CASE SCHOOL OF ENGINEERING

Engineering seeks to create new processes, products, methods, materials, or systems that impact and are beneficial to our society. To enable its graduates to lead the advancement of technology, the Case School of Engineering (http://engineering.case.edu) offers thirteen degree programs at the undergraduate level (eleven engineering degrees, plus the BS in computer science and the BS in data science and analytics). At the post-graduate level, the School of Engineering offers Master of Science programs and the Doctor of Philosophy for advanced, research-based study in engineering. The Case School of Engineering offers two specialized degrees at the master's level: a Master of Engineering specifically for practicing engineers, and an integrated Master of Engineering and Management jointly administered with the Weatherhead School of Management. The Case School of Engineering offers Graduate Certificates which provide an introductory graduate level understanding in the fields of Wireless Health, Wireless Health Product Development, Health Information Technology, Security in Computing, Mobility-Driven Computing and Wearable Computing. The Case School of Engineering also offers two dual-degrees at the graduate level jointly administered with the School of Medicine: a Doctor of Medicine/Master of Science and a Doctor of Medicine/Doctor of Philosophy. The faculty and students participate in a variety of research activities offered through the departments and the interdisciplinary research centers of the university.

At the core of its vision, the Case School of Engineering seeks to set the standards for excellence, innovation, and distinction in engineering education and research prominence.

Statement of Educational Philosophy

The Case School of Engineering prepares and challenges its students to take positions of leadership in the professions of engineering and computer science. Recognizing the increasing role of technology in virtually every facet of our society, it is vital that engineering students have access to progressive and cutting-edge programs stressing five areas of excellence:

- Mastery of fundamentals
- Creativity
- Societal awareness
- Leadership skills
- Professionalism

Emphasizing these core values helps ensure that tomorrow's graduates are valued and contributing members of our global society and that they will carry out the tradition of engineering leadership established by our alumni.

The undergraduate program aims to create life-long learners by emphasizing engineering fundamentals based on mathematics, physical, and natural sciences. Curricular programs are infused with engineering innovation, professionalism (including engineering ethics and the role of engineering in society), professional communications, and multi-disciplinary experiences to encourage and develop leadership skills. To encourage societal awareness, students are exposed to and have the opportunity for in-depth study in the humanities, social sciences, and business aspects of engineering. Undergraduate students are encouraged to develop as professionals. Opportunities include the Cooperative Education Program, on-campus research activities, and participation in the student chapters of professional societies. Graduates are prepared to enter the workforce and be strong contributors as practicing engineers, or continue for advanced study in engineering.

At the graduate level, the Case School of Engineering combines advanced classroom study with a rigorous independent research experience leading to significant results appropriate for publication in archival journals and/or presentation at leading technical conferences. Scientific integrity, engineering ethics, and communication skills are emphasized throughout the program.

Brief History

The Case School of Engineering was established on July 1, 1992, by an action of the Board of Trustees of Case Western Reserve University as a professional school dedicated to serving society and meeting the needs of industry, government and academia through programs of teaching and research.

The Case School of Engineering continues the tradition of rigorous programs based on fundamental principles of mathematics, science and engineering that have been the hallmark of its two predecessors, the Case School of Applied Science (1880) and the Case Institute of Technology (1947). The formation of the Case School of Engineering is a re-commitment to the obligations of the gift of Leonard Case, Jr., to serve the citizens of Northern Ohio. The Case School of Engineering has been a leader in many educational programs, being the first engineering school to offer undergraduate programs in computer engineering, biomedical engineering, polymer engineering, and systems and control engineering.

Accreditation

The following Bachelor of Science programs are accredited by the Engineering Accreditation Commission of ABET, www.abet.org (http://www.abet.org):

- Aerospace Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Electrical Engineering
- Engineering Physics
- Materials Science and Engineering
- Mechanical Engineering
- Polymer Science and Engineering
- Systems and Control Engineering

The following Bachelor of Science program is accredited by the Computing Accreditation Commission of ABET, www.abet.org (http://www.abet.org):

- Computer Science

Enrollment Statistics by Degree Program (Fall 2012 through Fall 2016). Data reflects sophomore, junior and senior declared Majors.

CSE Degree Program	Fall 2012	Fall 2013	Fall 2014	Fall 2015	Fall 2016
Aerospace Engineering	102	106	96	97	113
Biomedical Engineering	323	369	407	435	394
Chemical Engineering	92	123	145	175	183
Civil Engineering	48	48	52	58	67
Computer Engineering	41	36	58	54	56
Computer Science (BA and BS)	129	146	194	229	281
Electrical Engineering	91	79	84	118	131
Engineering undesignate	0	0	1	0	0
Engineering Physics	13	15	23	24	28
Materials Science and Engr	23	38	48	53	52
Mechanical Engineering	188	244	274	291	309
Polymer Science and Engr	32	43	61	73	73
Systems and Control Engr	13	12	14	15	18

Graduation Statistics by Degree Program (AY 2012-13 through AY 2016-17)

CSE Degree Program	2012-13	2013-14	2014-15	2015-16	2016-17
Aerospace Engineering	30	31	23	38	28
Biomedical Engineering	92	87	68	106	125
Chemical Engineering	33	34	30	54	67
Civil Engineering	20	13	19	16	21
Computer Engineering	13	19	7	15	24
BA in Computer Science	19	17	21	16	35
BS in Computer Science	26	27	26	43	65
Electrical Engineering	30	38	27	31	43
Engineering (Undesignated)	0	0	0	0	0
Engineering Physics	4	5	4	4	11
Materials Science and Engr	6	7	7	17	15
Mechanical Engineering	62	69	83	95	102
Polymer Science and Engr	10	11	13	24	29
Systems and Control Engr	3	5	4	6	3

Degrees Granted

Bachelor of Science in Computer Science (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext)

Bachelor of Arts in Computer Science (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext) (granted by the College of Arts and Sciences and administered by the Department of Electrical Engineering and Computer Science)

Bachelor of Science in Data Science and Analytics

Bachelor of Science in Engineering with the following major field designations:

- Aerospace Engineering (http://bulletin.case.edu/schoolofengineering/mechaeroeng/#undergraduatetext)
- Biomedical Engineering (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/#undergraduatetext)
- Chemical Engineering (http://bulletin.case.edu/schoolofengineering/chemicalengineering/#undergraduatetext)
- Civil Engineering (http://bulletin.case.edu/schoolofengineering/civilengineering/#undergraduatetext)
- Computer Engineering (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext)
- Electrical Engineering (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext)
- Engineering Physics (http://bulletin.case.edu/schoolofengineering/engineeringphysics)
- Materials Science and Engineering (http://bulletin.case.edu/schoolofengineering/materialsscienceengineering/#undergraduatetext)
- Mechanical Engineering (http://bulletin.case.edu/schoolofengineering/mechaeroeng/#undergraduatetext)
- Polymer Science and Engineering (http://bulletin.case.edu/schoolofengineering/macromolecularscieng/#undergraduatetext)
- Systems and Control Engineering (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext)

Bachelor of Science in Engineering (Undesignated) (http://bulletin.case.edu/schoolofengineering/engineeringundesignated) (for

programs that emphasize interdisciplinary areas or for programs that include some emphasis on non-technical fields)

Bachelor of Science in Engineering/Master of Engineering

Bachelor of Science in Engineering/Master of Science

- Aerospace Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Computing and Information Science
- Electrical Engineering
- Materials Science and Engineering
- Mechanical Engineering
- Polymer Science and Engineering/Macromolecular Science and Engineering
- Systems and Control Engineering

