Renewable Energy Technologies I

Exercise 10

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Instructions

- Please give the results in the units provided
- Round your results to a reasonable precision
- Formulae that are provided in the exercise will also be provided in the exam. If the formula is not given in the exercise it will also not be given in the exam.
- Exercises do NOT have to be submitted for correction
- Exercise solutions will be posted November 24.
- If you have questions, please email: brian.cox@psi.ch

1. Briefly describe pathways that can be used to convert waste into electrical energy using the following four initial processes: Incineration, Pyrolysis, Gasification, Digestion.

    1. **Incineration:** direct combustion of waste to produce steam that is used to turn a steam turbine
    2. **Pyrolysis:** convert waste stream into a syngas and char by using high temperatures in an anaerobic atmosphere. The syngas can be cleaned up and combusted in a gas engine to produce electricity. The char can either be used as a chemical feedstock or be gasified to produce a combustible gas that is either used for heating or electricity generation.
    3. **Gasification:** convert waste into syngas by using high temperatures in the presence of oxygen and/or steam. Excess heat can be used to create electricity. The syngas can be either used as a fuel, feedstock or converted into electricity in a gas turbine or fuel cells. A steam turbine may also be added on to the system downstream of the gas turbine of fuel cell in an integrated gasification combined cycle (IGCC) plant.
    4. **Anaerobic digestion:** waste can be digested to produce carbon dioxide and methane. This gas can be combusted to produce heat and electricity

2. Briefly describe three other uses for waste that can offset primary energy consumption

    1. Waste can be converted into a fuel that offsets fossil fuels. Pathways include pyrolysis, gasification and anaerobic digestion (and gas purification).
    2. Waste can be used to create heat for buildings in district heating networks. This heat reduces the need for oil or natural gas heating.
    3. Waste can be converted into a chemical feedstock (carbon) that reduces oil requirements.

4. Waste can be processes to recover metals and elements that would otherwise have to be produced from primary sources, which is energy intensive.

3. List several sources of waste that can be used for energetic purposes in Switzerland

   - Municipal solid waste (garbage)
   - Household compost
   - Waste plastic & rubber
   - Waste water (sewage)
   - Animal Waste (Manure)
   - Agricultural plant waste
   - Forestry waste (wood chips)

4. In Switzerland roughly 700 kg of municipal solid waste (MSW) is produced annually per person. Of this, approximately 50% is incinerated in order to produce electricity. The calorific value of MSW can be taken to be 10 MJ/kg.

   a) Assuming 10% efficiency in converting MSW into electricity, what is the annual amount of electricity (in kWh) that could be generated from MSW in Switzerland?

700 kg * 50% * 10 MJ/kg *0.277778 kWh/MJ * 10% = 97.2 kWh

   b) If the average, per capita, electricity demand in Switzerland is 850 W, what is the percentage of electricity demand could be covered by electricity from waste incineration?

(97.2 kWh / 8760 h/year) / 0.85 kW = 1.3%

5. Lead acid car batteries consist mostly of lead and plastic. Both of these materials can be recycled, allowing manufacturers to select either primary or recycled materials with no impact on quality or the rest of the manufacturing process. The manufacturing energy to produce batteries, regardless of material input is 10 MJ/kg of battery. Batteries can be assumed to weight 10 kg each. The energy to produce the materials lead and plastic, along with their share in batteries is listed below:

		Material Production Energy (MJ/kg battery)	
	% of dry battery weight	Primary	Recycled
Lead	85%	30	5
Plastic	15%	75	15

   a) Calculate the potential energy savings (in MJ/battery) of using recycled materials instead of primary materials for lead acid battery production.

Energy per primary material battery = 10*(0.85*30 + 0.15*75 + 10) = 467.5 MJ
Energy per recycled material battery = 10*(0.85*5 + 0.15*15 + 10) = 165 MJ
Energy savings per battery = 467.5-165 = 302.5 MJ

b) If there are 300 000 new cars sold each year in Switzerland (each with one 10 kg battery), what are the potential energy savings per year (in million liters of gasoline equivalent) of equipping all new cars with a battery made from recycled instead of primary materials?

