Introduction to Future Energy - Ordinary exam 2022

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.
If the global oil consumption is around 90 Mbpd. How many watts does that correspond to?

Choose one answer

- A:1.2 GW
- B: 5.5 GW
- C: 120 GW
- D: 1.2 TW
- E: 5.5 TW

Q2. Introduction ii.
Assume that 10% of the oil consumption is jet fuel (i.e. 9 Mbpd) - and that we are going to replace that by an "electrofuel" where we plan to make the electricity using off-shore wind turbines with a peak power of 10 MW each. Roughly how many such wind turbines would be needed if the energy conversion efficiency from electricity to jet fuel is 1/3?

Choose one answer

- A: 16500
- B: 36000
- C: 55000
- D: 165000
- E: 360000

Q3. Introduction iii.
Imagine a space-based photovoltaic power plant in an orbit around earth where it gets 100% solar illumination 100% of the time and where the solar-to-electricity efficiency is 35%. Assume a solar constant outside the earth's atmosphere (AM0) of 1350 W/m2. How big a solar collector would be needed to produce as much energy as Denmark's needs (total annual energy consumption of Denmark is ca 750 PJ, i.e. 7.5E17 J.

Choose one answer

- A: 18 km^2
- B: 51 km^2
- C: 159 km^2
- D: 18000km^2
- E: 159000km^2

Q4. Introduction iv.
Nuclear reactions convert mass into energy ("mass defect") via Einstein's famous relation $E = mc^2$
How much mass must be converted into energy to power (with energy of all kinds) Denmark for 1 year?

Choose one answer

- A: 8.3 g
- B: 77 g
- C: 8.3 kg
- D: 77 kg
- E: 8300 kg

Q5. Wind i.

The power curve of a wind turbine is shown in figure Q5 and the rotor diameter is D = 66 m. What is the power coefficient C_P of the turbine at the wind speed $v = 10$ m/s, if the mass density of the air is assumed to be $\rho = 1.225$ kg/m^3?

