NPRE 477
NPRE 498ESU
NPRE 498ESG
Energy Storage Engineering
Spring 2022

Online Temporary Alternative Coverage and access during Covid-19 Pandemic and possible resurgence through mutations and variants

1. Please read the assigned-reading lecture-notes chapters.
2. Then answer the corresponding written assignment,
3. For questions about the assignments, please access the teaching assistants by email:
https://www.mragheb.com/NPRE%20402%20ME%20405%20Nuclear%20Power%20Engineering/talist.htm
4. Submit the corresponding written assignment through email to https://canvas.illinois.edu
5. Please use either the Word or pdf formats
6. In case of internet "rationing" (e. g. to health and government authorities), instability, or collapse through overload, please read the lecture notes and submit the corresponding assignments. Already-taken tests and submitted assignments would be used in assessing the final grade.

A Future worth getting excited about
https://www.youtube.com/watch?v=YRvf00NooN8

Threat of Nuclear War:
https://www.youtube.com/watch?v=M7hOpT0lPGI

Regrettably, some 3,278 colleges and universities across the USA have been impacted by the Covid-19 pandemic, with many temporarily closing their campuses and switching to online classes, affecting more than 22 million students.

To all and everyone we wish good health and well-being.

<table>
<tr><th>Number</th><th>Date Assigned</th><th>Due Date</th><th>Description</th></tr>
<tr><td>1</td><td>1/19</td><td>1/26</td><td>
Reading Assignment
NEW Preface
Written Assignment
Using a Ragone plot, compare the following energy storage options:
1. Chemical storage using Li ion batteries,
2. Fuel cells using hydrogen as an energy carrier.
<table>
<tr><th>Country</th><th>Energy consumption
[kWe.hr / (capita.year)]</th></tr>
<tr><td>USA</td><td>12,878</td></tr>
<tr><td>Japan</td><td>7,432</td></tr>
<tr><td>Switzerland</td><td>7,206</td></tr>
<tr><td>Germany</td><td>6,027</td></tr>
<tr><td>Hong Kong</td><td>4,847</td></tr>
<tr><td>China</td><td>1,899</td></tr>
</table>
Using the table, estimate the needed rated power for a solar or wind energy installation to provide the power needs for a family of four in different countries, assuming the presence of
</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>a capability to store the energy in battery banks, an overall conversion efficiency of 30 percent, and an intermittence (capacity) factor of 40 percent for both wind and solar.</td></tr>
<tr><td>2</td><td>1/21</td><td>1/28</td><td>Reading Assignment
Introduction
Written Assignment
An electrical storage battery is charged from a power supply at 1 kW for an hour. If its efficiency is 60 percent, how long would it take to totally discharge it if it used to supply a load at 100 Watts?

List the advantages of energy storage in conjunction with renewable and conventional Energy systems.</td></tr>
<tr><td>3</td><td>1/24</td><td>1/31</td><td>Reading Assignment
1. Energy Storage Options
Written Assignment
In the simple pendulum without friction, energy that is stored as potential energy at the top of its stroke ($E_p = mgh$) is transformed into kinetic energy at the bottom of the stroke ($E_k = \frac{1}{2} mv^2$), then back as potential energy in a cyclic manner.
1. For a stored potential energy of 1 joule what would be the speed v of a 1 kg pendulum at the bottom of its stroke?
2. To what height h will the pendulum rise at the highest point in its stroke?</td></tr>
<tr><td>4</td><td>1/26</td><td>2/2</td><td>Reading Assignment
1. Energy Storage Options
Written Assignment
Balance the chemical reactions used in the high temperature Iodine Sulfur (IS) hydrogen production process:
$2H_2SO_4 \rightarrow 2H_2O + ? + O_2$
$2I_2 + ? + 4H_2O \rightarrow 4HI + ?$
$4HI \rightarrow 2H_2 + ?$
____
$2H_2O \rightarrow 2H_2 + ?$</td></tr>
<tr><td>5</td><td>1/28</td><td>2/4</td><td>Reading Assignment
2. Solar Thermal Power and Energy Storage Historical Perspective
Written Assignment
In the Concentrated Solar Power (CSP) projects shown in the following table, calculate the corresponding idealized Carnot Cycle efficiencies.
Rank the thermal energy storage media according to the achievable thermal cycle efficiency.
<table>
<tr><th rowspan="2">Project</th><th rowspan="2">Type</th><th rowspan="2">Storage medium</th><th rowspan="2">Cooling loop</th><th colspan="2">Nominal temperature [^oC]</th></tr>
<tr><th>Cold</th><th>Hot</th></tr>
<tr><td>Irrigation Pump Coolidge, Arizona, USA</td><td>Parabolic Trough</td><td>Oil</td><td>Oil</td><td>200</td><td>228</td></tr>
</table></td></tr>
</table>

