Supplementary Information (SI) for RSC Sustainability.
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EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. **[5]**

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$
$$x\ kg\ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

5

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	1066.05		117.30
Sodium hydroxide	453.10		
Carbon dioxide	677.35		233.45
Sulfuric acid	571.55		14.95
activated carbon	211,60		211.60
water			209.70
sodium sulfate			805.00
salicylic acid		1150	242.65

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$
$$x\ kg\ NaOH = 1150\ kg\ SA$$

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

2.5

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen** ***(Refer to Table 2 page 7)***

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945,11		
Oil of wintergreen	14,88,61		
water			178,63
salicylic acid		**1150**	
methanol			266,66
Sodium sulfate			5636,85

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$
$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas** ***(Refer to Table 3 page 7)***

1.5

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
methanol	**534.33**		**267.68**
water			149.28
acetic acid	1001.87		
methyl acetate		**616.67**	32.07

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 1. 3 [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	38.60%	39.48%
% Yield How efficient the chemical reactions are.	78.90%	94.72%
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	61.41%	29.23%

Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]	Route 3. Route 3 has a lower waste production (E-factor) and has a higher % Reaction mass efficiency and % yield thus making it more green.
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	~~to gate~~ gate to gate ✓
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	No change as the plants in route 3 can be farmed while the oil in route 1 is non-renewable
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	cost would go up as supply and demand states that a lower supply results in a higher demand hence a higher cost

Question 3

Answer the following questions in the space provided:	
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? [2]	Reusing waste for other processes and ensuring that the disposal of waste is not near populated areas as that would decrease the quality of life in that area. Reuse of waste products can decrease expenditure of raw materials for new processes.
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? [2]	Using renewable energy sources rather than non-renewables. less carbon emissions from renewable resources will increase quality of life as air quality has increased Using renewable resources increase brand image which leads to higher sale and profit.
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? [2] Give 2 examples?	labour, distribution and packaging
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? [2]	Refinement of chemical processes ensures efficiency and less waste production which leads to an increase of global sustainability.

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

Sustainable systems thinking is a mindset that helps us to untangle and work within the complexity of life on Earth. It helps us to better understand the impact of our work on the world around us and be responsible for what we create and how we innovate. An important step in developing a systemic approach is to find

the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.

Sustainability strives for:

- **Viable** environmental-economic impact: Business is executed with the environment and resources in mind.
- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. decrese costs
3. increase automation
4. ensure sustainability
5. ensure business growth
6. effective marketing strategies
7. increase production rate
8. tax fraud.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. ~~higher~~ employ local people
3. decrease cost of product
4. dont monopolize
5. do not decrese quality of life by damaging nature
6. ensure ~~an~~ quality of life through higher air quality
7. ensure equal representation of minorities in the business.
8. Community OutReach Programs

Enviromental Officer

1. Minimize deforestation
2. minimize carbon emmisions
3. minimize water use
4. ~~to~~ minimize contamination of water source
5. minimize methane emmisionse
6. reduse the use of non-renewable raw materials
7. use of renewable raw materials
8. ~~increase recycle rates.~~ Recycle more

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

Hint: You are welcome to refer to the **17 sustainable development goals**.

Asprin Manufacturing
Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. Have a community recycling division
4. Implement a community base water purification division
5. Ensure local accquisition of raw materials
6. Lower prices for involved community members
7. 0% carbon emmisions
8. Panda habitat (endangered species)
9. bursaries towards involved community members
10. Automate processes to ensure more time is put toward sustainable development.

Are all group members happy with the new plant design?	[✓ Yes]	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

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Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

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$$927\ kg\ C_6H_5OH = 1000\ kg\ SA$$

$$x\ kg\ C_6H_5OH = 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(*Refer to Table 1 page 7*)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	**1066.05**		**117.30**
Sodium hydroxide	453,10 ✓		
Carbon dioxide	677,35 ✓		233,45 ✓
Sulfuric acid	571,55 ✓		14,95 ✓
activated carbon	211,60 ✓		211,60 ✓
water			204,70 ✓
sodium sulfate			805,00 ✓
salicylic acid		**1150**	242,65 ✓

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$
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$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen**
(Refer to Table 2 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945,11 ✓		
Oil of wintergreen	1488,61 ✓		
water			178,63 ✓
salicylic acid		**1150**	
methanol			266,66 ✓
Sodium sulfate			5636,85 ✓

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$
$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas**
(Refer to Table 3 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**		**267.68**
water			149,29 ✓
acetic acid	1001,87 ✓		
methyl acetate		**616.67**	32,07 ✓

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 3. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	$\frac{1150}{2980,10} \times 100$ $= 38,60\%$	$\frac{1150}{5021,57} \times 100$ $= 22,90\%$ ②
% Yield How efficient the chemical reactions are.	$\frac{1150}{1359} \times 100 = 84,62\%$	$\frac{1150}{1191} \times 100 = 96,56\%$ ②
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	1829,65 kg	6082,14 kg ②

Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]	Route 1, less waste is generated and it has a greater mass efficiency.
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	Gate to gate
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	No it wont change because the green matrix results will remain the same.
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	It will increase the price of buying aspirin, because the demand of crude oil will increase whilst the supply decreases thus crude oil becomes expensive

Question 3

Answer the following questions in the space provided:

How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? **[2]**	Enviromental · Reforestration and ~~a~~ afforestration to replace the trees used to extract salicylic acid. Social: the sulphuric acid could be used to lower pH of the land, so that it could be easy to apply more agricultural activities Economic: because there is more agricultural activities, more job opportunities arise
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? **[2]**	Using solar panels to reduce the cost of energy and to produce energy in an environmentally friendly ~~was~~ way required by the plant
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** Give 2 examples?	The cost of disposing of waste materials. The cost of buying and maintaining the equipment used.
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? **[2]**	It enables us to choose a route which produces more desired outcomes and less waste products. This is beneficial for the environment

SYSTEMS THINKING IN SUSTAINABILITY

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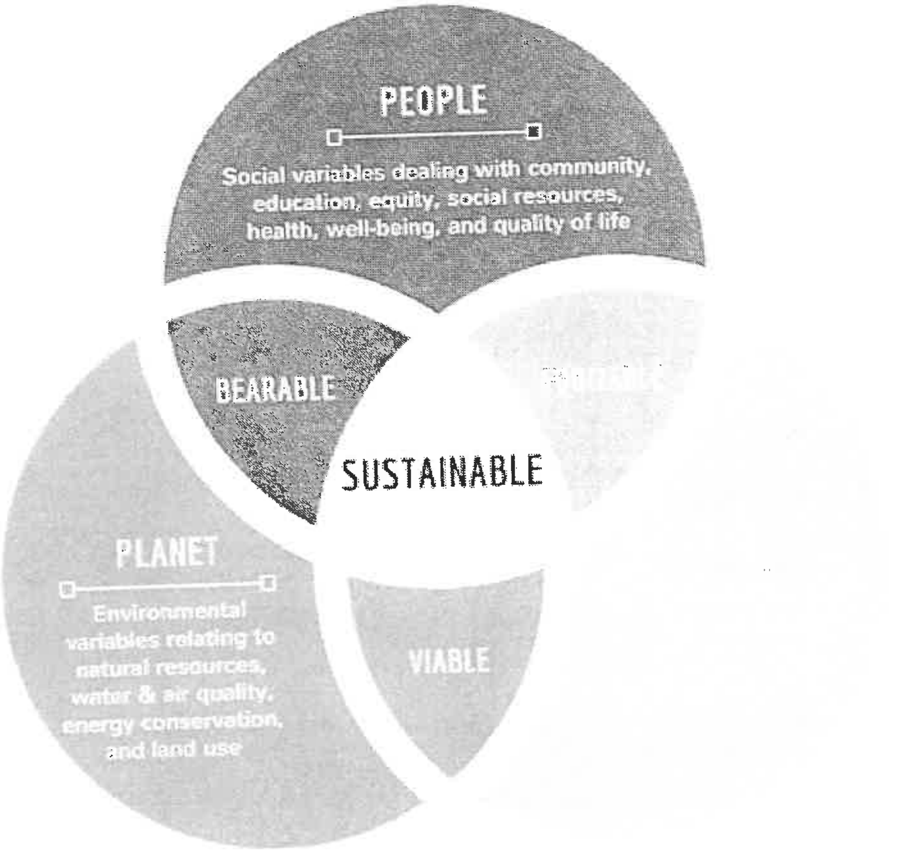
the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



Sustainability strives for:

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- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Asprin Manufacturing

Finance manager

1. Maximize profit
2. Minimize loss
3. buy quality equipment so it lasts longer
4. dispose waste ourselves, to reduce cost.
5. buy reuseable equipment.
6.
7.
8.

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Improves quality of life
3. Leads to longer life span
4. It should be easily accessible
5.
6.
7.
8.

Enviromental Officer

1. Minimize deforestation
2. to minimize air pollution
3. minimize water pollution
4. minimize climate change to reduce emission of greenhouse gases.
5.
6.
7.
8.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

Hint: You are welcome to refer to the **17 sustainable development goals**.

Asprin Manufacturing
Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. the new plant will reduce greenhouse gases
4. profits acquired from aspirin sales ~~is~~ will be invested to bettering community infastructure
5. It will improve aquatic life for beings depending on water ~~for~~ to live
6. It will lead to clean water and sanitation
7. Save money by disposing waste ourselves
8. The job creation reduces poverty
9. it is less expensive thus it is more accessible to a lot of people.
10. It ~~contributes~~ leads. to good health and well-being as it relievers pain and treat fever

Are all group members happy with the new plant design?	[✓ *Yes*]	*No*

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

> In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.
>
> Salicylic acid can be produced using 3 routes.
>
> LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. [5]

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

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$$x\ kg\ \ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	1066.05	—	117.30
Sodium hydroxide	453,10 ✓	—	—
Carbon dioxide	677,35 ✓	—	233.45 ✓
Sulfuric acid	571,55 ✓	—	14.95 ✓
activated carbon	2.11,60 ✓	—	211.60 ✓
water	—	—	204.70 ✓
sodium sulfate	—	—	805.00 ✓
salicylic acid	—	1150	242.65 ✓

453.10

5

$\frac{1150}{\quad} \times 100$

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ \ NaOH\ \ = 1150\ kg\ SA$$

$$x\ kg\ NaOH\ \ = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

2.5

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen**
(Refer to Table 2 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945,11 ✓		
Oil of wintergreen	1488,61 ✓		
water			178,63 ✓
salicylic acid		**1150**	
methanol			266.66 ✓
Sodium sulfate			5636,85

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = \ 1000\ kg\ MA$$

$$x\ kg\ \ CH_3OH\ \ = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH\ \ = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

1,5

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas**
(Refer to Table 3 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**		**267.68**
water			149,28 ✓
acetic acid	1001,87 ✓		
methyl acetate		**616.67**	32,07 ✓

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 2. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) 1829,65 [2]

d. Answer the four questions that follow. 13 [7]

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	$\frac{1150}{2979,65} \times \frac{100}{1}$ $= 38,60\%$ ✓	$\frac{1150}{5021,57} \times \frac{100}{1}$ $22,90\%$ ✓
% Yield How efficient the chemical reactions are.	$\frac{1150}{1359} \times 100\%$ $= 84,62\%$ ✓	$\frac{1150}{1191} \times 100\%$ $= 96,56\%$ ✓
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	$233,45 + 117.30 + 14.95 + 211.60 + 204.70 + 805.00 + 242.65$ $= 1829,65$ ✓	$178,63 + 266,66 + 5636,85$ $= 6082,14$ kg ✓

Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]	Route 1. Because the atom economy is higher for route 1 which means that there is less waste and its better for the environment (ecofriendly) ✓✓
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	Gate to gate ✓
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	Yes ✓ Because the raw material extraction process of route 3 is more sustainable than route 1. ✓
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	The depletion of crude oil would mean less availability of phenol since oil is a non renewable resource. Therefore the production of it would rise, hence the price of aspirin would increase. ✓✓

