Exam 47202 Introduction to future energy - December 2020

Dear participants. Welcome to the exam 2020 for 47202 Introduction to future energy.
The rules are simple: only one answer is correct for each question and you can only give one answer.

Q1. Introduction i. What is the current energy consumption of society?

Choose one answer

- A: 18 MW
- B: 18 GW
- C: 18 TW
- D: 18 PW
- E: 18 EW

Q2. Introduction ii. What has been the average annual growth rate of total energy consumption in the past few decades?

Choose one answer

- A: 1.5%
- B: 1.8%
- C: 2.1%
- D: 2.3%
- E: 3.1%

Q3. Introduction iii. What is the growth rate for total global population?

Choose one answer

- A: 80 M/yr
- B: 30 M/yr
- C: 8 M/yr
- D: Approximately zero
- E: -20 M/yr

Q4. Introduction iv. Which is currently the largest energy source for society?

Choose one answer

- A: Coal
- B: Natural gas
- C: Nuclear
- D: Oil
- E: Renewable (all combined)

Q5. Wind i. The IEC wind class III is characterized by an average wind speed V_{ave} of

Choose one answer

- A: 2-4 m/s
- B: 6-7 m/s
- C: 7-8 m/s
- D: 8-9 m/s
- E: 9-11 m/s

Q6. Wind ii. A turbine with a power rating of P_0 = 10 MW and a rotor diameter of D_0 = 178 m must be scale up in a new design to provide a power of P_1 = 15 MW. What must the rotor diameter D_1 of the new design be if the wind conditions and the power coefficient of the rotors are assumed the same?

Choose one answer

- A: D_1 = 200-210 m
- B: D_1 = 210-220 m
- C: D_1 = 220-230 m
- D: D_1 = 230-250 m
- E: D_1 = 250-270 m

Q7. Wind iii. An offshore wind turbine with a rated power of P = 15 MW is stated to have a capacity factor of 55 %. What is the average Annual Energy Production (AEP)?

Choose one answer

- A: AEP = 30-40 GWh/year
- B: AEP = 40-50 GWh/year
- C: AEP = 50-60 GWh/year
- D: AEP = 60-70 GWh/year
- E: AEP = 70-80 GWh/year

Q8. Wind iv. Consider the wind turbine with the power curve shown in Figure 8.28 of “Renewable Energy” by Stephan Peake (see below) and imagine that this turbine is installed in a place, where the wind speed distribution is given by Figure 8.29 in “Renewable Energy” by Stephan Peake(see below). How many hours per year is the turbine expected not to produce any power?