IEA-SSPS Almeria, Spain	Parabolic Trough	Oil	Oil	225	295
SEGS I Daggett, California, USA	Parabolic Trough	Oil	Oil	240	307
Solar One Barstow, California, USA	Central Receiver	Oil Sand Rock	Steam	224	304
CESA -1 Almeria, Spain	Central Receiver	Molten salt	Steam	220	340
THEMIS Targasonne, France	Central Receiver	Molten salt	Molten salt	250	450
Solar Two, Barstow, California, USA	Central Receiver	Molten salt	Molten salt	275	565

6	1/31	2/7

Reading Assignment

3. Thermal Energy Storage

4. Thermal Energy Storage with Solar Power Generation

Written Assignment

Henry E. Willsie identified the major weakness of all the previously built solar engines in their inability to overcome the intermittency problem of solar radiation. As an energy storage medium, he used large flat-plate collectors that heated water, which he kept warm all night in a large insulated basin. Identify the working medium that he used to extract the stored solar energy.
What was earlier pioneer Charles Tellier' s choice?

Calculate the theoretically achievable Carnot cycle efficiencies for the following liquid thermal energy storage media used in solar thermal applications

Storage medium	Operational Temperature	
	Cold [ºC]	Hot [ºC]
Mineral oil, liquid petroleum (alkanes, cyclic paraffins, petroleum jelly)	200	300
Synthetic oil, polyalphaolefin, synthetic esters, hydrocracked/hydroisomerized base oils.	250	350

<table>
<tr><td></td><td></td><td></td><td>
<table>
<tr><td>Silicone oil, polymerized siloxanes, …Si-O-Si-O-Si…</td><td>300</td><td>400</td></tr>
<tr><td>Nitrite salts, KNO_2, $NaNO_2$</td><td>250</td><td>450</td></tr>
<tr><td>Nitrate salts, $NaNO_3$, KNO_3</td><td>265</td><td>585</td></tr>
<tr><td>Carbonate salts, Na_2CO_3</td><td>450</td><td>850</td></tr>
<tr><td>Liquid Na</td><td>270</td><td>530</td></tr>
</table>
</td></tr>
<tr><td>7</td><td>2/4</td><td>2/11</td><td>
Reading Assignment
5. Battery Technology
Written Assignment
In the SI system of units, compare the units of the following figures of merits used to compare storage batteries:
1. Specific Energy,
2. Specific Power,
3. Energy Density,
4. Power density.

Compare the different options under consideration for a future fleet of Electrical Vehicles (EVs).
Describe the different usages of battery storage technology in:
1. Hybrid Electric Vehicles, HEVs,
2. Plug-in Hybrid Electric Vehicles, PHEVs,
3. Electric Vehicles EVs.
</td></tr>
<tr><td>8</td><td>2/7</td><td>2/14</td><td>
Reading Assignment
6. Electric Vehicles Technology
Written Assignment
Compare the specific energy content of hydrogen and lithium-ion batteries as energy storage media.

Compare a vehicle weight using hydrogen fuel cell vs. Li-ion batteries as a function of the attainable range.

