# 47202 Introduction to Future Energy - Ordinary exam 2023

Der anvendes en scoringsalgoritme, som er baseret på "One best answer"

Dette betyder følgende:
Der er altid netop ét svar som er mere rigtigt end de andre
Studerende kan kun vælge ét svar per spørgsmål
Hvert rigtigt svar giver 1 point
Hvert forkert svar giver 0 point (der benyttes IKKE negative point)

The following approach to scoring responses is implemented and is based on "One best answer"
There is always only one correct answer – a response that is more correct than the rest
Students are only able to select one answer per question
Every correct answer corresponds to 1 point
Every incorrect answer corresponds to 0 points (incorrect answers do not result in subtraction of points)

Q1. Introduction i.
In any real process, a certain thermodynamic quantity must always increase. This is the:

Choose one answer

- A: Temperature
- B: Energy
- C: Free Energy
- D: Enthalpy
- E: Entropy

Q2. Introduction ii.
Assume that 1 ton of  oil has an energy content of 42 GJ and that the density of fuel is 800 gram/liter.
If an electric car is charging at a fast charger at 250 kW, what is the equivalent flow rate of fuel?

Choose one answer

- A: 0.0059 l/s
- B: 0.0074 l/s
- C: 0.059 l/s
- D: 0.074 l/s
- E: 0.59 l/s

Q3. Introduction iii.
Global hydropower generation is around:

Choose one answer

- A: 1200 GW
- B:  12 TW
- C: 1200 MW
- D: 12 GW
- E: 12 EW

Q4. Introduction iv.
What is the (potential) issue with availability of by-product elements?

Choose one answer

- A: That their production pollutes more than that of main-products.
- B: That their crustal abundance is very low.
- C: That they tend to be radioactive.
- D: That their production tends to be price inelastic.
- E: That they tend to be easy to substitute with other elements.

Q5. Wind i.

A wind turbine with a rotor diameter of $D_{rotor}$ = 236 m is exposed to an air stream with a steady wind velocity of $V$ = 10 m/s and a mass density of $\rho$ = 1.225 kg / $m^3$. How many tons of air is passing the rotor area per second?

Choose one answer

- A: 100-200 ton/second
- B: 200-300 ton/second
- C: 300-400 ton/second
- D: 400-500 ton/second
- E:  500-600 ton/second

Q6. Wind ii.

How is the output power of a pitch regulated wind turbine limited when the wind speed $V$ is exceeding the rated wind speed $V_R$ of the turbine?

Choose one answer

- A: By turning the orientation of the rotor plane away from the wind direction
- B: By activating a mechanical brake
- C: By turning the orientation of the blades with respect to the incoming wind direction
- D: By slowing down the rotation speed of the turbine blades
- E: By sending less power to the grid

Q7. Wind iii. Consider a wind turbine with a power curve, where the cut-in wind speed is $V_{Cut\text{-}In}$ = 3 m/s. How many hours per year will such a turbine NOT produce any energy if placed in the wind conditions shown in Figure Q7 ( 8.29 below)?

