



California Institute of Technology

**Report of the Visiting Committee for the
Division of Chemistry and Chemical Engineering**

June 30 – July 1, 2015

2015 VISITING COMMITTEE MEMBERS

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Introduction

The Chemistry and Chemical Engineering Division is a jewel in the Caltech crown. The Chemistry and Chemical Engineering departments, despite their relatively small collective size of ~50 faculty, were ranked the number 1 and 2 departments, respectively, in the 2013 *US News and World Report* survey. The quality of the Division is also reflected in the number of active Nobel Laureates (3), National Medal of Science recipients (5), Wolf Prize recipients (3) and members of the National Academies of Science and Engineering (24). Moreover, despite its relatively small size, the Division is rather remarkable (and unusual) in its strengths within the various sub-disciplines of chemistry and chemical engineering, which allows the Division to broadly influence emerging areas of science that have the greatest scientific opportunities and societal impact: life sciences, medicine, energy, and the environment. Indeed, this collective strength should be exploited as Caltech replenishes its outstanding faculty with a younger generation of scientists and engineers. It is clear that the recent hires at Caltech continue the tradition of excellence, with respect to both the quality and creativity of their science. The eminence of the Division and its commitment to education are also reflected in the training and skills of the Division's graduate students and postdoctoral fellows who make up a disproportionate percentage of the faculties of the leading universities around the world. In addition, the Division has a very strong teaching and research relationship with the undergraduates at Caltech, which helps to underscore the advantages of the Caltech environment for undergraduate education. Finally, it should be remarked that the collegiality and enthusiasm of the faculty and their younger coworkers and students is really striking, further helping to make the Division a unique place in the world to carry out cutting edge research and to teach the next generation of scientists and engineers.

Our committee spent an informative and enjoyable 1.5 days at Caltech. In spite of the short duration of this visit, we are confident that we were able to develop an accurate and multifaceted understanding of the challenges and opportunities facing CCE. In an effort to assist the Institute and Division, we have suggested some actions in addition to our observations. We understand that coming from the outside some of these actions may be overly prescriptive. Clearly the CCE Leadership and Faculty in partnership with Caltech's Senior Administration are most capable to chart an optimal path forward.

Faculty Renewal

The aging of the faculty and slow pace of faculty renewal have created the Division's most serious problem. More than 25% of the faculty are 70 years of age or older and their positions need to be filled with younger faculty members who will collectively command a similar leadership role in science and engineering. What makes this task even more challenging is the fact that some of the oldest faculty members are among the most distinguished of their generation. These older faculty members have long been leaders of CCE and continuation of their scholarly activities within the Division is desirable. However, while their research efforts have continued, these faculty members have become less engaged in the operations (committee work) and the teaching mission of the Division than younger and mid-career CCE faculty. It is obviously not an ideal

situation to have a significant fraction of a department less engaged. The Committee found concern regarding this situation and it has the potential to erode the famously collegial fabric of CCE, which is a special quality that has distinguished it from other top departments in the country. It is apparent that strategies and efforts in recent years to promote a typical cycle of hiring and concurrent retiring have had limited effectiveness in transitioning the department to a more balanced average age distribution. The challenge and urgency of faculty renewal is recognized by the Division's leadership and by the entire faculty.

At the onset we recognize consensus on a comprehensive agreement to rebalance the faculty distribution in terms of age and a smooth transition for some of the senior faculty to either emeritus or non-tenured status is elusive (the designation of a faculty member as *emeritus* was viewed negatively by a number of the senior faculty and does not have to be used). As always, a "one size fits all" plan for the transition will not be workable in the opinion of this Committee. Nevertheless, the Committee believes that unless major progress is made in the near-term, the problem is certain to become worse. The stakes are high and we believe the future prestige of the Division is on the line. This problem is much easier to fix from the current position of strength than it will be 5-10 years from now when some of the more distinguished faculty are less research visible or active. The Committee sees the stature of CCE as heavily coupled to these senior faculty and their active role in faculty renewal is essential. Their participation in supporting new leadership, suggesting faculty appointments, and guiding/promoting the careers of the Division's younger and mid-career faculty is essential. Hence, we prescribe charting a course that leverages, and doesn't alienate, senior faculty. The situation will intensify soon and there was an acute sense of urgency for more aggressive hiring to fix the age imbalance in CCE. The Committee believes that there should be an aggressive effort to address the age imbalance in CCE.