Question 3

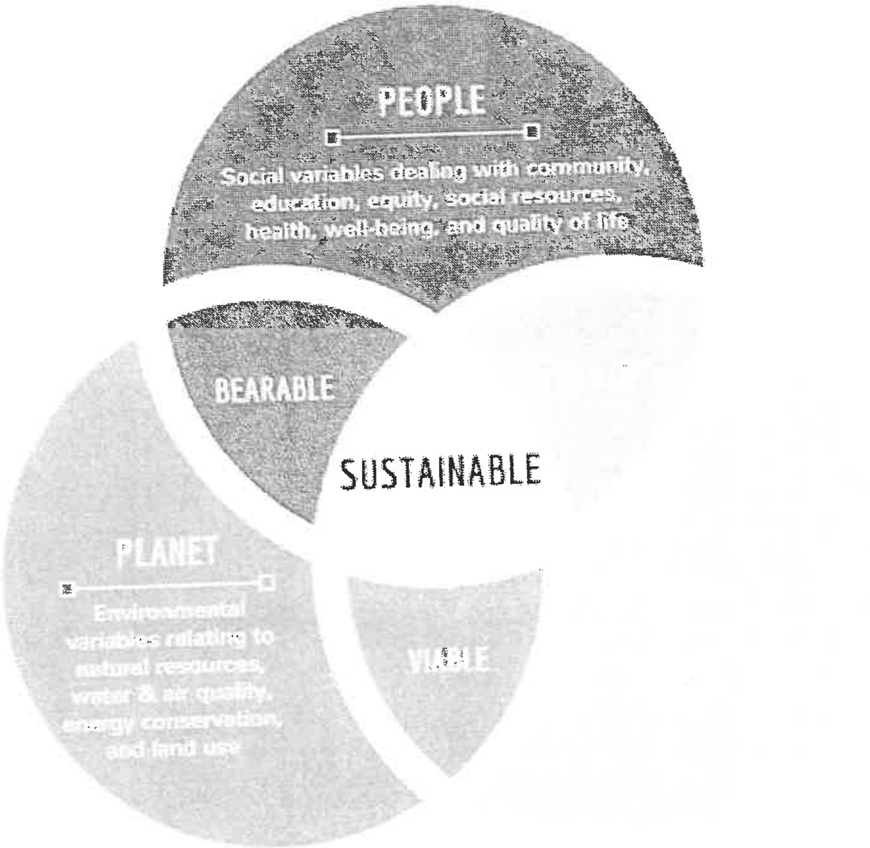
Answer the following questions in the space provided:	
Ⓐ How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? **[2]**	- By recycling by-products leads to a rise in job opportunities, ~~also~~ as well as minimize waste - Areas of extraction processes would be less polluted, if renewable processes were employed.
Ⓑ How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? **[2]**	- cost of transportation - cost of labour/ work force. Ⓒ
Ⓒ Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** Give 2 examples?	- Less usage of non-renewable processes, as well as the use of more renewable ones, would ensure minimal energy, which is then more sustainable Ⓑ - larger work forces would make the labour less intensive.
Ⓓ How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? **[2]**	Through chemistry, we are able to determine sustainable processes and improvements, to ensure that we have a more sustainable approach

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

Sustainable systems thinking is a mindset that helps us to untangle and work within the complexity of life on Earth. It helps us to better understand the impact of our work on the world around us and be responsible for what we create and how we innovate. An important step in developing a systemic approach is to find

the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



Sustainability strives for:

- **Viable** environmental-economic impact: Business is executed with the environment and resources in mind.
- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Reduce costs to produce product (Asprin)
3. Reduce production time
4. Backward Intergration (own supplier)
5.
6.
7.
8.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Increase employement
3. CSR (coperate social Responsibility)
4. Workshops
5. Educational Workshops
6.
7.
8.

Enviromental Officer

1. Minimize deforestation
2. Proper disposal of wastage
3. Ensure no Spilge of waste in water bodies
4. Reduce green-house gases
5.
6.
7.
8.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

  Hint: You are welcome to refer to the **17 sustainable development goals**.

Asprin Manufacturing
Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. Safe disposal of Asprin waste
4. Ensure efficent Asprin processes (time and cost effect)
5. Community workshops
6. water filtration.
7. Responsible consumption & production of Asprin
8. Affordable and clean energy. (to minimize wastage)
9.
10.

Are all group members happy with the new plant design?	[✓ ***Yes***]	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. [5] 4,5

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$
$$x\ kg\ \ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
phenol	**1066.05**		**117.30**
Sodium hydroxide	453,10 sf		
Carbon dioxide	617,35		233,45
Sulfuric acid	571,55		14,95
activated carbon	211,60		211,6
water			204,1
sodium sulfate			805
salicylic acid		**1150**	242,65

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]** ②

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ \ NaOH\ \ = 1150\ kg\ SA$$

$$x\ kg\ NaOH\ = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen**
(Refer to Table 2 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945,11 ✓		
Oil of wintergreen	1488,606 ✓ sf		
water			178,63 ✓
salicylic acid		**1150**	
methanol			266,66 ✓
Sodium sulfate			5636,89

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]** (1,5)

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ \ CH_3OH\ \ = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH\ = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas**
(Refer to Table 3 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
methanol	**534.33**		**267.68**
water			149,08 ✓ ½
acetic acid	1001,87 ✓		
methyl acetate		**616.67**	32,07 ✓

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 2. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	$\frac{1150}{2979,27} \times 100 = 38,60\%$ ✓	$\frac{1150}{286497} \times 100 = 40,14\%$
% Yield How efficient the chemical reactions are.	$\frac{1150}{1359} \times 100 = 84,62\%$ ✓	$\frac{~~450616~~}{1191} \times 100 = 51,78\%$ ✗ ③
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	1829,65 ✓	449,03 ✗
Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. (**[2]**)	Route 3, ✓ less waste is produced and it has a higher reaction ✓ mass efficiency	
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. **~~[1]~~**	Cradle to grave. ✗	
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief (**[2]**)	Yes, ✓ because if the method used to extract the raw materials is ✓ harmful to the environment, then it is not as sustainable	
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. (**[2]**)	It would increase ✓ the cost of buying aspirin as more costs will go into searching for phenol from crude oil which is being depleted as a non-renewable ✓ resource. A high demand and low supply would increase the cost.	

Question 3

Answer the following questions in the space provided:	
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable**?** **[2]**	• We can discard waste properly to prevent water from being Contaminated and ~~to reduce land~~ ~~and~~ the Soil. • We can re-use the outputs so that we can be able to Save money. • After removing the trees, another trees should be planted to avoid climate change.
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? **[2]**	• Companies can invest more in greener Sources of energy. • Companies who use fossil fuels can try ~~to~~
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** ② Give 2 examples?	• Repairing of machines and waste disposal •
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues**?** **[2]**	• It helped us to understand the roots of aspirin synthesis. • It helped us to be able to determine the most Sustainable route • It allows us to make products that are beneficial

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

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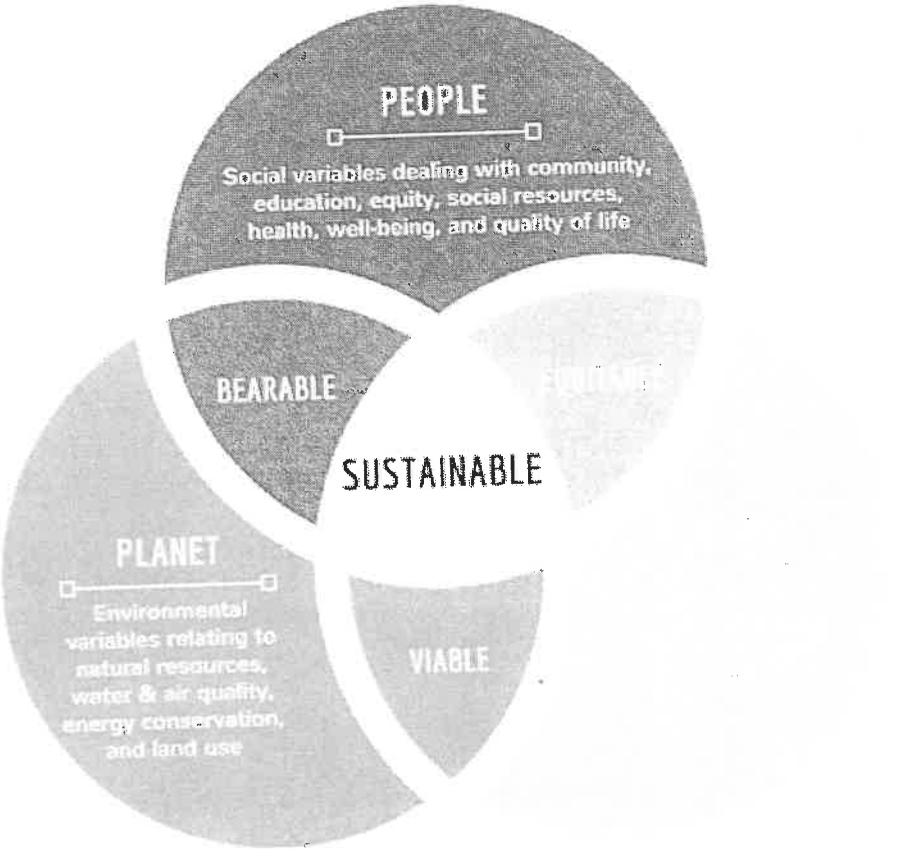
the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



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- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Reduce the cost of production
3. Market brand efficiency
4. Get investers to contribute to Capital
5. Charity work to reduce tax paid by company
6. Find most affordable method to discard of waste
7.
8.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Don't dump waste in community during disposal
3. Product must be benefical for users
4. Make affordable to all community members
5. Educate people on the product
6. Make product accessible to all rural and urban communities
7. Sell to local businesses (Support small businesses)
8. Charity work, provide medicine to underprivileged.

Enviromental Officer

1. Minimize deforestation
2. Try minimize pollution
3. Extract crude oil in areas with little aquatic life
4. Don't contaminate water during extraction of crude oil
5. Don't overuse water
6. Recycle waste products if possible
7. Use cleaner sources of energy
8. Reduce over extraction of raw materails.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

  Hint: You are welcome to refer to the **17 sustainable development goals.**

Asprin Manufacturing
Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. Get investors that specifically focus on sustainability
4. Affordable and efficient waste management
5. Create jobs for local ~~peolp~~ people
6. Support small businesses by working with them to distribute our product
7. Reduce over extraction of raw materials
8. Use more capital to go with a more sustainable production route
9. Recycle waste products
10. Prevent dumping in communal areas to reduce risk of diseases

Are all group members happy with the new plant design?	[✓ ***Yes***]	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. **[5]**

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$

$$x\ kg\ \ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	**1066.05**		**117.30**
Sodium hydroxide	453.10		
Carbon dioxide	677.35		233.45
Sulfuric acid	571.55		14.95
activated carbon	211.60		211.60
water			204.70
sodium sulfate			805.00
salicylic acid		**1150**	242.65

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ NaOH = 1150\ kg\ SA$$

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85}\ \boldsymbol{kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen**

(Refer to Table 2 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945.11		
Oil of wintergreen	1488.61		
water			178.63
salicylic acid		**1150**	
methanol			266.66
Sodium sulfate			5636.85

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = 534.33\ \boldsymbol{kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas**

(Refer to Table 3 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
methanol	**534.33**		**267.68**
water			149.28
acetic acid	1001.87		
methyl acetate		**616.67**	32.07

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 2. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	$\frac{1150}{2979.65} \times 100\%$ $= 38.60\%$	$\frac{1150}{5021.57} \times 100\%$ $= 22.90\%$ ②
% Yield How efficient the chemical reactions are.	$\frac{1150}{1359} \times 100\%$ $= 84.62\%$	$\frac{1150}{1191} \times 100\%$ $= 96.56\%$ ②
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	$233.45 + 14.95 + 211.60 + 204.77 + 805 + 242.65$ $= 1829.65$ kg	$178.63 + 266.66 + 5636.85$ $= 6082.14$ kg ②
Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2] ②	Route 1. This route produces less waste.	
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	✗ Cradle to grave	
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	Yes. An efficient raw material extraction process will result in the saving of energy, which is more sustainable.	
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	The cost of buying aspirin would increase, because the supply of aspirin is limited to the production of crude oil, so if the crude oil is depleted then the supply and demand of aspirin will not be equal leading to an increase in the price of aspirin.	