Master of Engineering (practice-oriented program)

Master of Engineering and Management

Master of Science with the following major field designations:

- Aerospace Engineering (http://bulletin.case.edu/schoolofengineering/mechaeroeng/#graduatetext)
- Biomedical Engineering (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/#graduatetext)
- Chemical Engineering (http://bulletin.case.edu/schoolofengineering/chemicalengineering/#graduatetext)
- Civil Engineering (http://bulletin.case.edu/schoolofengineering/civilengineering/#graduatetext)
- Computer Engineering (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#graduatetext)
- Computing and Information Science (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#graduatetext)
- Electrical Engineering (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#graduatetext)
- Macromolecular Science and Engineering (http://bulletin.case.edu/schoolofengineering/macromolecularscieng/#graduatetext)
- Materials Science and Engineering (http://bulletin.case.edu/schoolofengineering/materialsscienceengineering/#graduatetext)
- Mechanical Engineering (http://bulletin.case.edu/schoolofengineering/mechaeroeng/#graduatetext)
- Systems and Control Engineering (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#graduatetext)

Master of Science with the following major field designations and *optional track*:

- Biomedical Engineering:
  -Translational Health Technology
  -Wireless Health
- Electrical Engineering:
  -Wearable Computing
  -Wireless Health
- Macromolecular Science and Engineering:
  -Fire Science and Engineering
- Mechanical Engineering:
  -Fire Science and Engineering

Master of Science (Undesignated) (http://bulletin.case.edu/schoolofengineering/engineeringundesignated)

Doctor of Medicine/Master of Science

- Biomedical Engineering

Doctor of Philosophy with the following major field designations:

- Aerospace Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Computing and Information Science
- Electrical Engineering
- Macromolecular Science and Engineering
- Materials Science and Engineering
- Mechanical Engineering
- Systems and Control Engineering

Doctor of Medicine/Doctor of Philosophy with the following major field designations:

- Biomedical Engineering
- Mechanical Engineering

Engineering Minors

Students enrolled in other majors may elect to pursue a minor. The minor program advisor's approval is required. The successful completion of a minor will be indicated on a student's transcript. For a full list of engineering and university minors, go to the Office of Undergraduate Studies (https://case.edu/ugstudies/programs-requirements/majors-minors) website.

List of Minors

Engineering Minors

- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Computer Science
- Electrical Engineering
- Materials Science and Engineering
- Polymer Science and Engineering
- Systems and Control Engineering

University Minors

- Artificial Intelligence (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext)
- Applied Data Science (http://bulletin.case.edu/schoolofengineering/materialsscienceengineering/#undergraduatetext)
- Computer Gaming (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext)

- Mechanical Design and Manufacturing (http://bulletin.case.edu/schoolofengineering/mechaeroeng/#undergraduatetext)

Bachelor of Science in Engineering

In addition to the major department requirements, each engineering undergraduate degree program includes the Engineering Core (Engineering General Education Requirements), which provides a foundation in mathematics and sciences as well as aspects of engineering fundamentals for programs in engineering. The Engineering Core is also designed to develop communication skills and to provide a body of work in the humanities and social sciences. Requirements of the Engineering Core can be found in the Undergraduate Studies (http://bulletin.case.edu/undergraduatestudies/csedegree) section of this bulletin.

Details of the specific curricular requirements for the undergraduate majors are described in the respective departmental descriptions. Details of the requirements of the undesignated engineering undergraduate degree are described under the Engineering Undesignated description.

Bachelor of Science in Engineering/ Master of Science (http://bulletin.case.edu/schoolofengineering/(http://%20engineering.case.edu/current-students/%20academic-programs/bs-ms)

The integrated B.S./M.S. program is intended for highly motivated and qualified undergraduate students who wish to pursue an advanced degree. Students admitted to the program may, in the senior year, take up to nine credits of graduate courses that will count toward both B.S. and M.S. requirements.

Master of Science

Students who have received a B.S. degree in engineering or computer science from the Case School of Engineering, and who are accepted for admission into the Master of Engineering (M.E.) degree program within a period of 24 months after graduation, are entitled to transfer up to 6 credit hours of course work from their B.S. degree to their M.E. degree program.

The courses to be considered for transfer should be specified at the time of application to the M.E. program, and require approval by the director of the Master of Engineering Program and the Dean of Engineering. Once approved, a request for an internal transfer of credit will be sent to the Registrar, and these courses will be included in the student's planned program of study for the M.E. degree.

Master of Engineering

The Master of Engineering Program is a graduate degree program that targets engineers currently employed in industry. The objective of this program is to provide engineers in industry with technical as well as business, management, and teamwork skills. The program differs from a traditional Master of Science degree in engineering by combining core courses that focus on the engineering-business environment and technical elective courses that concentrate on contemporary industrial practice rather than on research.

The Master of Engineering Program prepares students to enhance their role as corporate leaders and provides an environment in which practicing engineering professionals can address the increasingly wide range of technical, management, financial and interpersonal skills demanded by an ever-expanding and diverse global industry base.

The Master of Engineering Program requires 30 credit hours of course work that include 18 credit hours of core courses and 12 credit hours of technical electives that are chosen from focus areas (see below). It is possible to complete the Master of Engineering degree program within a two-year (six semester), part-time, program of study, although most students choose to complete the program over a seven-nine semester period.

The program is composed of both online and traditional on-campus classes, with core courses aimed at equipping participants with knowledge on how engineering is practiced in contemporary industry, and technical electives that provide depth in a chosen specialty area. All core courses are provided in an exclusively online format. The technical elective sequences for Biomedical Engineering (EBME), Engineering Innovation, Management and Leadership (EIML), Mechanical Engineering (EMAE) and Systems & Control Engineering (SCS) are also in an online format. Other technical elective courses are held on campus in the late afternoon or evening hours, and in an online distance-learning format to minimize disruption at the workplace and home. Because the program makes extensive use of computers, participants need to have access to computer facilities.

The Master of Engineering degree is also available exclusively online. Visit online-engineering.case.edu/masters/ for more details.

Curriculum

The program consists of a set of six core courses and a four course technical elective sequence (a total of 30 credit hours are required). The core courses provide a common base of study and experience with problems, issues, and challenges in the engineering business environment. The technical course sequence provides an opportunity to update disciplinary engineering skills and to broaden interdisciplinary skills. Up to six transfer credits may be approved for graduate-level courses taken at Case Western Reserve or another accredited university.

Core Courses

EPOM 400	Leadership and Interpersonal Skills	3
EPOM 401	Introduction to Business for Engineers	3
EPOM 403	Product and Process Design and Implementation	3
EPOM 405	Applied Engineering Statistics	3
EPOM 407	Engineering Economics and Financial Analysis	3
EPOM 409	Master of Engineering Capstone Project	3
Total Units		18

Technical Electives

Four courses are chosen from the technical concentration areas below. For detailed course offerings in these areas, please refer to the Master

of Engineering (http://www.engineering.case.edu/meng) program information on the Case School of Engineering website.

- Biomedical Engineering
- Chemical Engineering
- Computer Engineering
- Infrastructure Engineering
- Macromolecular Science and Engineering
- Materials Processing and Synthesis
- Mechanical Engineering
- Robotics and Control
- Software Engineering
- Signal Processing and Communications

Master of Engineering and Management

The Master of Engineering and Management (MEM) program provides the business context and leadership skills needed to uniquely position graduates for rapid advancement in technology based organizations. This interdisciplinary, joint degree program combines the problem solving rigor of the Case School of Engineering and the organizational insights of the Weatherhead School of Management in a 12 month, lock-step program focused on delivering the high impact talent companies are actively seeking. This program evolved after years of research and interviews with over 110 professionals and twenty-eight corporations across the U.S. Students can enter this program after their junior year or upon graduation.

