Academic Program Review Self Study

Department of Chemical Engineering, College of Engineering, Seattle campus

B.S. Chemical Engineering
M.S. Chemical Engineering
Ph.D. Chemical Engineering
Year of last review: 2008-09
Jim Pfaendtner, Department Chair
March 25, 2019 – submission 1
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Part A: Required Background Information

Section I: Overview of Organization

Mission & Organizational Structure

The mission and vision of UW Chemical Engineering

Our vision statement (adopted ca. 2015), "*knowledge and solutions for a changing world,*" is informed by the deep desire among our faculty to leverage all of the tools of the chemical engineering profession in preserving and improving our planet.

Our mission statement (adoption date unknown),

To educate the next generation of visionaries, prepare students for leadership in diverse careers, create knowledge, and provide multidisciplinary solutions to broad societal problems

reflects our unique role as academic researchers, simultaneously training new chemical engineers and leading technological discovery. In the department of chemical engineering, we fully embrace this dual purpose, bringing passion and energy to these related but distinct endeavors.

Available degree programs and enrollment numbers

Table 1 summarizes our current degree programs where students matriculate, as well as recent enrollment and graduation details. Detailed degree codes are provided in the footnotes.

Table 1: Degree programs, enrollment and degrees awarded

Degree program	Enrollment[a] of students in each program (degrees awarded in parentheses) [calendar year basis]					
	2013	2014	2015	2016	2017	2018
B.S. in Chemical Engineering (CHEM E 00-16)	130 (51)	162 (43)	150 (56)	152 (63)	163 (59)	156 (59)
B.S. in ChemE, Nanoscience and Molecular Engineering Option (CHEM E 05-16)	13 (3)	7 (9)	10 (7)	10 (5)	10 (3)	3 (6)
Total ChemE B.S. awarded	54	52	63	68	62	65
M.S. in ChemE (00-26, 35-26)[b,c]	N/A	23 (15)	26 (19)	36 (24)	36 (29)	33 (37)
Ph.D. in ChemE (00-30, 00-41,25-30,25-41,45-30,45-41)[b,c,d]	N/A	74 (16)	86 (13)	83 (9)	73 (12)	72 (8)

[a] Enrollment figures for undergraduates use autumn quarter numbers
[b] The M.S. students counted here are those enrolled in our terminal self-funded M.S. degree. These figures are inclusive of graduate students who perform additional coursework for the data science options offered in our graduate programs (additional details are provided later in this document).
[c] Currently unused or rarely used degree codes include CHEM E-20-26 (interdisciplinary M.S. in Chemical Engineering) and CHEM-E-15-30/15-41 (Ph.D. tracks for nanotech and molecular engineering)

[d] Ph.D. programs retain two degree codes for pre/post candidacy

Some key takeaways from the enrollment data include:

- The undergraduate enrollment and degrees reflect a healthy graduation rate of our students and a department size in line with — or slightly exceeding — the current expectations of the dean of the UW College of Engineering (e.g., current state proviso targets).
- Our M.S. program has expanded over the past 5 years. It is research based, requiring each M.S. student to, at minimum, complete a two-quarter-long research project with a ChemE faculty member. Around two-thirds of the students choose to stay an extra year to complete a thesis M.S. degree.
- Enrollment in the ChemE Ph.D. program has been decreasing since it peaked in 2015 at 86 students. However, our faculty research is highly interdisciplinary, and as of January 2019, there were an additional 20 Ph.D. students from other programs supervised by our faculty members: 9.5 Molecular Engineering & Science, 3.5 Bioengineering, 2.5 MD/Ph.D., 2 MSE, 2 Chemistry, 1 Computer Science. (The MolES Ph.D. program began enrolling students in Autumn 2014.)
- Over the past two years, 14 graduate students (12 M.S., 2 Ph.D.) have graduated with a "ChemE Data Science" designation on their degree. In March 2019, there were an additional 29 graduate students (12 M.S., 17 Ph.D.) enrolled in our graduate programs and pursuing a data science designation.

Academic services support

The Academic Services Unit in Chemical Engineering oversees all administrative aspects of academic services for the department. It is staffed by 1.0 FTE academic services director, 1.0 FTE undergraduate academic counselor, and 0.8 FTE graduate academic counselor (see Appendix A). The unit is responsible for advising undergraduate and graduate students, admissions, recruitment, monitoring academic progress, managing records, and reporting. Advisers variously serve on undergraduate and graduate program committees pertaining to curriculum development and management. In partnership with key faculty, the Academic Services Director, with assistance from the two academic counselors, provides leadership for maintaining the excellence and integrity of the various degree programs, including the quality of the student experience and the accreditation of our degree programs.

Other departmental support and unit organization

The Chemical Engineering organizational chart is found in Appendix A. All department faculty report directly to the Chair. Staff reporting directly to the Chair include the Administrator, the Academic Services Director, and the Assistant to the Chair. The Administrator leads the Administrative Support and Technical Support units, and the Academic Services Director leads the Academic Advising unit. The External Advisory Board directly advises the Chair. There are nine faculty committees: Strategic Planning, Diversity, Infrastructure, ABET, Undergraduate Program, Graduate Program, Discovery Days, Awards, and Student Organizations. The chairs of these committees report directly to the Department Chair.

There are 17 department staff — two classified and 15 professional staff — and three student assistants. The Administrative Support unit includes staff who provide support in the areas of finance, human resources, risk management, research administration, communications, events, and administrative and fiscal services. The faculty committees for Strategic Planning and Diversity are included within this unit. The Technical Support unit includes staff who provide support in the areas of facilities, safety, technology, and computing and infrastructure; these staff also manage the unit operations lab, fabrication shop, and computer labs. The faculty committee for Infrastructure is included within this unit. The Academic Advising unit includes staff who provide support in the areas of graduate and undergraduate advising, in addition to academic events such as seminar series. The ABET, Undergraduate Program, Graduate Program, and Discovery Days faculty committees are included within this unit.

The Faculty unit is comprised of faculty — tenured/tenure-track, research faculty, lecturers, affiliate, and adjunct — professional and classified staff, research associates, and students. Individual faculty members manage employees who work in their labs. Administrative staff in the Faculty unit have a dotted-line connection to the Administrator. Faculty committees include Awards and the student organization advisers (for the Association of Chemical Engineering Graduate Students, Women in Chemical Engineering, and the American Institute of Chemical Engineers). There is currently one center in ChemE: the Center for the Science of Synthesis Across Scales (CSSAS), led by professor François Baneyx, which is a new DOE Energy Frontier Research Center started in September 2018. The program operates, in conjunction with the Clean Energy Institute, a training grant (NSF NRT program) involving 30 graduate students per year across four departments (Pfaendtner PI).

Shared governance of the unit

Shared governance is a standard practice in the department. The faculty is supplied with information on all significant policy, discusses and modifies recommendations, and votes on final approval. This includes issues ranging from the annual budget to educational policy issues to the membership of departmental committees. Faculty are also regularly updated on other information ranging from University and College issues to discussions and issues being dealt with by departmental committees. The current representation of faculty and the makeup of departmental committees is shown in the organizational chart in Appendix A.

The department regularly seeks the input of its students and professionals. Representatives from both graduate and undergraduate student organizations participate in departmental meetings and on departmental committees. The department has a large number of joint and adjunct faculty who provide a wider perspective to the department. Finally, the department has an advisory board (see current membership in Appendix D) consisting of industrial and academics professionals. The board meets once per year in Seattle for two days to provide the department with guidance and feedback. The previous two advisory board agendas are provided in Appendix D.

Budget & Resources

The department has five primary funding sources: grants and contracts (50.33%), gifts and discretionary (9.5%), state funding (34.03%), research cost recovery or RCR (5.86%), and other (0.29%). That last category includes the student technology fee (STF) and a self-sustaining revenue account. Data is provided for fiscal year 2013 through 2018 (with a fiscal year defined as July 1 – June 30) in Appendix B.

Chart 1 of Appendix B contains a pie chart and table of the six-year average expenditures by funding source. The amount of spending from individual sources fluctuated from year to year, but overall spending has increased since 2013, with a peak of $14 million in 2016. There are several reasons for this year-to-year variation. During this period, we hired six new tenured and tenure-track faculty: two in 2013 (James Carothers and Cole DeForest), two in 2015 (Venkat Subramanian and Vincent Holmberg), one in 2016 (Elizabeth Nance), and another in 2018 (Qiuming Yu). Start-up packages for these faculty were partially funded by the department, but the majority of the start-up funds were transferred from other departments, the Clean Energy Institute, the College of Engineering, and the Office of Research. The transferred start-up dollars came in the form of state funding, RCR, and gifts. This influx of additional funding in the department caused the spending increase leading up to the peak in 2016. In addition, the College received some proviso funds from the State Legislature, with ChemE receiving $80,000 in 2013 and another $80,000 in 2014. These funds were made permanent in the 2016-2017 biennium. There is a decrease in spending on RCR funds in 2015 due to the increased spending on state funding proviso funds in that same year. The department initiated a new Professional Master's Program in 2015, which contributed to state funding increases. Overall, spending has trended upwards by 13.86% since 2013. Comparing 2013 spending to 2018, state funding has increased by 39%, RCR has increased by 173%, and gifts have increased by 9.5%. Grant and contracts varied by year, but are essentially flat in growth overall.

