

Workshop report: Sustaining the combustion research community: ensuring the field doesn't burn out

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Abstract

This report describes the organization, discussion topics, and outcomes of a two-day workshop for US-based early career faculty researchers and researchers working in the area of combustion and fire, held in April 2017 in College Park, Maryland, USA. Using an unconference format, the 38 participants discussed issues facing the field clustered into two thrusts: cultural and technical. The discussion topics included attracting and retaining a more diverse community, public engagement, improving educational outcomes, hostile and confrontational climate, publishing (open data, open access, open software), collaboration, what does “combustion science” encompass?, and balancing fundamental and applied research. We make recommendations to the community to address each of the issues, summarize progress made to date, and describe plans for future activities. We also discuss some changes made in the community since the workshop.

Disclaimer: The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any agency of the U.S. government or the authors' employers. Furthermore, this report only serves to document the discussions and recommendations made by the US-based workshop participants, so it necessarily reflects their views. It does not seek to fully review all efforts by the combustion community or associated professional society, The Combustion Institute.

1 Introduction & motivation

While combustion is responsible for nearly 70% of energy consumption in the United States, and inevitably will remain a large component for decades to come, the future of the combustion research community is less certain to some of its junior members. Due to ineffective direct communication from the scientific community, the public and policymakers may be unaware of the often exciting and important research topics and ongoing breakthroughs in the field. This starkly contrasts other research communities such as nuclear engineering and astronomy that have thrived since adapting to modern, open research practices and have diversified through cross-pollination with connected fields. In contrast, some feel that many in the combustion community have resisted both changes. Finally,

the field faces challenges in attracting and retaining a more diverse community of researchers, with talented researchers at all experience levels leaving the field due to lacking a sense of community.

This report describes the discussions at a two-day workshop for US-based junior faculty working in combustion and fire research that sought to learn about and discuss future challenges in the field from the perspective of early-career researchers. Primary objectives included identifying challenges, educating the early-career participants about such challenges, and discussing possible solutions. Discussions were split into two thrusts, roughly corresponding to the two workshop days: (1) cultural issues and (2) technical issues facing the field. The workshop began with a discussion of the workshop Code of Conduct (see Appendix B), including the guidance for acceptable conduct, the sanctions for violation of the code, and the points of contact for reporting violations (Kyle Niemeyer and Nicole Labbe). The workshop used an “unconference” structure [1], where a short presentation by a workshop leader initiate discussions, and then participants chose the smaller sub-group they wanted to join to discuss each of the sub-topics, listed below, for 90 minutes. Each sub-group included a discussion facilitator who ensured productive conversation, elicited equal contribution from all sub-group participants, and took notes on the discussions. After two rounds of discussion for each topic, the facilitator synthesized the notes from all participants and presented the discussion results to the entire group. A short discussion followed with all participants, clarifying points and identifying clear action items that came from the discussions.

The workshop organizers¹ sent invitations to potential participants via email, and asked participants to register via a Google form on a first-come, first-serve basis. Invitations were sent to US academics who were pre-tenure or who recently received tenure, and early-career researchers from national laboratories. 38 participants attended the workshop from across the United States, representing 22 states, as shown in Figure 1; Appendix A contains a list of attendees. 35 of the participants were pre-tenure faculty, one participant was a recently tenured faculty member, and two participants came from national laboratories.

The remainder of this report outlines the discussion topics and outcomes from those discussions. The topics include:

- Attracting and retaining a more diverse community
- Public engagement
- Improving educational outcomes
- Hostile and confrontational climate
- Publishing: Open data, open access, open software
- Collaboration
- What does “combustion science” encompass?
- Balancing fundamental and applied research

In Section 5 we summarize our progress since the workshop and changes/updates in the community.

Note: The discussion that follows identifies what workshop participants consider issues or challenges facing the community of combustion and fire researchers in the US. We direct some of the recommendations that follow at the Combustion Institute, but these are really recommendations to the community as a whole. We do feel that the Combustion Institute, as the organization that represents and organizes this community, can lead on some of these issues. However, certain topics may be limited to the US Sections of the Combustion Institute (USSCI). Other recommendations aim at the practices of individual researchers or research groups.

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Obtain demographic statistics: Diversity has many meanings and can be especially challenging to quantify for an international organization, where the definition of a diverse group may change drastically from country to country. However, without any data on the demographics of our community, it is nearly impossible to assess the state of the diversity of the combustion field. The first major recommendation from this workshop to promote diversity is to conduct a comprehensive survey of the community. This survey should include demographic information as a metric to measure the diversity of the combustion community. Additionally, career status of Combustion Institute members should be regularly assessed to understand where our members are going. For example, students regularly leave the CI after graduation. Understanding the motivations for leaving the CI, as well as how those motivations change within minority demographics, is an invaluable tool for identifying the most effective methods for recruiting and retaining minority populations within the CI.

Promote policies to create a culture of inclusiveness: In light of recent national events, it has become evident that harassment and discrimination is still a problem in every field [13, 14]. As a first step to deter harassment and discrimination, the community needs to establish harassment and discrimination policies that condemn such behavior, provide clear guidelines on how to report issues, and describe the possible punishments for violating the policies. Furthermore, these policies convey a message of support for minority populations who are most vulnerable to harassment and discrimination.

