tampering with the system could cause serious injury.**

Line 486 - they used 20 and 30 slpm injections of 99.9% methane and got agreement to within 2.2%. That's good, but they don't tell us what their sample flow rate was during that checkout - 40 scfm, 1500, or something in between? It would be good to check it out at several sample flows.

**We agree that it should be checked out and different sample flow rates, especially those that are of interest to a particular measurement campaign. However, due to length restrictions we have provided a two-point verification at a single flow rate of 140 SCFM. This reference value has been included.**

**The results are presented in Table 1 for a system flow rate of 140 SCFM.**  
  
*Major Concerns:*  
N/a  
  
*Minor Concerns:*  
N/A  
  
*Additional Comments to Authors:*  
N/A  
  
  
**Reviewer #2:**   
*Manuscript Summary:*   
This paper presents a sampling approach for quantifying methane leaks from upstream components of the natural gas system. There currently is no standardized approach for these measurements, so the description of the Full Flow Sampling system (FFS) is timely and of interest to groups seeking to improve estimates of methane leakage rate. The FFS has been adapted from dilution systems used in automotive emissions certification, and employs a blower that pulls sample in via hose, then exhausts the sample air and dilution air through a mass flow sensor and sample probe, which is connected to a laser based methane analyzer. Instructions for calibrating the mass flow sensor and methane analyzer are given, as well as steps to quantify the leak. A "Snooper" software program was developed to handle the data and calculate leak rate. Overall uncertainty of methane emissions rate was demonstrated to be +/- 4.4%.

**We appreciate the feedback from the reviewer and have worked to address their concerns within the scope of this article.**

*Major Concerns:*  
-The text does not include a description of the methane analyzer. I see in the equipment list that it was a Los Gatos Research ultraportable greenhouse gas analyzer, but a description of it and how it works should be in the text. Why was the LGR chosen over any other methane analyzer?

**The LGR was chose during this initial phase because of its co-measurement of CO2, H2O, and CH4. It is also readily available in a rugged case for use in the field. The following paragraph was rewritten to include additional details but following the instruction not to include any commercial names.**

**Due to limitations of these methods and systems, a new quantification system was developed. The full flow sampling system (FFS) employs the same design concept as dilution systems used in automotive emissions certification 66-68. The FFS consists of a hose that feeds an explosive-proof blower that exhausts the leak and dilution air sample through a mass airflow sensor (MAF) and sample probe. The sample probe is connected to a laser based methane analyzer through a sampling tube. The analyzers uses cavity enhanced absorption for measurement of CH4, CO2, and H2O. The analyzer is capable of measuring CH4 from 0-10% by volume, CO2 from 0-20,000 ppm, and H2O from 0-70,000 ppm. Repeatability/precision (1-sigma) for this configuration is <0.6 ppb of CH4, <100 ppb CO2, and <35 ppm for H2O 69. The sample is drawn from the steam at a constant volumetric rate. The system is instrumented with data logging equipment. Figure 2 illustrates the schematic of the FFS. Prior to operating the FFS, the grounding connection on the sampler hose is attached to a surface that allows the system to be grounded. This is a preventive action to dissipate any static charge on the end of the hose, which could result from airflow through the hose. Data acquisition occurs on either a smart phone, tablet, or laptop computer. We developed software for data collection, processing, and reporting.**

-The authors presented current sampling methodologies with advantages/disadvantages of each in the introduction. In the discussion section, the authors should revisit this topic and present ways in which the FFS is superior or inferior to the other methodologies. For example, given that it uses an LGR analyzer it will be quite a bit more expensive than a Bacharach HI Flow sampler will but perhaps it has better sensitivity. This would be a very important part of the paper because if it cannot be demonstrated that the FFS is an improvement as a sampling approach then it does not have merit.

**We have added some additional detail on why the system is superior to currently available systems. Please see the edited last paragraph of the discussion section.**

**Overall, the system and its methods have proven beneficial in efforts to quantify accurately the methane emissions from various sources. The system is scalable and user friendly. The developed system has an uncertainty of +/-4.4% compared to current commercial systems with an uncertainty of +/-10% 74. With proper calibrations, this system can easily quantify leak rates up to 140 SCFM compared to current commercial systems that are capable of quantifying leaks up to 8 SCFM with full battery charges 64,74. While the system requires connection to house power, this offers advantages of consistent sample rates and sample rates much higher than current systems. The user interface reduces post-processing requirements and reduces reporting efforts. In addition, the laser-based sensors are non-destructive to the leak sample, which allows for direct measurement of the sample with multiple analyzers 65. Laser based measurements also do not require separate sensors for ambient, small and large leak measurements or sensor transitions, which contribute to additional sources of inaccuracy. Future studies focus on continued optimization of the FFS and its user interface. Additional research is being conducted which combines experimental research data and computation fluid dynamics to develop additional best practices to ensure consistent and optimal measurement techniques.**

-I have concerns about the screening for leaks with the handheld unit (step 4.2 under "Leak detection audit"). The sensitivity of this unit looks something like +/- 25 ppm. Potential leak points are excluded from quantification with the FFS if they are below detection with the Eagle II unit. What is the sensitivity of the FFS in g/hr? Uncertainty is given (+/- 4.4%) but how does that translate to sensitivity? One would have to report minimum detection based on the +/- 25 ppm sensitivity of the Eagle II if leaks that are too small to be picked up by the Eagle II are not quantified with the FFS.