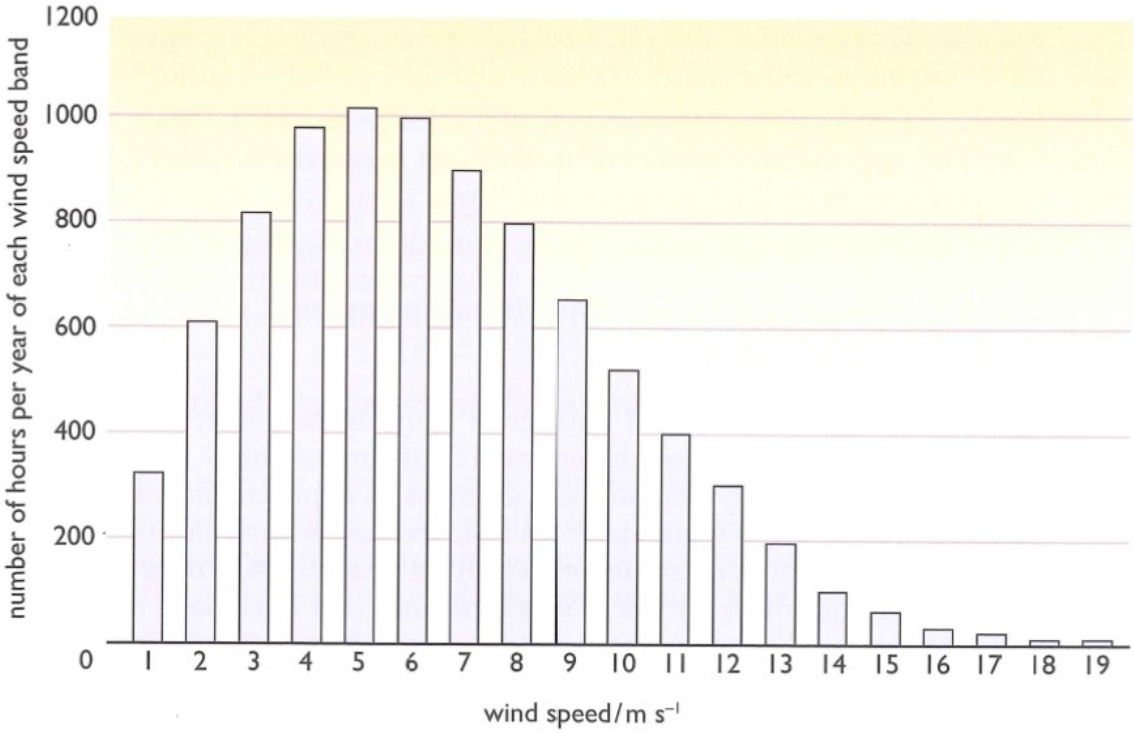


**Figure 8.29** A wind speed frequency distribution for a typical site

Choose one answer

- A: 200-400
- B: 400-700
- C: 700-800
- D: 800-1000
- E: 1000-1400

Q8. Wind iv.

A turbine with a rotor diameter of $D_{rotor}$ = 100 m and a power rating of $P$ = 3 MW is installed in a place where the capacity factor ($CF$) of the turbine is predicted to be 0.51. What is the expected Annual Energy Production($AEP$) of the turbine?

Choose one answer

- A: 5-10 GWh/year
- B: 10-15 GWh/year
- C: 15-20 GWh/year
- D: 20-25 GWh/year
- E: 25-30 GWh/year

Q9. Solar i.

How does the open circuit voltage of a photovoltaic cell depend on temperature?

Choose one answer

- A: Uoc goes down as T goes up because the short circuit current density goes down.
- B: Uoc goes down as T goes up because the saturation current density goes down.
- C: Uoc goes down as T goes up because the saturation current density goes up.
- D: Uoc goes down as T goes up because the fill factor goes up.
- E: Uoc goes down as T goes up because the band gap goes up.

Q10. Solar ii.
What is the "solar learning curve"/Swanson's law about?

Choose one answer

- A: The price of solar modules vs efficiency.
- B: The price of solar modules vs cumulative production.
- C: The efficiency of solar modules vs time.
- D: The LCOE of solar modules vs time.
- E: The degradation of solar module output vs age of the module.

Q11. Solar iii.
Estimate the optimum bandgap for a bottom cell to work in a tandem cell configuration with a top cell which has a bandgap of 1.68 V.

Choose one answer

- A: Ca 2.36 eV
- B: Ca 1.68
- C: 1.0 eV
- D: 0.84 eV
- E: 0.36 eV

Q12. Solar iv.
What does PEC (photoelectrochemistry) aim to achieve?