To its credit, in March 2017 the Combustion Institute established a Code of Ethics³, which includes a statement supporting diversity of members and establishes a sexual harassment policy for CI-funded conferences and summer schools. However, workshop participants felt that the CI should take a stronger stance against all forms of harassment and discrimination and write stronger policies to reflect that stance, including establishing—and enforcing—a robust Code of Conduct for all CI-organized events. Furthermore, it is not clear whether the CI sexual harassment policy applies at *all* CI-affiliated meetings in the US and around the world (e.g., section meetings), or just at the International Symposium and CI-funded summer schools.

As a second major recommendation, the workshop suggested that the CI implement a Diversity and Inclusion Officer to the Board of Directors. This officer would be responsible for improving the harassment and discrimination policies within the CI bylaws, implementing the comprehensive survey of the CI members, and supporting initiatives such as the existing Women in Combustion program to support minority members within the CI.

Increase visibility of minority members: As demonstrated by the number of women on the Board of Directors of the CI and the lack of women lecturers in the Princeton–Combustion Institute Summer School on Combustion, members from underrepresented backgrounds are not currently visible in the community. Continuing to use women as an example, with women only making up an estimated 10–15% of the CI membership, women often report feeling isolated, often being the only female combustion scientist at their respective institutes. Not having women featured as plenary speakers, session moderators, Summer School lecturers, etc., only further worsens the feeling of isolation for female members. Furthermore, evidence suggests that having more women help organize conferences significantly contributes to increasing participation by other women as speakers [15]. The same concept applies for other minority groups within the CI. A third recommendation resulting from this workshop is to have the CI regularly feature minority members at meetings as plenary

³<https://www.combustioninstitute.org/wp-content/uploads/2017/04/Code-of-Ethics-Approved-03-23-2017.pdf>

speakers, session chairs, and board members and to highlight minority members through research highlights and press releases using CI resources.

In addition to these three specific goals, other suggestions from the workshop include establishing specific travel grants for minority students to attend meetings, expanding support programs such as Women in Combustion to include other minority groups who also need support, creating a mentorship program to increase member support outside the scope of meetings and conferences, and establishing a room-share network for students to find roommates for conferences to ensure they always have an option to have a buddy when traveling to meetings. Furthermore, simply continuing to discuss the issues faced by women and other underrepresented groups may help maintain interest in research careers [16].

2.2 Public engagement

The US combustion community faces a challenging, contradicting trend: in an era of declining public support for combustion research, the 2017 US National Combustion Meeting saw the largest attendance in its 20-year history. The combustion community, like many other technical research areas, often struggles to explain the value and added societal benefits of our research to the general public in an interesting **and** informing way. When writing articles about our work, we write for an audience of our peers, and thus focus on technical detail and accuracy at the expense of clarity for a broad, non-technical audience. As a result, the public—including funders and policymakers—may not be aware of the exciting, important research ongoing in the community. This barrier has led to a poor view of combustion research by the public, policymakers, and funders compared to other areas. In addition, better public engagement could help recruit and retain students to the discipline, where currently they may be seeking out fields they perceive as “more exciting.” The workshop also identified a similar divide between industry and combustion researchers, particularly those on the more fundamental end. Lastly, workshop members viewed the Combustion Institute as somewhat separated from other scientific communities, with few formal collaborations or partnerships with other scientific and engineering societies. This limits visibility of combustion research from other fields, and potentially limits the complete story of the (often fundamental) research occurring in the combustion community.

The workshop discussed a number of possible solutions, mainly focused on either outreach via individual researchers or efforts by the Combustion Institute (as an institution organizing and representing the community). In addition, the current divide between combustion community research efforts and industry interests/needs frequently came up in discussions on public engagement.

On the individual side, researchers can take action immediately to improve their public engagement by writing one or two paragraph summary/impact statements about their published articles, intended for the general public [17, 18]. These statements could be featured on the Combustion Institute website, used by funding agencies, or pushed to policymakers. Participants did ask about training around outreach and engagement, something that could be organized at meetings.

Workshop participants also discussed communicating the importance of combustion to non-engineering undergraduate students in the context of increasing awareness amongst college students. In particular, we encourage the creation of a survey course at the undergraduate level focused on “energy literacy,” coincident with broader policy goals related to energy independence and sustainability. These courses could take the form of first-year seminars, and could be developed in partnership with faculty from other majors within the university, thereby expanding the impact of course material development outside of engineering and science.

Other potential solutions centered around community efforts organized by the Combustion Institute. Summaries of individual researcher’s articles represent one step to improve the public’s

perception and understanding of our research, but this can be challenging at the level of an individual article. (For example, while the importance of a study improving the rate parameters of a particular reaction may be obvious to those working in chemical kinetics, the societal benefits may be too indirect to clearly explain.) However, the Combustion Institute could help connect these stories, potentially by hiring a science writer. This person could also give feedback to CI members on their article summaries, and then feature them in stories on the CI website and social media accounts.⁴

In a related issue, the Combustion Institute website currently has no outward-facing resources intended for public consumption. A web page (or multiple pages) could be created that describes the public benefits of combustion research, and list articles that relate to these benefits with brief explanations of how. For the US sections, such a page could list the agencies that supported these projects. Other ideas for demonstrating the impact of funding for combustion research include a study supported by the CI board into the benefits of past investment in combustion research in terms of job creation, profits, health benefits, etc., in collaboration with researchers in policy, economics, and business. *Combustion and Flame* could also feature a special issue on techno/socioeconomic benefits of combustion research.