The Program

The program includes 42 credit hours of graded course work. The 11-course core sequence makes up 33 of the required credit hours. For the remaining 9 credit hours, students can choose from any 400 level engineering course for which prerequisites are met or from the list below. The program prepares participants to function as technical leaders with a unique blend of broadened engineering and management skills which can have strategic impact on an organization's bottom line.

Required Core Courses (33 credit hours)

IIME 400	Leadership Assessment and Development (LEAD)	3
IIME 405	Project Management	3
IIME 410	Accounting, Finance, and Engineering Economics	3
IIME 415	Materials and Manufacturing Processes	3
IIME 420	Information, Design and Systems	3
IIME 425	Understanding People and Change in Organizations	3
IIME 430A	Product and Process Design, Development, and Delivery I	3
IIME 430B	Product and Process Design, Development, and Delivery II	3
IIME 435	Enterprise Resource Planning in the Supply Chain	3
IIME 440	Six Sigma and Quality Management	3
IIME 450 Technology Entrepreneurship (Fall 2017)		3
Total Units		33

Elective Courses (9 credit hours)

A total of 9 credit hours, typically 3 courses, may be chosen from 400 level engineering courses or from the approved courses listed below.

IIME 446	Models of Health Care Systems (*)
IIME 447	Regulatory Affairs for the Biosciences (*)
IIME 470	Independent Projects
IIME 472	BioDesign
IIME 473	Fundamentals of Clinical Information Systems
IIME 475	Technology Marketing Strategy
BAFI 444	Entrepreneurial Finance
DSCI 451	Exploratory Data Science
EBME 440	Translational Research for Biomedical Engineers
EECS 474	Advanced Control and Energy Systems
ENTP 428	Entrepreneurship and Innovation
HSMC 412	Lean Services Operations
HSMC 421	Health Economics and Strategy
MGMT 467	Commercialization and Intellectual Property Management
MKMR 408	Marketing Metrics
OPMT 475	Supply Chain Logistics
ORBH 450	Executive Leadership
ORBH 491	Leadership in Diversity and Inclusion: Towards a Globally Inclusive Workplace

*courses are 1.5 credit hours and are generally taken together in one semester.

Master of Science

Recognizing the different needs and objectives of resident and non-resident graduate students pursuing the master's degree, two different plans are offered. In both plans, transfer of credit from another university is limited to six hours of graduate-level courses, taken in excess of the requirements for an undergraduate degree, approved by the student's advisor, the department chair, and the dean of graduate studies.

All Master of Science degree programs require the submission of a Planned Program of Study via the Student Information System where it will be routed for appropriate approvals. Students must submit an approved program of study by the end of the second semester. A revised program of study must be submitted via the Student Information System when any change in the original plan occurs.

Master's Thesis Plan (Plan A)

Minimum requirements for the degree of Master of Science in a major field under this plan are:

1. Completion of 18 hours of graduate course work at the 400 level or higher. The courses must be approved by the department offering the degree.
2. Completion of nine hours of thesis work culminating in a thesis examination given by at least three professors, plus approval by the chair of the department offering the degree. A student with

research experience equivalent to a thesis may petition the Graduate Committee of the Case School of Engineering for substitution of nine hours of course work for the thesis requirement. In this case, the thesis examination above is replaced by a similar examination covering the submitted research work and publications.

Master's Comprehensive Plan (Plan B)

Students may pursue either a project or non-project track under this option. Minimum requirements for the degree of Master of Science in a major field under this plan are one of the following:

Project track

Completion of 27 hours of graduate course work at the 400 level or higher, including three to six hours of Special Problems. Special Problems course work must consist of an engineering project approved by the chair of the department offering the degree, and may be carried out at the student's place of employment with nominal supervision by a faculty advisor or in the school's laboratories under direct supervision. The project must culminate in a written report and examination by at least three professors plus approval by the chair of the department offering the degree. The Special Problems course may be waived for students who have had industrial design or research experience and who submit sufficient evidence of this experience in the form of a publication or internal report. For these students, a minimum of 27 hours of course work and the final oral examination covering the submitted publications or reports as well as related course material will be required for the master's degree.

Non-project track

Completion of 27 hours of graduate course work at the 400 level or higher, not including Special Problems course work, must, also, pass satisfactorily a comprehensive examination to be administered by the department or curricular program committee. The examination may be written or oral, or both. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master's Comprehensive Exam before taking the examination.

Distance Education

The Case School of Engineering offers five graduate degree programs exclusively online, giving working engineers the opportunity to advance their careers from anywhere.

Specialized online degrees (http://online-engineering.case.edu) are available in the following disciplines:

- Master of Engineering (https://online-engineering.case.edu/masters)
- Master of Science in Biomedical Engineering (https://online-engineering.case.edu/biomedical)
- Master of Science in Mechanical Engineering (https://online-engineering.case.edu/mechanical)
- Master of Science in Civil Engineering (https://online-engineering.case.edu/civil)
- Master of Science in Systems & Control Engineering (https://online-engineering.case.edu/systems)

The programs are designed for working professionals and can be completed in fewer than two years. All courses are taught by the same world-renowned faculty who teach graduate students on campus. With the same in-depth, rigorous content delivered in a convenient online format, students who participate in the online programs receive the same robust education and training as traditional on-campus master's students.

Learn more and apply. (https://online-engineering.case.edu)

Additional Distance Learning Opportunities

In addition to the online-exclusive programs, the Case School of Engineering offers select classes in its campus-based graduate degree programs in a convenient online format designed for students who need additional flexibility.

Learn more about available online courses. (http://engineering.case.edu/current-students/distance-learning/registration)

Doctor of Medicine/Master of Science (http://casemed.case.edu/admissions/education/dual_programs.cfm?program_id=11)

Medicine is undergoing a transformation based on the rapid advances in science and technology that are combining to produce more accurate diagnoses, more effective treatments with fewer side effects, and improved ability to prevent disease. The goal of the MD/MS in Engineering is to prepare medical graduates to be leaders in the development and clinical deployment of this technology and to partner with others in technology based translational research teams.

For further information, see the MD/MS Program in the Biomedical Engineering graduate section of this bulletin (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/#graduatetext). Interested students should apply through the biomedical engineering department.

The student's PhD program should be designed to prepare him or her for a lifetime of creative activity in research and in professional engineering practice. This may be coupled with a teaching career. The mastery of a significant field of knowledge required to accomplish this purpose is demonstrated by an original contribution to knowledge embodied in a thesis and by satisfactory completion of a comprehensive course program which is intensive in a specific area of study and includes work in other areas related to, but not identical with, the major field. The necessity for breadth as well as depth in the student's education cannot be overemphasized. To this end, any engineering department may add additional requirements or constraints to ensure depth and breadth appropriate to its field.