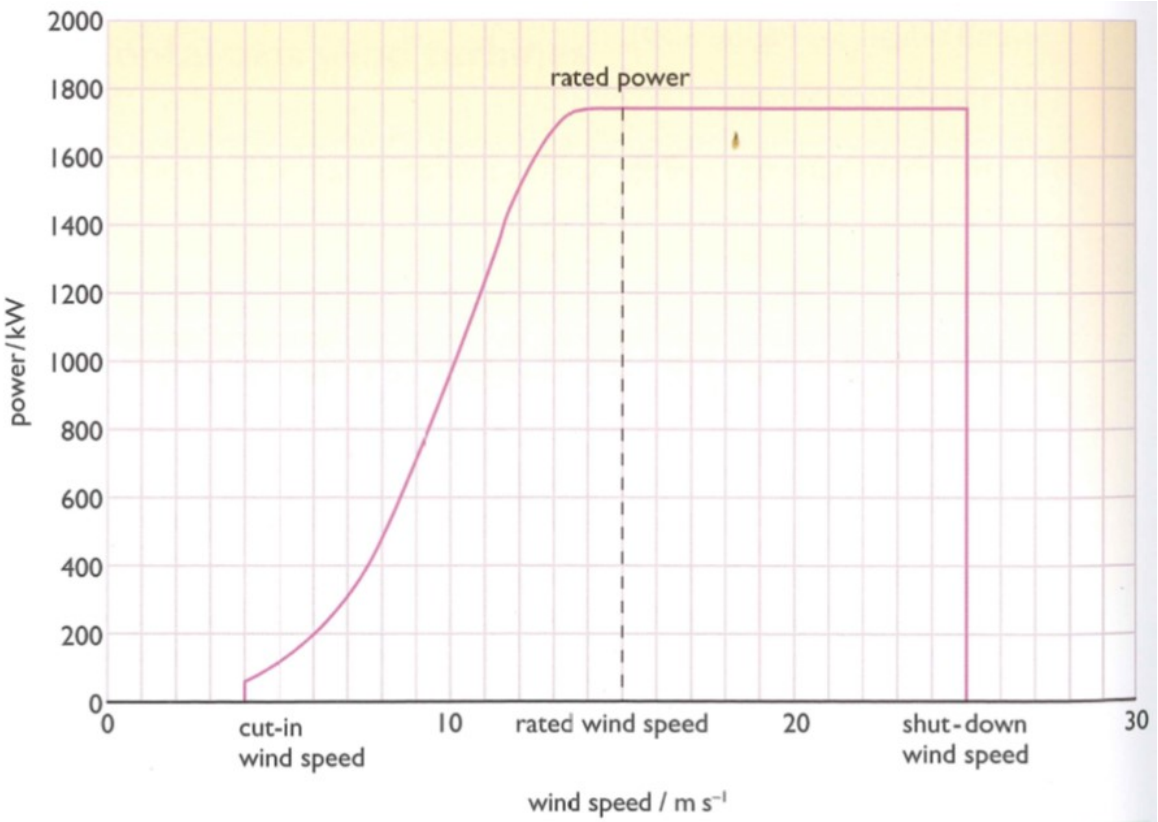

Figure 8.28 Typical wind turbine wind speed–power curve

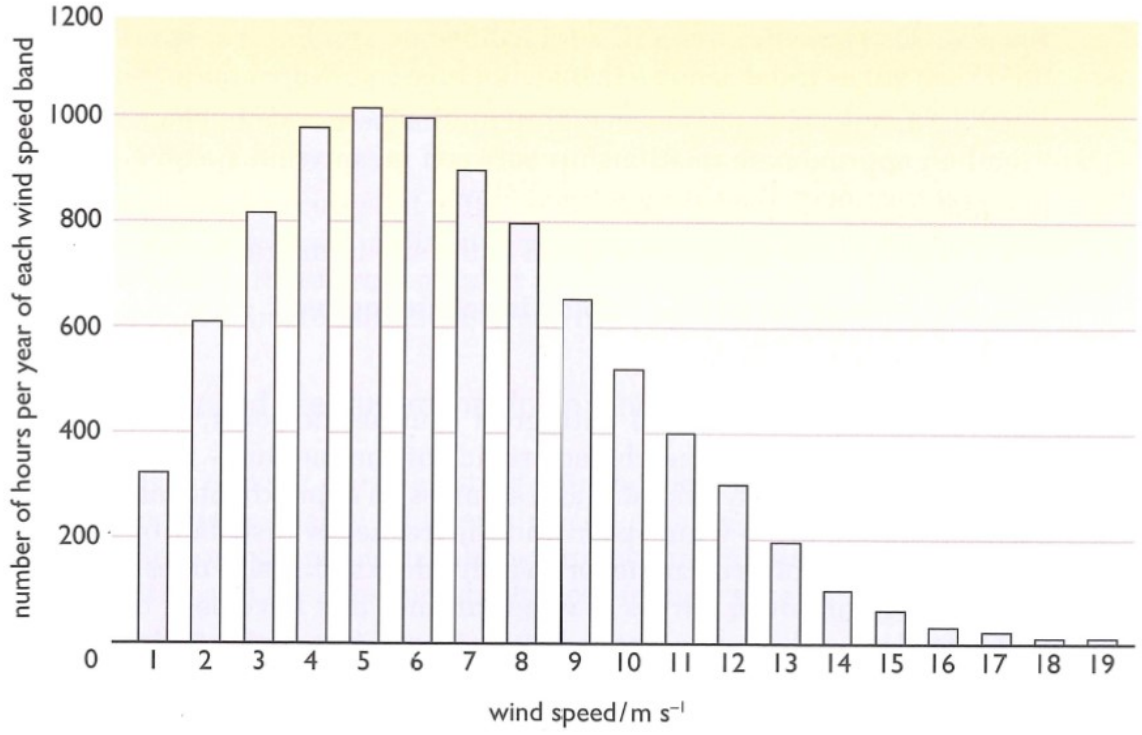

Figure 8.29 A wind speed frequency distribution for a typical site

Choose one answer

- A: 200-300 hours/year
- B: 500-700 hours/year
- C: 700-900 hours/year
- D: 1000-1200 hours/year
- E: 1600-1800 hours/year

Q9. Solar i. A solar cell is operating at 60 degress Celsius and the gives it's highest power at 620 mV. What would be the open circuit voltage of the cell under the same conditions (assume the cell is "ideal")?

Choose one answer

- A: 707 mV
- B: 679 mV
- C: 645 mV
- D: 620 mV
- E: 533 mV

Q10. Solar ii. Approximately how much total solar energy lands on a square meter of flat field in Denmark over the course of a year?

Choose one answer

- A: 1 kWh (3.6 MJ)
- B: 10 kWh (36 MJ)
- C: 100 kWh (360 MJ)
- D: 1 MWh (3.6 GJ)
- E: 10 MWh (36 GJ)

Q11. Solar iii. If you are designing a tandem solar cell (a two-absorber stacked cell) how should you choose the difference in band gap between the two absorbers?

Choose one answer

- A: So that the voltage delivered by both (sub)cells is the same.
- B: So that the current delivered by both (sub)cells is the same.
- C: So that the fill-factor (FF) of both (sub)cells is the same.
- D: So that the power at the maximum power point (MPP) of both cells is the same.
- E: So that the apparent color of the two (sub)cells is the same.

Q12. Solar iv. A solar cell gains voltage (OCV) as the band gap is increased, so why is there an optimum band gap for a single-junction solar cell?