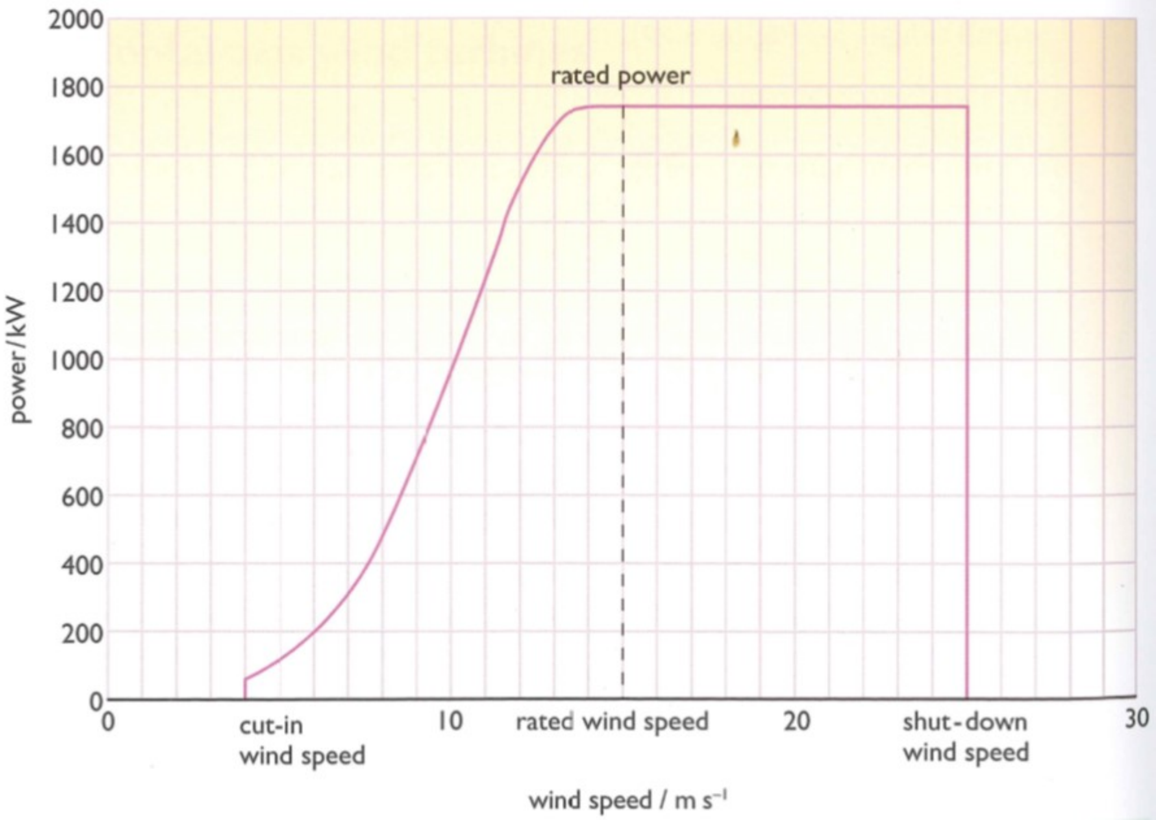

Figure 8.28 Typical wind turbine wind speed–power curve

Choose one answer

- A: 0.0 - 0.1
- B: 0.1 - 0.2
- C: 0.2 - 0.3
- D: 0.3 - 0.4
- E: 0.4 - 0.5

Q6. Wind ii.
The wind turbine with the power curve shown in figure Q5 is installed at a site, where the wind speed distribution is shown in figure Q6. A developer is planning to use the turbine for producing hydrogen and what to find out how many hours per year that the turbine is producing more than half of the rated power (P > 875 kW), since the electricity price is expected to be low. How many hours per year is the turbine producing more than half of rated power ?