Workshop participants also found value in the Combustion Institute reaching out to other professional science/engineering societies like American Society of Mechanical Engineers (ASME), American Institute of Aeronautics and Astronautics (AIAA), Society of Automotive Engineers (SAE), and American Chemical Society (ACS) to hold combustion-related sessions, plenary talks, and panel discussions at conferences. SAE's TechHub TED-style talk series was raised as an example for the combustion community to consider. The CI could also co-sponsor student or professional competitions with these other societies for publicity.

Discussion also focused on the current lack of strong industry participation in the community as a major related issue. Currently, we only transfer information *to* industry, without much feedback on whether they are getting what they need. Of course, academia and industry do not typically share the same priorities, but we can improve how we speak to them and understand their priorities. Some open problems with industry interaction were identified:

- Industry funding is typically valued less for promotion and tenure purposes at many universities in the US; similarly, academic culture undervalues the MS students typically supported by industry-funded projects. Community members should advocate for increasing appreciation of both.
- Some academic researchers have “split” industry funding to advance their own fundamental research along with the applied work of interest to the company; this may reduce enthusiasm for companies providing funding in the future.
- Industry participants may be less likely to submit to or attend CI meetings in the US due to the low visibility (and citability) of proceedings compared with those of ASME, SAE, and AIAA meetings. One solution could be to raise the level of prestige for US National Combustion Meeting articles through peer review, balanced perhaps by reducing the work needed for sectional meetings (e.g., primarily talks with no or brief paper/extended abstract).
- Lastly, the Combustion Institute could organize job expos at the US Meetings and International Symposia, rather than just industry booths where companies try to sell equipment. This could be paired with an online job board.

⁴This content would be a much stronger outreach effort than the CI's current Twitter strategy, as one example, which mainly involves sharing miscellaneous trivia and unrelated hashtags.

Based on the discussion around public engagement, the workshop identified four specific, actionable solutions for community members and the Combustion Institute to consider:

- The Combustion Institute should create a portal for sharing outreach and educational materials.
- The makeup of Combustion Institute committees, particularly the Media & Outreach and Industry Relations Committees, should better match the composition of the CI membership. For example, these committees should have some fraction of junior and mid-career faculty represented on the committees, and could potentially have one or two students.
- The job board on the CI website should be improved (including the submission process), and industry opportunities should be added.
- The CI Media and Outreach Committee should pursue additional outreach efforts, such as hiring a media/science writer staff member that can write about and publicize (for the general public) research published in CI journals and other venues.

Open questions remain about how the combustion community can more effectively engage with local, state, and the federal government. One suggestion is more frequent visits to Congress, like the one that followed the 2017 US National Combustion Meeting [19], to advocate for the continued (or increased) role of federal funding in combustion research. In addition, one workshop participant posed a challenging—and possibly frightening—question: how do we state the future of combustion research in an optimistic way? The field should be broader than just fossil energy (discussed in Section 3.3).

2.3 Improving educational materials

In addition to improving public engagement, we have a unique opportunity to improve the dissemination and understanding of the field of combustion through educational efforts in universities and national laboratories. As many participants in the workshop were tenure-track or recently tenured faculty, we reach students at both the undergraduate and graduate level through interaction in our classrooms, laboratories, and research groups. The workshop discussion groups identified three opportunities in education at the undergraduate level: integration of combustion fundamentals and applications into classroom environments, opportunities for undergraduate researchers, and development of regional or university-specific student activities sponsored, in part, by the Combustion Institute.

First, and most critically, we identified the importance of integrating combustion fundamentals, applications of combustion, and our own research into our classroom teaching. While numerous studies have shown the value in integrating “real-world” examples in teaching concepts at the undergraduate level [20], we see the opportunity for increasing students’ exposure to combustion through the repeated introduction of combustion-related examples and technologies in classrooms. For example, we identified courses such as thermodynamics, fluid dynamics, propulsion, gas dynamics, and (chemical engineering) kinetics as prime opportunities for integrating combustion topics. We have identified case studies as a particularly effective way of introducing these subjects. Case studies, which include pre-class reading, in-class discussion, online content, and other materials, help integrate fundamental theory with application, and require students to think at a systems level about a particular subject [21]. In this way, we can impart on students the important role that combustion plays in a range of critical technologies, from transportation to industrial processing to cooking and heating. To support this goal, we are currently developing an online source of

educational materials related to combustion. The outward-facing portion of the website would allow students to explore videos and online tools for learning about combustion in the context of different classroom subjects. The inward-facing portion of the website would house a repository of teaching materials shared by the combustion community, from exam questions to case studies to projects, available for use across the world at both the undergraduate and graduate level. Building this database will make it easier for faculty, particularly assistant professors, to integrate innovative combustion content into classes.

Second, it is critical to continue to engage undergraduate researchers in our laboratories to broaden their educational experience and identify potential graduate students for the field of combustion. To support this goal, we recommend that the Combustion Institute make competitive travel grants available for undergraduate researchers to attend US National and Sectional conferences, allowing students to share their work and network with other combustion researchers. (These should differ from the existing strong program of travel awards to students, graduate and undergraduate, who give presentations at CI conferences.) These efforts should particularly target a diverse population of undergraduate students, and improvements to the climate of Combustion Institute events will help provide these students a supportive and inspiring experience.