Compare the material compositions (other than Li) of the following Li -ion batteries:
1. LCO
2. NCA
3. LMO
4. NMC

How do the LCO batteries differ from the other types?
</td></tr>
<tr><td>9</td><td>2/9</td><td>2/16</td><td>
Reading Assignment
7. Energy Hydrogenation and Decarbonization
Written Assignment
Write a summary of the article:
https://finance.yahoo.com/news/lithium-feast-famine-future-keeps-000100783.html
</td></tr>
</table>

			Compare the voltages generated by a single fuel cell element when it is operated at: a. 20 °C, b. 100 °C. Use: $\Delta S = 163.2\ J/K$, $\Delta H = 285{,}800\,J$, F (Farady's constant) = 96,487 [Coulombs] or [Joules/Volt], n=2. What would the implications regarding the obtained different values? How many cells are needed for a 12-Volt battery?
10	2/11	2/18	**Reading Assignment** **7. Energy Hydrogenation and Decarbonization** **10. High Temperature Water Electrolysis for Hydrogen Production** **Written Assignment** Plot the graph describing the energy requirement for the electrolysis method for hydrogen production. Discuss the effect on the overall process efficiency of: 1. Low temperature electrolysis, 2. High temperature electrolysis. Write a one-page summary of the paper discussed in the class: Rachel Beck and Magdi Ragheb, "Production of Carbon-Neutral Hydrocarbons From CO_2 and H_2 In Lieu of Carbon Capture and Storage (CCS)," 10th International Conference on "Role of Engineering Towards a Better Environment, RETBE14, Alexandria University, Faculty of Engineering, 15-17 December 2014. Write down the equations describing the production of green diesel fuel from carbon dioxide and hydrogen.
11	2/14	2/21	**Reading Assignment** **8. Steam Reforming** **9. Carbon Dioxide Reforming** **11. Thermochemical Iodine Sulfur Process for Hydrogen Production** **12. The Hydrogen Economy** **Written Assignment** In the Fischer Tropsch industrial process carbon monoxide is reacted with hydrogen to synthesize hydrocarbons. The synthesis conditions are at 150 bar and 700 K in the presence of a catalyst. In the case of natural gas methane to liquids applications the suggested basic chemical reaction would be: $CH_4 + \frac{1}{2}O_2 \rightarrow 2H_2 + ?$ With Ni and Co used as catalysts, the following reaction would occur: $nCO + 2nH_2 \xrightarrow[Ni,Co]{} nH_2O + ?$ If, instead, a Fe catalyst is used the reaction proceeds as follows: $2nCO + nH_2 \xrightarrow[Fe]{} nCO_2 + ?$ List the methods considered for the storage of hydrogen. Give examples for the considered storage media.

12	2/16	2/23	**Reading Assignment** **31. Kinetic Energy Flywheel Energy Storage** **Written Assignment** **Reading assignment** **31. Kinetic Energy Flywheel Energy Storage** **Written Assignment** Consider a straight filament of length R and weight W rotating around a vertical spin axis with rotational angular speed ω radians/sec. 1. Write the expression for the stored kinetic energy of the rotating element. 2. Derive the expression of its specific energy content. 3. What would happen to the stored kinetic energy if the rotational speed a) is doubled, b) is tripled. Use for the moment of inertia for a thin rod: $I = R^2W/3g$
13	2/18	2/25	**Reading Assignment** **26. Pumped Energy Storage** **27. Pumped Storage in Association with the Red Sea to Dead Sea Peace Canal** **28. Pumped Storage Qattara Depression Solar Hydroelectric Power Generation** **Written Assignment** Consider a hydroelectric pumped energy storage facility producing power from stored sea water at a discharge rate of 39 m^3/sec from a height of 500 m. a) Calculate the theoretical rated power production of the station. b) For a conversion efficiency of 85 percent, what would be the effective power generation? c) Calculate the potential yearly energy production in MW.hrs. Write a one-page summary of the paper: Patricia Weisensee and Magdi Ragheb, "Integrated Wind and Solar Qattara Depression Project with Pumped Storage as Part of Desertec," The Role of Engineering Towards a Better Environment, RETBE'12, 9th International Conference, Alexandria University, Faculty of Engineering, December 22-24, 2012**.**
14	2/21	2/28	**Reading Assignment** **32. Sustainable Global Energy, Desertec Concept** **39. Ultra Capacitors Electrostatic Energy Storage** **Written Assignment** In order to meet today's global power demand of 18,000 TWh / year, it would suffice to equip about three thousandths of the world's deserts, an area of about 90,000 km^2 with solar collectors of solar thermal power plants. 1. Calculate the fraction of the area of the Sahara Desert that this area would cover. 2. What is the cost of covering the electrical demands of North Africa and the Middle East as well as 15 percent of Europe's electricity by 2050 in dollars and euros? Briefly describe "Graphene" and its use in super capacitors manufacture.
15	2/23	3/2	**Reading Assignment** **29. Cryogenic Energy Storage** **30. Compressed Air Energy Storage** **33. Electrochemical Supercapacitor** **Written Assignment** Briefly describe what is a "Carbon Aerogel"