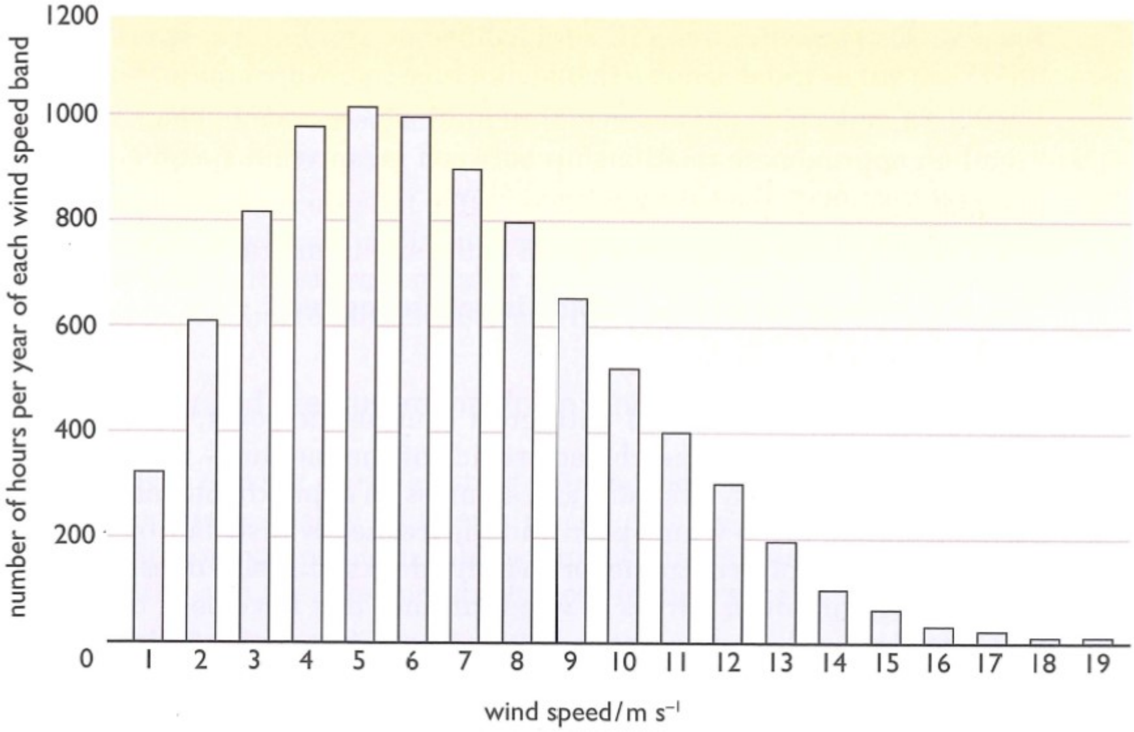

Figure 8.29 A wind speed frequency distribution for a typical site

Choose one answer

- A: 200-1000 hours / year
- B: 1000-2000 hours / year
- C: 2000-4000 hours/ year
- D: 4000-6000 hours/year
- E: 6000 - 8760 hours / year

Q7. Wind iii.
A wind turbine is designed according to the IEC wind class II. What is the corresponding average wind speed V_{ave} for the Weibull distribution of the wind speeds?

Choose one answer

- A: 6.5 m/s
- B: 7.5 m/s
- C: 8.5 m/s
- D: 10 m/s
- E: 12 m/s

Q8. Wind iv.
The Annual Energy Production(AEP) of a wind turbine with a rotor diameter of D = 222 m and a generator of a rated power of P = 14 MW is measured to be AEP = 67 GWh/year. What is the corresponding capacity factor (CF) of the turbine?

Choose one answer

- A: 20-30 %
- B: 30 - 40 %
- C: 40 - 50 %
- D: 50 - 60 %
- E: 60 - 70 %

Q9. Solar i.
What is the primary advantage of Concentrated Solar Power(CSP) compared to PhotoVoltaics (PV)

Choose one answer

- A: Lower cost/watt of electric output.
- B: Lower cost/J of electric output.
- C: Lower risks for local wildlife.
- D: Ability to utilize sites with poor light conditions (i.e. cloudy weather).
- E: Ability to store energy and generate electricity in the dark.

Q10. Solar ii.
Assume that a CSP unit stores heat in a molten-salt mixture at 500 degree Celcius. How much electrical power would it be possible to extract (i.e. what is the theoretical upper limit) from 1 GJ such thermal energy assuming that a heat sink at 10 degree Celcius is available.

Choose one answer

- A: 30 MJ
- B: 230 MJ
- C: 430 MJ
- D: 630 MJ
- E: 830 MJ

Q11. Solar iii.
If you are designing a tandem PV cell (i.e. a stacked two-bandgap solar cell) for the standard AM1.5G solar spectrum and the bandgap of the lower cell (bottom cell) is 1.4 eV what would be the optimal bandgap for the upper cell?

Choose one answer

- A: 1.4 eV
- B: 1.9 eV
- C: 2.8 eV
- D: 3.2 eV
- E: infinite bandgap would be ideal (i.e. as high as possible)

Q12. Solar iv.
A 2 square meter photovoltaic panel is illuminated with a flux of 800 W/m2 and has an efficiency of 21%. How much heat must the panel reject to its surroundings in steady state?

Choose one answer

- A: 1600 W
- B: 1264 W
- C: 800 W
- D: 632 W
- E: 336 W

Q13. Water i.
Which of the following water based renewable energy sources has the largest share worldwide of electricity production

Choose one answer

- A: Wind power
- B: Solar power
- C: Hydropower
- D: Wave power
- E: Tidal and ocean current power

Q14. Water ii.
Is a Pelton turbine best suited for high or low head?

Choose one answer

- A: The head height doesn't matter at all
- B: Low head because the water velocity in the Pelton turbine must be low to secure high utilization
- C: Low head and very high flow where other turbines cannot be used
- D: High head and very high flow where other turbines cannot be used
- E: High head because the turbine requires a high velocity water jet which is best generated by the high pressure of a high head

Q15. Water iii.
What is most likely the biggest challenge for a successful utilization of wave energy?

Choose one answer

- A: Corrosion of the construction in the wet saline environment
- B: Conversion of the linear movement into rotation for the generator
- C: Insulation of the electrical components in the wet saline environment
- D: Mechanical durability
- E: Regulations between countries

Q16 Water iv.

