THE BRAKE PAD PARTNERSHIP

Compilation of Technical Reviewers and Stakeholders Comments on Generating a Representative Sample of Brake Pad Wear Debris Draft Report

November 17, 2005

Background

The Brake Pad Partnership (BPP) is a multistakeholder effort to understand the impacts on the environment that may arise from brake pad wear debris generated in the use of passenger vehicles. Manufacturers, regulators, stormwater management agencies, and environmentalists are working together to understand the impacts that may arise from brake pad wear debris generated by passenger vehicles on the environment. BPP efforts are aimed at developing an approach for evaluating potential impacts of copper from brake pads affecting water quality in the South San Francisco Bay as an example. Brake pad manufacturers have committed to adding this evaluation approach to their existing practices for designing products that are safe for the environment while still meeting the performance requirements demanded of these important safety-related products.

To accurately model the movement of copper from brake pad wear debris through the environment, additional information is needed on the chemical and physical characteristics of the wear debris particles. As a part of the brake manufacturing industry's participation in the Brake Pad Partnership (BPP) a representative sample of brake pad wear debris (BPWD) was generated by the Brake Manufacturer's Council (BMC) for use by the BPP in order to conduct physical and chemical characterization of brake pad wear debris. The methodology was developed with technical input and analysis from the Brake Manufacturers Council-Product Environmental Committee (BMC-PEC) in close consultation with the BPP Steering Committee.

As a part of the Brake Pad Partnership's overall effort, the effort was subject to the following conditions and constraints: 1) The representative sample of wear debris represents the nationwide brake pad wear debris of copper-containing Original Equipment Manufacturers (OEM) pads only, and therefore does not include aftermarket pads or non copper-containing OEM pads; 2) Budget constraints allowed minimal run times for generating wear debris. 3) Sample identification and collection methods were devised to protect manufacturers' proprietary interests.

The information generated on wear debris characteristics will be used to inform subsequent environmental modeling studies aimed at understanding the role of copper in brake wear debris in stormwater and surface water quality in the San Francisco Bay. The representative sample of BPWD was sent to team of researchers from Clemson University to determine total copper and iron content, and solubility and leaching potential of copper in a representative sample of brake pad wear debris. The results of these tests will be used by the Brake Pad Partnership to inform our efforts to model the transport and fate of brake wear debris in the environment.

The Brake Pad Partnership Steering Committee is seeking an independent expert review of the Draft Report on the Methodology for Generating a Representative Sample of Brake Pad Wear Debris to ensure that the approach and results of this element of the Partnership's work are technically sound, and to help build in-depth understanding of and confidence in the technical studies on the part of the Steering Committee and the stakeholder communities.

CHARGE

With the aim of meeting these objectives, the Steering Committee has developed the following questions on which it is seeking specific comments from the reviewers:

1. What is your assessment of the work performed here and the reliability for the methodology for generating a representative sample of brake pad wear debris?

2. Based on your experience, what are the strengths and weaknesses of this methodology?

3. Is the approach for generating a representative sample of brake pad wear debris, as presented in the report, suitable for conducting and evaluating the potential for copper and iron leaching from brake pad wear debris in the environment?

4. Does the report clearly describe the approach, selection methodology, constraints and/or uncertainties?

Comments Received

Comments of Rod McLellan, Managing Director, Rod McLellan Associates (November 7, 2005)

The Reviewer's comments presented below are restricted to the four specific questions posed by the Steering Committee:

1. What is your assessment of the work performed here and the reliability for the methodology for generating a representative sample of brake pad wear debris?

The test methodology and test procedure described within SAE 02 BRAKE-43 paper entitled "Disc Brake Wear Debris Generation and Collection" authored by Dr. Jim Trainor, Tim Duncan and Robert Mangan provides a detailed protocol for the laboratory collection of wear debris resulting from the medium duty usage of phenolic composite/Cast Iron passenger car disc brake friction pairs. Within these restrictive parameters, it is the Reviewer's opinion that the paper proposes an appropriate methodology for generating a representative sample of laboratory produced friction pair wear debris.