			Show a diagram comparing the performance of electrochemical supercapacitors to other energy storage options. Compare the energy input needs for the storage of Hydrogen in different forms: **Compressed Hydrogen** For the adiabatic compression of hydrogen, the compression energy in MJ/kg (1 MJ = 1,055 BTU) is: 47 MJ/kg, for 10,000 psi 36 MJ/kg, for 5,000 psi **Liquefied hydrogen** For cryogenic liquid hydrogen, the theoretical cooling energy expenditure is: 2.94 MJ/kg, for gas from 25 ^{o}C to 20 K 0.45 MJ/kg, for gas to liquid at 20 K Total: 3.40 MJ/kg However, liquefaction involves a reverse Carnot Cycle efficiency of: $\eta_{\text{Reverse Carnot}} = \frac{Q_{extraction}}{Q_{rejection} - Q_{extraction}} = \frac{T_2 \Delta S}{T_1 \Delta S - T_2 \Delta S} = \frac{T_2}{T_1 - T_2}$ For liquefaction from T_1 = 25 ^{o}C = 25 +273 K= 298 K to T_2 = 20 K, $\eta_{\text{Reverse Carnot}} = \frac{20}{(25+273)-20} = \frac{20}{298-20} = \frac{20}{278} = 0.0719 = 7.19\ percent$ This lead to actual liquefaction energies for a refrigeration efficiency of 7.19 percent of: Refrigeration energy = 3.4 / 0.0719 = 47.3 MJ/kg, for gas to liquid at 20 K Vaporization and warmup = 3.4 MJ/kg Total = ??? MJ/kg
16	2/25	3/2	**Reading Assignment** **41.** Algae Growth for Biodiesel Production **48.** Salt Gradient Solar Pond **Written Assignment** List the applications of solar ponds for solar energy storage. Include a diagram of a proposed energy production cycle. List the contemplated future uses and algae growth research.
17	2/28	3/2	**Reading Assignment** **36.** Battery and Fuel Cell Aircraft **52.** Gravitational Potential Energy Storage **53.** Aerodynamic Solar Electric Vehicles **Written Assignment** Search the internet and then write a one page description of a recent European or USA fuel cell powered aircraft. What is the perceived advantages of such a concept?

			Compare the electricity cost from gravitational potential energy storage to other storage choices. List the requirements in the design of effective solar electric vehicles.
Wed	3/2	During class period	First Midterm Exam
18	3/4	53/11	**Reading Assignment** **15. Hydrogen Storage** **Written Assignment** List the main methods adopted for hydrogen energy storage, List some chemical hydrides used in hydrogen energy storage. List some borohydrides used in hydrogen energy storage
19	3/7	3/21	**Reading Assignment** **16. Metal Hydrides** **55. Flow Cell Batteries,** **Written Assignment** Describe the main properties of $LaNi_5H_6$ as a hydrogen storage medium. List the advantages and disadvantages of Flow Cell Batteries.
20	3/9	3/21	**Reading Assignment** **13. High Voltage Direct Current for Wind Power** **Written Assignment** List the options available in the use of HVDC for High Voltage Direct Current power transmission.
21	3/11	3/21	**Reading Assignment** **13. High Voltage Direct Current for Wind Power** **Written Assignment** To transmit a given amount of power $P = IV$, where V = voltage and I = current, show that high voltage V is needed to minimize the magnitude of the ohmic resistive heating losses: I^2R, where R is the resistance of the transmission line wire. In what way does HVDC power transmission reduce the resistive heating losses compared with HVAC? Explain and sketch two diagrams showing the advantages of HVDC over HVAC for the long-distance conveyance of electrical power from the perspectives of: 1. Capital costs, 2. Transmission energy losses as ohmic heating and corona discharge.
22	2/21	3/28	**Reading Assignment** **13. High Voltage Direct Current for Wind Power** **14. Smart Electrical Grid and Metering** **Written Assignment** Briefly describe the following devices used in HVDC power transmission: 1. Thyristor 2. IGBT (Insulated-Gate Bipolar Transistor).