The geothermal installation at Amager (Copenhagen area) harvests hot water at 73 ^{o}C and distributes it through the district heating system. A heat pump is integrated in the system. What is most likely the reason for that?

Choose one answer

- A: The heat pump increases the temperature of the water to match that of the district heating grid
- B: The heat pump increases the Carnot efficiency of the overall system
- C: The heat pump in this case is a heat driven pump that pumps the hot water up by utilizing some of the heat of the hot water
- D: The heat pump generates electricity and the remaining low grade heat is used in the district heating system
- E: The heat pump is a backup solution at days where the power rate of the geothermal source is low

Q17. Nuclear i.
Which of the following is NOT a generation-IV reactor

Choose one answer

- A: Molten salt reactor (MSR)
- B: Boiling water reactor (BWR)
- C: Lead-cooled fast reactor (LFR)
- D: Gas-cooled fast reactor (GFR)
- E: Very high temperature reactor (VHTR)

Q18. Nuclear ii.
A CANDU reactor uses heavy water (D_2O) instead of normal water (H_2O) for cooling and neutron moderation. The CANDU can operate on natural uranium fuel (unenriched) due to D_2O's

Choose one answer

- A: Higher scattering cross section
- B: Better neutron moderation properties
- C: Higher heat capacity
- D: Lower neutron absorption cross section
- E: Smaller thermal expansion coefficient

Q19. Nuclear iii.
The energy released by fission of 1g of U-235 is approx. 20000 kWh. With 5% enrichment, a 300 MW (thermal) reactor consumes each hour approx. the fuel amount

Choose one answer

- A: 0.26 g
- B: 260 g
- C: 2.6 kg
- D: 260 kg
- E: 2600 kg

Q20. Nuclear iv.
High-level waste (HLW) is ultimately deposited in geological repositories. How many of the countries with nuclear power have established such final repositories?

Choose one answer

- A: No country
- B: A few countries
- C: About 50%
- D: Most countries
- E: All countries

Q21. Biomass i.
What is the total consumption of renewable energy in Denmark (in 2018)?

Choose one answer

- A: About 100 PJ
- B: About 200 PJ
- C: About 300 PJ
- D: About 400 PJ
- E: About 500 PJ

Q22. Biomass ii.
Concerning negative carbon emissions. What statement is not true?

Choose one answer

- A: Negative carbon emissions can be generated by producing biochar
- B: Negative carbon emissions can be generated by CCS on a biomass power plant
- C: Negative carbon emissions can be generated by CCS on a biomass gasification plant used for fuel production
- D: Negative carbon emissions can be generated by CCS combined with air capture of CO_2
- E: Negative carbon emissions can be generated by CCS on a natural gas power plant

Q23. Biomass iii.
Consider a future CCU plant on the waste incineration plant ARC in Denmark. It could capture 500.000 tons CO_2 per year. At continuous operation that would correspond to a mass flow of CO_2 of 16 kg/s. How much electricity would be required to produce the required hydrogen to convert this mass flow of CO_2 to methanol. The electrolyser can be assumed to have an efficiency of 60 %. LHV_H2 = 241.8 MJ/kmol.

Choose one answer

- A: 264 MW
- B: 300 MW
- C: 400 MW
- D: 440 MW
- E: 680 MW

Q24. Biomass iv.
Consider the same CCU plant as above. How much methanol would it produce? LHV_methanol = 638 MJ/kmol.

Choose one answer

- A: 192 MW
- B: 202 MW
- C: 212 MW
- D: 222 MW
- E: 232 MW

Q25. Thermodynamics and electrochemistry i.
An air to air heat pump delivers 10 kW heat to heat a building. It is powered by 3.5 kW electricity. calculate the coefficient of performance (COP) and the thermal power, p_{low} it consumes at the low temperature source. Disregard heat losses.

Choose one answer

- A: COP = 1.44, p_{low} = 6.5 kW
- B: COP = 1.44, p_{low} = 10 kW
- C: COP = 2.86, p_{low} = 10 kW
- D: COP = 2.86, p_{low} = 6.5 kW
- E: COP = 1.86, p_{low} = 6.5 kW

Q26. Thermodynamics and electrochemistry ii.
Acetylene (C_2H_2) is often used for welding. Calculate the molar lower heating value of aceltylene form the table below.

