

Part 1. Multiple Choice Questions (60%).

Answer all questions. There is only one correct answer so you must choose the best answer. Answer A, B, C... (Capital letters). A correct answer gives for each of the problems **4 percentage points (4%)** in total towards the final score. Incorrect answers will be awarded **-1 percentage points (-1%)**, blank (unanswered) questions, or multiple answers to the same question will be awarded **0 points (0%)**.

Only the answer will be marked.

Write the answers for the multiple choice questions on the answer sheet you turn in using a table similar to the following (note that the answers in this table are examples of how you should do it – not the real correct answers!):

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Answer	D	C	A	B	E	A	C	A	E	D	B	A	A	A	C

Good luck!

Problems:

Part I (multiple choice)

1. Recall the world consumption graph. What is the part of renewables (hydro and nuclear including) according to the world consumption graph?

- A. 4%
- B. 7%
- C. 15%
- D. 30%

2. What is the part of nuclear energy according to the world consumption graph?

- A. 2%
- B. 4%
- C. 7%
- D. 9%

3. According to the latest statistical report of BP 2022, what are the three countries with the biggest total proved reserves of oil?

- A. Venezuela, United Arab Emirates, Iran
- B. Norway, Iraq, Iran
- C. Venezuela, Saudi Arabia, Canada
- D. Saudi Arabia, Canada, Iraq

4. What country is a net exporter of bioethanol?

- A. USA
- B. Argentina
- C. Brazil
- D. UK

5. A bicyclist expends energy at the rate of 60 Watt. How many calories of energy will he expend in 10 minutes of driving?

- A. 120
- B. 3600
- C. 7200
- D. 8600

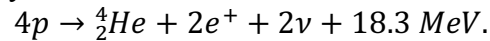
6. With an albedo of 0.3 and an atmosphere with a long-wavelength transmission of 0.15 and a short wavelength transmission of 0.85 we have seen that the equilibrium temperature of the Earth is around 287 K. A gas is introduced into the atmosphere that decreases the mean long wavelength transmission of the atmosphere from 0.15 to 0.12. If the mean short wavelength transmission of the atmosphere remains unchanged at 0.85 and the albedo remains at 30%, what is the resulting temperature of the Earth?

- A. 287 K
- B. 289 K
- C. 293 K
- D. 300 K

7. Calculate the wavelength (λ_{\max}) for the maximum intensity of the black body radiation from a human being, assuming a surface temperature of 32°C.

- A. 15 microns
- B. 0.2 microns
- C. 500 nm
- D. 9.5 microns
- E. 794 nm

8. A star generates energy by nuclear fusion reaction of H nuclei into helium



It fuses 6×10^8 tons of hydrogen per second. What is the total energy in MeV the star produces per second?

- A. 3.14×10^{10} MeV per sec
 - B. 1.65×10^{39} MeV per sec
 - C. 2.06×10^{-11} MeV per sec
 - D. 6.02×10^{64} MeV per sec
9. The commercial nuclear power reactors are based on nuclear fission reactions induced by:
- A. protons,
 - B. electrons,
 - C. photons,
 - D. neutrons.
10. The amount of energy released in the fusion process: ${}^2\text{D} + {}^3\text{T} \rightarrow {}^4\text{He} + \text{n}$
- A. 1.76 KeV
 - B. 17.6 KeV
 - C. 1.76 MeV
 - D. 17.6 MeV
11. What is the half-life of tritium in years?
- A. 0.5
 - B. 12.3
 - C. 32
 - D. 64
12. During COVID in 2020 the world consumption of primary energy fell down to 13200 MTOE. Assume that the wind blows at 13m/s for 1/3 of the time (and that there is no wind at other times), that the efficiency of a wind turbine is 70% of the maximum theoretical value and the density of air is 1.2 kg/m^3 . How many wind turbines with a diameter of 60m would be needed to supply this total energy?
- A. 1.1×10^4 turbines
 - B. 5.6×10^7 turbines
 - C. 3.3×10^7 turbines
 - D. 1.3×10^8 turbines
13. What is the typical efficiency for commercial silicon solar cells?

- A. 8-10 %
- B. 15-18%
- C. 28-30%
- D. 45-48%

14. How large an area needs to be covered with solar cells to generate 11 TWh of electric energy in one year? Assume that the annual solar irradiation is 900 kWh.m^{-2} and that the solar cell has a typical efficiency.

- A. 42 km^2
- B. 81 km^2
- C. 102 km^2
- D. 1640 km^2

15. The mechanism of extracting energy from biomass is

- A. fusion
- B. fission
- C. combustion
- D. emission of radiation

Part 2. Calculations (40%)

Answer all questions. The number in brackets represents the contribution of each sub-question to the total score. Each problem counts for 10 points.