Choose one answer

- A: Because no known materials have higher band gap than GaP (2.24 eV band gap).
- B: Because too high band gap causes the cell to become too hot when it's under full sun.
- C: Because as the band gap goes up, the fill factor (FF) goes down negating the gain.
- D: Because high band gap comes at significant economic cost, and cells with very high band gap are simply too expensive.
- E: Because a high band gap cannot utilize many low energy photons leading to lower cell current.

Q13. Biomass i. What is primarily produced on Danish agricultural land?

Choose one answer

- A: Food for human consumption
- B: Fodder production for animals
- C: Energy crops
- D: Maize
- E: Beets

Q14. Biomass ii. In pyrolysis of biomass, how much of the mass is converted to gas?

Choose one answer

- A: approx. 25%
- B: approx. 50%
- C: approx. 75%
- D: approx. 90%
- E: all the organic matter

Q15. Biomass iii. 1 kg of biomass contains about 45 wt% of carbon. If all carbon is converted to DME, what is the output of DME (CH3OCH3) per kg of biomass input?

Choose one answer

- A: 0.45 kg
- B: 0.67 kg
- C: 0.79 kg
- D: 0.86 kg
- E: 0.1.00 kg

Q16. Biomass iv. Consider the following synthesis reaction for DME production: 2 CO + 4 H2 -> CH3OCH3 + H2O. What is the energy efficiency for the conversion of syngas to DME? LHV_H2: 241.8 MJ/kmol, LHV_CO: 283.0 MJ/kmol, LHV_DME: 1328 MJ/kmol

Choose one answer

- A: 80%
- B: 82%
- C: 84%
- D: 87%
- E: 100%

Q17. Nuclear i. Typical energy of fast and thermal neutrons, respectively?