Finally, the workshop discussed the possibility of the Combustion Institute partnering with other professional organizations, including SAE, AIAA, the Society of Fire Protection Engineers (SFPE), and others, to sponsor student competition teams in topics related to combustion. Many of these activities, including Formula SAE and Design-Build-Fly, include significant combustion-related components, and participation by CI would increase students' exposure to combustion science and engineering.

On the graduate level, a common concern amongst workshop participants was the "siloeing" of disciplines within combustion, and the lack of breadth that graduate students are exposed to as a result. For example, students studying turbulent combustion physics with high-speed laser diagnostics may not have exposure to, and therefore appreciation of, the chemical kinetics present in the flames they study. Similarly, students doing computational work may not understand the intricacies or limitations of the experimental techniques used to obtain the validation data they are using, and visa versa. This siloeing continues into their professional lives, limiting their opportunities for employment and making it difficult to work in collaborative teams. To rectify the situation, the workshop participants propose the development of a "graduate student exchange," where small stipends be made available by the CI for graduate students to travel for four to six months to work with collaborators in multidisciplinary teams, enhancing their exposure to different material and methods. In this scenario, two PIs, who either work together on an existing grant or want to begin a collaboration, trade graduate students for the period of the exchange. In the end, these exchanges would help foster a more inclusive community with a greater diversity of thought, helping to enhance our research and researchers.

2.4 Hostile/confrontational climate

A common concern amongst workshop participants was hostility, particularly at conferences but also in the review process. This hostility must be distinguished from the usually give-and-take that is required for the advancement of good science. Instead, it is typified by emotionally charged language that seeks to denigrate the integrity or intellectual capacity of one party. Common examples include: making an assertion rather than asking a question, pointedly insisting that the work is either unimportant or unoriginal, and intentionally asking students questions beyond their understanding, typically with the intent to "score points" against their advisor.

Such behavior should be considered a violation of the Code of Conduct (which we recommend

establishing at all Combustion Institute meetings). Accordingly, we propose three solutions that should help to reduce the level of hostility at conferences. First, make reading the Code of Conduct a required step in the registration process. Second, include guidance on thoughtful Q&A in the slides in the session rooms between sessions. Third, educate and empower the session chairs to be more assertive: ensure that assertions are either rephrased as questions or dismissed, and make sure that the question is appropriate for the speaker.

3 Challenges and possible solutions: research

3.1 Publishing: open access, open data, open software

Some scientific communities have embraced open sharing of technical articles (in particular, physics and related fields), data, and research software, but members of the combustion community have slowly embraced these trends. In addition, the workshop raised concerns about the reproducibility of combustion research, due to the lack of available material. Beyond the ethical and technical issues brought about by not sharing research products—discussed next—there are practical reasons to change behavior: most federal funders are beginning to require open availability of papers, data, and software produced using public funds.

3.1.1 Making articles openly available

Currently, the combustion field lacks reputable fully open-access journals. The flagship CI-affiliated combustion journals (*Combustion and Flame*, *Proceedings of the Combustion Institute*, *Progress in Energy and Combustion Science*, *Combustion Science and Technology*, and *Combustion Theory and Modelling*) are published by for-profit commercial publishers, with articles generally only available via costly subscriptions or per-article charges. Although most academic institutions subscribe to some or all of these journals (at increasing cost—some institutional libraries in the US and around the world have begun balking at these fees), the closed nature of these journals limits visibility of our research to the public, industry, and researchers in less-affluent parts of the world. Furthermore, some researchers negatively view the commercial publishing model, where researchers—typically supported by public funds—provide all content for free, and the publishers charge readers for content they did not generate, and to which they may add little value [22].

Some options already exist for making research articles openly available, about which the combustion community could benefit learning. The simplest option is for authors to pay a (steep) article processing charge to make their articles free-to-read; however, this does not reduce the cost of subscriptions to institutional libraries, and the fees range \$2000–3300 per article for the aforementioned combustion journals. Alternatively, authors can consider the *Journal of Combustion*, which the publisher Hindawi started in 2016 as a gold open-access journal (i.e., the journal is fully free to read, with article processing charges paid by the authors). However, most academic researchers—particularly untenured assistant professors—face pressure to publish in the top society journals, so it may not be practical to start publishing in a new open-access journal due to its reputation. (Although one study found that publishing multiple papers in *any* journals strongly correlates to junior faculty success regardless of journal “impact” [23].)

The most pragmatic option—and one taken by some in the community, including workshop participants—is to continue publishing articles in the traditional journals, while simultaneously making the content available via preprint or eprint servers such as arXiv and engrXiv, or more general online repositories like Zenodo and Figshare. Nearly all publishers—including Elsevier—accept this practice prior to submission or after some embargo period, known as green open-access

or self-archiving, as long as the version submitted is the “author-accepted” text without journal formatting (i.e., the final text following peer review but preceding copyediting). This model makes available the actual content of the research at no cost to either the author or the reader.

In addition, workshop participants suggested that the Combustion Institute consider the (likely controversial) idea of shifting its journals from a commercial-publisher model to a nonprofit society-journal model. As an exemplar, the UK’s Royal Society of Chemistry successfully transitioned its *RSC Advances* journal (the world’s largest chemistry journal) from a subscription journal to a gold open-access journal [24]. This model relies on authors to pay article processing charges—which the journal set at £750, lower than most others—to support the journal’s operations, with discounts and waivers available to researchers in less-affluent countries. Our discussion raised some concerns about a pay-to-publish model, and whether this was the best approach for publishing. Also, creating a new open-access journal (or converting a closed-access one) will not eliminate existing subscription-based journals.