Standard enthalpies of formation (kJ mol^{-1})

	C_2H_2	O_2	CO_2	H_2O (l)	H_2O(g)
	+227.4	0.0	-393.5	-285.8	-241.8

Choose one answer

- A: 227.4 kJ mol^{-1}
- B: 863 kJ mol^{-1}
- C: 907 kJ mol^{-1}
- D: 1256 kJ mol^{-1}
- E: 1300 kJ mol^{-1}

Q27. Thermodynamics and electrochemistry iii.
Which statement regarding the term *overvoltage* is correct?

Choose one answer

- A: A larger positive overvoltage means a more energy efficient process
- B: A larger negative overvoltage means a more energy efficient process
- C: Overvoltages are highly desired in batteries and fuel cells
- D: An overvoltage quantifies the deviation from the the electrochemcial equilibrium voltage
- E: Overvoltges are always positive deviations from equilibrium, negative deviations are labelled *undervoltages*

Q28. Thermodynamics and electrochemistry iv.
The anode process of a direct methanol fuel cell involves oxidation of methanol (CH_3OH) in an aqueous solution to CO_2 and protons (H^+). The oxidation involves 6 electrons per methanol molecule. Which of the following electrochemical equations is balanced correctly?

Choose one answer

- A: $CH_3OH + H_2O$ -> $CO_2 + 6H^+ + 6e^-$
- B: $CH_3OH + H_2O + 6e^-$ -> $CO_2 + 6H^+$
- C: $CH_3OH + 2H_2O$ -> $CO_2 + 6H^+ + 6e^-$
- D: $6CH_3OH + 6H_2O$ -> $6CO_2 + 6H^+ + 6e^-$
- E: $CH_3OH + 2H_2O$ -> $CO_2 + 8H^+ + 6e^-$

Q29. Storage i.
Rank the following energy storage technologies according to their expected lifetime (high to low)

Choose one answer

- A: Li-ion batteries > flywheels > Compress Air Energy Storage (CAES) > Pumped Hydro Storage (PHS)
- B: Pumped Hydro Storage (PHS) > Compress Air Energy Storage (CAES) > flywheels > Li-ion batteries
- C: Compress Air Energy Storage (CAES) > Li-ion batteries > Flywheels > Pumped Hydro Storage (PHS)
- D: Flywheels > compress Air Energy Storage (CAES) > Pumped Hydro Storage (PHS) > Li-ion batteries
- E: Li-ion batteries > Pumped Hydro Storage (PHS) > flywheels > Compress Air Energy Storage (CAES)

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

Choose one answer

- A: The globally installed energy storage capacity per year went up from 2018 to 2019
- B: Pumped hydro storage (PHS) has a higher efficiency than flywheels and Compress Air Energy Storage (CAES)
- C: All phase change materials (PCMs) require the same amount of energy to change between their different phases
- D: Thermal energy storage can be divided into sensible, latent and chemical energy storage
- E: Pumped hydro storage (PHS), Compress Air Energy Storage (CAES), and flywheels belong to the class of mechanical energy storage technologies

Q31. Storage iii.
Which of the following countries installed the largest energy storage capacity in 2018 according to the IEA?

Choose one answer

- A: Denmark
- B: Korea
- C: USA
- D: China
- E: Germany

Q32. Storage iv.
Which of the following thermal energy storage solutions can store the most energy if heated from 20 to 80 deg. C:
(I) 1.0 m^3 water (specific heat: 4182 J/kg K; density: 988 kg/m^3);
(II) 10^3 kg air (specific heat: 1006 J/kg K; density: 1.27 kg/m^3);
(III) 1.0 m^3 concrete (specific heat: 880 J/kg K; density: 2200 kg/m^3);
(IV) 10^3 kg paraffin wax (specific heat: 2200 J/kg K; density: 900 kg/m^3; latent heat of fusion: 173.6 kJ/kg; melting point: 64 deg C)

Choose one answer

- A: Water > concrete > air > paraffin wax
- B: Air > water > paraffin wax > concrete
- C: Paraffin wax > water > concrete > air
- D: Concrete > air > water > paraffin wax
- E: Water > concrete > paraffin wax > air

Q33. Fuel cells and hydrogen i.
Which transport process is NOT relevant in the gas diffusion layer of a fuel cell electrode?