Choose one answer

- A: Combine photovoltaics with solar heat capture.
- B: Use illuminated semiconducting powders suspended in electrolyte to run uphill electrochemical reactions.
- C: Use electrochemical reactions to generate light.
- D: To photograph (in situ) how electrochemical reactions proceed on an electrode surface.
- E: Run uphill electrochemical reactions directly on an an illuminated semiconductor.

Q13. Water i.
What is the origin of the Osmotic Power?

Choose one answer

- A: Temperature difference in the sea
- B: Difference in salinity between fresh water and seawater
- C: Ocean current
- D: Ocean move
- E: None of the listed

Q14. Water ii.
Which of the following power types is a thermal system?

Choose one answer

- A:  Hydro power
- B: Wave power
- C: Tidal current power
- D: Geothermal energy
- E: Osmotic power

Q15. Water iii.
Which of the following types has the largest share of installed capacity in 2021?

Choose one answer

- A: Hydro power
- B: Marine power
- C: Geothermal power
- D: Wind power
- E: Solar PV

Q16 Water iv.
Which of the following turbine types is suitable for small flow (<1 $m^3/s$) but high head (>500 m)?

Choose one answer

- A: Pelton
- B: Francis
- C: Kaplan
- D: Propellor
- E: None of the listed

Q17. Nuclear i.
What is the outlet coolant temperature in a boiling water reactor?

Choose one answer

- A: 220 $^{o}$C
- B: 290 $^{o}$C
- C: 370 $^{o}$C
- D: 450 $^{o}$C
- E: 520 $^{o}$C

Q18. Nuclear ii.

In the liquid drop model of the atomic nucleus, which term always contributes with a positive binding energy?

Choose one answer

- A: Volume term
- B: Surface term
- C: Coulomb term
- D: Asymmetry term
- E: Pairing term

Q19. Nuclear iii.
A 3000 MW (thermal) power reactor shuts down by SCRAM. What is the thermal power of the reactor one minute after SCRAM?

Choose one answer

- A: 0 MW
- B: 0.01 MW
- C: 0.2 MW
- D: 10 MW
- E: 200 MW

Q20. Nuclear iv.
In a light water reactor, neutrons thermalize in the

Choose one answer

- A: Uranium pellet
- B: Fuel rod cladding
- C: Water
- D: Control rods
- E: Reactor containment

Q21. Biomass i.
Concerning fluid bed biomass gasification. What statement is not true?

Choose one answer

- A: It can convert practically all biomass types
- B: The sand in the bed behaves like a liquid
- C: Gas is injected in bottom
- D: It has a fast conversion of biomass
- E: It generates a syngas with almost no tar and $CH_4$

Q22. Biomass ii.
Concerning pyrolysis of biomass. How much carbon can be sequestered as biochar?

Choose one answer

- A: Approx. 10% of the input carbon in biomass
- B: Approx. 20% of the input carbon in biomass
- C: Approx. 30% of the input carbon in biomass
- D: Approx. 50% of the input carbon in biomass
- E: Approx. 70% of the input carbon in biomass

Q23. Biomass iii.
A biomass gasifier can have the following gas composition at outlet (mol%): 40% CO, 40% $H_2$, 10% $H_2O$, 10% $CO_2$. The total flow of gas is 10 kmol/s. How much methanol can potentially be produced if hydrogen is added from electrolysis?

Choose one answer

- A: 3 kmol/s
- B: 4 kmol/s
- C: 5 kmol/s
- D: 6 kmol/s
- E: 7 kmol/s

Q24. Biomass iv.
Consider the same gasifier as above. How much methanol can be produced if hydrogen from electrolysis is not included? The water gas shift reaction is used to generate hydrogen.

Choose one answer

- A: 1.7 kmol/s
- B: 2.0 kmol/s
- C: 2.3 kmol/s
- D: 2.7 kmol/s
- E: 3.0 kmol/s

Q25. Thermodynamics and electrochemistry i.
Which statement regarding the Gibbs free energy is correct?