The energy content of gasoline may be assumed to be 42 MJ/kg, with a density of 0.75 kg/l

$$\text{Energy Savings} = 300000\ [\text{batteries}] \times (467.5 - 165) \left[\frac{\text{MJ}}{\text{battery}}\right] \times \frac{1}{42}\left[\frac{\text{kg}}{\text{MJ}}\right] \times \frac{1}{0.75}\left[\frac{\text{l}}{\text{kg}}\right]$$
$$= 2.88 \text{ million liters of gasoline equivalent}$$

c) If the average fuel economy of a new car in Switzerland is assumed to be 5 L of gasoline per 100 km, how far how far could a new car travel using the energy saved by using recycled lead instead of primary lead in its battery?

$$\text{Distance} = (467.5 - 165)\left[\frac{\text{MJ}}{\text{battery}}\right] \times \frac{1}{42}\left[\frac{\text{kg}}{\text{MJ}}\right] \times \frac{1}{0.75}\left[\frac{\text{l}}{\text{kg}}\right] \times \frac{100}{5}\left[\frac{\text{km}}{\text{l}}\right] = 192\ [\text{km/battery}]$$

Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

Brian Cox, Dimitrios Potamias

Renewable Energy Technologies I

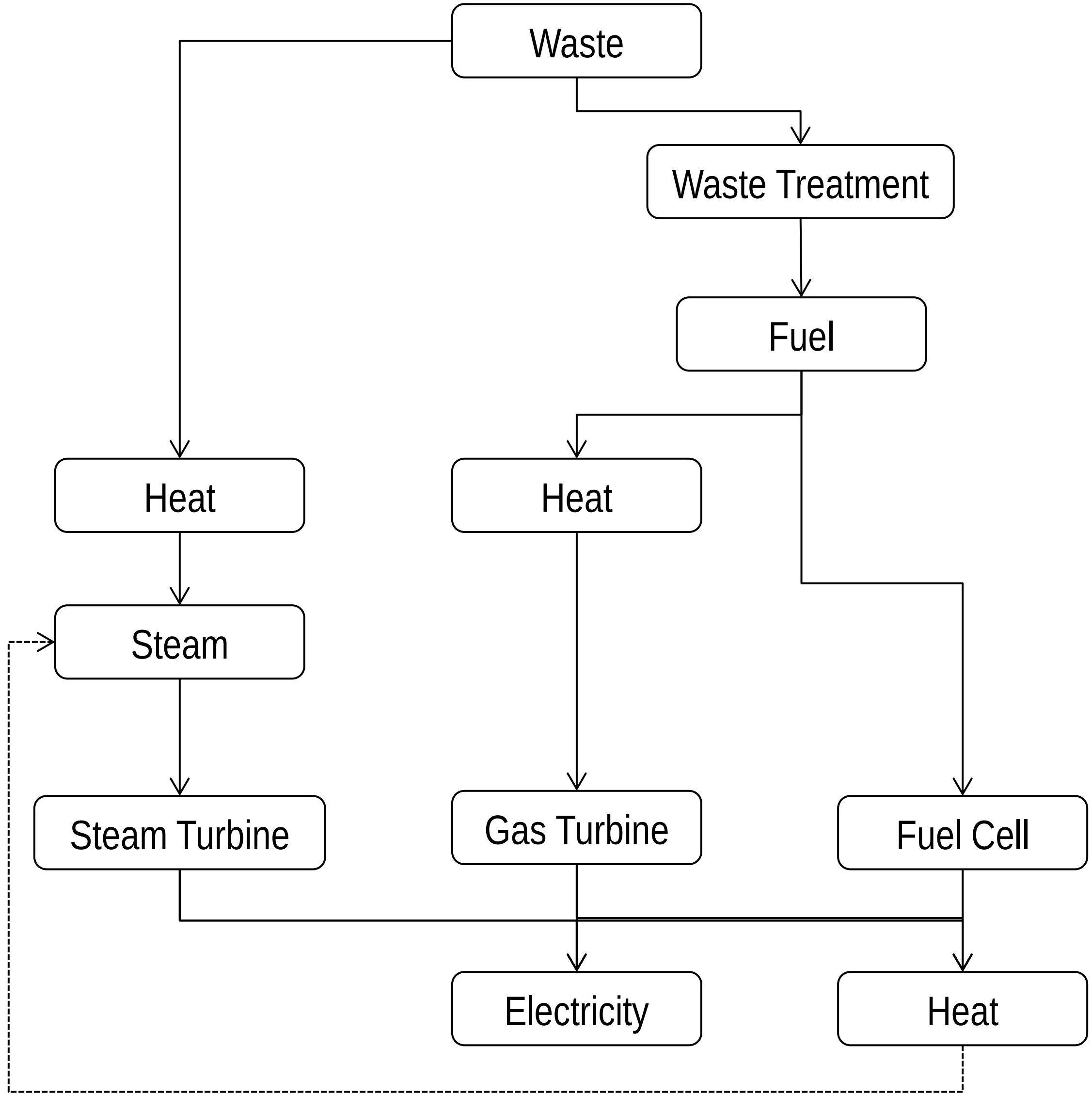
Exercise 10

Question 1

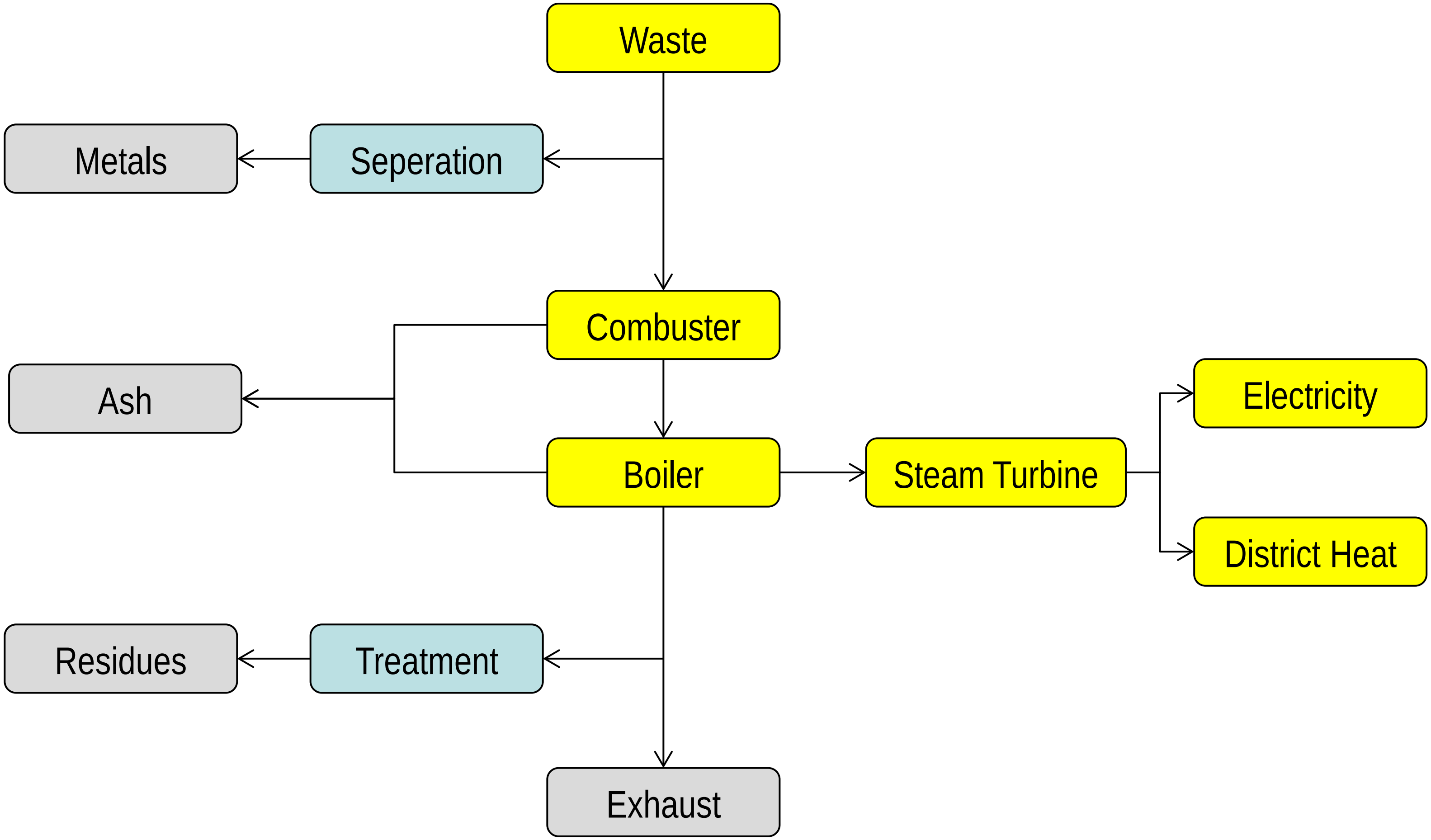
Briefly describe pathways that can be used to convert waste into electrical energy using the following four initial processes:

- Incineration
- Pyrolysis
- Gasification
- Digestion

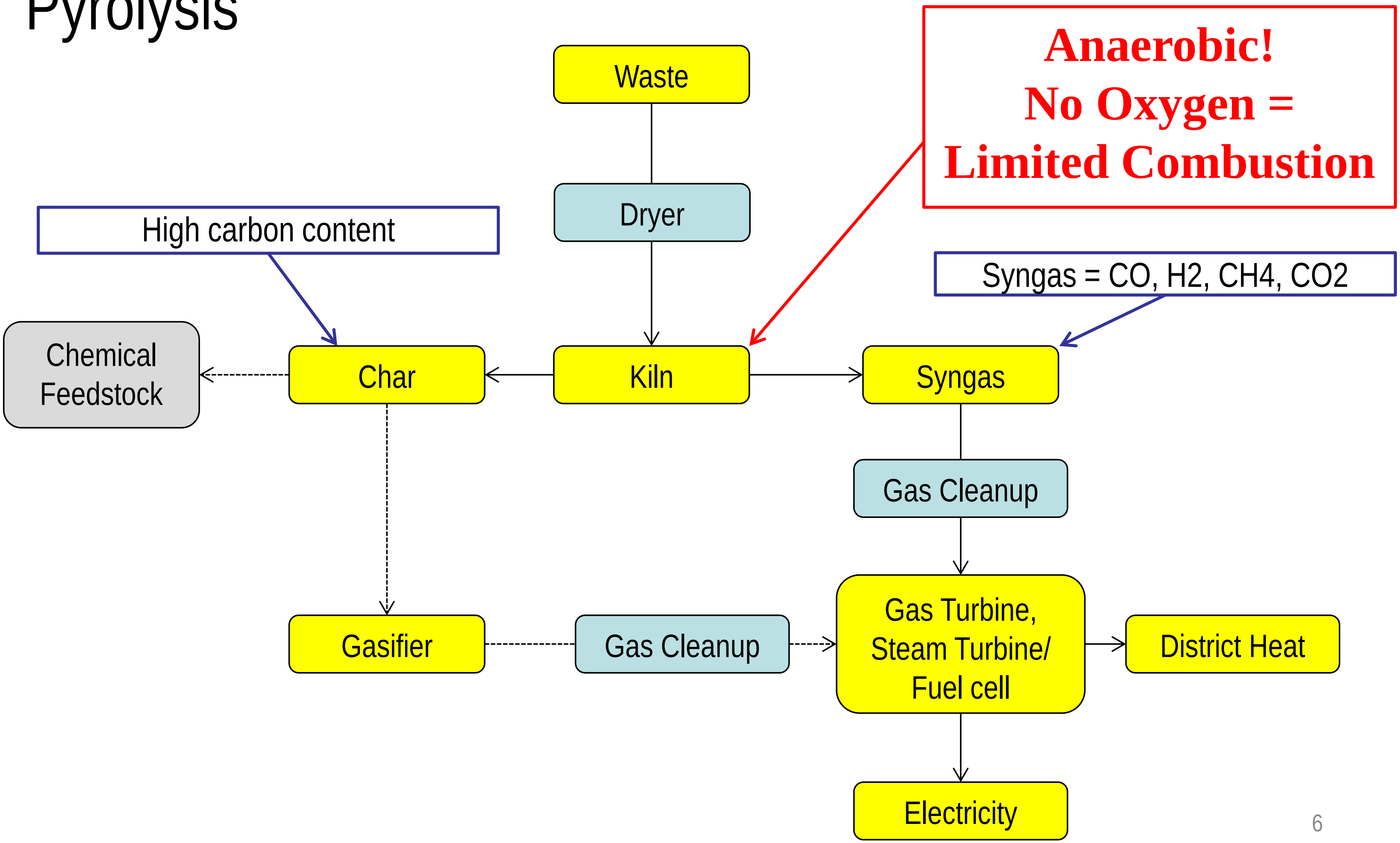
Question 1 – Quick recap:



Incineration

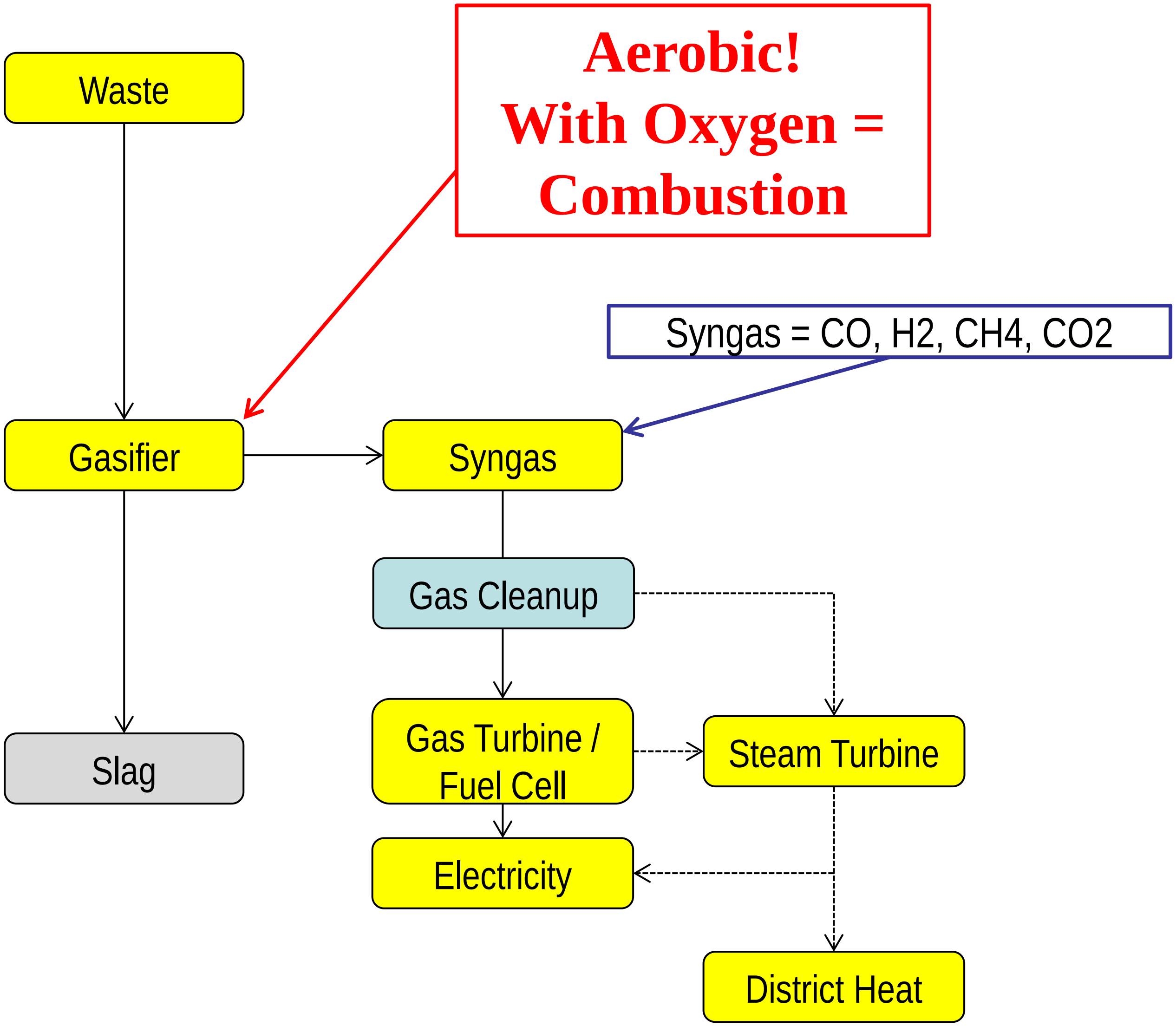


Pyrolysis


Anaerobic!
No Oxygen =
Limited Combustion
Waste
Dryer
High carbon content
Syngas = CO, H2, CH4, CO2
Chemical Feedstock
Char
Kiln
Syngas
Gas Cleanup
Gasifier
Gas Cleanup
Gas Turbine, Steam Turbine/ Fuel cell
District Heat
Electricity