2. Based on your experience, what are the strengths and weaknesses of this methodology?

The major strength of the procedure as presented lies with its linkages and cross-references to existing standards with respect to SAE and NHTSA test requirements and EPA sample collection methods. Additionally, the procedure as described closely defines the relevant parameters to ensure repeatability. There are few weaknesses of the procedure as related to the brief. The inappropriate cost base of the equipment and test procedure developed when measured against scientific relevance and real world application is of concern. In this respect, the procedures developed will have no valid application at the friction material manufacturers. Specifically, the apportionment of wear debris into airbourne, wash-down and pipe coating has little relevance to real world application where road shock and road surface contamination are of great significance, and these will influence the way in which solid phase wear debris is distributed within the environment. From a body of knowledge viewpoint, as a 'standard industry evaluation' procedure, the procedure will contribute nothing to the knowledge base already available through the normal application of academic rigour to the basic chemistry of the constituent parts of the friction pair. The total omission of the gaseous bi-products of the friction pair interaction should be of major concern to any chemist or researcher.

3. **Is the approach for generating a representative sample of brake pad wear debris, as presented in the report, suitable for conducting and evaluating the potential for copper and iron leaching from brake pad wear debris in the environment?**

The specific chemical and physical interactions with brake pad wear debris which potentially support the leaching of copper and iron into the environment are not addressed by this paper. The paper restricts its focus to the generation and collection of friction pair solid wear debris. As such, the test protocol defined in the paper will, under tightly controlled laboratory conditions, produce a form of solid wear debris suitable for subsequent analysis. It must also be stressed that the wear debris generated is from the friction pair, and not exclusively the friction material element.

4. **Does the report clearly describe the approach, selection methodology, constraints and/or uncertainties?**

The report clearly describes the approach and selection methodology. The constraints and uncertainties relating to the overall impact of disc brake pad wear debris on the environment are not realistically presented. In the situation where the copper and iron constituents of the friction pair are to be considered in isolation, this lack of detail is of no consequence.

Comments of Kevin Reinert (AMEC) and Ray Arnold (Copper Development Association) (November 7, 2005)

1. **What is your assessment of the work performed here and the reliability for the methodology for generating a representative sample of brake pad wear debris?**

The samples are probably representative, but the report is lacking in detail; merely citing the SAE protocol (available on the website, but at cost to others) may not be appropriate. The report should provide more detail on approach, data treatment and analysis.

2. **Based on your experience, what are the strengths and weaknesses of this methodology?**

The actual approach is difficult to recreate due to the paucity of details in the report.

3. **Is the approach for generating a representative sample of brake pad wear debris, as presented in the report, suitable for conducting and evaluating the potential for copper and iron leaching from brake pad wear debris in the environment?**

Probably developed a representative sample, although some of the mass balance and treatment of various components of the debris are not clear. The use of market-based amounts of wear and time on the dynamometer appear to be relevant, although I do not understand how masses of debris are not more proportional to time in the dynamometer. Finally, were the pads against the rotors for the period of time noted or were they pulsed like real world events (I did not check the SAE protocol)?

4. **Does the report clearly describe the approach, selection methodology, constraints and/or uncertainties?**

As noted above, the report lacks in detail in many areas. Table 1 requires more detail to stand alone. It is not clear in the second ‘Table 1’ (in Results) why the tray loses mass and where the filter materials end up – collected and washed to? How is the total collected of 30.3 g calculated? Should the

specifications for this table be listed and not just referred to in 'emails' that are not attached? Finally, the single cycle of stop data is not attached as noted below the table.

Comments of Robert Frosch, Belfer Center for Science and International Affairs, Harvard University (November 8, 2005)

This document bases its procedures and protocol on SAE Technical Paper 2002-01-1280, **Brake Dynamometer Measurement of Airborne Brake Wear Debris**, by Sanders, P.G. et al (hereafter referred to as 1280), and on: **02 Brake-43: Disc Brake Wear Debris Generation and Collection**, hereafter referred to as 43). It is a straightforward application of the procedures and equipment described in those documents, which apparently represent the SAE standard for such measurements.