Question 3

Answer the following questions in the space provided:

How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable**?** [2]	Environmental • Using resources efficiently. • Maximizing the use of the reactants in order to reduce waste.
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? [2]	• By reproducing the resources such as planting more trees (wintergreen) or finding alternative methods to produce other inputs (synthetically).
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? [2] Give 2 examples?	• Cost of packaging. • Distribution costs.
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues**?** [2]	The exercise educates us more about sustainability which shows that chemistry is putting in necessary measures, such as the program of Green Chemistry. Which aims to minimize the environmental impact during the production and use of chemicals.

SYSTEMS THINKING IN SUSTAINABILITY

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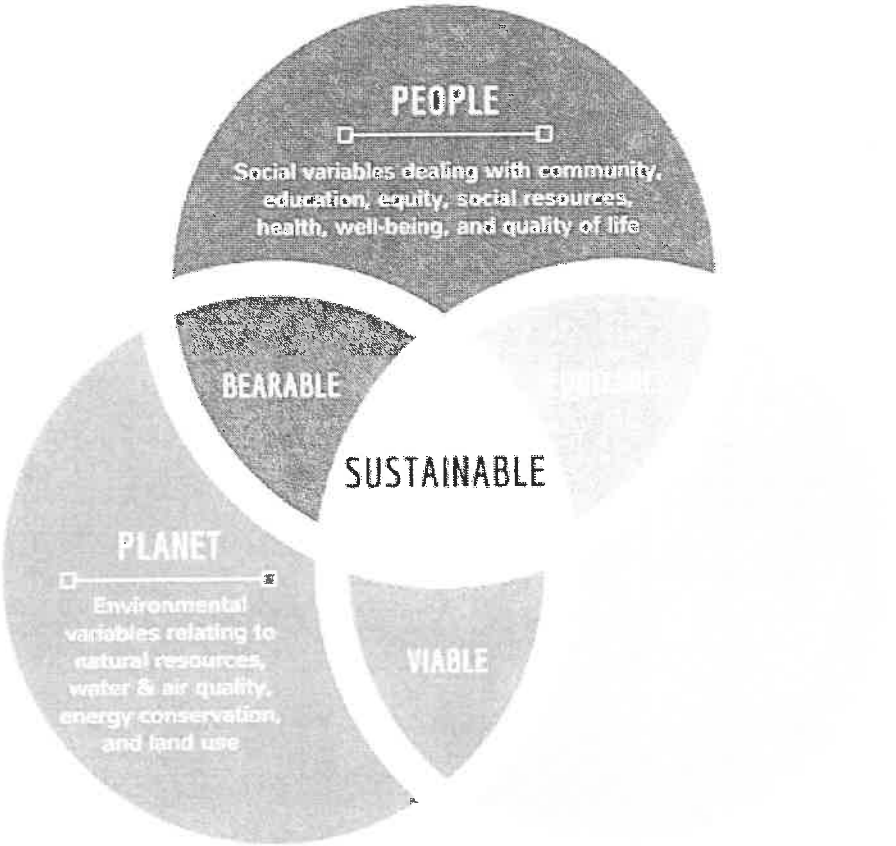

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ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Contributes to the tax
3. Contributes to they gross of the country.
4. increase the supply and decrease demand leading
5. the low price rate.
6.
7.
8.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. To ensure safety of the local People
3. Advocate for the necessary human rights
4. Promote the education of local People
5. about the plant and how it works.
6.
7.
8.

Enviromental Officer

1. Minimize deforestation
2. Minimize pollution
3. Educate people on global warming and
4. climate change.
5. Promote the habit of recycling and
6. reusing.
7.
8.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

  Hint: You are welcome to refer to the **17 sustainable development goals**.

Asprin Manufacturing
Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. The community will form a local recycling program.
4. The community represantatives will educate the locals on sustainability.
5. The reforestation will improve air quality therefore reduce air pollution.
6.
7.
8.
9.
10.

Are all group members happy with the new plant design?	[✓ *Yes*]	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. [5]

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

4,5

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$
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$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

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(Refer to Table 1 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	**1066.05**		**117.30**
Sodium hydroxide	453.10 ✓		
Carbon dioxide	677.35 ✓		233.45 ✓
Sulfuric acid	571.55 ✓		14.95 ✓
activated carbon	211.60 ✓		211.60 ✓
water			204.70 ✓
sodium sulfate			805.00
salicylic acid		**1150**	242.65 ✓

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ NaOH = 1150\ kg\ SA$$

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen** ***(Refer to Table 2 page 7)***

2.5

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945.11		
Oil of wintergreen	1488.61		
water			178.63
salicylic acid		**1150**	
methanol			266.66
Sodium sulfate			5636.85

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = 534.33\ kg$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas** ***(Refer to Table 3 page 7)***

1.5

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**		**267.68**
water			149.28
acetic acid	1001.87		
methyl acetate		**616.67**	32.07

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**. Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 3. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. 7 [7]

<table>
<tr><th colspan="3">Table 4</th></tr>
<tr><th>Green matrix and meaning</th><th>Route 1</th><th>Route 3</th></tr>
<tr><td>% Atom economy
How efficient the process is in terms of atoms</td><td>65.22 %</td><td>54.88 %</td></tr>
<tr><td>% Reaction mass efficiency
How efficient the process is in terms of amount of inputs to product</td><td>38.60 %</td><td>40.14 %</td></tr>
<tr><td>% Yield
How efficient the chemical reactions are.</td><td>84.62 %</td><td>51.78 %</td></tr>
<tr><td>E-factor (Total waste) (in kg)
How efficient the chemical reactions in terms of waste produced.</td><td>~~61.40 %~~
1829.65</td><td>~~29.23 %~~
449.05</td></tr>
<tr><td>Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]</td><td colspan="2">Route 3 because it produces less waste</td></tr>
<tr><td>What type of system boundary (Cradle to gate or Gate to grave or Cradle to grave or Gate to gate) is implemented in this inventory?
Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]</td><td colspan="2">Gate to gate</td></tr>
<tr><td>Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route?
Explain in brief [2]</td><td colspan="2">It wouldn't because Route 3 uses wintergreen oil from trees which can be replanted unlike Route 1 which uses crude oil which depletes</td></tr>
<tr><td>Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin?
Briefly explain. [2]</td><td colspan="2">Aspirin prices would increase because more costs would beincurred to access crude oil due to its scarcity</td></tr>
</table>

Question 3

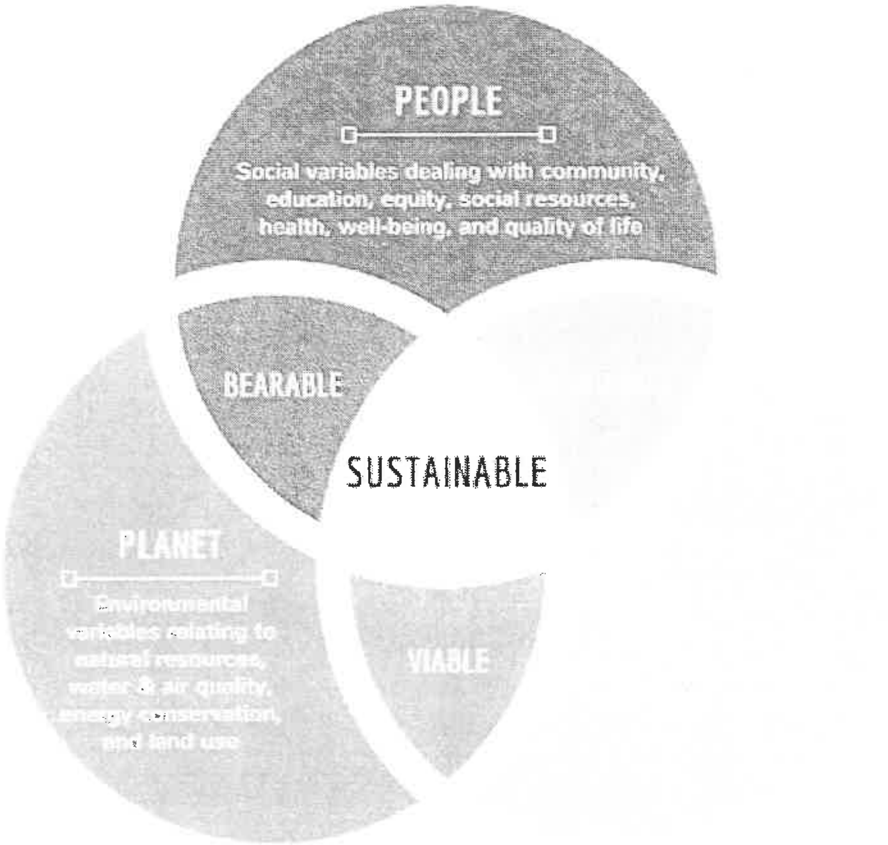
Answer the following questions in the space provided:	
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? **[2]**	recycling, reusing and reducing awareness campaigns hefty fines for those that are ignorant to sustainable use of resources investment in catalytic convertors
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? **[2]**	use of renewable energy sources that have minimal impacts e.g solar, wind turbines etc
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** Give 2 examples?	labour costs waste management disaster management e.g spills or explosions within the Factory 2
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? **[2]**	we can find alternative aspirin production methods with higher carbon efficiency and lower waste production 2

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

Sustainable systems thinking is a mindset that helps us to untangle and work within the complexity of life on Earth. It helps us to better understand the impact of our work on the world around us and be responsible for what we create and how we innovate. An important step in developing a systemic approach is to find

the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



Sustainability strives for:

- **Viable** environmental-economic impact: Business is executed with the environment and resources in mind.
- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. High demand leading to high supply
3. cheaper labour
4. longer lasting equipment
5. minimise waste production to minimise costs
6. plan for unexpected costs
7. maximise production
8.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. improve living standards
3. urbanisation of local community.
4. improved security
5. improved quality of education
6. gender equality
7.
8.

Enviromental Officer

1. Minimize deforestation
2. minimize land pollution
3. minimize water pollution
4. use renewable energy sources
5. invest in reusing and recycling methods
6. efficient & sustainable waste management
7. reduce carbon emission
8. use biodegradable packaging

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

Hint: You are welcome to refer to the **17 sustainable development goals**.

Asprin Manufacturing
Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. Plant will employ more local citizens
4. Plant will bring development to community through roads etc
5. The community will have impacued security as the plant has to be in a secure place.
6. Better healthcare will be provided in community
7. Plant will invest in recycling methods
8.
9.
10.

Are all group members happy with the new plant design?	[✓ Yes]	No

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. **[5]**

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$
$$x\ kg\ \ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
phenol	**1066.05**		**117.30**
Sodium hydroxide	453.10		
Carbon dioxide	677.35		
Sulfuric acid	1945.11		
activated carbon	211.60		
water			204.70
sodium sulfate			805.00
salicylic acid		**1150**	242.65

⑤

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ \ NaOH\ = 1150\ kg\ SA$$

$$x\ kg\ NaOH\ = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

2.5

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen**

(Refer to Table 2 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945.11		
Oil of wintergreen	1488.61		
water			178.63
salicylic acid		**1150**	
methanol			266.66
Sodium sulfate			4262.27

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ \ CH_3OH\ = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH\ = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

1.5

Table 3: Material balance for the production of **616.67 kg** of **methyl acetate from natural gas**

(Refer to Table 3 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
methanol	**534.33**		**267.68**
water			149.28
acetic acid	1001.87		
methyl acetate		**616.67**	32.07

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route ~~2~~ 3. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

Table 4

Green matrix and meaning	Route 1	Route 3
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	27,78%	5,10%
% Yield How efficient the chemical reactions are.	84,62%	96,56%.
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	7,38%	0%.
Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]	Route 3 because there is no waste	
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	Gate to gate.	
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	Yes as adding raw materials to route 3 would result in waste.	
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	Price of Aspirin would increase as only two routes can be used to produce Asprin.	

Question 3

Answer the following questions in the space provided:	
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? **[2]**	By recycling the byproducts ~~used~~ produced in the process. These byproducts can be used to produce other products and in doing so it is not necessary to discard it as waste. This reduces the environmental impact as there is less waste and can also influence the economic impact because you get raw materials for free.
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? **[2]**	By making use of renewable energy instead of relying on fossil fuels we can reduce the pollution caused by burning fossil fuels and minimize the environmental impact
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** Give 2 examples?	The cost of waste management and the cost of the ~~emploe~~ employees salary.
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? **[2]**	Chemistry can be used to find new ways to produce certain products or to maximize the ~~efficei~~ efficiency of the process, and in doing so increase the sustainability.