No student may be admitted to candidacy for the PhD degree before approval of his or her Planned Program of Study via the Student Information System. After this approval has been obtained, it is the responsibility of the student's department to notify the dean of graduate studies of his or her admission to candidacy after the student has fulfilled any additional department requirements. Minimal requirements in addition to the university requirements are:

1. The minimum course requirement beyond the BS level is 36 credit hours of courses taken for credit, at least 18 hours of which must be taken at Case Western Reserve University. The following courses taken for credit will be acceptable for a PhD program of study:
   i. All 400-, 500-, and 600-level courses
   ii. Approved graduate-level courses taken at other institutions

2. A minimum depth in basic science equivalent to six semester hours (for credit) is required. This requirement is to be satisfied by courses that have been previously approved by the faculty of the department in which the student is enrolled.
3. The requirement for breadth is normally satisfied by a minimum of 12 semester hours of courses (for credit) outside the student's major area of concentration as defined by the student's department and does not include courses taken to fulfill the basic science requirement.
4. A minimum of three teaching experiences as defined by the student's department. All programs of study must include departmental 400T, 500T, and 600T courses to reflect this requirement. All students fulfilling teaching duties must complete UNIV 400A or UNIV 400B.
5. The minimum requirement for research is satisfied by at least 18 hours of thesis (701) credits.
6. A cumulative quality-point average of 3.0 or above in all courses taken for credit as a graduate student at Case Western Reserve University (excluding grades in thesis research and grades of R) is required for the award of the doctoral degree.

Qualifying Examination

The student must pass a qualifying examination relevant to his or her area of study as designated by the curricular department with which he or she is affiliated. For students who obtain the MS degree from Case Western Reserve University, the qualifying examination should be taken preferably before the end of the student's fourth semester of graduate study but no later than the end of the fifth semester at the university. For students entering with the master's degree, the examination should be taken no later than the end of the third semester at the university.

Planned Program of Study

Each student is required to submit a Planned Program of Study, detailing his or her course work, thesis schedule, and qualifying examination schedule and indicating that all the minimum requirements of the university and the faculty of the Case School of Engineering are satisfied. This Planned Program of Study must be submitted via the Student Information System for approval before registering for the last 18 credits hours of the program.

If the student is pursuing the PhD degree without acquiring the MS degree, a petition to waive the requirement of the MS degree should be approved by the departmental advisor and the chair and submitted to the dean of graduate studies. All required courses taken at the university beyond the BS degree should be shown on the Planned Program of Study with the grade if completed. If the requirements are to be fulfilled in ways other than the standard described above, a memorandum requesting approval should be submitted to the dean of graduate studies.

The Planned Program of Study must be submitted within one semester after passing the qualifying examination.

Doctor of Medicine/Doctor of Philosophy (http://mstp.case.edu)

Students with outstanding qualifications may apply to the MD/PhD program. Students interested in obtaining a combined MD/PhD, with an emphasis on basic research in biomedical engineering or mechanical engineering, are strongly encouraged to explore the Medical Scientist Training Program (MSTP), administered by the School of Medicine. For further information, please see the Medical Scientist Training Program (MSTP) in the School of Medicine section of this bulletin. Interested students should apply through the MSTP office in the Medical School.

Graduate Certificates

Graduate Certificates are discipline independent and intended to enable knowledgeable entry into the field of study. They are prescribed 3-course, 9-credit subsets of our MS degree offerings

- **Wearable Computing**
- **Wireless Health**

For more details, please refer to the Graduate Certificate (http://engineering.case.edu/sandiego/gc) information on the Case School of Engineering - San Diego website.

Interdisciplinary research centers act as intensive incubators for students and faculty doing research and studying applications in specialized areas. Research centers and research programs at the Case School of Engineering have been organized to pursue cutting-edge research in collaboration with industrial and government partners. The transfer of technology to industry is emphasized in all the centers.

The educational programs of these centers encompass the training of graduate students in advanced methods and strategies, thus preparing them to become important contributors to industry after graduation; the involvement of undergraduates in research; the presentation of seminars that are open to interested members of the community; and outreach to public schools to keep teachers abreast of scientific advances and to kindle the interest of students in seeking careers in engineering.

Advanced Manufacturing and Mechanical Reliability Center (AMMRC)

White Building (7205)
Phone: 216.368.4234
John J. Lewandowski, Director
john.lewandowski@case.edu

The Advanced Manufacturing and Mechanical Reliability Center (AMMRC) was established to provide advanced manufacturing (e.g. deformation processing, extrusion, forming, etc.) and mechanical characterization (e.g. mechanical testing, reliability testing, fatigue, etc.) expertise to the CWRU campus, medical, industrial, legal, outside university, and government laboratory communities. The center, housed in the Charles M. White Metallurgy building, currently maintains equipment valued in excess of $4.5M and has been accessed by the local, national, and international communities. The CWRU campus community can access the facility via the use of a valid CWRU university account number that will be charged at an internal rate for machine time, including set up and any technician time involved. Long term testing can be provided at pro-rated charges in consultation with the center directors. Arrangements can be made to train users on the equipment and reserve time for equipment use by contacting the center co-director. Outside (i.e. non-CWRU) users can access the facility via a number of different mechanisms by contacting the center director.

In general, the center is capable of mechanically evaluating and deformation processing materials that range in size scale from the micrometer range up through bulk quantities. This unique facility enables mechanical characterization at loading rates as low as one micrometer/

hour (i.e. rate of fingernail growth!) up through impact (e.g. 3-4 meters/sec) at temperatures ranging from -196C (i.e. liquid nitrogen) up to 1400C. Hot microhardness testing up to 1000C is available. Monotonic as well as cyclic fatigue testing is possible in addition to evaluations of mechanical behavior and processing with superimposed pressures up to 2 GPa. Novel high-rate and multiple-deformation sequence forging simulations are possible with the use of a multi-actuator forging simulator, in addition to sheet metal forming experimentation with independent control of forming rate and blank hold down force. Hot extrusion is also possible at temperatures up to 900C on 0.5" diameter billets. Materials systems that have been investigated span the range of organic and inorganic materials, including metals, ceramics, polymers, composites, electronic materials, and biomedical materials systems. Descriptions of specific equipment and capabilities are provided with the website link.

Advanced Platform Technology (APT) Center

Louis Stokes Cleveland Veterans Affairs Medical Center
10701 East Boulevard, Mail Stop 151 W/APT
Cleveland, Ohio 44106
Phone: 216.707.6421 Fax: 216.707.6420
Ronald J. Triolo, Executive Director
ronald.triolo@case.edu

The Advanced Platform Technology (APT) Center at the Louis Stokes Cleveland Veterans Affairs Medical Center (LSCVAMC) is one of 13 designated Centers in the Rehabilitation Research and Development Service. The APT Center focuses on serving veterans with sensorimotor dysfunction, cognitive impairment, or limb-loss using cutting edge technologies and rehabilitation techniques, translating them from proof of concept to viable clinical options. Advances in material science, microfabrication and microsystem design, neural engineering, mechanics and communications are captured and integrated for applications in prosthetics/orthotics, neural interfacing, wireless health monitoring and maintenance and all forms of enabling and emerging technologies. The APT Center is able to provide or facilitate access to the following resources:

1. Neural modeling and analysis of interface designs
2. Polymer and bioactive material development
3. Microelectromechanical (MEMS) systems design and fabrication
4. 3-D and laser printing/prototyping, mechanical testing and dynamic simulation
5. Pre-clinical *in vitro* and *in vivo* verification of device performance
6. Circuit, sensor and software design and fabrication
7. System validation and design control documentation
8. Professional engineering support and project management
9. Administrative support for intellectual property protection, regulatory affairs, and quality systems

The APT Center was established in 2005 as a collaboration between the LSCVAMC and Case Western Reserve University (CWRU). Over 50 Engineers and Clinician Scientists at the LSCVAMC, CWRU, Cleveland Clinic, University Hospitals, Cleveland State University, Kent State University, University of Michigan, and Cornell University are affiliated with the APT Center and contribute to its mission.

