Activity: Unit Conversions in Biofuel Applications

Grade Level: 9th grade Algebra 1

Alignment to Algebra 1 Standards:

> **A1.N.Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

Learning Objectives:

- Understand the importance of unit analysis in approaching a problem with unfamiliar quantities.
- Use unit analysis to correctly interpret a problem and arrive at correct answer.

Materials: Unit conversion sheet (supplied)

Time Required: 40 minutes

Background Information: Bioenergy is energy derived from living matter on the surface of the earth. In the United States, we are at a historic high of renewable energy use. Bioenergy is the highest source of renewable energy. Biomass, the raw source of bioenergy, includes forests, agriculture, trash and algae.

Planted crops regularly harvested as biomass include miscanthus, corn, switchgrass, sorghum and bamboo. During harvesting there are many calculations that are made such as capacity of the machines, product yield and fuel costs. Dimensional or unit analysis is invaluable to understanding how to find desired quantities.

Below is a flow chart that shows the general steps that are taken in creating biofuel from agriculture. The following problem focuses on the bolded section.

Instructor's notes: There are some new quantities, such as field capacity, field efficiency and material capacity. The first sheet of the has new terms defined and some examples. It is suggested that these are done together as a class. The second sheet has some general information that apply to the ten problems on the page. It is suggested that the teacher do one or two with the class, if you anticipate them having difficulty identifying needed information. Lastly, a unit conversion sheet has been supplied.

Terms defined and example calculations:

Field capacity is the rate in amount per hour at which a harvester can operate. The **theoretical field capacity** (TFC) only take the machine width and the average traveling speed of the harvester into account. Note: 1 acre (A) = 4046.86 m^2

Example 1: Find the theoretical field capacity of a harvester, in acres per hour, that is 4 meters wide and an average speed of 50 meters per minute.

$$\underline{\hspace{2cm}} \; \square \; \underline{\hspace{2cm}} \; \square \; \underline{\hspace{2cm}} \; \square \; \underline{\hspace{2cm}} = \underline{\hspace{2cm}} \frac{A}{hr}$$

Effective field capacity (EFC) takes into account time loss due to the harvester slowing down to turn around, unloading biomass, refueling operator breaks, etc. The ratio of effective to theoretical field capacities is called the **field efficiency** (FE) and is usually recorded as a percent.

Example 2: The effective field capacity of the harvester in example 1 is 2.5 acres per hour. Calculate the field efficiency of the harvester.

Example 3: The field efficiency of a larger harvester is 72%. If the theoretical field capacity is 6 acres per hour, what is the effective field capacity?

Material capacity (MC) is the quantity of material, in kg or tons, harvested per hour. Material capacity is calculated by multiplying the effective field capacity by the average crop yield per acre.

Example 4: The harvester from examples 1 and 2 is operating in a field that produces 5 tons per acre. What is the material capacity of the harvester in tons per hour?

$$\underline{\hspace{2cm}} \; \square \; \underline{\hspace{2cm}} = \underline{\hspace{2cm}} \frac{t}{hr}$$

Biofuel Application: NRG University has 8 acre crop of switchgrass that is growing for biofuel research purposes. As part of the research they are calculating quantities to analyze their results. Here are the data that they have on the discbine mower (seen right) and the crop for their calculations:

- The mower has a 14 ft cut width.
- The mower at a speed of 6 mph
- The mower can process 200 kg per minute
- The mower has a field efficiency of 70%
- The mower works 7 hr/day
- The mower uses 12 L/hr of fuel
- Fuel costs $0.65/L

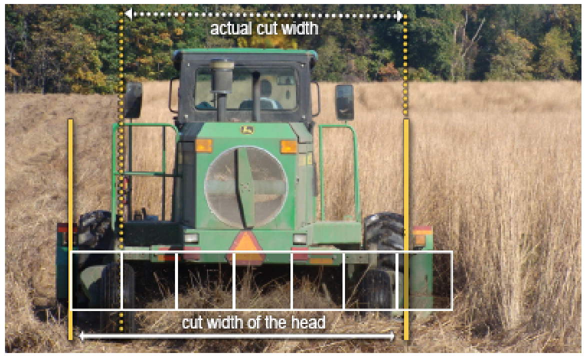

Photo of discbine mower cutting switchgrass (from http://agsci.psu.edu/elearning/course samples/abe_885_sample/Ln_5/L5_5.htm)

Calculate each of the following. Show your unit analysis.

1) What is the theoretical field capacity of the mower in acres per hour?

2) What is the speed of the mower in kilometers per hour?

3) What is the speed of the mower in meters per second?

4) What is the effective field capacity of the mower in acres per hour?

5) How many acres will the mower process in one day?

6) How many tons of are mowed in 1 mile of mower travel?

7) What is the material capacity in tons per day?

8) What is the fuel consumption of the mower in kilometers per liter in no-stop harvesting?

9) What is the fuel cost to mow one ton of switchgrass?

10) What is the fuel cost to mow one acre of switchgrass?