Choose one answer

- 2 MeV and 20 eV
- 2 MeV and 20 meV
- 2 keV and 20 eV
- 2 keV and 20 meV
- 2 eV and 20 meV

Q18. Nuclear ii. In a thermal reactor, neutrons are moderated in order to

Choose one answer

- A: increase the probability for fission
- B: have more neutrons emitted per fission
- C: have more energy released per fission
- D: have better fuel utilization
- E: None of the above

Q19. Nuclear iii. Today, the main technology for enrichment is

Choose one answer

- A: Gas diffusion
- B: Laser separation
- C: Gas centrifuges
- D: Column chromatography
- E: Electroplating

Q20. Nuclear iv. Generation IV reactors are mostly

Choose one answer

- A: thermonuclear reactors
- B: high temperature reactors
- C: fast reactors
- D: modular reactors
- E: Thorium reactors

Q21. Water i. Which of the principles are utilized for harvesting wave energy?

Choose one answer

- A: Oscillating body, oscillating water column and ocean current
- B: Oscillating water column, ocean current and overtopping
- C: Oscillating body, oscillating water column and overtopping
- D: Only oscillating body
- E: Only Oscillating body and oscillating water column

Q22. Water ii. The operating principle of OTEC is

Choose one answer

- A: Electric power is extracted from deep sea hot water by a heat engine
- B: Electric power is extracted from cooling warm ocean surface water by a heat engine and returning it in the deep sea
- C: Electric power is generated by pumping hot water to the deep see
- D: Electric power is generated from warm surface water driven by the temperature difference between the ocean surface water and the cold deep sea
- E: Electric power is generated by utilizing the difference in buoyancy of warm and cold water

Q23. Water iii. Where is wave energy most energetic?

Choose one answer

- A: Near equator where the weather systems of the northern and the southern hemisphere meet
- B: As close to the poles as possible
- C: At latitudes roughly halfway between equator and the poles
- D: Where the water is deepest and the waves are least damped
- E: Where salinity is high and consequently, the specific density of the water high

Q24. Water iv. Which statement is correct for geothermal energy

Choose one answer

- A: Geothermal energy is only realistic in countries with volcanic activity
- B: Geothermal energy always require a heat pump because the temperatures available are always very low
- C: The term “geothermal energy” covers all heat pump facilitated heating technologies that utilize underground circulating fluids – including small private garden installations
- D: Geothermal energy requires deep drilling if not in areas with geothermal activity close to the surface (like in Iceland) and can be used for power generation as well as domestic heating.
- E: Geothermal energy is already close to being completely utilized and a further extension can only be very limited

Q25. Thermodynamics and electrochemistry i. Why is the thermodynamic function enthalpy, *H*, used more often than internal energy, *U*?

Choose one answer

- A: It is easier to assign absolute values to *H* than to *U*
- B: *H* is more practical at constant pressure because it compensates for the necessary volume changes
- C: ΔH determines the maximum amount of work obtainable from at process. ΔU does not
- D: ΔH can be calculated directly from the heat capacity and the temperature change. ΔU cannot
- E: *H* is more practical than *U* when the temperature is not fixed

Q26. Thermodynamics and electrochemistry ii. Calculate the standard enthalpy of combustion (= - higher heating value) of propane (C_3H_8) from the following standard enthalpies of formation: $\Delta H_f°$ (C_3H_8): -130.9 kJ/mol , $\Delta H_f°$ (CO_2): -393.5 kJ/mol, $\Delta H_f°$ (H_2O (liquid)): -285.8 kJ/mol , $\Delta H_f°$ (H_2O (gas)): -241.8 kJ/mol.

Choose one answer

- A: -504,4 kJ/mol
- B: -548,4 kJ/mol
- C: -2016,8 kJ/mol
- D: -2192,8 kJ/mol
- E: -2220 kJ/mol

Q27. Thermodynamics and electrochemistry iii. Combustion of methanol follows $CH_3OH + 1.5O_2 \rightarrow CO_2 + 3H_2O$. The standard enthalpy change of the process is −726.6 kJ/mol and the standard Gibbs free energy change of the process is -702.5 kJ/mol. Calculate the standard reversible cell voltage if methanol is consumed directly in a fuel cell (all species in the standard condition). The process involves 6 electrons.