The good news is that there are no fundamental institutional impediments to faculty renewal. The Division reported that current space resources are available for making up to four new appointments, and with near-term contraction of some research groups, additional space will become available. The financial support provided in terms of start-up packages is consistently comparable or superior to any offered in the country. Caltech also has many attractive features that should enable it to compete for the very best talent in the world. Aside from the core feature of being a premier institution wherein professors and students alike reach their highest professional aspirations, it has other resources that provide a high quality of life. The faculty child-care center, Athenaeum, physical infrastructure, outstanding students, lack of bureaucracy, historic reputation for excellence, and weather combine to make Caltech a singularly unique and enjoyable place to work.

The seriousness and time-sensitive nature of the faculty renewal issue warrants a multifaceted approach to guarantee success prior to any risk of erosion to CCE's preeminence. The Division Chair confirmed repeatedly that the Provost is highly supportive and has unconditionally authorized advertised searches in all of the subareas in recent years. However, there is the sense that there are still impediments, some of which appear to be sociological, to hiring. In particular, we observed that some faculty

applied excessively narrow definitions to their subfield when making the case for additional targeted appointments. For example, it was asserted that no biochemistry appointments had been made in 10 years and that the last chemical biology hire was 15 years ago. However, the three Assistant Professors who presented their research to the Committee have programs in Molecular Life Science and all of these individuals are contributing to the field of biochemistry. Such comments suggest that some faculty are applying restrictive definitions of research areas that can impede hiring and even more importantly, negatively impact an effort to increase faculty diversity. Subject matter experts are critical in evaluating potential faculty candidates, but broader search committee composition is recommended. We understand that this has been recognized in the Division and that a single divisional search covering all sub-areas was attempted recently and found to be ineffective. Hence, searches with some focus and with balanced search committee membership may prove to be more effective. The best future will come from expanded participation and a CCE that operates as a collective and unified group in defining the critical new directions and hiring opportunities. Faculty nearing the end of their own careers tend to feel that it is best to empower the next generation to have a strong role in determining the future of a department. Indeed, there was the suggestion, perhaps not made with full seriousness, that the present assistant professors (perhaps in collaboration with recently tenured professors) should be given the power to determine new hires. While this is an intriguing idea, we believe there is an important visionary role to be provided by the senior faculty in embracing the future directions for the department with new hires.

The Committee's perception is that in spite of the assurances from the Division Chair that Caltech will provide for a temporary expansion of CCE FTEs, sub-disciplines may be concerned about "spending" their positions on a new appointment that is not squarely in a preconceived area. We suggest that the Division may be more effective in searches if a longer-range (five-year) hiring plan were enacted wherein the CCE would be given a commitment of seven appointments that could be a combination of junior and senior level appointments. Diversity should be integrated into the five-year plan, not just an afterthought. It is understood that such a commitment by Caltech's senior administration is non-trivial and that the Division will need to work with the most senior faculty members to free up positions. Creative incentives are needed to free up salary lines, but still provide senior faculty with a continuing role in the Division and an identity as Caltech Professors. It is possible that the best inducements may not be salary based, but could come in the form of a special non-tenured appointment as an Institute Research Professor and/or discretionary support to allow faculty to stop seeking external research support for a graceful reduction in research activities. One-on-one discussion with each senior faculty member could include consultation with a financial planner to assure that the financial goals of each senior faculty member are fully met when the transition to non-tenured status occurs.

The process of faculty renewal is also an opportunity for increasing the diversity of the department. Faculty recruitment in general, and promoting greater diversity in particular, would benefit from creating a database of outstanding potential candidates and maintaining frequent contact with them for extended periods. Particular emphasis should be given to the cultivation and tracking of diversity candidates who may be identified at

early stages of their professional development. This process will be most effective if there is broad participation from the majority of faculty members in suggesting and cultivating these individuals. Concerns that quality individuals will not be competitive for tenure is often an impediment to diversity hires and this is complicated by the fact that judgments can be influenced by unconscious bias. It is assumed with faculty hiring that not all candidates will eventually be competitive for tenure at Caltech. Overtly recognizing and accepting this fact is critical for the Division to make hires that might be high risk, but also high impact. It is a fact that conservative hiring is fundamentally at odds with promoting diversity, which is a Division and Institute priority.

