UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE : **AAB4022 - LIFE CYCLE ASSESSMENT OF ENGINEERING MATERIALS**

DATE : **7 AUGUST 2024 (WEDNESDAY)**

TIME : **9.00 AM - 11.00 AM (2 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **SIX (6)** pages in this Question Booklet including the cover page and appendix.

ii. **DOUBLE-SIDED** Question Booklet.

1. A company is conducting a Life Cycle Assessment (LCA) for its product, which goes through multiple stages from raw material extraction to final disposal. During the assessment, the company needs to allocate the environmental impacts among different life cycle stages and processes.

   a. Discuss **TWO (2)** potential challenges associated with allocation in LCA.

   [10 marks]

   b. Propose **TWO (2)** strategies that can be employed to address the challenges of allocation in LCA. Justify your answer with an example.

   [10 marks]

2. Based on your understanding of the Life Cycle Assessment (LCA) evaluation process. Answer the questions below.

   a. Discuss **TWO (2)** rules for defining the system boundaries in LCA. Support your answer with an example.

   [10 marks]

   b. Distinguish **THREE (3)** differences between the process based and input output (I/O) approach for the inventory analysis.

   [10 marks]

3. Based on your knowledge about the life cycle impact assessment of engineering materials and the data given in **TABLE Q3**, answer the following questions.

TABLE Q3. Inventory of emissions and extractions for product system

Substance	Units	MAT1	MAT2	MAT3
Energy	MJ	4043	3061	2193
CO_2	kg	253.9	176.4	134.6
CO	kg	0.294	0.045	0.047
CH_4	kg	0.154	0.122	0.112
N_2O	kg	0.0013	0.0005	0.0015
NO_x	kg	0.221	0.172	0.156
SO_2	kg	0.439	0.348	0.315
Particles	kg	0.0383	0.0136	0.0287

a. Illustrate the impact assessment framework from the Life Cycle Inventory (LCI) results to include midpoint categories and damage categories.

[8 marks]

b. Estimate the damage impact score on human health of the product made of materials as given in **TABLE Q3** using IMPACT World+ methodology. Damage factors as per IMPACT World+ are provided in **TABLE A1** in the **APPENDIX A**. The damage impact should cover Global Warming (CO_2, CH_4, N_2O), Respiratory Inorganics-fine particulate matter (Particles, NO_x, SO_2).

[14 marks]

c. Identify which material from **part (b)** give the highest and lowest impact on human health based on normalized damage score (person year/FU) and weighted damage score (RM/FU). Used the normalization factor NHH of 0.022 DALY/person-year and weighing factor WHH of RM 74,000/DALY. Justify your answer.

[8 marks]

4. An automotive company in Malaysia is developing a new front-end module for an upcoming model, as shown in **FIGURE Q4.** The new design requires it to be environmentally friendly. As a life cycle analyst, you are asked to perform a life cycle assessment (LCA) and select suitable material to be used in the new front-end module. Three different types of materials will be assessed for the font end module: steel, composite, and recycled aluminum.

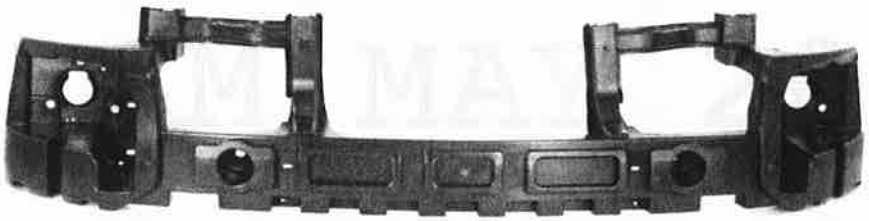

FIGURE Q4: Front end module.

a. Propose the function, functional unit and reference flow of the front-end module shown in **FIGURE Q4.**

[6 marks]

b. Develop the system boundary (cradle to grave) of the front-end module. Justify your decision.