Choose one answer

- A: 1.17 V
- B: 1.21 V
- C: 1.26 V
- D: 3.6 V
- E: 3.8 V

Q28. Thermodynamics and electrochemistry iv. Which of the following statement on thermodynamics and kinetics is correct

Choose one answer

- A: The kinetics of a reaction is determined by thermodynamics
- B: A catalyst makes a reaction faster, and thus the reaction can reach a new equilibrium, which is more in favor of the products.
- C: If the equilibrium of a reaction predicts an almost full conversion to the product, there is no need for a catalyst.
- D: The equilibrium cell voltage of an electrochemical cell is determined by the reaction kinetics
- E: Kinetics can be optimized (faster reaction) by a proper catalyst, but this cannot change the equilibrium of the reaction.

Q29. Storage i. Rank the following energy storage technologies according to their global installed capacity: (I) thermal; (II) pumped hydro storage (PHS); (III) mechanical (excl. PHS); (IV) electro-chemical; (V) chemical (hydrogen storage)

Choose one answer

- A: Thermal > PHS > electro-chemical > chemical > mechanical
- B: PHS > thermal > electro-chemical > mechanical > chemical
- C: Mechanical > thermal > electro-chemical > chemical > PHS
- D: Electro-chemical > chemical > PHS > thermal > mechanical
- E: Chemical > thermal > PHS > mechanical > electro-chemical

Q30. Storage ii. Which one of the following statements is **false**:

Choose one answer

- A: Flywheels are suitable for short time-scale and high-power energy storage
- B: Na-S batteries are suitable for stationary energy storage
- C: A phase change material (PCM) can store different amounts of energy in its different phases
- D: Thermal energy storage can be divided into sensible, latent and thermo-chemical energy storage
- E: Compressed Air Energy Storage (CAES) has a cycle efficiency of 80% or higher

Q31. Storage iii. Rank the following energy storage technologies according to their power output (rating), going from high to low: (I) Li-ion batteries; (II) Compressed Air Energy Storage (CAES); (III) flywheels ; (IV) flow batteries ; (V) Pumped Hydro Storage (PHS)

Choose one answer

- A: Flow batteries > flywheels > PHS > Li-ion > CAES
- B: Li-ion > PHS > flywheels > CAES > flow batteries
- C: PHS > CAES > flow batteries > Li-ion > flywheels
- D: CAES > flow batteries > flywheels > PHS > Li-ion
- E: Flywheels > CAES > Li-ion > flow batteries > PHS

Q32. Storage iv. Which of the following thermal energy storage solutions can store the most energy in 1 m^3 of the given material, if it is heated from 25 to 75 deg. C:
(I) water (specific heat: 4182 J/kg K; density: 1000 kg/m^3); (II) granite (specific heat: 774 J/kg K; density: 2700 kg/m^3); (III) steel (specific heat: 465 J/kg K; density: 7840 kg/m^3); (IV) stearic acid (specific heat: 2480 J/kg K; density: 900 kg/m^3; latent heat of fusion: 202.5 kJ/kg; melting point: 69 deg C)

Choose one answer

- A: Water > stearic acid > steel > granite
- B: Granite > stearic acid > steel > water
- C: Stearic acid > water > steel > granite
- D: Steel > water > granite > stearic acid
- E: Granite > water > stearic acid > steel

Q33. Fuel cells and hydrogen i. What is role of the electrolyte in a fuel cell?

Choose one answer

- A: It is an insulator preventing the passage of the current of any charged species
- B: It conducts ions, but not electrons or gasses
- C: It blocks the passage of ions and molecules but conducts electrons
- D: It catalyzes the electrochemical processes on the electrodes
- E: It closes the electrical circuit by conducting electrons

Q34. Fuel cells and hydrogen ii. Which of the following statement is correct in relation to fuel cells and Carnot's limitation (on the maximum conversion efficiency)?