See Chart 2 (Appendix B) for expenditures by budget category and year. Our budget categories are defined as faculty (including postdocs, research faculty, and lecturers), teaching assistants, research assistants, staff (both classified and professional), hourly employees (both staff and students), fellowships and trainees, operational and research costs, benefits, and student tuition costs. Spending in all budget categories but two have increased steadily since 2013. The exceptions are faculty salaries, which have increased at a much higher rate than the other categories, and operations and research costs, which peaked in 2016 and dropped significantly in 2018. The increase for faculty salaries can be attributed to adding faculty and several unit adjustments, funded by the University and the College, to bring tenured and tenure-track faculty pay into alignment with market values and to alleviate salary compression across ranks.

The data points for operational and research costs vary widely from year to year. The variability can be attributed to large equipment purchases with start-up funds, amounting to almost $1 million in 2013, $300,000 in 2014, $761,00 in 2015, $1.5 million in 2016, and $1.2 million in 2017. Adjusting the numbers to exclude equipment results in a much more realistic picture for operational and research spending for the department (see Chart 3). As start-up dollars are expended, overall department spending has gone down slightly; grants and contract awards have not picked up enough to make up the difference. We expect grant and contracts to increase as our junior faculty develop in their fields. Our mentoring plans for junior faculty include significant support for learning effective grantsmanship. The vast majority of our research dollars come from the federal government, with the top five funding organizations being the National Science Foundation, the Department of Energy, the National Institutes of Health, the Office of Naval Research, and the Defense Threat Reduction Agency. The Chair and the Administrator use financial data and other metrics to analyze and make decisions about funding, human capital, and other resources.

See Table 1 (Appendix B) for expenditures total current endowments. In the ten years since our last program review, we've added 18 endowments, representing a 37% increase. The new endowments include nine scholarships, two fellowships, one professorship, one lectureship, and five program support funds. In 2018, the total department endowment value stood at $22M.

We have our alumni to thank for the majority of contributions; one faculty, two faculty emeriti, and family/friends of an alumnus also contribute substantially. We have two dedicated advancement officers in the College who continually cultivate and steward donors. Further, the department cultivates alumni relations through the Moulton Distinguished Alumni Awards, industry seminars, reunions, and regular communications.

These generous gifts from our donors largely benefit undergraduate students, graduate students, and faculty in the form of scholarships, fellowships, and professorships. The department issues every incoming Ph.D. student one quarter of fellowship support, ensuring that their first quarter is devoted to their studies and acclimating to the department. This year we awarded 41 deserving undergraduate students with endowment-funded scholarships. ChemE has six endowed professorships, which are invaluable in supporting faculty research and students. Program support endowments are used to pay a Senior Lecturer to manage our shared instrument facilities and to teach or assist faculty in teaching some of our classes. About 10% of program support dollars are used to provide awards and prizes to students, both undergraduate and graduate. The remaining program support distributions pay for operations and Chair's initiatives.

Note: We cannot produce data from the previous three biennia (2012-2013, 2014-2015, 2016-2017). The 2018-2019 biennium is incomplete and fiscal year 2012 data is no longer available in the financial system, as we are past the retention period. Instead, data is provided for the period of 2013-2018, which is the equivalent time period but not technically the "unit's three most recent biennia".

Academic Unit Diversity

Chemical Engineering Diversity Plan

The department has not voted on adopting a formal diversity plan. Our 2018-19 academic year diversity report is provided in Appendix E. This is effectively a working diversity plan, developed and executed by the department's Diversity Committee. The report facilitates the department's ability to make data-driven decisions that will:

- enable ChemE to attract and retain diverse student, staff, and faculty
- work toward cultivating an inclusive department climate
- improve accountability and transparency
- create an equitable department culture
- assess diversity needs and make appropriate changes in approach.

Plans are underway to formally adapt the report into a formal departmental diversity plan and vote on department-wide adoption, no later than Autumn 2019. The department recognizes that women, many ethnic and cultural minorities, and many from low-income background are underrepresented both in this department and in the chemical engineering field as a whole. We are seeking to remedy this underrepresentation in order to improve the quality of our department, and to drive innovation in the field that is not possible without the variety of goals and views that people of diverse backgrounds bring to our work as chemical engineers. ChemE is actively engaged in the recruitment, retention, and support of diverse students, faculty and staff through outreach, advising, participation in diversity fairs and conferences, funding and more. In the Appendix, we have detailed actionable items identified by the Diversity Committee, in discussion with the Chair and student-led department organizations.

Chemical Engineering Diversity Committee

The ChemE department's work to promote diversity and inclusion involves the effort of many individuals and groups. The UW ChemE Diversity Committee, formed in 2016, has involvement from faculty, staff, and students. The Diversity Committee meets once per quarter, maintains all data, resources, information, and documentation on a UW Google Drive, and takes meeting notes available upon request by department members. Diversity committee members serve two-year terms, and the overarching goals of each committee are outlined below in Table 2.

Table 2: Diversity committee composition and goals

	2016 – 2018	2018 – 2020
Faculty	Assistant: James Carothers (chair), Elizabeth Nance Associate: Stu Adler, Brad Hold, Lilo Pozzo	Assistant: Elizabeth Nance (chair) Associate: James Carothers Full: Jim Pfaendtner (Dept. Chair), Lilo Pozzo
Staff	Graduate student advisor: Allison Sherrill Undergraduate student advisor: Nicole Minkoff	Graduate student advisor: Allison Sherrill Undergraduate student advisor: Nicole Minkoff Assistant to chair: Stephanie Ashby
Students	NA	Undergraduate: Kyle Elliot Graduate: Gabrielle Tosado, Griffin Ruehl, Jaime Rodriguez
Primary Goals	• To develop and collect best practices for enhancing all levels of departmental diversity, be it undergraduate or graduate, faculty or staff, or related to our recruiting and hiring practices. • Create a diversity and inclusion page on the department website • To produce a roadmap to successfully build diversity and cultivate inclusion in Chemical Engineering	• Implement climate survey • Identify departmental diversity events that can become programmatic and coordinate with students groups the timing and carrying out of these events to enable student recruitment and retention of diverse and underrepresented populations • Implement best practices for hiring, recruitment, evaluation and recognition of diversity efforts

Chemical Engineering Faculty Diversity

In the last 10 years, we have hired 6 new tenure-track faculty (33% female, 17% URM): Jim Pfaendtner, James Carothers, Cole DeForest, Vincent Holmberg, Elizabeth Nance and Qiuming Yu. A snapshot of the faculty diversity statistics vs. key comparison groups is provided in Appendix E.

Recruitment, retention, and support of faculty and students from underrepresented groups

ChemE routinely utilizes resources provided through the UW ADVANCE Center for Institutional Change for the recruitment, retention and promotion of faculty from underrepresented identities.

Faculty recruitment: The department initiated a faculty search in October 2018. In aiming to improve upon diversity hiring and further build an inclusive department culture, the faculty search committee required a diversity statement in the requested application materials. The diversity statement needed to address the candidate's experience with diversity, and proposed solutions or ideas for improving diversity in the field of chemical engineering. The search committee attended "best practice" faculty hiring workshops. Further, rubric-based evaluations have been developed for all stages of the interview process to reduce implicit bias in faculty candidate review, with guidance from ADVANCE Center for Institutional Change staff. Importantly, the merits of this diversity statement were evaluated in the first round of applicant reviews, and the candidate's diversity statement was equally weighted with research ability, research potential, and teaching potential. The makeup of the top-five candidate list from this search is 40% female and 20% URM. (Final interview stages are ongoing.) This application requirement and application evaluation will be implemented in all future faculty searches. In on-campus interviews, the department facilitates the introduction of faculty candidates to UW ADVANCE leadership.