Choose one answer

- A: If the change of Gibbs free energy of a chemical reaction is negative, the quantity determines the maximum energy that can be liberated by the reaction.
- B: If the change of Gibbs free energy of a chemical reaction is negative, the quantity determines the maximum work that can be generated by the reaction.
- C: The change of enthalpy of a chemical reaction gives the thermodynamic limit of the total work that can be generated by the process, while the Gibbs free energy determines the amount of work that can practically be produced in real systems
- D: The change of Gibbs free energy of a chemical reaction cannot be positive, because then the reaction cannot take place
- E: If the change of Gibbs free energy of a chemical reaction is negative, the reaction cannot proceed spontaneously.

Q26. Thermodynamics and electrochemistry ii.
What is the maximum *electrical efficiency* that can be obtained if a fuel is converted to electricity in a fuel cell?

*H* and *G* are enthalpies and Gibbs free energy, respectively. Subscript "r" and "f" denote "of reaction" (i.e., the fuel oxidation reaction) and "of formation", (of the fuel) respectively.

Choose one answer

- A: $\Delta G_r / \Delta G_f$
- B: $\Delta G_f / \Delta H_f$
- C: $\Delta H_f / \Delta G_f$
- D: $\Delta G_r / \Delta H_r$
- E: $\Delta H_r / \Delta G_r$

Q27. Thermodynamics and electrochemistry iii.
In a lead-acid battery , the reaction during discharge is

$$PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$$

The process written this way involves the transfer of 2 electrons.

Calculate the reversible cell voltage based on the following thermodynamic functions

| | $PbO_2$ | Pb | $H_2SO_4$ | $PbSO_4$ | $H_2O$ |
|---|---|---|---|---|---|
| $\Delta H_f$ (kJ mol$^{-1}$) | -277.4 | 0 | -814.0 | -920.0 | -285.8 |
| $\Delta G_f$ (kJ mol$^{-1}$) | -217.3 | 0 | -690.0 | -813.0 | -237.1 |

*Note, the calculated cell voltage is somewhat different from the ca. 2 V known from starter batteries in traditional vehicles because in a real battery, $H_2SO_4$ is dissolved in water and this changes the thermodynamics a little compare to this simplified case.*

Choose one answer

- A: 0.0026 V
- B: 0.74 V
- C: 0.59 V
- D: 2.61 V
- E: 2.62 V

Q28. Thermodynamics and electrochemistry iv.
Which statement regarding the electrolyte of an electochemical cell is correct

Choose one answer

- A: The electrolyte in an electrochemical cell can only be a liquid
- B:  The electrolyte in an electrochemical cell can only be a solid
- C: The electrolyte in an electrochemical cell can be a liquid, a solid or a gas
- D: The electrolyte in an electrochemical cell can be a liquid or a solid
- E:  The electrolyte in an electrochemical must be a good electron conductor

Q29. Storage i.
Which of the following has the highest gravimetric energy density (per unit of mass)?

Choose one answer

- A: Lithium ion battery
- B: Natural gas
- C: Gasoline
- D: Diesel
- E: Liquid hydrogen

Q30. Storage ii.
Which of the following energy storage technologies has the shortest response time?

Choose one answer

- A: Supercapacitor
- B: Hydrogen
- C: Molten salt
- D: Compressed air energy storage
- E: Pumped hydro

Q31. Storage iii.
Among the different energy storage technologies, which of the following has the largest share of installed capacity (up to 2015)

Choose one answer

- A: Battery
- B: Power to X
- C: Hydrogen
- D: Pumped hydro
- E: Thermal energy storage

Q32. Storage iv.
Which of the following energy storage technologies has the highest peak power (per kg)?