3.1.2 Openly sharing other products of research (data & software)

Workshop participants also observed that many in the combustion community—with notable exceptions—remain hesitant to openly share the data produced and software developed in their research. In some cases, this may be lack of awareness of the simple sharing tools now available, inertia from past behavior, or hesitation due to lack of credit (e.g., by promotion and tenure committees); others may fear their data will be reinterpreted incorrectly (in their view) or that they will be proved “wrong.” Alternatively, retaining exclusive access to data and software ensures unique research capabilities, which may improve the competitiveness of funding proposals.

However, many experimental studies can only be built upon by others when authors make the associated data openly available (e.g., shock tube measurements of ignition delay times), and nearly all studies cannot be reproduced without complete input data or specifications. This issue compounds for computational studies; as put by Jon Claerbout, a pioneer of reproducible research, and paraphrased by Buckheit and Donoho in 1995: “An article about a computational result is advertising, not scholarship. The actual scholarship is the full software environment, code and data, that produced the result.” [25]. Computational research is only reproducible when the software used, and all its inputs, are openly available.

Similar to the solutions for articles, options exist for making data and software openly available. GitHub is the industry standard for openly sharing (and collaboratively developing) open-source software, while online repositories like Zenodo and Figshare can be used to permanently archive both software and data and obtain a citable object (i.e., with a DOI).

The main reasons for lack of adoption of these practices in the community seem to be lack of awareness of the simple tools now available, lack of sufficient motivation from the combustion community (i.e., by journal editors and reviewers), and lack of credit for these activities from promotion & tenure committees. The latter issue may be resolved by talking to and educating our peers about the importance of these practices, and including information such as use of software or data in tenure dossiers and funding proposals. In the combustion field, awareness can be improved through leading by example (e.g., publish reproducible articles, cite software and data appropriately, share all products, self-archive articles) and by establishing community-recommended best practices. Such best-practices can be shared with the community, and presented at conferences; for example, the Eastern States Section of the CI had a “How to write an abstract” talk at a regional meeting, and similar talks could be given at other regional meetings on software development, data sharing, etc. Then, the community can hold members accountable to these practices by including availability of materials in journal review criteria; this may be complemented by providing reviewers with

more guidelines on journal expectations, and editors must then enforce quality and completeness of reviews.

3.1.3 Action items

To summarize, there are some practical and cultural issues around openness and sharing that need to be fixed. The workshop identified four actionable steps that could be taken to solve some of these problems:

- Community members and leaders should encourage better practices in making their research products available—lead by example. For example, self-archiving of papers is an easy step with few downsides, but goes a long way to increasing the availability of community research.
- The CI website should add a section on resources for best practices in sharing research.
- CI-affiliated journals should add an “availability of materials” (e.g.) metric to review forms, and ensure that editors follow up on this.
- *Combustion and Flame* should organize a special issue on replication and reinterpretation of prior results.

3.2 Collaboration

Collaborative and cross-disciplinary research is highly valued within the scientific community, but the current funding environment and tenure structure makes it difficult to develop these collaborations early in an academic career. While a change to the funding structure seems unlikely, the workshop participants identified a number of actionable steps that would help boost collaboration and, in doing so, support the careers of early career researchers. First, the workshop participants have established a peer mentoring group on LinkedIn⁵ to help members of the community network and establish contacts within the community. While the group is focused on peer mentoring, the group provides a platform for establishing connections and potential collaborations. To support these efforts, we also recommend that CI establish networking opportunities for early-career researchers (tenure-track and newly tenured professors and similarly-ranked researchers at national labs and in industry) at CI conferences.

Additionally, we strongly recommend the inclusion of cross-disciplinary talks at CI conferences as both plenary speakers as well as invited speakers in individual sessions. Plenary speakers from related disciplines at all levels of CI conferences will help foster a culture of multidisciplinary research within the community, and emphasize the importance of this type of work to our field. Additionally, these talks will provide the plenary speakers, leaders in their own field, with the opportunity to understand more about combustion and help establish more connections between disciplines. We also strongly recommend the inclusion of invited speakers within individual tracks, as opposed to creating “multidisciplinary tracks,” to encourage discussion of multidisciplinary topics within sessions. Inclusion within the individual tracks will improve the attendance of cross-disciplinary talks, as researchers, particularly younger researchers, will not have to choose between attending a session in multidisciplinary work and their home field. Encouraging multidisciplinary work in our field and discussions at our conferences will enhance the work of combustion researchers and broaden the definition of combustion research, ensuring our field does not “burn out.”

Truly innovative science often occurs at the grain boundaries between disciplines. By fostering the kind of cross-disciplinary talks at CI conferences and mini-symposia, the next generation of

⁵Group name: “Early Career Combustion Faculty and Scientists”

combustion scientists will thrive by exporting our core skills to new fields, while simultaneously importing new best practices from them.

3.3 What does “combustion” encompass?

This emphasis on the cross-disciplinary and collaborative nature of combustion research in the twenty-first century raises a fundamental question: what should combustion encompass? Junior faculty are concerned that the specific research topics listed by the Combustion Institute, while no doubt central to the field, may be unnecessarily constraining, particularly in the current funding environment. A more general definition is sought that would enable the combustion community to continue to develop these central concepts, but also to branch out into new fields.