SYSTEMS THINKING IN SUSTAINABILITY

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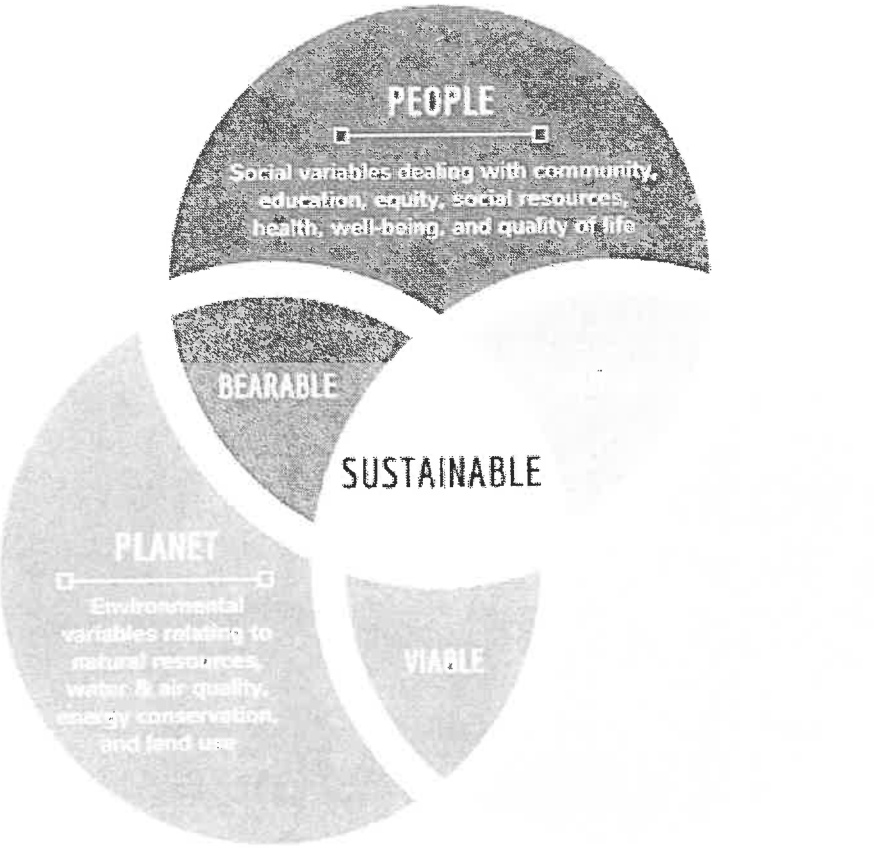
the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



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- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Maximize efficiency of the system
3. Maximize prices of Asprin
4. Increase demand and supply
5.
6.
7.
8.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Increase tax contribution
3. Increase quality of life
4. Increase longevity of life
5. Allocate resources into the community
6. Decrease drug dependency and abuse
7.
8.

Enviromental Officer

1. Minimize deforestation
2. Minimize waste produced
3. Minimize water pollution
4. Minimize air pollution
5. minimize extraction of raw materials.
6.
7.
8.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

Hint: You are welcome to refer to the **17 sustainable development goals.**

Asprin Manufacturing Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. Allocate funds and resources for educational purposes in the community
4. New plant will use renewable resources.
5. The plant will support and partnership with local businesses.
6. Ensure gender equality in job opportunities.
7. Provide medical aid for all employees.
8. Company and community will have environmental programmes to ensure clean water/environment.
9.
10.

Are all group members happy with the new plant design?	[✓ ***Yes***]	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. [5]

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$
$$x\ kg\ \ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol** ***(Refer to Table 1 page 7)***

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	1066.05	~~948.75~~	117.30
Sodium hydroxide	453.10 ✓		
Carbon dioxide	677.35 ✓		233.45 ✓
Sulfuric acid	571.55 ✓		14.95 ✓
activated carbon	211.60 ✓		211.60 ✓
water			204.70 ✓
sodium sulfate			805.00 ✓
salicylic acid		1150	242.65 ✓

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ NaOH = 1150\ kg\ SA$$

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen**
(Refer to Table 2 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945.11		
Oil of wintergreen	1488.61		
water			~~155.33~~ 178.63
salicylic acid		**1150**	
methanol			266.66
Sodium sulfate			5636.85

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas**
(Refer to Table 3 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**		**267.68**
water			149.28
acetic acid	1001.87		
methyl acetate		**616.67**	32.07

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**. Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 2. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

Table 4

Green matrix and meaning	**Route 1**	**Route 3**	
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.54.88 %	
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product $\frac{1150kg}{2768.09kg} \times 100 =$	41.55%	17.40% $\frac{1150kg}{609.42kg} \times 100 =$ X	①
% Yield How efficient the chemical reactions are. $\frac{1150kg}{1359kg} \times 100 =$	84.62 %	$\frac{1150kg}{1191kg} \times 100 = 96.56\%$	②
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	~~1829.65kg / 2768.09kg ×100 = 65.39% = 56.80%~~ 1829.65kg	~~6082.14kg / 6609.42kg ×100 = 92.02%~~ 6082.14kg	②

Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]	Route 1, because it has a better atom economy than route 2, ~~aswell~~ ~~has~~ and less waste aswell.
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	Gate to gate
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	No, it does not ~~m~~ reduce the waste by improving waste management.
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	~~An,~~ A decrease in the oil supply would increase the cost of production as the price of oil increases. Therefore the price of asprin will increase and less sales.

Question 3

Answer the following questions in the space provided:

How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? [2]	• Implement a better waste manage-ment system, to benifit the environment and economy.
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? [2]	• Find a renewable energy source to replace burning fossil feuls to benefit the environment and social aspects, because of less polution and rely less on the power grid.
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? [2] Give 2 examples?	• Costs of protective equipment • Costs of training personnel to follow procedures, when dealing with hazardous chemicals.
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? [2]	~~Wha~~ We use chemistry to calculate the most efficient routes and most sustainable options beforehand.

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

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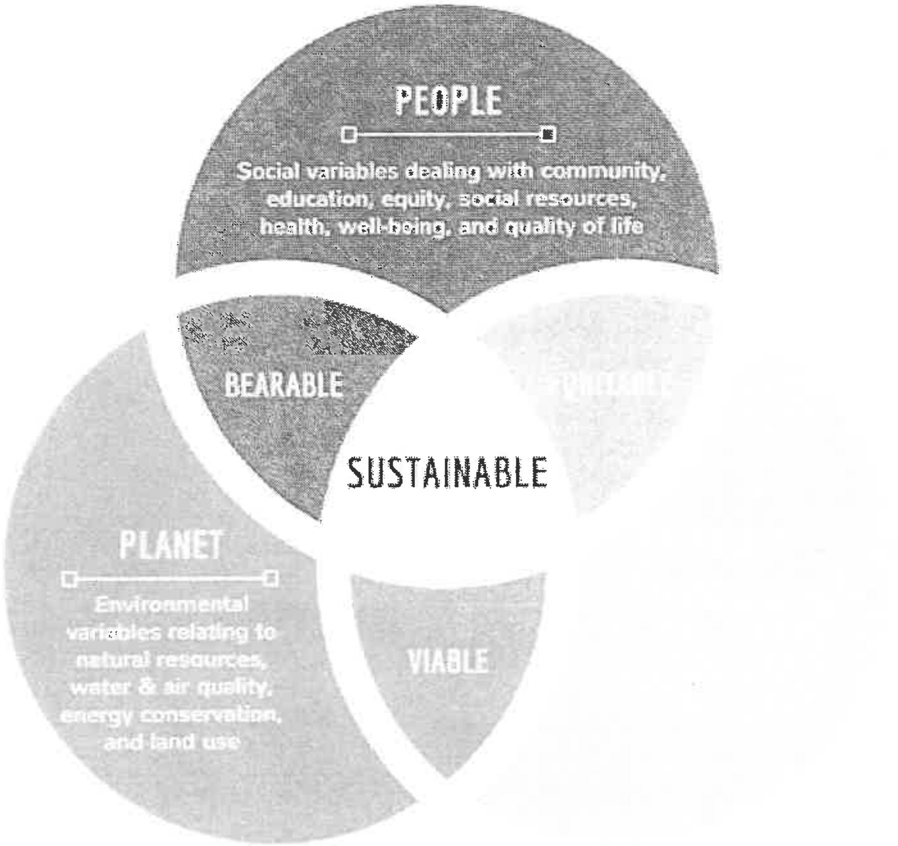

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- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Reduce costs
3. Find cheaper suppliers.
4. Find a more efficent way for packaging.
5.
6.
7.
8.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Do workshops/training for the community.
3. Start bursary funds for students
4. Do a charity for the community.
5.
6.
7.
8.

Enviromental Officer

1. Minimize deforestation
2. Reduce waste
3. Reduce carbon footprint.
4. Donate to environmental fighters.
5. Minimize water waste.
6. Find a renewable energy source.
7.
8.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

  Hint: You are welcome to refer to the **17 sustainable development goals**.

Asprin Manufacturing Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. no descrimanation depending on your sex
4. Employ the community.
5. Fair labour regulations.
6. Implement a waste management system, for water.
7. Use local suppliers to support them.
8. Create a community fund to feed community.
9.
10.

Are all group members happy with the new plant design?	[✓ ***Yes***]	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. [5]

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH \leftarrow 1000\ kg\ SA$$

$$\boxed{x\ kg\ C_6H_5OH} \leftarrow 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol** ***(Refer to Table 1 page 7)***

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	**1066.05**	—	**117.30**
Sodium hydroxide	453.10	—	—
Carbon dioxide	677.35	—	233.45
Sulfuric acid	571.55	—	14.95
activated carbon	211.60	—	211.60
water	—	—	204.70
sodium sulfate	—	—	805.00
salicylic acid	—	**1150**	242.65

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ \ NaOH\ = 1150\ kg\ SA$$

$$x\ kg\ NaOH\ = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85}\ \boldsymbol{kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen**

(Refer to Table 2 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	1587.85	—	—
Sulfuric acid	1946.11 ✓	—	—
Oil of wintergreen	1488.61 ✓	—	—
water	—	—	178.63 ✓
salicylic acid	—	1150	—
methanol	—	—	266.66 ✓
Sodium sulfate	—	—	5636.85 ✓

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ \ CH_3OH\ = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH\ = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = 534.33\ \boldsymbol{kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas**

(Refer to Table 3 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	534.33	—	267.68
water	—	—	149.28 ✓
acetic acid	1001.87 ✓	—	—
methyl acetate	—	616.67	32.07 ✓

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 3. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

Table 4

Green matrix and meaning	**Route 1**	**Route 3**	
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %	
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	actual mass of desired product / total mass of all reactants x100 ~~= 1150/2768.05 x100 = 41.55 %~~ = 1150/2979.65 x100 = 38.60 %	= 1150/5021.57 x 100 = 22.90 %	(2)
% Yield How efficient the chemical reactions are.	= actual mass of desired product / expected mass of desired product x100 = 1160/1359 x100 = 84.62 %	= 1150/1191 x 100 = 96.56 %	(3)
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	1829.65 kg	6072.14 kg	(7)
Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]	We would choose Route 1, as there is less waste produced and there is better utilization of reactants, as shown by % atom economy		
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	Gate to gate		
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	No, as you will be adding in a step which will contradict sustainability as an extra step means more room for waste production		
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	The price of aspirin will increase as the raw materials used to produce it will be scarce. ~~and~~		

Question 3

Answer the following questions in the space provided:

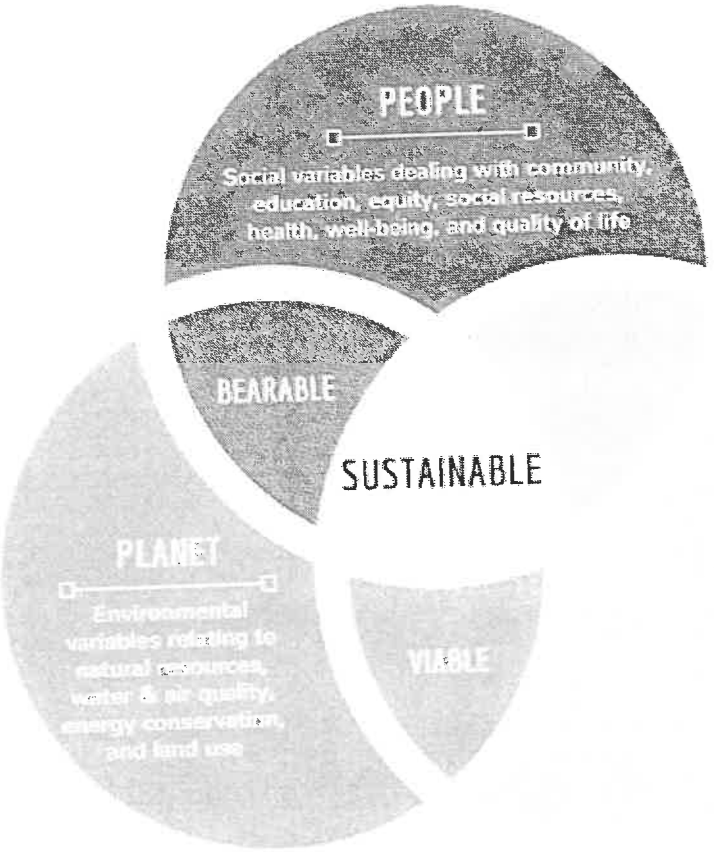
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? [2]	The impact can be minimited or managed by shortening the process by eliminating unnecessary steps because you will be limiting waste, thus producing more product. ~~Start~~ using renewable resources so that fuel, ~~none~~ renewable fuel, is reduced and the environment is saved from unnecessary toxicity
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? [2]	Cost efficient energies or fuels can be used example, local energies and fuels reducing the cost importing, benefiting economy by job creation and less carbon footprint without transport. ? { renewable energies
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? [2] Give 2 examples?	~~It would~~ Example 1 would be the cost of moving your waste to waste plantations to discard of them Example 2 would be labor costs
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? [2]	It shows us that in a chemical reaction a chemical production the use of an expanded process can result in a large sum of wastage which is contradicting to sustainability as with wastage depletion is a result.