Case Metal Processing Laboratory (CMPL)

113 White Building
Phone: 216.368.5070 Fax 216.368.3209
Matthew A. Willard, Faculty Director
matthew.willard@case.edu

The CMPL houses state-of-the-art, melting and casting capabilities for a wide range of ferrous and non-ferrous alloys. The facility is a unique combination of laboratory and industrial scale equipment. Research projects with federal and industrial support are carried out by teams of faculty, graduate and undergraduate students. Manufacturing of castings are from Computer Aided Design, flow and solidification simulation, rapid prototyping, molding to melting and casting. Provides hands-on experiential learning opportunities for engineering students in laboratory classes and summer research programs.

- Industrial UBE 350 Ton Vertical Squeeze casting machine for casting high integrity parts
- 350kW/1000MHz Inductotherm solid-state melting power supply with furnaces up to 1,500 lb. steel
- 50 lb. vacuum melting and casting furnace driven by a new 35kW/10kHz Inductotherm power supply
- Sand molding and sand testing equipment
- Permanent molds for casting test bars and evaluation of molten metal quality
- Foseco rotary degasser for non-ferrous alloys
- Lindberg 75 kW electrical melting furnace for 800 lb. of aluminum
- Denison four post, hydraulic 50 ton rapid acting squeeze caster
- Squeeze casting tooling with preheatable dies
- Equipment for melting and casting magnesium alloys
- Computer modeling workstations with flow and heat transfer finite element software
- Thermal Fatigue Testing Units for cyclical immersion in molten aluminum (Dunkers)
- Centorr vacuum heat treating furnace

Center for Advanced Polymer Processing (CAPP)

Kent Hale Smith Building, 3rd floor
Phone: 216.368.6372 Fax 216.543.4202
Joao Maia, Director
joao.maia@case.edu

CAPP is a state-of-the-art center for advanced polymer blending and compounding and reactive extrusion at CWRU able to perform basic research and applied research and development in support of the Ohio and US plastics industry. The main tools of CAPP are:

- State-of-the-art sensors that allow multiple rheological, physical, chemical and morphological quantities to be measured along the screw axis of twin-screw extruders;
- Advanced multi-scale computational simulation capabilities to build physical-chemical-structural models of polymer systems under flow in realistic polymer transformation processes;
- Integration of on-line sensors and multi-scale softwares to develop new advanced and functional multiphase complex materials or optimize the performance of existing ones.

Center for Biomaterials

202 Wickenden Building (7207)
William Marx, Interim Director

william.marx@case.edu

Anirban Sen Gupta, Associate Director
Phone: 216.368.4564
anirban.sengupta@case.edu

The Center for Biomaterials carries out research and development projects to investigate new biomaterials, tissue engineered materials, and targeted drug delivery systems for use in cardiovascular applications and implants. The Center for Biomaterials also provides researchers access to shared use facilities, which includes high resolution microscopy such as AFM, molecular spectroscopies, surface analysis, and polymer and peptide synthesis capabilities. The chemical and mechanical interface between the biomaterial and the host tissue are the focus of major study, with the goals being to improve biologic function and biocompatibility in the response of the human body to implants. Current projects include investigation of thrombosis (blood clotting) and infection mechanisms due to cardiovascular prosthesis, biomimetic design of novel biomaterials for cardiovascular and neural implants; and cardiovascular and neural tissue engineering based on biomimetic designs. Studies at the cell and molecular level assist our understanding of the underlying mechanisms so that novel biomedical materials may be designed, prepared, and characterized.

Center for Computational Imaging and Personalized Diagnostics (CCIPD)

Wickenden Building Room 523
Phone: 216.368.8519
Anant Madabhushi, Director
anant.madabhushi@case.edu

The Center of Computational Imaging and Personalized Diagnostics at Case Western Reserve University is involved in various different aspects of developing, evaluating and applying novel quantitative image analysis, computer vision, signal processing, segmentation, multi-modal co-registration tools, pattern recognition, and machine learning tools for disease diagnosis, prognosis, and theragnosis in the context of breast, prostate, lung, head and neck, and brain tumors. The group is also exploring the utility of these methods in studying correlations of disease markers across multiple length scales, modalities, and functionalities - from gene and protein expression to spectroscopy to digital pathology and to multi-parametric MRI and CT.

Center for Dielectrics and Energy Storage (CDES)

312 Kent Hale Smith Building
Phone: 216.368.5861
Lei Zhu, Director
lxz121@case.edu

CDES mission is to discover, develop, and translate novel dielectric technologies for energy storage and capacitor applications. Researching high energy density, high temperature, and low loss dielectric film capacitors, we integrate these innovations with storage devices, hybrid electric vehicles, multi-megawatt power conditioning, pulsed power, and high energy physics applications. Originating from the Center for Layered Polymeric Systems (CLiPS), a National Science Foundation Science and Technology Center focusing on research, innovation, and education through a unique multilayer film technology, CDES extends this technology into new energy frontiers.

CDES has access to state-of-the-art equipment, which includes process equipment for fabricating, stretching, and testing dielectric films, including:

- Novocontrol Concept 80 Broadband Dielectrics Spectrometer
- Radiant Premier II Ferroelectric Tester
- Bruckner Kato IV Biaxial Stretcher

In addition to research, CDES plays a significant role in educating undergraduate students, graduate students, and post-doctoral associates to work in advanced energy material fields.

Center for the Evaluation of Implant Performance

Wearn Building Room 511
Phone: 216.844.1745
Clare Rimnac, Director
clare.rimnac@case.edu

The mission of the Center for the Evaluation of Implant Performance is to pursue engineering and scientific analysis of retrieved joint reconstruction devices and to evaluate the performance of implants during patient use. This mission is achieved through IRB-approved collection, maintenance, and protection of clinical and radiographic information and total joint replacement components obtained at revision or removal surgery. The goal is to advance the science of joint replacement durability and improved performance for better patient outcomes through improvements in implant materials and design. To this end, the Center for the Evaluation of Implant Performance works in partnership with the Center for Joint Replacement and Restoration at University Hospitals Case Medical Center.

Center for Layered Polymeric Systems (CLiPS)

NSF Science and Technology Center
420 Kent Hale Smith Building (7202)
Phone: 216.368.4203 Fax 216.368.6329
Eric Baer, Director
eric.baer@case.edu

CLiPS researchers and educators work together to accomplish the Center's mission of advancing the nation's science and technology agenda through development of new materials systems and for educating a diverse American workforce through interdisciplinary education programs.

CLiPS research focuses on exploration of multilayered polymeric systems at the micro- and nano-layer levels and has revealed unique properties and capabilities that are different, and often not predicted, from systems involving the same materials on a larger scale. Technology refined within CLiPS allows the production of films and membranes composed of hundreds or thousands of layers. These extremely thin layers promote interactions approaching the molecular level between the materials used in the process.

The research activities are organized into five platforms to exploit the microlayer and nanolayer structures: (1) **Rheology and New Processing** focuses on integrating rheology into the multilayering process, and will explore combinations of rheologically dissimilar materials to create new polymer-based structures; (2) advanced **Membranes and Transport Phenomena** that exploit the layered

hierarchy to achieve unique transport properties; (3) novel **Optic and Electronic Systems** based on the advanced layered materials; (4) **Science and Technology Initiatives** that probe a fundamental understanding and explore new opportunities for the layered structures; and (5) **Templated Interfaces and Reactions** looking at polymer materials that are amenable to patterning and ordering, and exhibit a specific field response. Of particular interest are polymer systems and nanomaterials that are appropriate for biological applications.