The more general definition could be simply reactive flow. The community should be willing to consider any scientific and engineering problems that involve thermo-fluids and chemical kinetics, and we should be applying the rigorous, fundamentally driven analysis to these problems that has been the hallmark of combustion research to date.

3.4 Balancing fundamental vs. applied research

Workshop participants began by discussing and defining the differences between science and engineering. Science strives to understand and explain how and why things are as they are, develops a hypothesis, and works towards a fundamental understanding that allows us to predict things that have not yet been observed. Engineering is about designing and optimizing things; one needn't understand how something works, as long as it works today, and works better tomorrow. Engineering is more immediately helpful, but most innovative step-changes and breakthroughs come from a fundamental scientific understanding; engineering will make our current engines better, but to invent the next type of engine will need scientific R&D. The dichotomy between science and engineering raises some questions and poses some challenges to the combustion community, which does both.

There is a perception that studying the science of combustion is not useful (the marginal benefit to society is zero from a small delta of scientific research), but also that our engineering of combustion is not scientific—when it works, it is for the wrong reasons, and thus cannot be predictive. For example, an over-fitted kinetic model may “work” but be fundamentally incorrect. It is thus easy to criticize all combustion research. Researchers, requiring grant funding, feel they are pulled in different directions: proposal reviewers criticize work for being not useful enough on one side, or not scientific enough on the other.

A lot of issues come down to funding: the types of funding available for “basic science” is so limited in amount and extent that the types of scientific questions we can pose cannot make an impact; the ways we are tackling the problem will never solve the problem. Should industry be paying for things that are useful, and agencies such as the NSF be funding science that is merely interesting? (Industrial interactions are discussed in other sections).

Suggested action items: The first three suggestions tie in to the “Public Engagement” ideas discussed in Section 2.2; the fourth could involve a mentorship program run by the CI, as discussed elsewhere, or through special journal issues or plenaries at CI conferences:

- Lobby to incorporate combustion into the National Academy of Engineering (NAE) “Grand Challenges.”

- Devise a new problem definition or goal for combustion research that motivates people and resonates more than “make this engine more efficient.”
- Convince people (i.e., society, funding agencies, industry) to think long-term; use anecdotes from the past of unexpected breakthroughs resulting from fundamental scientific research.
- Have experienced practitioners in the field specify what they see as the “grand challenges” in combustion research that need help, so that younger researchers can read them and think “Hey, I can help with that!” rather than expecting the younger generation to forecast the future of the field and shoot in the dark when proposing new research projects. One mechanism for this may be the new “perspective” short article format offered by *Progress in Energy and Combustion Science* [26].

4 Feedback from participants

The organizers solicited feedback from participants regarding their impressions of the workshop. 36 participants responded to the survey; 34 of those identified the workshop as a success, and two participants left the answer blank. 35 of the 36 participants indicated their wish to participate in follow-on activities, including future workshops and initiatives derived from the current workshop. Additionally, participants were asked to provide freeform responses about the workshop. A sampling of the responses to the question “From your perspective, was this workshop successful, and why?” are provided here:

From my perspective, this workshop was a huge success. I always felt that a faculty position was (very) isolating: PIs looking for money, doing cool stuff on their own, managing their army of grad students, and interacting briefly (bragging and competing is more like how I saw it many times) during conferences. It was a revelation to find out that the combustion “community” can be so much more. We are not alone, we can actually talk to each other and it is great! The discussions were refreshing, vibrant, and very interesting, and virtually all of them ended up with concrete action items (some already done) with positive impact on so many things. Out of everything, I will choose the creation of the Slack team as the single most impactful outcome. If we manage to keep those channels active post-conference (which I have no doubt we can), even create new ones to bring together different groups of people, the possibilities for collaborations and brainstorming are endless. Ok, perhaps that is somewhat idealistic and the result of a post-conference high, hopefully not. But nevertheless, I am now for the first time in peace with my decision 5 years ago to embark on a tenure-track career in the field of combustion. So thank you!

Yes. Perspectives offered were the most honest and actionable I’ve seen in the combustion community. Rather than mostly complaining about problems, the focus was on identifying root causes and finding realistic ways (even if small) to begin addressing a variety of issues impacting the community. I see the spirit of genuine cooperation in this particular assembly of faculty/natl. lab researchers, which is breath of fresh air that rekindles my own interest in remaining more seriously involved in combustion research and the combustion community.

Yes! It was a great opportunity for early-career faculty to get together and affirm our commitment to a more just combustion community.

Yes. Healthy discussion, positive action items, good networking - strengthened some ties and formed many new ones, and a feeling of momentum (some action items already achieved!).

The workshop was quite successful on a number of levels. First, it coalesced the next generation of leaders in the combustion field so we have a shared vision across a number of arenas - i.e. a spirit of inclusion, a commitment to diversity, and the desire to expand/grow the definition of combustion. Secondly, it provided a welcoming and open platform for early career academics to discuss issues (and solutions) with respect to our respective careers. Third, it was a wonderful catalyst for identifying collaborators at other institutions.

The workshop was awesome, it was a great to meet other junior faculty and see that I'm not alone in the academic struggle. I think the workshop facilitated meeting people much better than the standard conference format, breaking up into small groups allowed the sharing of ideas and experiences in a very low pressure way that could then be summarized to the group by the table discussion leader. I think I enjoyed this conference more than any other I've been to. The only thing I might add to future workshops is a time at the end to let people verbally volunteer to work on the topics discussed. That way when we all leave there is a list of people who are going to try to get together afterwards and make some progress. In conclusion, I think the workshop was a resounding success, and was exceedingly beneficial to the attendees.