Faculty retention and support: Junior faculty have participated in a wide range of ADVANCE activities aimed at promotion and retention, such as:

- Peer mentoring circles
- Writing circles
- NSF CAREER award panels and preparation sessions
- Ongoing mentorship provided by ADVANCE leadership

In 2008, the department implemented a formal faculty mentoring program, where a new assistant professor was paired with a senior faculty in ChemE. Mentor pairs are encouraged to meet on a regular basis to discuss any aspect of the tenure process, building a lab, recruiting and mentoring students, etc. In addition to an assigned faculty mentor, new assistant professors meet regularly with the department chair, and formally on a yearly basis to evaluate progress towards tenure. The department prioritizes and supports new faculty in several ways: (1) encouraging placement of top graduate students in the labs of new faculty (2) protecting time from service, (3) annual teaching reviews, and (4) priority on teaching preferences.

Chemical Engineering utilization of institutional resources for student recruitment and retention: Diversity Committee members and advising staff attend quarterly meetings at the College of Engineering to engage and benefit from Graduate Opportunities and Minority Achievement Program (GO-MAP) expertise for best practices in recruiting and retaining a diverse student body. The department has a holistic application review process at the undergraduate and graduate level with heavy weighting on student essays and letters of support. Examples of departmental outreach strategies and initiatives ChemE has employed to create an environment that recruits, retains, and supports the academic success of underrepresented students of color, women, students with disabilities, and LGBTQ students are included below in Table 3. More details are provided in Appendix E.

Table 3: Representative departmental diversity activities that support recruitment and retention

Focus	Example Activities
Student recruitment	• Tabling and other recruitment activities at national conferences: SACNAS, NOBCChE, NSBE • Women's Networking Session at ChemE graduate recruitment weekend • Faculty and student participation in events for regional and national minority organizations hosted on the UW campus • Annual participation in COE Admitted Student Preview Days, Women in Science and Engineering (WiSE) mentor nights, and the STARS program
Outreach	• Creation and participation in activities for women in STEM: created "Introduce a Girl to" series in partnership with the Girl Scouts; perform demos at Expand Your Horizons, Time-to-Invent, and TechBridge events • Partner with summer research programs for URMs (UW GenOM, Clean Energy ALVA, WiSE UP-Bridge, Math Academy, LSAMP, and UW STEM Prep) to host URM students in ChemE labs. • Engagement with K-12 schools for underserved student populations via workshops, demos, science fair judging, and STEM career panels
Retention (i.e. through creating an inclusive department environment)	• One-on-one mentoring and advising with both faculty and staff advisors • Celebration of diverse student body with ChemE Pride and ChemE Veteran's Day celebrations • Foundation of Women in Chemical Engineering (est. 2016) – an RSO with the primary purpose of educating, empowering, and advocating for women in ChemE, and their supporters • Recognition of diverse student body through student stories on our website and social media platforms

Section II: Teaching & Learning

Student Learning Goals and Outcomes

Undergraduate Program: B.S. in Chemical Engineering: Our undergraduate program is ABET accredited in Chemical Engineering. The core curriculum is built around a series of Program Educational Objectives (PEOs), which fulfill the overall mission of the Department, College, and University while satisfying all of the requirements to ensure sustained accreditation by ABET. During the 2018-19 academic year, the department is undergoing ABET review and accreditation. The relevant section of our draft 2019 ABET Self Study Report — Chapter 4 – Continuous Improvement — is attached as Appendix F. This chapter includes a detailed description of the following items relevant to the operation and evaluation of our undergraduate program:

- A detailed description of UW ChemE's continuous improvement cycle for our educational programs
- A detailed description of the ABET student outcomes that we measure, a description of the performance indicators (e.g., "Can the student design a heat exchanger subject to design constraints?") used to assess the outcome, and a rubric for assessing each performance indicator alongside the course(s) where those indicators are assessed

We use the continuous improvement cycle described in Appendix F as our primary vehicle for bringing about improvements in the program via curricular changes and resource allocation. The most noteworthy example is the concerted departmental curriculum reform that took place between 2006-2012. Pages 16-17 of Appendix F describe in detail the process by which the faculty consulted key constituencies and then set about a detailed plan to increase coverage of molecular and nanoscale phenomena in our undergraduate curriculum. This involved development of new courses and labs and introducing a series of modules across nearly all of the core ChemE undergraduate curriculum.

Graduate Programs: M.S. and Ph.D. in Chemical Engineering: The department offers two tracks for entry into the graduate program. Graduate students admitted into the Ph.D. program are fully funded and carry out a series of coursework and examinations en route to the Ph.D. in order to ensure key milestones (e.g., ability to make progress in original independent research) are met. The average time to complete at Ph.D. is 5-6 years. All Ph.D. students complete an M.S. degree en route to the Ph.D. Graduate students admitted into the M.S. program all currently enter a "research track." These students are assigned to a PI and complete, at minimum, a two-quarter-long research project under the supervision of a faculty member. Around 75% of the M.S. students elect to stay for an extra year to complete a thesis M.S., which is expected to produce a significant independent research outcome (e.g., a journal publication or similar level of research).

Graduate student attrition: Over the last decade ChemE has experienced a steady, ~15% attrition rate of Ph.D. students. These figures were collected for a 2015 NSF NRT training grant

(Pfaendtner, PI) and re-verified for this report. During the 2007-2012 period, 11 Ph.D. students (3 female, 0 URM) left the program early, and from 2013 to 2018, 12 Ph.D. students (4 female, 1 URM male) left the program early. Of these 21 students, 3 could not pass their prelim exams, 5 were found to not meet research expectations and RA/TA funding was not renewed, and the remainder self-selected to leave for professional or personal reasons. All 21 earned an M.S. degree (mostly non-thesis) prior to leaving.

Instructional Effectiveness

The department places a priority on excellence in teaching and approaches this in a thoughtful and collaborative way. We measure our instructional effectiveness in the following ways:

- Assessment of each course (end of class surveys) via the UW Instructional Assessment System with a copy of the results going to the Chair
- An annual faculty peer review system in which a committee reviews the most recent offering of each undergraduate core course and provides feedback to the instructor and the faculty
- A system for assessment of undergraduate student performance conforming to the requirements of ABET, the national accreditation organization (see Appendix F)
- An assessment by the UW Office of Educational Assessment (OEA) of graduating seniors in their last quarter. An OEA facilitator divides the senior class into small groups, asking each to develop a list of program strengths and weaknesses. The facilitator then brings the groups together to discuss each list and develop consensus findings.
- Surveys of exiting graduate students administered by the Graduate School.
- New TAs must attend the annual UW TA training event. Instructors are expected to provide TAs with specific written duties and to supervise them closely. At the end of each course, the instructor submits a written TA evaluation as required by the Graduate School

In order to facilitate continuous improvement of the curriculum, our outcomes, and the faculty's capacity as instructors, we use 1-2 hours of our annual All Day Faculty Meeting to discuss student outcomes and CIDR surveys, and brainstorm together about specific areas of improvement for the upcoming academic year. Several examples of how this survey and other data inform the faculty in continuous improvement of the undergraduate curriculum and programs are provided in pages 13-17 of Appendix F.

Teaching and Mentoring Outside the Classroom

Faculty member involvement in undergraduate and graduate student learning

Undergraduate: Each faculty member serves as a mentor for 6-15 undergraduates. Undergraduates must meet with their faculty mentors at least once per quarter in order to receive permission to enroll in core courses. In their quarterly meetings with undergraduates, faculty not only advise students on course content, but they also provide guidance on careers, getting involved with research or special projects, applying to graduate school, and applying for scholarships and fellowships.

Undergraduates are strongly encouraged to participate in research, and 50% percent of a typical graduating class will have done so for at least one quarter. In most cases, such students integrate into active research teams and participate for several quarters, working closely with graduate students, postdocs, and faculty members. It is common for undergraduates to co-author a paper and present their work at conferences or competitions. In the case of special design research, teams of students participate in business case competitions and innovation challenges while being advised by their faculty member on not only engineering research but also technology commercialization. Students have also participated in research and activities involving real-world application of chemical engineering concepts. One example is a team that prepared for and then traveled to Puerto Rico to learn about how renewable energy technologies can be used to help rebuild disaster areas in resilient ways.

Our faculty also serve as advisers for student organizations, which provide even more programming and opportunities for students. Faculty advisers help those organizations connect to broader professional organizations and networks, develop leadership skills, and get involved in chemical engineering.

Graduate: Faculty involvement beyond the classroom is critical to fostering graduate student success from the pre-admission phase through graduation and beyond. To ensure that potential students understand the benefits our department has to offer, faculty participate in the graduate school fair at the AIChE meeting to make connections with prospective students. In addition, we publicize our program with a full-page listing in the annual Chemical Engineering Education "Grad Guide" and attend other conferences including NSBE, SHPE and SWE. Our departmental website is a key resource for prospective students, and we maintain comprehensive information there on our different degree programs (B.S., M.S. and Ph.D.), the application process, financial support, housing and more.