Choose one answer

- A: Super capacitor
- B: Battery
- C: Gasoline
- D: Fuel cell
- E: Methanol

Q33. Fuel cells and hydrogen i.
The actual cell voltage of a fuel cell differs from the thermodynamic equilibrium voltage. Select the correct statement

Choose one answer

- A: It is higher because of over-voltages
- B: It is slightly higher because of the catalysts at the electrodes
- C: It can be both higher and lower depending on how the fuel cell is optimized
- D: It is higher because higher voltage is needed to overcome the over-voltages
- E: It is lower because of over-voltages

Q34. Fuel cells and hydrogen ii.
A PEM fuel cell stack with 122 cells each of 25 cm by 12 cm is operated at 1.2 A $cm^{-2}$ with a a single cell voltage of 0.68 V. What is the electrical power generated by the stack?

Choose one answer

- A: 30 kW
- B: 40 kW
- C: 50 kW
- D: 60 kW
- E: 90 kW

Q35. Fuel cells and hydrogen iii.
What is an advantage of hydrogen as compared to other fuels and batteries?

Choose one answer

- A: Hydrogen can be made from abundant water and renewable energy and liberates no polluting exhaust when converted back to elecricity
- B: Hydrogen is the lightest fuel and therefore hydrogen vehicles can save weight with same driving range as compared to gasoline or diesel cars
- C: When the chemical energy of hydrogen is converted to electrical energy in a fuel cell, the electrical efficiency is higher than of combustion engines because there is no heat production in the fuel cell.
- D: The round trip efficiency (from primary electricity to hydrogen and back to electricity) is higher for a hydrogen system than for a battery (charge - discharge)
- E: Since hydrogen is a fuel, the need for infrastructure changes is minimal

Q36. Fuel cells and hydrogen iv.
A hydrogen powered fuel cell is operated at 0.74 V. What is the voltage effiecency based on the higher heating value?

Choose one answer

- A: 43 %
- B: 47 %
- C: 50 %
- D: 59 %
- E: 62 %

Q37. Batteries i.

Which of the following statements about redox flow batteries is true

Choose one answer

- A: In a redox flow battery, the energy storage capacity and the power density can be scaled independently
- B: Redox flow batteries are suitable for use in the aviation industry
- C: Organic redox flow batteries are promising due to their high energy density and long-term stability
- D: The efficiency of a vanadium redox flow battery is higher than Li-ion batteries
- E: In a redox flow battery, the anolyte needs to be pumped mechanically, while the catholyte is a solid

Q38. Batteries ii.
Arrange the following battery systems according to the amount of stored energy, ranging from lowest to highest: 1) A 70 kg [Ni-MH] battery with a gravimetric energy density of 80 Wh/kg; 2) a 10.000.000 C (Coulombs) and 3.6 V [Li-ion] battery; 3) A 210 kg lead-acid [Pb] battery at 40 Wh/kg; 4) a 480 L vanadium redox flow battery [VRFB] with a volumetric energy density of 0.025 kWh/L

Choose one answer

- A: 1: [Ni-MH] < 2: [Li-ion] < 3: [VRFB] < 4: [Pb]
- B: 3: [Pb] < 4: [VRFB] < 2: [Li-ion] < 1: [Ni-MH]
- C: 4: [VRFB] < 2: [Li-ion] < 3: [Pb] < 1: [Ni-MH]
- D: 1: [Ni-MH] < 3: [Pb] < 2: [Li-ion] < 3: [VRFB]
- E: 3: [Pb] < 1: [Ni-MH] < 3: [VRFB] < 2: [Li-ion]

Q39. Batteries iii.
Charging a Tesla Semi 8 truck battery from at 33% to 66% of its maximum capacity at a C-rate of C/5 takes

Choose one answer

- A: 300 min
- B: 100 min
- C: 30 min
- D: 10 min
- E: 3 min

Q40. Batteries iv.