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

Sustainable systems thinking is a mindset that helps us to untangle and work within the complexity of life on Earth. It helps us to better understand the impact of our work on the world around us and be responsible for what we create and how we innovate. An important step in developing a systemic approach is to find

the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



Sustainability strives for:

- **Viable** environmental-economic impact: Business is executed with the environment and resources in mind.
- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. minimize costs
3. mini mize labor costs.
4. resource conservation ie renewable locally
5. flexible planning that grow with company.
6. Resource allocation, reduce wastage.
7. monitering the financial costs
8. Evaluation of expenditure.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. support local suppliers
3. communicate openly with community.
4. socially responsible ensuring safety & health workers.
5. fair labor practices, promotion.
6. Promotion of education
7. Bursaries to STEM kids.
8. community events & fundraising for

Enviromental Officer

1. Minimize deforestation
2. Use renewable resources
3. reducing waste
4. reduce energy consumption.
5. reduce emissions (fuel and air pollution)
6. Promote biodiversity by being eco
7. upgraded water
8. water conservation.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

Hint: You are welcome to refer to the **17 sustainable development goals**.

Asprin Manufacturing
Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. The new plant will reduce the emission of greenhouse gases which will be climate action.
4. ~~The~~ The new plant lead to job creation; increase in economic growth, decrease poverty
5. The new plant provides gender equality ie fair labor practices
6. The plant will promo education as it will be used as research plant for tertiary educa
7. The new plant will provide the reduction greenhouse which will reduce acidic rain & save life below water.
8. The new plant recycles water, usage of up cycled water.
9. The new plant recycles old plastic tubes and used recycled goods.
10. The new plant has a hand in none profitable organizations helps with orphans and funding of schools.

Are all group members happy with the new plant design?	[✓ *Yes*]	*No*

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. [5]

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH = 1000\ kg\ SA$$
$$x\ kg\ C_6H_5OH = 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

5

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(*Refer to Table 1 page 7*)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	**1066.05**	948.75	**117.30**
Sodium hydroxide	453,10 ✓	453,10	0
Carbon dioxide	677.35 ✓	443.90	233.45 ✓
Sulfuric acid	571.55 ✓	556.60	14.95 ✓
activated carbon	211.60 ✓	0	211.60 ✓
water	0	204.70	204.70 ✓
sodium sulfate	0	805.00	805.00 ✓
salicylic acid	0	**1150**	242.65 ✓

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ NaOH = 1150\ kg\ SA$$

2.5

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85}\ \boldsymbol{kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen** (***Refer to Table 2 page 7)***

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**	1587.85	0
Sulfuric acid	1945.11	1945.11	0
Oil of wintergreen	1488.61	1488.61	0
water	0	178.63 ~~178.63~~	178.63
salicylic acid	0	**1150**	~~1150~~
methanol	0	266.66	266.66
Sodium sulfate	0	5636.85	5636.85

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = 534.33\ kg$$

1.5

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas** (***Refer to Table 3 page 7)***

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**	266.65	**267.68**
water	0	149.28	149.28
acetic acid	1001.87	1001.87	~~0~~
methyl acetate	0	**616.67**	32.07

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**. Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 2. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

11

Table 4		
Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	$\frac{1150 \times 100}{1587.85+1945.11+1488.61}$ $= 22.90\%$	swap $\frac{1150 \times 100}{1066.05+453.10+677.35+571.55}$ $= 38.60\%$
% Yield How efficient the chemical reactions are.	$\frac{1150}{1359} \times 100$ $= 84.62\%$	$\frac{1150}{1191} \times 100$ $= 96.56\%$
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	~~242.65~~ 1712.35 kg	7232.14 kg

Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]	Route 1. It produces less waste than Route 3
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	Gate to gate
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	Yes, collection of oil of winter-green is more environmentally friendly than the collection of crude oil
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	It would increase the price of Aspirin because the supply would decrease therefore the demand would increase which increases the price.

Question 3

Answer the following questions in the space provided:

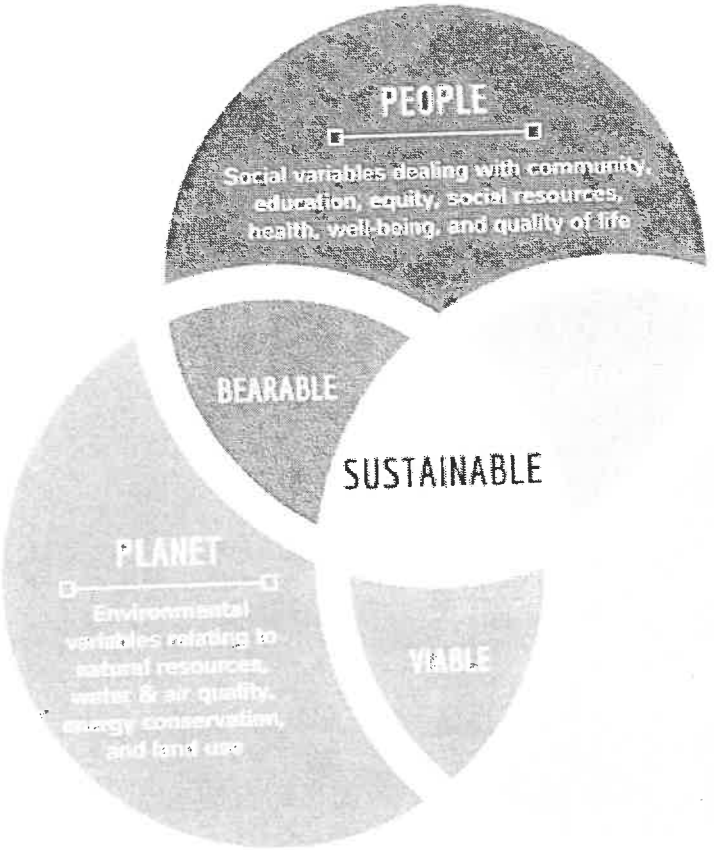
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? **[2]**	~~Route 3~~ Oil from route 3 is more sustaintable than that of the one in route 1 . - ~~yo~~ use wintorgreen oil rather than crude oil because it is more sustainable and environmentally friendy.
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? **[2]**	-Use greener energy like solar power, wind, hydropower. rather -than fossel fuels.
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** Give 2 examples?	*Salaries to workers * ~~Sustaining the~~ r * Maintenance ~~Maintance~~ of the machines
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? **[2]**	-To create more Sustainable Systems for the future.

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

Sustainable systems thinking is a mindset that helps us to untangle and work within the complexity of life on Earth. It helps us to better understand the impact of our work on the world around us and be responsible for what we create and how we innovate. An important step in developing a systemic approach is to find

the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



Sustainability strives for:

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- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Reduce costs by eliminating unnecessary steps
3. Use renewable energy for lower energy cost.
4. Eliminate waste
5. Evaluate production processes.
6. Cut out surplus
7. optimise ~~workfore~~ workforce effiency
8. Smart investments.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Teach students about sustainability
3. Donate to charity
4. Reduce inequality in the workplace
5. ensure there is clean water and sanitation
6. Improve healthcare
7. Reduce the usage of toxic chemicals
8. Improve safety measures.

Enviromental Officer

1. Minimize deforestation
2. Minimize waste
3. Minimize Air pollution
4. Minimize water contamination
5. Reduce the usage of toxic reagents
6. Reduce Soil pollution
7. Reduce Radioactive contamination
8. Reduce thermal pollution

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

  Hint: You are welcome to refer to the **17 sustainable development goals.**

Asprin Manufacturing Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. The community will spread awareness about gender ~~e~~ inequality
4. Companies will ~~Smart~~ invest in sustainable systems.
5. Companies will be forced to use greener energy
6. Use safer processes to ensure the health of workers.
7. Open more recycling companies around local communities
8. Spread awareness of drug addiction
9. Donate to Charity
10. Donate money to help clean the oceans.

Are all group members happy with the new plant design?	~~*Yes*~~	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. **[5]**

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$
$$x\ kg\ \ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
phenol	**1066.05**		**117.30**
Sodium hydroxide	453,10		
Carbon dioxide	677,35		233,45
Sulfuric acid	571,55		14,95
activated carbon	211,60		211,60
water			204,70
sodium sulfate			805,00
salicylic acid		**1150**	242,65

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ NaOH = 1150\ kg\ SA$$

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen** ***(Refer to Table 2 page 7)***

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945,17		
Oil of wintergreen	1488,~~606~~ 61		
water			178,63
salicylic acid		**1150**	
methanol			266,66
Sodium sulfate			5636,85

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

1

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas** ***(Refer to Table 3 page 7)***

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**		**267.68**
water			149,28
acetic acid	1001,87		
methyl acetate		**616.67**	32,06684

S,F

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 2. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	$= \frac{1150}{913,6} \times 100$ $= 60,10\%$	$= \frac{1150}{5021,57} \times 100$ $= 22,90\%$ ①
% Yield How efficient the chemical reactions are.	$= \frac{1150}{1359} \times 100$ $84,62\%$	$= \frac{1150}{1191} \times 100$ $96,56\%$ ②
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	1829,65 kg	6082,14 kg ②
Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]	Route 1 because less waste was produced.	
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]	Cradle to ~~gate~~ Grave.	
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief [2]	Yes as the Material extraction processe results in less sustainable extraction	
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. [2]	Cost of aspirin would inflate because the resources required would be less available	