My only comments on the documents relate to the question of whether **VI. <u>Generation of representative samples</u>** (page 5) provides a satisfactory representation of 'real world' results. While 43 suggests on the top of its third page that: "…each wear debris generation test should be run with a new, original equipment rotor" (and this suggestion appears to have been followed in our case), 1280 notes on its 4th page, left column, second paragraph: "Green (new linings and rotor) hardware exhibits higher wear rates…..the average wear per test was obtained after the wear rate has plateaued…"

Given the stated facts, it is not clear that weighting the car populations by running the pads for different times is the best procedure. I would have thought that one ought to run each pad for enough stops so that the wear had led to the plateau, then rune each pad for the same time to generate a reasonable sample, with the data from the different materials then weighted according to the population of cars using them. This procedure would assume that the various kinds of cars (and their brake pads) do not differ in the number of stops they make, or that, in all cases the majority of the material comes from the larger number of stops made with 'plateaued' material. (This assumes that brakes wear in fairly rapidly in normal use (which I think is true), and thus that most of the material in a life time of stops from a given pad is generated during the 'plateaued' use. This will be the case unless the higher wear of green hardware is very much higher; 1280 does not say.

On the other hand, the variability may well be such that these differences are minor, and can be ignored. Perhaps the brake manufacturers know, and can tell us? At any rate, they might tell us why they chose this particular generation procedure.

Comments of Kelly Moran, representing the Bay Area Stormwater Management Agencies Association (November 11, 2005)

Thank you for circulating the Generating a Representative Sample of BPWD Draft Report for our review. More importantly, I want to thank the BMC-PEC for completing the brake pad wear debris generation for our joint project. I recognize that preparation of this short report has been a challenge--and appreciate the efforts of the BPP's industry representatives to see it to completion.

Below I have attached an e-mail from 2004 that outlined my recommendations for the format and content of the report. I know that the BMC-PEC took this input quite seriously, which I appreciate. I can see that the current report follows closely those recommendations for format and content, with a few exceptions. Below, I've identified the exceptions that I feel will be important for the credibility of the final report--and have tried to explain what I meant more clearly, recognizing that my intent may not have been sufficiently clear in the 2004 e-mail. My intent in identifying these items is to strengthen the report, since we will rely on it heavily for all our work together.

(1) Analysis of the Prevalence of Copper Forms. It would be helpful if the paragraph prior to Table 2 would include a definition of a Pareto Analysis and if it explained what was done to complete the Pareto Analysis. I'm making this request because many readers will not be familiar with this analysis (though the logic of it is very straightforward). Adding this bit of explanation will cause the selection of materials to make a lot more sense to many readers--and therefore be a lot more credible.

I believe that this analysis relies on confidential information from the BMC-PEC survey. If that's correct, it would be best to explain that the BMC-PEC collected actual use frequencies for the different copper types and used it in the analysis, but considers that information trade secret, so has not included it in this report. I think stakeholders can live with the idea that some information is trade secret--and they will want to know that the BMC-PEC analysis was based on quantitative information, as that makes the selection more credible. This will help readers understand the source of the numbers that appear in table 2.

(2) Generation of representative samples. This section could use a bit more explanation:
--how were the rotors selected? Is this in the protocol? Even if it is in the protocol, since wear debris includes some rotor debris, description of the rotor and anything that can be said about its copper content would be helpful to clarify what the debris content might be coming from.
--How were the run times calculated? A paragraph and perhaps a table walking the reader through these calculations would make the run time selection clear. I believe that this is simple mathematics--but it involves values not included in the report (total number of vehicles) and selection of a value from the ranges given for each type in table 2. If some of these data (e.g., total number of vehicles) are confidential, I think there still would be a way to make this calculation more concrete via example (and if so, specifically explaining that these data were used, but are trade secret).

(3) Results. This section could really benefit from a discussion of the data in Table 1. When I say "discussion", what I mean is:
--Define "initial weight," "final weight," and "Change in Mass."
--Explain why there are negative values and what these indicate.
--Answer questions that people are likely to have when reviewing the data (why do mass quantities differ? Why such a small amount of mass from the pad that ran the longest? Why is the total collected less than the total loss? etc.). (Some of these questions have been asked by other reviewers). While this answering will involve description of various possible reasons (since most of these answers are not known), it is an important part of the report, as it will help all of us understand the possible effects of the generation conditions on the sample of material that was created. I expect that Prof. Mark Schlautman or one of our other scientific advisors could provide valuable advice on how to construct this section of the report in a manner that would be valuable and not speculative.

(4) References. It looks like this is really a list of project participants, which is very helpful (perhaps this section should be retitled?). The types of references I was thinking about in my 2004 e-mail are provided as footnotes (which are perfect).

I would be happy to discuss and clarify these comments with you and/or with appropriate BMC-PEC representatives.