Fundraising Priorities

The Committee is enormously impressed with the vision of the Institute in working to raise endowment to fully support graduate students over the course of their PhD studies. Success in this effort is certain to promote even greater innovation in research at Caltech. It will also put the Institute ahead of the pack in adapting to a certain continued decrease in federal research support. We predict that success in this area will make Caltech an even more attractive venue for top academic talent. We are similarly impressed with the extraordinary progress Division Chair Barton has already made toward the goal of endowing graduate student support.

Science and engineering research activities are increasingly dependent on specialized facilities for advanced characterization of molecular function and structure. As such, establishing and maintaining strategic facilities is necessary to maintain competitiveness. CCE has benefited from private foundational support for facilities dating back to the founding of the Beckman Institute, and more recently by the Gordon and Betty Moore Foundation for the Center for Chemical Signaling, the Catalyst Center, and the Molecular Observatory. Ongoing support for these centers is particularly important at Caltech, because the smaller user base will not likely generate adequate fee-for-service revenue. As a result, an optimal and sustainable future will require creating endowments to underwrite the operation of these facilities, to supply matching funds for new equipment proposals, and for periodic modernization of existing instruments. The Committee was encouraged to learn that the Caltech administration has recognized this need and wants to encourage it as a continued priority.

Programmatic Challenges

The small size of Caltech has a number of attractive attributes that we have mentioned, but also presents limitations in terms of the ability to cover all areas of chemistry and chemical engineering. Over the last 30 years, the Division has been remarkably successful in achieving excellence in the traditional as well as emerging areas of chemistry and chemical engineering. However the chemical sciences continue to diverge to confront challenges posed by the fields of medicine, biology, environmental science, energy conversion, and materials science. Going forward CCE will be faced with tough

choices with regard to the fields in which they choose to establish excellence. It is clear that there has been a major push in the biological sciences over the last 20 years, however CCE should also be building strategic excellence in multiple other areas.

In this context, the Committee recognizes that the physical chemistry area will need new appointments to maintain its strength. We recognize that Caltech has exceptional senior scientists in physical chemistry with two Nobel Laureates, and a history of producing seminal advances in Physical Chemistry. Recent junior hires also appear to be very strong. Opportunities for strengthening the CCE Division include hiring a young or mid-career senior theorist and/or experimentalist and an ideal candidate will have an interdisciplinary program that supports/leverages other strategic programs at Caltech and/or the JPL connection. The latter connectivity ensures diversified sustainable resources that are necessary to meet the high capital costs that are often associated with modern experimental physical chemistry.

Although mentioned in the Chair's presentation, the Committee notes the relative absence of discussion regarding energy as an important future direction of the Division. CCE has been successful in the past with individual efforts on this subject as well as with the NSF-supported Center for Chemical Innovation (CCI) on Solar Hydrogen led by Harry B. Gray. (The CCI has three more years of funding in its full NSF funding cycle.) The awarding of the DOE Hub, now known as the Center for Artificial Photosynthesis (JCAP), brought an enormous injection of research support to Caltech, as well as great attention to the Institute and its partner UC-Berkeley, on the question of solar energy conversion to liquid fuels. However, it is widely known within the solar energy conversion community that this center encountered leadership and administrative issues that have created frictions. JCAP has recently been renewed for five years at a reduced, but still significant amount of \$14,000,000 per year (this amount includes support for efforts at both Caltech and UC-Berkeley). The impetus to hire new faculty with research interests in renewable energy research is thus great, but the factious environment needs to be addressed in order to optimize the success in such recruiting.

Research problems in energy connect well to chemistry and chemical engineering. The sub-disciplines of chemistry that will benefit from improved energy-based research include traditional inorganic, physical and organic chemistry, as well as materials science, photochemistry, catalysis, chemical biology, hydrogen generation and oxygen evolution. The subject of energy storage chemically using hydrocarbons, carbon allotropes, boron compounds, framework materials and even ammonia is also highly relevant, as is the delivery of such energy from fuel cells or batteries. These topics all contain key questions about materials and catalysis that are fundamentally chemical in nature. The Committee thinks that CCE should work to leverage the special position that Caltech has in energy research (CCI, JCAP and the Resnick Institute for Science, Energy and Sustainability) to attract key faculty talent. Leadership in CCI, JCAP and the Resnick Institute for Science, Energy, and Sustainability should be able to formulate and promote a more cohesive energy strategy for CCE that will be effective in recruiting new faculty.