During the first autumn quarter, new students in the research M.S. program and the Ph.D. program become members of a professor's research group where they conduct original research under the guidance of a faculty mentor. In addition to the research M.S. and the Ph.D. programs, we have recently introduced a one-year non-thesis data science-focused Master of Science in Chemical Engineering. While these students do not join research groups, they will complete a faculty-led, team-based capstone project to cement their skills and build a data science portfolio.

Ensuring student success and steady academic progress

The UW chemical engineering department is committed to providing clear information regarding satisfactory progress milestones and support to help students at all levels meet those goals.

Undergraduate students: Undergraduate students are required to meet with the undergraduate adviser and their faculty mentor at least once per quarter. The faculty mentor, guided by the student's ongoing progress report, must approve the courses the student plans to take the following quarter. The department restricts access to required departmental courses until the advising meetings have occurred.

Satisfactory completion of the chemical engineering curriculum is assured by an auditing process using the progress database and by the quarterly advising meetings. Advising staff review all students individually to ensure they're staying on track to graduate with their cohort. They contact any students who have failed to meet the requirements to notify them of academic probation or being dropped from the department and to guide them through the process for appeals. Students who fail to meet the following requirements are dropped from the department, as outlined in the continuation policy:

- Students must follow the plan of study and be prepared to start our cohort-based core by taking CHEM E 310 spring quarter of the sophomore year and completing the following courses or their equivalents before autumn quarter of the junior year: CHEM 142, 152, 162, 237, 238; MATH 124, 125, 126, 307, 308; PHYS 121, 122, 123; ENGL 131 and AMATH 301 or CSE 142.
- Students must receive a minimum 2.0 grade in CHEM E 310.
- Students are placed on academic probation if they fail to maintain a minimum 2.0 quarterly GPA, cumulative GPA, and chemical engineering GPA. If they are not able to improve grades enough in the quarter they are on probation, they are dropped from the department.

In addition, in their final year, each student must file a graduation application using the UW Degree Audit Reporting System (which guarantees that all degree requirements have been met).

Graduate students: We maintain graduate student handbooks for both the M.S. and Ph.D. programs and graduate students have a 0.8 FTE graduate student adviser to clarify requirements and support students in their efforts to meet them. In addition, faculty advisers are expected to mentor their students at every stage.

The following assumes the student holds a B.S. in chemical engineering. If a student enters with another degree, the Graduate Program Coordinator defines satisfactory progress on a case-by-case basis. Our programs include the research-based M.S. (which permits a thesis or non-thesis option), the one-year non-thesis Data Science M.S. and the Ph.D.

Research M.S. and Data Science M.S. Program Satisfactory Progress Requirements:

- Explore research groups, indicate preferences and accept placement with a research adviser before the end of the first autumn quarter. M.S. students enrolled in the Data Science Track (*new for Autumn 2019*) will not be placed in research groups and instead complete a team-based capstone project.
- Complete coursework requirements with grades of 2.7 or above. Required core courses include ChemE 512, 525, 530 for all M.S. students. Research M.S. students' core courses also include ChemE 514 and 560, while data science M.S. students register for ChemE 545 and 546 instead. Research M.S. students must also complete 8 credits of electives.

- Non-thesis research M.S. students conduct research under at least 6 credits of ChemE 600 and produce a written report and presentation at the end of study
- Thesis research M.S. students must complete a project under a combination of at least 9 credits of ChemE 600 and 12 credits of ChemE 700, and write and defend a thesis
- Maintain a minimum GPA of 3.0

Ph.D. Program Satisfactory Progress Requirements:

- Explore research groups, indicate preferences and accept placement with a research adviser before the end of the first autumn quarter
- Complete at least 18 credits of graded coursework with grades of 2.7 or above. Core courses include ChemE 512, 525 and 530. Additional coursework is subject to a course breadth requirement to ensure a comprehensive education.
- Form an approved supervisory committee before the end of spring quarter of the first year
- Pass the preliminary exam on either the first or second try (no third tries are possible)
- Complete the M.S. en route to the Ph.D. between the preliminary and general exams
- Pass the general exam before the end of the third year
- Pass the final exam before the end of the sixth year
- Receive a grade of CR or 3.0 or higher in each quarter of ChemE 600 or 800 credits
- Maintain a minimum GPA of 3.0

If a student does not meet one of the above milestones, they are subject to being placed on probation. The GPC will consult with the student's committee (in the case of a Ph.D. student) or the student's PI (Master's student) to determine whether probationary status is appropriate. Once a student is placed on probation, the department provides specific requirements that the student must meet to rectify the deficiency. If a student does not return to normal status within one quarter, they are subject to being placed on final probation for a second quarter. If deficiencies remain by the end of the second quarter of probation, the department may drop the student from the program, and its financial support obligations terminate.

Preparing our students for what comes next

The chemical engineering department recognizes that students need comprehensive professional development opportunities to be fully prepared for success after graduation whether they enter academia or industry.

UW Chemical Engineering offers three highly-informative seminar series throughout the year that serve as professional development tools: the Department Seminar Series, the Leadership Seminar Series and the Distinguished Young Scholars Seminar Series. The Department Seminar Series takes place weekly during autumn, winter and spring quarters, and is geared toward graduate students. We invite a variety of academic and industrial professionals to give presentations on their areas of research and expertise. The Leadership Seminar is a one-credit seminar that serves as a forum for industrial, academic and government leaders to share their experiences and insights with primarily undergraduate students, but many graduate students attend as well. During summer quarter, our graduate students run the Distinguished Young Scholars Seminars. Speakers are Ph.D. students who are within six months of completing their doctorate, and postdoctoral scholars who have not yet accepted their first permanent position. Our graduate students took the lead to develop DYSS in 2011. They handle all facets of the series to further their own professional development and to provide the same to rising stars in chemical engineering.

Undergraduate Students: Each week, advising staff publishes a newsletter outlining announcements regarding the course of study, professional development opportunities, and other meaningful activities students can pursue during their studies. Activities promoted include campus-wide activities, those activities provided by the Career Center @Engineering, and activities identified or sponsored by the department or related research centers. Advising staff assist students throughout the year on preparing resumes, cover letters, interviews, and negotiating and managing job offers through individual appointments and drop-in hours. When discussing course choices and advising students on academics, advising staff ask about plans for after graduation and offer advice about preparing for those plans in addition to planning coursework.

Each spring, our two professional associations, AIChE and WChE, coordinate with the faculty on a Grad School Info Session intended to help students understand the purpose of graduation education, the application process, and how to write strong application materials. On an ongoing basis, faculty assist students with their application materials in one-on-one appointments.

Since approximately 85% of students wish to enter industry upon graduation, the department has taken an increasingly active position in helping them to prepare for an industrial career. We encourage undergraduates who are planning an industrial career to participate in a summer internship or six-month co-op experience. The Academic Services Director (currently Dave Drischell) coordinates with the professor teaching the first core course in the major (currently Brad Holt) on a resume/cover letter extra credit project that involves a workshop on resume writing, finding an internship to prepare materials for, and meeting individually with advising staff to revise job materials.

The department provides guidance on resumes and cover letters, career fair success, and how to effectively engage with employers through workshops and one-on-one meetings with advisers. One major professional development workshop is offered in the weeks before the two UW engineering career fairs that take place in October. A further professional development opportunity, the Fall Industry Panel, is organized by the Women in Chemical Engineering student organization. This event, which has been offered for the past three years, is comprised of several panels featuring alumni that are leaders in their respective fields of industry sharing their experiences and advice with current graduate and undergraduate students. In addition, the advising staff directly coordinate on-campus information meetings and provide interview space to better connect companies with our students.

Graduate Students: We have several active student professional organizations and seminar series intended to expose our students to the full breadth of work in their field and help them forge useful connections and skills that will benefit them after they have completed their studies. In addition, we encourage our students to attend a variety of professional gatherings.

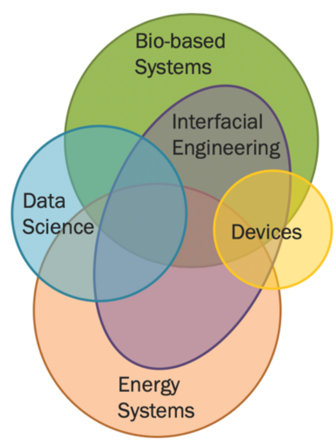
Attendance at professional conferences is essential for students to network among their current and future colleagues and to have a forum to present their own work. Our faculty frequent these conferences and encourage their students to attend as well. PIs often support grad student attendance, and many grads apply for and are granted travel funding through the UW Graduate School or the Graduate and Professional Student Association. Our students return from conferences having been recognized for their excellence in poster presentations and other talks. Some recent student conference awards include a poster award at the International Conference on Bioinspired and Zwitterionic Materials (Mary Beth O'Kelly), the Electrochemical Society Travel Grant for Hack Day and Oral Presentation Award (Yanbo Qi) and the Travel Award for the 2018 Ewha-Luce International Seminar (Brittany Bishop).