Choose one answer

- A: Transport of reactants and products
- B: Transport of voltage
- C: Transport of electrons
- D: Transport of ions
- E: Transport of heat

Q34. Fuel cells and hydrogen ii.
A PEM fuel cell is operated at 0.72 V and 1.2 A cm^{-2}. Calculate the heat produced per cm^2 with the assumption that water is generated as a liquid. Thermal energy contents of reactants and products can be disregarded.

Choose one answer

- A: 0.585 W cm^{-2}
- B: 0.864 W cm^{-2}
- C: 0.912 W cm^{-2}
- D: 1.19 W cm^{-2}
- E: 1.776 W cm^{-2}

Q35. Fuel cells and hydrogen iii.
What are the advantages of hydrogen powered fuel cell vehicles over battery-electric vehicles?
a) Faster fueling/charging
b) Higher roundtrip efficiency (electricity to electricity)
c) Higher onboard stored energy density
d) Fueling infrastructure already in place

Choose one answer

- A: a) and b)
- B: a) and c)
- C: b) and c)
- D: b) and d)
- E: c) and d)

Q36. Fuel cells and hydrogen iv.
Which of the following drawbacks does NOT apply to liquid hydrogen?

Choose one answer

- A: Self discharge due to constant evaporation
- B: High energy demand for hydrogen liquefaction
- C: Expensive tank
- D: High energy demand for hydrogen release
- E: High purity hydrogen required

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

Choose one answer

- A: The charging overpotential (η_{ch}) is the difference between the charging potential (V_{ch}) and the open circuit voltage (V_{OC})
- B: The energy and power density cannot be scaled independently in a Li-ion battery
- C: The Na-S battery chemistry has a higher theoretical specific energy than a Li-O_2 (“Li-Air”) battery (Wh/kg)
- D: The gravimetric energy density is ranked as follows: Li-ion > Ni-MH > Ni-Cd > Pb-acid
- E: Flow batteries batteries typically have a lower efficiency than Li-ion batteries

Q38. Batteries ii.
What is the theoretical capacity of a (I) $LiFeBO_3$ and a (II) $LiMnBO_3$ battery electrode (molar masses: M_{Li} = 6.94 g/mol; M_B = 10.811 g/mol; M_O = 15.999 g/mol ; M_{Fe} = 55.85 g/mol, M_{Mn} = 54.938 g/mol; Faradays constant: F = 96485 C/mol)

Choose one answer

- A: (I) 793 C and (II) 799 mAh/g
- B: (I) 220 mAh/g and (II) 222 mAh/g
- C: (I) 793 mAh/g and (II) 799 mAh/g
- D: (I) 220 Wh/kg and (II) 222 Wh/kg
- E: (I) 220 C and (II) 222 C

Q39. Batteries iii.
The following reaction can take place at the positive electrode during discharging of a lithium manganese borate battery: $MnBO_3 + Li^+ + e^- \rightarrow LiMnBO_3$. Which of the following is statements about the reaction is **true:**

Choose one answer

- A: Boron is reduced, while manganese and lithium are oxidized
- B: Manganese is reduced, while neither boron nor oxygen are reduced or oxidized
- C: Lithium and boron are reduced, while manganese is oxidized
- D: Neither lithium, manganese nor boron are reduced or oxidized
- E: Lithium is reduced, boron is oxidized and manganese is neither oxidized nor reduced

Q40. Batteries iv.