5 Impact to Date and Community Changes

The workshop has had a number of measurable outcomes to date. First, the workshop participants requested that a Code of Conduct be established for the US National Meeting, immediately following the workshop. The meeting organizer, Dr. Arnaud Trouvé, announced the Combustion Institute Code of Ethics at the beginning of the meeting in his opening remarks, signaling the workshop's first outcome a mere day after the conclusion of the workshop.

Participation of early career faculty and researchers on the executive boards of the US States Sections of the Combustion Institute has grown since the workshop. At the time of the workshop, early career participation on the executive boards included:

- Western States Section:
 - Guillaume Blanquart - Vice Chair
 - Erica Belmont - Treasurer
 - Kyle Niemeyer - Communications Chair
 - Chris Hagen - Member at Large
 - David Blunck - Member at Large
- Central States Section:
 - Will Northrop - Member at Large
 - Waruna Kulatilaka - Member at Large
- Eastern States Section:

- Michael Mueller - Treasurer
- Perrine Pepiot - Program Chair
- Wenting Sun - Member at Large

Since the workshop, additional early career participants have become involved with section leadership. For example, nine (of 11) early career academics and researchers were nominated for executive board elections in the Eastern States Section. The four elected members—Michael Burke, Jacqueline O’Connor, Stephen Tuttle, and Richard West—are all early career members. The Western States Section elected Nicole Labbe as Secretary, and Vi Rapp and Bret Windom as members-at-large.

These early career executive board members each made a request, in their respective section board meetings, to form a sub-committee focused on diversity and inclusion at the section level. This process is ongoing in all sections, but with the increase in the number of workshop participants on the executive committees, we expect that issues related to diversity and inclusion will receive more treatment in the Combustion Institute sections.

Influenced in part by this workshop, early career advisory committees have been established at both the international level of the Combustion Institute as well as the US Section level (the CI Early Career Advisory and USSCI Early Career & Diversity Development Committees, respectively). Several workshop participants are now members of both committees, and are using these advisory committees to further the action items identified at the workshop, including building mentoring networks, sharing combustion-related teaching materials, enhanced public outreach, and creation of more early-career awards.

The workshop identified Women in Combustion events as being opportunities to expand support for minority members of the Combustion Institute. At the US Meeting, Women in Combustion expanded from a coffee-break format, which was less effective due to its short time duration, to a luncheon format with an interactive discussion presented at each meeting. The US Meeting Women in Combustion event was a success with nearly 100% female attendance. During this event, women discussed several topics, including the first implementation of a Code of Conduct at the US Meeting. Attendees said having a Code of Conduct at the meeting was “refreshing” and conveyed the message that the Combustion Institute takes harassment and discrimination issues seriously. Additionally, the idea of implementing a mentorship network within the Combustion Institute was enthusiastically encouraged with many attendees looking to get involved.

As a result of the success of the Women in Combustion event and interest from this workshop, Diversity and Inclusion events are being held at each US section meeting, which had previously never been done, and attendance for these events are open to all interested members. Specifically, the Spring 2018 Diversity and Inclusion events for all three of the US Sections plan to discuss and brainstorm how to implement a mentorship program to serve the needs of Combustion Institute members. Furthermore, two workshop attendees are also now planning the International Symposium Women in Combustion event in Dublin, Ireland in summer 2018. This event is also expanding to a luncheon format rather than a coffee break to encourage further interactions between the female members of the Combustion Institute.

Finally, the workshop generated significant enthusiasm amongst the participants and a new sense of community and camaraderie. A Slack group has been formed with all participants, including channels for each of the discussion topics for sharing updates on progress and interesting news. Workshop participants, particularly the original coordinators, communicate frequently on this medium. In addition to many new friendships, new research partnerships were formed as a result of this workshop. Additionally, a number of participants have added action items from the workshop into Broader Impacts plans for NSF proposals, including CAREER proposals.

6 Future Plans

The enthusiasm from workshop participants will provide the momentum to continue making an impact on the combustion community. Future plans for the workshop include the following:

- **Diversity and inclusion workshops at the US sectional meetings in Spring 2018:** The three US sectional meetings (Western, Central, and Eastern) during Spring 2018 are hosted by early-career faculty who participated in the workshop. As such, we are collaborating to host a diversity and inclusion session at each of the section meetings. The focus of these sessions will be to brainstorm ideas for building a successful mentoring network within the Combustion Institute.
- **Women in Combustion session at the International Symposium:** Workshop organizers Nicole Labbe and Jacqueline O'Connor are organizing a luncheon for Women in Combustion at the International Symposium in August 2018. This event will bring together women of all ages and backgrounds within the community for networking and discussion, particularly focusing on the topic of mentoring.
- **Follow-on workshop at the 2019 US National Meeting:** The newly formed Early Career & Diversity Development Committee of the USSCI (with six of the seven members having helped organize or participated in this workshop) plan to organize a follow-on workshop at the 11th US National Meeting in 2019. All of the workshop survey respondents indicated they were interested in participating in follow-on activities, though we also hope to involve additional early career participants.