[6 marks]

c. Based on the above-mentioned materials, calculate all **THREE (3)** inventories of emissions and extractions for the front-end module using given data in **TABLE A2** and **TABLE A3** in the **APPENDIX A**. The calculations should include energy, CO_2, CH_4, N_2O, NO_x, SO_2 and particles.

[12 marks]

d. Select the best material to be used for the front-end module with the least environmental impact based on energy usage and CO_2 emission as calculated in **part (c).** Justify your answer.

[6 marks]

- END OF PAPER-

APPENDIX A

Table A1. Midpoint characterization factor from IMPACT Word+

	Midpoint Characterization Factor ($CF^{midpoint}$)
(a) Global Warming	
Units	$kg_{CO_2,eq}/kg_i$
CO_2	1
CH_4	25
N_2O	298
(b) Respiratory Inorganics (Fine Particulate Matter)	
Units	$kg_{PM2.5}/kg_i$
Particles	0.6
NO_x	0.0077
SO_2	0.038

Table A2. Reference flow and main intermediary flows for a front-end module transported from vendor manufacturing facility to automotive assembly line.

	Unit	Steel	Composite	Virgin Aluminum	Recycled Aluminum
Materials					
Weight	kg	10.0	7.0	3.8	3.8
Manufacturing					
Electricity	kWh	19.7	4.7	15.2	15.2
Oil	kg	2.3	0.56	1.8	1.8
Use					
Gasoline	L	80.0	56.0	30.4	30.4
End of life					
Incineration	kg	-	7.0	-	-
Controlled Landfilling	kg	-	-	3.8	-
Landfill	kg	10.0	-	-	-

Table A3. Aggregate emission and extraction factors for inputs involved in the production of front-end module transported from vendor manufacturing facility to automotive assembly line.

		Steel	Composite Material	Nonrecycled Aluminum	Recycled Aluminum	Electricity	Oil	Gasoline	Landfilled Steel	Landfilled Aluminum	Propylene Incineration
		kg	*kg*	*kg*	*kg*	*kWh*	*kg*	*L*	*kg*	*kg*	*kg*
Resources											
Energy	*MJ*	24.7	79.9	162	21.8	10.5	56.9	43.2	0.21	0.53	0.21
Emissions to Air											
CO2	*kg*	1.28	1.85	9.50	1.20	0.45	3.67	2.80	0.01	0.02	2.54
CO	*kg*	0.023	0.00076	0.0057	0.0011	0.00016	0.0013	0.00067	0.000042	0.000097	0.00026
CH4	*kg*	0.0027	0.006	0.015	0.0015	0.00064	0.0032	0.0013	1.8E–05	3.8E–05	2.2E–05
N2O	*kg*	3.8E–05	1.3E–07	0.00027	2.5E–05	1.1E–05	4.1E–05	8.1E–06	2.1E–07	5.4E–07	4.8E–06
NOx	*kg*	0.0054	0.0096	0.022	0.0025	0.00082	0.0037	0.0018	0.00015	0.00029	0.00039
SO2	*kg*	0.004	0.013	0.038	0.0035	0.0018	0.0052	0.0044	1.1E–05	3.0E–05	1.9E–05
Particles	*kg*	0.0021	0.00038	0.0055	0.00043	0.00012	0.00024	0.00018	1.4E–05	2.8E–05	1.3E–05
Pb	*kg*	5.6E–06	5.1E–09	1.9E–06	4.2E–05	6.5E–08	3.5E–07	1.7E–07	2.3E–09	1.0E–08	7.7E–09
Emissions to Water											
Nitrates	*kg*	1.6E–05	1.9E–05	1.9E–04	1.6E–05	7.9E–06	1.1E–05	7.4E–06	5.3E–08	1.9E–07	5.4E–05
Pb	*kg*	1.5E–05	1.0E–06	1.1E–05	4.8E–06	4.5E–07	1.3E–06	7.1E–07	2.9E–08	2.6E–05	1.5E–06