ME 469/669 Energy Storage Technology
3 Credits

Instructor and Teaching Assistants

Instructor: Prof. Adam Gladen
Email: adam.c.gladen@ndsu.edu Please include ME 469/669 in subject line
Office: Dolve 101A
Office Hours: M,W 3-4pm, F 9:30-10:30am , if available, or by appointment*

Teaching Assistant(s):
Prantik Chowdhury
Email: prantikroy.chowdhury@ndsu.edu
Please include ME 469/669 in subject line
Office: Dolve 11

Text

No Text is required for this course. Material will be pulled from multiple textbooks. Necessary information will be provided in the lecture notes and on Blackboard
However, the following are suggested reference materials:
General Energy Storage:

- "Engineering Energy Storage" by Odne Stokke Burheim, Academic Press, 2017, ISBN: 978012811007.
- "Energy Storage" by Robert A. Huggins, Springer, 2010; ISBN: 978-1-4419-1023-3
- "Energy Storage for Power Systems," by A. Ter-Gazarian, Peter Peregrinus Ltd., 1994

Thermal Energy Storage:

- "Solar Engineering of Thermal Process" by John Duffie and William Beckman, 4th ed, 2013, Wiley (note there is a 5th edition titled: "Solar Engineering of Thermal Processes, Photovoltaics, and Wind")
- "Thermal Energy Storage: Systems and Applications", by Ibrahim Dincer and Marc A. Rosen,, 3rd Edition, Wiley, 2021; ISBN: 97881119713159
- "Thermal Energy Storage and Regeneration" by Frank Schmidt and A. John Willmott, McGrawHill, 1981

Batteries

- "Linden's Handbook of Batteries" 5th ed., Kirby W. Beard, McGrawHill, 2019.
- "Electrochemical Energy Storage: Batteries, Fuel Cells, and Hydrogen Technologies," Petrovic, Kurzweil, and Garche, McGrawHill, 2022.

Additional reference materials are provided on Blackboard

Course Location and Times

Class Times

Day(s)	Time	Location
Mon., Wed., Fri.	*2:00 – 2:50 pm*	*Dolve 118*

Final Exam

Monday, May 6th at 8am --- Location: Dolve 118

Health and Safety Expectations

Currently (as of August 16th, 2022), NDSU does not require masks campus wide but allows faculty members discretion to require masks in their individual classes. And while masks are not required on campus, individuals should feel free to continue to wear a mask based on their individual circumstances.

Consistent with ND Department of Health, it is expected that people who are infected or close contacts who are unvaccinated will avoid campus during their five-day isolation. Fee testing kits can be picked up at the NDSU Bookstore, Library or Student Health Services.

I expect you to follow the CDC guidelines (https://www.cdc.gov/coronavirus/2019-ncov/your-health/isolation.html) in regards to isolation and quarantining, and mask-wearing post isolation.

Changes in these policies may occur depending on infection rates, and changes to CDC and NDSU recommendations/guidelines.

Attendance

According to NDSU Policy 333 (www.ndsu.edu/fileadmin/policy/333.pdf), attendance in classes (in-person) is expected when it is safe to do so in accordance with NDSU guidance regarding COVID-19. Veterans and student service members with special circumstances or who are activated are encouraged to notify the instructor as soon as possible and are encouraged to provide Activation Orders. Attendance will be taken for labs.

In-person attendance is expected, however, with the changing conditions of COVID-19, this may change. If so, you will be updated accordingly.

Do not come to class if you are sick, have been exposed to individuals who tested positive for COVID-19, and/or have been notified to self-quarantine due to exposure. **If you are unable to attend class for health reason, please contact me so that we can arrange alternatives for you.**

Communication

The primary methods by which course-related information will be communications during class, postings to the Blackboard page, and your NDSU email address. Check the Blackboard page regularly as it will be strongly relied upon.

Course Description and Prerequisites

This course will cover the fundamentals of energy storage. It will provide an introduction to the principles of thermal, mechanical, and electrochemical storage technologies

ME 469 Prerequisites: Admission to professional program, ME 351, Math 266

ME 669 Prerequisites: Admission to graduate program

Course Outcomes

The anticipated course outcomes are listed below along with the affected ABET student outcomes in parentheses. At the conclusion of this course, students will be able to:

- Identify the underlying mechanisms by which the different types of energy storage technologies store the energy and evaluate the storage technologies based on design criteria such as capacity, power output, and demand requirements. (1)
- Explain the basic principles of the different thermal energy storage methods (1)

- Use principles of thermo-fluids, to formulate models of thermal energy storage (TES) systems and apply appropriate methods to predict performance (1,2)
- Describe basic battery concepts such as battery construction, categorization, and materials (1)
- Utilize the fundament concepts of electrochemistry to analyze the thermodynamic behavior of batteries (1)
- Predict the heat generated during charging/discharging of batteries and evaluate techniques to maintain the desired battery temperature (1,2)
- Describe the fundamental principles and calculate the thermodynamic performance of other forms of energy storage technologies, e.g., compressed air energy storage and pumped hydro (1)

Additional Course Outcome(s) for Graduate students

- Demonstrate ability to extend the energy storage concepts discussed in class to other energy storage applications
- Develop and execute numerical model of energy storage systems

Grading

Course Grade

The course grade will be determined based on assessments which include homework, a semester project, and three exams. The percent contribution for each assessment type is given in the table below.