CLiPS was established in 2006 with funding by the National Science Foundation as a Science and Technology Center. It is the first NSF STC ever to be established at Case Western Reserve University. CLiPS is a national center involving close partnership with the University of Texas, Fisk University, the University of Southern Mississippi, and the Naval Research Laboratory, and an important educational partnership with the Cleveland Metropolitan School District.

Cleveland Functional Electrical Stimulation Center (FES)

10701 East Boulevard, Cleveland, Ohio 44106
Phone: 216.231.3257 Fax: 216.231.3258
Robert J. Kirsch, Executive Director
info@FEScenter.org

Functional Electrical Stimulation (FES) is the application of electrical currents to either generate or suppress activity in the nervous system. FES can produce and control the movement of otherwise paralyzed limbs, for standing and hand grasp; activate visceral bodily functions, such as micturition; create perceptions such as skin sensibility; arrest undesired activity, such as pain or spasm; facilitate natural recovery; and accelerate motor relearning. FES is particularly powerful and clinically relevant, since many people with neurological disabilities retain the capacity for neural conduction and are thus amenable to this intervention. The center focuses its activities in four major areas:

- Fundamental studies to discover new knowledge
- Enabling technologies for clinical application or the discovery of knowledge
- Clinical research that applies this knowledge and technology to individuals with neurological dysfunction
- Transfer of knowledge and technology to the clinical community and to industry.

The FES Center was established as a VA RR&D Center of Excellence in 1991 and is based at the Louis Stokes Cleveland VAMC (VAMC). The center is a consortium with four institutional partners: VAMC, Case Western Reserve University (CWRU), the MetroHealth Medical Center (MHMC), and University Hospitals of Cleveland (UHC). The center accomplishes its mission by integrating and facilitating the efforts of scientists, engineers, and clinicians through common goals and directions in the major clinical areas, and by providing mechanisms to accomplish these goals across the institutional partners.

Control and Energy Systems Center (CESC)

Olin Building, 6th Floor
Phone: 216.368.5122
Mario Garcia-Sanz, Director
mario@case.edu

Website: http://cesc.case.edu

With an interdisciplinary and concurrent engineering approach, the Control and Energy Systems Center (CESC) focuses on bridging the gap between fundamental research and applied industrial projects in Advanced Control and Systems Engineering, with special emphasis in energy innovation, wind energy, power systems, water treatment plants, sustainability, spacecraft, environmental and industrial applications. Fundamental research is conducted to gain knowledge and understanding on multi-input-multi-output systems, distributed parameter systems and nonlinear plants with uncertainty, and to develop new methodologies to design quantitative robust controllers to improve the efficiency and reliability of such systems.

The CESC's expertise has been applied to real-world problems with industrial partners and space agencies in the following main areas:

- Multi-Megawatt Onshore and Offshore Wind Turbines
- Airborne Wind Energy Systems
- Renewable Energy Plants, Advanced Energy Systems
- Power System Dynamics and Control, Grid Integration, Energy Storage
- Large Radio Telescope Control, Optical Telescope Control
- Formation Flying Spacecraft, Satellites with Flexible Appendages
- Wastewater Treatment Plants, Desalination Systems
- Heating Systems, Fluid Dynamics
- Robotics, Parallel Kinematics

The CESC's capabilities and equipment include:

- Fully instrumented wind tunnel to test prototypes at wind speeds up to 20 m/s
- Lab-scale wind turbine blade manufacturing units
- State-of-the-art computer programs for commercial wind turbine design
- Aerodynamics, Solid modeling and Electrical design CAD/CAE software
- Advanced software to design robust QFT control systems
- Software for analysis and simulation of dynamic systems
- Multiple laboratory scale wind turbines with a variety of collinear and orthogonal rotors, electrical generators, gearboxes, sensors, actuators and hierarchical real-time torque/pitch/yaw control systems
- Lab-scale wind farms with flexible configurations
- Fully-controlled 6-DOF Stewart platform for lab-scale Floating Wind Turbine experimentation
- Laboratory helicopter to test advanced control systems

Electronics Design Center (EDC)

112 Bingham (7200)
Phone: 216.368.2935 Fax: 216.368.8738
Chung-Chiun Liu, Director
chung-chiun.liu@case.edu

The Electronics Design Center (EDC) is a multi-disciplinary educational and research center focusing on the applications of microfabrication processing to the advancement of chemical and biological micro-systems specializing in application-oriented electrochemical based biosensors. The center has complete thick film and thin film processing facilities, including screen printing, ink jet printing and sputtering

equipment. Other facilities supporting the microfabrication processing are also readily available. The EDC is a resource for industrial and academic researchers, offering access to equipment, laboratories and trained staff.

Great Lakes Energy Institute (GLEI)

305 Olin Building (7074)
Phone: 216.368.0748
Alexis Abramson, Director
alexis.abramson@case.edu

The Great Lakes Energy Institute empowers faculty, students and partners to catalyze breakthroughs in energy sustainability that address the most pressing problems facing our world. Since 2008, GLEI has helped catalyze a five-fold increase in energy research, won awards from NSF, DOE, (ARPA-E, EERE, OE), Ohio Third Frontier and other organizations, attracted over $80 million in awards, worked with over 100 different industry partners, and encouraged multidisciplinary proposals throughout the university. At the heart of these efforts are over 90 engaged faculty, hailing from engineering, arts & sciences, management, and law. And while GLEI's work supports all types of energy, the focus lies in five priority areas:

Future Power - CWRU's energy program is underpinned by research in power systems. Strengths in controls, sensors, and electronics provide a core foundation for smart grid connectivity of energy and storage.

Energy Storage - Storage research builds on historical strengths in electrochemistry, materials and lifetime and degradation science. Recent research awards include ARPA-E and DOE.

Solar - Research in next generation photovoltaics (PV) focuses on organics and lifetime and degradation science, stemming from a strong reputation in materials, research, and development.

Wind Energy - Wind energy emphasizes offshore deployment and is founded on wind and ice measurement, controls, power management, and grid interface expertise. Much of this work is supported by DOE awards and the State of Ohio.

Oil and Gas - Research focuses on technologies that enhance safe extraction, transport and processing of shale gas and oil in Ohio. Strengths are present in macromolecules, sensors, corrosion-resistant casings, cementitious materials, and modeling and simulation of hydro-fracking process.

The role of CWRU in energy also touches economic development and education. Through research and investment, university spin-outs are poised to contribute to a new energy economy while working toward a clean and sustainable future. Students undertake key roles in the research and commercialization of the energy technologies contributing to worldwide impact.

Materials for Opto/Electronics Research and Education Center (MORE)

616 White Building (7204)
Phone: 216.368.4007
Ina Martin, Director
ina.martin@case.edu

The Materials for Opto/Electronics Research and Education (MORE) Center advances science and innovation with facilities and expertise enabling the fabrication and characterization of materials and devices for emerging electronic and optoelectronic technologies, including solar cells and lighting. Located in the Charles M. White Metallurgy Building, the MORE Center is a hub for undergraduate and graduate research, education, and collaboration. The center has 30 tools available for both direct use and service work; in addition to a suite of thin film deposition options, the MORE Center has large-area profilometry, ellipsometry, mechanical testing, and microscopy characterization tools, a cleanroom facility, electron and photolithography capabilities, and inert gloveboxes for work with air-sensitive materials.

Established in 2011, the MORE Center has amassed over 300 users from 30 research groups across the College of Arts and Sciences, the Case School of Engineering, and the CWRU School of Medicine. The MORE Center is open to internal and external academic and industrial users.