For the past eleven years, our graduate student group, the Association of Chemical Engineering Graduate Students, has run an annual Graduate Student Symposium to provide graduate students the opportunity to present their work to representatives from industry. Those industry leaders learn about the exciting work our students are conducting and make contacts that frequently turn into productive professional relationships. This symposium includes presentations and a poster session mixer. The keynote speaker is typically a prominent industry leader, whom our graduate students identify and recruit for the talk.

The student talks from the 2018 Graduate Student Symposium can be viewed by following this link, which will remain live for the duration of the 2018-19 10-year review.

Section III: Scholarly Impact

Faculty Research by the Numbers



To facilitate alignment with relevant interdisciplinary research institutes in the College of Engineering (Clean Energy Institute and Molecular Engineering and Science Institute), our faculty often align their applied research projects along the axes of *Bio-Based Systems* and *Energy Systems* (see inset, right). A major cross-cutting fundamental research theme across the department is *Interfacial Engineering*, which covers much of our molecular/nanoscale work, surface studies and reaction engineering, colloidal science, and much of the materials science work in the department. Many faculty also pursue engineering of *Devices,* and an emerging cross-cutting basic research area is *Data Science*.

Our faculty boast an accomplished portfolio of peer reviewed research complementing the research expenditures outlined in Appendix B. Since 2014[1], 395 peer-reviewed publications have been cited over 7,000 times, nearly 18 citations per item. This results in a "departmental h-index" over this period of 40. Other select accolades include:

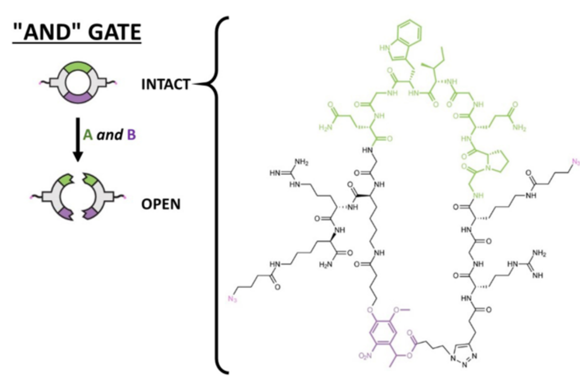
- Four faculty earned early career awards since the last 10-year review, including 2 NSF CAREER (DeForest, Pfaendtner), DOE Early CAREER (Pozzo) and a $2.5M NIH "NanoMed Inspired Young Investigator".
- Sam Jenekhe (2/3 ChemE) was recognized as a 2018 "World's Most Influential Mind" by Clarivate Analytics
- Dan Schwartz received 2018 Presidential Award for Excellence in STEM Mentoring
- Cole DeForest was selected as a 2017 "AIChE 35 under 35"

Our faculty heavily involve postdocs and students at all levels in their research. A winter 2019 survey showed the approximate involvement of trainees in ChemE faculty research to be 90 Ph.D. students (70 ChemE + 20 non-ChemE), 30 M.S. students, 20 postdocs, 80 undergrads (n.b., precise numbers are difficult to obtain due to variety of enrollment statuses, funding sources, etc.; these numbers have been rounded *down* to the nearest 10).

Faculty Research Examples and Impacts

A powerful example of a faculty member putting their research talents to work for social good is the recent work of professor Lilo Pozzo in founding and executing the Hurricane Maria Energy & Health Project. Supported by the UW Clean Energy Institute and the UW Global Innovation Fund, Pozzo has led a team of students in working with local communities in Puerto Rico affected by the 2017 devastation by Hurricane Maria. The team has been working cooperatively with the community to identify critical energy infrastructure needs and deploying microgrids based on renewable energy (solar + battery). The work is ongoing, and preliminary findings have been published in *IEEE Power & Energy Magazine*. More information can be found at: http://www.washington.edu/boundless/puerto-rico-solar/

In the area of biotechnology and biomaterials, the group of professor Cole DeForest (Cole is a 100% ChemE faculty, 5th year on tenure track) is breaking new ground in the design of programmable biomaterials that can assist in protection and repair of cells in the human body. This work was featured in a 2018 *Nature Chemistry* paper (lead author is a ChemE grad student) and received significant press coverage along with a lengthy write-up by the UW news



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1 Data were accessed from ISI Web of Science on 3/23/19 using address search "Univ Washington, Dept Chem Engn, Seattle, WA 98195 USA". Citation report generated with ISI tools.

and communications team. The work represents a new type of stimulus-responsive chemical "logic gate" (see inset). The team demonstrated that this technology can provide selective delivery of chemotherapy agents to cancer cells, and they will use this platform to develop a class of truly smart therapeutic delivery systems and tissue engineering tools with high specificity for organs, tissues or even disease states such as tumor environments.

Another example of UW Chemical Engineering faculty leading in impactful work in the *Bio-Based Systems* area can be found in the recent study by the work of professor Shaoyi Jiang in development of novel nanoparticle materials that effectively scavenge nerve agents such as sarin gas and can remain circulating in the body, undetected by the immune system, for days. The development of ultra-low fouling biomaterials in the Jiang group has led to many other technological advances, and the nerve agent study published in a 2019 *Science Translational Medicine* article received coverage in *Science News*.

In the *Energy Systems* cluster, a recent pair of 2018 grants illustrates the department's growing portfolio in *Data Science*. The group of professor Hugh Hillhouse, in collaboration with ChemE faculty David Beck and UW Statistics faculty Marina Meila, has been awarded $1.5M by the DOE Solar Energy Technology Office for the development of high throughput screening and analysis to improve the environmental stability and performance of thin film perovskite solar cells. These materials represent a potential breakthrough technology for solar energy, but further discoveries are needed in order optimize the materials for use in the real world. The team will apply statistical learning methods to the high throughput screening results in an effort to understand fundamental connections between nanoscopic and microscopic material features, and macroscopic solar cell performance and stability (learn more). Another example of applying data science tools to clean energy research is in the subaward to ChemE faculty Jim Pfaendtner and David Beck from a large DOE Bioenergy Technology Office project led by Iowa State University. The UW team will develop new methods for data mining the research literature and identifying potential lead molecules that have both desired functionality and sufficient molecular similarity with plant secondary metabolites to enable production via a hybrid biological+synthetic route.

Intersection of ChemE with Other UW Centers and Institutes

Our faculty are highly collaborative, supporting — and in many cases leading — a large number of research centers and institutions across the UW campus. A subsection of ChemE faculty involvement in campus interdisciplinary research is detailed below.

UW Clean Energy Institute: ChemE professor Dan Schwartz serves as the founding director of the UW CEI, which was founded in 2013 with state funding from the WA legislature. Through faculty hiring, research infrastructure support, seed grants, and graduate research fellowships, the CEI will accelerate our adoption of a clean energy future based on scalable, next generation solar energy and battery materials and devices. CEI research also supports integration of clean energy technologies with the energy grid and other systems.

CEI support has been hugely impactful to the ChemE department's research and teaching mission. Funds from CEI directly support the salaries of multiple ChemE faculty hires, including Venkat Subramanian (100% ChemE) and Jun Liu (1/3 ChemE, 2/3 MSE). Equipment and startup funds have led the development of core facilities in battery systems simulations (Subramanian) and the nanomaterials synthesis lab of Vincent Holmberg. A 2015 CEI Faculty Exploration and Research seed grant funded a team (led by Pfaendtner) that ultimately received a $3M training grant in the NSF National Research Traineeship program. CEI operates the NRT program as a sub-program within the CEI Graduate Fellowship Program. Finally, the number of ChemE faculty with Ph.D. students supported by CEI fellowships is enormous. A partial list includes: Adler, Hillhouse, Holmberg, Pfaendtner, Pozzo, Schwartz, Stuve, Subramanian and Yu. In fact, ChemE ranks at or near the top each year in terms of the total number of CEI graduate fellowships awarded.

UW Molecular Engineering and Sciences Institute: Closely following the impact of CEI is the UW MolES Institute. The UW MolES Institute was founded in 2011 by bioengineering faculty Pat Stayton. The physical home of the institute is the MolES Building, located near Benson Hall on campus. This building houses three current ChemE faculty (Castner, Carothers and Hillhouse), including their faculty offices and labs, as well as around half of the lab space of the Holmberg group. The institute and building were essential to the recruitment of both Carothers and Hillhouse. The MolES Institute provides intellectual leadership around the major research themes of cleantech and biotech. A weekly seminar series and interdisciplinary Ph.D. program are the main continuing elements of the institute (in addition to the space and facilities). There are currently around 10 Ph.D. students from the MolES Ph.D. program who are supported by ChemE faculty. The institute operates an essential core research facility, the Molecular Analysis Facility (MAF). This facility houses key surface analysis, spectroscopy, microscopy and biophysics core labs and is widely used by the ChemE department. Nearly all of the UW ChemE faculty are members of MolES and participate regularly in their events. Several faculty have previously held leadership positions, including Education Director (Rene Overney) and MAF Director (Dave Castner). François Baneyx was the director of the UW Center for Nanotechnology, which was integrated into the core functions of MolES/MAF in 2012.