------- Original Message --------
Subject: Re: FW: Draft Memo for the Development Representative Brake Wear Sample (please review for comments and feedback)
Date: Wed, 04 Aug 2004 13:38:58 -0700

From: Kelly Moran <kmoran@tdcenvironmental.com>
To: Connie Liu <cliu@suscon.org>
References: <0BC3BA02DD3DD8479C9A732AEEFA890916B362@theserver.suscon.org>

Connie,
Thanks for putting this together. I appreciate that you are doing this--and recognize that it is rather awkward for Sustainable Conservation to be writing up activities conducted by others.

This is a very important procedure that you are trying to write up. It should have the same type of structure and level of detail as the workplans or the technical reports for this project--in other words, a short-report type of format. It needs to stand alone as the full and complete documentation of the creation and generation of the representative sample of brake pad wear debris. All our physical and chemical characterization work relies on this step--so if it is not treated with respect and not very well documented, the whole basis of our characterization work will be doubted.

When I'm thinking of a short report format, I am envisioning a document with a structure and content along the lines of this:
A. Cover Page
B. Table of Contents
C. Introduction: Background, purpose
D. Selection of brake pad materials to use to create representative sample (this is a big section with subsections that describe the previous surveys, explain why these don't provide the info needed to structure the sample generation, describe in detail the new survey done by manufacturers, provides the tables of the materials types and frequency of appearance in products, explains what a pareto analysis is and provides that analysis, and concludes with the selection of the materials).
E. Generation of representative sample (this is a big section that explains that the selected materials were formulated into pads of a standard shape on a standard backing, describes the rotors used, gives in great detail the procedure used to generate the wear debris at Link [and/or references the procedure and describes each and every modification made to that procedure], gives the specifics of how it was collected, and the specifics of how the material is being apportioned to create the overall sample; it may also note the special labeling, special sample set-aside for separate testing by manufacturers, relationship to related testing, and so forth, as appropriate).
F. Results should be presented (e.g., any mass measurements taken, etc.) in a results section. If there are no results here, there will need to be a separate report with those results, which cites this procedure. The two reports would need to be fully consistent.
G. References (all sources should be cited; a reference list is essential to the credibility of the document).
H. Appendices. All data sheets, test records, etc. should be included as appendices (unless they are in a separate, related report).

As you read this, you will probably see that my comments relate not only to structure, but also to content--there's a lot more information needed to make this a credible report.

Although we all trust that these procedures have been handled properly, we generally agree in the "trust but verify" approach. With that in mind, I think we'll want to take the fully developed version of this through our Scientific Advisory Team to ensure we've properly thought through and documented the procedures used and to give all stakeholders confidence in the procedures--and the all-important material that has been generated.

Please call me if you have any questions. I'd be happy to discuss this--and want to ensure that my thoughts can be translated into clear input for you.

Additional Comments of Kelly Moran, representing the Bay Area Stormwater Management Agencies Association, (November 11, 2005)

After I completed my comment this morning, I received additional input from BASMAA. Based on that input, here are some additional comments:

(a) Background. It would be useful to provide additional background for the lay reader to fully understand what the sample is representative of--and what are the general strengths and weaknesses of the approach used to select the pads used to generate the "representative" sample. This will be somewhat more elementary than what is in the document right now. What is needed in this section is conceptual in nature (not the actual details of what was done) so the reader can connect how (ideally) we get from: brakes in car fleet > OEM fraction > pad distribution by maker/model > distribution of Cu forms among pads > distribution of Cu forms among the "representative pads" chosen for dynamometer. A BASMAA reviewer found these ideas hard to follow (and I agree). What we need is to know how to interpret what the representative sample means in comparison to actual wear debris being generated on the road. (Not that we fully know the latter--the request is for context, not for omniscience).

(b) Summary under table 1. This text appears to be a description of some of the details of running the testing. It appears from the reference to "specifications provided in emails" that some adjustments were likely made to the protocol and/or that the lab was provided with directions to clarify the procedures. These are exactly the sorts of details that should be included in Section VI, Generation of representative samples. This paragraph should be relocated to Section VI and expanded to provide the full testing details. By "full testing details" I mean enough information about the procedure that it would be possible for another lab to reproduce the experiment with this report and the Trainor protocol.

(c) Results. The results section should specifically discuss sources of uncertainty and error. Another example of the types of questions that should be addressed in the discussion is:

- There looks to be significant variation in relative mass lost from Samples B vs C, presumably reflecting differences in overall formulation. How likely is it that these are artifacts of the selection of these particular pads for B and C, vs differences in wear that really correlate with the forms of copper, vs just an addition to general uncertainty?