Future Competitiveness

Division Chair Barton indicated to the Committee that the biggest impediment to faculty recruitment is the 2-body issue. Caltech is effectively an island that is isolated from proximate attractive employment opportunities for dual PhD couples. One long-range (30 year) strategy to address this issue is to create a Kendall Square or Silicon Valley-like environment around Caltech. All Divisions of Caltech would benefit from an improved local technology eco-system for transitioning of inventions, demonstrating value to the taxpayer, and providing exciting professional opportunities for Institute graduates and spouses. A more substantial local industrial base will also create jobs that provide value to the region. Strategies for attracting venture capital and business experts will be central to the success of such an endeavor. Although Los Angeles is not known for a thriving venture capital community, it is a center of wealth and hence promoting a local start-up culture has the prospects for not only attracting established VCs, but the nucleation of new funds. Caltech could use its outstanding reputation to convene individuals and organizations that are interested in promoting a sustained high tech economy in the LA area. Beyond financing of companies, it would be valuable to promote technology translation by including Caltech funding that is targeted to reduce technology risk and market risk through the entrepreneurial mentoring and education of students and faculty. We were told that Caltech has created some funds that help entrepreneurs to cross the “valley of death” and that a high percentage of undergraduates are taking business courses. However, to effectively translate the intellectual property of Caltech to market we suggest the Institute also consider a center similar to MIT’s Deshpande Center, which provides funding, mentorship, market analysis, and facilitated access to prospective partners and investors. This is an issue for the entire Institute and perhaps a campus-wide task force including local industry, faculty entrepreneurs, and Caltech Board members would be able to facilitate progress. Multi-university initiatives such as collaborations with UCLA or USC could accelerate this transformation.

Safety

It is apparent to the Committee that the Division has made great progress in promoting a culture of safety and should be commended for the safety day event that was mentioned by a number of faculty and students. We were encouraged that students indicated that they considered safety important and that safety violations are not tolerated by the faculty or coworkers. However, the department indicated frustration in their relationship with the EH&S office, with the exception of radiation safety. The analysis of the situation is that there is a need for a more technically sophisticated EH&S staff member with a Chemistry PhD and exposure to, if not expertise in, chemical synthesis. An EH&S staff member having this level of training, and a collaborative attitude towards Chemistry personnel, will be best prepared to understand the more challenging, and potentially dangerous, wet chemistry experiments that are routinely performed within the CCE. It is anticipated that a personable, technically sophisticated staff member could change the perception of the EH&S office as a resource rather than an enforcement organization. We want to emphasize that engagement is a two-way street. The Committee is confident that

CCE has been progressive in promoting safe laboratory practices, and Caltech leadership should ensure that the EH&S office has a reciprocal commitment.

Physical Infrastructure

We were informed that Caltech provides generous renovation funds for laboratories as part of faculty recruitment and we did not hear of significant un-met needs related to research facilities. However two of Chemistry's teaching facilities are in need of renovation. Specifically, the Linus Pauling Lecture Hall (22 Gates) is effectively out of commission as a result of its poor condition. We understand that a renovation will incur extra expenses to make it handicapped accessible, however it is clear that a rejuvenated lecture hall will receive heavy use and provide an enduring benefit to Caltech's faculty and students. The Mead Teaching Laboratories are now 33 years old and although once state of the art, are now clearly sub-standard for an elite educational institution. This laboratory serves to educate the entire Caltech undergraduate student body and fixing it is imperative.

The Committee asserts that the CCE should not be excessively burdened with the responsibility of raising funds for renovating these teaching resources. These projects should be funded outright or given priority as part of the bricks and mortar portion of the impending campaign.