All questions should be answered. NO CREDIT will be given for a correct numerical answer unless the work is shown in all details!

The answers can be written by hand.

1. The oceans contain about $1.3 \times 10^{24} \text{ cm}^3$ of water. Deuterium constitutes 0.028% by mass of natural hydrogen.

a) What is the total energy in Joules available from this Deuterium by D-D fusion? Assume 4.0 MeV per fusion event. (5)

b) For how many years could fusion reactors with 50% efficiency supply 2.0 million MW? (5)

2. Calculate the power in megawatts during outflow from a tidal power plant that encloses a rectangular area of $1 \times 2.5 \text{ km}$, and which fills to a height of 3.6 m above the outlet. Assume an efficiency of 94%, and an emptying time of 1.5 hour. (10)

3. The world primary energy consumption 5 years ago was approximately 13 000 Mtoe. Assuming that flat panel solar cells at a sunny location in Spain can harvest $8 \text{ kWh/m}^2/\text{day}$, what area is required (at that location) to supply the energy needs of the earth? (10)

4. In a submitted patent an inventor claims to have developed a novel heat engine that operates with a not so hot nonpolluting flame at 150°C and transfers waste heat to the environment at 20°C . His promotional flyer claims that 45% of the fuel energy is converted into useful work. Calculate the maximum efficiency of such an engine and compare it to the claim. (10)

APPENDIX

Energy conversion factors

	J	kWh	Btu	toe
1 Joule (J)	1	2.78×10^{-7}	9.5×10^{-4}	2.38×10^{-11}
1 kilowatt-hr (kWh)	3.6×10^6	1	3413	8.6×10^{-5}
1 calorie (cal)	4.184	1.16×10^{-6}	3.97×10^{-3}	1×10^{-10}
1 British thermal unit (Btu)	1055	2.93×10^{-4}	1	2.5×10^{-8}
1 Electron volt (eV)	1.6×10^{-19}	4.45×10^{-26}	1.52×10^{-22}	3.8×10^{-30}

Storage material	MJ per kilogram	MJ per liter (litre)
Deuterium–tritium	330 000 000	0.14
Uranium-235	83 140 000[3]	1 546 000 000
Hydrogen (compressed at 70 MPa)	123	5.6
Gasoline (petrol) / Diesel	~46	~36
Propane (including LPG)	46.4	26
Fat (animal/vegetable)	37	
Coal	24	
Carbohydrates (including sugars)	17	
Protein	16.8	
Wood	16.2	

Density of water $1.02 \times 10^3 \text{ kg/m}^3$

density of air $\sim 1.2 \text{ kg/m}^3$

acceleration due to gravity 9.8 m/sec^2

Avogadro's number 6.02×10^{23} (# per mole)

Formulas

$$P(t) = \frac{1}{\beta} \left(1 - \frac{Q(t)}{Q_{\infty}} \right) Q(t)$$

$$Q(t) = \frac{Q_{\infty}}{1 + Ae^{-t/\beta}}$$

$$P(t) = P_0 \left(\frac{Q_{\infty}}{Q_0} \right)^2 \frac{e^{-t/\beta}}{(1 + Ae^{-t/\beta})^2}$$

$$\beta = (Q_{\infty} - Q_0) \frac{Q_0}{Q_{\infty} P_0}$$

$$t_m = \left(1 - \frac{Q_0}{Q_{\infty}} \right) \frac{Q_0}{P_0} \ln \left(\frac{Q_{\infty}}{Q_0} - 1 \right)$$

$$P_m = P(t_m) = \frac{Q_{\infty}^2 * P_0}{4Q_0(Q_{\infty} - Q_0)}$$

$$P = \frac{\Delta E}{\Delta t}$$

$$\eta = 1 - \frac{Q_L}{Q_H}$$

$$\eta_{carnot} = 1 - \frac{T_L}{T_H}$$

$$COP = \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$$

$$E = \frac{hc}{\lambda}; \quad hc = 1.98 \times 10^{-25} \text{ J} \cdot \text{m}$$

$$hc = 1.23 \times 10^{-6} \text{ eV} \cdot \text{m}$$

$$P = I^2 R$$

$$\frac{P}{A} = \epsilon \sigma T^4 \quad \sigma = 5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^4$$