Acknowledgements

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A Workshop participants

Name	Institution
Kareem Ahmed	University of Central Florida
Ben Akih-Kumgeh	Syracuse University
Patton Allison	Michigan State University
Mohsen Ayooobi	Wayne State University
Marc Baumgardner	Gonzaga University
Erica Belmont	University of Wyoming
Josh Bittle	University of Alabama
Guillaume Blanquart	Caltech
Michael Burke	Columbia University
Cosmin Dumitrescu	West Virginia University
W. Ethan Eagle	Wayne State University
Mohsen Ghamari	Wilkes University
Franklin Goldsmith	Brown University
Michael Gollner	University of Maryland
Francis Haas	Rowan University
Peter Hamlington	CU Boulder
Lulin Jiang	University of Louisiana at Lafayette
Kerry Kelly	University of Utah
Prashant Khare	University of Cincinnati
Janardhan Kodavasal	Argonne National Laboratory
Nicole Labbe	CU Boulder
Ya-Ting Liao	Case Western Reserve University
Hunter Mack	University of Massachusetts Lowell
Michael Mueller	Princeton University
Kyle Niemeyer	Oregon State University
Jacqueline O'Connor	Pennsylvania State University
Perrine Pepiot	Cornell University
Vi Rapp	Lawrence Berkeley National Laboratory
Greg Rieker	CU Boulder
Scott Rockwell	Eastern Kentucky University
Brandon Rotavera	University of Georgia
Omid Samimi-Abianeh	Wayne State University
Raymond Speth	Massachusetts Institute of Technology
Wenting Sun	Georgia Institute of Technology
Subith Vasu	University of Central Florida
Richard West	Northeastern University
Huahua Xiao	University of Maryland
Yuan Xuan	Pennsylvania State University

B Code of Conduct

This workshop is a community event intended for discussion, networking, and collaboration. We value the participation of every member of the community and want all attendees to have an enjoyable and fulfilling experience. Accordingly, all attendees are expected to show respect and courtesy to other attendees throughout the event and in interactions online associated with the event.

The workshop organizers are dedicated to providing a harassment-free experience for everyone, regardless of gender, gender identity and expression, age, sexual orientation, disability, physical appearance, body size, race, ethnicity, religion (or lack thereof), technology choices, or other group status.

To make clear what is expected, everyone taking part in the workshop and associated discussions—organizers and participants—is required to conform to the following Code of Conduct.

All workshop participants are expected to follow this code throughout the event, and you may also contact the anyone on Code of Conduct subcommittee (Kyle Niemeyer and Nicole Labbe) directly by email; see contact information below. All communication will be treated as confidential.

To that end, we ask all attendees to adhere to the following guidance:

- Communicate appropriately for a professional audience including people of many different backgrounds. Sexual language and imagery are not appropriate for any event.
- Be kind to others. Do not insult or put down other attendees. Be mindful of jargon, which can sometimes exclude others from engaging in the discussion.
- Behave professionally. Remember that harassment and sexist, racist, ageist, or exclusionary behavior are not appropriate.

Note that as a community event, we take a community approach to ensuring the safety and comfort of all attendees. Everyone is responsible for assisting in any circumstances where anyone appears to not following the Code of Conduct.

B.1 Conflict Resolution

If someone makes you or anyone else feel unsafe or unwelcome, please report it as soon as possible to a member of the Code of Conduct subcommittee if you are hesitant about addressing the person yourself. At any time, you can reach the subcommittee either in person or via email (see contact information below). The subcommittee is committed to address and resolve the issue in question to the best of their abilities.

Harassment and other code of conduct violations reduce the value of our event for everyone. We want you to be happy at our event. A harassment-free environment makes our event more conducive to research creativity and productivity.

You can make a report either personally or anonymously.

B.2 Sanctions

Participants asked to stop any behavior that makes others uncomfortable are expected to comply immediately. If a participant engages in harassing behavior, organizers will take any action they deem appropriate, including warning the person in question, removing the harasser from the event, or banning the offender from a mailing list.

Specific actions may include but are not limited to:

- warning the person to cease their behavior and that any further reports will result in other sanctions
- requiring that the person avoid any interaction with, and physical proximity to, their victim for the remainder of the event
- immediately ending any event, volunteer responsibilities, and privileges the harasser holds and requiring that the person to not volunteer for future events (either indefinitely or for a certain time period)
- requiring that the person immediately leave the event and not return
- banning the person from future events (either indefinitely or for a certain time period)
- banning the person from participation in follow-on activities (e.g., report or paper writing)
- publishing an account of the harassment

Workshop organizers can be identified by their name badges, and will help participants contact hotel/venue security or local law enforcement, provide escorts, or otherwise assist those experiencing harassment to feel safe for the duration of the event.

If an incident occurs, please use the following contact information:

B.3 Code of Conduct (CoC) subcommittee

- Nicole Labbe: <Nicole.Labbe@Colorado.edu>
- Kyle Niemeyer: <kyle.niemeyer@oregonstate.edu>

We expect participants to follow these rules at all workshop venues, workshop-related social events, community gatherings, and online communication channels.

Thank you for your participation in this community, and your efforts to keep our workshop a safe and friendly space for all participants!

(Based on the WSSSPE4 Code of Conduct [28], which was based on the FORCE11 Code of Conduct [29], Code4Lib Code Of Conduct [30], and inspired by the ADA Initiative’s conference anti-harassment policy resources [31].)