23	3/23	3/30	**Reading Assignment** NEW **46. Electrical Generation and Grid System Integration** **Written Assignment** What do the following acronyms in the utility business stand for? 1. RTO, 2. ISO, 3. FERC, 4. PJM, 5. MISO. Briefly describe: 1. The causes, 2. The progression, of the August 14, 2003 Blackout.
24	3/25	4/1	**Reading Assignment** NEW **17. Primary and Secondary Storage Batteries** **Written Assignment** Draw a diagram showing the components and write the equations describing the electrochemistry reactions in: 1. Ni-Cd batteries 2. Zn/MnO_2 alkaline batteries
25	3/28	4/4	**Reading Assignment** NEW **18.Battery Power Density, Life Cycle and Cost** NEW **19.Nickel Cadmium and Lithium Ion Batteries** **Written Assignment** List the factors determining the cost of batteries. Draw a diagram showing the configuration and ions flow in a typical Li-ion battery.
26	3/30	4/4	**Reading Assignment** NEW **21. Redox Flow Batteries and Regenerative Fuel Cells** **Written Assignment** Briefly describe the advantages and disadvantages of flow batteries as an energy storage option. Draw a diagram of a flow battery Write the equations at the cathode and anode of a vanadium flow battery.
27	4/1	4/4	**Reading Assignment** NEW **24.Carbon Capture and Storage** NEW **40. Natural Gas as a Bridge Fuel Toward Renewables** **Written Assignment** Write down the equations describing the production of green diesel fuel from carbon dioxide and hydrogen. List the additives added to the Hydraulic Fracturing fluids List the environmental impacts and sustainability of the process of Hydraulic Fracturing (Fracking)
	4/4		Second midterm exam. During class period

28	4/6	4/13	**Reading Assignment** **24.**Carbon Capture and Storage **34.**Safety Aspects of Thermal Energy Installations **35.** Urea Power **Written Assignment** Write a one-page summary of the paper: Rachel Beck and Magdi Ragheb, "Production of Carbon-Neutral Hydrocarbons From CO_2 and H_2 In Lieu of Carbon Capture and Storage (CCS)," 10th International Conference on "Role of Engineering Towards a Better Environment, RETBE14, Alexandria University, Faculty of Engineering, 15-17 December 2014. List the safety issues encountered in solar energy storage and production. List the impediments to the use of urea as a source of hydrogen in fuel cells operation.
29	4/11	4/18	**Reading Assignment** **37.** Metal Hydrides Alloys for Hydrogen Storage **Written Assignment** **Compare the energy input needs for the storage of Hydrogen in different forms:** **Compressed Hydrogen** For the adiabatic compression of hydrogen, the compression energy in MJ/kg (1 MJ = 1,055 BTU) is: 47 MJ/kg, for 10,000 psi 36 MJ/kg, for 5,000 psi **Liquefied hydrogen** For cryogenic liquid hydrogen, the theoretical cooling energy expenditure is: 2.94 MJ/kg, for gas from 25 °C to 20 K 0.45 MJ/kg, for gas to liquid at 20 K Total: 3.40 MJ/kg However, liquefaction involves a reverse Carnot Cycle efficiency of: $\eta_{\text{Reverse Carnot}} = \frac{Q_{extraction}}{Q_{rejection} - Q_{extraction}} = \frac{T_2 \Delta S}{T_1 \Delta S - T_2 \Delta S} = \frac{T_2}{T_1 - T_2}$ For liquefaction from T_1 = 25 °C = 25 +273 K= 298 K to T_2 = 20 K, $\eta_{\text{Reverse Carnot}} = \frac{20}{(25+273)-20} = \frac{20}{298-20} = \frac{20}{278} = 0.0719 = 7.19\ percent$ This lead to actual liquefaction energies for a refrigeration efficiency of 7.19 percent of: Refrigeration energy = 3.4 / 0.0719 = 47.3 MJ/kg, for gas to liquid at 20 K Vaporization and warmup = 3.4 MJ/kg Total = ??? MJ/kg **Metallic Hydrogen** 1. Compressing hydrogen to 20 atm = 12.0 MJ/kg 2. Unextractable heat of absorption = 7 kcal / kg =14.6 MJ/kg 3. Energy for refrigeration to 10 °C = 14.6 MJ/kg Coefficient of performance, COP = 5 Cooling Energy = 14.6 / 5 = 3.0 MJ/kg 4. Energy for desorption, using waste heat = 0.0 MJ/kg Total energy expenditure: ??? MJ/kg