Question 3

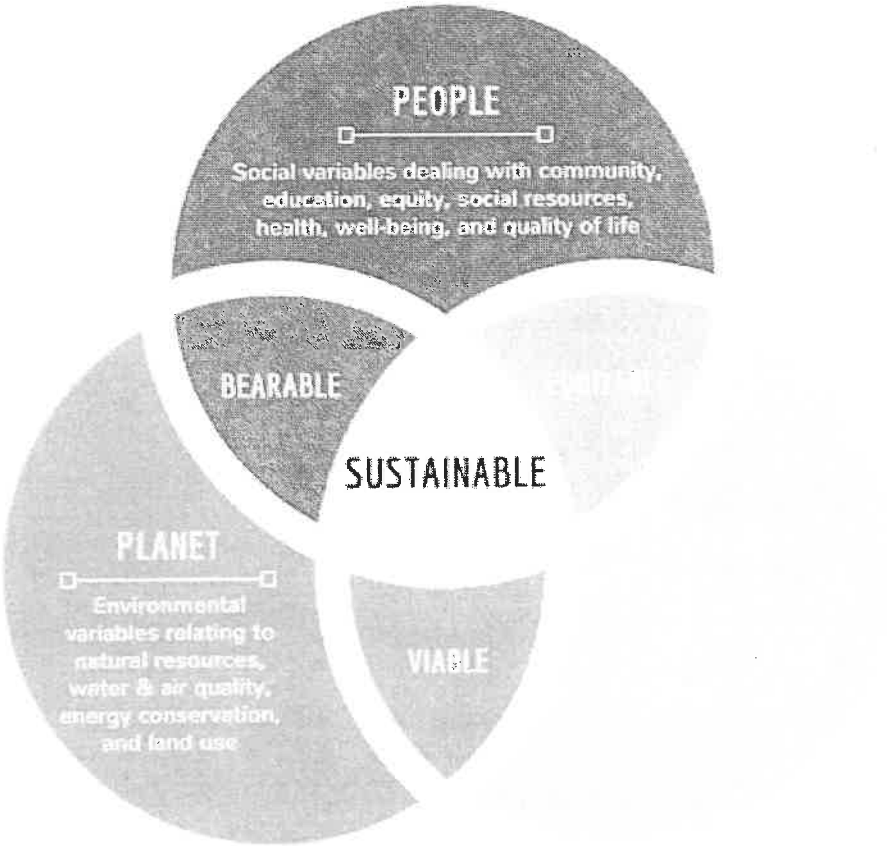
Answer the following questions in the space provided:	
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? [2]	Environmental : The process whereby we obtain crude oil utilises extensive amounts of energy which is terrible for waste management. Using trees as an energy source will result in rapid deforestation which would be harmful to the environment.
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? [2]	Environmental: we should prioritise the use of renewable resources as this would drastically decrease the energy required to obtain the non-renewable resources.
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? [2] Give 2 examples?	- The cost of machinery and its maintenance. - The cost of labour to oversee the process and ensure that the machinery is maintained.
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? [2]	The synthesis of aspirin is not dependent on a single route of manufacture, as there are multiple different routes to obtain the resources needed to synthesis the aspirin. This allows for the recooperation of ~~materials~~ natural resources expended.

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

Sustainable systems thinking is a mindset that helps us to untangle and work within the complexity of life on Earth. It helps us to better understand the impact of our work on the world around us and be responsible for what we create and how we innovate. An important step in developing a systemic approach is to find

the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



Sustainability strives for:

- **Viable** environmental-economic impact: Business is executed with the environment and resources in mind.
- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Reduce loss of profit due to poor waste management.
3. Tax contribution
4. Increases employment.
5.
6.
7.
8.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Involve the community to replant trees to decrease deforestation.
3. Ensure that there is no contamination
4. in water and food sources.
5. Reduce the pollution in the surroundings.
6.
7.
8.

Enviromental Officer

1. Minimize deforestation
2. Reduce the need for crude oil.
3. Begin research to discover renewable alternati
4. Discover a method focused on oil of wintergreen
5.
6.
7.
8.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

  Hint: You are welcome to refer to the **17 sustainable development goals**.

Asprin Manufacturing Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. The new plants should result in an increase in revenew.
4. The new. plants should be ~~and~~ an additive towards tax contribution.
5. The new plants should create jobs for people.
6. the new plants. should maximize profit.
7.
8.
9.
10.

Are all group members happy with the new plant design?	[✓ *Yes*]	*No*

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. [5] ④

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH = 1000\ kg\ SA$$
$$x\ kg\ C_6H_5OH = 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(*Refer to Table 1 page 7*)

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
phenol	**1066.05**		**117.30**
Sodium hydroxide	453.10		~~233~~
Carbon dioxide	677.3~~5~~4		233.~~45~~
Sulfuric acid	571.8~~5~~		~~14.95~~ 15.0
activated carbon	211.60 SL		~~211.6~~ 212 S.L
water			205.~~7~~
sodium sulfate			~~805~~ 805 SL
salicylic acid		**1150**	243. SL

2768.05

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$

$$x\ kg\ NaOH = 1150\ kg\ SA$$

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen** ***(Refer to Table 2 page 7)***

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945.11		
Oil of wintergreen	1488.61		
water			178.63
salicylic acid		**1150**	
methanol			266.66
Sodium sulfate			5636.85

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$

$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas** ***(Refer to Table 3 page 7)***

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**		**267.68**
water			149.28
acetic acid	1001.87		
methyl acetate		**616.67**	32.07

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**. Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 2. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg.** A

For route 3 theoretical yield of salicylic acid is **1191 kg.** T

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

<table>
<tr><th colspan="3">Table 4</th></tr>
<tr><th>Green matrix and meaning</th><th>Route 1</th><th>Route 3</th></tr>
<tr><td>% Atom economy
How efficient the process is in terms of atoms</td><td>65.22 %</td><td>54.88 %</td></tr>
<tr><td>% Reaction mass efficiency
How efficient the process is in terms of amount of inputs to product</td><td>$\frac{1150}{1066.05+4531+677.35+571.55+} \times 100$
41.55%</td><td>$\frac{1150}{1587.25+1945.11+1488.61} \times 100$
= 22.90% ②</td></tr>
<tr><td>% Yield
How efficient the chemical reactions are.</td><td>$\frac{1150}{1359} \times 100$
84.62%</td><td>$\frac{1150}{1191} \times 100$
= 96.5% ②</td></tr>
<tr><td>E-factor (Total waste) (in kg)
How efficient the chemical reactions in terms of waste produced.</td><td>117.30 + 233.45 + 1495 + 211.6 + 2094.7 + 805
=1830</td><td>178.63 + 266.66 + 5636.85
=6082.14 ②</td></tr>
<tr><td>Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. [2]</td><td colspan="2">Route 1, It has a higher efficiency and less waste</td></tr>
<tr><td>What type of system boundary (Cradle to gate or Gate to grave or Cradle to grave or Gate to gate) is implemented in this inventory?
Refer to Figure 3, Page 4 of the Aspirin Manufacture document. [1]</td><td colspan="2">Gate to gate</td></tr>
<tr><td>Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route?
Explain in brief [2]</td><td colspan="2">NO, route 1 is the more sustainable route, because it produces less waste and higher reaction mass efficiency</td></tr>
<tr><td>Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin?
Briefly explain. [2]</td><td colspan="2">The cost of aspirin would increase as the crude oil availability would decrease in the production of aspirin</td></tr>
</table>

Question 3

Answer the following questions in the space provided:

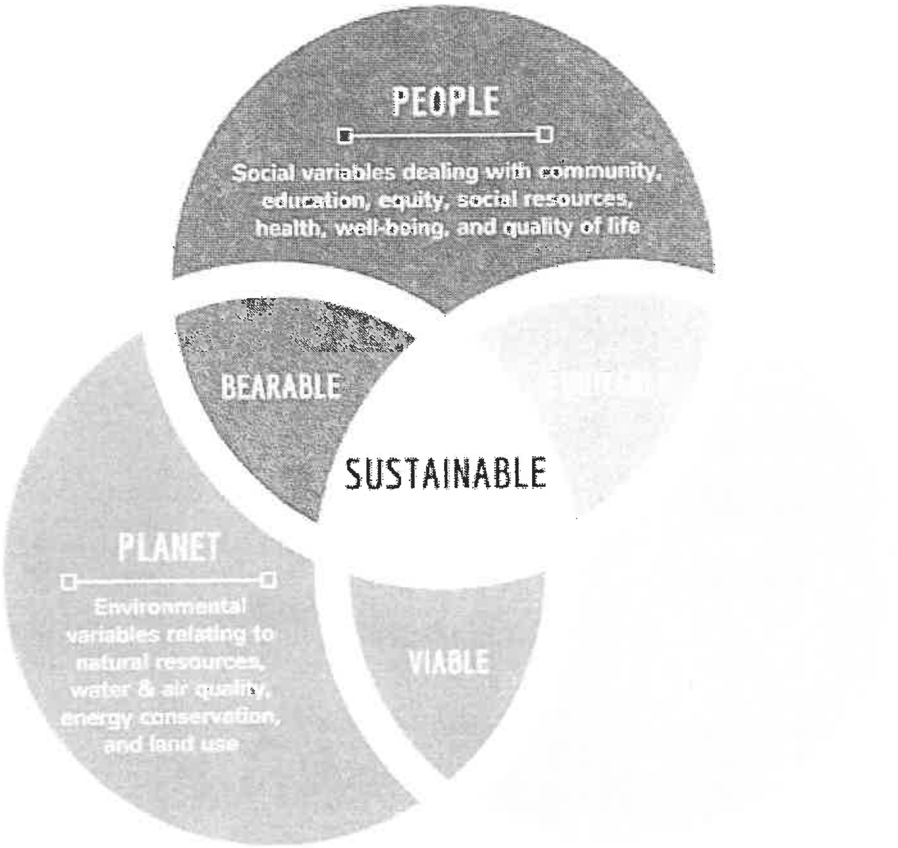
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? [2]	Environmental; replace toxic reagants and products with environmentally friendly products Reduce the usage or generation of toxic compounds substances
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? [2]	Economic; reduce the energy required to produce the desired product either by the use of faster processes or by the use of renewable energies involving lower energy cost with equal efficiency
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? [2] Give 2 examples?	cost of labour in production cost of equipments maintenance
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? [2]	Replace toxic reagants and products with environmentally friendly Reduce waste generated in any preparation and handling of chemicals

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

Sustainable systems thinking is a mindset that helps us to untangle and work within the complexity of life on Earth. It helps us to better understand the impact of our work on the world around us and be responsible for what we create and how we innovate. An important step in developing a systemic approach is to find

the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



Sustainability strives for:

- **Viable** environmental-economic impact: Business is executed with the environment and resources in mind.
- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Reduce cost by elimnating unnecessary steps
3. High Tax contribution
4. Prices of chemicals and drugs to decrease
5. Meet all supply and demand
6. expectations
7.
8.

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. No contamination of any water sources
3. No contamination of any food source
4. (crops)
5. Longevity of life increase
6. Increase quality of life
7.
8.

Enviromental Officer

1. Minimize deforestation
2. Reduce the generation of toxic compound substence
3. Replace toxic products with environmentally
4. friendly products
5. No contamination of any water
6. sources
7. Reduce the waste produced
8.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

  Hint: You are welcome to refer to the **17 sustainable development goals.**

Asprin Manufacturing Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. High Tax contribution
4. Maximize profit
5. Increase employment
6. Increase quality of life
7. No contamination of any water resources
8. Reduce the waste produced
9.
10.

Are all group members happy with the new plant design?	[✓ ***Yes***]	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. **[5]**

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$

$$x\ kg\ \ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05}\ \boldsymbol{kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	**1066.05**		**117.30**
Sodium hydroxide	453.10 ✓		
Carbon dioxide	677.35 ✓		233.45 ✓
Sulfuric acid	571.55 ✓		14.95 ✓
activated carbon	211.60 ✓		211.60 ✓
water			204.70 ✓
sodium sulfate			805.00 ✓
salicylic acid		**1150**	242.65 ✓

5

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$
$$x\ kg\ \ NaOH\ \ = 1150\ kg\ SA$$

$$x\ kg\ NaOH\ = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen** 2,5
(Refer to Table 2 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945.11 ✓		
Oil of wintergreen	1488.61 ✓		
water			178.63 ✓
salicylic acid		**1150**	
methanol			266.66 ✓
Sodium sulfate			5636.85 ✓

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$
$$x\ kg\ \ CH_3OH\ \ = 616.67\ kg\ MA$$

1,5

$$x\ kg\ CH_3OH\ = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas**
(Refer to Table 3 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**		**267.68**
water			149.28 ✓
acetic acid	1001.87 ✓		
methyl acetate		**616.67**	

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 2? 3 **[2]**

b. **in row 3** the % yield of salicylic acid for the two routes. **[2]**

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) **[2]**

d. Answer the four questions that follow. **[7]**

8+1

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	$= \frac{1150\ kg}{2979\ kg} \times 100$ $= 38.60\ \%$ ✓	$= \frac{1150\ kg}{5021.57} \times 100$ $= 22.90\ \%$ ✓
% Yield How efficient the chemical reactions are.	$= \frac{1150\ kg}{1359\ kg} \times 100$ $= 84.62\ \%$ ✓	$= \frac{1150\ kg}{1191\ kg} \times 100$ $= 96.56\ \%$ ✓
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	1829.65 kg ✓	6082.14 kg ✓

Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. **[2]**	Route 1 ✓, because it produces less waste ✓
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. **[1]**	It was not mentioned how do they get raw materials Cradle to gate
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief **[2]**	No, the route 1 and Cradle to gate are not harmful to the environment
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. **[2]**	* Raw material cost ✓ * Transport and logistics cost explain.

