NTNU – Trondheim
Norwegian University of
Science and Technology

Department of Physics

Examination paper for FY2290 Energy Resources

Academic contact during examination: Turid Worren Reenaas

Phone: 4121 5871

Examination date: May 16, 2017

Examination time (from-to): 9-13

Permitted examination support material: any non-graphing calculator

Other information:

Language: English and Bokmål

Number of pages:

Number of pages enclosed

Checked by:

Date Signature

FY2290 Exam 2017

Note there is an Appendix with useful information attached to the back of the exam.

Write all your calculations and answers in the exam book.

NO CREDIT will be given for a correct numerical answer unless the work is shown, and answers without units will not earn points.

All questions should be answered. (Points for each question are shown as subscripts)

SHORT ANSWERS

1)$_5$ Approximately how many more years are fossil fuels expected to last (not counting methane clathrates)? (give a range that is not more than a factor of two wide)

100-200 years

2)$_5$ Define methane clathrates and give one danger of their release to the atmosphere

Methane clathrates are cage-like molecules containing H2O and methane, stable only under low temperature and moderate pressure . They occur in the continental shelf, primarily. As methane is a powerful greenhouse gas, their release will increase global warming, and if the oceans warm sufficiently, this will cause a positive feedback mechanism with additional release.

3)$_5$ Name a method associated with a high cost per kW of electricity, and one much lower

PV has high capital costs and small operating costs for a high total score; gas- or coal- fired plants have low capital costs and low enough operating costs for a low total.

4)$_6$ Name two major ways in which humans have altered methane emissions on earth

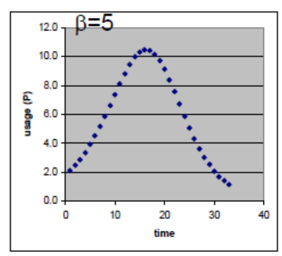
Farm animals, particularly beef, emit methane. Rice as an agricultural crop is a major contributor, as are leakage events during oil and gas extraction.

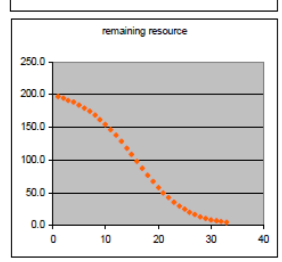
5)$_4$ Which of the following units are energy (not power)?

kWh, GW, BTU, EJ, eV, Watts, Quads

kWh, BTU, EJ, eV, Quads

6)$_6$ When an energy resource is tapped, the time evolution is often expressed by the equation $dQ/dt = (1/\beta)\, Q\, (1 - Q/Q_T)$ Identify the terms, and give three different temporal regions that can be used to approximate the equation as the resource is used. (Use a graph)





This is the logistic model, not the Hubbert…β is the exponent at short time scales, Q_T is the total amount of resource and Q is the resource at a given time. Initially, the use is dominated by exponential behavior, it then becomes linear when the resource is about half used, and at large t, approaches Q_T slowly.

7)$_4$ What is the difference between an energy resource and an energy vector? Give two examples of each.

Energy resource – source of energy (stored) e.g. nuclear fuel or oil reserves
Energy vector – way of transporting energy that is not normally present in a stored form – i.e. wind, EM radiation, hydrogen, electricity

8)$_5$ What is the chemical difference between oil, coal and a carbohydrate, and how are they related to their use/efficiency as fuels?

Oil is composed of hydrocarbon chains of mixed length, coal is a primarily carbon 3-dimensional networked solid containing sulfur and other impurities, and carbohydrates have considerable amounts of oxygen. The higher the ratio of H to C, the higher the energy density of the fuel, so oil wins, coal comes second, and since carbohydrates are partially oxidized ("burned"), they have low energy densities.

9)$_4$ What are known environmental problems associated with shale gas extraction? (mention at least 2)

Contamination of ground water, seismic disturbance

10)$_6$ How can you store electrical energy? Explain two methods and give a challenge for each of them.This question judged ambiguous - full credit given to all

Batteries and capacitors. The chemicals in batteries are potential pollutants, and the energy release is typically slow, while capacitors do not store huge amounts of energy, but the release can be very fast.

11)$_5$ Compare blackbody radiation from the sun and the earth, giving numerical values of important parameters.

The sun's peak wavelength is in the visible (~600 nm) while the earth's is in the infrared (10,000 nm). Since the intensity of the radiation goes as σT^4, and the sun is both hotter (6000K vs 300 K), and larger than the earth, its power emission is much higher.