I would be happy to discuss and clarify these additional comments with you and/or with appropriate BMC-PEC representatives.

Comments of Jim Lawrence, (November 11, 2005)

Response to charge for reviewers:

1. **What is your assessment of the work performed here and the reliability for the methodology for generating a representative sample of brake pad wear debris?**

When the US EPA first developed the "MOBIL" to measure exhaust emissions from automobiles they selected a route or map that included specific streets in and between the Detroit - Ann Arbor

metro areas. This evolved to the use of chassis dynamometers and software to determine regulatory compliance. A spin off of this is the fuel economy projections and their associated "individual results may vary" cautions. The EPA compliance protocol is an example of an industry / government successful effort to standardize and eliminate as many variables as practicable.

Brake manufacturers use a Los Angeles route / map to measure performance on individual vehicles. Although the map remains constant, the recorded decelerations, temperatures and pressures are vehicle specific. Similar to EPA, we drew lines through these data and developed "representative" decelerations and temperatures for the dynamometer. Step two was to develop and tune the collection hardware. Today the protocol and hardware at Link is the only source of representative wear debris. It is what it is, the only industry supported source therefore eliminating the site to site and technician training variables.

2. Based on your experience, what are the strengths and weaknesses of this methodology?

Strength of course is the documentation and repeatability. Weakness, limited scope.

3. Is the approach for generating a representative sample of brake pad wear debris, as presented in the report, suitable for conducting and evaluating the potential for copper and iron leaching from brake pad wear debris in the environment?

It is merely a tool for producing and size segmenting wear debris. It provides an input for other DOE (design of experiment) and models. It is an excellent tool, so is a hammer, when properly used.

4. Does the report clearly describe the approach, selection methodology, constraints and/or uncertainties?

I believe not.

For example, "III Purpose" - line two "in the San Francisco Bay Area" is misleading and should be deleted even though its limitations are mentioned later in the paragraph.

Eight years ago the leading North American brake pad manufacturers partnered with others to assess the environmental impact of brake pad wear debris. Working with Suscon they collected copper use data from the member participants in order to have a benchmark and monitor use trends among the nations vehicle designers and purchasers. Albeit limited, the information is now available in the public domain. Persons using this "tool"are responsible for its proper use. It is conceivable that the manufacturing members of the BPP may through attrition and competition eventually not represent the industry as a whole. It is important for the researchers that follow understand the limitations and constraints.

Comments of Glynis Lough, Environmental Chemistry and Technology, University of Wisconsin-Madison (November 16, 2005)

Response to charge for reviewers:

1. **What is your assessment of the work performed here and the reliability of the methodology for generating a representative sample of brake wear debris?**

The methods for determining the appropriate representations of copper formulations are very clearly defined, and the report cited for methods of sample generation is clear. The methodology is reliable for obtaining a sample of brake wear.

2. **Based on your experience, what are the strengths and weaknesses of this methodology?**

This methodology is a good way to obtain a sample of brake wear representative of the chosen formulations. The main weakness is the tendency of consumers of the information to ignore the inherent uncertainties and assumptions simply because the methodology for choosing formulations was rigorous.

3. **Is the approach for generating a representative sample of brake pad wear debris, as presented in the report, suitable for conducting and evaluating the potential for copper and iron leaching from brake pad wear debris in the environment?**

Yes, provided that the users of the data have an understanding of the limitations arising from the assumptions made in choosing a representative formulation and obtaining the sample.

4. **Does the report clearly describe the approach, selection methodology, constraints and/or uncertainties?**

The approach and selection methodology are clear. However, the report is definitely not clear enough about the constraints of the assumptions made. As this work is intended for use in modeling studies, the uncertainties associated with those assumptions need to be very clear – exactly what is represented by the sample should be clear. These things don't need to be exhaustively explained, but anyone referencing this methodology in the future should be aware of exactly what is - and what is not - represented by this representative sample. An additional brief section IV below "Purpose" would be sufficient. Some of the things that should be discussed in more than a brief footnote:

a) The prevalence of aftermarket pads and their copper content

b) The fact that this representative sample represents some amount less than 40% of OEM equipment from model year 2002 automobiles (this is mentioned under "Background" only in terms of what the BMC-PEC collects, not in terms of how it applies to this study)

c) How the composition of this market-composite sample can be expected to relate to the overall fleet composition in the area

d) Impact of heavy vehicles

e) Concerns about relationships between brake dyno wear and on-road vehicle braking patterns and emissions

f) The use of three copper-containing formulations to represent a wide range of copper-containing formulations. Although these pads were specially formulated, their wear properties are not necessarily similar to the range of formulations they are supposed to represent (ie, copper fiber in several formulations will be present in different amounts and configurations, the formulations may wear in different patterns, different particle sizes may be emitted, etc.)

