Loughborough University

ENERGY SYSTEMS ANALYSIS

22WSC804

Semester 1 2022 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Loughborough University

ENERGY SYSTEMS ANALYSIS

(22WSC804)

January 2023 | 2 Hours

Answer **ALL FOUR** questions.

Questions carry the marks shown.

Any approved University calculator is permitted.

Each student may bring **ONE DOUBLE-SIDED HAND WRITTEN** A4 page into the exam.

1.

a) What is exergy and how does it differ from energy? [2 marks]

b) How does useful work differ from actual work? [2 marks]

c) For what kind of system is the useful work equal to the actual work? [2 marks]

d) A freezer unit has been designed to maintain a refrigerated space at -6°C by removing heat at a rate of 2 kW. The power input to the freezer is 0.6 kW and the surrounding air is at 20°C. Determine:

i. The reversible power input [2 marks]

ii. The irreversibility [2 marks]

iii. The second law efficiency of the freezer [2 marks]

e) Water is situated in a reservoir 100 m above the surface of the river below it. How would you define your dead state to allow a useful exergy analysis? [2 marks]

f) For surroundings at 1 bar (absolute) and 300 K, is the exergy of ice at -20°C going to be positive or negative? [1 mark]

2.

a) A semiconductor processing plant uses steam for silicon wafer annealing. The steam is supplied at 20 MPa and 1100°C and is throttled to 6 MPa for the annealing system. Determine the wasted work potential [$kJ.kg^{-1}$] during this throttling process. Assume the surroundings are at 25°C. [6 marks]

b) Combustion gases enter a gas turbine at 1000 K, 1 MPa, and 50 $m.s^{-1}$ at a rate of 3 $kg.s^{-1}$. The gases leave at 800 K, 400 kPa and 100 $m.s^{-1}$. It is estimated that heat is lost from the turbine at a rate of 40 kW. Assume C_p = 1.121 $kJ.Kg^{-1}.K^{-1}$, R = 0.287, and the surroundings to be at 25°C and 100 kPa. Determine:

i. The actual and reversible power outputs [kW] of the turbine. [10 marks]

ii. The exergy destroyed within the turbine [kW] [2 marks]

iii. The second law efficiency of the turbine [2 marks]

c) A chemical plant includes a process that requires the thermal cycling of an aqueous solution to complete a process reaction. The process is a continuous flow process that runs 14 hours per day and 320 days per year at a rate of 18 $kg.s^{-1}$. The aqueous solution is heated from 20°C to 75°C using hot water generated using a natural gas fired boiler that has an efficiency of 68%. After heating, the solution is cooled using cold water at 12°C. The cost of natural gas is 4.5 $p.kWh^{-1}$

To save energy, and money, the plant operators decide to install a regenerator that has an effectiveness of 75%, with the solution entering one side of the regenerator at 75°C and leaving at 30°C. Assume the solution is water with C_p = 4.18 $kJ.Kg^{-1}.K^{-1}$.

i. How much energy [kWh] and money [£] will be saved per year by installation of the regenerator; [6 marks]

ii. Calculate the exergy destroyed in the regenerator [kW]. [7 marks]

iii. How could you reduce the exergy destroyed in the regenerator? [2 marks]

 /continued

3.

a) Briefly define the following system 'lenses' which can be used to help understand the energy transition. You may illustrate your answer with a rough, but carefully annotated, sketch or diagram.

For each lens discuss how it might influence government policy to drive and accelerate the transition to a zero carbon society.

i. The Energy Trilemma [4 Marks]

ii. Innovation Systems [4 Marks]

iii. Multi-Level Perspective [4 Marks]

b) Other than concerns about the global warming potential (GWP) and abiotic resource depletion potential (RDP), briefly describe three other environmental impacts, giving the key cause of the impact, which may feature in a thorough lifecycle assessment, giving the units usually employed. [6 Marks]

The table below shows the abiotic resource depletion potential of elements used in solar photovoltaic panels in units of kgSbeq/kg. Silicon, derived from Silica (SiO2), is used in conventional solar panels. Cadmium Telluride (CdTe) is used in newer thin film photovoltaic technology.

Element	**Atomic Mass**	**ADP kg_{sb}/kg**
Cadmium (Cd)	112.4	1.60E-01
Tellurium (Te)	127.6	4.10E+01
Silicon (Si)	28	1.40E-11
Oxygen (O)	16	3.20E-09

The weight of material used for a solar panel, rated at 1 kW, is given in the following table.

Technology	**Mass of material kg/kW**	**Chemical Formula**
Cadmium Telluride Thin Film	0.093	CdTe
Silicon Poly-crystalline	2.64	SiO_2

c) Show that the ratio by weight of Cd to Te and Si to O is 47:53 in each case. [4 Marks]

d) Calculate the abiotic resource depletion potential of each technology for a 1kW system of Silicon and CdTe technologies. [4 Marks]

e) As well as the significantly difference values for ADP, why else is Cadmium Telluride likely to have other significant environmental impact? [2 Marks]

4. The Barrow offshore Windfarm is rated 90 MW and generates 315.6 GWh of electricity per year. The Farr onshore Windfarm is rated 90 MW and generates 236.7 GWh of electricity per year. (Values are averages and proportioned to 365.25 days per year).

a) Give the equation for capacity factor and, expressing your answer to the nearest whole percent, what is the capacity factor for each wind farm? [4 Marks]

b) Briefly explain the difference in capacity factors of the two windfarms. Compare and contrast the predictors for typical capacity factors for new renewables and thermal plant [4 Marks]

The total unit cost of installation for Barrow is £2 Million/MW installed capacity. In contrast, for onshore wind in Farr the unit cost is £1 Million/MW.

The estimated operational expenditure for offshore wind is £70 Thousand / MW installed capacity and for onshore it is £35 Thousand.

Each wind farm sells generated electricity with a power purchase agreement for £90/MWh.

c) Calculate the total CAPEX, annual OPEX and average annual revenue from electricity sales and net annual income for each windfarm. [3 Marks]

d) Showing your working for each windfarm calculate the simple pay-back period. [2 Marks]

e) Give the formula for Net Present Value (NPV) with a discount rate i and the revenue for year n, denoted R_n. [2 Marks]

f) Using a discount rate of 5%, calculate the Net Present Value after ten years of operation for the respective capital investments in each project. Clearly show your calculations. [6 Marks]

g) Discuss whether investors expecting a 5% rate of return might choose to support each project. [1 Mark]

E Long
P Leicester