Question 3

Answer the following questions in the space provided:

How can the impact (**environmental, social or economic**) of the inputs and output be minimized or managed to make the process sustainable? **[2]**	* Consider using renewable resources, eco-friendly materials and non-toxi substances which reduces the negative to environment. Reuse and recycling. * Consider social aspects of the process including labor conditions, worker safety and community well-being. * Collaborate with suppliers and encourage sustainable practices throughout the supply chai ✓ 2
How can the impact (**environmental, social or economic**) of energy be minimized or managed to make the process sustainable? **[2]**	* Investing in renewable energy such as hydro and solar power helps reduce greenhou gases emissions. * Provide insulators and efficient equipment which reduces wasting energy * By shifting energy-intensive activities to off-pea ✓
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** Give 2 examples?	Labor costs ✓ Energy expenses ✓ 2 Facility maintenance Costs
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? **[2]**	> Green chemistry principles promote the development of environmentally frien-dly processes such as minimize the use of hazardous materials ✓ 2 > By carefully selecting reaction conditions, catalyst and purification methods can be used to minimize the production of unwante byproducts or toxics. ✓

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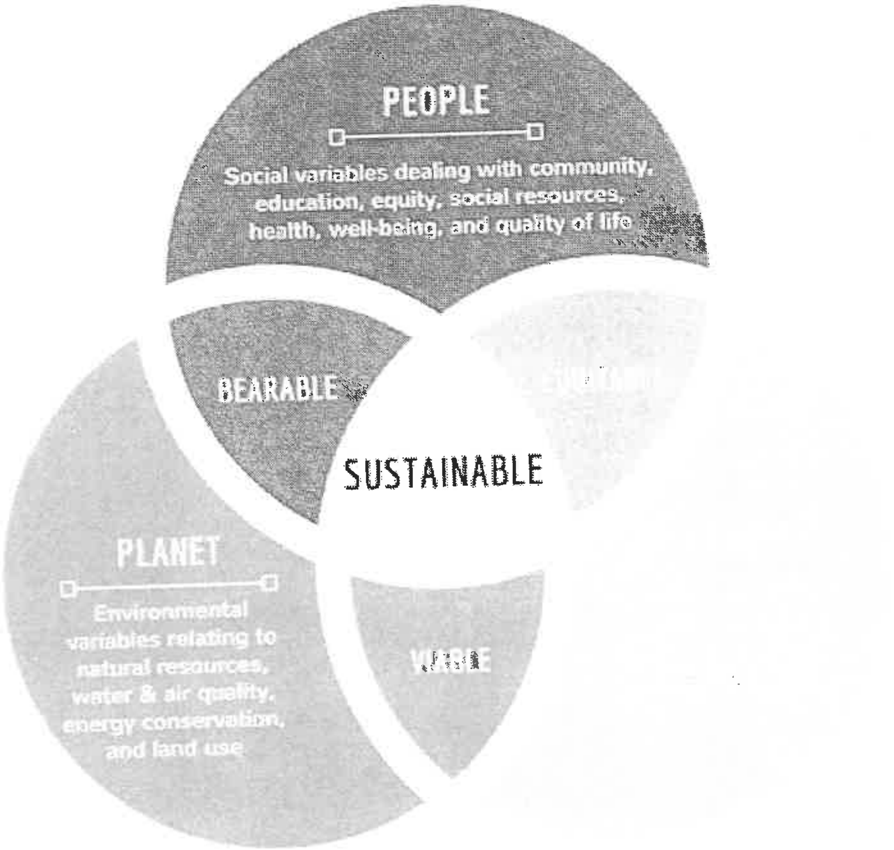

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ROLE PLAY ACTIVITY

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- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Financial Reporting
3. Capital structure and financing
4. Investment Analysis and Management
5. Financial Compliance and governance
6. Financial strategy and decision
7. Capital structure and financing
8. financial risk management

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Advocacy
3. Communication engagement
4. Problem solving and conflict
5. Relationship Building
6. Resource Mobilization
7.
8.

Enviromental Officer

1. Minimize deforestation
2. Environtal compliance
3. Environmental Impact
4. Sustainability Initiatives
5. Environmental Training and Education
6. Stakeholder engagement
7.
8.

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

Hint: You are welcome to refer to the **17 sustainable development goals.**

Asprin Manufacturing Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. Green chemistry
4. Energy Efficiency
5. Water conservation
6. Waste Management
7. Sustainable Raw materials
8. Renewable energy Sources
9. Continuous Improvement and Innovation
10. Environmental Monitoring and reporting

Are all group members happy with the new plant design?	***Yes*** ✓	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate.

Salicylic acid can be produced using 3 routes.

LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. **[5]**

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 1 on page 7:

4

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH\ =\ 1000\ kg\ SA$$
$$x\ kg\ \ C_6H_5OH\ =\ 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	**1066.05**		**117.30**
Sodium hydroxide	453,10		
Carbon dioxide	677,35		233,45
Sulfuric acid	511,55		14,95
activated carbon	211,60		211,60
water			204,70
sodium sulfate			536,67
salicylic acid		**1150**	161,77

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]**

Refer to the Table 2 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$
$$x\ kg\ NaOH = 1150\ kg\ SA$$

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

2

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen**
(Refer to Table 2 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
Sodium hydroxide	**1587.85**		
Sulfuric acid	194$\overset{5}{4}$,65 ✓		
Oil of wintergreen	1488,61 ✓		
water			178,63 ✓
salicylic acid		**1150**	
methanol			266,66 ✓
Sodium sulfate			5636,85 ✓

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]**

Refer to the Table 3 *DATA SHEET* on page 7 in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$
$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

1,5

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas**
(Refer to Table 3 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
methanol	**534.33**		**267.68**
water			1949,28 ✓
acetic acid	1001,87 ✓		
methyl acetate		**616.67**	32,07 ✓

Question 2

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route ~~2~~ 3. [2]

b. **in row 3** the % yield of salicylic acid for the two routes. [2]

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) [2]

d. Answer the four questions that follow. [7]

9

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	41,55%	17,40%
% Yield How efficient the chemical reactions are.	$\frac{1150}{1359}$ ×100 = ~~84~~ 84,62%	$\frac{1150}{1191}$ ×100 = 96,56%
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	233,47 + 14,95 + 11,60 + 204,70 + 536,674 = 1465,91 Kg	178,3 + 266,66 + 5636,85 = 6082,14 Kg
Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. **[2]**	Route 1, the is a high chance to quantify the efficiency and environmental performance of chemical processes.	
What type of system boundary (~~Cradle to gate~~ **Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. **[1]**	Cradle to grave disposal ~~B~~ extraction of raw material was not mentioned.	
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief **[2]**	Yes, the extraction process itself may result in more environmental damage than good, defeating the whole aim.	
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. **[2]**	- Crude oil will become hard to obtain, hence the will be lower supply, driving the price up. Crude oil become more expensive, resulting in an increase in the price of producing aspirin, and ultimately a higher price to buy for the consumers.	

Question 3

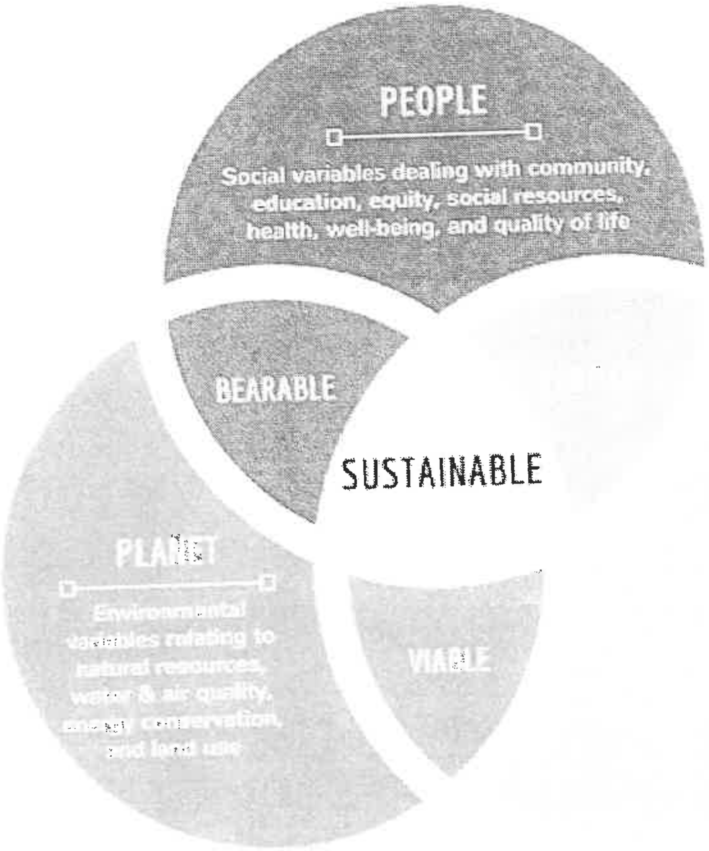
Answer the following questions in the space provided:	
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? **[2]**	- We could Improve the handling of chemicals and how? - We could reduce waste by recycling and reusing 2 - Advanced technology could be used. ~~to~~
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? **[2]**	- We could make use of solar energy; it's a cleaner form of energy and much more cheaper/affordable in the long run.
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** Give 2 examples?	~~- Unnecessary steps in the process~~ ~~such as~~ ~~such as~~ - labour (salaries) - Cost of Waste disposal.
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? **[2]**	- Chemistry can be used to develop new water purification processes and treatment. This reduces pollution and protects environment. 1 4 - Chemistry can be used to develop new energy sources such as solar cells and batteries. These energy sources help reduce reliance on fossil fuels.

SYSTEMS THINKING IN SUSTAINABILITY

Sustainability is all about systems and making sure we are thinking about the entire picture so we can address a problem from all angles. It is important that we start seeing the Earth as a system. Within this system, there are other systems such as People, Planet and Profit. All three systems are tightly interconnected and initiatives to address one often overlap with the other. Just like, there would not be people without a planet, there would not be a business without people, and there would not be prosperity without business.

Sustainable systems thinking is a mindset that helps us to untangle and work within the complexity of life on Earth. It helps us to better understand the impact of our work on the world around us and be responsible for what we create and how we innovate. An important step in developing a systemic approach is to find

the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



Sustainability strives for:

- **Viable** environmental-economic impact: Business is executed with the environment and resources in mind.
- **Bearable** socio-environmental impact: Develop healthy habits that benefit the society and the environment.
- **Equitable** socio-economic impact: The generation of economic opportunity for both businesses and individuals.

ROLE PLAY ACTIVITY

- An Engineer in partnership with a chemist decides that there is a need to upgrade the aspirin manufacturing plant for sustainability. They takes up the idea to the board, which includes the **Finance manager, the Environmental officer and the Community representative.**

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Reduce Costs by cutting unecessary expenditure.
3. Obtain funding for project
4. Manage financial Risks
5. Conduct financial Analysis
6. Provide financial report to management
7. Develop a financial Plan for project
8. Cater In unexpected Costs

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. improve quality life of individual in community
3. update the community about the plant
4. monitor the plant make sure doesnt negatively affect community
5. work with company to identify needs of community
6. Get involved early in the planning process
7. Be persistent
8.

Enviromental Officer

1. Minimize deforestation.
2. Minimize air pollution by using clean energy
3. Conduct environmental assessments
4. Developing environmental impact statements
5. Promoting environmental sustainability
6. Comply with environmental regulations
7. Recycle waste and byproducts
8. Dispose of toxic waste properly

- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

  Hint: You are welcome to refer to the **17 sustainable development goals.**

Asprin Manufacturing Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. Supply people in community with jobs
4. Development of infrastcure in community
5. Improve standard of living.
6. Economic development
7. Plant made from recycled material
8. Use means of production that lead to less carbon emission.
9. ~~Dispose toxic~~ To have designated waste disposal site.
10. Money generated from plant used to provide bursaries.

Are all group members happy with the new plant design?	[✓ ***Yes***]	***No***

EXPERIMENTAL DATA

FUNCTIONAL UNIT: This LCI is for the manufacture of **1500 kg** of Aspirin.