12)$_5$ Explain the reason the equilibrium temperature of the earth is higher than that given by a simple energy balance calculation

The greenhouse effect – the atmosphere transmits well in the visible , the earth warms to 300K where it emits IR radiation which is absorbed by the atmosphere. The atmosphere reradiates the energy in all directions, including some back to the Earth, increasing the temperature.

PROBLEMS

A) A refrigerator with a COP of 1.2 consumes 50kWh (1.8 MJ) of electrical energy while operating over a particular period of time. During this time,

a)$_5$ How much heat energy is removed from the refrigerator 60kWh (1.2x 50)
b)$_5$ How much heat energy is removed (dissipated) by the condenser?110kWh (50+60)

B)$_5$ A tidal energy plant has one 20 MWe turbine. If operating at full power, what is the water flow per second, assuming the water change in height is 4 m, the water density is 1.02 x 10^3 kg/m^3, and the conversion efficiency is 95%?

Energy in water =20 x 10^6 W/.95=h*density *g*Volume; volume =525 m^3

C)$_5$ *Thermal transport/efficiency*

A 2.5 cm thick layer of wood (k=0.12 W°C^{-1}m^{-1}) is glued to a 10 cm thick cement (k=1.3) wall as shown. The face of the wood is held at 30 C and the far side of the cement is held at 10 C. What is the power transmitted through each square meter of the wall, and what is the temperature at the cement/wood interface (T)?

Driving force = Temp difference = 20C=flow*resistance =>flow =Q per m^2=70W/m^2

resistances for each substance are L/k (per m^2)

20=(2.5e-2/.12 +1/1.3)Q/m^2

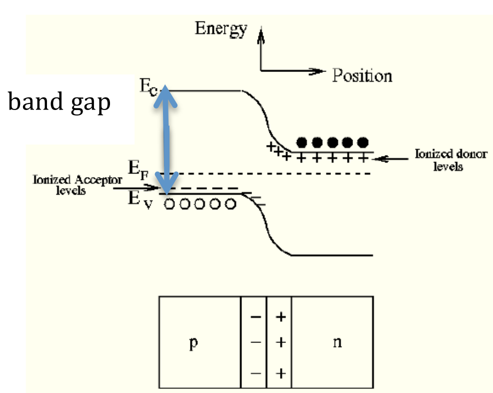
temperature in the middle; heat flow is the same in both, so delta T = R*Q for either material; T=30-14.6 =15.4

D) Photovoltaics

a)$_5$ Draw a sketch of the energy bands in a silicon p-n junction. Label the valence band, conduction band and the band gap.

Ec is the conduction band and Ev is the valence band energy. the band gap is the difference between them

b)$_6$ Explain what happens when a photon is absorbed in the vicinity of the junction, and how this leads to electrical power generation. The photon gives energy to an electron which may move to the conduction band, leaving an electron hole in the valence band. The energy level of the electron is enough above the valence band that it can deliver energy to a circuit element between these two - i.e. there is a voltage, a current can flow, and electrical power is delivered.



Appendix

Energy conversion factors

	J	kWh	Btu	toe
1 Joule (J)	1	2.78 x 10^{-7}	9.5 x 10^{-4}	2.38 x 10^{-11}
1 kilowatt-hr (kWh)	3.6 x 10^{6}	1	3413	8.6x10^{-5}
1 calorie (cal)	4.184	1.16 x 10^{-6}	3.97x 10^{-3}	1x 10^{-10}
1 British thermal unit (Btu)	1055	2.93 x 10^{-4}	1	2.5 x 10^{-8}
1 Electron volt (eV)	1.6x 10^{-19}	4.45x 10^{-26}	1.52 x 10^{-22}	3.8 x 10^{-30}

Equations

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

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

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

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

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

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

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

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

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

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

$$E = \frac{hc}{\lambda}; \quad hc = 1.98x10^{-25}\,J.m$$

$$hc = 1.23x10^{-6}\,eV \cdot m$$

$$P = I^2 R$$

$$\frac{P}{A} = \varepsilon\sigma T^4 \qquad \sigma = 5.67 \text{ x } 10^{-8}\ Wm^{-2}K^{-4}$$

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

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

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

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

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

$$\frac{P}{A} = 6.1x10^{-4}\,v^3[kW/m^2]$$

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

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

$$R = 1/k$$

$$Q = mC\Delta T$$

$$m = \rho V$$

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

$$V = IR$$

$$J = E*cg \sim 1\ kW/m^3 s\ *T\,H^2$$

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

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 $1.02 \times 10^3 kg/m^3$
density of air $\sim 1.2 \ kg/m^3$
acceleration due to gravity $9.8 \ m/sec^2$
Avogadro's number 6.02×10^{23}(# per mole)