Which of the following statements is true for a Zinc (Zn) - bromine (Br2) battery

Choose one answer

- A: Zinc is the negative electrode and bromine is reduced during charging
- B: Bromine is the negative electrode and zinc is reduced during discharge
- C: The open circuit voltage of a Zn-Br2 battery is lower than a Zn-Cu battery (a Daniel Cell)
- D: The half cell potential for zinc is: E^0(V) = 1.83 V for Zn^+1 + e^-1 -> Zn
- E: The discharge potential is the open circuit potential minus the discharge overpotential

Q41. Power-to-X i.
In which types of electrolyzers must water be supplied on the cathode side?

Choose one answer

- A: AEC nd PEMEC
- B: PEMEC and SOEC
- C: SOEC and AEC
- D: All
- E: None

Q42. Power-to-X ii.

A solid oxide electrolyzer if fed with water vapour at its working temperature of 800 °C. It is operated at 1.35 V and 0.8 A $cm^{-2}$. The reversible cell voltage is 0.969 V and the thermoneutral voltage 1.285 V at this temperature. Is the cell a net heat consumer or producer?

Choose one answer

- A: The cell is a net heat consumer, because electrolyzers are always heat consumers
- B: The cell is a net heat producer because the cell voltage is above the thermoneutral voltage at this temperature
- C: The cell is a net heat producer because the cell voltage is above the reversible voltage at this temperature
- D: The cell is a net heat consumer because the cell voltage is above the thermoneutral voltage at this temperature
- E: The cell is a net heat consumer because the cell voltage is above the reversible voltage at this temperature

Q43. Power-to-X iii.
Which statement regarding the concept of converting hydrogen into carbon based fuels are true?

1) The energy efficiency becomes higher
2) The energy density of the final fuel becomes higher
3) Storing and fuelling become easier
4) It requires a source of carbon
5) The exiting distribution and fuelling infrastructure can be used
6) Storage tanks are cheaper in case of conventional liquid fuels

Choose one answer

- A: Only 2, 3, 4, 5 and 6
- B: Only 4, 5 and 6
- C: Only 2, 3, 5 and 6
- D: Only 1, 2, 3 and 4
- E: All

Q44. Power-to-X iv.
Which electrolyzer technology is the best for 1) high power density, 2) low cost, 3) high electrical efficiency?

Choose one answer

- A: 1) AEC, 2) PEMEC, 3) PEMEC
- B: 1) PEMEC, 2) AEC, 3) SOEC
- C: 1) PEMEC, 2) AEC, 3) PEMEC
- D: 1) AEC, 2) PEMEC, 3) SOEC
- E: 1) PEMEC, 2) AEC, 3) AEC

Q45. Infrastructure i.
Estimate: How much fuel is burnt daily by all cars in Germany?

Choose one answer

- A: Between 5e4 l/day and 2.5e7 l/day.
- B: Between 5e5 l/day and 2.5e6 l/day.
- C: Between 5e6 l/day and 2.5e7 l/day.
- D: Between 5e7 l/day and 2.5e8 l/day.
- E: Between 5e8 l/day and 2.5e9 l/day.

Q46. Infrastructure ii.
What is the cost of equity if the weighted average cost of capital is 10% and the effective interest rate is 5% and the split between equity financing and debt financing is 60% / 40%?

Choose one answer

- A: 5%
- B: 7.5%
- C: 10%
- D: 13.3%
- E: 15%

Q47. Infrastructure iii.
You are given 4 sets of projected net economic returns, $R_x$ ={return year0, return year1, return year2, return year3}, for 4 different projects (a,b,c,d): $R_a$ = {0,3,2,1}, $R_b$ = {0,2,2,2}, $R_c$ = {0,1,2,3}, $R_d$ = {0, 1,2,4} and are asked to evaluate their relative attractiveness.

What can you say about their relative attractiveness from an NPV standpoint assuming some (positive, but unknown) discount rate?

Choose one answer

- A: You cannot really say anything without knowing the discount rate.
- B: $R_d$ is most attractive.
- C: $R_a$, $R_b$, $R_c$ are equally attractive.
- D: $R_a$ is most attractive.
- E: $R_a$ and/or $R_d$ is most attractive depending on the discount rate.