30	4/**13**	4/**20**	**Reading Assignment** **49. Quantum Glass Battery** **50. Solid State Batteries** **51. Structural batteries** **Written Assignment** List the composition of glasses used in solid quantum glass batteries. Describe the perceived advantages of suggested structural batteries.
31	4/**15**	4/22	**Reading Assignment** **45. Powerwall and Powerpack Tesla Batteries** **Written Assignment** Briefly describe the envisioned role of battery storage in the following energy fields: 1, Individual consumers, 2. Small businesses, 3. Electrical utilities
32	4/18	4/25	**Reading Assignment** **42. Global Climatic Variation and Energy Use** **Writing Assignment** Describe the circumglobal equatorial current system Write a one-page summary of the paper: Magdi Ragheb, "Restoring The Global Equatorial Ocean Current Using Nuclear Excavation," i-manager's Journal on Future Engineering & Technology, Vol. 5, No. 1, pp. 74-82, August-October, 2009.
33	4/20	4/27	**Written Assignment** Write a one-page summary about: **Vitor Ferreira Grizzi, "Solid State Energy Storage Batteries" pptx**
34	4/22	4/29	**Written Assignment** Write a one-page summary about: **Ahmed Kazan, "Sodium ion batteries, availability, potential and comparison with other batteries" pptx**
35	4/25	5/2	**Written Assignment** Write a one-page summary about: **Ousmane Ndiaye, "Chemical and Thermal Energy Storage in conjunction with nuclear power generation" pptx**
36	4/27	5/4	**Written Assignment** Write a one-page summary about: **Rajadnya, Atharva "Printable Solar Cells" pptx**
37	4/29	5/4	**Written Assignment** Write a one-page summary about: **Saurav Subhash "Concentrated Solar Plant CSP with TES Storage and Cost Analysis"**
38	5/2	5/6	**Written Assignment** Write a one-page summary about: **Julian Herrera, "Hydrogen peroxide H2O2 as a hydrogen energy storage medium" pptx**
39	5/4	5/**6**	**Written Assignment** Write a one-page summary about:

	Last day of classes		**Veeresh Chitradurga Gangadhara, "Ammonia NH3 as a possible hydrogen energy storage medium" pptx**

Assignments Policy

Assignments will be turned in at the beginning of the class period, one week from the day they are assigned.
The first five minutes of the class period will be devoted for turning in, and returning graded assignments.
Late assignments will be assigned only a partial grade. Please try to submit them on time since once the assignments are graded and returned to the class, late assignments cannot be accepted any more.
If you are having difficulties with an assignment, you are encouraged to seek help from the teaching assistants (TAs) during their office hours. Questions may be emailed to TA's, but face-to-face interaction is more beneficial.
Although you are encouraged to consult with each other if you are having difficulties, you are kindly expected to submit work that shows your individual effort. Please do not submit a copy of another person's work as your own. Copies of other people's assignments are not conducive to learning, and are unacceptable.
For further information, please read the detailed assignments guidelines.