Microfabrication Laboratory (MFL)

342 Bingham Building (7200)
Phone: 216.368.6117 Fax: 216.368.6888
Christian Zorman, Director
christian.zorman@case.edu

MFL houses a state-of-the-art facility that provides the latest in microfabrication and micromachining processes. The laboratory focuses on the applications of microfabrication and micromachining technology to a wide range of sensors, actuators and other microelectromechanical (MEMS) systems. In addition to silicon based technology, the laboratory has a unique strength in silicon carbide micromachining that is particularly valuable for applications in harsh environments. To support the development of flexible microsystems, polymer micromachining is also available. Undergraduate students, graduate students, and post-doctoral assistants use the laboratory's facilities to carry out their research or special projects.

Researchers not affiliated with CWRU can also use the laboratory through a facilities use agreement.

National Center for Space Exploration Research (NCSER)

21000 Brookpark Rd., MS 110-3
Phone: 216.433.5031
Mohammad Kassemi, Director
mohammad.kassemi@case.edu

The National Center for Space Exploration Research (NCSER) is a collaborative effort between the Universities Space Research Association (USRA), Case Western Reserve University (CWRU), and NASA Glenn Research Center (GRC) that under the NASA Advanced Research and Technology Service (ARTS) contract provides GRC with specialized research and technology development capabilities essential to sustaining its leadership role in NASA missions. Expertise resident at NCSER includes reduced gravity fluid mechanics, reduced gravity combustion processes; heat transfer, two-phase flow, micro-fluidics, and phase change processes; computational multiphase fluid dynamics, heat and mass transfer, computational simulation of physico-chemical fluid processes and human physiological systems. This expertise has been applied to:

- Cryogenic fluid management
- On orbit repair of electronics
- Spacecraft fire safety

- Exploration life support
- Energy storage
- Dust management
- Thermal management and control
- Environmental monitoring/control
- ISS experiment development Integrated system health monitoring
- Astronaut health
- Planetary Surface Mobility
- In situ resource utilization
- Materials synthesis
- Bio-fluid mechanics
- Biosystems modeling
- Fluid-Structural-Interaction and tissue mechanics in physiological systems.

Neural Engineering Center (NEC)

112 Wickenden (7207)
Phone: 216.368.3974 Fax: 216.368.4872
Dominique Durand, Director
dominique.durand@case.edu

The research mission of the center is to bring to bear combined tools in physics, mathematics, chemistry, engineering and neuroscience to analyze the mechanisms underlying neuronal function and to solve the clinical problems associated with neuronal dysfunction. Research areas include: Neuromodulation, Neuroprostheses, Quantitative Neurophysiology, Neural Dynamics, Neuro-Mechanical Systems, Neural Regeneration, Neural Interfacing, Neural Imaging and Molecular Sensing, Neuro-Magnetism, and Systems Neuroscience. The education mission of the center is to provide engineers and scientists with an integrated knowledge of engineering and neuroscience capable of solving problems in neuroscience ranging from the molecules to the clinic. The center is also an outlet for technology transfer of new ideas to be commercialized by industrial partners. The center's goals are accomplished by fostering interdisciplinary research between clinicians, scientists, students and local industry, educational experiences including didactic material, laboratory experience and clinical exposure, and close ties to industrial partners.

Nitinol Commercialization Accelerator (NCA)

White Building (7205)
Phone: 216.368.4234
John J. Lewandowski, Director
john.lewandowski@case.edu
James D. McGuffin-Cawley, Co-Director
David Schwam, Co-Director

The Ohio Third Frontier Wright Projects Program has funded the Nitinol Commercialization Accelerator (NCA), a collaborative effort between the Cleveland Clinic, CWRU, University of Toledo, NASA Glenn Research Center, and Norman Noble, Inc. in order to develop a better understanding of the metallurgical processing and mechanical characterization of nitinol for use in biomedical and aerospace applications. Biomedical applications range from orthodontia to implantable devices while higher temperature shape memory alloys are of interest for aerospace. The collaboration is designed to create synergy amongst collaborators in the research and development of nitinol products.

The laboratory housed at CWRU's Material Science and Engineering Department contains processing and characterization (thermal and mechanical) equipment that allows for the manufacture and analysis of nitinol products. Processing equipment includes a vacuum arc casting unit, vacuum heat treatment system, and hot extrusion capabilities. Thermal characterization equipment includes a high temperature Differential Scanning Calorimeter (DSC) while mechanical characterization equipment for testing wire/foil includes a number of flex bending fatigue machines, rotary bending fatigue machines, and tabletop tension testing machines.

The Cleveland Clinic and NASA Glenn Research Center also house equipment associated with the NCA program including: Raydiance-Rofin Femtosecond Laser, Techne FB-08 Precision Calibration Bath, MTS Cryo-chamber and Grips, and an Aramis/Optotrak Certus 3D Strain Mapping system.

SDLE Research Center

Labs: White Building, 5th Floor / Sun Farm: CWRU West Campus
Phone: 216.368.3655/216.368.0374
Roger H. French, Director
roger.french@case.edu

Christopher Littman, Business Development Director & Operations Manager
christopher.littman@case.edu

The SDLE Research Center was established in 2011 with funding from Ohio Third Frontier, and is dedicated to advancing the field of lifetime and degradation science. The research center activities focus on durability and degradation of environmentally exposed, long lived materials and technologies such as photovoltaics (PV), energy efficient lighting, and building envelope applications. The Center develops real-time and accelerated protocols for exposure to solar radiation and related environmental stressors to enable the evaluation of the environmental durability and lifetime of materials, components, and products. Data scientists identify statistically significant relationships using a data analytics platform (Energy-CRADLE) developed in the center. Researchers perform post-exposure optical and thermo-mechanical measurements to develop quantitative mechanistic models of degradation processes. The SDLE Research Center's capabilities and equipment include:

- Outdoor solar exposures: SunFarm with 14 dual-axis solar trackers with multi-sun concentrators, and power degradation monitoring
- Solar simulators for 1-1000X solar exposures
- Multi-factor environmental test chambers with temperature, humidity, freeze/thaw, and cycling
- A full suite of optical, interfacial, thermo-mechanical and electrical evaluation tools for materials, components and systems

Swagelok Center for Surface Analysis of Materials (SCSAM)

110 Glennan Building
Phone: 216.368.3868
Frank Ernst, Faculty Director
frank.ernst@case.edu

Amir Avishai, Director
amir.avishai@case.edu

The Swagelok Center for Surface Analysis of Materials is one of Case Western Reserve University's largest core facilities, providing a variety of instrumentation for microstructural and compositional characterization of materials as well as surface and near-surface chemical analysis. A staff of professionals are available to assist and train academic researchers and commercial users of the Center's equipment. Fully trained users are permitted independent access to the instruments, while users with particularly difficult samples or those who are unsure how to obtain the best possible data can utilize the services of staff experts. Some of the routine services offered include guidance with sample preparation, technical assistance to obtain data, and data analysis. Additionally, the expert staff are available to meet with research groups to assist with acquiring data needed for proposal submission as well as consulting and developing methods tailored to fit specific research needs.

The Center is administered by the Case School of Engineering and used by undergraduate students, graduate students, post-doctoral researchers. SCSAM instruments are utilized by more than 40% of the Engineering School's faculty as well as researchers from the College of Arts and Sciences, the School of Medicine and the Dental School. Further, the Center serves as a micro-characterization hub for over 100 external commercial and non-profit entities, including the NASA Glenn Research Center, the Cleveland Clinic, numerous Ohio universities, and over 70 industrial R&D laboratories. Combined internal and external usage of the Center exceeds 250 users each year. Instruments are housed in a centralized area, allowing convenient access to the equipment and expert knowledge to provide state-of-the-art solutions.