**Many sources in literature use 500 ppm as the leak quantification threshold. The sensitivity of the Eagle II is 5 ppm above local background (zeroed at the site). We have added a note on this. In addition, we have reported on the minimum detection limit of the current system in the last paragraph.**

**Note: The sensitivity of the handheld unit is 5 ppm above background when zeroed on ambient air.**

**The minimum detection limit of the current system is 0.24 g/hr or 3.0x10-3 SCFM.**

-A better description of the Snooper software would be beneficial. Perhaps a flowchart of prompts/data input steps could be included as a figure.

-The use of the infrared camera seems arbitrary. Is it recommended for use for this system or not? These cameras are very expensive.

**We agree the cameras are expensive. The system is focused on use of the handheld methane detector but the note and alternative method were included for those that may have access to this method.**

**Note: Optical gas imagining cameras are typically expensive but do reduce the time required to scan components for leaks. Use of high sensitivity modes may be required for small leaks.**

-The authors presented results for three different types of leaks. Were these controlled releases? It does not seem as though they were, but the paper should demonstrate the accuracy of the FFS by measuring controlled leaks with known methane emission rate, and also compare its readings to those obtained via another approach such as a HiFlow sampler.

**These were not controlled releases and the actual sources are provided. Pursuant to the standards of this journal, representative results are to be presented and we have provided those in this article. We have though, presented results of a gas recovery test at two known methane leak rates. These results are presented in the paragraph starting at line 510. The goal of the paper is to highlight the system and the protocols for use of the system. While we provide our advantages compared to currently available systems we did not complete a direct comparison to the currently available products. A direct comparison is beyond the scope of this article but would be an interesting research project.**

-Unless more discussion is included, I do not yet see how this system is a clear improvement over "bagging" or HiFlow samplers. It seems like it would be more time consuming and expensive. The limitation of bagging not being suitable for abnormally shaped components can be solved with different sized bags and creative sealing. The limitations of the HiFlow sampler having problems switching from catalytic to thermal sensor can be overcome by more frequent calibration checks.

**We have highlighted the advantages of the system in the final paragraph, which we present here again for ease of reference. Based on review of recent publications there is still debate over whether more frequent calibration checks overcome the current limitations of the HI Flow sampling system. Our focus are on other advantages such as improved accuracy (even compared to a properly operating HI FLOW +/-10% compared to our +/-4.4. Our system also has a wider leak capture range. See below.**

**Overall, the system and its methods have proven beneficial in efforts to quantify accurately the methane emissions from various sources. The system is scalable and user friendly. The developed system has an uncertainty of +/-4.4% compared to current commercial systems with an uncertainty of +/-10% 74. With proper calibrations, this system can easily quantify leak rates up to 140 SCFM compared to current commercial systems that are capable of quantifying leaks up to 8 SCFM with full battery charges 64,74. While the system requires connection to house power, this offers advantages of consistent sample rates and sample rates much higher than current systems. The minimum detection limit of the current system is 0.24 g/hr or 3.0x10-3 SCFM. The user interface reduces post-processing requirements and reduces reporting efforts. In addition, the laser-based sensors are non-destructive to the leak sample, which allows for direct measurement of the sample with multiple analyzers 65. Laser based measurements also do not require separate sensors for ambient, small and large leak measurements or sensor transitions, which contribute to additional sources of inaccuracy. Future studies focus on continued optimization of the FFS and its user interface. Additional research is being conducted which combines experimental research data and computation fluid dynamics to develop additional best practices to ensure consistent and optimal measurement techniques.**   
  
*Minor Concerns:*  
-The "Snooper" program is referenced in 4.1 of section 4 (Leak detection audit) but it had not been previously described or defined.

**Reference to “Snooper” has been removed.**

-In lines 285-286, 4.4% is suggested as an acceptable error but no justification for the selection of this number is given.

**The 4.4% is suggested as acceptable as this is the relative measurement of uncertainty of the entire system. The note was modified per below. 4.4% was calculated based on propagation of uncertainty of individual components, which are presented in Table 2.**

**Note: Upon completion of sampling the software will create a report showing the error of the between the known gas flow rate and the recovered gas flow rate. An error of ±4.4% is acceptable (relative measurement uncertainty of the system), but the targeted recovery error is ±2%.**

-The sentence in lines 98-99 does not make sense and should be reworded. Its meaning is unclear.

**Both sentences were modified for clarity. See below.**

**However, there is a consensus that fugitive methane emissions occur at every stage of the natural gas life cycle and further research in accurately measuring and reporting these values is important 19. Studies have reported fugitive emissions from specific sectors with results varying by up to twelve orders of magnitude 19, 22-28.**  
  
*Additional Comments to Authors:*  
N/A  
  
  
**Reviewer #3:**   
*Manuscript Summary:*   
The section describing the protocol would benefit from a few introductory paragraphs describing the steps in the over-all protocol and their rationale, before providing a detailed description of each step.

**This is our first time using this Journals formatting. We have included some statements within the protocols as notes for the readers. We have, based on this request, added a few introductory sentences to each protocol section. We will work with the editor in the final process to see if these statements should remain or be placed in the discussion section. We appreciate this feedback.**  
*Major Concerns:*  
None  
  
*Minor Concerns:*  
None  
  
*Additional Comments to Authors:*  
N/A