$$I_0 \frac{\pi R^2}{4\pi R^2} = 342 \text{ W/m}^2$$

$$\frac{1}{4} I_0 = \frac{1}{4} \alpha I_0 + I_A$$

$$\lambda_m [\mu\text{m}] = \frac{2898}{T(\text{K})}$$

$$E_{pot} = mgh = \rho Vgh$$

$$E_{kin} = \frac{1}{2} mv^2$$

$$\frac{P}{A} = 6.1 \times 10^{-4} \text{ v}^3 [\text{kW/m}^2]$$

$$A = \pi r^2 = \pi \left(\frac{d}{2} \right)^2$$

$$\frac{\Delta Q}{\Delta t} = \frac{A}{R} \Delta T = AU \Delta T$$

$$R = 1/k$$

$$Q = mC\Delta T$$

$$m = \rho V$$

$$F = ma = m \frac{\Delta v}{\Delta t}$$

$$V = IR$$

$$J = E * c g \sim 1 \text{ kW/m}^3 \text{ s} * T \text{ H}^2$$

$$P = 0.59 \text{ A/2}(\rho u^3)$$

Periodic Table of the Elements

1 H Hydrogen 1																		2 He Helium 4																	
2 Li Lithium 3		3 Be Beryllium 9																		5 B Boron 11		6 C Carbon 12		7 N Nitrogen 14		8 O Oxygen 16		9 F Fluorine 19		10 Ne Neon 20					
11 Na Sodium 23		12 Mg Magnesium 24																		13 Al Aluminum 27		14 Si Silicon 28		15 P Phosphorus 31		16 S Sulfur 32		17 Cl Chlorine 35.5		18 H Argon 40					
19 K Potassium 39		20 Ca Calcium 40		21 Sc Scandium 45		22 Ti Titanium 48		23 V Vanadium 51		24 Cr Chromium 52		25 Mn Manganese 55		26 Fe Iron 56		27 Co Cobalt 59		28 Ni Nickel 59		29 Cu Copper 64		30 Zn Zinc 65		31 Ga Gallium 70		32 Ge Germanium 73		33 As Arsenic 75		34 Se Selenium 79		35 Br Bromine 80		36 Kr Krypton 84	
37 Rb Rubidium 86		38 Sr Strontium 88		39 Y Yttrium 89		40 Zr Zirconium 91		41 Nb Niobium 93		42 Nb Niobium 96		43 Tc Technetium 98		44 Ru Ruthenium 101		45 Rh Rhodium 103		46 Pd Palladium 106		47 Ag Silver 108		48 Cd Cadmium 112		49 In Indium 115		50 Sn Tin 119		51 Sb Antimony 122		52 Te Tellurium 128		53 I Iodine 127		54 Xe Xenon 131	
55 Cs Cesium 133		56 Ba Barium 137		57 La Lanthanum 139		58 Hf Hafnium 179		59 Ta Tantalum 181		60 W Tungsten 184		61 Re Rhenium 186		62 Os Osmium 190		63 Ir Iridium 192		64 Pt Platinum 195		65 Au Gold 197		66 Hg Mercury 201		67 Tl Thallium 204		68 Pb Lead 207		69 Bi Bismuth 209		70 Po Polonium 210		71 At Astatine 210		72 Rn Radon 222	
87 Fr Francium 223		88 Ra Radium 226		89 Ac Actinium 227		90 Unq Ununquadium 257		91 Unp Ununpentium 260		92 Unh Ununhexium 263		93 Uns Ununseptium 262		94 Uno Ununoctium 265		95 Uue Ununennium 266																			

58 Ce Cerium 140		59 Pr Praseodymium 141		60 Nd Neodymium 144		61 Pm Promethium 147		62 Sm Samarium 150		63 Eu Europium 152		64 Gd Gadolinium 157		65 Tb Terbium 159		66 Dy Dysprosium 136		67 Ho Holmium 165		68 Er Erbium 167		69 Tm Thulium 169		70 Yb Ytterbium 173		71 Lu Lutetium 175	
90 Th Thorium 232		91 Pa Protactinium 231		92 U Uranium 238		93 Np Neptunium 237		94 Pu Plutonium 244		95 Am Americium 243		96 Cm Curium 247		97 Bk Berkelium 247		98 Cf Californium 249		99 Es Einsteinium 254		100 Fm Fermium 253		101 Md Mendelevium 256		102 No Nobelium 254		103 Lr Lawrencium 257	

Heat of combustion (calorific value) of various fuels.

Fuel	MJ/kg	MJ/L
Wood green	~ 8	~ 6
Wood oven dry	~ 16	~ 12
Methane	56	0.038
petrol/gasoline	47	37
crude oil	44	35
Coal	27	