Comments of Carlos Agudelo (Engineering Manager, Link Test Laboratories) November 17, 2005

<u>Response to charge for reviewers:</u>

1. **What is your assessment of the work performed here and the reliability for the methodology for generating a representative sample of brake pad wear debris?**

The work performed so far is a technically sound approach to obtain physical samples for evaluating the copper content on brake pad wear debris. It follows testing and measurement practices used before and made available to the public as the SAE Paper 02-BRAKE-43 from Dr. Jim Trainor, Tim Duncan and Robert Mangan. The findings of the initial study (SAE Paper 02-BRAKE-43) that gave the foundation for the recent work on sample wear debris were also presented to the Brake industry during the 2002 SAE Brake Colloquium in Phoenix, AZ. The workflow is well described including the different steps and people involved. The mass balance obtained gives a high level of confidence of the validity of the wear debris collected for future study and analysis. The details of the statistical validation are not included in the document. Including details of the sampling technique to demonstrate to the different stakeholders a reliable population representation of the vehicles running in the San Francisco Bay area would be a plus to the project. The study is a proof of the firm commitment and interest by the industry (represented by the BMC Brake Pad Partnership task-force) to gain knowledge on the issue using hard-facts that should support larger efforts to improve the overall quality and stability of the San Francisco Bay biodiversity.

2. **Based on your experience, what are the strengths and weaknesses of the methodology?**
   - **a strengths:**
     - i used an inertia-dynamometer protocol to ensure repeatable test and wear debris collection
     - ii used test procedures and techniques proven before after an industry peer-review process over the past years
     - iii relied on an actual vehicle driving pattern that mimics in a controlled environment the wear debris generation rates using a representative vehicle application
     - iv it uses a multidisciplinary team that provided insight from very different perspectives keeping all the stakeholders interest well represented
     - v used standard techniques for the chemical and quantitative analysis of the wear debris generated
   - **b areas with potential for improvement:**
     - i a more clear description of the methodology used to select the three samples used in regards to the different factors that determine the actual wear debris composition present due to automotive brake wear debris like:
       - (1) passenger car/SUV-light and medium duty trucks/commercial vehicles, friction material composition and contribution-wise due to wear rates and brakes size
       - (2) Original Equipment (new vehicles)/Aftermarket (after first brake service job probably). Marketing and technological factors can influence the actual copper content and type present on a brake pad or lining

(3) Front brakes wear debris/Rear brake wear debris due to different formulations and wear rates

ii Reference, or description in lieu of a public standard (ASTM, ISO, etc.), to the different test and quantification methods for assessing and quantifying copper types and quantities

iii Include a description of the technique proposed or used to estimate population-level copper content from the sample-level measurements taken on the inertia-dynamometer tests

3. Is the approach of generating a representative sample of brake pad wear debris, as presented in the report, suitable for conducting and evaluating the potential of copper and iron leaching from brake pad wear debris in the environment?

The statistical estimation for the San Francisco Bay vehicle population seems to be headed in the right direction. Further details on the actual estimation technique are not included on the report. The survey results and the Pareto analysis will support additional studies. A market survey or estimation that combines vehicle population breakdown and friction material composition should support a sound statistical validation methodology. Chemical analysis of a larger sample of brake pads and lining could support the statistical validation of the test results. This is probably already included on the scope of work for the Brake Pad Partnership. Documenting and publishing the different methods will increase the reliability and acceptance of the different finding and conclusions derived from this important industry effort.

4. Does the report clearly describe the approach, selection methodology, constraints and/or uncertainties?

The overall approach is clear and well described. The methodology is documented on the report and previous documents already published and presented to the Industry. Constraints and uncertainties around statistical validation and population estimation could be improved.

Hope this helps and I apologize for my delayed response. Please feel free to contact us for additional questions or future work related to this industry effort.