Choose one answer

- A: All devices converting fuel energy to work must obey the Carnot limitation
- B: Fuel cells are only limited by Carnot if they are net heat producers
- C: It is the temperature of the reacting hydrogen and air that determines to which extend the fuel cell process I limited by Carnot
- D: Any hydrogen powered fuel cells can in principle obtain 100 % electrical efficiency, even at room temperature and consequently, it cannot be limited by Carnot
- E: A fuel cell is not limited by Carnot

Q35. Fuel cells and hydrogen iii. A hydrogen powered fuel cell fuel is operated at 0.74 V and produces 100 W electricity. How much heat does it produce? (Assume the produced water is liquid and consider only the fuel cell - disregard the system around it)

Choose one answer

- A: Fuel cells produce electricity (work) only and not heat
- B: The cell is at maximum 82 % efficient so the total energy converted is (100 W/0.82) 122 W and thus the heat production is 22 W
- C: The reversible cell voltage is 1.23 V and the cell voltage 0.74 V so the total energy converted is (100 W x 1.23/0.74) 166 W and thus the heat production is 66 W
- D: The thermoneutral cell voltage is 1.48 V and the cell voltage 0.74 V so the total energy converted is (100 W x 1.48/0.74) 200 W and thus the heat production is 100 W
- E: Below the thermo-neutral voltage, an electrochemical cell does not produce heat

Q36. Fuel cells and hydrogen iv. Fuel cell vehicles powered by hydrogen use the following hydrogen storage technology:

Choose one answer

- A: Compressed hydrogen, mostly at 700 bar in fiber composite tanks
- B: Liquid hydrogen at 20 K
- C: Metal hydrides for safety reasons
- D: Liquid organic hydrogen carriers
- E: Compressed hydrogen at 200 bar in steel taks

Q37. Batteries i. Which of the following statements about batteries is **false**:

Choose one answer

- A: The open circuit voltage (OCV) is the difference between the electrochemical potentials of the negative and positive electrodes
- B: The gravimetric energy density is ranked as follows: Li-ion > Ni-MH > Ni-Cd > Pb-acid
- C: The energy and power density can be scaled independently in a flow battery
- D: The lithium-oxygen (Li-air) battery chemistry has the highest theoretical specific energy (Wh/kg)
- E: It takes 4 times longer to charge a battery at a C-rate of 2C than at C/2

Q38. Batteries ii. The following two reactions can take place in a lithium iron fluoride (FeF_3/Li) battery:
(I) $FeF_3 + Li^+ + e^- <-> LiFeF_3$ and (II) $LiFeF_3 + 2Li^+ + 2e^- <-> Fe + 3LiF$
Which of the following elements are being reduced, oxidized or neither of the two during reaction (II):

Choose one answer

- A: Neither lithium, iron nor fluorine is reduced or oxidized
- B: Fluorine is oxidized, while iron and lithium are reduced
- C: lithium and fluorine are oxidized, while iron is reduced
- D: Iron is reduced, while lithium and fluorine are neither oxidized nor reduced
- E: lithium is oxidized, fluorine is reduced and iron neither oxidized nor reduced

Q39. Batteries iii. What are the capacities of the two reaction steps: (I) FeF_3 + Li+ + e- <-> $LiFeF_3$ and (II) $LiFeF_3$ + 2Li+ + 2e- <-> Fe + 3LiF (molar masses: MLi = 6.94 g/mol; MF = 19.00 g/mol ; MFe = 55.85 g/mol).

Choose one answer

- A: (I) = 237 mAh/g and (II) 475 mAh/g
- B: (I) = 237 Wh/kg and (II) 475 Wh/kg
- C: (I) = 237 Wh/kg and (II) 712 Wh/kg
- D: (I) = 475 mAh/g and (II) 712 Wh/kg
- E: (I) = 855 mAh/g and (II) 1710 mAh/g

Q40. Batteries iv. A given battery retains 74% of its initial capacity Qini after 200 cycles. What is a) it's average Coulombic Efficiency (CEav) of a single charge-discharge cycle and b) how many cycles will it take before it has 40% of its initial capacity left?