In order to produce **1500 kg of Aspirin**, we have to start with **1150 kg salicylic acid** and **616.67 kg** of methyl acetate. Salicylic acid can be produced using 3 routes. LCI will be used to find the greener route of producing **1150 kg of salicylic acid.**

Refer to the aspirin manufacture information document where necessary.

Question 1

Complete Table 1-3 below by calculating the mass of the components needed to synthesize the product per table. **Do not calculate the shaded blocks in the tables.**

a. Complete Table 1 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***1150 kg of salicylic acid*** from phenol. **[5]**

Refer to the Table 1 *DATA SHEET* on page 7 in the aspirin manufacture document.

5

From Table 1 on page 7:

927 kg phenol was put in to produce 1000 kg of Salicylic acid

$$927\ kg\ C_6H_5OH = 1000\ kg\ SA$$
$$x\ kg\ C_6H_5OH = 1150\ kg\ SA$$

$$x\ kg\ C_6H_5OH = \frac{927\ kg\ C_6H_5OH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1066.05\ kg}$$

Table 1: Material balance for the production of **1150 kg of salicylic acid from phenol**
(Refer to Table 1 page 7)

COMPONENT	INPUT (kg)	PRODUCT (kg)	WASTE (kg)
phenol	**1066.05**		**117.30**
Sodium hydroxide	453.10 ✓		
Carbon dioxide	677.35 ✓		233.45 ✓
Sulfuric acid	591.55 ✓		14.95 ✓
activated carbon	211.60 ✓		211.60 ✓
water			204.70 ✓
sodium sulfate			805.00 ✓
salicylic acid		**1150**	242.65 ✓

b. Complete Table 2 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize 1150 kg of salicylic acid from oil of wintergreen. **[2.5]** 2.5

Refer to the Table 2 ***DATA SHEET*** **on page 7** in the aspirin manufacture document.

From Table 2 on page 7:

1380.74 kg sodium hydroxide was put in to produce 1000 kg of Salicylic acid

$$1380.74\ kg\ NaOH = 1000\ kg\ SA$$
$$x\ kg\ NaOH = 1150\ kg\ SA$$

$$x\ kg\ NaOH = \frac{1380.74\ kg\ NaOH\ x\ 1150\ kg\ SA}{1000\ kg\ SA} = \mathbf{1587.85\ kg}$$

Table 2: Material balance for the production of **1150 kg of salicylic acid from oil of wintergreen** ***(Refer to Table 2 page 7)***

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
Sodium hydroxide	**1587.85**		
Sulfuric acid	1945.11 ✓		
Oil of wintergreen	1488.61 ✓		
water			178.63 ✓
salicylic acid		**1150**	
methanol			266.66 ✓
Sodium sulfate			5636.85 ✓

c. Complete Table 3 below by calculating the exact mass (in kg to two decimal places) of the components needed to synthesize ***616.67 kg of methyl acetate.*** **[1.5]** 1.5

Refer to the Table 3 ***DATA SHEET*** **on page 7** in the aspirin manufacture document.

From Table 3 on page 7:

866.48 kg methanol was put in to produce 1000 kg of methyl acetate

$$866.48\ kg\ CH_3OH = 1000\ kg\ MA$$
$$x\ kg\ CH_3OH = 616.67\ kg\ MA$$

$$x\ kg\ CH_3OH = \frac{866.48\ kg\ methanol\ x\ 616.67\ kg\ MA}{1000\ kg\ MA} = \mathbf{534.33\ kg}$$

Table 3: Material balance for the production of **616.67 kg of methyl acetate from natural gas** ***(Refer to Table 3 page 7)***

COMPONENT	**INPUT (kg)**	**PRODUCT (kg)**	**WASTE (kg)**
methanol	**534.33**		**267.68** ✓
water			149.28
acetic acid	1001.87 ✓		
methyl acetate		**616.67**	32.07 ✓

Question 2

12

The % atom economy (calculated in the pre-practical) for route 1 and route 3 is shown in **Table 4 row 1**.

Refer to the **calculated mass in Table 1 and 2 and calculate:**

a. **in row 2** the % reaction mass efficiency of salicylic acid for the route 1 and route 3 **[2]**

b. **in row 3** the % yield of salicylic acid for the two routes. **[2]**

For route 1 theoretical yield of salicylic acid is **1359 kg**.

For route 3 theoretical yield of salicylic acid is **1191 kg**.

c. **in row 4** the E-factor (total waste) (in kg) **[2]**

d. Answer the four questions that follow. **[7]**

Table 4

Green matrix and meaning	**Route 1**	**Route 3**
% Atom economy How efficient the process is in terms of atoms	65.22 %	54.88 %
% Reaction mass efficiency How efficient the process is in terms of amount of inputs to product	$= 38.60\%$ $\frac{1150}{2979.65} \times 100$	$\frac{1150}{5021.75} \times 100$ $= 22.90\%$
% Yield How efficient the chemical reactions are.	$\frac{1150}{1359} \times 100$ $= 84.62\%$	$\frac{1150}{1191} \times 100$ $= 96.56\%$
E-factor (Total waste) (in kg) How efficient the chemical reactions in terms of waste produced.	117.30 + 233.45 + 14.95 + 211.60 + 204.70 + 805.00 + 242.65 = 1829.65 kg	178.63 + 266.66 + 5636.85 = 6082.14 kg
Consider the calculated green metrics and decide which SA synthetic route you would select for your company. Justify your choice. **[2]**	Route 1 as it produces less waste than route 3.	
What type of system boundary (**Cradle to gate or Gate to grave or Cradle to grave or Gate to gate**) is implemented in this inventory? Refer to Figure 3, Page 4 of the Aspirin Manufacture document. **[1]**	Gate to Gate.	
Would expansion of the boundaries to include the raw material extraction processes likely result in your change of choice of the more sustainable route? Explain in brief **[2]**	Yes, as trees (oil of wintergreen) serves as a renewable resource unlike crude oil which isn't.	
Phenol is obtained from crude oil. Crude oil is a non-renewable resource. What effect would depletion of crude oil reserves have on the cost of buying aspirin? Briefly explain. **[2]**	It would increase the cost of Asprin as ~~less peop~~ demand would increase while supply decreases. Less people would get acess.	

6

Question 3

Answer the following questions in the space provided:	
How can the impact (**environmental, social or economic)** of the inputs and output be minimized or managed to make the process sustainable? **[2]**	Teaching workers the proper disposal ~~methods~~ and manufacturing methods ~~t~~in order to decrease the total wastage will reduce the impact of subsionce on enviroment. ✓ ✓ Being able to be best productivity by ensuring efficiency which can reduce costs.
How can the impact (**environmental, social or economic)** of energy be minimized or managed to make the process sustainable? **[2]**	The reduction of pollution and impact on envirornent can be attained by ~~use~~ more use of renewable resources and decrease usage of non-renewable resources. ✗
Besides the energy costs and the buying all the raw materials, what other cost implications do you anticipate the aspirin manufacturing process to incur? **[2]** Give 2 examples?	* Cost of ~~all~~ catalyst substances such as H_2SO_4. ✓ * Packaging of the product. ✓ * Transportation of the product.
How does the exercise you just carried out on synthesis of aspirin display the central role of chemistry in the mitigation of global sustainability issues? **[2]**	* Chemistry can be one of the most impactful factor to sustainability issues if one isn't aware of ~~the~~ ~~efficiency~~ ~~and~~ sustainable management of production. ✓ ✓

SYSTEMS THINKING IN SUSTAINABILITY

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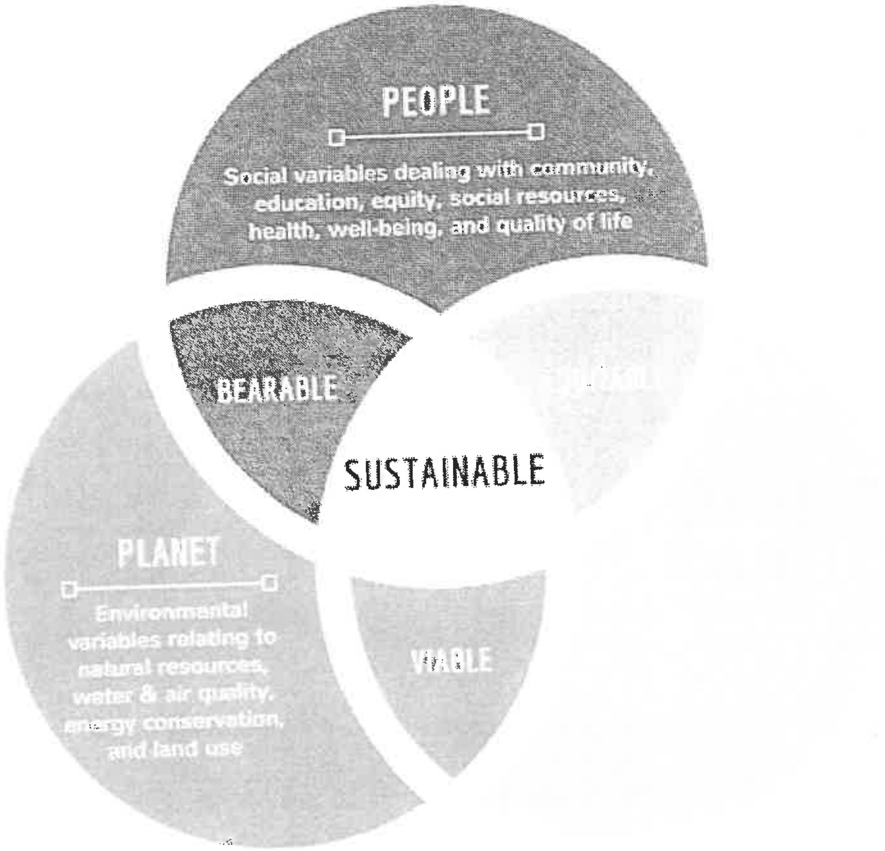
the source of the problems, as these increases the chances of identifying the leverage. Leverage is a small, focused action, that can produce significant changes with a minimum effort. Leverage can also be achieved by weakening the symptomatic response to the problem while strengthening the fundamental solution. Leverages results in viable, bearable and equitable options during problem solving. The aspirin manufacture forms a part of the aspirin system, which includes engineering, the planet, people, human health, and economics.



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- Lastly, all group members should discussion amongst themselves and write down their ideal sustainable plant. There will be leverages, compromises, adjustments, and amendments as **viable, bearable and equitable spheres of sustainability** should be taken into consideration when designing the new sustainable plant.

Hint: You are welcome to refer to the **17 sustainable development goals.**

Asprin Manufacturing Plant for sustainability

Financial manager, Enviromental officer and the community representative

1. The new plant will have solar panels
2. The community will assist with reforestation.
3. Recycling of waste to useful products
4. More job opportunities will be created for local community
5. Provide food hamper and clothing for disadvantaged local community residents
6. Treat waste ~~to protect~~ and correct waste disposal to protect nature, aquatic life etc
7. Major contributor to the Country's Gross Domestic Product
8. Patnering with big ~~int~~ World ~~local~~ trade patners
9. Building a health facility for Workers and local Community residents
10. Patnering with water Sanitation companies

Are all group members happy with the new plant design?	[✓ ***Yes***]	***No***

- Carry out a role play in which each group member assumes the stated role in the meeting. In the space provided, each member should write down his or her own expectations of the new plant.

Finance manager

1. Maximize profit
2. Financially stable for the next decade
3. cost efficiency
4. ~~£~~ Capital expenditure control
5. Budget control
6. Reduce financial risk takes.
7. efficient workers better than more workers (and is cost effective).
8. Have high net-worth value

Asprin Manufacturing

Commnunity represantative

1. Create jobs for local peoplemize profit
2. Attract tourist, to tour the new plant.
3. Prioritising fair working conditions for local people
4. Offer learning or educational programmes.
5. building a health-care facility for locals and workers
6. Charity work, through providing food hampers
7. Don't poison ~~out~~ the water.
8. Offer bursaries (from profits) for local students

Enviromental Officer

1. Minimize deforestation
2. Minimize air pollution
3. Minimize water pollution
4. ~~Use of waste for energy~~ recycle waste to useful ~~energy~~ energy
5. Minimize depletion of non-renewable resources.
6. reduce water consumption.
7. reduce chemical wastes
8. reduce carbon footprint