Center for Dialysis Innovation: In 2017, Buddy Ratner (25% ChemE, 75% BioE) and Jonathan Himmelfarb (UW Nephrology) founded the Center for Dialysis Innovation with a large gift from the Northwest Kidney Centers. CDI seeks to revolutionize the treatment of patients with chronic kidney disease and funds research projects toward the goal of improving dialysis therapies. In a short time, CDI has involved a number of faculty, students and postdocs from ChemE, currently sponsoring projects in the labs of professors Jiang, Pfaendtner, Stuve and Ratner.

Molecular Engineering Materials Center (MEMC): This center is a new NSF MRSEC program led out of the Department of Chemistry by professor Daniel Gamelin. MEMC began in 2017 with the goal of improving capacity for the design and development of new complex nanomaterials across a range of applications including information processing, sensing, energy and research tools. Two UW faculty (Hillhouse and Holmberg) are member faculty in MEMC and receive research support from the center.

Center for the Science of Synthesis Across Scales (CSSAS): In 2018, François Baneyx (then ChemE Chair) assembled a team largely comprised of faculty and researchers from UW and Pacific Northwest National Lab (PNNL) to compete for a DOE Energy Frontier Research Center (EFRC). Baneyx's new center, CSSAS, was awarded over $11M over 4 years to start this interdisciplinary research program. Its research will harness the complex functionality of hierarchical materials by mastering the design of high-information-content macromolecular building blocks that predictively self-assemble into responsive, reconfigurable, self-healing materials — and direct the formation and organization of inorganic components. In addition to Baneyx, this center involves ChemE faculty Jim Pfaendtner (center thrust lead) and Sam Jenekhe.

Northwest Institute for Materials Physics, Chemistry, and Technology: Also known as NW IMPACT, this new joint effort of PNNL and UW in the aforementioned areas was started in 2018. This institute seeds collaborative research teams in a 2 UW + 2 PNNL investigator format, provides funding (on the scale of $100-$200K/project) to plan for larger team scale proposals. It also provides funding for students to work at PNNL. There have been two rounds of seed funding with two projects funded in each round. ChemE faculty including Baneyx, Holmberg and Pfaendtner have been funded, representing three of the four funded projects.

ChemE Shared Facilities that Enable Research and Teaching

This section provides a brief overview of core shared research and teaching facilities used by many of our faculty in carrying out their research and teaching mission.

Benson Hall Computer Lab: The computer lab spaces in Benson Hall are dedicated to fulfilling the computing needs of chemical engineering students, whether it be for academic purposes, industrial training, or some other capacity that advances their careers. Typical users are both graduate students and undergraduates, including sophomores admitted in the spring quarter. The Undergraduate Computer Lab houses 38 high-performing iMac desktop workstations, dual booted with Windows 10 and macOS. This combination of computing power and software flexibility greatly improves the students' ability to learn the tools that drive success after their education. Key software components include:

- aspenONE Software Suite - campus exclusive to Benson Hall
- COMSOL Multiphysics - campus exclusive to Benson Hall
- MATLAB & Simulink

John C. Berg Laboratory for Surface and Colloid Science: The Berg lab accommodates the department's course on Surface and Colloid Science (Chem E 455), which has been required of all undergraduates since 2010 [*detailed description in contextual information provided in Unit Defined Question 3]*. Representative equipment in the lab includes atomic force microscopy

(AFM), Langmuir-Wilhelmy film balance apparatus, micro-electrophoresis and dynamic light scattering.

Bindra Innovation Lab: The Bindra Innovation Lab is the main shared instrumentation facility within Chemical Engineering, providing tools for nanoparticle, thermal, chemical, and rheological analyses. There are over 80 registered users of the lab as of March 2019. The typical user is a ChemE graduate student, however several ChemE undergraduate students use the instruments for research with the guidance of a graduate student or postdoc. Ten research groups within ChemE currently benefit from using the equipment. Two research groups outside ChemE use the lab (for an hourly fee per instrument). Four start-up companies use the facility under contract. The Bindra Lab is also used for teaching Advanced ChemE Lab (ChemE 514) in winter and Polymer Chemistry (ChemE 460) lab in spring. Chemical Engineering Lab II (ChemE 437) students make use of the HPLC in winter. Key equipment components include:

- **Nanoparticle sizing by dynamic light scattering (DLS)** – Malvern Zetasizer Nano ZS, particle sizing 1 – 1000 nm, capable of time- and temperature-dependent studies
- **Zeta potential by phase-analysis light scattering (PALS)** – Malvern Zetasizer Nano ZS
- **Thermogravimetric analysis (TGA)** – TA Instruments Q50
- **Differential scanning calorimetry (DSC)** – TA Instruments Q200, glass transition, melting point, heat of melting, oxidative stability
- **High performance liquid chromatography (HPLC)** – Shimadzu Prominence, refractive index and UV-Vis detectors, chemical concentration and polymer molecular weight distribution
- **Rheology** – Anton Paar MCR301, parallel plate, storage and loss moduli
- **Microplate reader** – Molecular Devices SpectraMax M5, UV-VIS, fluorescence, luminescence
- **Laser cutter** – Universal Laser Systems M300, 50W CO_2
- **3D printer** – MakerBot Relicator 2X, two-color printing
- **Spin coater**
- **Benchtop Centrifuge** - Sorvall ST8
- **Gas Chromatograph**
- **Calorimeter** – IKA C200
- **Raman Microscope**
- **Streaming Potential/Streaming Current**

ChemE Shared Tissue Culture Facility: The Chemical Engineering Shared Tissue Culture Facility (BNS B23) provides free access and training in sterile cell culture techniques to any interested student part of ChemE or working in a ChemE-based lab. The facility features all equipment for basic mammalian cell culture, including two biosafety cabinets, a light microscope, and several incubators. The facility is heavily utilized by members of the DeForest and Nance groups, with additional usage from the Jiang and Baneyx groups. This facility was created and is actively overseen by the DeForest group.

ChemE Microscopy Facility: The Microscopy Lab, located in Benson 254, currently contains a Nikon epifluorescence scope with 4 laser lines, 3 objectives and Metamorph imaging software. Seven PIs in the department — DeForest, Nance, Jiang, Baneyx, Pozzo, Ratner and Castner _ use the microscopy facility, along with shared users in chemistry, materials science, and bioengineering. Graduate students, undergraduate students, and summer high school students have also used the facility for imaging applications related to thesis, REU, and summer program projects. The average usage per day is 6 hours, and the average number of users is ~18 per quarter.

The Microscopy Lab was renovated in 2017 to include carpet, dark wall paint, controlled lighting and space for multiple pieces of equipment. In 2019, work began on adding blackout curtains to transition a Nikon A1 confocal microscope (owned by PI Nance) into the room. In addition, Nance submitted a $250K (Direct) equipment supplement request to purchase a spinning disk confocal from Nikon.

Promotion, Tenure and Mentoring

The guidelines for promotion and tenure of the chemical engineering faculty mirror those specified by the UW College of Engineering and Faculty Code. Since 1997, there has been a formal set of ChemE P&T guidelines to provide some additional guidance as to the standards of our department (see 2009 10-Year Review, Appendix N, provided by the UW Graduate School and on the 2019 10YR file sharing site). Our P&T standards largely follow those of peer institutions, placing a strong emphasis on scholarship and teaching activities for promotion to associate professor with tenure, and increasing the emphasis on research scholarship, especially recognition at the international level, for promotion to full professor.

Due to the general atmosphere of congeniality and support in the department, previous chairs have operated an informal mentoring system, consistent with that described in the 2009 10-Year Review document. At the time of hiring, the chair assigns a senior faculty as a mentor with an implicit assumption that the junior faculty will seek mentorship when needed, and that the senior faculty will occasionally check in and follow the progress of the junior faculty member. An informal survey of the last six tenure-track faculty showed that this system has mixed results, with extremes ranging from “I was not assigned a mentor” to “scheduled lunches at least one a month, usually more.”