Choose one answer

- A: 95% and ~400 cycles
- B: 98,5% and ~500 cycles
- C: 99,85% and ~600 cycles
- D: 99,99% and ~800 cycles
- E: 99,999% and ~1000 cycles

Q41. Electrolysis and synfuels i. Which electrolyzer type is dependent on noble metals?

Choose one answer

- A: The alkaline electrolyzer
- B: The PEM electrolyzer
- C: The solid oxide electrolyzer
- D: None of them
- E: All of them

Q42. Electrolysis and synfuels ii. A water electrolyzer is operated at 25 °C producing hydrogen and oxygen, both at 1 bar. The operating voltage is 1.77 V. Which one of the following statements is correct?

Choose one answer

- A: The cell is a net producer of heat
- B: The cell is a net consumer of heat
- C: The electrochemical process of electrolysis is endothermal and thus electrolyzers are always consuming heat
- D: The electrochemical process of electrolysis is exothermal and thus electrolyzer are always producing heat
- E: It cannot be determined from the cell voltage if the cell is a net producer or consumer of heat

Q43. Electrolysis and synfuels iii. The Sabatier process, $4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$ at 300 °C, is exothermic. Which one of the following statements is NOT correct?

Choose one answer

- A: It leads to an increased fuel quality in the sense that energy density of methane as a compressed gas is higher that of hydrogen at a similar pressure
- B: It increases the energy content of a flow of fuel going through the process because the molar *higher heating value* of methane is higher than that of hydrogen
- C: It leads to a loss of fuel energy (enthalpy) because the process is exothermal resulting in a loss of energy form the system
- D: The standard change of entropy is negative, but this is balanced by dissipated heat from the process.
- E: Hydrogen delivers the energy to the final fuel and CO*2* only delivers carbon atoms without providing any fuel energy.

Q44. Electrolysis and synfuels iv. Which of the following processes is not considered as *power-to-X*?

Choose one answer

- A: Conversion of wind power to hydrogen by electrolysis
- B: Conversion of solar electricity to ammonia for further production of fertilizers
- C: Conversion of natural gas to hydrogen in combination with CO_2 sequestration
- D: Conversion of wind power to synthetic natural gas
- E: Conversion of wind power to methanol

Q45. Infrastructure i. Estimate how many cubic kilometers of oil humanity burns in a year

Choose one answer

- A: 0.8 km^3
- B: 5 km^3
- C: 30 km^3
- D: 150 km^3
- E: 700 km^3

Q46. Infrastructure ii. Infrastructure ii. You perform a service for an employer of impeccable credit worthiness. Assuming zero inflation, which of the following payments would you prefer if your discount rate is 10% p.a.:

Choose one answer

- A: 1000 kr today
- B: 1150 kr in 1.5 years from now
- C: 330 kr today + 300 kr in 1 year + 270 kr in two years
- D: 2000 kr in 8 years from now
- E: 500 kr today + 600 kr one year from now

Q47. Infrastructure iii. Infrastructure iii. Suppose in the previous question that the inflation rate is 2% p.a. but your discount rate is only 5% p.a. Which payment would you prefer in that case?

Choose one answer

- A: 1000 kr today
- B: 1150 kr in 1.5 years from now
- C: 330 kr today + 300 kr in 1 year + 270 kr in two years
- D: 2000 kr in 8 years from now
- E: 500 kr today + 600 kr one year from now

Q48. Infrastructure iv. Suppose you wish to finance an offshore wind turbine installation and you raise 60% of the money from that bank which charges 7% annual interest and 40% from investors whom you promise 12% annual returns. Assuming that your tax rate is 40%, which of the following statements about your capital structure is true:

Choose one answer

- A: WACC is 7.12% and gearing is 0.6
- B: WACC is 7.32 and gearing is 0.67
- C: WACC is 9.00 and gearing is 1.5
- D: WACC is 7.12 and gearing is 0.67
- E: WACC is 7.32 and gearing is 1.5