Education and Curriculum

Caltech attracts undergraduates with extraordinary abilities and enthusiasm for science and engineering. The culture of informality and flexibility is reflected in the undergraduate education, much of which appears to include free-flowing non-traditional courses as opposed to lecture style courses. It was stated that the faculty feel that Caltech undergraduates do not need to be spoon-fed information in conventional course structures. Although this is likely true for many students, it may not be optimal for all students. In our discussions with graduate students, it was indicated that courses taught at high levels often exceeded the abilities of the students and they often required extensive assistance that places a burden on the TAs. The undergraduates expressed a love-hate feeling for the more challenging courses. They complained about the demanding nature of the courses, but felt empowered by the knowledge they gained. A couple of students indicated that the introductory chemistry courses had too much emphasis on remedial material. This suggests that multiple tracks could lead to an optimal experience. A lower track can ensure that students understand the basics, and advanced students can enroll in a higher-level course. It is prudent for any academic unit to review the core curriculum from time to time, and the Committee suggests that, in the not too distant future, such an analysis may generate new educational innovations. This may be particularly important in introductory courses, many of which have been taught the same way for generations.

The graduate program appears to be in good shape. The more synthetically oriented graduate students, as well as some of the undergraduates, were very happy with the mechanistic tutorials that are now being offered. Chemistry has a long tradition of eschewing cumulative exams and has, for more than 30 years, used proposal writing as an alternative vehicle to evaluate a student's abilities. PhD candidacy is determined by a research report and two proposals. Those on the Committee who went through this system and chose to become academics, clearly benefited from the creative thinking that this system encourages. Chemical Engineering has a written qualifying exam and requires five courses as compared to four courses in Chemistry. Biochemistry and Molecular Biophysics requires six courses.

We noted that graduation times in CCE are exceeding five years and are getting closer to six years in Chemistry. In general, longer times to graduate are not in the best interest of students, many of whom wish to start a family after completing graduate school. Mechanisms may be necessary to ensure that graduation times do not get progressively longer. We noted that there is a CCE policy that students cannot be appointed to TA positions after their 6th year. However, this would not seem to be an adequate impediment. The responsibility to move students through a PhD program in a timely fashion rests both with the faculty and students. We suggest that requiring a petition for registering beyond six years or having students prepare a plan to finish with a clear timeline and structured reporting on progress are potential mechanisms to prevent future problems.

The accreditation process imposed on Chemical Engineering Departments by ABET is a burden that is not conducive to a creative, modern curriculum. The consensus opinion is that there is no value provided by this process. Nevertheless these historic standards are unique to Engineering and compliance is promulgated by concerns about the consequences of not being an accredited department. Although Caltech Chemical Engineering could unilaterally drop out of this system, it may be prudent to seek solidarity with other Chemical Engineering Departments and collectively cease to seek ABET accreditation.

Diversity

A central issue to the science and engineering community is how best to promote diversity. At the undergraduate level there have been considerable improvements in recruiting women. This is particularly impressive in Chemistry wherein the majority of their undergraduates are women. Underrepresented Minority recruitment remains a challenge for most educational institutions. There continues to be a significant gap in the United States between the demographics of the general population and the representation of minorities in academics at all levels. In the case of women, participation decreases as individuals progress from undergraduate student → graduate student → postdoctorate → professor. Given that a pipeline of female talent exists, it is important for departments to identify interventions that can be implemented to plug the leaks that are leading women to choose alternative career paths at a higher percentage than men. The Committee encourages the Division, as well as the Institute, to introduce innovations that will set standards that other universities will aspire to emulate. For example, the introduction of

affordable day care facilities for students and postdocs was repeatedly suggested as an effective means for supporting the careers of junior female scientists and improving their representation in the pipeline.

Undergraduate Students

The undergraduate students were unequivocally satisfied and happy. Every student expressed without reservation that they were glad to be at Caltech. All answered with a Chemistry or Chemical Engineering course when asked about their favorite class. They affirmed that Caltech is an ideal place for individuals who are interested in the highest academic demands, and that this was made crystal clear to them from the moment they first visited campus. It was particularly nice to learn that they had developed strong relationships with faculty and that the informality and small size of Caltech was a critical element in fostering this special atmosphere.