ANALYTICAL SERVICES

Electron Microscopy

- FIB-SEM (Focused ion beam / scanning electron beam microscopy), including XEDS (X-ray energy-dispersive spectroscopy), EBSD (electron backscatter diffraction), TKD mapping (transmission Kikuchi diffraction), 3D imaging and reconstruction.
- TEM (transmission electron microscopy), including scanning TEM, XEDS, EELS (electron energy-loss spectrometry), and high-resolution grain orientation mapping using a TopSpin system.

Surface Analysis Scanning

- Scanning Auger microprobe.
- XPS/ESCA (X-Ray photoelectron spectrometry).
- ToF-SIMS (Time-of-flight secondary ion-mass spectrometry).

Other Methods

- Scanning probe microscopy, including AFM (atomic force microscopy) and MFM (magnetic force microscopy).
- Light-optical microscopy.
- XRD (X-Ray diffractometry).
- Nanomechanical testing, including nanohardness, nanoscratching, and nanowear testing.
- Ion polishing.
- Nanomill post-preparation of TEM specimens.
- Semi-automated metallographic specimen preparation.

A detailed equipment list and description are available at http://engineering.case.edu/centers/scsam/.

Wind Energy Research and Commercialization (WERC) Center

307 Olin Building
Great Lakes Energy Institute
Phone: 216.368.1366, Fax: 216.368.3209
David H. Matthiesen, Director
david.matthiesen@case.edu

The WERC Center is a multidisciplinary center for use by students, faculty, and industry providing instrumentation for wind resource characterization and research platforms in operating wind turbines. The WERC Center was established in 2010 with funding from the Ohio Department of Development Third Frontier Wright Project and the Department of Energy. Additional support was provided by the following inaugural industrial partners: Cleveland Electric Laboratories, The Lubrizol Corporation, Parker Hannifin Corporation, Azure Energy LLC., Rockwell Automation, Inc., Swiger Coil Systems LLC., and Wm. Sopko & Sons Co.

The instruments in the WERC Center include:

- A continuous scan ZephIR LiDAR, manufactured by Natural Power. This instrument measures horizontal and vertical wind velocity along with wind direction at 15 second intervals at five user set heights up to 200 m.
- Five meteorological measurement systems: 3 on campus; 1 with the off-campus wind turbines; and one at the City of Cleveland's water intake crib located 3.5 miles offshore in Lake Erie.
- An ice thickness sensor that is deployed at the bottom of Lake Erie each fall and retrieved in the spring.
- A NorthWind 100 wind turbine manufactured by Northern Power Systems in Barre, Vermont, USA. This 100kW community scale wind turbine has a direct drive generator with full power inverters, stall control blades with a 21 m rotor diameter, and a 37 m hub height. This wind turbine is located on campus just east of Van Horn field and began operation in November, 2010.
- A Vestas V-27 wind turbine originally manufactured by Vestas in Denmark. This 225kW medium scale wind turbine has a gearbox drive generator, pitch controlled blades with a 27 m rotor diameter, and a 30 m hub height. In addition it has a 50kW generator for low wind generation. This wind turbine is located at an industrial site in Euclid, OH about 15 minutes from campus and began operation in March, 2012.
- A Nordex N-54 wind turbine originally manufactured by Nordex in Germany. This 1.0MW utility scale wind turbine has a gearbox drive generator, stall control blades with a 54 m rotor diameter, and a 70 m hub height. In addition it has a 200kW generator for low wind generation. This wind turbine is located at an industrial site in Euclid, OH about 15 minutes from campus and began operation in October, 2012.

Educational Facilities

CSE Portal (https://cseportal.cwru.edu)

The CSE Portal is a virtual computer lab available to students, faculty, and staff in the Case School of Engineering. The virtual lab utilizes Citrix technology to deliver Windows desktops and software applications to users at any time, in any location, and on any device. Users can run available applications, such as SolidWorks or Matlab, on Windows and Mac computers, as well as Android, iOS, and Windows tablets and

smartphones. All application processing takes place on the secure CSE server infrastructure, so users experience consistent performance regardless of the device being used.

To use the CSE Portal from a desktop or laptop, simply go to the following website from your browser: https://cseportal.cwru.edu

For instructions on how to setup your tablet or smartphone to access the CSE portal, please visit: http://engineering.case.edu/it/citrix

For a complete list of applications currently available on the CSE Portal, please visit: http://engineering.case.edu/it/available-applications-through-citrix-xenapp

Nord Computer Laboratory (http://engineering.case.edu/about/facilities/nord-computer-lab)

The Nord Computer Laboratory is a general purpose computer facility, provided by the Case School of Engineering, open 24 hours a day, available to all CWRU students. The lab contains 56 Thin Clients running Windows 7 Enterprise. Software includes MS Office, MATLAB, SolidWorks, Aspen, MultiPhysics, ChemBioDraw, CES EduPack, and many others. Facilities for color printing, faxing, copying and scanning are provided.

Larry Sears and Sally Zlotnick Sears think[box] (http://thinkbox.case.edu)

Housed in the newly opened, newly renovated Richey Mixon Building, the Larry Sears and Sally Zlotnick Sears think[box] houses all the resources budding innovators need to bring their ideas to life. At 50,000 square feet, it is one of the world's largest campus-based innovation centers. The first four floors are now open to the public, each dedicated to a specific stage of the innovation process, including open areas and meeting spaces for interaction, prototyping tools and equipment, a fabrication machine shop and project space.

Three additional floors are planned for subsequent phases of construction, dedicated to project building, entrepreneurship resources, incubator space and community programming.

Vision

The vision of think[box] is to change the economic and social culture of the university and region by emphasizing cross-discipline and cross-institution collaborative endeavors that push creativity and innovation to their limits. Think[box] will provide a project-based learning environment where students from all courses of study have an opportunity to understand how innovation and creativity can lead to economic and social advancement. This exposure will encourage entrepreneurial thinking among our students, who will then be poised to become the leaders and innovators of the future. Simultaneously, think[box] will create an entrepreneurial environment where these ideas can be nurtured, developed, funded, and commercialized.

Mission

The mission of think[box] is to establish, on campus, a physical and cultural focal point that will:

- Provide an educational environment that fosters collaboration, creativity, and invention.
- Provide comprehensive resources for innovation and value creation.
- Create an engine for entrepreneurial growth within our community by identifying and nurturing the talents and expertise of CWRU students, faculty, and staff, as well as those of the surrounding community.

Administration

James McGuffin-Cawley, PhD
(Case Western Reserve University)
Interim Dean of the Case School of Engineering and Arthur S. Holden Professor of Engineering

Marc Buchner, PhD
(Michigan State University)
Associate Dean of Academics

Lisa Camp, MS
(Case Western Reserve University)
Associate Dean of Strategic Initiatives

Daniel Ducoff, MS
(University of California, Berkeley)
Vice Dean for External Relations of the Case School of Engineering

Cena Hilliard, MS
(University of Wisconsin-Madison)
Associate Dean of Finance, Administration, and Business Operations

Deborah J. Fatica, MA
(Bowling Green State University)
Assistant Dean of the Division of Engineering Leadership and Professional Practice

K. Peter D. Lagerlof, PhD
(Case Western Reserve University)
Faculty Director of Program Evaluation and Assessment