M1.(a) Percentage of oxygen by mass = 100 – 40.9 – 4.5 = 54.6

1

	C	H	O
%	40.9	4.5	54.6
Divide by A_r	12	1	16
	= 3.41	= 4.5	= 3.41

1

Divide by smallest =	$\frac{3.41}{3.41} = 1$	$\frac{4.5}{3.41} = 1.32$	$\frac{3.41}{3.41} = 1$
Nearest whole number ratio =	1 × 3	1.32 × 3	1 × 3

= 3 : 3.96 : 3

Nearest integer ratio = 3 : 4 : 3

1

Empirical formula $C_3H_4O_3$

Empirical formula mass = 88 = molecular formula mass

Therefore, molecular formula is same as the empirical formula - $C_3H_4O_3$

1

(b) $C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$

1

(c) Advantage – ethanol is produced at a faster rate

1

Disadvantage – more energy is used / required in the reaction

1

(d) Air gets in / oxidation occurs

1

(e) Alcohol OH absorption in different place (3230–3550 cm^{-1}) from acid OH absorption (2500–3000 cm^{-1})

1

The C=O in acids has an absorption at 1680–1750 cm^{-1}

1

[10]

M2.(a) (i) CH_2O

Atoms in any order

Accept a clear indication that $C_6H_{12}O_6$ yields CH_2O as the answer

1

(ii) No peak / no absorption / no C=O in the **range 1680 to 1750** (cm^{-1}) (suggesting no evidence of C=O)

Allow the words "dip", "spike", "low transmittance" and "trough" as alternatives for absorption

Ignore references to other wavenumbers

1

(b) M1 $C_6H_{12}O_6 \longrightarrow \mathbf{2}CH_3CH_2OH + \mathbf{2}CO_2$

Penalise (C_2H_6O)

*Allow multiples of the equation in **M1***

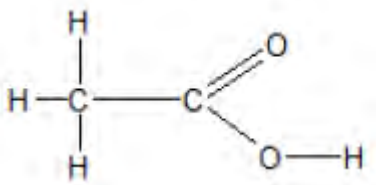
Either order
M2 (enzymes from) yeast or zymase

M3 25 °C ≤ T ≤ 42 °C OR 298 K ≤ T ≤ 315 K

*For **M2** and **M3***
Ignore "aqueous"
Ignore "anaerobic / absence of oxygen"
Ignore "controlled pH"
Ignore "warm"

3

(c) (i) Displayed formula for CH_3COOH



All bonds must be drawn out, but ignore bond angles

1

(ii) $O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$

Ignore state symbols

Negative charge on electron not essential

Accept multiples

Accept electrons subtracted from RHS

1

(iii) $CH_3CH_2OH + H_2O \longrightarrow CH_3COOH + 4H^+ + 4e^-$

(C_2H_6O or C_2H_5OH)

Ignore state symbols

Negative charge on electron not essential

Accept multiples

Accept electrons subtracted from LHS

1

(iv) M1 Acidified potassium or sodium dichromate

*For **M1**, it must be a whole reagent and / or correct formulae*

OR H_2SO_4 / $K_2Cr_2O_7$ OR H^+ / $K_2Cr_2O_7$ etc.

Do not penalise incorrect attempt at formula if name is correct or vice versa

OR correct combination of formula and name

If oxidation state given in name, it must be correct, but mark on from an incorrect attempt at a correct reagent.

M2 (requires an attempt at M1)
orange to green

*Credit **acidified** potassium chromate(VI) / H_2SO_4 + K_2CrO_4*

Possible alternative
M1 (acidified) potassium manganate(VII) ***OR*** $KMnO_4$ / H_2SO_4

M2 purple to colourless

*Other alternatives will be accepted but **M2** is dependent on **M1** in every case*
__M2__ requires an attempt at a correct reagent for __M1__
Ignore reference to states

2

(d) (i) An activity which has no net / overall (annual) carbon emissions to the atmosphere / air

The idea that the carbon / CO_2 given out equals the carbon / CO_2 that was taken in from the atmosphere / air

OR

An activity which has no net / overall (annual) greenhouse gas emissions to the atmosphere / air.