The current ChemE chair has implemented a more hands-on mentoring approach. All current assistant professors are asked to meet with the chair on a regular basis, hopefully once per month. This is scheduled by the assistant to the chair to reduce the burden on the junior faculty. The purpose of the meetings is to identify areas where the department can help in research, teaching or any other matter. In addition, it is a useful opportunity to discuss expectations for promotion and tenure (as appropriate). All new assistant professors will be assigned a mentoring committee of two faculty with clear expectations for a quarterly meeting (scheduled and facilitated by the senior faculty) and a brief annual report to the chair.

Section IV: Future Directions

This section reviews the major research and teaching strategic direction (molecular/nano principles) that was highlighted in the last 10 year review (2009) and briefly discusses where we are taking it as a department. Following that, a department initiative in the area of entrepreneurship and innovation in chemical engineering is discussed. From 2012–2015, the department ran a Graduate Assistance in Areas of National Need (GAANN) grant in, which supported launching our work in this (primarily) educational initiative. Finally, since 2017, the department has been pursuing a strategic initiative (primarily research and graduate education) at the nexus of data science and chemical engineering. The ChemE+DS initiative is discussed below. This section concludes with a few brief remarks about possible future directions, including a rapidly emerging opportunity in the area of Quantum Information Science (QIS).

Molecular and Nanoscale Principles

The last 10-year review (2009 ChemE 10-Year Review, Appendix F) provided a detailed roadmap for the department's strategic initiative to capitalize on its strengths in molecular and nanoscale principles. This included a near-total revamp of several of our undergraduate courses, as well as the development of specific modules within all of the undergraduate content. The basic value proposition of the initiative was that a ChemE curriculum focusing on nanoscale principles and molecular engineering would complement our significant research portfolio in this area and prepare our students for changing employment opportunities. Appendix F of this document contains a selected excerpt (in draft form) of our 2019 ABET self-study. The reader is referred to section 4D2 for a thoughtful narrative on the process by which the ChemE faculty executed this wholesale curriculum reform.

Current status: The concepts of molecular engineering and nanoscale principles are now thoroughly embedded in the fabric of our entire department. In addition to the successful curriculum reform (now part of our regular ABET and departmental review cycle), our faculty hiring has been very focused on faculty who bring a strong molecular/nano focus to their research. Since the last 10-year review, the following tenure-track faculty have been added to the department: Pfaendtner, Hillhouse, Carothers, DeForest, Holmberg, Subramanian, Nance, Yu, Liu (1/3). With the exception of Subramanian (who was part of a battery systems focused hire within CEI), all of these faculty have brought unique dimensions to our molecular/nanoscale research focus; their applications span both the *Bio-Based Systems* and *Energy Systems* thrusts (n.b., Liu joined in Feb 2019, but brings a strong battery materials focus, aligned with the nanomaterials area). In searching for new faculty, it is noteworthy that this strong emphasis on molecular engineering and nanoscale phenomena nearly always emerges in the discussion of candidates' research and teaching interests.

Entrepreneurship and Product Design

Motivated by shifts in employment for chemical engineering graduates (i.e. decreased manufacturing employment and increased R&D, high-tech, consulting and product development), in 2012 professor Dan Schwartz proposed an alternative capstone design project sequence to serve a fraction of seniors interested in learning about chemical product design and technology-based entrepreneurship. The new course sequence would focus on instruction of the fundamentals of chemical product design, and it would extend over a period of three quarters (i.e. all of senior year). The sequence, which consists of 10 total credits (3 research and 7 design credits), would serve as an alternative to the traditional senior capstone design project (ChemE 486, 4 credits, spring quarter). Participating students would engage in hands-on chemical product design activities including: problem definition, background research, ideation/brainstorming, product specification, laboratory research, prototyping, market analysis, business planning, scale-up calculations, regulatory framework analysis, intellectual property, technology roadmapping and competitive landscape analysis. Participating students would continue to enroll in the first process design course (ChemE 485), which provides deep instruction in process design principles and economics, but they would not need to enroll in the capstone design project (ChemE 486) if they completed the ChemE 497 sequence.

Table 4: Entrepreneurial design topics by year

Team Name	Year	Umbrella Topic	Project Description
Pallicera	2018-19	Sustainability	Design of emulsion-based pediatric drug formulations with taste-masking capabilities
PuriCake	2018-19	Sustainability	Urinal tablets for adsorption and breakup of dissolved drugs in hospitals and geriatric centers
ElectroSolar Oxygen	2018-19	Sustainability	System design for efficient electrochemical oxygen production through solar energy in remote clinics
DermaDot	2017-18	Data Science	Image analysis for medical diagnosis of skin allergens using mobile devices (telemedicine)
GreenFeed	2016-17	Sustainability	Sustainable aquaculture feed from supermarket waste
SwarmFX	2016-17	Sustainability	Unmanned vehicles equipped with firefighting capabilities (joint ChemE–Aerospace Capstone Project)
DecafStyle	2015-16	Food technology	Design of in-cup decaffeination ‘tea-bags’ based on selective absorption beads
SiliCar9	2014-15	Open	Development of silica-based affinity purification of proteins

In the initial year (2012), four seniors participated in the new course. Since then, the ChemE 497 sequence has engaged between 5 and 15 students each year out of a total of 60-75 students enrolled in the graduating senior classes (typically 10-20% participation). Since 2012, the course experienced multiple variations and fine-tuning to improve the educational experience. For example, over a period of three years (2013-2016), the program involved graduate students as team-members and mentors to the undergraduate students via funding from a GAANN grant through the Department of Education. In recent years, undergraduate seniors and juniors have been paired up in cross-class teams in order to work on longer-term projects and to encourage inter-class interactions. Juniors participate in the teams for research credit (ChemE 499) and need to enroll in the capstone course sequence during their senior year to obtain credit. In 2016-17, an interdisciplinary team of ChemE and Aerospace Engineering students (SwarmFX) also participated jointly in the capstone design experience. Table 4 shows several examples of teams and the topics of their capstone design project with a short description. The course was designed with flexibility in mind and it continues to evolve as new opportunities for capstone design projects become available. More recently, the framework has also been applied to some industry-sponsored design projects (e.g. Novo Nordisk).

Course Structure:
In spring quarter, an orientation on the course sequence is provided to sophomores and juniors who are invited to apply for participation in the next academic year. Students complete an application that includes a short statement of interest and a CV. Selection is made on the basis of their motivation for participation and also their academic standing in the department. Given that this course sequence is more time-demanding than the course it replaces, students with poor academic standing are less likely to be selected.

- **Fall:** In early fall, project topics are presented to students and groups of 4–6 are formed. Each year, the topical umbrella theme for projects changes (e.g. food tech, data science, sustainability). Students are not provided with explicit project formulations. Rather, they need to identify opportunities on their own through brainstorming and analysis sessions. The objective for fall quarter is for students to arrive at the product idea that will become the focus of their capstone project for the rest of the year. Students enrolled in fall quarter do so for research credit (ChemE 499). At the end of the quarter, groups are also given an opportunity to discontinue the course sequence if they are unable to identify/formulate a project and/or if the group has a difficult time working together. Grading in fall is based on student’s participation and contributions as assessed via weekly meetings with the instructor, weekly memos and an individual final report of activities.
- **Winter:** During winter quarter senior students enroll in 497 for 3 credits and focus their work on product specification, prototyping and initial business planning. Teams are provided with prototyping funds through the College of Engineering, the ChemE department and the Buerk Center for Entrepreneurship. Teams use dedicated laboratory work space and meeting spaces, and can also access all shared research instrumentation within ChemE and externally (e.g. makerspaces across campus). During this time, students also produce rough initial business plans and materials to enter one or more technology competitions such as the Hollomon Health Innovation Challenge, the Alaska Airlines Environmental Innovation Challenge and the Foster School Business Plan Competition. Deliverables for winter include a preliminary group report and an individual activity report. No grades are provided during winter, a final grade for all 7 credits is provided at the end of spring quarter.
- **Spring:** During spring quarter (ChemE 497, 4 credits), students finalize prototypes; pitch their products and ideas in public forums to established entrepreneurs, industry representatives and investors at one or more of the competitions; and continue to work on finalizing their chemical product designs. Work at this stage focuses more on evaluation of process/product economics, pricing, scale-up planning, IP protection (if applicable) and technology development. Groups also work on the final report, which includes a compilation of documents that they have been producing throughout the year. Although the report primarily focuses on group work, it also includes one or more

sections that are ‘owned’ by individual students. This is used to provide individual assessment of a student’s design capabilities. Students also evaluate their peers, and this allows us to assess individual students’ abilities to work in groups. Final grades for both spring and winter quarters are provided at the end of the project.