Rank the following combinations of half-cell reactions according to the highest theoretical cell potential for discharge: (I): E°(Cu/Cu^{2+}) - E°(Zn/Zn^{2+}); (II): E°($Cl/2Cl^{-}$) - E°(Zn/Zn^{2+}) and (III): E°($F_2/2F^{-}$) - E°(L/Li^{+})

Choose one answer

- A: (II) E°($Cl/2Cl^{-}$) - E°(Zn/Zn^{2+}) > (III) E°($F_2/2F^{-}$) - E°(L/Li^{+}) > (I) E°(Cu/Cu^{2+}) - E°(Zn/Zn^{2+})
- B: (I) E°(Cu/Cu^{2+}) - E°(Zn/Zn^{2+}) > (II) E°($Cl/2Cl^{-}$) - E°(Zn/Zn^{2+}) > (III) E°($F_2/2F^{-}$) - E°(L/Li^{+})
- C: (I) E°(Cu/Cu^{2+}) - E°(Zn/Zn^{2+}) > (III) E°($F_2/2F^{-}$) - E°(L/Li^{+}) > (II) E°($Cl/2Cl^{-}$) - E°(Zn/Zn^{2+})
- D: (III) E°($F_2/2F^{-}$) - E°(L/Li^{+}) > (II) E°($Cl/2Cl^{-}$) - E°(Zn/Zn^{2+}) > (I) E°(Cu/Cu^{2+}) - E°(Zn/Zn^{2+})
- E: (II) E°($Cl/2Cl^{-}$) - E°(Zn/Zn^{2+}) > (I) E°(Cu/Cu^{2+}) - E°(Zn/Zn^{2+}) > (III) E°($F_2/2F^{-}$) - E°(L/Li^{+})

Q41. Power-to-X i.
Which of the following products does NOT fit the "X" in the concept *Power-to-X*?

Choose one answer

- A: Hydrogen
- B: Ammonia
- C: Methanol
- D: Chemicals
- E: Water

Q42. Power-to-X ii.
An electrolyzer is operated at 1.75 V with the total power input 2 MW. What is the voltage efficiency with
respect to the higher heating value (HHV) and what is the power of the heat produced?

Choose one answer

- A: Efficiency: ca. 118 %, heat: ca. 300 kW
- B: Efficiency: ca. 70 %, heat: ca. 600 kW
- C: Efficiency: ca. 71 %, heat: ca. 580 kW
- D: Efficiency: ca. 69 %, heat: ca. 780 kW
- E: Efficiency: ca. 85 %, heat: ca. 300 kW

Q43. Power-to-X iii.
An electrolyzer stack is composed of 300 circular cells each with a diameter of 1.5 m. It is operated at 80 °C at 0.4 A cm^{-2} and 1.75 V per cell. calculate the total electrical power consumed (disregard all peripheral components like power electronics and pumps)

Choose one answer

- A: 210 W
- B: 12 kW
- C: 3.7 MW
- D: 6.6 MW
- E: 111 MW

Q44. Power-to-X iv.
Why is ammonia considered as a fuel for shipping?

Choose one answer

- A: Its maufactue does not rely on carbon but nitrogen, which is easier to extract from air
- B: It is safer to store and handle than methanol and methane due to its characterisitc smell
- C: I has a higher mass specific energy content than the hydrogen it is made from.
- D: It is liquid at ambient pressure and temperature and thus convenient to store and transfer
- E: It cannot be used as a fuel. Fuels must contain carbon.

Q45. Infrastructure i.
A proposed project will result in the following cash flow:
year 0: 100
year 1: 100
year 2: 100
Assuming a WACC of 10% p.a. what is the total DCF of the project?

Choose one answer

- A: 274
- B: 300
- C: 330
- D: 331
- E: 364

Q46. Infrastructure ii.
Assume that the project from the previous question also has the following expenses:
year 0: 90
year 1: 100
year 2: 110
Again, assuming a WACC of 10%, what is the NPV of this project?

Choose one answer

- A: 1.58
- B: 1.73
- C: 0
- D: -1.58
- E: -1.73

Q47. Infrastructure iii.
You have a choice between two investments which pay the following net payouts over six periods (e.g. years):
a) 0, 0, 100, 200. 300
b) 100, 100, 100, 100, 100
You are told that both investments have the same IRR.
What does that tell you?

Choose one answer

- A: That the WACC is zero
- B: That the WACC is increasing over time
- C: That the original investment was 600
- D: That the WACC is infinite
- E: That the NPV is zero