Answer must refer to the atmosphere or air

OR

There is no change in the total amount of carbon dioxide / carbon /greenhouse gas present in the atmosphere / air

1

(ii) Renewable / sustainable ONLY

Ignore references to global warming or greenhouse gases

1

(iii) **Any one statement about this process from**

Subject to weather / climate

Ignore "batch"

OR

Depletes food supply OR the land use for (specified) food

OR

Requires use of / uses more fossil fuels

OR

Not carbon-neutral OR CO_2 produced during a named process (eg harvest, transport etc.)

OR

Slow process / slow rate of reaction / takes a long time (to grow crops)

OR

This route leads to the production of a mixture of water and ethanol / impure ethanol <u>that requires separation / further processing</u>

1

[13]

M3. (a) **M1 Safety (in Process 1)**

<u>Sodium hydroxide / alkali</u> is <u>corrosive /</u> <u>harmful</u> / <u>caustic</u> or <u>sodium hydroxide</u> is <u>alkali(ne)</u>

Ignore references to chromium compounds

OR

<u>Bromine compounds</u> are <u>toxic / poisonous</u>

*"Carbon-neutral" alone is insufficient for **M2***

M2 Environmental

Ignore references to greenhouse gases

Process 2 could be used as a <u>carbon sink / for carbon capture</u>

OR

<u>uses waste / recycled CO_2</u> / <u>CO_2 from the factory</u> / <u>CO_2 from the bioethanol</u> (or <u>biofuel</u>) production

OR

<u>reduces or limits</u> the amount of <u>CO_2 released / given out</u> (into the atmosphere)

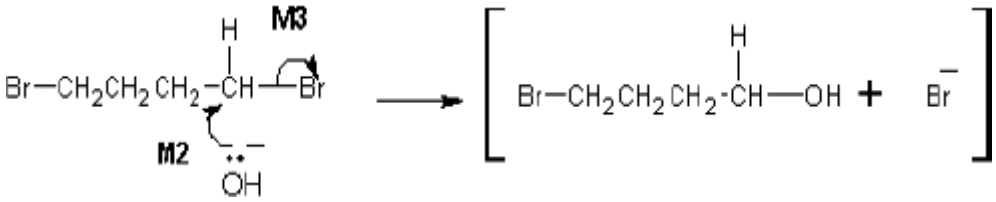
OR

Process 2 uses <u>renewable</u> glucose / <u>renewable</u> resource(s)

2

(b) (i) M1 <u>nucleophilic substitution</u>

*For **M1, both words** required*



M2 must show an arrow from the lone pair of electrons on the oxygen atom of the negatively charged hydroxide ion to the C atom.

*Penalise **M2** if covalent NaOH / KOH is used*

*Penalise one mark from **M2** or **M3** if half-headed arrows are used*

M3 must show the movement of a pair of electrons from the C–Br bond to the Br atom. Mark **M3** independently provided it is from the <u>original molecule</u>

*Penalise **M3** for formal charge on C of the C–Br or incorrect partial charges on C–Br*

Penalise once only for a line and two dots to show a bond.

For **M2** and **M3** award full marks for an S_N1 mechanism

*For **M2** and **M3**, maximum 1 of 2 marks for the mechanism if wrong reactant is used.*

*Penalise **M3** if an extra arrow is drawn from the Br of the C–Br bond to, for example, K^+*

Accept the correct use of "sticks

NB The arrows here are double-headed

3

(ii) **M1** B

M2 C

M3 A

3

(c) **M1** <u>fermentation</u>

*Mark **M2** to **M4** independently*

Three conditions <u>in any order</u> for M2 to M4

Penalise "bacteria" and "phosphoric acid" using the list principle

M2 (enzymes from) yeast or zymase

M3 25°C ≤ T ≤ 42°C OR 298 K ≤ T ≤ 315 K

Ignore reference to "aqueous" or "water", "closed container", "pressure, "lack of oxygen",

"concentration of ethanol" and "batch process" (i.e. not part of the list principle)

M4 anaerobic / no oxygen / no air OR neutral pH

4

(d) **M1** primary OR 1° (alcohol)

Mark independently

M2 <u>acidified potassium or sodium dichromate</u>

*For **M2**, it must be a whole reagent and/or correct formulae*

OR H_2SO_4 / $K_2Cr_2O_7$ OR H^+ / $K_2Cr_2O_7$

Do not penalise incorrect attempt at formula if name is correct or vice versa

Accept phonetic spelling

If oxidation state given in name, it must be correct.