Graduate Students

Our discussions with the graduate students also revealed a content group with no regrets about attending Caltech. When asked, they all indicated that they would recommend CCE for their colleagues who were interested in graduate school. They described the faculty as friendly and proactive in dealing with the special situations of individuals. They all felt that the small size, flexibility, and lack of bureaucracy at Caltech was highly desirable and a contrast from most of their undergraduate experiences. Some of the married students with children (all of whom were men) praised the additional financial support given to them to pay for family health insurance.

We were told earlier in the day that a student survey revealed that 95% of the students indicated that they “joined the lab they wanted to join”. This cohort of graduate students was surprised by this statistic and thought that perhaps it did not reflect the fact that some students had changed groups. In particular, students in molecular biosciences felt that they would have benefited from research rotations between groups. Such schemes are common in the biological sciences, but not typical in Chemistry or Chemical Engineering. The fact that BMB has research rotations is also contributing to the desire for this option to be more widely available. However, students indicated that participation in research rotations endangered their prospects for getting into their first choice research group. Specifically, they indicated that all slots would be taken by the November 1 date when students are allowed assignment to individual research groups. It would appear that an expanded first year research rotation scheme would benefit some of CCE’s graduate students. We encourage the development of mechanisms/policies that will provide students wishing to do rotations with assurances that they will not be at a disadvantage with regard to group selection.

It was also indicated that there was no guidance for students wishing to investigate career options outside of traditional academic and industrial tracks. We suggest that formal

programs can be enacted to provide this guidance. Specifically, graduate student led seminars and workshops that bring in local experts and alumni for discussions about career opportunities for Chemists and Chemical Engineers in law, government, publishing and other non-traditional industries, could provide this guidance with minimal effort and cost.

Postdoctoral Researchers

This group was decidedly less happy than the undergraduate and graduate students. At least two of them had spent extended time (5 years) as postdoctoral researchers and were struggling with the high costs of supporting a family under these circumstances. Reflecting what is perhaps a general attitude among postdoctoral researchers nation-wide, they expressed a feeling that there were no programs or support to help them with career advancement. They also suggested a lack of community for facilitating association within the Institute. We were informed that Caltech in fact offers many of the support services that are desired and has an office to assist postdoctoral students with professional development. Hence, it may be possible to remedy many of the postdoctoral issues by fostering better communication with the Institute and tools for directing postdoctoral researchers to available resources. Public events/lectures/workshops directed at postdoctorate and senior graduate researchers on job search, alternate careers, and grant writing would also serve to address concerns from this cohort.

Chemical Engineering

It is impressive that Chemical Engineering ranks #2 in the US, with only 11 faculty members. The small size of this particular Caltech jewel necessitates sensitivity to their unique needs. In particular, supplemental appointments may be necessary from time to time to provide stability. A major issue appears to be that the department feels handicapped by their small size in competing for top student and postdoctoral talent. Larger programs at Stanford and in particular at MIT are formidable competition and in some areas can provide a greater diversity of research opportunities in Chemical Engineering. From the data given it would appear that the Chemical Engineering Faculty have compensated for the limited access to students from their own department by recruiting students from other departments and divisions. Specifically, 44 graduate students, or nearly half of their students, are recruited from other departments. This cross-fertilization was highlighted as a strength of the group and indeed likely contributes the innovations that enable this group to perform at such a high level

Guidance for Future Visiting Committees

This Visiting Committee had an informative and enjoyable visit to Caltech and was impressed with the openness and accommodating atmosphere presented by the Senior Leadership, Division Chair, Faculty and Staff. However, the committee members felt

that future committees would benefit from additional resources. We were provided data about the success rates of hiring during the meeting when it was requested, and we appreciated this responsiveness. However, a number of the Committee members felt that other data and analysis would have been useful. In executive sessions the committee wondered about the tenure rates within CCE. It was highlighted multiple times that the Division is careful in hiring and this leads to high, if not close to 100%, tenure rates. Some analysis of tenure rates over 30, 20, and 10-year time frames and as a function of sub-discipline would have been useful. This is not to overtly question the objectivity of the tenure process at Caltech, but we also think that having this data is important for institutional self-awareness. The need for advanced instrumentation came up several times and when asked we were told that there was no strategic analysis for giving priority. In our final session with Division Chair Barton, we were assured that there was such a list, however it was likely developed in relative isolation by a few faculty. Larger self-studies that help the department develop priorities would be useful in creating the most effective strategies.