Category	Percent of final grade	
	ME 469	ME 669
Homework	20%	20%
Exam 1	20%	15%
Exam 2	20%	15%
Exam 3	20%	15%
Project	---	15%
Final Exam	20%	20%

The final course grade will be assigned per the following absolute scale:

$A \geq 90\%$
$90 > B \geq 80\%$
$80 > C \geq 70\%$
$70 > D \geq 60\%$
$F < 60\%$

The final grade will be calculated use a weighted average. Note, the overall homework grade is calculated based on total points earned divided by possible points. The *lowest individual homework grade will be dropped* when calculating the homework score.

Regrades:

With the exception of arithmetic errors, all requests for re-grading of a problem must be submitting in writing. Please write a short note detailing the perceived mistake and why your solution merits points back. *Requests for regrades must be submitted to Dr. Gladen within a week of receiving the graded material*.

Assessments

1. Homework

Reading and homework assignments will be given during class lecture and posted to Blackboard. In general, homework problems will be due one week from the assignment date. Homework must be in

acceptable engineering form including labeled drawings of the system being considered. An overview of proper engineering homework format is provided in your textbook (Section 1.5. Also see any example problem in the textbook, all follow proper format). The examples worked in class are also in the proper format.

Experience has shown that working through problems on one's own is the best way to learn this material, and it will help your performance on the exams. As such, each student is expected to do their own work and must turn in their own homework set. Working in groups, as well as discussions with other students and the instructor/TA are encouraged, but the problem set that you hand in should be your own work. To be fair to all students, *late homework will not be accepted*. Additionally, if a wrong problem is submitted, that problem will receive a zero. The *lowest individual homework grade will be dropped* when calculating the overall homework grade.

2. Exams

There will be two tests and a final. The tentative schedule** is as follows. It could change:

- *Exam 1 – Week 5: 02/09/2024 (Friday)*
- *Exam 2 – Week 9: 03/15/2024 (Friday)*
- *Exam 3 – Week 14: 4/12/2024 (Friday)*
- *Final Exam – Finals Week:*
    - *5/06/2024 at 8am*

The final exam will be comprehensive but weighted to the material presented after Exam 3

**This schedule is subject to change.

If you expect to miss an exam for an excused absence (e.g. University Sanctioned Event, Military Duties, Pregnancy or other Medical - see Policy 333), please talk with the instructor to make arrangements. Note: wanting to leave early for a vacation is not an excused absence.

3. Semester Project – ME 669 (Graduate students)

The graduate students will have an individual semester project. The students will need to develop a presentation on a topic related to energy storage not covered in class. Details on the project requirements will be provided nearer to when the project is assigned.

Tentative Topic Schedule

Note: This schedule is subject to change

Topic	# Weeks
Overview and introduction to energy storage Review of thermodynamics and heat transfer	2.5
Thermal energy storage (TES) Principles of Sensible, Latent, and Thermochemical TES Thermodynamics analysis of TES Modeling of TES	6
Electrochemical Energy Storage Introduction to batteries Principles of electrochemical processes Thermodynamics of batteries and common chemistries Basic model of batteries Thermal management of batteries	6
Mechanical Forms of Energy Storage	2

Pumped hydro Compressed air energy storage Flywheels Other Forms: Hydrogen for energy storage	

Assistance

My goal is to help you learn the material and to assist you in having a positive and effective learning experience. As such, please let me know if you have any questions or concerns about the course or if there is something which may aid you in learning the material.

Do not neglect your mental health during the semester. The NDSU Counseling Center (https://www.ndsu.edu/counseling/) has numerous resources to help students. These resources include therapy dogs, single-time sessions, and multiple sessions.

NDSU ACE Tutoring (https://www.ndsu.edu/ace/) provides additional resources including individual and group sessions.

AMERICANS WITH DISABILITIES ACT FOR STUDENTS WITH SPECIAL NEEDS

Any students with disabilities or other special needs, who need special accommodations in this course, are invited to share these concerns or requests with the instructor and contact the Disability Services Office (www.ndsu.edu/disabilityservices) as soon as possible.

Veterans and Student Soldiers

Veterans and student service members with special circumstances or who are activated are encouraged to notify the instructor as soon as possible and are encouraged to provide Activation Orders.

Academic Honesty

The academic community is operated on the basis of honesty, integrity, and fair play. NDSU Policy 335: Code of Academic Responsibility and Conduct applies to cases in which cheating, plagiarism, or other academic misconduct have occurred in an instructional context. Students found guilty of academic misconduct are subject to penalties, up to and possibly including suspension and/or expulsion. Student academic misconduct records are maintained by the Office of Registration and Records. Informational resources about academic honesty for students and instructional staff members can be found at www.ndsu.edu/academichonesty.

ABET Student Outcomes

To foster attainment of the educational objectives, the ME Department has developed a curriculum that insures students will achieve the following outcomes by the time of graduation:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences

4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.