*For **M2** accept acidified potassium manganate(VII)*

OR correct combination of formula and name

M3

$HOCH_2CH_2CH_2CH_2OH + \mathbf{4}[O] \longrightarrow HOOCCH_2CH_2COOH + \mathbf{2}H_2O$

*For **M3** structures must be correct and not molecular formula*

3

[15]

M4.(a)

M1 $C_6H_{12}O_6 \longrightarrow \mathbf{2}CH_3CH_2OH\ (2C_2H_5OH) + \mathbf{2}CO_2$

*Penalise C_2H_6O for ethanol in **M1**.*

M2 and **M3**

*Mark **M2** and **M3** independently.*

Any **two** conditions **<u>in any order</u>** for **M2** and **M3** from

- (enzymes from) yeast or zymase
- 25 °C ≤ T ≤ 42 °C OR 298 K ≤ T ≤ 315 K
- <u>anaerobic / no oxygen / no air</u> OR neutral pH

  A lack of oxygen can mean either without oxygen or not having enough oxygen and does not ensure <u>no oxygen</u>, therefore only credit "lack of oxygen" if it is qualified.

  Penalise 'bacteria', 'phosphoric acid', 'high pressure' using the list principle.

M4 (fractional) distillation or GLC

Ignore reference to 'aqueous' or 'water' (ie not part of the list principle).

M5 Carbon-neutral **in this context** means

There is no net / overall (annual) carbon dioxide / CO_2 emission to the atmosphere

OR

There is no change in the total amount / level of carbon dioxide / CO_2 present in the atmosphere

*For **M5** – must be about CO_2 and the atmosphere.*

The idea that the carbon dioxide / CO_2 given out equals the carbon dioxide / CO_2 that was taken in from the atmosphere.

5

(b) **M1** q = m c ΔT (this mark for correct mathematical formula)

*Full marks for **M1**, **M2** and **M3** for the correct answer.*

*In **M1**, do not penalise incorrect cases in the formula.*

M2 = (75 × 4.18 × 5.5)

1724 (J) **OR** 1.724 (kJ) **OR** 1.72 (kJ) **OR** 1.7 (kJ)

(also scores **M1**)

*Ignore incorrect units in **M2**.*

M3 Using 0.0024 mol

therefore ΔH = **− 718** (kJ mol^{-1})

(Accept a range from −708 to −719 but do not penalise more than 3 significant figures)

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect. Therefore **+718 gains two marks**.*

*If units are quoted in **M3** they must be correct.*

*If ΔT = 278.5, CE for the calculation and penalise **M2** and **M3**.*

M4 and **M5** in any order

Any **two** from

- incomplete combustion
- heat loss
- heat capacity of Cu not included
- some ethanol lost by evaporation

- not all of the (2.40×10^{-3} mol) ethanol is burned / reaction is incomplete

*If c = 4.81 (leads to 1984) penalise **M2** ONLY and mark on for **M3** = − 827*

5

(c) (i) **M1** enthalpy / heat / energy change (at constant pressure) or enthalpy / heat / energy needed in breaking / dissociating (a) covalent bond(s)

Ignore bond making.

M2 averaged for that type of bond over different / a range of molecules / compounds

Ignore reference to moles.

2

(ii) **M1**

$\sum$ B(**reactants**) − $\sum$ B(**products**) = ΔH

OR

Sum of bonds broken − Sum of bonds formed = ΔH

OR

B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O)
– 4B(C=O) – 6B(O–H) = ΔH = −1279

Correct answer gains full marks.

*Credit **1 mark for − 496** (kJ mol^{-1})*

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**).*

*If no AE, check for a correct method; this requires either a correct cycle with $2CO_2$ and $3H_2O$ OR a clear statement of **M1** which could be in words and scores **only M1**.*

M2 (also scores **M1**)
348+360+463+5(412)+ 3B(O=O)

(**3231**) (or **2768** if O–H cancelled)
− 4(805) − 6(463) = ΔH = − 1279

(**5998**) (or **5535** if O–H cancelled)

3B(O=O) = **1488** (kJ mol^{-1})

*Credit a maximum of one mark if the only scoring point is bonds formed adds up to **5998 (or 5535) OR** bonds broken includes the calculated value of **3231 (or 2768)**.*

M3

B(O=O) = **<u>496</u>** (kJ mol^{-1})

Award 1 mark for −496

Students may use a cycle and gain full marks

3

[15]