Current status and outcomes: Overall the experience has been very well received by our students; they have consistently rated the course highly. Moreover, ChemE students used this experience as a catalyst for developing careers in entrepreneurship. Several team projects have also turned into real student-run technology ventures procuring significant external funding. Importantly, graduates of the Special Design Program have continued to stay involved in the department years after graduation providing internship opportunities to ChemE students, research collaborations with ChemE faculty and advising on strategies to further improve the program.

Future challenges: The most significant challenge in this course sequence is the instructional cost that comes with one-on-one and small group advising by faculty. The relatively low number of student contact hours is deceptive: the amount of effort the faculty must invest in the success of the students is disproportionally high due to the large variance in the subject matter and variety of projects. This currently limits the capacity of the program to less than 15 students per year. The sustainability and growth of the course sequence would require increased participation of faculty to properly mentor more teams. Fortunately, over the past few years, capacity has tracked well with the student demand. However, if the ChemE program grows significantly and/or student interest in Special Design increases abruptly, it is almost certain that some students would be underserved.

Nexus of Data Science and Chemical Engineering

The following excerpt is from a vision statement written by Jim Pfaendtner during the selection process of the current chair (Autumn 2018). It is meant to guide the 10-year review committee in understanding ChemE’s response to the opportunities presented by the current moment.

The field of chemical engineering is at a crossroads. In our research we face an increasing number of data-related challenges, ranging the spectrum from the exciting (*our students are figuring out ways to enable high-throughput processing of large data sets*) to the mundane (*how should a new ChemE research center share data to maximize collaboration*). In the classroom we are met with a growing number of students who are enthusiastic to learn about the intersection of data science and our profession, but we must balance new offerings with the requirements of a credit-intensive degree program. I believe this challenge to be far more existential than the "bio" or "nano" waves of the previous two or three decades. While chemical engineers have always generally been very strong at the application of mathematics, the use of the computer as a research instrument in our field has been often relegated to those with expertise in "simulation" or "modeling." Today, advances in computer speed, cheap storage and memory, and free software have placed a new suite of tools, applicable across a huge spectrum of research and teaching, at our fingertips. If we do not adapt, our field risks stagnation due to our failure to 1) maintain a competitive edge by participating in cutting-edge research, 2) win new resources to run our departments and programs, and 3) attract and retrain top students in our classrooms and labs, because the top jobs are going to students with different degrees.

Risk and opportunity are two sides of the same coin, and the benefits of successfully leading a transition into a data centric ChemE profession are immense. I believe there is no better place in the country to make this vision a reality. We are very fortunate to be in a leading tech city and on a campus that has shown tremendous leadership nationwide in the development of a data science ecosystem (e.g., eScience Institute and the Data Science Studio) to support departments such as our own in rising to the challenge of transitioning our field from a data-*limited* to a data-*enabled* worldview.

ChemE has identified the applications of data science as pervasive and highly relevant to its strategic growth in the coming years. Inspired by recent success in faculty research and student training stemming from Beck's participation as a co-PI on a 5-year NSF IGERT program (2013–2018) and Pfaendtner's leadership as a PI on a 5-year NSF NRT (successor to IGERT) (2016–2021). Beck (lead author) and Pfaendtner (senior corresponding author) defined the nexus of data science and chemical engineering in a 2016 AIChE Journal perspective article (link). These early experiences have helped refine our thinking about the key contributions we can make in the area and what are concrete next steps that we can take. The 2016–17 academic year and autumn of 2017 served as a planning period for the department to identify a number of concrete steps to establish leadership in this space, enhance our research portfolio, and expand our teaching and opportunities for our students.

Current status: Bringing data science into the graduate curriculum was a logical first step given the tremendous resources provided by the two aforementioned training grants. Graduate students can now select a variety of pathways to acquire data science training, and there are two different credentialed "options" available for our students. The "Data Science Option" is a 3-course sequence directly stemming from the NRT program that is based in the chemical/materials sciences. This academic year, we have initiated a soft launch of a "DS Track" Chemical Engineering M.S. degree — a traditional non-thesis ChemE degree paired with our 3-course "Data Science Option." For students who wish further training, there is an additional "Advanced Data Science Option," consisting of advanced DS coursework offered outside the department (primarily in CSE and Statistics).

The centerpiece of the ChemE contribution to this graduate coursework is the 3-class sequence: ChemE 545/546/547. The first two courses, taught concurrently, are the meat of the program:

basic principles of scientific software development in Python in the context of Molecular Data Science (546), and a survey of modern data science methods taught in the context of molecules and materials (545). More information can be found on our course website (link). The capstone projects are taught as a 3-credit independent study in 547. The most recent formal evaluation of the NRT program is attached to this document (Appendix G) as an evidence base of the efficacy of our implementation of the new training program.

The additions to the graduate coursework have proven to be extremely popular. Over the past two years, 14 graduate students (12 M.S., 2 Ph.D.) have graduated with a "ChemE Data Science" designation on their degree. In March 2019, there were an additional 29 graduate students (12 M.S., 17 Ph.D.) enrolled in our graduate programs and pursuing a DS designation.

The faculty are in active discussions about possible next steps for integration of data science within the ChemE curriculum. Due to the very short time we have with undergraduate students (spring of sophomore year to graduation), there are very real concerns about overcrowding more content into this window that could potentially take away from the ChemE core. We are taking a "wait and see" approach to understand if there is rising interest in the ChemE DS track as a 5th-year option for our students, and we are also exploring ways to develop an "engineering data science" identity at the college level, possibly building some of this curriculum into the freshman/sophomore years.

With regard to research and faculty, during the 2017–18 academic year, the department invested in several "seed funding" projects to support the data science initiative. These included promoting student participation an industry-based capstone project with Novo Nordisk to exploratory projects developing new undergrad Unit Ops lab modules. Autumn 2018 brought $2M in new funding to ChemE faculty Beck, Hillhouse and Pfaendtner (described in Section III). And there are additional ongoing data science related projects in the groups of Nance, Pozzo and Schwartz. Our faculty search this year specifically focused on hiring in the data science area, and at the time of submission of the self-study, two faculty were considering offers (1.0 ChemE faculty and a 0.0 ChemE / 1.0 Biology hire). Both bring significant experience and interest to ChemE data science. At the time of writing this document, Pfaendtner and Beck have been converging on leading a focused "engineering data science" effort (heavily involving ChemE) that will cover two fronts: a collaborative effort with PNNL's new Data Model Convergence"laboratory initiative, as well as joining the UW eScience Institute to compete for team and center funding under NSF's Harnessing the Data Revolution program.

Planning for What's Next

We expect that in another 3-4 years, it may be time to renew a broad discussion with the faculty about defining our research mission and direction. The faculty have already had some preliminary discussions about possible next directions. With the launch of the National Quantum Initiative in 2017, there has been growing enthusiasm around the area of quantum information sciences (QIS). Several efforts across UW are underway, with some preliminary involvement from ChemE. Holmberg is serving on the UW QuantumX steering committee and brings expertise in quantum effects in nanomaterials. Pfaendtner services an additional role as Associate Vice Provost for Research Computing, which encompasses supporting joint research computing efforts with PNNL. Together with counterparts from Microsoft and PNNL, the three institutions have launched the Northwest Quantum Nexus, which we expect to grow a large research and teaching portfolio in the coming years, hopefully involving multiple ChemE faculty.

Part B: Unit-Defined Questions

As needed, additional information is described below each of the unit-defined questions. In many cases the information has been presented in Part A of this document, and reference to the relevant sections is provided.

1. How can the department make its data science initiative a success?

   No additional information provided, please refer to relevant background information provided in Part IV of Section A of this report, subtitle "Nexus of Data Science and Chemical Engineering".

2. What other research and educational directions should the department pursue to distinguish itself and provide opportunities for its students?

   No additional information provided.

3. Laboratory experiences are an important component of the Chemical Engineering education. How can the department maintain, grow, and improve these experiences?

   To assist the 10 Year Review Committee, we asked each faculty member who is teaching an undergraduate or graduate lab course to prepare a short writeup about the current status, outcomes and challenges of their lab-based teaching.

4. How can the department sustain and improve its entrepreneurial design program?

   No additional information provided, please refer to relevant background information in Part IV of Section A of this report, subtitle "Entrepreneurship and Product Design"

Part C: Appendices

The appendices are uploaded onto the main 10-Year Review file sharing site

Appendix A: Organizational Chart

Appendix B: Budget Summary

Appendix C: Information About the Faculty

Appendix D: Advisory Board and Agendas

Appendix E: 2018-19 Departmental Diversity Report

Appendix F: DRAFT of 2019 ABET Self-Study Report: Section 4 Continuous Improvement

Appendix G: Copy of 2018 Evaluation Report of the Data Science NRT Program

Appendix H: Brief Vignettes of ChemE Laboratory Classes

Appendix I: Additional requested materials