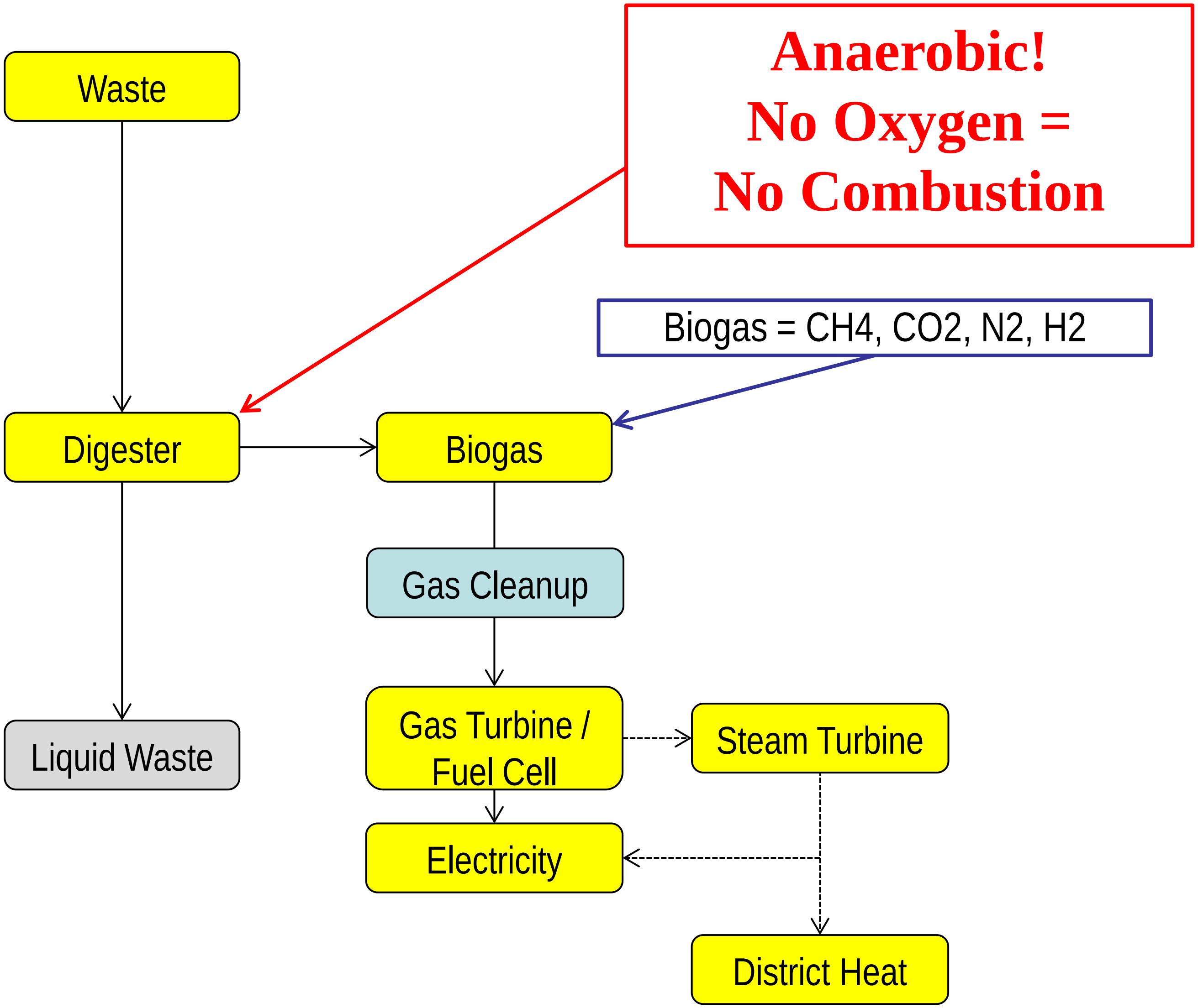
Question 1

Gasification



Question 1

Digestion



Question 2

Briefly describe three other uses for waste that can offset primary energy consumption:

- Waste – Fuel (e.g. biodiesel)
- Waste – Heat (e.g. district heat)
- Waste – Chemical feedstock (e.g. carbon)
- Waste – Recycled material (e.g. aluminium)

Question 3

List several sources of waste that can be used for energetic purposes in Switzerland:

- Municipal solid waste (garbage)
- Household compost
- Waste plastic & rubber
- Waste water (sewage)
- Animal Waste (Manure)
- Agricultural plant waste
- Forestry waste (wood chips)

Question 4

In Switzerland roughly 700 kg of municipal solid waste (MSW) is produced annually per person. Of this, approximately 50% is incinerated in order to produce electricity. The calorific value of MSW can be taken to be 10 MJ/kg.

a) Assuming 10% efficiency in converting MSW into electricity, what is the annual amount of electricity (in kWh) that could be generated from MSW in Switzerland?

700 kg * 50% * 10 MJ/kg *0.278 kWh/MJ * 10% = 97.2 kWh

Question 4

In Switzerland roughly 700 kg of municipal solid waste (MSW) is produced annually per person. Of this, approximately 50% is incinerated in order to produce electricity. The calorific value of MSW can be taken to be 10 MJ/kg.

b) If the average, per capita, electricity demand in Switzerland is 850 W, what is the percentage of electricity demand could be covered by electricity from waste incineration?

(97.2 kWh / 8760 h/year) / 0.85 kW = 1.3%

Question 5

Lead acid car batteries consist mostly of lead and plastic. Both of these materials can be recycled, allowing manufacturers to select either primary or recycled materials with no impact on quality or the rest of the manufacturing process. The manufacturing energy to produce batteries, regardless of material input is 10 MJ/kg of battery. Batteries can be assumed to weight 10 kg each.

		Material Production Energy (MJ/kg battery)	
	% of dry battery weight	Primary	Recycled
Lead	85%	30	5
Plastic	15%	75	15

Question 5

a) Calculate the potential energy savings (in MJ/battery) of using recycled materials instead of primary materials for lead acid battery production.

We know:
The manufacturing energy 10 MJ/kg of battery.
Batteries can be assumed to weight 10 kg each.

		Material Production Energy (MJ/kg battery)	
	% battery weight	Primary	Recycled
Lead	85%	30	5
Plastic	15%	75	15

Energy per **primary** material battery =
10 kg*(85%***30** MJ/kg + 15%***75** MJ/kg + 10 MJ/kg) = 467.5 MJ

Energy per **recycled** material battery =
10 kg *(85%***5** MJ/kg + 15%***15** MJ/kg + 10 MJ/kg) = 165 MJ

Energy savings per battery = 467.5-165 = 302.5 MJ/ Battery

Question 5

b) If there are 300 000 new cars sold each year in Switzerland (each with one 10 kg battery), what are the potential energy savings per year (in million liters of gasoline equivalent) of equipping all new cars with a battery made from recycled instead of primary materials?

The energy content of gasoline may be assumed to be 42 MJ/kg, with a density of 0.75 kg/l

$$\text{Energy Savings}$$
$$= 300000\ [\text{batteries}] \times (467.5 - 165)\left[\frac{\text{MJ}}{\text{battery}}\right] \times \frac{1}{42}\left[\frac{\text{kg}}{\text{MJ}}\right] \times \frac{1}{0.75}\left[\frac{\text{l}}{\text{kg}}\right] = 2.88\ \text{million liters of gasoline equivalent}$$

Question 5

c) If the average fuel economy of a new car in Switzerland is assumed to be 5 L of gasoline per 100 km, how far how far could a new car travel using the energy saved by using recycled lead instead of primary lead in its battery?

$$\text{Distance} = (467.5 - 165)\left[\frac{\text{MJ}}{\text{battery}}\right] \times \frac{1}{42}\left[\frac{\text{kg}}{\text{MJ}}\right] \times \frac{1}{0.75}\left[\frac{\text{l}}{\text{kg}}\right] \times \frac{100}{5}\left[\frac{\text{km}}{\text{l}}\right]$$

$$= 192\ [\text{km/battery}]$$