Unit Conversions

1 inch = 2.54 centimeters
1 meter = 39.37 inches
1 meter = 3.281 feet
1 mile = 5,280 feet
1 mile = 1,760 yards
1 mile = 1.609 kilometers
1 kilometer = 0.62 mile

1 acre = 4046.86 m^2

1 pound = 16 ounces
1 pound = 0.454 kilograms
1 kilogram = 2.2 pounds
1 ton = 2,000 pounds

Answer Key

Terms defined and example calculations:

Field capacity is the rate in amount per hour at which a harvester can operate. The **theoretical field capacity** (TFC) only take the machine width and the average traveling speed of the harvester into account. Note: 1 acre (A) = 4046.86 m^2

Example 1: Find the theoretical field capacity of a harvester, in acres per hour, that is 4 meters wide and an average speed of 50 meters per minute.

$$\frac{4\ m}{} \times \frac{50\ m}{min} \times \frac{60\ min}{hr} \times \frac{1\ A}{4046.86\ m^2} = \frac{2.97\ A}{hr}$$

Effective field capacity (EFC) takes into account time loss due to the harvester slowing down to turn around, unloading biomass, refueling operator breaks, etc. The ratio of effective to theoretical field capacities is called the **field efficiency** (FE) and is usually recorded as a percent.

Example 2: The effective field capacity of the harvester in example 1 is 2.5 acres per hour. Calculate the field efficiency of the harvester.

$$\frac{2.5\ A/hr}{2.97\ A/hr} \times 100 = 84\%$$

Example 3: The field efficiency of a larger harvester is 72%. If the theoretical field capacity is 6 acres per hour, what is the effective field capacity?

$$\frac{EF}{6\ A/hr} = 0.72$$

$$EF = 0.72(6\ A/hr)$$

$$\boxed{EF = 4.32\ A/hr}$$

Material capacity (MC) is the quantity of material, in kg or tons, harvested per hour. Material capacity is calculated by multiplying the effective field capacity by the average crop yield per acre.

Example 4: The harvester from examples 1 and 2 is operating in a field that produces 5 tons per acre. What is the material capacity of the harvester in tons per hour?

$$\frac{2.5\ A}{hr} \times \frac{5\ t}{A} = \frac{12.5\ t}{hr}$$

Biofuel Application: NRG University has 8 acre crop of switchgrass that is growing for biofuel research purposes. As part of the research they are calculating quantities to analyze their results. Here are the data that they have on the discbine mower (seen right) and the crop for their calculations:

- The mower has a 14 ft cut width.
- The mower at a speed of 6 mph
- The mower can process 200 kg per minute
- The mower has a field efficiency of 70%
- The mower works 7 hr/day
- The mower uses 12 L/hr of fuel
- Fuel costs $0.65/L

Photo of discbine mower cutting switchgrass (from http://agsci.psu.edu/ elearning/course samples/abe_885_sample/Ln_5/L5_5.htm)

Calculate each of the following. Show your unit analysis.

11) What is the theoretical field capacity of the mower in acres per hour?

$$14\,ft \cdot \frac{6\,mi}{hr} \cdot \frac{1\,m}{3.281\,ft} \cdot \frac{1609\,m}{1\,mi} \cdot \frac{1\,A}{4046.86\,m^2} = \boxed{10.179\,\frac{A}{hr}}$$

12) What is the speed of the mower in kilometers per hour?

$$\frac{6\,mi}{hr} \cdot \frac{1.609\,km}{1\,mi} = \boxed{9.654\,km/hr}$$

13) What is the speed of the mower in meters per second?

$$\frac{9.654\,km}{hr} \cdot \frac{1\,hr}{3600\,s} \cdot \frac{1000\,m}{1\,km} = \boxed{2.681\,m/s}$$

14) What is the effective field capacity of the mower in acres per hour?

$$\frac{EF}{10.179\,\frac{A}{hr}} = 0.70 \Rightarrow EF = 0.70(10.179\,A/hr) = \boxed{7.125\,A/hr}$$

15) How many acres will the mower process in one day?

$$\frac{7.125\,A}{hr} \cdot \frac{7\,hr}{day} = \boxed{49.875\,A/day}$$

16) How many tons of are mowed in 1 mile of mower travel?

$$\frac{200\,kg}{min} \cdot \frac{1\,hr}{6\,mi} \cdot \frac{60\,min}{1\,hr} \cdot \frac{2.2\,lbs}{1\,kg} \cdot \frac{1\,t}{2000\,lbs} = 2.2\,\frac{t}{mi}$$

2.2 tons in one mile

17) What is the material capacity in tons per day?

$$\frac{200\,kg}{min} \cdot \frac{7\,hr}{day} \cdot \frac{60\,min}{1\,hr} \cdot \frac{2.2\,lb}{1\,kg} \cdot \frac{1\,t}{2000\,lbs} = \boxed{92.4\,t/day}$$

18) What is the fuel consumption of the mower in kilometers per liter in no-stop harvesting?

$$\frac{6\,mi}{hr} \cdot \frac{1.609\,km}{1\,mi} \cdot \frac{1\,hr}{12\,L} = \boxed{0.805\,km/L}$$

19) What is the fuel cost to mow one ton of switchgrass?

$$\frac{\$0.65}{L} \cdot \frac{1\,L}{0.805\,km} \cdot \frac{1\,km}{0.62\,mi} \cdot \frac{1\,mi}{2.2\,ton} = \boxed{\$0.59 \text{ for one ton}}$$

20) What is the fuel cost to mow one acre of switchgrass?

$$\$0.65 \cdot \frac{12L}{hr} \cdot \frac{10.179\,hr}{A} = \boxed{\$0.77 \text{ for one acre}}$$